ESL-TH-02/05-01

THE PERSISTENCE OF SAVINGS

OBTAINED FROM COMMISSIONING OF EXISTING BUILDINGS

A Thesis

by

SOOL YEON CHO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2002

Major Subject: Mechanical Engineering

THE PERSISTENCE OF SAVINGS

OBTAINED FROM COMMISSIONING OF EXISTING BUILDINGS

A Thesis

By

SOOLYEON CHO

Submitted to Texas A&M University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Approved as to style and content by:

W. Dan Turner
(Chair of Committee)

David E. Claridge
(Member)

Jeff S. Haberl
(Member)

for N. K. Anand

John Weese
(Head of Department)

May 2002

Major Subject: Mechanical Engineering

ABSTRACT

The Persistence of Savings Obtained from Commissioning of Existing Buildings

(May 2002)

Sool Yeon Cho, B.S., University of Ulsan, Ulsan, Korea

Chair of Advisory Committee: Dr. W. Dan Turner

The objective of this study is to investigate the reasons why the performance of mechanical systems degrades over time after commissioning and to recommend intervals at which testing should be performed to maintain the integrity of the commissioning process. The initial phase of this study investigated the energy savings in ten buildings commissioned between 1996 and 1997. The results of this study show that hot water, chilled water and electric savings have all degraded. Aggregate annual cost savings for the ten buildings decreased by 17% from 1998 to 2000 from $1,192,884 to $985,626. The investigation has found that the decreased savings are due to numerous changes in control settings since the commissioning and to significant control malfunctions in two buildings.

To determine the impact of changes of control settings on energy consumption, calibrated simulation was utilized to investigate these changes for the five buildings. Simulations were conducted for a pre-CC period, a post-CC period and for the year

2000. While performing the simulation process, it was learned that the Kleberg building experienced both control changes and significant component malfunctions. The changes in consumption observed following commissioning in the other four buildings were consistent with those due to the identified controls changes, with an RMS difference of only 0.3%. This suggests that the changes in savings for these four buildings were almost entirely due to the control changes.

Based on the results, it is recommended that energy use data from commissioned buildings be continuously monitored and that CC engineers examine building operation again whenever consumption deviates from the post-CC baseline by some set amount. Research is needed to determine this amount. The examination of the building would determine reasons for the observed changes and provide a new optimized set of control settings as necessary. Changes in control will be necessary in some cases, but it is recommended that access to the control program for more than a temporary override be limited to specific personnel who are able to determine the energy and comfort impact of proposed control changes and consider that impact as part of the decision to change control settings.

ACKNOWLEDGEMENTS

I would like to acknowledge my committee members Dr. W. Dan Turner, Dr. David E. Claridge and Dr. Jeff S. Haberl for all of their help, guidance and insight.

This project was sponsored by the California Energy Commission PIER Program (via a subcontract under the High Performance Commercial Building Systems Project with the Lawrence Berkeley National Laboratory). Personnel in the Texas A&M University Physical Plant also provided assistance, and I would like to thank the Office of Energy Management for their support. I also would like to express my appreciation for the help from members of the Continuous Commissioning Group, Energy Systems Laboratory, Texas A&M University.

Finally, I would like to thank my Lord for giving me the strength, the patience, the wisdom, and the heart to write this thesis.

TABLE OF CONTENTS

LIST OF FIGURES

Figure Page

Figure Page

Figure Page

Figure Page

Figure Page

Figure Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

1.1 Background: Continuous Commissioning^{SM} (CC^{SM})

The Continuous Commissioning^{SM} (CC^{SM}) process was originated in 1993 by the Energy Systems Laboratory (ESL) and was initially funded by the Texas LoanSTAR program, a $98.6 million revolving loan program administered by the Texas Governor's Energy Office for energy retrofits of public buildings. Engineers and researchers in the Energy Systems Laboratory (ESL) at Texas A&M University developed the methodology to save additional energy in buildings receiving LoanSTAR loans. The technology and processes developed have been applied to buildings both on and off the Texas A&M University campus (Liu, 1999).

The definition of CC was introduced in the 6th National Conference on Building Commissioning (NCBC). While the traditional commissioning process leaves the building tuned to the original design intent, CC process includes continuous monitoring and follow-up to make sure the savings obtained from commissioning continue to persist

---

This thesis follows the style and format of *ASHRAE Transactions*.

after the commissioning is completed. If the metered and monitored data give notice of any building operation changes, or if difficult operational problems are reported from the facilities staff, the ESL engineers revisit the building, identify the problems, and then fix them with the facilities staff, hence the term Continuous Commissioning (Turner et al., 1998).

In general, existing-building commissioning is a process for improving and optimizing the Operations and Maintenance (O&M) of a building, and it takes place after construction, focusing on energy-using equipment with the goal of reducing energy waste. Retro-commissioning is a systematic process intended not only to optimize how equipment and systems operate, but also to optimize how the systems function together, fixing existing problems and saving energy (Haasl and Sharp, 1999). Retro-commissioning and CC differ in that CC provides the follow-up and continuous monitoring after commissioning.

CC on the Texas A&M University campus began during the summer of 1996. CC is one of the most cost effective and attractive energy saving measures, both solving comfort problems and improving energy performance in buildings. Typical Continuous Commissioning measures include sensor calibration, implementation of optimum hot deck and cold deck temperature reset schedules, static pressure reset schedules, control of outside air, optimized use of economizer cycles, air and water balances, and changes in terminal box airflow settings. The implementation of CC on the Texas A&M campus and overall results of this program have been reported elsewhere (Claridge et al., 2000a and 2000b), and CC applications to retrofitted buildings, buildings prior to retrofits, and even new construction were reported (Turner et al., 1996). The average savings from those reports are around 24 ~ 25 %, typically with a simple payback of under two years.

On the Texas A&M University campus, like many campuses, there are a number of different groups with responsibility for maintaining the buildings. Area maintenance has the day-to-day responsibility for maintaining occupant comfort. The Energy Office has overall responsibility for the controls system and handles most of the central controls settings. The campus Energy Management and Control System (EMCS) is a Siemens Apogee™ system, and Siemens technicians have access to the buildings' controls systems, while working under the supervision of the Energy Office. The ESL engineers and technicians work with all these entities during the CC process and also assist with troubleshooting comfort problems in buildings before and after commissioning. All groups thus have access to all the buildings in this study and have contributed to the results of the original CC effort.

The ESL had at least nine months of baseline energy consumption data from data loggers in each building prior to the onset of commissioning. Energy use data from energy monitoring equipment were used to determine savings after CC, and the data before CC were used to create baselines. Ten buildings commissioned in 1996 and 1997 were investigated to determine the persistence of savings in this study. These 10 buildings had almost complete building energy data, from which the annual savings could be determined.

1.2 Objectives

The world's energy usage continues to rise every year. It was not considered a serious problem several decades ago because energy was relatively cheap, and energy efficiency was not a big factor in design. Typically, buildings are one of the most energy-consuming facilities. The HVAC equipment in buildings constructed in the 1970's and 1980's usually had excessive capacity to condition the space and there was a lot of energy waste. The commissioning process, therefore, started in the 1990's for existing buildings and for new construction to ensure that buildings operated according to the owner's design intent. The CC process began in 1993 as an enhanced Operation and Maintenance (O&M) measure to improve building energy performance and to save energy. However, until this study there has not been an in-depth, systematic investigation to determine the persistence of savings after commissioning, nor has there been an attempt to quantify the extent of performance degradation and the factors responsible.

This thesis, therefore, is an investigation of the persistence of savings obtained from Continuous Commissioning (CC) performed on existing buildings on the Texas A&M University campus. The purposes are to determine:

(1) the degree to which energy savings from commissioning change over time;

(2) the degree to which optimized operating settings and practices are changed over time;

(3) whether certain commissioning measures are routinely disabled by operators; and

(4) whether steps can be taken to improve the retention of optimum operating practices and savings.

This thesis includes results on the extent to which energy savings from commissioning have changed in 10 buildings over a four-year period and the changes in optimized operating settings during this same period. Analysis of the changes made and reasons for them have been conducted. The investigation has analyzed five years of measured heating, cooling, and other electric consumption data from the buildings to see how savings have changed over time.

Changes in operating practice were determined by examining the CC reports and any other information available to determine the EMCS settings implemented during commissioning, followed by an examination of the controls system for each building to determine the current EMCS settings. This was supplemented by visits to the buildings, as necessary, to verify the current building operation. If any controls were in manual operation, that was also noted.

A calibrated simulation method was implemented to verify the expected impacts of EMCS changes. Five out of the ten buildings that were utilized for savings calculations were selected and simulated in detail. This process was also applied for three different periods of pre-CC, post-CC and year 2000 in each building to see what parameters were affected and how much they contributed to the energy consumption changes.

The focus of this investigation is not on the detailed measures implemented in each building but rather on the degree to which the measures implemented in the commissioning process have been maintained, as indicated by examination of energy use data, the CC reports, and the control settings in place on the main energy management control system (EMCS).

CHAPTER II

EFFORTS ON MAINTAINING SAVINGS AND SAVINGS DETERMINATIONS - LITERATURE REVIEW

2.1 Introduction

Two issues, one for energy savings determination and one for efforts on maintaining savings, will be discussed in this chapter. There are several ways to assess energy savings, and the methods have their own strong and/or weak points and sometimes have special requirements for application. From a literature survey of the various savings determination methods, the most appropriate and reliable approach will be selected for the analysis of the ten buildings selected for this research. The ten buildings have very good metered chilled water, hot water and electricity consumption data from the pre-CC period through the year 2000 which can be utilized for the savings determinations. While there is much literature available on savings analysis methods, there are relatively few efforts on the issue of maintaining savings obtained from commissioning.

The following presents a brief background on the modeling of energy use and some energy savings results from commissioning as well as the persistence of savings from commissioning. The calibrated simulation process is also mentioned as a way of verifying the impact of control changes to energy consumption.

2.2 Efforts on Maintaining Savings

Several efforts on the issue of persistence of energy savings have been previously reported (Haberl, 1988; Fels and Reynolds, 1988); however, these dealt with persistence of energy retrofit savings. This thesis is concerned with savings commissioning. The interest in this thesis is on the savings persistence after commissioning is completed. After completing the commissioning of an existing building, engineers leave the building with improved comfort and significant energy savings. Unfortunately, several years later they are sometimes confronted with the issue of re-commissioning. It is a waste of energy, money, and time to have to go back and re-commission the building. Buildings do need minor tune-ups over time, but major controls and operational changes will degrade building performance.

2.2.1 Savings from Commissioning

Average energy savings achieved through building tune-ups as a retro-commissioning activity are commonly 5% to 15% with paybacks of around two years. As an example, energy savings of 11.8% from 13 existing buildings were obtained by the conventional retro-commissioning process (Gregerson, 1997).

Continuous Commissioning (CC) activity at the Energy Systems Laboratory (ESL) of Texas A&M University has achieved savings of about 20% beyond the retrofit savings with paybacks of often less than one year and rarely over two years (Claridge et al., 1994, 1996; Turner et al., 1998). Average energy savings from 21 non-retrofitted buildings, which had undergone CC, were 28% for chilled water, 54% for hot water, and 2-20% for electricity (Claridge et al., 2000b).

2.2.2 Savings Degradation

Kats et al. (1996) indicated that savings from retrofits were expected to decrease to 50-80% of initial savings over the 10 year period, but would appear to base this on anecdotal evidence since no source is cited. To improve the reliability and consistency of savings and to maintain savings over time, national consensus standards for energy measurements were required. The North American Energy Measurement and Verification Protocol (NEMVP), published in April 1996, was expected to increase the reliability and quality of savings determination and to improve realized savings since this protocol describes practical methodologies for measuring efficiency savings and provides the steps that engineers should follow to make consistent, reliable, and cost-effective efficiency installations.

Kats et al. (1996) reported that many installations undertaken without any protocol obtain less savings than initially projected and encounter faster degradation of savings, but installations made following a protocol come near the level of estimated savings and maintain savings over time because the protocol requires measurement and verification. Both cases, however, have same starting period of savings degradation, 3-6 months for existing buildings and 1-2 years for new buildings, even though they show different degrees of initial savings and different rates of savings degradation.

2.2.3 Persistence of Savings

The installation of hourly metering and monitoring equipment is increasingly required by measurement and verification protocols. The metered data allows the engineer to determine how the building is using the energy and allows the development of good baseline models. Haberl and Vajda (1988) reported the results using metered data to improve building O&M from two buildings and they found that metered data analysis has provided the administrative and maintenance staffs with useful information related to potential energy conservation measures. Continued metering and monitoring will allow the commissioning engineer to determine if the savings are continuing and optimum operations are being maintained.

The Texas LoanSTAR program, which was conceived by the Texas Energy Office and approved by the U.S. Department of Energy as a statewide demonstration program for building energy efficiency (Turner et al., 2000) initiated an extensive metering and monitoring program as part of the demonstration program. The Energy Systems Lab

(ESL) at Texas A&M University was selected as the monitoring and verification provider, and at one time was monitoring over 300 state buildings retrofitted under LoanSTAR. Using metered data and recognizing that additional savings were possible from additional modeling and simulation, the CC process was begun. The purpose was to optimize the comfort of the occupants and to reduce energy consumption in the buildings. The CC process involves continuous monitoring and follow-up to ensure the savings continue to persist, using the metered and monitored data (Turner et al., 1998).

The ESL reported 145% of engineering estimates for energy savings, including around 26% obtained from operations and maintenance improvements without any retrofits. Kats et al. (1996) investigated performance data for projects for over 900 retrofitted buildings. The realization rates were compared with one another, and the LoanSTAR program involving the metered and monitored data achieved an average of 155 %, which is 42 % higher rate than the other programs without monitoring achieved, on average. The higher savings rate from the LoanSTAR program cannot directly represent persistence of savings over time, and neither can they indicate that good M&V resulted in realization rates that increase over time, because the buildings of the projects were relatively new and few projects had data available for persistence analysis. It is, however, clear that the LoanSTAR program, using good M&V and commissioning practices, improved the level of savings and maintained the benefits obtained from the retrofit over time (Kats et al., 1996).

2.2.4 Factors on Persistence of Savings

There are many feasible reasons for savings degradation after the commissioning is completed. If we think what tasks are generally performed during the commissioning process, it is not very difficult to understand how the degradation can occur. Typically, the commissioning process involves balancing water and air flow, fixing physical and equipment problems, and optimizing the Energy Management Control System (EMCS). Changing the position of a balancing valve, putting systems into manual operation, or simply changing EMCS settings all impact the results of CC. Since the EMCS is relatively easy to access by several individuals, changes to the EMCS seem to be one of the major reasons for shifting energy consumption patterns.

Liu et al. (1994) mentioned that the restoration and re-commissioning of Energy Management and Control System (EMCS) is one major effort of the LoanSTAR O&M program and proper EMCS maintenance is also crucial to the persistence of energy savings, since the building energy cost can be reduced from 10% to 60% in the optimization of HVAC system operation by tuning the EMCS control strategies.

For example, Liu et al. (1994) optimized operation schedules by trial and error using calibrated simulation for the Basic Science building at UTMB, increasing the constant cold deck temperature of 54 ^{o}F to 61 ^{o}F when T_{OA} (Temperature of Outside Air) is below 58 ^{o}F and then linearly decreasing to 57.5 ^{o}F until T_{OA} is at 96 ^{o}F. The estimated energy savings were 27% of the building's thermal energy costs using the baseline cold deck schedule. The actual measured energy savings of this building by raising cold deck temperature from 54 F to 59 F on July 2, 1993 was 21% annually. He also reported that little effort on EMCS maintenance in some of the LoanSTAR agencies has led to total system failure within one year.

2.2.5 Summary of Efforts in Maintaining Savings

The study of persistence of savings is not common in the building commissioning field because it is a relatively new area. There were no papers dealing with building commissioning in the ASHRAE Transactions in 1990 and 1991, and then four papers about commissioning of new systems appeared in 1992 (Claridge et al. 1994). Five years ago Kats et al. (1996) reported the savings results from comparing over 900 buildings retrofitted in early 1990s. His study revealed some reasons for persistence of savings, even though only a few of the 900 buildings had data available for persistence analysis. The ESL had metering and monitoring programs in building commissioning from the LoanSTAR program and reported savings from metered data; however, there has been no systematic approach to savings degradation. The savings results are reported monthly in LoanSTAR, based on pre-post savings models. The optimization and maintenance of EMCS settings are important to the persistence of savings.

2.3 Savings Determination

To determine energy savings, several approaches are currently used. The simplest and one of the earliest methods for savings calculation is the direct comparison of utility bills (Fels, 1986), which is easy to understand and requires only minimal input. But this method has a deficiency in that weather changes are unaccounted for. It has been determined that weather change can result in a 10-20 % estimation error for the annual baseline use (Wang, 1996). Weather normalization greatly improves the accuracy of monthly utility bill modeling, but utility bill tracking is commonly used as an accounting procedure and for savings determination.

Energy use modeling is a widely used method for calculating savings. In the field of energy use modeling, there are usually three different types of categories, forward models, inverse models, and hybrid models. The hybrid modeling method uses the characteristics of both the inverse and forward methods. Forward modeling utilizes the features of the building envelope, equipment, and occupancy schedules to make calculations for predicting energy consumption using engineering models. Forward modeling, such as DOE-2 (LBL, 1981) and the AirModel program (Liu, 1993), involves a calibrated simulation process. DOE-2, a calibrated (or un-calibrated) building simulation program, is utilized for new construction design simulation and for evaluating the impact of energy conservation retrofits on existing buildings as well. Efforts on calibration procedures for DOE-2 and DOE-2.1D appeared in several papers (Bronson et al., 1992; Haberl and Bou-Saada, 1998). AirModel, a simplified HVAC system simulation program, is used to simulate building thermal and electric energy consumption. The advantages of using AirModel compared to the DOE-2 program are the significant reductions of input data by adopting a steady state method. The accuracy is suitable for predicting savings.

Inverse modeling has been used for several purposes of identifying energy savings from building retrofits, estimating the performance of an existing building under future weather conditions, constructing a model of HVAC subsystems for optimal control, and diagnosing faulty HVAC systems. This technique uses the measured energy consumption of buildings to develop empirical regression models. These can be simplified by assuming steady-state behavior of the building; therefore, this technique is divided into two categories. Steady state inverse models, the simplest form of inverse models, are developed by utilizing a regression analysis on utility consumption data against average billing period temperature. Dynamic inverse models, complex forms of inverse models, are able to model complicated systems having more than one independent parameter. The dynamic inverse models are not easily developed because they require a high degree of interaction and knowledge of the building (ASHRAE 1997).

The simulation and calibration process of forward modeling is time-consuming and may be too costly. They largely rely on the user's experience, knowledge, and detailed building HVAC operation and weather information. On the other hand, weather-normalized analysis using statistical regression models is less costly and can significantly reduce the 10-20 % baseline estimation error of the direct utility bill comparison method. They are preferred and widely used. In this thesis steady-state inverse regression energy use modeling is applied as the method for savings determination.

2.3.1 Inverse Regression Models: Modeling Programs

For commercial buildings, inverse regression models are likely to be a benchmark to develop the energy use models. These models have been used to document energy savings (Kissock, 1993) and to identify the operation and maintenance problems (Haberl and Claridge, 1987). Emodel, developed by the Energy Systems Laboratory at Texas A&M University in 1993, is one of the commercial software packages available which uses weather as the major variable for explaining energy changes in commercial and residential buildings. Advanced PRISM (Fels et al., 1994), FASER (Heinz, 1996), and Metrix (SRC, 1996) are proprietary software programs with similar capabilities.

The major difference between Emodel and PRISM, both of which utilize change point linear regression models, is that Emodel uses daily average temperatures, while PRISM uses variable-based degree-days (Reddy et al. 1996). PRISM was originally developed to model energy use in residential buildings and then was later upgraded to be utilized for commercial buildings (Haberl and Komer 1990a, Haberl and Komer 1990b, Fels and Reynolds 1991). FASER, using a simple linear regression between energy use and degree-days, provides a tool to check for irregular energy consumption. The program also helps track and analyze electricity and gas consumption (Heinz, 1996). Metrix utilizes simple linear regression methods to model energy use versus degree hours for each billing history period by using daily outdoor temperature measurements. It also allows the user to input additional variables that may influence energy consumption (SRC. 1996). Their effectiveness in analyzing energy consumptions has been shown in many applications.

A degree day is measure of the heating or cooling load on a facility created by the outdoor temperature. When the mean daily outdoor temperature is one degree below a stated reference temperature, such as 18 °C, for one day, it is defined that there is one heating degree day. If this temperature difference prevailed for ten days there would be ten heating degree days counted for the total period. If the temperature difference were to be 12 degrees for 10 days, 120 heating degree days would be counted. When ambient temperatures are above the reference, cooling degree days are counted. Any reference temperature may be used for recording degree days, usually chosen to reflect the temperature at which heating or cooling is no longer needed.

2.3.2 Steady-State Inverse Models

Although a lot of factors such as solar radiation, ventilation, internal loads, lighting, and heat transfer all impact the building heating and cooling load, the most significant one is outside air temperature. As seen in equation 2.1, Q is almost linearly dependent on T_{OA} since the other variables, U, A and T_{ROOM}, are fairly constant.

$$Q = U*A*(T_{ROOM} - T_{OA}) \tag{2.1}$$

Where Q: transmission load

U: thermal conductivity

A: building external surface area

T_{ROOM}: designed room temperature

T_{OA}: outside air temperature

Therefore, Single Variable Regression Analysis (SVRA) using T_{OA} as a unique variable can be utilized to develop energy use models. It has not only been primarily implemented for the Texas LoanSTAR program to build baseline energy use models, but also satisfactorily shown in the results for residential and commercial applications (Fels, 1986; Claridge et al., 1990; Ruch et al., 1991).

The single variable regression models using outside air dry-bulb temperature as the only regression variable are usually divided into several different types, which are two, three, four (Claridge et al., 1990), and five parameter models (Fels et al. 1995). The two parameter models (2P) constitute linear correlation between the energy use and outdoor temperature and are often appropriate for weather dependent energy use, such as cooling and heating energy use in constant air volume systems without control options such as economizer cycles and hot deck reset schedules. This two parameter model can be used, for example, for a building with its own heating and cooling system year round and with relatively low internal loads. Equation 2.2 expresses the functional form of two parameter models, and Figure 2.1 shows the relationship graphically.

$$E = a + b * T_{OA} \tag{2.2}$$

where E is the energy use, a and b are the regression coefficients, and T_{OA} is the outside air dry bulb temperature.

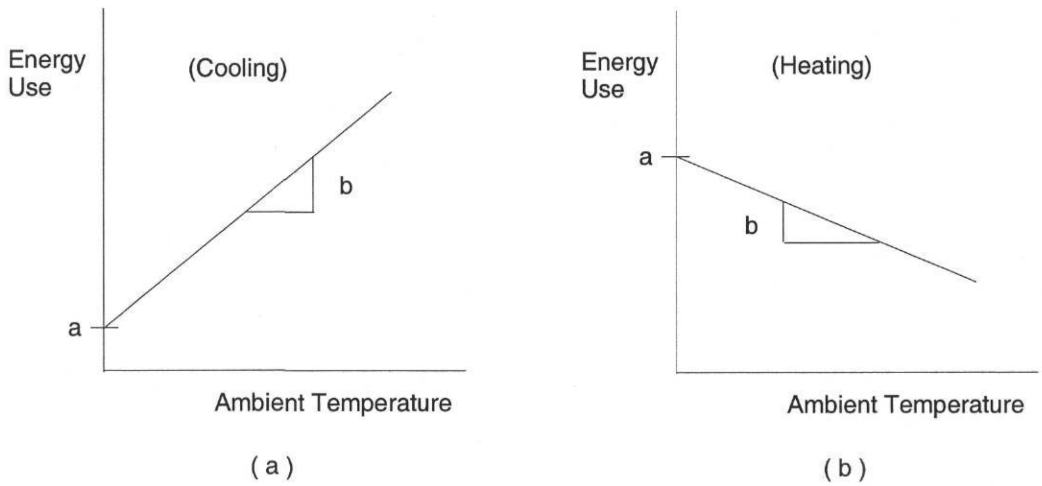


Figure 2.1 Two-parameter single variable regression models for cooling and heating

The three-parameter model (3P), which is often useful for describing energy use in single zone, skin dominated buildings, is composed of two different parts, one part of constant load with temperature and the other part of linearly changing load with temperature (Kissock et al., 1994). The three-parameter model applies very well for residential houses with both daily and monthly data but not for commercial buildings since scheduling effects play a major role in the energy consumption pattern of most commercial buildings (Liu, 1993). The equations 2.3 and 2.4 express the functional form of three-parameter models, and Figure 2.2 shows the relationship graphically.

For cooling,

$$E = a + b * (T_{OA} - T_{CP})^{+} \tag{2.3}$$

For heating,

$$E = a + b * (T_{OA} - T_{CP})^{-} \tag{2.4}$$

where a is the energy use at the change point temperature, Tcp, and b is the slope. The notation $(\ )^{+/-}$ indicates that the quantities within the parenthesis should be positive or negative whichever it says; otherwise they are set to zero.

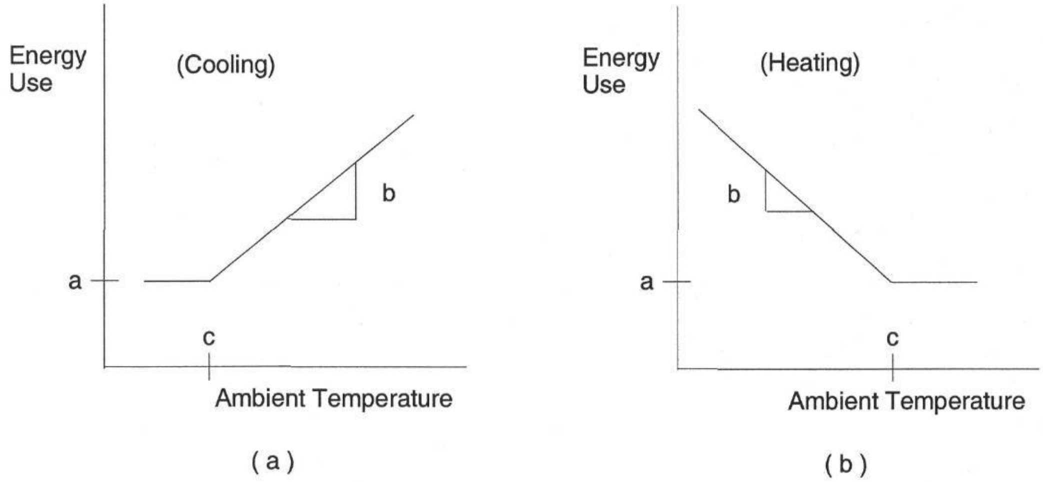


Figure 2.2 Three-parameter single variable regression models for cooling and heating (C indicates the change-point temperature location)

The four-parameter model (4P) consists of two segmented linear models and is useful when describing thermal energy use in multi zone, commercial buildings (Kissock, 1994). The difference between 3P and 4P models is that 3P models assume a constant temperature-independent baseload while 4P models do not. Most commercial buildings have two zones, one for interior zones that are internally load dominated and one for exterior zones that are weather dominated. This model then can be utilized for these types of buildings and has historically given better and more reasonable results for many commercial buildings than the three parameter model (Ruch and Claridge, 1991).

Equation 2.5 expresses the functional form of four parameter models, and Figure 2.3 shows the relationship graphically.

$$E = a + b_1 * (T_{OA} - T_{CP})^- + b_2 * (T_{OA} - T_{CP})^+ \qquad (2.5)$$

where the notation follows that used in the three parameter models.

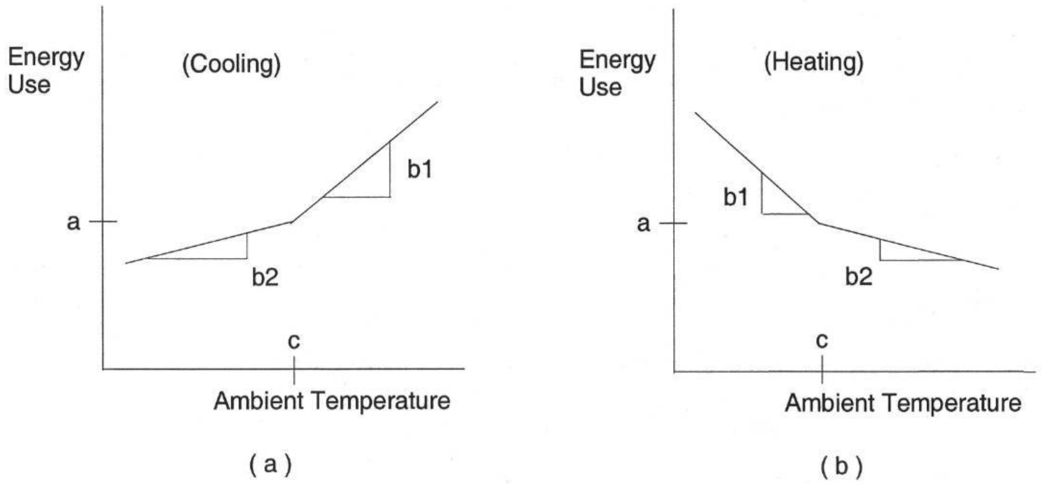


Figure 2.3 Four-parameter single variable regression models for cooling and heating

Finally, the five-parameter model (5P) can be helpful to develop models for buildings that are cooled and heated by electricity. This model, as shown in Figure 2.4, forms a base level energy consumption value and two change points on an ambient temperature axis. Equation 2.6 expresses the functional form of five parameter models.

$$E = a - b_1 * (T_{OA} - T_{CP1})^- + b_2 * (T_{OA} - T_{CP2})^+ \tag{2.6}$$

where the notation follows that used in the three parameter models.

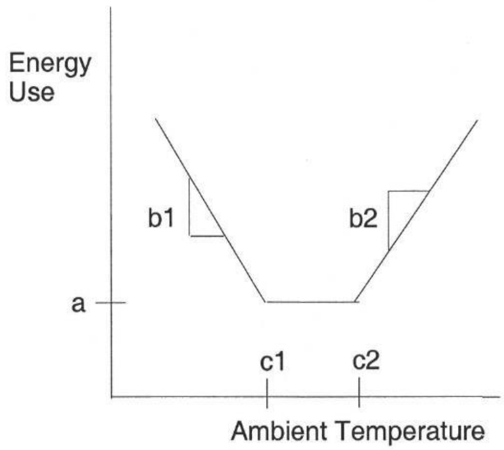


Figure 2.4 Five-parameter single variable regression models for cooling and heating with separate change points (C1 and C2 are the change-point locations for heating and cooling, respectively)

2.3.3 Summary of Savings Modeling

To help calculate and document energy savings using standard procedures, the U.S. Department of Energy (US DOE) organized a committee to develop measurement protocols. The initial document issued is The North American Energy Measurement and Verification Protocol (NEMVP), which was published in 1996 by the United States Department of Energy (US DOE. 1996b). The NEMVP was succeeded by the International Performance Measurement and Verification Protocol (IPMVP), issued by the U.S. Department of Energy in 2000 (US DOE 2001). IPMVP consists of three volumes in which Volume I deals with concepts and options for determining savings, Volume II covers indoor environmental quality (IEQ) issues, and Volume III contains applications. Volume I of IPMVP introduces four options of Measurement and Verification (M&V), Option A-D, and defines general procedures for each option to achieve reliable and cost-effective determination of savings.

To determine energy savings using Option A, Partially Measured Retrofit Isolation, utilizes engineering calculations and short term or continuous post-retrofit measurements in conjunction with stipulation of some parameters. Option B, Retrofit Isolation, utilizes engineering calculations using short term or continuous measurement. Option C, Whole Facility, does analysis of whole facility utility meter or sub-meter data using techniques from simple comparison to regression analysis for savings determination. Option D, Calibrated Simulation, performs energy use simulation calibrated with hourly or monthly utility billing data and/or end-use metering to determine savings.

In this thesis Option C of the IPMVP is implemented to determine energy savings since the ten buildings selected have enough whole building metered data for cooling, heating and electricity to be able to make baseline use models and post-CC use models. The three and four parameter linear regression energy use models are then formed based on daily average temperature changes. The yearly energy use is calculated and compared to analyze the persistence of savings.

CHAPTER III

METHODOLOGY

3.1 Building Selection

A preliminary group of 20 buildings on the Texas A&M campus, which had been commissioned in 1996 or 1997, was initially selected. An office review of information on the commissioning measures implemented and available information on operating parameters before and after commissioning was then conducted. Based on this review, the 10 buildings with the most complete information concerning the commissioning process and energy consumption data were selected for the persistence study. None of the buildings in this group received capital retrofits during the period 1996-2000.

Five buildings were commissioned in 1996 and the other five were finished in 1997. Since all 10 buildings are located on the Texas A&M campus, the buildings are typically classrooms, laboratories, and offices, except for the G. R. White Coliseum which is a basketball arena. The Koldus building has the smallest conditioned area (97,920 ft^2) and the conditioned areas of the other nine buildings range from 110,000 ft^2 to 260,000 ft^2.

Five of the ten buildings have dual duct Air Handling Unit (AHU) systems and the other five buildings have single duct AHU systems. Major air handlers in nine of the ten buildings are Variable Air Volume (VAV) systems. There are two buildings that have Outside Air Handling Units (OAHUs) that distribute outside air to each AHU, and the rest of the buildings have normal outdoor air intakes for each AHU. Chilled water for cooling and hot water for heating are supplied by the Central Plant on campus. The Heating, Ventilating, and Air-Conditioning (HVAC) systems in all of these buildings are connected to the Siemens Direct Digital Control (DDC) Energy Management Control System (EMCS). Brief summary information for the 10 buildings is shown in Table 3.1.

Building energy use data for chilled water, hot water, and electricity have been retrieved from the ESL energy monitoring equipment, and data on major measures and EMCS settings during commissioning activities have been collected from commissioning reports. For additional information about the buildings, engineers currently working in the Energy Systems Laboratory (ESL) were consulted as necessary.

Table 3.1 Summary Information for the 10 Texas A&M University Buildings Selected for the Study

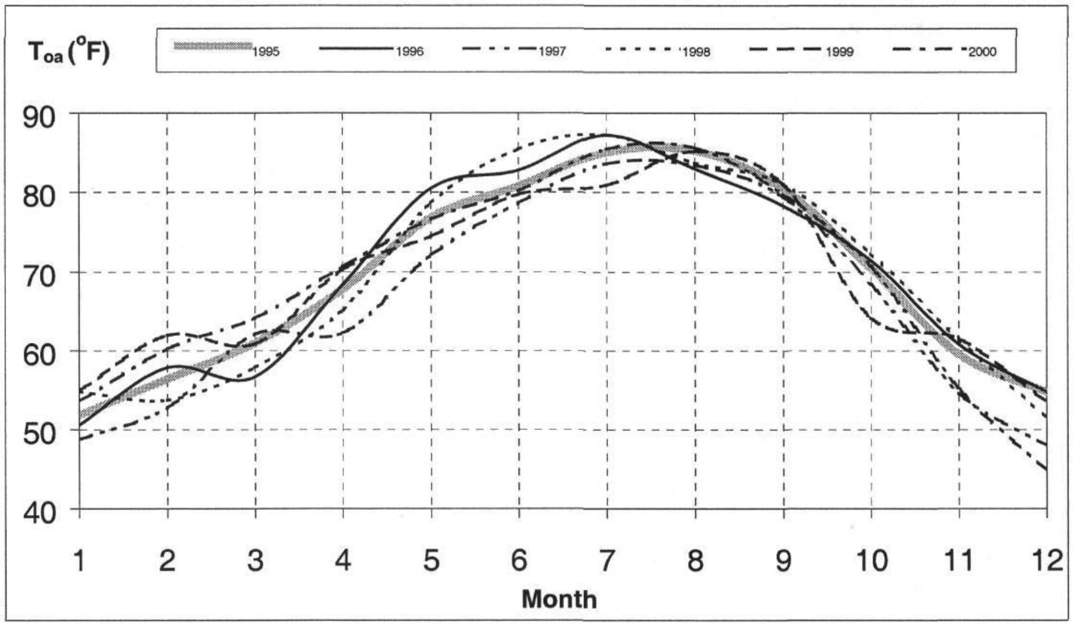
No.	Building Name	Area (ft^2)	HVAC System Types	CC Period
1	Blocker	255,490	10 DDVAV AHUs & 2 100% OA units 2 SDCV AHUs & 1 Liebert unit	2 / 97 - 4 / 97
2	Eller O&M	180,316	4 DD-Dual Fan VAV AHUs 2 CV MZ Units	2 / 97 - 3 / 97
3	G.R.White Coliseum	177,838	13 CV AHUs 5 SDCV AHUs with reheat coil (Pneumatic)	5 / 97 - 7 / 97
4	Harrington Tower	130,844	1 - 200 hp DDVAV AHU 3 smaller SD AHUs for 1st floor	7 / 96 - 8 / 96
5	Kleberg Building	165,031	2 x 100 hp SDVAV AHUs 2 x 25 hp return air fans	4 / 96 - 7 / 96
6	Koldus Building	97,920	5 SDVAV AHUs 5 SDCV AHUs	3 / 97 - 4 / 97
7	Rich. Petroleum	113,700	7 SDVAV AHUs 2 SDCV AHUs	9 / 96 - 9 / 96
8	Vet Med Center Addition	114,666	5 SDVAV AHUs 4 out of 5 AHUs are 100% OA	10/ 96 - 11/ 96
9	Wehner CBA	192,001	6 DDVAV AHUs 3 SDVAV AHUs	11/ 96 - 12/ 96
10	Zachry Engr Center	258,600	12 DD-Dual Fan VAV AHUs 3 SDCV AHUs	12/ 96 - 3 / 97

3.2 Data Requirements

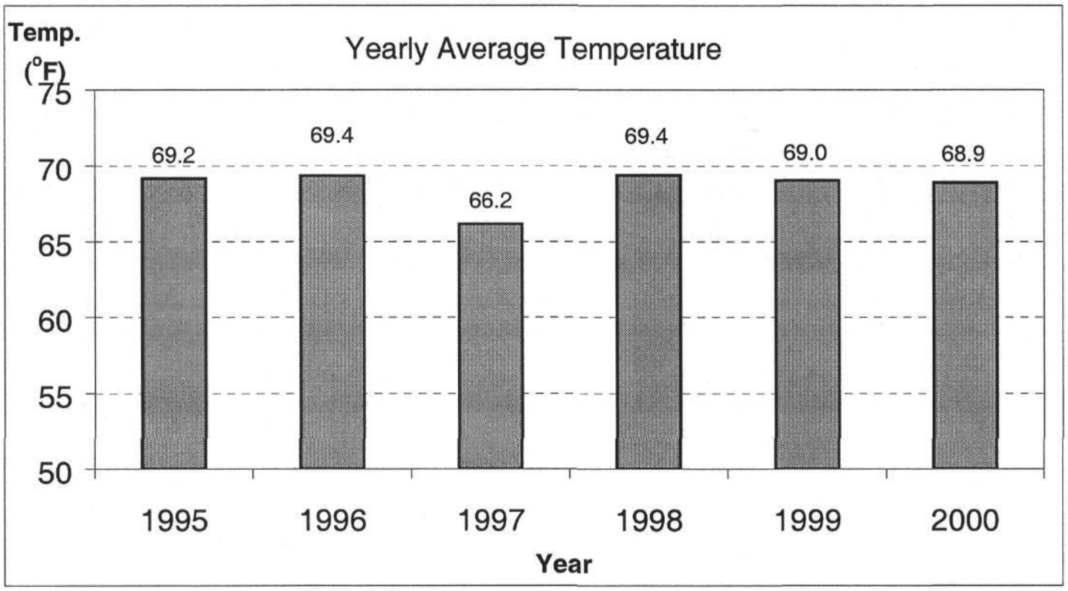
The following is a description of the procedures that were followed in the study of the persistence of savings obtained from the continuous commissioning process. The 10 buildings were required to have at least three years of history after CC. Second, the hourly monitored data set was required to be reasonably complete, including chilled water, hot water, and electricity consumption. Third, a well-documented CC report needed to be available.

3.2.1 Normalizing the Consumption Data for Weather Variation: Weather Selection

Energy consumption of the pre-CC and post-CC periods has been measured on a continuous basis. However, to assure that variations in the savings determined were not the result of year-to-year weather variations, it was decided to normalize all savings to a common weather year. After comparing the years 1995 through 2000, it was decided to use 1995 as the "normal" year. Figure 3.1 shows the annual and monthly average temperatures for 1995-2000 in College Station, TX. The year 1995 not only had an average temperature nearest to the average for the period, but the average temperature for every month was within the extremes for that month as well.



(a)



(b)

Figure 3.1 Monthly average and annual average temperature data for college station during the period of 1995 - 2000

3.2.2 Determining the Savings: Baseline Models

Energy savings are determined by comparing energy use before and after the commissioning process has been completed. Generally,

$$\text{Energy Savings} = \text{Pre-CC Energy Use} - \text{Post-CC Energy Use} \tag{3.1}$$

The energy use quantities in Equation 3.1 can be obtained by techniques such as utility bill analysis, metering, computer simulation, etc. Savings from the commissioning process here have been determined using a variant of Option C of the International Performance Measurement and Verification Protocol (IPMVP, 2000), which determines savings using measured energy use at the whole facility level. This required that baseline models of the consumption be determined for each major energy use in each building. The variant of Option C presented here normalizes the savings determined for several years to remove year-to-year savings variation due to weather differences.

CHW and HW energy consumption have been measured for each year, and three-parameter or four parameter change-point models of cooling and heating consumption have been determined as functions of ambient temperature using E-Model (Kissock et al., 1994), a program for data processing, graphing, and modeling energy consumption data. One full year of data was used to develop the baseline models whenever sufficient data were available. However, in several cases, a full year of pre-CC data is not available and in those cases, baseline models were developed using less than a full year of data.

Electricity savings were determined without normalization since the buildings do not contain chillers, and electricity consumption is not appreciably affected by ambient temperature.

3.2.3 Three-Parameter and Four-Parameter Change Point Models

To generate the models, ambient temperature was used as the only independent variable. Two model forms were used for energy use determination, one of which is a 3-Parameter Change Point (3-P CP) Model and the other of which is a 4-Parameter Change Point (4-P CP) Model described in Chapter II of this thesis.

3.2.4 Determining the Savings

In most situations, the weather data during the period for which savings are determined is used in the baseline model to determine baseline consumption. In this study, the primary interest is in the persistence of the savings from one year to the next. Consequently, it was decided to minimize savings variation due to year-to-year weather variation by using the same weather year for not only the baseline model, but also the years for which savings were desired. This required that models be developed from the measured data for each of the years 1997 - 2000 in addition to the baseline models.

Thus the 1997 HW savings for Blocker, for example, were determined by creating a 3P model of the 1997 HW consumption, and using 1995 weather data in the 1997 HW model to determine 1997 HW consumption normalized to 1995 weather. This normalized 1997 HW consumption was then subtracted from baseline HW consumption (determined by using 1995 weather data in the baseline HW model) to determine the 1997 HW savings.

This process required developing five separate CHW models and five HW models for each building, one for each year, including the baseline model. The consumption and savings for each year were then normalized to 1995 weather by using the models for each year's data with the 1995 temperature data to determine the savings for each year.

3.3 Calibrated Simulation

After the savings calculations were completed, an analysis was made to investigate the reasons why the savings have degraded over time since commissioning was completed. When significant deterioration of savings was found, a further analysis was needed to determine why the degradation occurred.

The calibrated simulation method for energy savings calculations is generally best applied when the energy use data for either pre or post energy conservation measures are unavailable or unreliable. The usage of this method is described in detail as Option D of the International Performance Measurement and Verification Protocol (IPMVP, 2000).

In this thesis, however, this method, calibrated simulation, has been implemented to investigate how control changes impact the energy consumption during the period of savings determination. The ten buildings selected for the persistence study have good records of EMCS changes that are well documented during the commissioning process. These include parameters such as cold deck, hot deck and static pressure schedules, total air and outside air flow settings, room temperature settings for day and night, minimum flow for occupied and unoccupied periods, etc. The calibrated simulation approach can be applied in this instance to determine the impact of EMCS settings on building energy savings.

3.3.1 Simulation Program Used: AirModel

There are different types of building simulation models, as discussed in the ASHRAE Handbook (1997). DOE maintains its own building energy simulation programs, DOE-2 and BLAST, but they are very complicated. To calculate building energy consumption accurately, intense computational requirements and high levels of designer expertise are needed, because the energy consuming systems in buildings are not only nonlinear and dynamic but also complex. These simulation methods, therefore, are very time consuming and costly. Relatively simple and timesaving methods are frequently needed since there are situations where energy consumption should be estimated quickly to investigate energy consumption trends, to compare systems, and to identify the operation problems.

When the parameters for simulation, such as internal loads, types of HVAC systems, and heat loss or gain models are not too complex, techniques using simplified energy analysis procedures can be used. AirModel (Liu and Claridge, 1995), a simplified HVAC system simulation program, was first developed by Liu (1993) based on extensive engineering experiences of the Continuous Commissioning group at the Energy Systems Laboratory and was used to identify Operation and Maintenance (O&M) problems in LoanSTAR buildings. The purposes of this program are to identify the operation problems, to evaluate energy savings, and to improve O&M and commissioning.

The advantages of using AirModel compared to DOE-2 and BLAST are the significant reductions of input data and the reduction in simulation time. This allows the CC engineer to concentrate on the main problems they are investigating while spending less time on simulation. Therefore the AirModel program was selected and used here for the calibrated simulation process to verify the effect of EMCS changes on energy savings degradation. AirModel is a steady state model, but its accuracy is considered suitable for predicting the energy savings from CC and for comparing the effects of EMCS changes modeled in this thesis.

3.3.2 Data Needed for Simulation

To run the AirModel program, users prepare two files, an input file and a weather source file. For the weather file, hourly measured chilled water and hot water energy use data and bin weather data, which includes dry bulb and dew point temperatures, have been retrieved from the ESL database for the same periods of time.

For the input file, the following information for each building has been collected;

1) HVAC system type
2) Conditioned floor area
3) Internal zone fraction
4) Total flow rate and outside air flow rate
5) Building occupancy schedule
6) Room temperature settings
7) Minimum air flow
8) Internal gain level
9) Building envelope heat transfer coefficient

10) Deck control schedule: Design and current schedules

11) Preheat setting

12) Other miscellaneous data

The input data were obtained from architectural and mechanical drawings, from EMCS program (APOGEE), from the CC reports, and from field investigations.

3.3.3 Calibrated Simulation Procedure

After the input information and operational data are collected, the steps followed for calibrated simulation are as shown below.

1. Create an input file (inp.dat). The input file consists of nine sections; section 1 is for general information, sections 2~8 are for sub-system information, and section 9 is for plant information. More detail instructions for each section are available in the User's Manual for Air Side Simulation Programs (Liu 1997).
2. Simulate building cooling and heating energy consumption with initial input (or revised) data. An output file (out.dat) is created after the simulation program is run, and the file involves the simulated energy consumption and measured energy use as well.

3. Develop time series graphs and ambient-temperature-based scatter plots to compare simulated daily cooling and heating energy consumption patterns with measured energy use patterns. In the same plot residuals need to appear.

4. Compute the values of Coefficient of Variation of the Root Mean Square Error (CVRMSE) and Mean Biased Error (MBE). These values help users determine how much the simulation result deviates from measured use. These statistical indices are defined below (IPMVM 2000).

$$CVRMSE = 100 \times [\, \Sigma\, (y_{p,i} - y_{d,i})^2 / (n - p)\,]^{1/2} / Y_d$$

$$MBE = 100 \times [\, \Sigma\, (y_{p,i} - y_{d,i})\,] / [\,(n - p) \times Y_d\,]$$

Where:

$y_{d,i}$	data value of the dependent variable corresponding to a particular set of the independent variables
$y_{p,i}$	predicted dependent variable value for the same set of independent variables above
Y_d	arithmetic mean value of the dependent variable of the data set
n	number of data points in the data set
p	total number of regression parameters in the model

5. Compare the simulated cooling and heating energy consumption with measured energy use based on the information of steps 3 and 4. If both cooling and heating

energy consumption results are in between the CVRMSE value of ±10% through ±20%, it is considered that the simulation using those parameters appropriately represents the building energy consumption pattern. When the simulation achieves this accuracy, go to step 8, otherwise go to step 6.

6. Revise previously used input data within the range of reasonable and explainable limits to achieve simulation results reasonably close to the measured energy use. The HVAC systems are different for every building, and include single duct constant (or variable) air volume (SDCV or SDVAV) system, dual duct constant (or variable) air volume (DDCV or DDVAV) system, and so on. When calibrating input parameters, users can take advantage of the signatures (Wei et al., 1998) for different parameters on the heating and cooling energy consumption for some typical air handling units mentioned above. The signatures are useful to make quick decisions about how much a certain parameter will affect the cooling and/or heating energy consumption for a specific system during the calibration process and to find reasonable parameters that can increase or decrease cooling and/or heating energy in a particular ambient temperature range. For example, if the simulation result is higher than measured energy use, the conditioned floor area or the airflow rate is probably higher than the actual values. Conversely, in case of lower values of simulated models than those of measured models, some reasons include the actual cold deck temperatures are higher than the scheduled temperatures and/or the hot deck temperatures are lower than the designed values. In those cases the signatures quantitatively help to know how much a given amount of change, i.e. raising or

dropping a certain parameter in a specific air handling system, will impact the final energy consumption.

7. Go back to step 2 when the modified input file is prepared. Repeat these procedures until the simulation results agree with the measured energy use within the specified limits.

8. Calculate yearly cooling and heating energy consumption. The final calibrated input data are used for the calculation of annual energy consumption using the weather data of 1995 as the normalized year. The hourly output was summed for the 8760 total hours in a year to get the annual output

The regression models are daily models, and since the weather file is composed of hourly data, after running the simulation program the output data needs to be converted into daily data for the analysis of daily energy consumption patterns. Therefore in step 3 the hourly energy consumption is summed into daily, and the hourly temperature is averaged into daily. The graphs, plots and values in steps 3 and 4 can be easily developed by using spreadsheets such as an Excel program and can be then automatically created from the 2nd simulation by pasting the newly simulated data into the old data.

CHAPTER IV

PERSISTENCE OF NORMALIZED SAVINGS FROM COMMISSIONING

4.1 Introduction

The chilled water and hot water savings after CC were normalized as previously described, but electric savings were not normalized as discussed the electricity consumption did not show a weather dependent relationship. Table 4.1 and Figure 4.1 show the savings for each building for the years 1997 - 2000. The savings results were calculated by using the Emodel program with normalized weather data of 1995. All ten buildings show reduced chilled water and hot water energy consumption since the CC activities, although the savings have generally decreased somewhat with time. Eight buildings had larger HW savings in 1998 than in 1997 as a consequence of hot water loop optimization conducted in 1997 and final commissioning actions. The Richardson Petroleum, VMC Addition and the Wehner buildings show small increases in electrical consumption (negative savings).

Table 4.1 Normalized Measured CHW and HW Consumption and Savings and Measured Electricity Consumption and Savings for the 10 Buildings for the Periods of 1997 - 2000

Building Name	Type	Baseline Use (MMBtu) (MWh) / yr	1997		1998		1999		2000	
			Use (MMBtu) (MWh) / yr	Saving (%)	Use (MMBtu) (MWh) / yr	Saving (%)	Use (MMBtu) (MWh) / yr	Saving (%)	Use (MMBtu) (MWh) / yr	Saving (%)
Blocker	CHW	22,955	16,723	**27**	19,530	**15**	20,164	**12**	21,083	** 8
	HW	8,735	4,093	**53**	1,676	**81**	3,330	**62**	4,344	** 50
	Elec	4,832	3,773	**22**	3,883	**20**	3,936	**19**	3,859	**20**
Eller O&M	CHW	30,625	18,846	**38**	18,660	**39**	19,012	**38**	20,360	**34**
	HW	7,584	2,578	**66**	1,154	**85**	1,831	**76**	4,712	**38**
	Elec	4,891	3,698	**24**	3,675	**25**	3,823	**22**	3,874	**21**
G.R.White Coliseum	CHW	18,872	8,717	**54**	8,511	**55**	14,548	**23**	15,858	**16**
	HW	21,155	6,091	**71**	549	**97**	4,923	**77**	10,111	**52**
	Elec	1,480	1,297	**12**	1,168	**21**	1,171	**21**	1,291	**13**
Harrington Tower	CHW	14,179	7,109	**50**	8,420	**41**	7,660	**46**	9,032	**36**
	HW	6,896	2,603	**62**	914	**87**	1,629	**76**	3,519	**49**
	Elec	1,666	1,297	**22**	1,336	**20**	1,341	**20**	1,353	**19**
Kleberg Building	CHW	59,271	34,864	**41**	34,969	**41**	36,731	**38**	41,965	**29**
	HW	40,812	6,523	**84**	1,215	**97**	8,030	**80**	10,591	**74**
	Elec	5,511	5,458	**1**	5,067	**8**	4,778	**13**	4,684	**15**
Koldus Building	CHW	* 21,964	12,177	**45**	12,988	**41**	12,740	**42**	11,804	**46**
	HW	2,103	704	**67**	399	**81**	634	**70**	649	**69**
	Elec	2,850	2,511	**12**	2,597	**9**	2,624	**8**	2,592	**9**
Rich. Petroleum	CHW	28,526	13,599	**52**	15,637	**45**	15,078	**47**	17,702	**38**
	HW	* 18,227	6,565	**64**	5,588	**69**	5,098	**72**	2,171	**88**
	Elec	1,933	1,898	**2**	1,914	**1**	1,991	**-3**	2,153	**-11**
VMC Addition	CHW	40,892	23,115	**43**	24,080	**41**	22,915	**44**	23,307	**43**
	HW	3,569	887	**75**	2,041	**43**	2,097	**41**	2,051	**43**
	Elec	4,186	3,996	**5**	4,140	**1**	4,236	**-1**	4,056	**3**
Wehner CBA	CHW	19,193	12,327	**36**	13,339	**31**	12,530	**35**	11,609	**40**
	HW	13,393	10,876	**19**	9,715	**27**	6,581	**51**	6,350	**53**
	Elec	2,555	2,410	**6**	2,446	**4**	2,552	**0**	2,581	**-1**
Zachry Engr. Center	CHW	40,824	16,737	**59**	17,377	**57**	18,148	**56**	20,225	**50**
	HW	7,676	1,630	**79**	3,230	**58**	2,226	**71**	4,271	**44**
	Elec	7,502	6,762	**10**	6,793	**9**	7,099	**5**	6,955	**7**
Type		*Total*	*Total*	***Average***	*Total*	***Average***	*Total*	***Average***	*Total*	***Average***
Chilled Water		297,298	164,215	**44.8**	173,509	**41.6**	179,527	**39.6**	192,946	**35.1**
Hot Water		130,149	42,549	**67.3**	26,482	**79.7**	36,380	**72.0**	65,508	**49.7**
Electricity		37,407	33,100	**11.5**	33,018	**11.7**	33,552	**10.3**	33,399	**10.7**

* The baseline energy use for these buildings was estimated from the average savings of the other buildings because insufficient data was available to create reliable baselines.

** The Blocker building had insufficient chilled water and hot water energy use data in 2000 to determine normalized annual consumption. So the savings were estimated from the average degradation that occurred between 1999 and 2000 in the other 9 buildings.

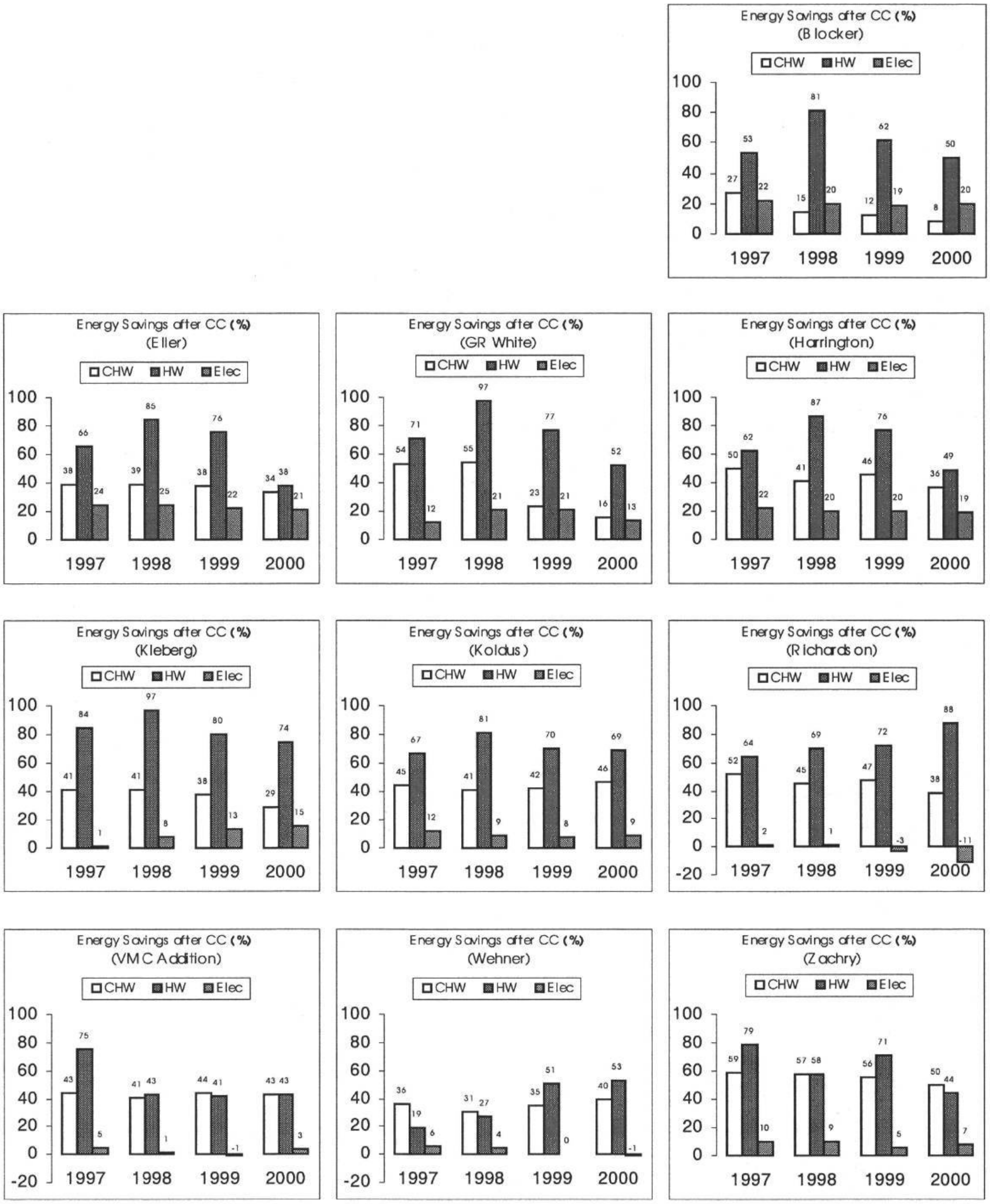
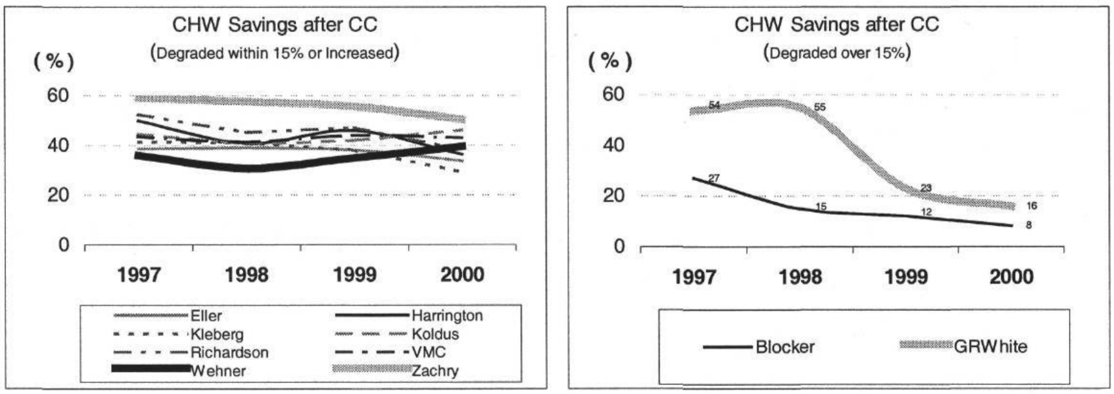


Figure 4.1 Summary of annual percentage energy savings for 1997 - 2000 after CC activity for 10 buildings at Texas A&M University

4.2 Savings Analysis

4.1.1 Chilled Water Savings

To see clearly the chilled water savings after CC, the ten buildings were divided into two groups, one for the buildings that show good persistence of savings (less than 15 % change during the 3-4 years after CC) and one for the buildings with significant degradation. Overall, chilled water savings for the period averaged 39.3% of the pre-CC baseline. Figure 4.2 (a) is the grouping of eight buildings showing little change in savings while Figure 4.2 (b) shows the two buildings with degraded performance.



(a) (b)

Figure 4.2 Normalized yearly CHW energy savings after CC activity

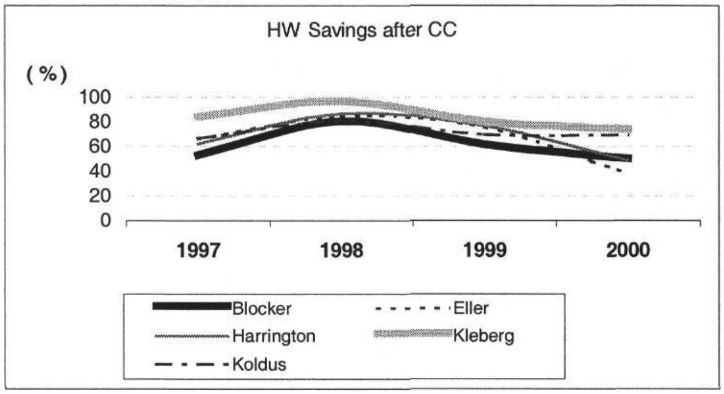
As seen in Figure 4.2, chilled water savings for eight buildings have changed by less than 15% over the period 1997 - 2000, while the Blocker building shows 19% degradation. The G. R. White Coliseum shows a dramatic savings degradation of 38%. The AHU control in this building was malfunctioning. There are 13 single duct AHUs serving the basketball coliseum. Supply air temperatures for two AHUs were, as shown in Table 3, around 120 °F, which means they were operating in the heating mode, and the others were between 49 °F and 72 °F, which means they were operating in the cooling mode. This simultaneous heating and cooling increased both chilled water and hot water use.

Table 4.2 Supply and Return Temperature Readings on AHUs in the G. R. White Coliseum

No.	AHU No.	Return Air Temperature (°F)	Supply Air Temperature (°F)
1	AHU 5	73	**121**
2	AHU 10	67	**118**
3	AHU 7	74	**72**
4	AHU 8	74	**72**
5	AHU 11	76	**70**
6	AHU 4	74	**62**
7	AHU 3	77	**54**
8	AHU 12	70	**54**
9	AHU 2	77	**53**
10	AHU 6	78	**53**
11	AHU 1	77	**52**
12	AHU 9	75	**49**
13	AHU 13	64	**49**

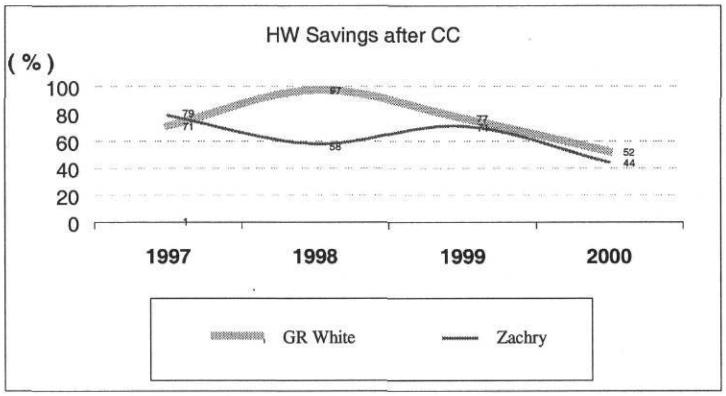
4.1.2 Hot Water Savings

Hot water consumption has been significantly reduced since CC was performed, but the savings fluctuate widely from year to year. Savings increased from 1997 to 1998 in most buildings due to optimization in the hot water loop during 1997, and some ongoing CC work. Figure 4.3 (a) shows the results for the five buildings with fairly consistent savings. Figure 4.3 (b) shows widely varying results for the HW savings, and Figure 4.3 (c) shows the savings increased for two buildings. Reasons for these increases have not yet been determined. The 10 buildings averaged hot water savings of 65.0 % after CC.

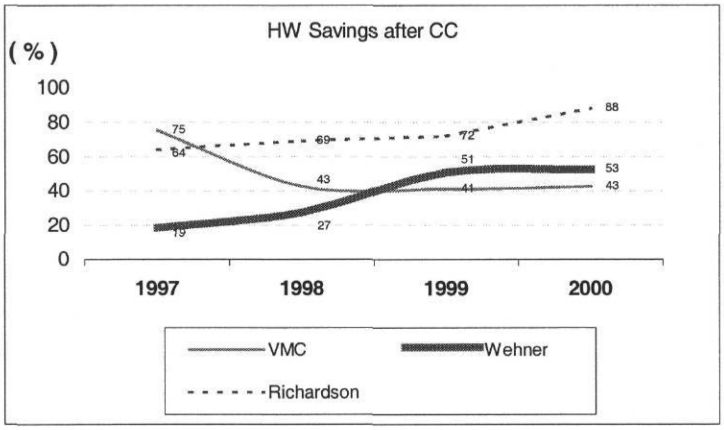


(a)

Figure 4.3 Yearly percentage HW energy savings after CC activity. (a)five buildings showing consistent savings, (b)two buildings show varying results every year, and (c)two buildings show savings increases and one building showing consistent savings since 1997



(b)

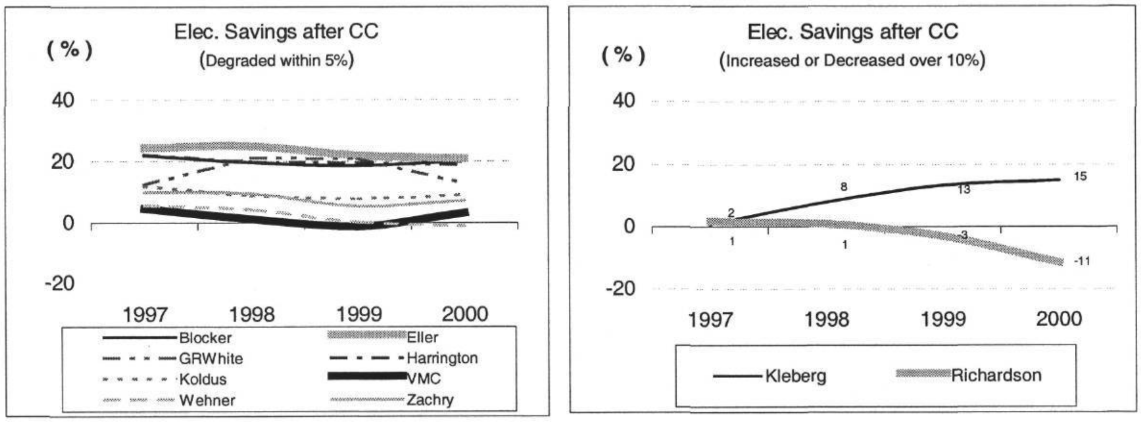


(c)

Figure 4.3 Continued

4.1.3 Electricity Savings

Electric savings have been consistent for eight buildings after CC, as noted in Figure 4.4 (a), but two buildings display a wider range of variation, as noted in Figure 4.4 (b). One of these buildings showed increased savings over time after CC, and the other building (Richardson) has negative electrical savings overall. The average savings for the 10 buildings are 10.8% during the periods from 1997 to 2000.



(a) (b)

Figure 4.4 Yearly electric energy savings after CC activity based on pre-CC energy consumption baseline

4.3 Persistence Analysis

The 10 buildings investigated here were commissioned and did not have any retrofits other than minor controls upgrades during 1996 - 2000. Table 4.3 summarizes the cost savings for all 10 buildings. Energy cost savings were calculated by using the historic campus energy costs of $4.67/MMBtu for chilled water, $4.75/MMBtu for hot water, and $0.02788/KWh for electricity. Recent energy price increases have approximately doubled campus energy costs.

The cumulative savings from CC in these 10 buildings were $4,439,000 for the period 1997 - 2000. As seen in Table 4.3, only three buildings, Koldus, VMC Addition and Wehner, have year 2000 savings greater than 1998 savings. The savings of the other buildings have decreased.

Chilled water savings for the 10 buildings averaged 40.6% in 1998 and electric savings 11.8% as shown in Figure 4.5. Heating savings averaged 72.5% in 1998. Savings in all three categories decreased significantly over the next two years, with the largest percentage drop occurring for hot water. Annual cost savings in the 10 buildings decreased by 17% in 2000, from $1,192,884 to $985,626. Thus it is clear that while the savings are still substantial, the operating changes that have been made in the buildings have resulted in very substantial increases in consumption. Considerable effort was expended on this thesis to determine the reasons for these changes and to determine methods for improving the persistence of the savings.

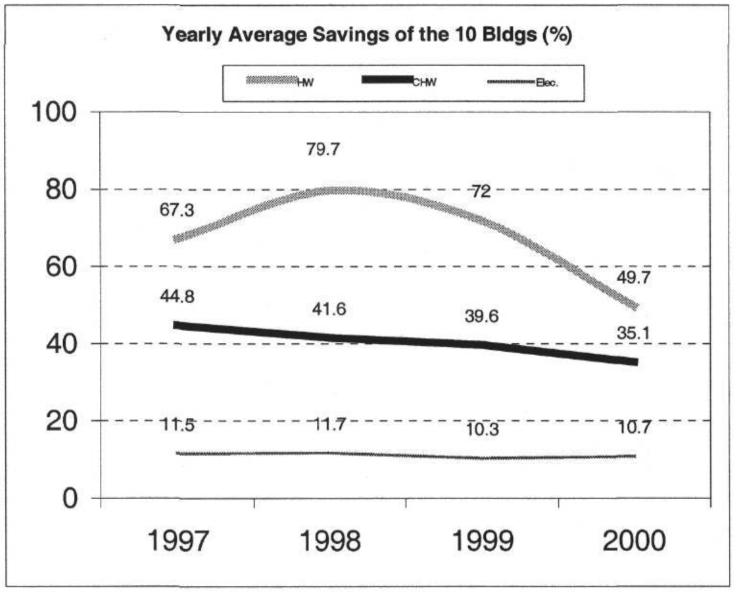


Figure 4.5 Trends of savings for the 10 buildings after Continuous Commissioning

Table 4.3 Cost Savings Calculations for the Year 1998 and the Year 2000

No.	Buildings	Type	Baseline Energy Use (MMBtu/yr) (MWh/yr)	Year 1998 Savings				Year 2000 Savings
				Energy Use (MMBtu/yr) (MWh/yr)	Savings	Cost Savings		
					MMBtu/yr MWh/yr	Each $/yr	Total $/yr	Total $/yr
1	Blocker	CHW	22,955	19,530	3,425	$ 15,993	$ 76,003	$ 56,738
		HW	8,735	1,676	7,060	$ 33,533		
		Elec.	4,832	3,883	950	$ 26,477		
2	Eller O&M	CHW	30,625	18,660	11,965	$ 55,875	$ 120,339	$ 89,934
		HW	7,584	1,154	6,429	$ 30,539		
		Elec.	4,891	3,675	1,217	$ 33,925		
3	G.R.White Coliseum	CHW	18,872	8,511	10,361	$ 48,386	$ 154,973	$ 71,809
		HW	21,155	549	20,605	$ 97,875		
		Elec.	1,480	1,168	312	$ 8,712		
4	Harrington Tower	CHW	14,179	8,420	5,759	$ 26,895	$ 64,498	$ 48,816
		HW	6,896	914	5,982	$ 28,413		
		Elec.	1,666	1,336	330	$ 9,189		
5	Kleberg Building	CHW	59,271	34,969	24,302	$ 113,491	$ 313,958	$ 247,415
		HW	40,812	1,215	39,597	$ 188,086		
		Elec.	5,511	5,067	444	$ 12,380		
6	Koldus Building	CHW	* 21,964	12,988	8,975	$ 41,916	$ 57,076	$ 61,540
		HW	2,103	399	1,704	$ 8,093		
		Elec.	2,850	2,597	253	$ 7,067		
7	Richardson Petroleum	CHW	28,526	15,637	12,889	$ 60,191	$ 120,745	$ 120,666
		HW	* 18,227	5,588	12,639	$ 60,035		
		Elec.	1,933	1,914	19	$ 519		
8	VMC Addition	CHW	40,892	24,080	16,812	$ 78,513	$ 87,059	$ 92,942
		HW	3,569	2,041	1,528	$ 7,260		
		Elec.	4,186	4,140	46	$ 1,286		
9	Wehner CBA	CHW	19,193	13,339	5,854	$ 27,339	$ 47,834	$ 68,145
		HW	13,393	9,715	3,678	$ 17,469		
		Elec.	2,555	2,446	109	$ 3,026		
10	Zachry Engr Center	CHW	40,824	17,377	23,447	$ 109,496	$ 150,400	$ 127,620
		HW	7,676	3,230	4,445	$ 21,114		
		Elec.	7,502	6,793	710	$ 19,789		

Type	Totals				Year 1998	Year 2000
Chilled Water	297,298	173,509	123,789	$ 578,096	$ 1,192,884	$ 985,626
Hot Water	130,149	26,482	103,667	$ 492,417		
Electricity	37,407	33,018	4,389	$ 122,371		

* The baseline energy use data for two buildings were created based on the average savings of the other buildings because they did not have enough data.

CHAPTER V

COMPARISONS BETWEEN PRE-CC, POST-CC, AND CURRENT EMCS SETTINGS

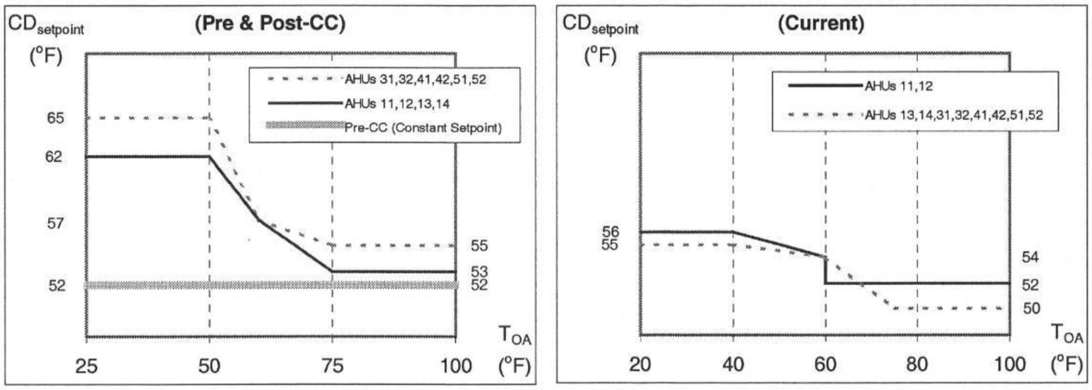
5.1 Introduction

Checking and optimizing Energy Management Control System (EMCS) settings are some of the most important CC activities. All buildings in this study are being controlled by a Direct Digital Control (DDC) system, which has been installed by Siemens™. Many local settings, including cold deck and hot deck temperatures, and static pressures, are not only controlled and set with the computer, but also measured by CC engineers in the field during CC activities. Based on the CC measures implemented during 1996 and 1997 and based on current control settings, some reasons for the savings trends are evident. In this chapter five buildings are selected to illustrate why the savings have decreased.

5.2 Cold Deck / Discharge Temperature Settings

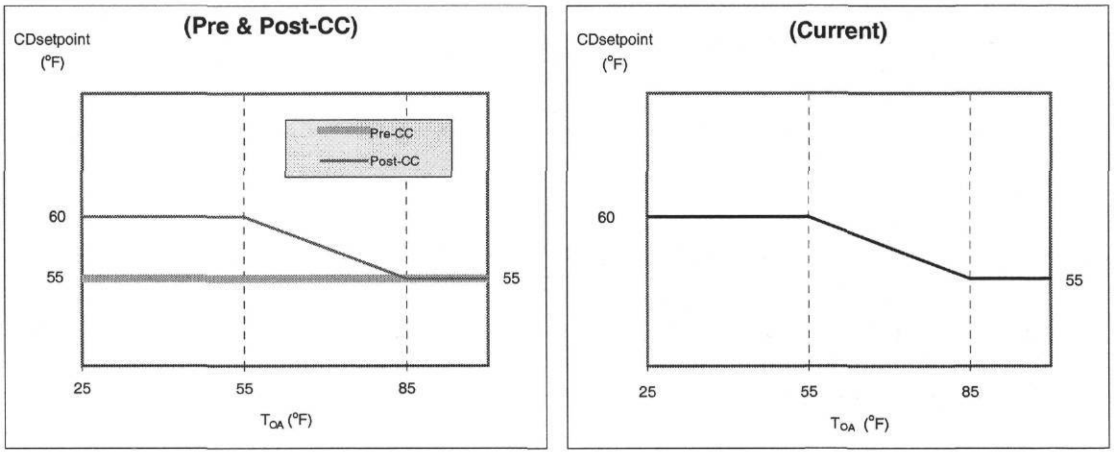
Cold deck or cooling coil discharge temperature settings affect CHW consumption. The settings in the Blocker building are shown as an example, since this building shows typical EMCS set-point histories and a relatively large degradation of savings after CC.

As shown in Figure 5.1 (a), the cold deck set points for 10 AHUs in the Blocker building had been constant at 52 F and then were reset during CC; however, the reset points are not the same as current settings, and the current settings require more cooling. The exact time when the cold deck settings were changed is not known, but it is likely that several reset processes could have occurred since CC completion. Seven of the ten buildings currently have cold deck discharge schedules which demand more energy use than those set during the CC. The only exception is the Koldus building whose current cold deck schedule is the same as that set during CC as shown in Figure 5.2.



(a) (b)

Figure 5.1 Comparison of pre-CC, post-CC, and current cold deck schedules in the Blocker building

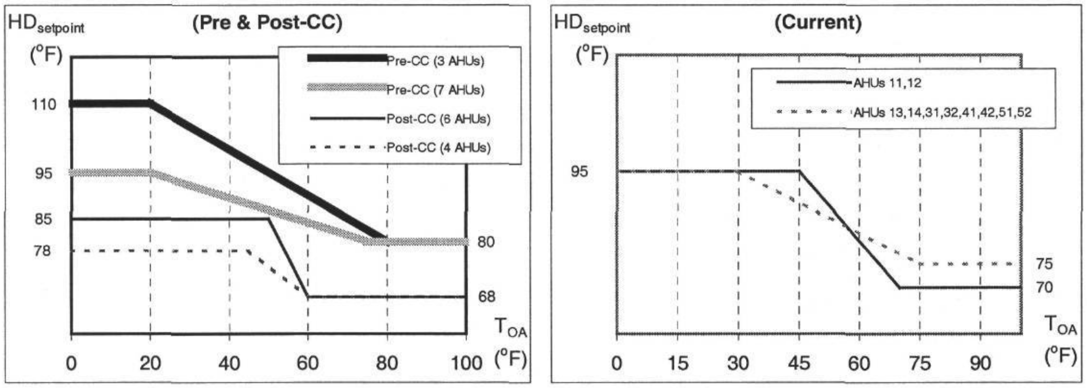


(a) (b)

Figure 5.2 Comparison of pre-CC, post-CC, and current cold deck schedules in the Koldus building

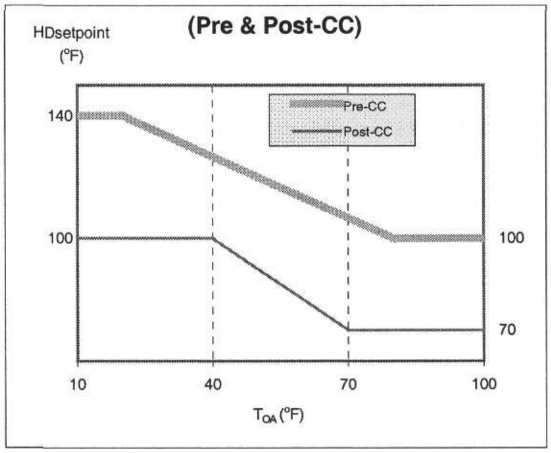
5.3 Hot Deck Settings

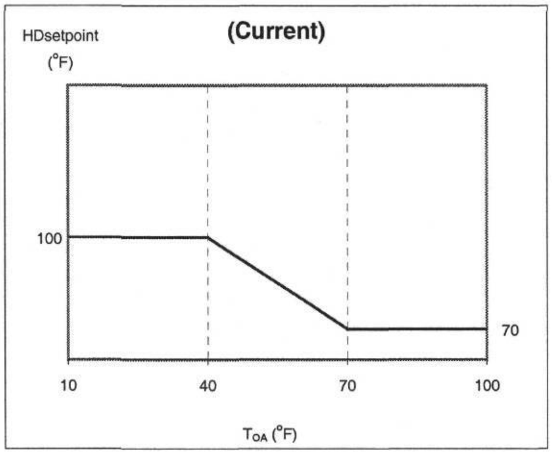
Five out of the ten buildings have dual duct AHU systems; so these buildings have hot deck settings. Hot deck settings are one of the main factors affecting hot water consumption. Two buildings (Wehner & Zachry) currently have the same hot deck settings implemented during CC, and the other three have different set points, which now call for more heating. The Blocker building set points have been changed since the CC activity, as shown in Figure 5.3, and demand more hot water during the entire year. The hot deck temperature settings for the summer may not cause higher consumption because many of the area maintenance operations staff will manually turn off the hot water valves in the summer. Figure 5.4 shows that the settings implemented during CC in the Wehner building are still in place.



(a) (b)

Figure 5.3 Comparison of pre-CC, post-CC, and current hot deck schedules in the Blocker building





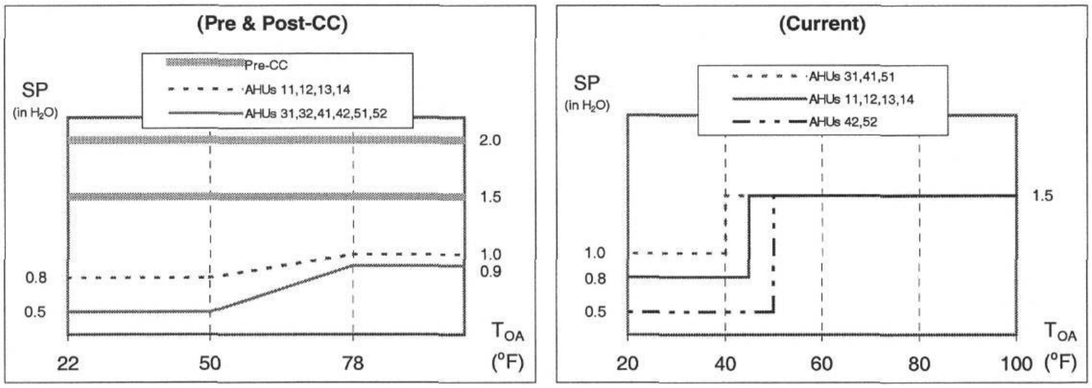
(a) (b)

Figure 5.4 Comparison of pre-CC, post-CC, and current hot deck schedules in the Wehner building.

5.4 Static Pressure Settings

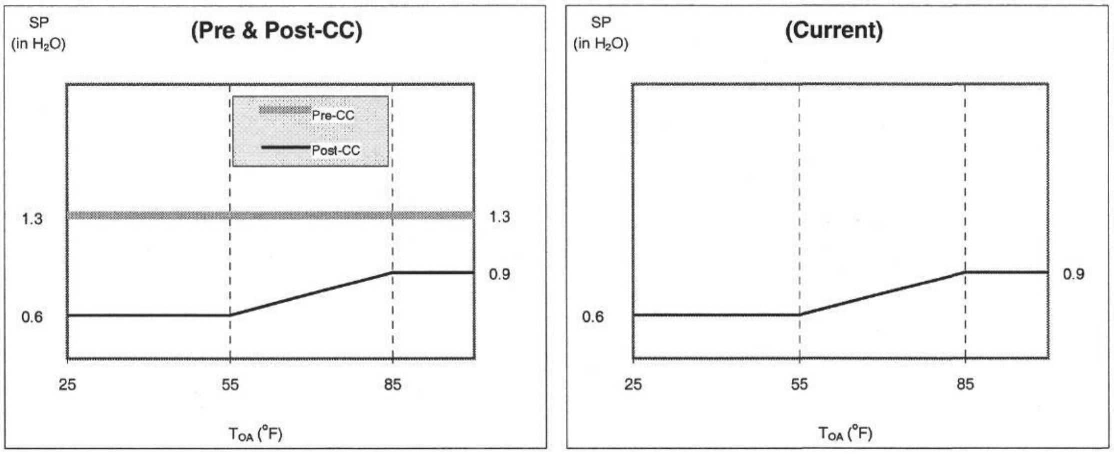
Static pressure settings can affect not only CHW and HW consumption, but also electricity consumption. There are nine buildings equipped with Variable Air Volume (VAV) systems and the G.R. White Coliseum is the only building that has only Constant Air Volume (CAV) systems. The Koldus building has had the same settings since CC activity, as shown in Figure 5.6, but the others have current settings that demand more static pressure, which means cooling, heating, and electrical demands have increased over time. Figure 5.5 (a) has the pre and post-CC settings for the Blocker building, and

Figure 5.5 (b) shows the current static pressure settings for the various air handlers.



(a) (b)

Figure 5.5 Comparison of pre-CC, post-CC, and current static pressure schedules in the Blocker building



(a) (b)

Figure 5.6 Comparison of pre-CC, post-CC, and current static pressure schedules in the Koldus building

5.5 Other Settings

Building differential pressure settings and control of outside air are also important CC measures to save energy and to maintain comfort. These control schemes generally have not been changed after CC. Some buildings also have economizer cycles to achieve comfortable conditions by using ambient air without refrigeration. The Harrington Tower, for example, uses two types of economizers, one temperature-controlled and one enthalpy-controlled. Changes in these parameters will impact the CC energy consumption, but these have not been investigated in detail in this thesis.

CHAPTER VI

VERIFICATION OF EXPECTED IMPACT OF CONTROL CHANGES USING CALIBRATED SIMULATION METHOD

6.1 Introduction

From the previous investigation the trends of energy savings degradation have been discussed. Some intuitive reasons for the degradation resulted from tracking the EMCS settings history. But the questions of how much and how directly the changes of EMCS settings have affected the energy consumption over time after commissioning remained. So the calibrated simulation method using AirModel program was implemented to verify the effect of EMCS changes on energy consumption. At the same time, the work order history for the 10 buildings has been examined to see what this tells us, and interviews with people in charge of the buildings have been conducted to investigate reasons for control changes made since commissioning was completed.

The work order history for the 10 buildings has been retrieved from the Energy Office database. This had only brief information about complaints from tenants at a certain time, for example, titles, persons who complained, places hot or cold, time, etc. Unfortunately, the database did not contain the specific changes from the requests, and there is no way to search the documents for these activities. The frequencies of the hot and cold calls in a certain period were the only information accessible. Interviews and discussions with CC engineers were stated in each simulation process to validate control changes implemented in calibrated simulation.

6.1.1 Calibrated Simulation

Five of the ten buildings were selected for calibrated simulation. These buildings are Eller O&M, Harrington Tower, Kleberg, VMC Addition, and Wehner. The other five buildings, Blocker, Koldus, Richardson, Zachry, and G.R.White, were not simulated due to the data and equipment problems described below. As noted in Table 4.1, the Blocker, Koldus, and Richardson buildings were deemed to have too much missing data during the baseline period or year 2000 to perform a complete calibration. The baseline cooling and heating energy use of the Zachry building is based on the use of cooling data from 1996 which is right before CC and heating data from the period between the winter of 1994 and the spring of 1995 because the heating energy use data is unavailable in 1996. Lastly, the G.R. White building has experienced significant savings degradation due to HVAC equipment malfunctions which occurred after CC, so the savings degradation was not from EMCS changes.

The five buildings selected for simulation all have quite complete information needed for the simulation process, such as commissioning reports, EMCS settings history and current working status from the control program. The Eller O&M, Harrington Tower and Wehner buildings have dual duct air handling systems and the other two have single duct systems. All these AHUs are equipped with variable air volume control.

For each building three different periods were simulated to investigate how EMCS changes have impacted the energy consumption. The periods simulated were pre-CC period, post-CC period shortly after commissioning, and year 2000. The simulation process started with year 2000 thermal energy use data since this year is the most recent period so we could access building HVAC information more easily and accurately than for the pre- and post-CC periods. After the first simulation with year 2000 data, two more calibrated simulations followed for the selected pre- and post-CC periods.

The final calibrated input data for each period are then used for the calculation of normalized annual energy consumption for that period using the weather data of 1995 as the "normal" year. The hourly output data for each of the three periods are summed up over 8760 hours to determine the normalized annual consumption.

6.1.2 EMCS Settings

All buildings in this study have their own EMCS schedules, including key parameters such as cold deck temperature, hot deck temperature, duct static pressure set points, and pump static pressure set points; however, sometimes operators override the control sequences. This means that the HVAC equipment does not follow the programmed schedule but maintains the value input by the operator. Systems may now have a constant set point that no longer varies with ambient temperature or any other variable. While investigating the status of control systems for the five buildings, it was found that three buildings are currently not working as scheduled but are running on "operator mode" in which the scheduled set points are ignored and overruled by a constant value from an operator.

These changes were considered while doing simulation. While performing calibrated simulation for the pre- and post-CC periods some additional factors have to be considered and modeled. During the commissioning activity many EMCS settings are changed; in addition, physical problems such as leaking or broken valves, reversed controls, bad sensors, etc. are repaired to improve the energy efficiency and the tenants' comfort. These must also be considered in the simulations.

6.2 Calibrated Simulation 1: Kleberg Building

6.2.1 Site Description

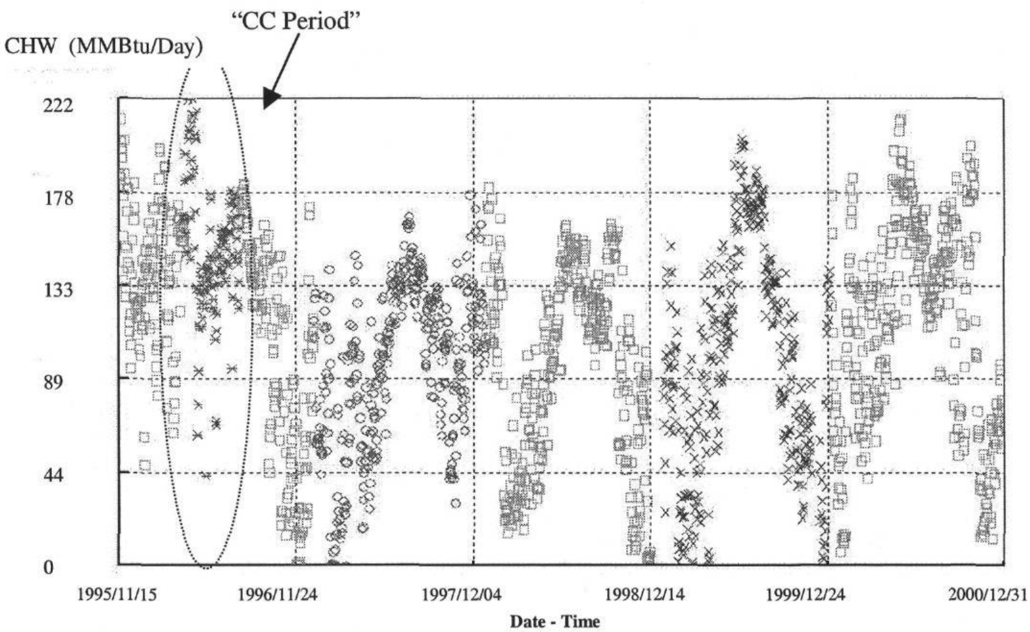
The Kleberg building is located on the west campus of Texas A&M University in College Station. The building has a total floor area of 165,031 square feet on four floors plus a basement with an atrium in the center of the building. The atrium begins on the first floor and goes up to the fourth floor. This building houses classrooms, offices and laboratories. There are offices and classrooms on the first floor, labs on the exterior area from the second through the fourth floor, and offices in the interior zones.

Hot water and chilled water are provided by a central plant on campus. Electricity consumed by this building is mainly used for lighting, equipment, pumps, and AHUs. There are two large single duct variable air volume AHUs (AHUs 1&2, each with 100 HP motors) with preheat and terminal box reheat that serve most of this building. Each of these large AHUs is equipped with a return fan. There are also two smaller single duct, constant air volume AHUs that serve lecture halls on the 1st floor. These small AHUs are couple-controlled and maintain the room air temperature based on a return air temperature sensor. Two pumps circulate the supply chilled water and are equipped with variable frequency drives.

The offices have 100 fan-powered, VAV boxes with terminal reheat. Thermostats in rooms send a pressure signal to the VAV boxes so that they control office temperatures. This building has 12 lab zones, and each lab has fan-powered boxes with terminal reheat. To maintain the labs slightly negative, the amount of supply air should be lower than the air being exhausted by the fume hoods.

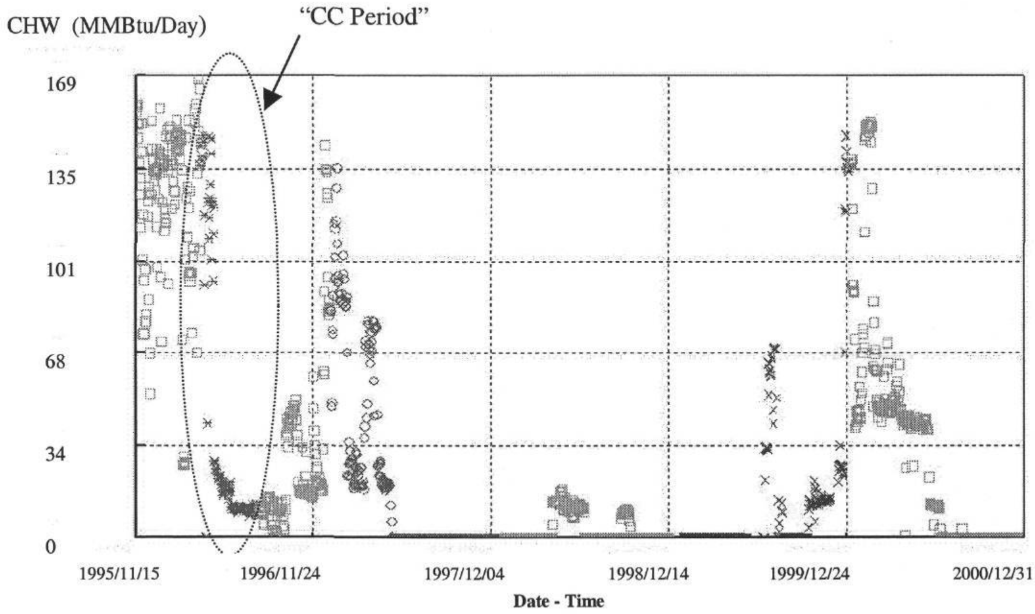
The Kleberg building has been commissioned two times. The first CC was completed in August of 1996. During the initial CC activity, the engineers reset cold deck and preheat schedules, activated the economizer cycle, performed a lab air balance, reduced building pressure and exhaust duct pressure, and optimized chilled water pumping control. Further CC measures were implemented in April of 1999. This involved optimization of the VAV boxes, fume hoods, and fans in the laboratories.

Figure 6.1 shows chilled water and hot water energy use for the Kleberg building and indicates the time of initial CC activity. The chilled water and hot water consumption decreased after commissioning, but they have increased somewhat subsequently.



(a)

Figure 6.1 The Kleberg building daily chilled water and hot water energy use from 1995 to 2000



(b)

Figure 6.1 Continued

6.2.2 Calibrated Simulation with Year 2000 Data

The information for simulation has been gathered from a number of sources. Chilled water use, hot water consumption, dry bulb temperature, and dew point temperature data have been retrieved from the LoanSTAR database. To get the building envelope and HVAC system information, architectural and mechanical drawings were investigated. The APOGEE energy management program and control system (EMCS) installed in the building has been reviewed to determine point readings and to check current control schedules and operating status. For more detailed technical information, meetings and interviews with CC engineers and facilities personnel were performed.

Here are the major parameters initially used to simulate the Kleberg building.

HVAC system type: SDRHMA (Single Duct with Reheat Mixing Air)

Air supply: VAV (Variable Air Volume)

Conditioned floor area: 165,031 sq-ft

Internal zone fraction: 0.5

Exterior wall area / U value: 36000 sq-ft / 0.17 Btu/sq-ft hr F

Exterior window area / U value: 14880 sq-ft / 1.09 Btu/sq-ft hr F

Supply air fan HP / control model: 200 HP / VFD (Variable Frequency Drive)

Return air fan HP / control model: 50 HP / VFD (Variable Frequency Drive)

Room temperature (heating and cooling): 70 ^{o}F 74 ^{o}F

Total air flow rate: 1.10 cfm/sq-ft

Outside air flow rate: 0.33 cfm/sq-ft

Minimum air flow: 0.92 cfm/sq-ft

Cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

T_{SET} = 65 ^{o}F, if T_{OA} is below 40 ^{o}F

T_{SET} = 55 ^{o}F, if T_{OA} is above 70 ^{o}F

$T_{SET} = 1/3 * (235 - T_{OA})$, if T_{OA} is between 40 ^{o}F and 70 ^{o}F

Preheat schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

T_{SET} = 55 °F, if T_{OA} is below 40 °F

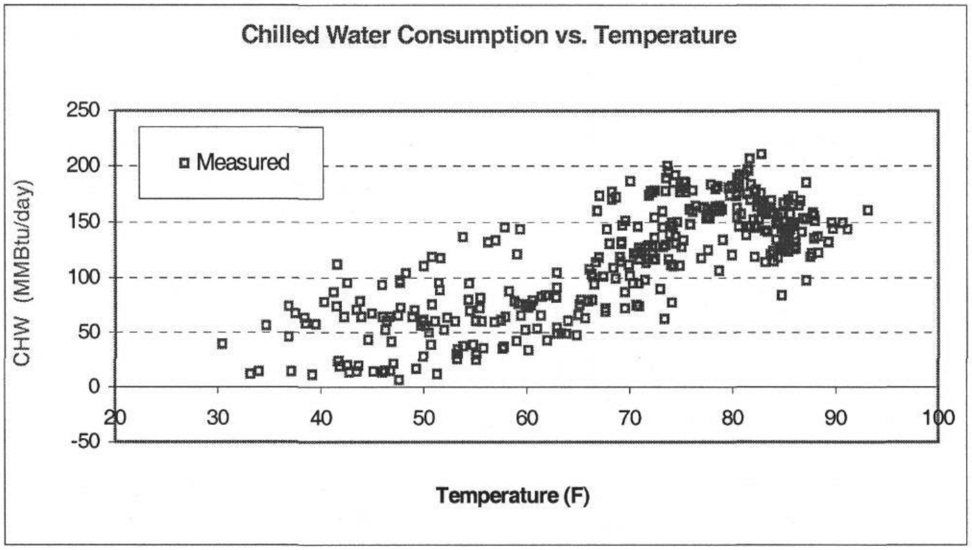
T_{SET} = 45 °F, if T_{OA} is above 70 °F

T_{SET} = 1/3 * (205 - T_{OA}), if T_{OA} is between 40 °F and 70 °F

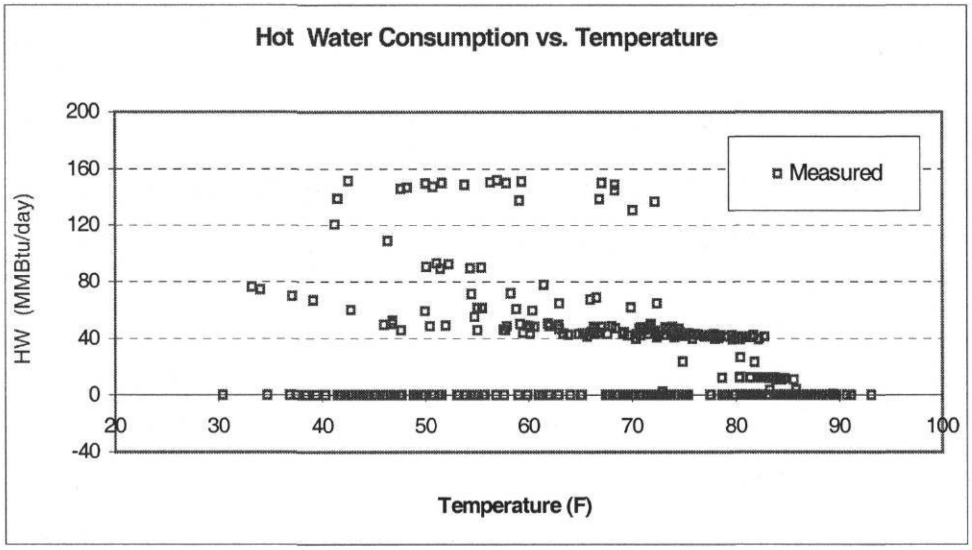
Internal heat gain: 2.40 W/sq-ft

Before the simulation process was performed, measured chilled water and hot water energy consumption data was analyzed and, as shown in Figure 6.2 and Figure 6.3, there appear to be at least three different energy consumption patterns in year 2000. It was concluded that the hot water data from 6/16/2000 to 12/31/2000 is bad data. This conclusion was initially based on comparison of simulated and measured consumption before and after June 16. This comparison showed that a simulation that closely predicted hot water consumption before June 16 abruptly quit predicting hot water use then, but continued to accurately predict chilled water use. Subsequently it was learned that the hot water valves were never closed so that this building had to consume hot water in this period.

This building experienced some abnormally high thermal energy consumption from January to the middle of February; the hot water energy use was exceptionally high some days and chilled water use was also high during this period, so it was simulated with different operational parameters.

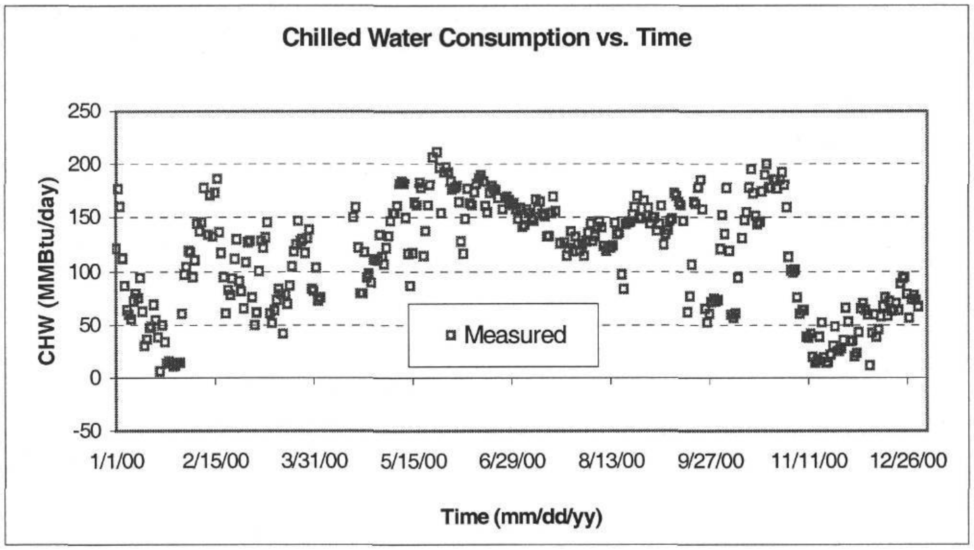


(a)

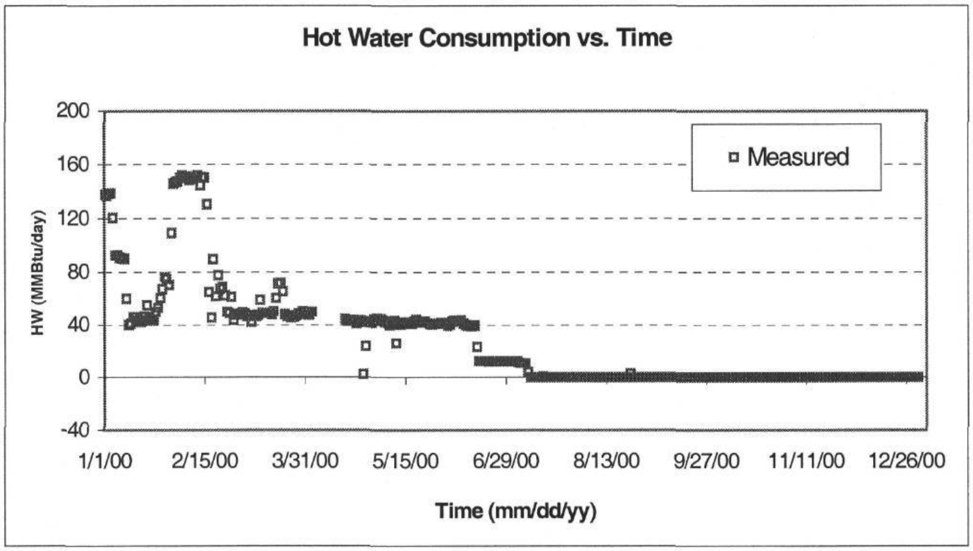


(b)

Figure 6.2 The Kleberg Building chilled water and hot water energy consumption as a function of temperature (year 2000)



(a)



(b)

Figure 6.3 Time series plots of the Kleberg building chilled water and hot water energy consumption for year 2000

The first simulation was performed using the parameters listed above and the simulated output for chilled water and hot water consumptions was much lower than the measured uses. The CVRMSE values for chilled water and hot water were 17.1% and 31.8% respectively and Mean Bias Errors (MBE) were –20.0 MMBtu/day for chilled water and –13.0 MMBtu/day for hot water.

The cold deck and preheat schedules were changed based on information obtained from Mr. Deng and Mr. Chen of the ESL staff. These two parameters were simultaneously calibrated and rearranged. The original cold deck temperature schedule was 65 °F at outside air temperatures of 40 °F or below and 55 °F at ambient temperatures of 70 °F or higher. Between these temperatures, the cold deck temperature moves down linearly from 65 °F to 55 °F as ambient temperature goes up from 40 °F to 70 °F. To increase the simulated energy consumption this schedule was changed so that the cold deck set temperatures were decreased by 2 °F for the entire outside air temperature range since it was reported that the measured values of cold deck temperatures were approximately 2 °F lower than scheduled.

Chen et al. (2002) presented the verification and follow-up efforts for the Kleberg building. They identified control problems in AHUs and VAV systems; the majority of the VFDs were running at a constant speed of between 90% and 100%, VFD control on two chilled water pumps were by passed to run at full speed, two chilled water valves were leaking badly, a failed pressure sensor and two failed CO_2 sensors put all outside air dampers to the full open position, and additional problems were identified.

The preheat deck is scheduled to have temperature set points 10 °F lower than the cold deck in the control program. But it did not appear that this control scheme performed as designed due to component failures (Chen et al., 2002). Mr. Chen (2001) reported in his CC verification report that this building has frequently experienced preheat temperatures of 105 °F, and Mr. Deng recommended based on his experiences in this building that the preheat temperature be raised to much higher values shown in the control schedule, particularly at high ambient temperatures. Although the control program had the optimized schedules for preheat, it was found that there was no temperature sensor between the pre-heat coil and cooling coil and that this building experienced open preheating valves even at outside air temperatures of 85 °F or higher. So this schedule was rearranged that the preheat is maintained at 74 °F until the outside air rises to 40 °F, then starts increasing linearly to 76 °F until the outside air reaches 70 °F. The final values of CVRMSE with calibrated parameters are 10.5 % for cooling and 13.0 % for heating and MBEs are -3.4 MMBtu/day for cooling and 2.0 MMBtu/day for heating. Below is the comparison between the initial and calibrated parameters.

Cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: T_{SET} = 65 °F, if T_{OA} is below 40 °F

T_{SET} = 55 °F, if T_{OA} is above 70 °F

T_{SET} = 1/3 * (235 - T_{OA}), if T_{OA} is between 40 °F and 70 °F

Calibrated: T_{SET} = 63 °F, if T_{OA} is below 40 °F

T_{SET} = 53 °F, if T_{OA} is above 70 °F

T_{SET} = 1/3 * (229 - T_{OA}), if T_{OA} is between 40 °F and 70 °F

Preheat schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: T_{SET} = 55 °F, if T_{OA} is below 40 °F

T_{SET} = 45 °F, if T_{OA} is above 70 °F

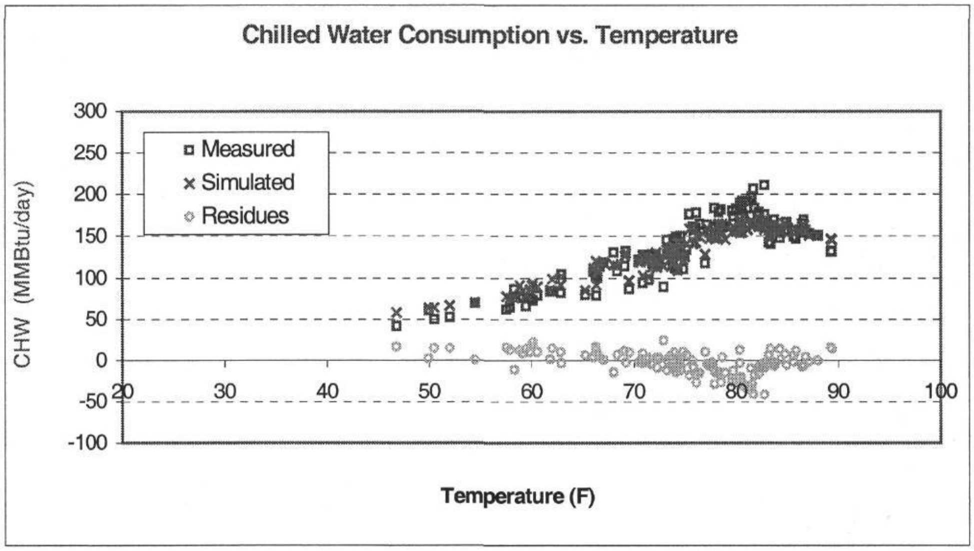
T_{SET} = 1/3 * (205 - T_{OA}), if T_{OA} is between 40 °F and 70 °F

Calibrated: T_{SET} = 74 °F, if T_{OA} is below 40 °F

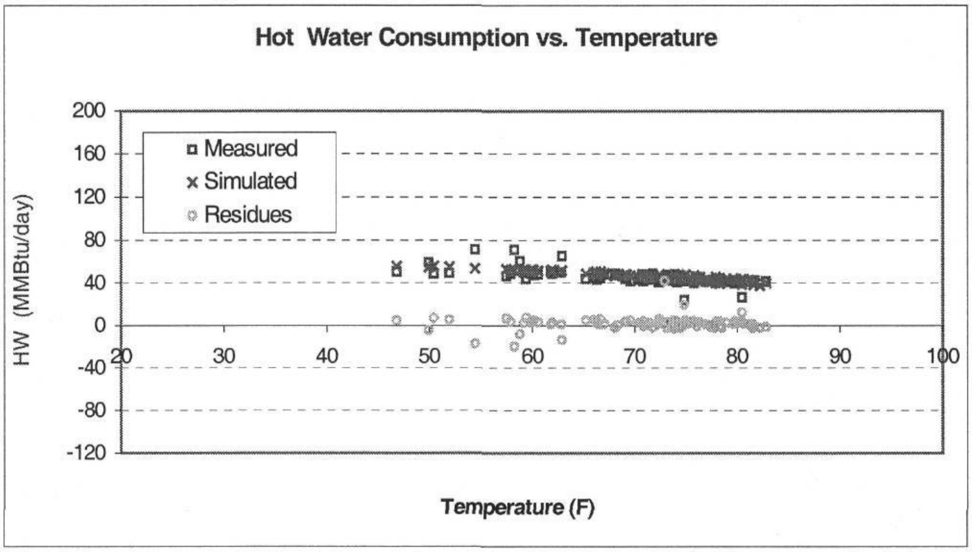
T_{SET} = 76 °F, if T_{OA} is above 70 °F

T_{SET} = 1/15 * (1070 + T_{OA}), if T_{OA} is between 40 °F and 70 °F

Figure 6.4 shows the daily measured values of chilled water and hot water and predictions of the calibrated simulation as a function of outside air temperature and the differences (simulated – measure) between these values or residues. Figure 6.5 gives time series plots of the same quantities.

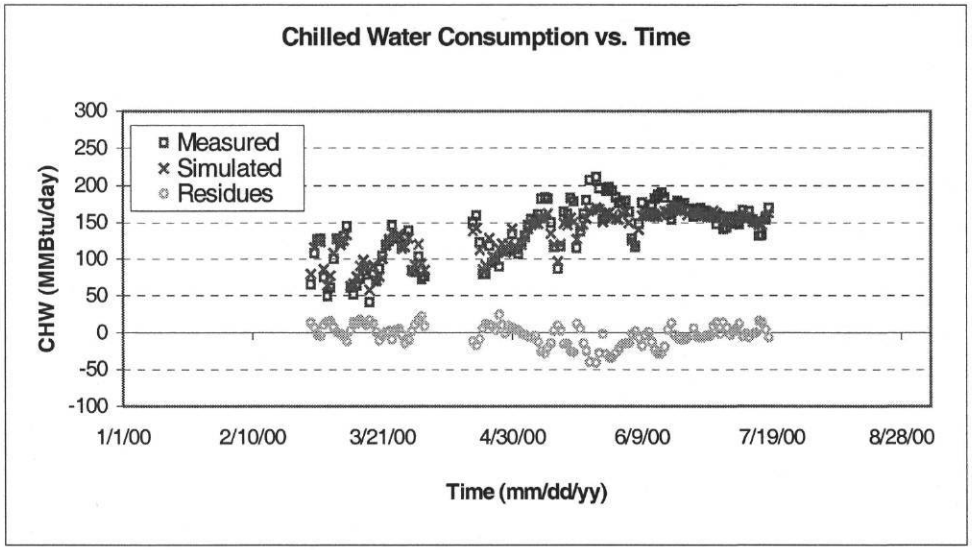


(a)

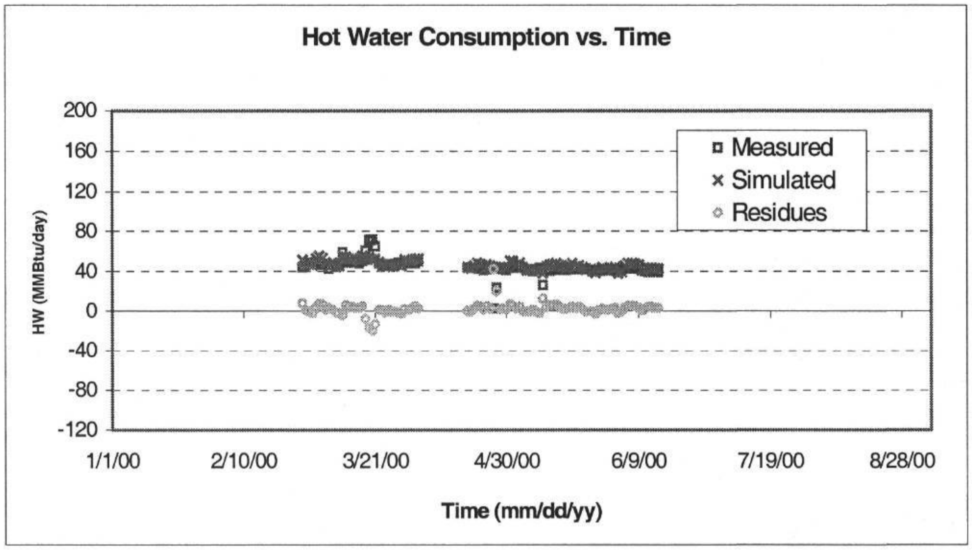


(b)

Figure 6.4 The Kleberg building measured and simulated heating and cooling energy consumption as a function of ambient temperature for the period from 02/28/2000 to 07/18/2000 for cooling and to 06/15/2000 for heating excluding the period from 04/04/2000 to 04/17/2000



(a)



(b)

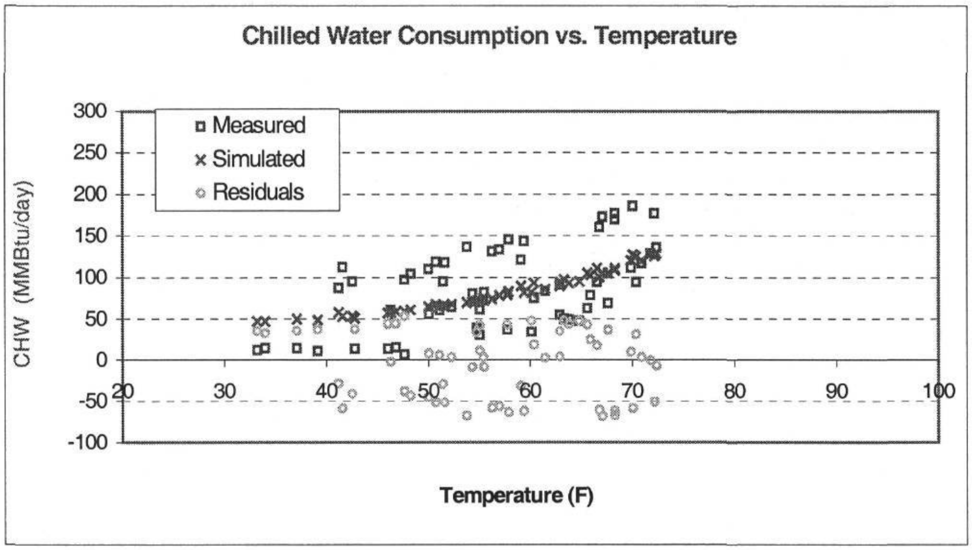
Figure 6.5 The Kleberg building measured and simulated heating and cooling energy consumption as a function of time for the period from 02/28/2000 to 07/18/2000 for cooling and to 06/15/2000 for heating excluding the period from 04/04/2000 to 04/17/2000

To simulate the first two months of this year the same calibrated input parameters above were used and the plots of simulation result are shown in Figure 6.6 and Figure 6.7.

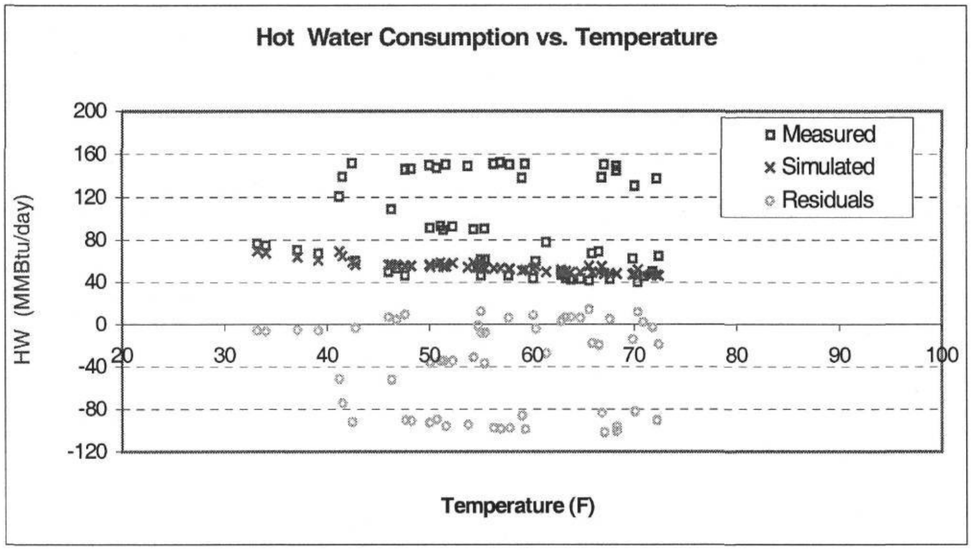
The figures show that there are several different consumption patterns. As seen in the figures, the simulation results agree with the measured values only for two short periods and the period during January when chilled water agrees is different from the January period of agreement for hot water.

Parameters were calibrated several times to try to match with measured consumption, but chilled water and hot water consumption patterns were not changing uniformly in the same time periods.

This building experienced some exceptionally high or low chilled water and hot water energy use.

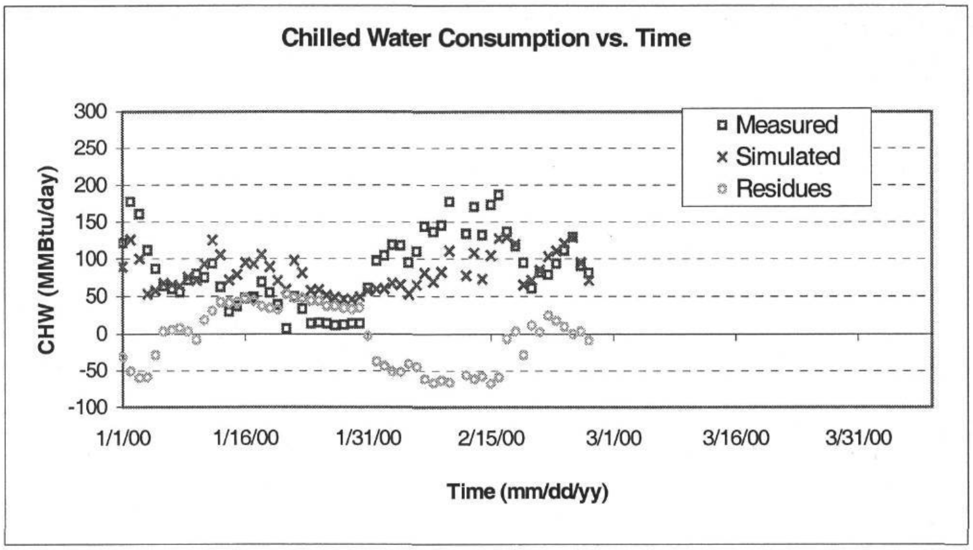


(a)

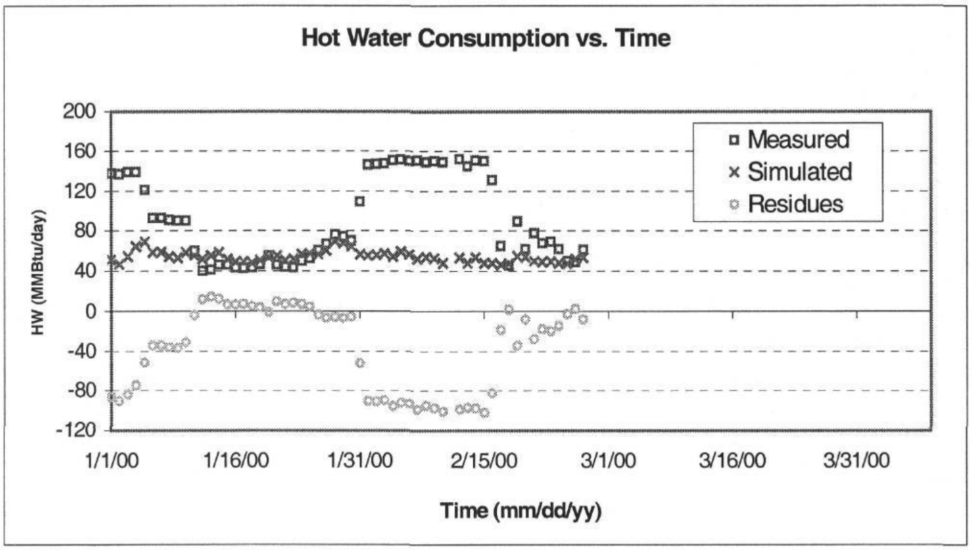


(b)

Figure 6.6 The Kleberg building measured and simulated heating and cooling energy consumption as a function of ambient temperature for the period from 01/01/2000 to 02/27/2000



(a)



(b)

Figure 6.7 The Kleberg building measured and simulated heating and cooling energy consumption as a function of time for the period from 01/01/2000 to 02/27/2000

6.2.3 Calibrated Simulation with Pre-CC and Post-CC Data

After the calibrated simulation was done with data from 2000, the periods of pre-CC and post-CC data were simulated. For these two periods the input data used for 2000 simulation were basically applied, except for cold deck and preheat schedules. For the pre-CC period from 11/16/1995 to 04/17/1996 the cold deck had a constant temperature of 55 ^{o}F, and the preheat information was not available so the simulation for the pre-CC period started with the preheat schedule used in the final simulation for 2000.

The first output of the pre-CC simulation with the initial data described was consistently low compared to measured energy use and had CVRMSE values of 42% for cooling and 49% for heating. After trying various schedules, the simulation results reached an acceptable CVRMSE range of 7.7% for cooling and 8.7% for heating. Figures 6.8 and 6.9 show the comparison between measured and simulated results for the pre-CC period as functions of outside air temperature and time, and the initial and calibrated parameters are shown below.

Cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: $T_{SET} = 55\ ^oF$ – Constant temperature

Calibrated: $T_{SET} = 55\ ^oF$ – Constant temperature

Preheat schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled (n/a, so 2000 calibrated data used):

$T_{SET} = 74\ ^oF$, if T_{OA} is below $40\ ^oF$

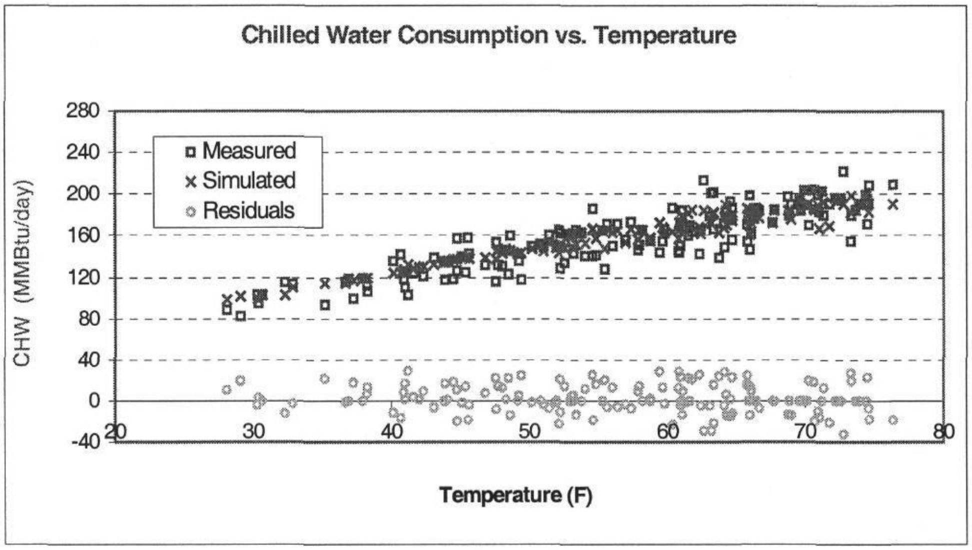
$T_{SET} = 76\ ^oF$, if T_{OA} is above $70\ ^oF$

$T_{SET} = 1/15 * (1070 + T_{OA})$, if T_{OA} is between $40\ ^oF$ and $70\ ^oF$

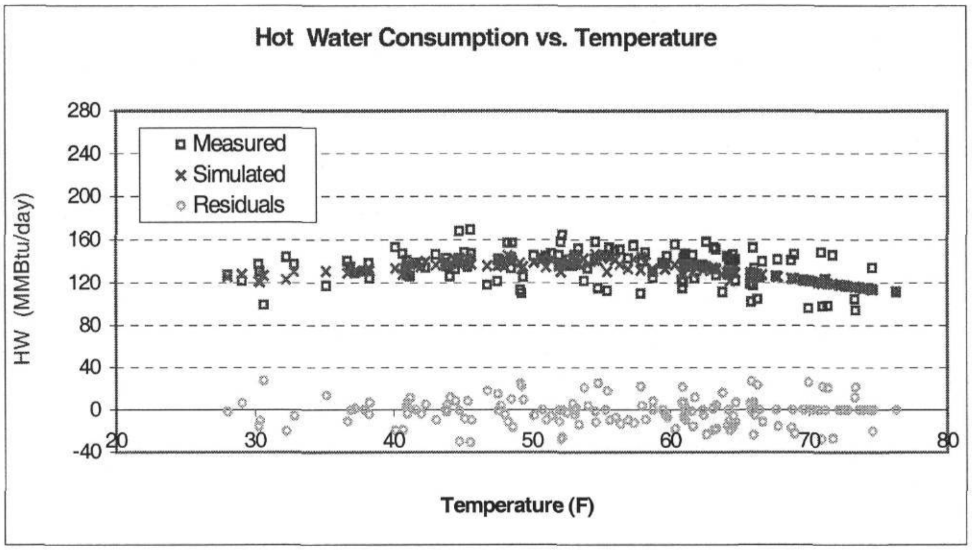
Calibrated: $T_{SET} = 75\ ^oF$, if T_{OA} is below $30\ ^oF$

$T_{SET} = 98\ ^oF$, if T_{OA} is above $55\ ^oF$

$T_{SET} = 1/25*(1185 + 23*T_{OA})$, if T_{OA} is between $30\ ^oF$ and $55\ ^oF$

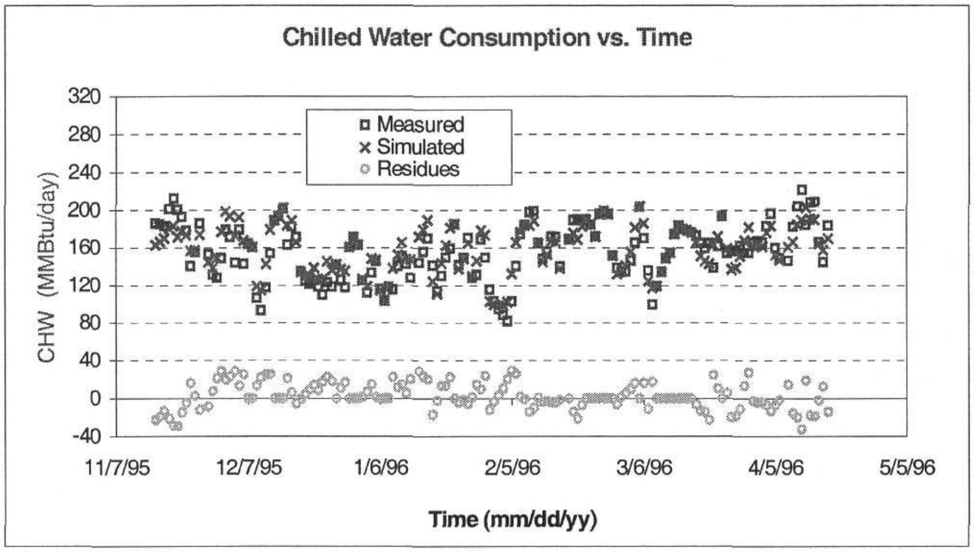


(a)

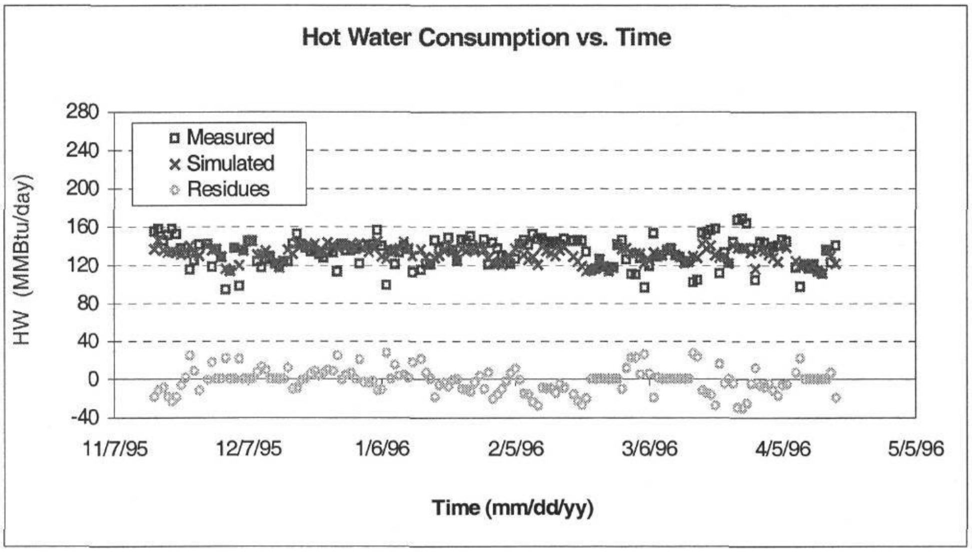


(b)

Figure 6.8 The Kleberg building measured and simulated heating and cooling energy consumption as functions of ambient temperature after calibration for the pre-CC period from 11/16/1995 to 04/17/1996



(a)

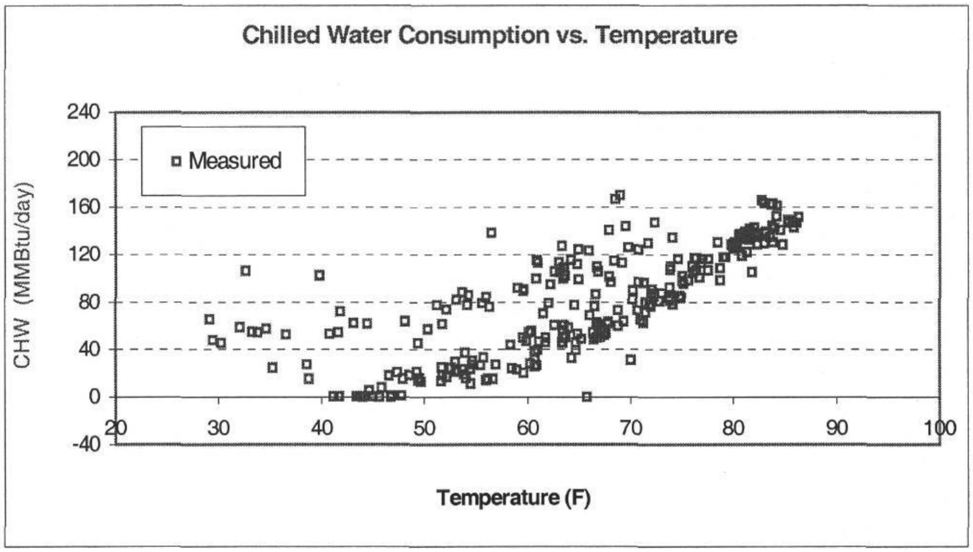


(b)

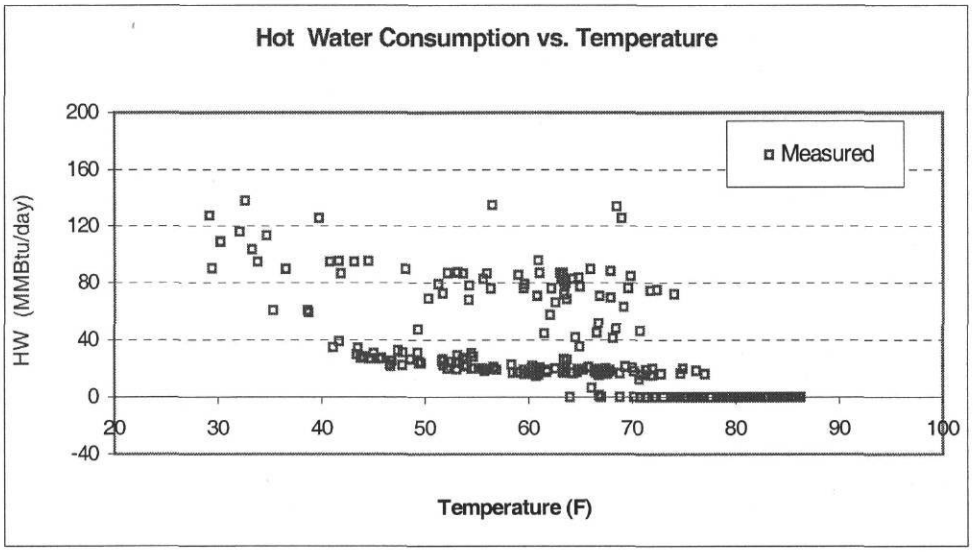
Figure 6.9 Time series plots of the Kleberg building measured and simulated heating and cooling energy consumption for the pre-CC period from 11/16/1995 to 04/17/1996 after calibration

After commissioning was performed this building had updated control settings and optimized operation schedules. Thermal energy consumption data was retrieved from the database for the period from 11/01/1996 to 07/31/1997 after CC, and, as shown in Figures 6.10 and 6.11, it was noted that the consumption patterns are irregular with the chilled water and hot water use much higher than normal during two or three periods and hot water either off or the meter was bad from the 7^{th} of May onward.

Discussion with commissioning engineers revealed that during the commissioning process, the engineers changed the preheat settings in the EMCS. The new control settings were saved in the EMCS main server, but not in the computers in the Area Maintenance Shops. In early 1997, during some EMCS interruptions (e.g. power failure, server failure, etc.), the old incorrect AHU preheat coil control valve settings were downloaded from the Area Maintenance Shop computers to the field panel when the system rebooted, and the preheat valves again operated when there was no need for preheat. This happened twice. It was manually corrected in the field panel the first time, and the source of the incorrect setting was identified as the Area Maintenance Shop computer the second time the problem occurred. The correct settings were then programmed in all the system computers.

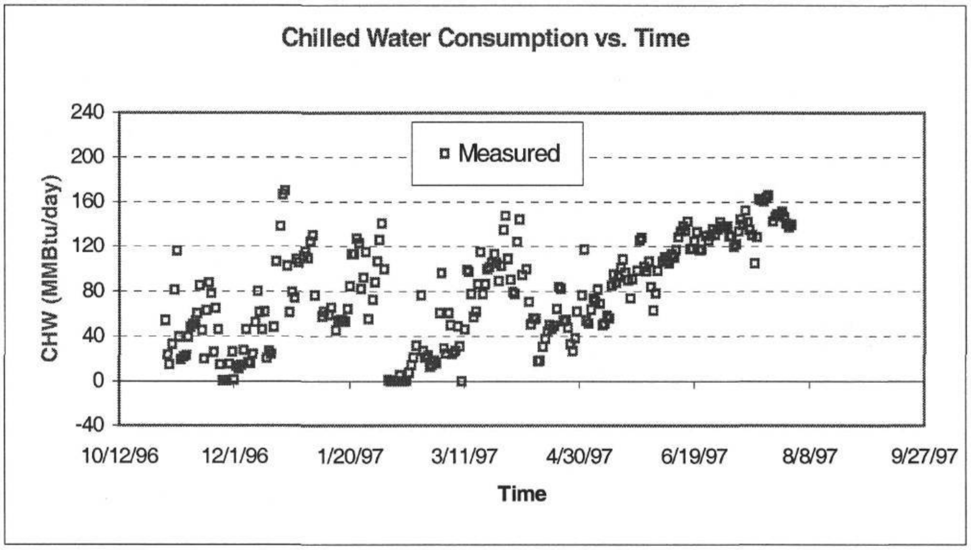


(a)

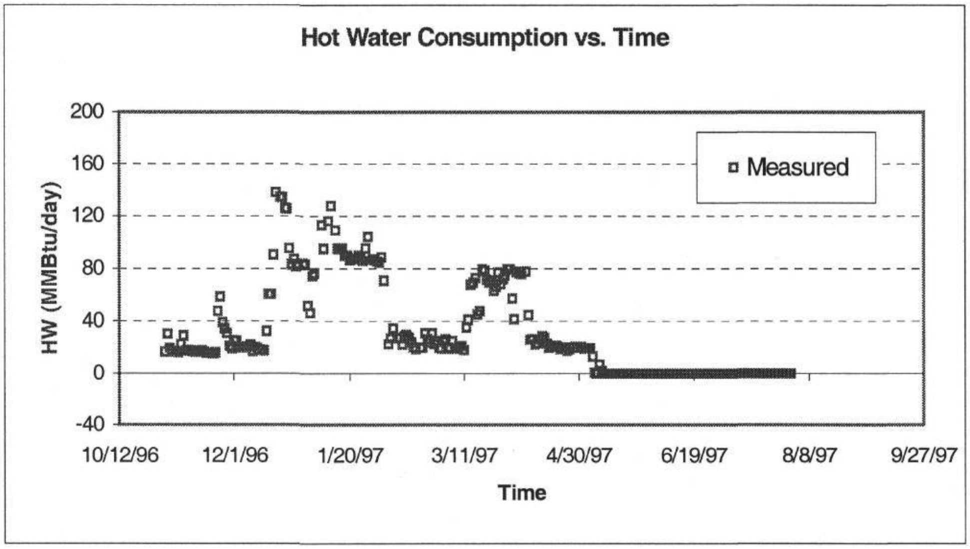


(b)

Figure 6.10 The Kleberg building chilled water and hot water energy consumption as functions of temperature for the post-CC period from 11/01/1996 to 07/31/1997



(a)



(b)

Figure 6.11 The Kleberg building chilled water and hot water energy consumption as functions of time for the post-CC period from 11/01/1996 to 07/31/1997

The calibration of the simulation for the post-CC period, therefore, was performed without using the data from these two periods from 12/16/1996 to 02/04/1997 and 03/12/1997 to 04/08/1997 when preheat operation was incorrect. During the CC period the major measure was rescheduling of the cold deck set point from constant temperature of 55 °F. The cold deck set point after CC was 62 °F when ambient temperature is 40 °F or below and 57 °F when ambient temperature is 60 °F or higher. The preheat control was also changed from coupled control based on discharge temperature to variable temperatures that are 10 degrees lower temperatures than cold deck set points.

In the first simulation using scheduled data in the EMCS the CVRMSE was 24.0% for chilled water and 19.5% for hot water. The simulated chilled water consumption was very low in the summer weather condition and very high in the winter weather condition, and the simulated hot water consumption matched well in the summer period but very low in the winter period. These differences between simulated and measured use are typically caused if the outside air flow rate used in the simulation is too low. The measured value of outside air flow rate is not more than 30 % of the total air flow rate corresponding to 0.33 cfm/sq-ft, which was used as the initial simulation parameter. However, the commissioning engineer reported that it was discovered in 1997 that the building exhaust fans were causing highly negative air pressure in parts of the building. This undoubtedly led to additional outside air entering the building as infiltration.

This situation was approximated in the simulation by increasing outside air flow and agreement with the measured energy use was achieved by increasing the outside air flow rate to 47%. The CVRMSEs dropped to 13.9 % for chilled water and 16.0 % for hot water, and the MBEs to 2.6 MMBtu/day for chilled water and –1.7 MMBtu/day for hot water. Figures 6.12 and 6.13 show the measured and calibrated daily energy consumption for this post-CC period as functions of temperature and time, respectively, and below are EMCS schedules and calibrated values of cold deck and preheat schedules as implemented by the CC process. The calibrated preheat schedule was set 10 degrees lower than the calibrated cold deck schedule to follow the preheat control scheme implemented by the commissioning team.

Post-CC cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: $T_{SET} = 62\ ^{o}F$, if T_{OA} is below $40\ ^{o}F$

$T_{SET} = 57\ ^{o}F$, if T_{OA} is above $70\ ^{o}F$

$T_{SET} = 1/6 * (412 - T_{OA})$, if T_{OA} is between $40\ ^{o}F$ and $70\ ^{o}F$

Calibrated: T_{SET} = 62 °F, if T_{OA} is below 40 °F

T_{SET} = 57 °F, if T_{OA} is above 70 °F

$T_{SET} = 1/6 * (412 - T_{OA})$, if T_{OA} is between 40 °F and 70 °F

Preheat schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: T_{SET} = 52 °F, if T_{OA} is below 40 °F

T_{SET} = 47 °F, if T_{OA} is above 70 °F

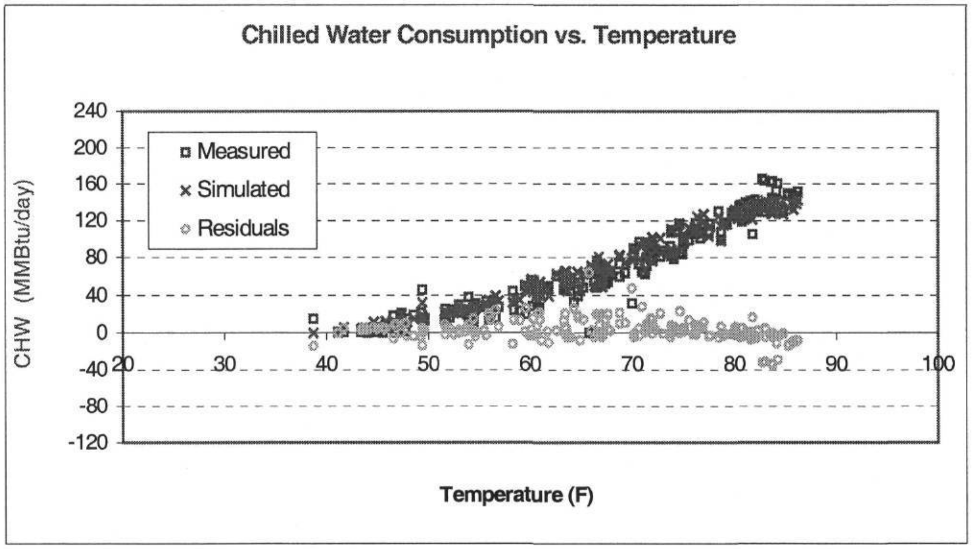
$T_{SET} = 1/6 * (352 - T_{OA})$, if T_{OA} is between 40 °F and 70 °F

Calibrated: T_{SET} = 52 °F, if T_{OA} is below 40 °F

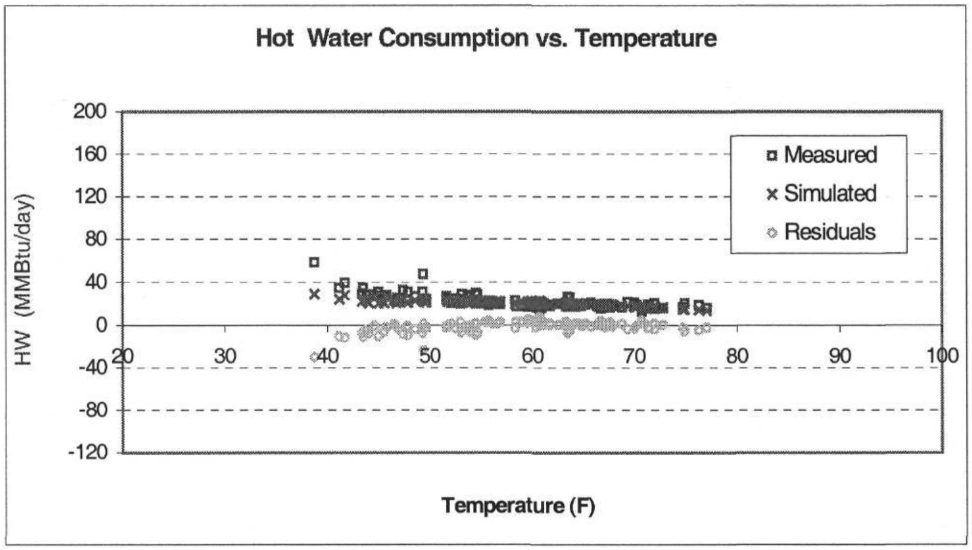
T_{SET} = 47 °F, if T_{OA} is above 70 °F

$T_{SET} = 1/6 * (352 - T_{OA})$, if T_{OA} is between 40 °F and 70 °F

Comparisons of input parameters for each simulation period are shown in Table 6.1.

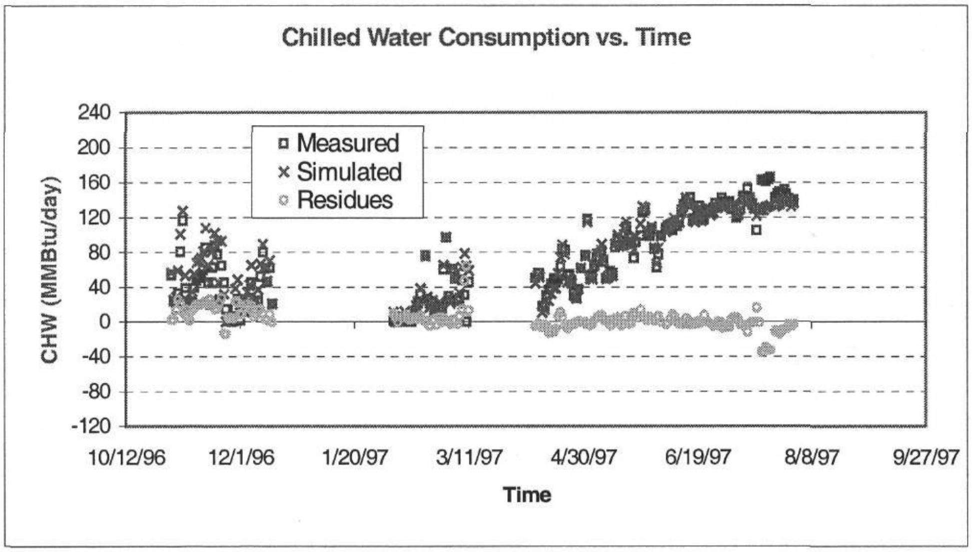


(a)

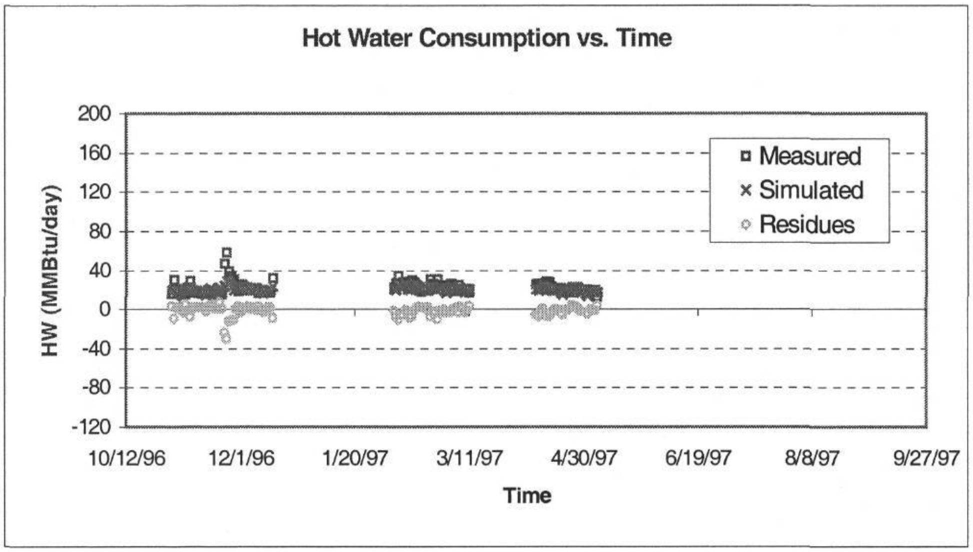


(b)

Figure 6.12 The Kleberg building measured and simulated heating and cooling energy consumption as a function of temperature for the post-CC period from 11/01/1996 to 07/31/1997 for cooling and to 05/06/1997 for heating excluding the periods from 12/16/1996 to 02/04/1997 and 03/12/1997 to 04/08/1997



(a)



(b)

Figure 6.13 The Kleberg building measured and simulated heating and cooling energy consumption as a function of time for the post-CC period from 11/01/1996 to 07/31/1997 for cooling and to 05/06/1997 for heating excluding the periods from 12/16/1996 to 02/04/1997 and 03/12/1997 to 04/08/1997

6.2.4 Simulation Comparison of Three Different Periods (Pre-CC, Post-CC and Year 2000)

The commissioning activity in this building reduced heating and cooling consumption by more than half but the savings have subsequently decreased significantly. As shown in Table 6.1, the chilled water and hot water consumption in the post-CC period dropped significantly with annual savings of 59.7 % for cooling and 88.4 % for heating. But for the year 2000 the savings numbers decreased to 37.7% for cooling and 62.2% for heating relative to the pre-CC energy use.

The CC report and calibrated simulation indicate that three system parameters changed significantly between the pre-CC period and the 1997 post-CC period. The cold deck temperatures increased and minimum air flow rate and preheat temperatures decreased. All these changes contributed to the thermal energy savings. By 2000 the minimum air flow rate returned to the same value used before commissioning and cold deck schedule had risen by 3 ^{o}F at the outside air temperature of 40 ^{o}F or below and dropped by 2 ^{o}F at the outside air temperature of 70 ^{o}F or higher compared to the post-CC schedule. As the result of this change, the preheat settings were also modified to follow the control scheme that sets the preheat 10 ^{o}F lower than the cold deck temperature. However, due to a faulty control valve and high water-side pressure, the building was effectively operating with much higher pre-heat temperatures as shown.

The calibrated simulation used to determine normalized annual consumption values with 1995 weather data exhibit some Mean Bias Error (MBE) which can lead to appreciable error in the savings determination.

The table entries denoted "MBE applied" have had the annual energy use adjusted by multiplying the daily MBE by 365 and adding or subtracting this value depending on the sign of MBE from the annualized consumption. These values of energy use and savings with MBE are closer to the real values. The same process was performed using the EMCS settings for each period and shown in Table 1.

The energy use and savings calculated with the application of MBE from both calibrated and scheduled settings agree quite well. Since the information of preheat schedule for the pre-CC period was not available the same input parameters were used for the calculation of the calibrated and simulated energy consumption; so the results are the same values in the table.

As shown in the year 2000 savings results in Table 6.1, the differences of the yearly CHW and HW energy consumption between MBE-applied and the values without MBE adjustment using scheduled parameters are quite noticeable; MBE-applied consumption is 20% higher for CHW and 46% higher for HW compared to the cases without MBE adjustment. In year 2000, this building experienced several control changes, which are included in the "scheduled" simulations. The cold deck schedule was changed as shown. VFD control on two CHW pumps was put on manual; therefore, the pumps ran at full speed. Two chilled water valves were leaking badly, along with pressure and CO2 sensor failures that caused OA dampers to operate in the full open position. Chen et al. (2002) provides more details.

This resulted in the building using considerably more energy as shown in the calibrated results. The building was effectively operating with the cold deck schedule and preheat schedule shown for the calibrated case. Hence the consumption increases in HW and CHW were roughly equally due to control changes and component failures. The pumps were set on manual due to a serious vibration occurring at certain VFD speeds, and in that sense, virtually all the increased consumption was due to component problems.

Table 6.1 The Kleberg Building Energy Consumption Results from Calibrated Simulation and Input Parameter Comparisons for the Pre-CC, Post-CC and Year 2000 Periods

	Type	Baseline (Pre-CC) (MMBtu/yr)	Post-CC		2000	
			Use (MMBtu/yr)	Savings (%)	Use (MMBtu/yr)	Savings (%)
Calibrated	CHW	72589	30343	58.2%	44183	39.1%
Calibrated	HW	44678	4414	90.1%	17082	61.8%
Calibrated	CHW (MBE applied)	72935	29392	59.7%	45431	37.7%
Calibrated	HW (MBE applied)	43296	5024	88.4%	16351	62.2%
(Scheduled)	CHW (MBE applied)	72935	29392	59.7%	43888	39.8%
(Scheduled)	HW (MBE applied)	43296	5024	88.4%	15199	64.9%
(Scheduled)	CHW	72589	30343	58.2%	36574	49.6%
(Scheduled)	HW	44678	4414	90.1%	10444	76.6%

	Parameter	Pre-CC	Post-CC	2000
1	Room Temperature (Heating/Cooling)	70 74	70 74	70 74
2	Total Air Flow Rate (cfm/sq-ft)	1.10	1.10	1.10
3	Outside Air Flow Rate (cfm/sq-ft)	0.51	0.51	0.33
4	Min. Air Flow Rate (cfm/sq-ft)	0.92	0.70	0.92
5	Cold Deck Calibrated (Scheduled)	55 (55)	62 40 57 60 * (62 40 57 60)	**63** 40 **53** 70 (65 40 55 70)
6	Pre-heat Calibrated (Scheduled)	75 30 98 55 (n/a)	52 40 47 60 (52 40 47 60)	**74** 40 **76** 70 (55 40 45 70)

* The notation shown here for cold-deck and pre-heat schedules means the deck set point is at the first number (62 °F) when outside air temperature is below the second (40 °F). The set-point then increases linearly with outside air temperature, reaching the third number (57 °F) when outside air temperature reaches the fourth number (60 °F) and remains constant for higher outside air temperatures.

6.3 Calibrated Simulation 2: Eller O&M Building

6.3.1 Site Description

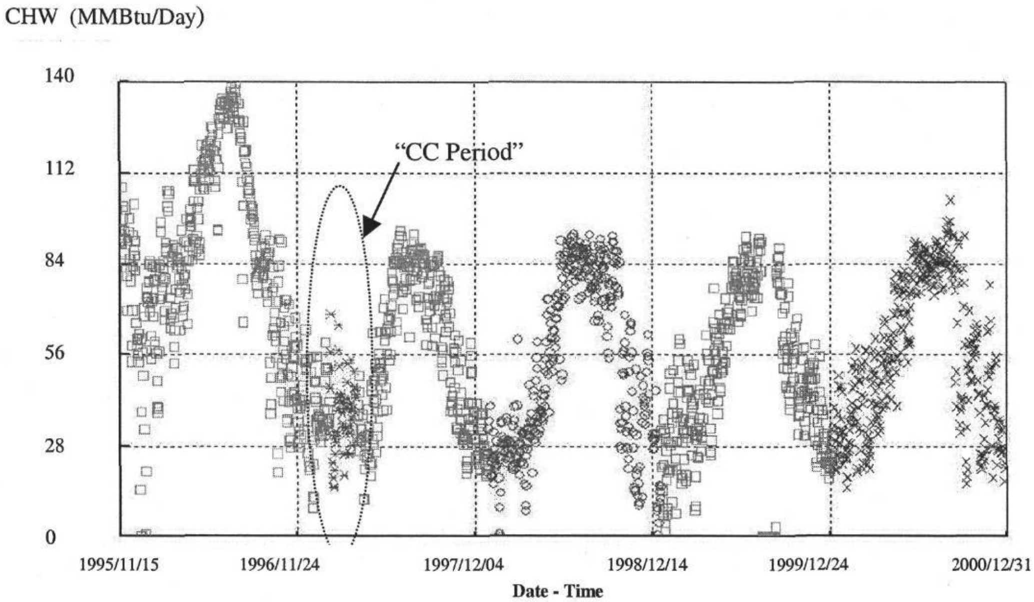
The Eller O&M (Oceanography and Meteorology) building is located on the main campus of Texas A&M University, College Station, TX, and has 14 stories with a basement. The total conditioned area is 180,316 square feet. The usage of this building is for classrooms, laboratories, and offices.

There are four major dual duct air-handling units with variable air volume systems (DDVAV). Each of these AHUs has two fans, two banks of chilled water coils, and one hot water coil. Two of four major AHUs are on the fourth floor and the other two are on the ninth floor. There are also two small constant-volume, multi-zone air-handling units (MZCV AHU) on the 14^{th} floor and the basement respectively. These small units are on standalone controllers and are not connected to the Landis & Staefa (L&S) EMCS, while the 4 major AHUs are controlled through the L&S system. The central plant on campus supplies chilled water and hot water to this building.

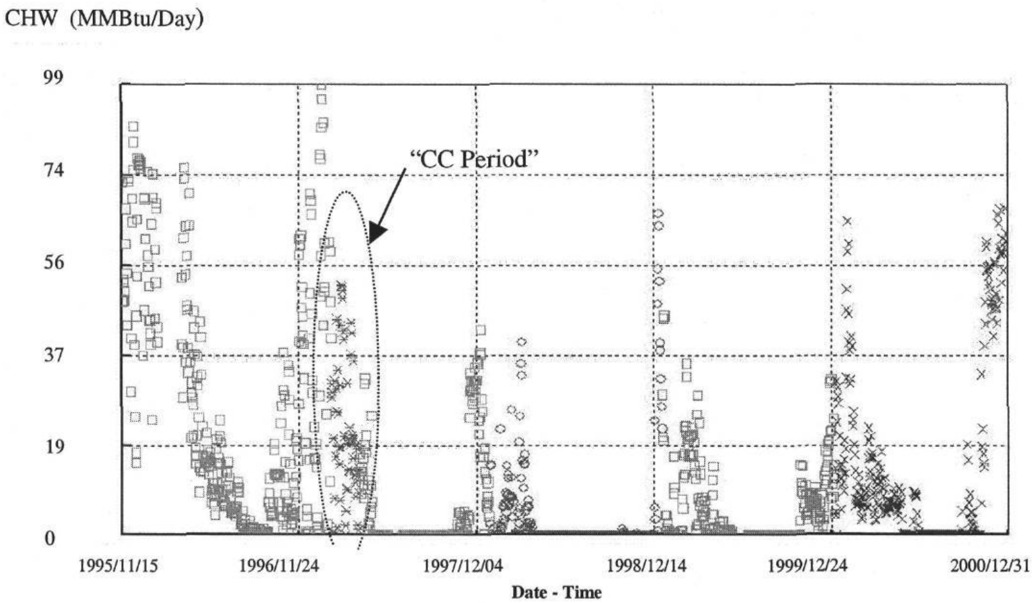
The two chilled water pumps and two hot water pumps are equipped with variable frequency drives (VFD). The pumps are controlled by the relative positions of the two chilled water and two hot water control valves of the 9^{th} floor AHUs. They are programmed to run at the same speed. The hot water pumps are programmed to shut down if the outside air temperature exceeds 57 ^{o}F and to come on if the outside air temperature drops below 55 ^{o}F.

The CC work on this building was finished in March of 1997. The main measures were loop tuning for control valves, optimization of cold deck, hot deck, and static pressure reset schedules, reschedule of minimum supply air, day and night temperature reset, and tune-up for chilled water and hot water pumping.

As seen in Figure 6.14, moderate chilled water energy savings have persisted for four years since commissioning was finished in March of 1997. An exception was found in the winter period of 1998 when the chilled water use was lower than during any other winter. Hot water consumption also shows fairly similar patterns over time.



(a)



(b)

Figure 6.14 The Eller O&M building daily chilled water and hot water energy use from 1995 to 2000

6.3.2 Calibrated Simulation with Year 2000 Data

Here are the major input parameters initially used in year 2000 simulation for the Eller O&M building,

HVAC system type: DDPOA (Dual Duct with Preheat Outside Air)

Air supply: VAV (Variable Air Volume)

Conditioned floor area: 180,316 sq-ft

Internal zone fraction: 0.5

Exterior wall area / U value: 63248 sq-ft / 0.20 Btu/sq-ft hr F

Exterior window area / U value: 26208 sq-ft / 0.98 Btu/sq-ft hr F

Supply air fan HP / control model: 400 HP / VFD (Variable Frequency Drive)

Return air fan HP / control model: 0 HP / n/a

Room temperature (heating and cooling): 70 °F 74 °F (70 °F 78 °F : Night)

Total air flow rate: 1.30 cfm/sq-ft

Outside air flow rate: 0.19 cfm/sq-ft

Minimum air flow: 0.75 cfm/sq-ft

Cold deck schedule for 2 AHUs:

(T_{SET} = set temperature, T_{OA} = outside air temperature)

T_{SET} = 60 °F, if T_{OA} is below 55 °F

T_{SET} = 55 °F, if T_{OA} is above 70 °F

$T_{SET} = 1/3 * (235 - T_{OA})$, if T_{OA} is between 55 °F and 70 °F

Cold deck schedule for the other 2 AHUs:

(T_{SET} = set temperature, T_{OA} = outside air temperature)

T_{SET} = 60 °F, if T_{OA} is below 55 °F

T_{SET} = 52 °F, if T_{OA} is above 100 °F

T_{SET} = 1/45 * (3140 – 8*T_{OA}), if T_{OA} is between 55 °F and 100 °F

Hot deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

T_{SET} = 90 °F, if T_{OA} is below 50 °F

T_{SET} = 80 °F, if T_{OA} is above 60 °F

T_{SET} = 140 - T_{OA}, if T_{OA} is between 50 °F and 60 °F

Preheat schedule: 55 °F

Internal heat gain: 1.40 W/sq-ft

The cold deck schedules of the 4 AHUs were a little different in the year 2000. Two AHUs had cold deck set point of 60 °F at outside temperatures of 55 °F or below and 55 °F at outside air temperatures of 70 °F or higher, while the other two AHUs had set points of 60 °F at outside air temperatures of 55 °F or below and 52 °F at outside air temperatures of 100 °F. Even though there were two different sets of cold deck schedules, the real settings and readings from the EMCS equipment were the same for all four AHUs with the cold deck settings and readings of 54 °F at outside temperatures of 75 ^{o}F or above. So the cold deck schedule used for simulation ranged from 60 ^{o}F to 54 ^{o}F for the cold deck as the ambient temperature changes from 55 ^{o}F to 75 ^{o}F.

The hot deck schedules in the control program were 90 ^{o}F and 80 ^{o}F when ambient temperatures reach 50 ^{o}F and 60 ^{o}F respectively, but the actual operating status was different in the energy management control system. In the winter period the hot deck settings of two AHUs were overridden to 110 ^{o}F, and the hot deck temperature sensor readings were not constant, moving from 90 ^{o}F to 114 ^{o}F, indicating the coil was not responding to the controls properly. For example, one day the temperature readings were around 90 ^{o}F with an "operator mode" of 110 ^{o}F and another day they were around 110 ^{o}F. To approximate this behavior the simulation of this building was carried out assuming two subsystems, one set at 110 ^{o}F and one set at 90 ^{o}F for the hot deck settings in the winter, as shown in the parameter listing that follows.

The simulated chilled water and hot water energy consumption using the design data was initially not very far from the measured energy use, but still needed to be calibrated by changing some appropriate parameters. The values of CVRMSE obtained from the first simulation with the scheduled data were 9.5% for chilled water and 26.0% for hot water, and Mean Bias Error (MBE) values were –1.6 MMBtu/day for chilled water and –0.9 MMBtu/day for hot water. The chilled water consumption pattern matched with measured energy pattern within an acceptable range, but the hot water consumption showed different patterns where the simulated results were lower than the measured results in cold weather and higher than measured results in hot weather. To adjust this simulated pattern to the measured one, cold deck and hot deck set points were calibrated based on the information mentioned above. These initial and calibrated parameters are listed below.

Cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled for subsystem 1:

$T_{SET} = 60\ ^{o}F$, if T_{OA} is below $55\ ^{o}F$

$T_{SET} = 55\ ^{o}F$, if T_{OA} is above $70\ ^{o}F$

$T_{SET} = 1/3 * (235 - T_{OA})$, if T_{OA} is between $55\ ^{o}F$ and $70\ ^{o}F$

Scheduled for subsystem 2:

$T_{SET} = 60\ ^{o}F$, if T_{OA} is below $55\ ^{o}F$

$T_{SET} = 52\ ^{o}F$, if T_{OA} is above $100\ ^{o}F$

$T_{SET} = 1/45 * (3140 - 8*T_{OA})$, if T_{OA} is between $55\ ^{o}F$ and $100\ ^{o}F$

Calibrated for all subsystems:

$T_{SET} = 60\ ^{o}F$, if T_{OA} is below $55\ ^{o}F$

$T_{SET} = 54\ ^{o}F$, if T_{OA} is above $75\ ^{o}F$

$T_{SET} = 1/10 * (765 - 3*T_{OA})$, if T_{OA} is between $55\ ^{o}F$ and $75\ ^{o}F$

Hot deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled for all subsystems:

T_{SET} = 90 °F, if T_{OA} is below 50 °F

T_{SET} = 80 °F, if T_{OA} is above 60 °F

T_{SET} = 140 - T_{OA}, if T_{OA} is between 50 °F and 60 °F

Calibrated for subsystem 1:

T_{SET} = 90 °F, if T_{OA} is below 50 °F

T_{SET} = 80 °F, if T_{OA} is above 60 °F

T_{SET} = 140 - T_{OA}, if T_{OA} is between 50 °F and 60 °F

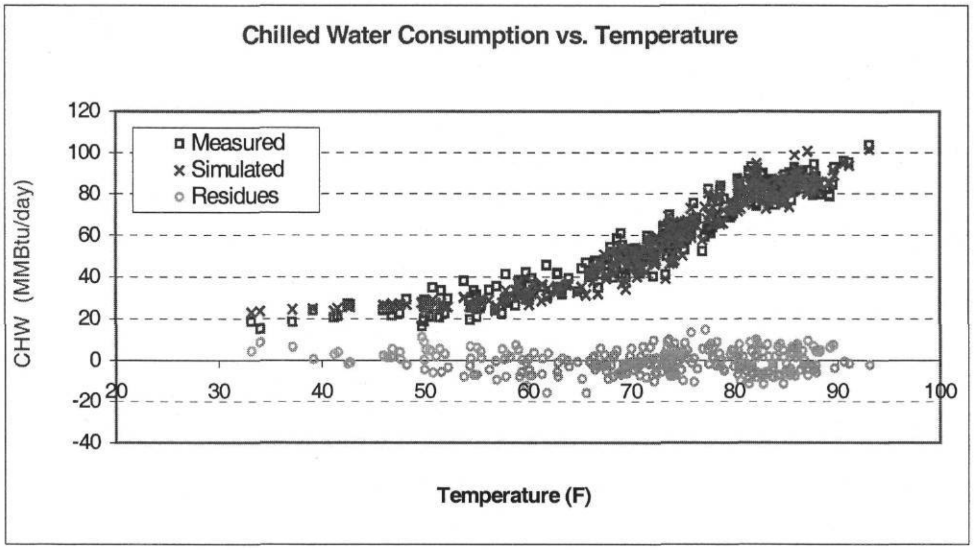
Calibrated for subsystem 2:

T_{SET} = 110 °F, if T_{OA} is below 50 °F

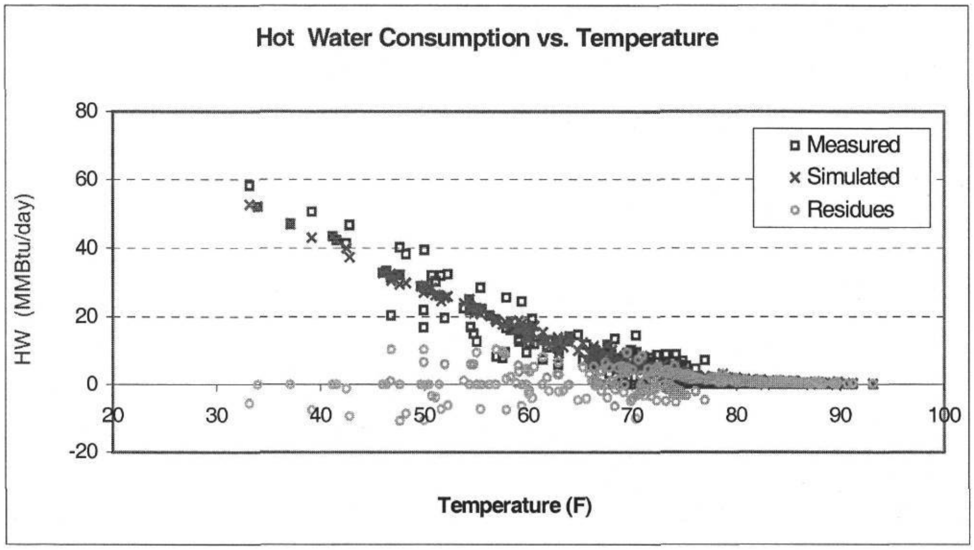
T_{SET} = 80 °F, if T_{OA} is above 60 °F

T_{SET} = 260 – 3*T_{OA}, if T_{OA} is between 50 °F and 60 °F

With the calibrated parameters, the final simulation result had CVRMSE values of 9.3% for chilled water and 20.8% for hot water. MBE values were –0.6 MMBtu/day for chilled water and 0.6 MMBtu/day for hot water. The changes of parameters in this simulation did not substantially affect the chilled water energy consumption pattern, but developed the hot water energy consumption pattern of simulation. Figures 6.15 and 6.16 show the measured and calibrated simulation energy consumption for cooling and heating as functions of ambient temperature and time, respectively.

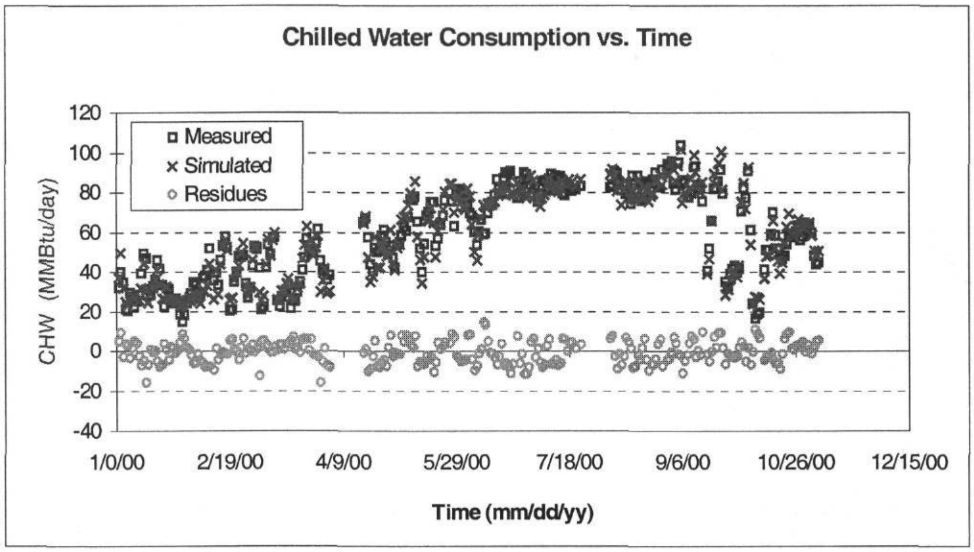


(a)

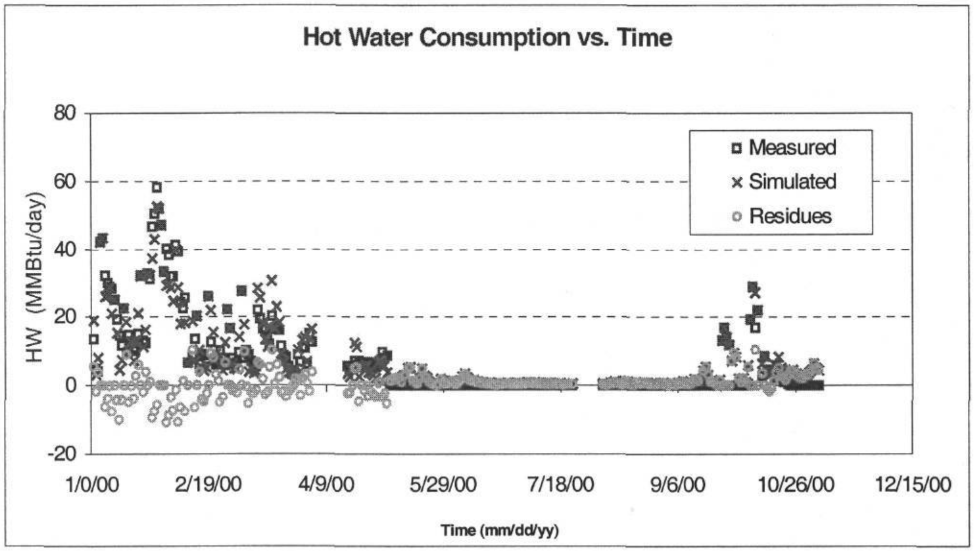


(b)

Figure 6.15 The Eller O&M building measured and simulated heating and cooling energy consumption after calibration as a function of ambient temperature for the period from 01/01/2000 to 11/05/2000



(a)



(b)

Figure 6.16 The Eller O&M building measured and simulated heating and cooling energy consumption after calibration as a function of time for the period from 01/01/2000 to 11/05/2000

6.3.3 Calibrated Simulation with Pre-CC and Post-CC Data

To simulate the pre-CC year for this building, 1996, the period was divided into two parts because there were two distinct energy use patterns. The early part of 1996 showed around twice as much energy use as the later part of 1996. It is reported that in the summer of 1996 there was a Direct Digital Control (DDC) upgrade of the terminal boxes from Constant Air Volume (CAV) to Variable Air Volume (VAV) systems. The simulation, therefore, was performed for the period from 08/28/1996 to 02/02/1997. The measured energy use of this period showed considerable scatter so that it was difficult to achieve a good value of CVRMSE for the hot water consumption.

With the schedule based on the information from the commissioning report, the cold deck settings are constant at 55 °F at outside air temperatures of 55 °F or higher and then increase up to 65 °F as the outside air temperature drops from 55 °F to 25 °F. The hot deck temperature decreases from 105 °F to 80 °F as the ambient temperature changes from 50 °F to 75 °F. The first simulation was performed with these schedules and other parameters utilized were those used for the simulation of the 2000 period.

The initially simulated consumption was lower than the measured use, especially during cold weather, with the CVRMSE value of 12% for chilled water and 35% for hot water. The simulation changes focused on the low ambient temperatures. To increase energy consumption during cold weather, cold deck and hot deck schedules were changed so the cold deck was set to a constant temperature of 55 °F for all outdoor temperatures condition and the hot deck was changed to move from 110 °F to 80 °F as the ambient temperature increases from 50 °F to 75 °F. These calibrated cold deck and hot deck schedules are based on information obtained from the CC report, which showed average measured data for cold deck temperatures of 55 °F and hot deck temperatures of 105 °F for two AHUs and 110 °F for the other two AHUs during cold weather. Consequently the simulation used two subsystems to represent these two different hot deck schedules as shown below. The final simulation with calibrated parameters had a CVRMSE of 9.5 % for chilled water and 27.7 % for hot water and had MBE values of 1.8 MMBtu/day for chilled water and 0.1 MMBtu/day for hot water. The initial and calibrated parameter values are shown below.

Cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: T_{SET} = 62 °F, if T_{OA} is below 25 °F

T_{SET} = 55 °F, if T_{OA} is above 55 °F

$T_{SET} = 1/30 * (2035 - 7*T_{OA})$, if T_{OA} is between 25 °F and 55 °F

Calibrated: T_{SET} = 55 °F, constant temperature

Hot deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled for all subsystems:

T_{SET} = 105 °F, if T_{OA} is below 50 °F

T_{SET} = 80 °F, if T_{OA} is above 75 °F

$T_{SET} = 155 - T_{OA}$, if T_{OA} is between 50 °F and 75 °F

Calibrated for subsystem 1:

$T_{SET} = 105\ ^{o}F$, if T_{OA} is below $50\ ^{o}F$

$T_{SET} = 80\ ^{o}F$, if T_{OA} is above $75\ ^{o}F$

$T_{SET} = 155 - T_{OA}$, if T_{OA} is between $50\ ^{o}F$ and $75\ ^{o}F$

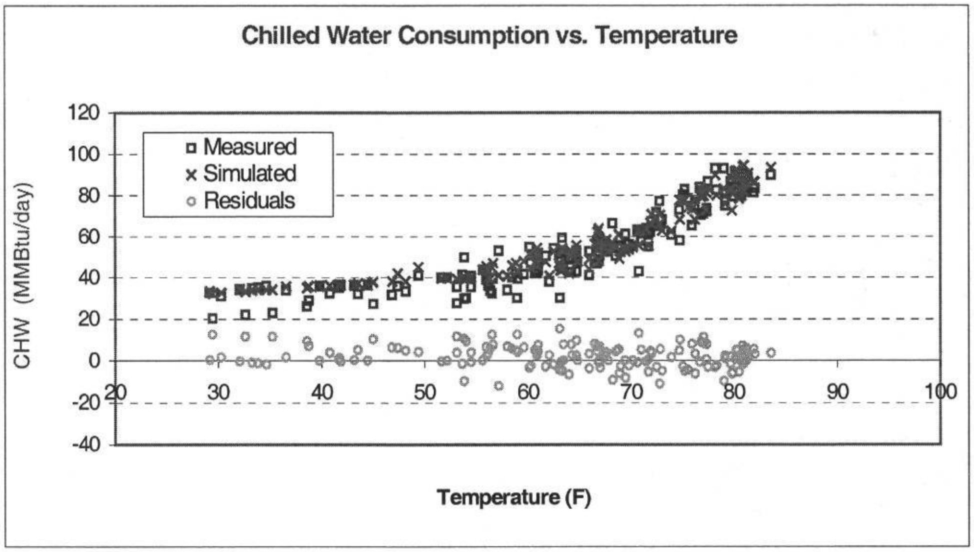
Calibrated for subsystem 2:

$T_{SET} = 110\ ^{o}F$, if T_{OA} is below $50\ ^{o}F$

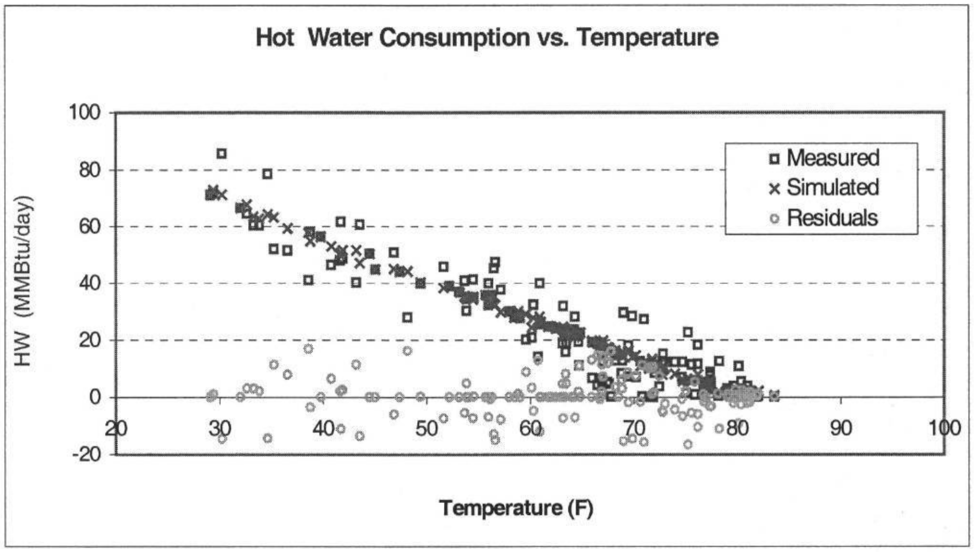
$T_{SET} = 80\ ^{o}F$, if T_{OA} is above $75\ ^{o}F$

$T_{SET} = 170 - 6/5*T_{OA}$, if T_{OA} is between $50\ ^{o}F$ and $75\ ^{o}F$

Figure 6.17 and Figure 6.18 show measured and simulated energy consumption for cooling and heating as functions of ambient temperature and time for the pre-CC period from 08/28/1996 to 02/02/1997.

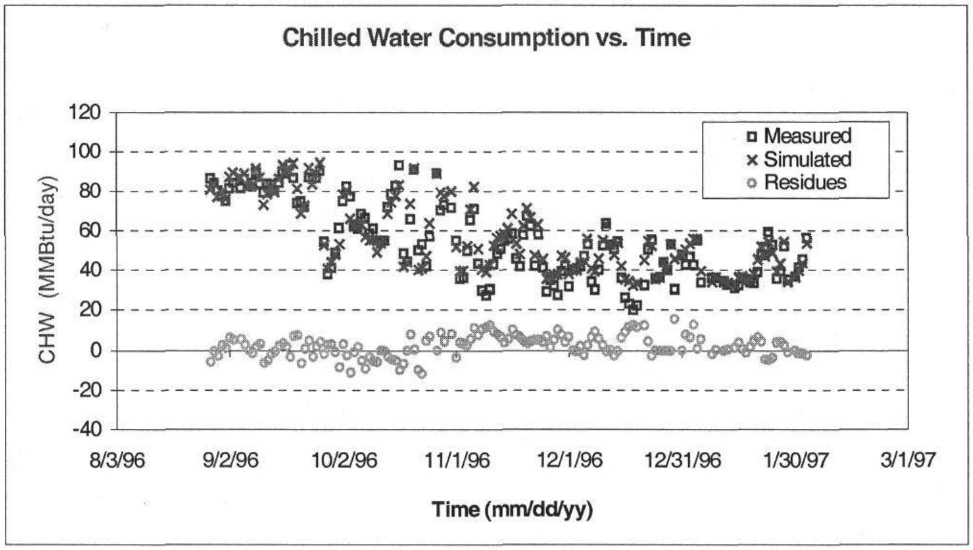


(a)

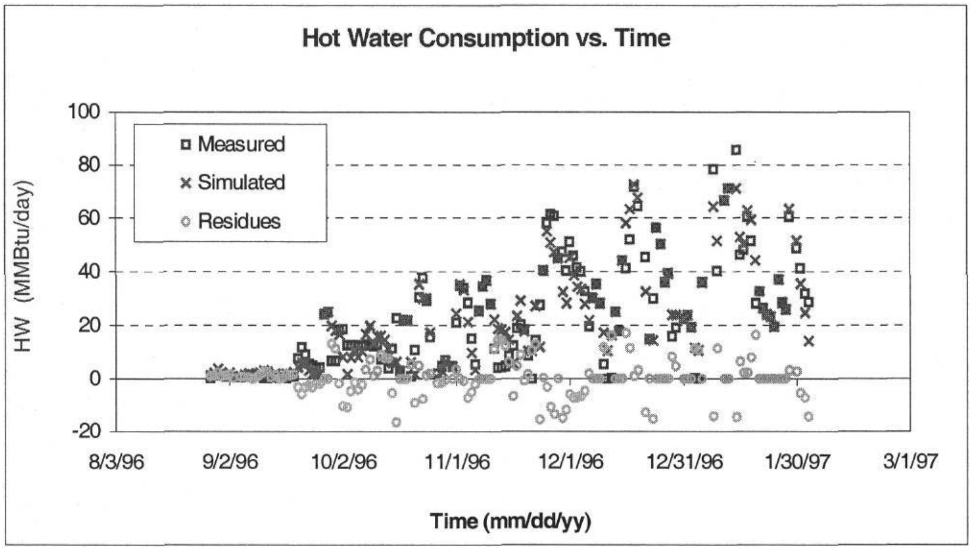


(b)

Figure 6.17 The Eller O&M building measured and simulated heating and cooling energy consumption as a function of ambient temperature after calibration for the pre-CC period from 08/28/1996 to 02/02/1997



(a)



(b)

Figure 6.18 Time series plots of the Eller O&M building measured and simulated heating and cooling energy consumption for the pre-CC period from 08/28/1996 to 02/02/1997 after calibration

The CC process implemented changes in the energy management and control system settings for this building intended to optimize performance. The cold deck temperature increased, hot deck temperature decreased, and static pressure decreased from a constant 2 in H2O to 1 in H2O at outside air temperatures of 60 ^{o}F or below and 1.3 in H2O at outside air temperatures of 70 ^{o}F or higher. The simulation for the post-CC period from 03/19/1997 to 08/31/1997 was performed with scheduled data documented in the CC report where the cold deck temperature moves from 60 ^{o}F to 55 ^{o}F as outside air temperature rises from 55 ^{o}F to 85 ^{o}F, and the hot deck temperature changes from 90 ^{o}F to 70 ^{o}F as the outside air temperature increases from 50 ^{o}F to 70 ^{o}F.

The CVRMSE values of cooling and heating energy from the first simulation were 13% and 54% respectively. The simulated chilled water energy consumption was higher in the hot weather and lower in cold weather than the measured chilled water use. There were some possible ways to fit the patterns by changing the cold deck and hot deck set points. The cold deck schedules finally used for the post-CC simulation are the same as scheduled during CC. But the hot deck temperature settings of the calibrated simulation are different and higher than initially used for two AHUs in the wintertime. This calibration was based on the information in the CC report. The CC report includes hot deck temperature readings for the post-CC period for 4 AHUs, and the measurements were done in the winter, 1997. Two out of four AHUs had the same scheduled and measured hot deck temperatures, but the other two AHUs had measured hot deck temperatures that were about 10 degrees higher than scheduled on average. The final calibrated parameters are shown below.

Cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: $T_{SET} = 60\ ^{o}F$, if T_{OA} is below 55 ^{o}F

$T_{SET} = 55\ ^{o}F$, if T_{OA} is above 85 ^{o}F

$T_{SET} = 1/6 * (415 - T_{OA})$, if T_{OA} is between 55 ^{o}F and 85 ^{o}F

Calibrated: $T_{SET} = 60\ ^{o}F$, if T_{OA} is below 55 ^{o}F

$T_{SET} = 55\ ^{o}F$, if T_{OA} is above 85 ^{o}F

$T_{SET} = 1/6 * (415 - T_{OA})$, if T_{OA} is between 55 ^{o}F and 85 ^{o}F

Hot deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled for all subsystems:

$T_{SET} = 90\ ^{o}F$, if T_{OA} is below 50 ^{o}F

$T_{SET} = 70\ ^{o}F$, if T_{OA} is above 70 ^{o}F

$T_{SET} = 140 - T_{OA}$, if T_{OA} is between 50 ^{o}F and 70 ^{o}F

Calibrated for subsystem 1:

$T_{SET} = 90\ ^{o}F$, if T_{OA} is below 50 ^{o}F

$T_{SET} = 70\ ^{o}F$, if T_{OA} is above 70 ^{o}F

T_{SET} = 140 - T_{OA}, if T_{OA} is between 50 °F and 70 °F

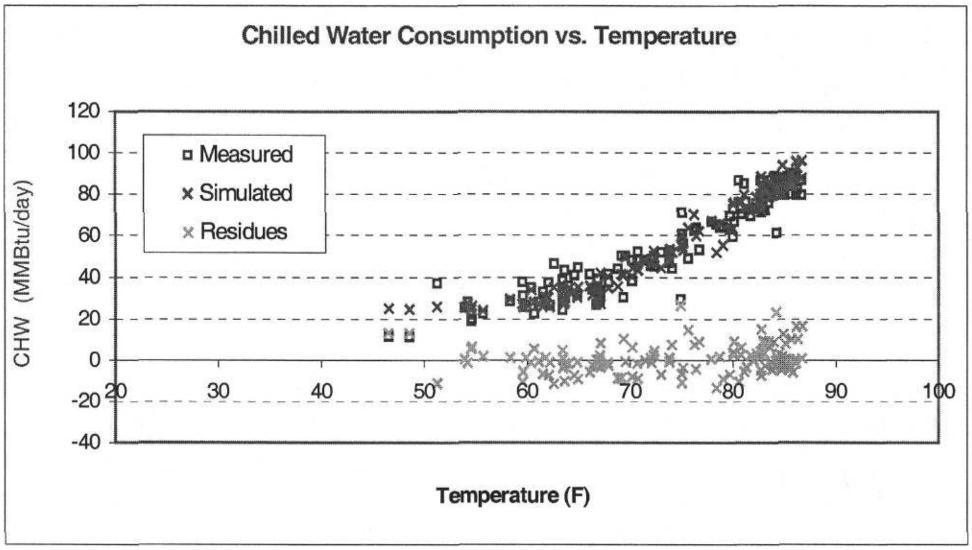
Calibrated for subsystem 2:

T_{SET} = 100 °F, if T_{OA} is below 50 °F

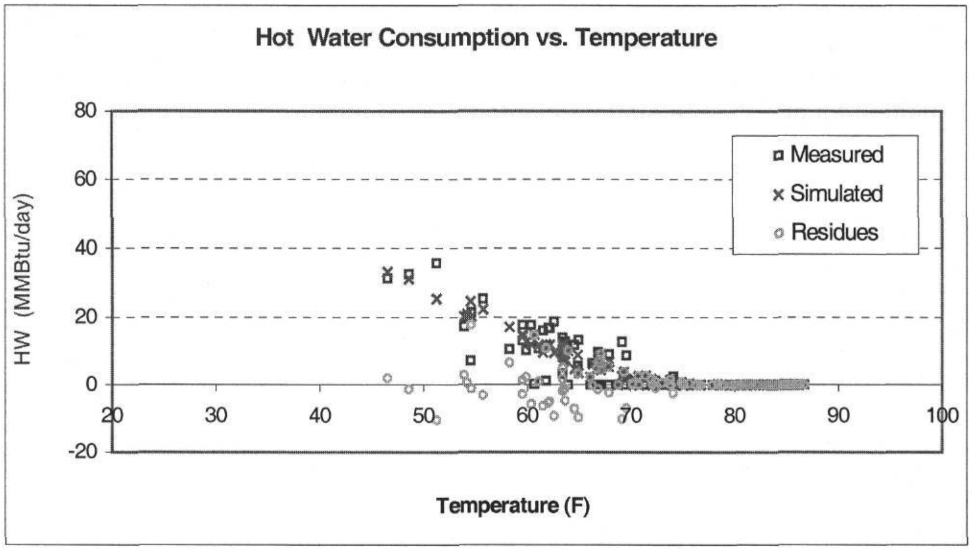
T_{SET} = 70 °F, if T_{OA} is above 70 °F

T_{SET} = 175 – 3/2*T_{OA}, if T_{OA} is between 50 °F and 70 °F

The final MBE values with calibrated simulation are 0.6 MMBtu/day for chilled water and –0.7 MMBtu/day for hot water, and CVRMSE is 12.1% for chilled water and 34.0 % for hot water. The CVRMSE of 34.0% for hot water is somewhat high due to insufficient energy use data for that period. Figures 6.19 and 6.20 show the results of calibrated simulation of the Eller O&M building for the post-CC period from 03/19/1997 to 08/31/1997.

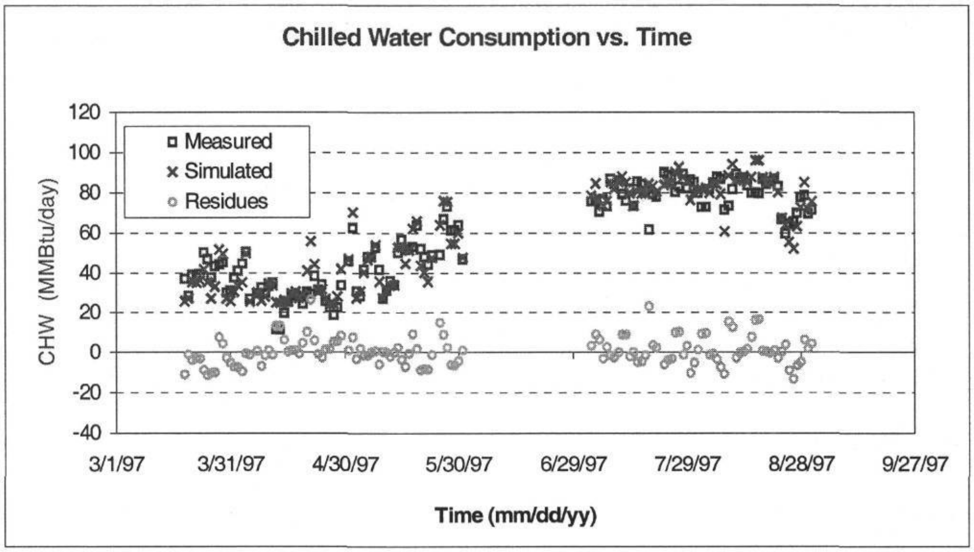


(a)

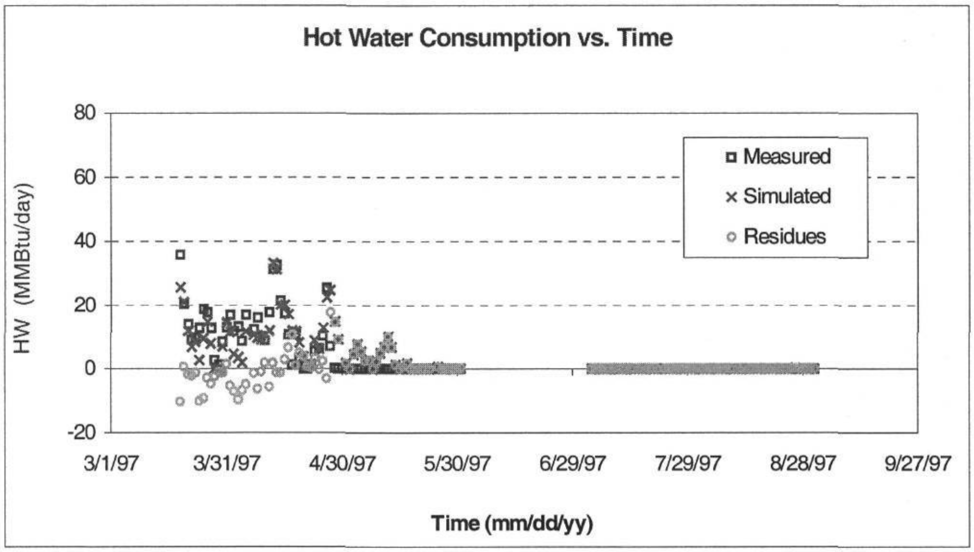


(b)

Figure 6.19 The Eller O&M building measured and simulated heating and cooling energy consumption as a function of temperature for the post-CC period from 03/19/1997 to 08/31/1997 (data for June was missing)



(a)



(b)

Figure 6.20 The Eller O&M building measured and simulated heating and cooling energy consumption as a function of time for the post-CC period from 03/19/1997 to 08/31/1997 (data for June was missing)

6.3.4 Simulation Comparison of Three Different Periods (Pre-CC, Post-CC and Year 2000)

This building reduced cooling energy by 13.5 % and heating energy use by 42.6 % for the first year after CC was completed. Increasing cold deck temperature settings and decreasing hot deck temperature settings in the simulation, as seen in Table 6.2, accounted for these savings. In year 2000 after three years have passed, the savings decreased to 7.9 % for cooling energy while heating energy savings were virtually unchanged. This degradation came from decreasing cold deck temperatures and increasing hot deck temperatures as shown in the table. The parameters in bold characters in Table 6.2 are to show that they are the numbers calibrated. The 6^{th} parameter, hot deck setting, has numbers combined like 110/105 meaning that they are used in different subsystems, 110 for subsystem 1 and 105 for subsystem 2. But if a single number is shown, the parameter is used in both subsystems. Comparison of the scheduled and calibrated values shows that the decrease in CHW savings is closely accounted for by the schedule changes.

Table 6.2 The Eller O&M Building Energy Consumption Results from Calibrated Simulation and Input Parameter Comparisons for the Pre-CC, Post-CC and Year 2000 Periods

	Type	Baseline (Pre-CC) (MMBtu/yr)	Post-CC		2000	
			Use (MMBtu/yr)	Savings (%)	Use (MMBtu/yr)	Savings (%)
Calibrated	CHW	23132	19673	15.0%	20494	11.4%
	HW	6147	3246	47.2%	3795	38.3%
	CHW (MBE applied)	22487	19444	13.5%	20703	7.9%
	HW (MBE applied)	6099	3503	42.6%	3571	41.5%
(Scheduled)	CHW (MBE applied)	22389	19349	13.6%	20609	7.9%
	HW (MBE applied)	5561	3409	38.7%	3462	37.7%
	CHW	22588	19331	14.4%	20202	10.6%
	HW	5624	2919	48.1%	3505	37.7%

	Parameter	Pre-CC	Post-CC	2000
1	Room Temperature Occ/Unocc (Heating/Cooling)	70 74 70 78	70 74 70 78	70 74 70 78
2	Total Air Flow Rate (cfm/sq-ft)	1.30	1.30	1.30
3	Outside Air Flow Rate (cfm/sq-ft)	0.19	0.19	0.19
4	Min. Air Flow Rate (cfm/sq-ft)	0.75	0.75	0.75
5	Cold Deck Calibrated (Scheduled)	**55** (65 25 55 55)	60 55 55 85 (60 55 55 85)	60 55 54 75 (60 55 54 75)
6	Hot Deck Calibrated (Scheduled)	**110**/105 50 80 75 (105 50 80 75)	**100**/90 50 70 70 (90 50 70 70)	**110**/90 50 80 60 (90 50 80 60)
7	Pre-heat Schedule	55	55	55
8	Internal Heat Gain (W/sq-ft)	1.40	1.40	1.40

6.4 Calibrated Simulation 3: Harrington Tower

6.4.1 Site Description

The Harrington Education Tower is an eight-story building with a basement and is located on the main campus of Texas A&M University in College Station. This building consists of classrooms, offices, computer laboratories, and meeting rooms. The total floor area is 130,844 square feet.

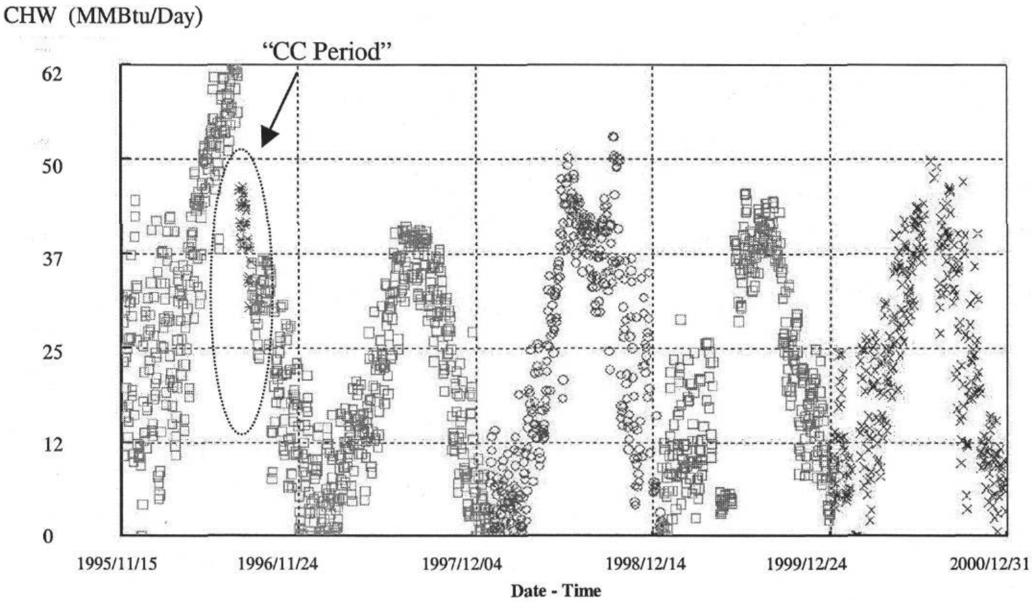
A total of four air handling units serve this building, but one big unit provides ventilation and conditioned air for the 2nd floor through 8th floor, including the basement. This large unit is a dual duct AHU with variable air volume (DDVAV), and is located in the basement. The 200 HP fan motor has a variable speed drive, or variable frequency drive (VFD) system. The other three smaller AHUs are single duct units and serve the first floor. Chilled water and hot water are provided by the central plant on campus.

The Harrington Tower was commissioned in August of 1996. The major CC measures implemented were cold deck and hot deck schedules, day and night room temperature set points were implemented, duct static pressure was reduced from 1.5 to 1.2 in H_2O, maximum and minimum air flow rate was changed to 1.0 cfm/sf and 0.3 cfm/sf respectively, and chilled water and hot water pumping control was optimized.

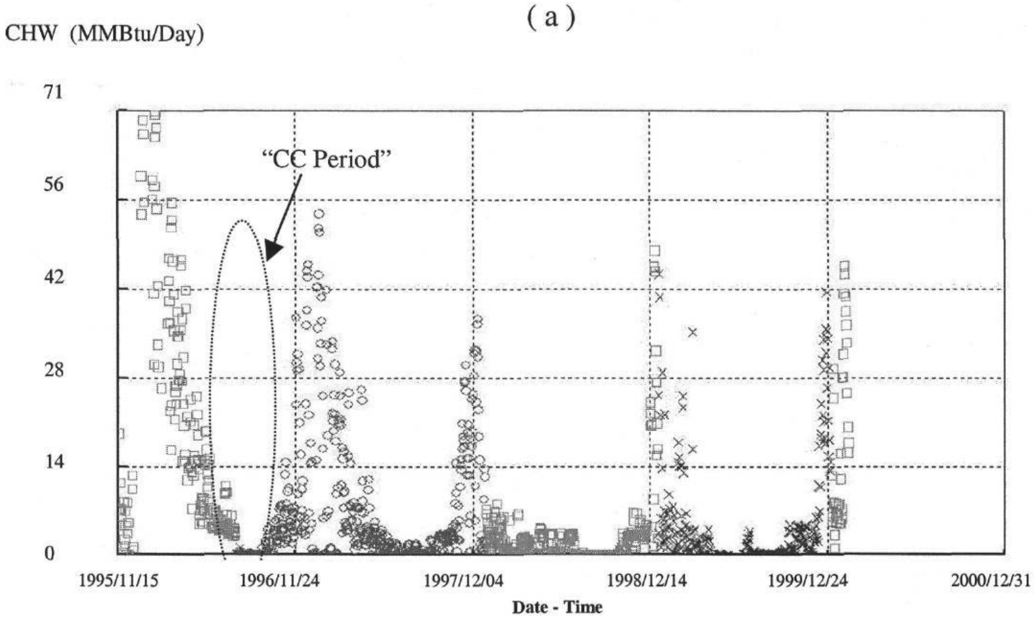
Figure 6.21 shows daily chilled water and hot water energy use patterns from the end of 1995 through 2000.

The chilled water energy use was very high before CC and then dropped significantly after CC, but has risen slowly over the years.

The hot water energy use also decreased a lot after CC and the HW savings obtained from CC have been maintained over time.



(a)



(b)

Figure 6.21 The Harrington Tower daily chilled water and hot water energy use from 1995 to 2000

6.4.2 Calibrated Simulation with Year 2000 Data

The major input parameters initially used for the simulation of the Harrington Tower are:

HVAC system type: DDPOA (Dual Duct with Preheat Outside Air)

Air supply: VAV (Variable Air Volume)

Conditioned floor area: 130,844 sq-ft

Internal zone fraction: 0.5

Exterior wall area / U value: 41200 sq-ft / 0.20 Btu/sq-ft hr F

Exterior window area / U value: 19017 sq-ft / 0.80 Btu/sq-ft hr F

Supply air fan HP / control model: 230 HP / VFD (Variable Frequency Drive)

Return air fan HP / control model: 0 HP / n/a

Room temperature (heating and cooling): 72 °F 75 °F

Total air flow rate: 1.10 cfm/sq-ft

Outside air flow rate: 0.15 cfm/sq-ft

Minimum air flow: 0.61 cfm/sq-ft

Cold deck schedule (T_{SET} T_{OA}): 55 °F (First day), 60 °F~55 °F (Second day)

Hot deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

T_{SET} = 105 °F, if T_{OA} is below 40 °F

T_{SET} = 75 °F, if T_{OA} is above 70 °F

T_{SET} = 145 - T_{OA}, if T_{OA} is between 40 °F and 70 °F

Preheat schedule: no preheat

Internal heat gain: 0.82 W/sq-ft

The control schemes for cold deck, hot deck, and static pressure were changed by the commissioning process implemented in 1996. The cold deck temperature settings were separated into day and night modes. They were set from 60 °F to 55 °F in daytime as ambient temperature moves from 40 °F to 80 °F, and from 65 °F to 60 °F with outside air temperature of 40 °F through 80 °F in nighttime.

In year 2000, however, they were changed to a different control system that the cold deck temperatures were set based on outdoor enthalpy, which depends on both dew point and ambient temperature. The enthalpy-based set points were similar to the post-CC schedule. The enthalpy-based settings and constant 55 °F settings were implemented on alternate days from September 1999 to February 2001 as part of a test of the effectiveness of enthalpy control.

The hot deck temperature settings varied from 100 °F to 70 °F as outside air temperature changed from 40 °F to 70 °F during the post-CC period, and then changed to an alternating day mode during the enthalpy control test. The enthalpy-control days had the same settings as the post-CC period, and the second days had hot deck schedules that were 10 °F higher with the same outside air ranges.

The alternating days schedule was approximated in the simulation by a cold deck schedule that decreases from 58 °F to 55 °F as the outside air temperature rises from 40 °F to 80 °F. The hot deck temperature decreases from 105 °F to 75 °F as outside air temperature moves from 40 °F to 70 °F. This simulation resulted in hot water and chilled water consumption patterns that were systematically low in the winter period with the CVRMSE values of 18% for chilled water and 27% for hot water.

Actual sensor readings were then retrieved from APOGEE, an energy management control system, and these values were used in the simulation. The monitored cold deck temperature averaged 55 °F and the hot deck temperature averaged 75 °F when outside air temperature is 70 °F or higher. The calibrated schedule is only one degree lower temperature in the winter period for chilled water as shown below. The MBE values are 0.5 MMBtu/day for chilled water and 1.2 MMBtu/day for hot water. The initial and calibrated parameters are shown below.

Cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Initial: T_{SET} = 58 °F, if T_{OA} is below 60 °F

T_{SET} = 55 °F, if T_{OA} is above 80 °F

$T_{SET} = 67 - 3/20 * T_{OA}$, if T_{OA} is between 60 °F and 80 °F

Calibrated: T_{SET} = 57 °F, if T_{OA} is below 60 °F

$T_{SET} = 55\ ^{o}F$, if T_{OA} is above $80\ ^{o}F$

$T_{SET} = 63 - 1/10 * T_{OA}$, if T_{OA} is between $60\ ^{o}F$ and $80\ ^{o}F$

Hot deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: $T_{SET} = 105\ ^{o}F$, if T_{OA} is below $40\ ^{o}F$

$T_{SET} = 75\ ^{o}F$, if T_{OA} is above $70\ ^{o}F$

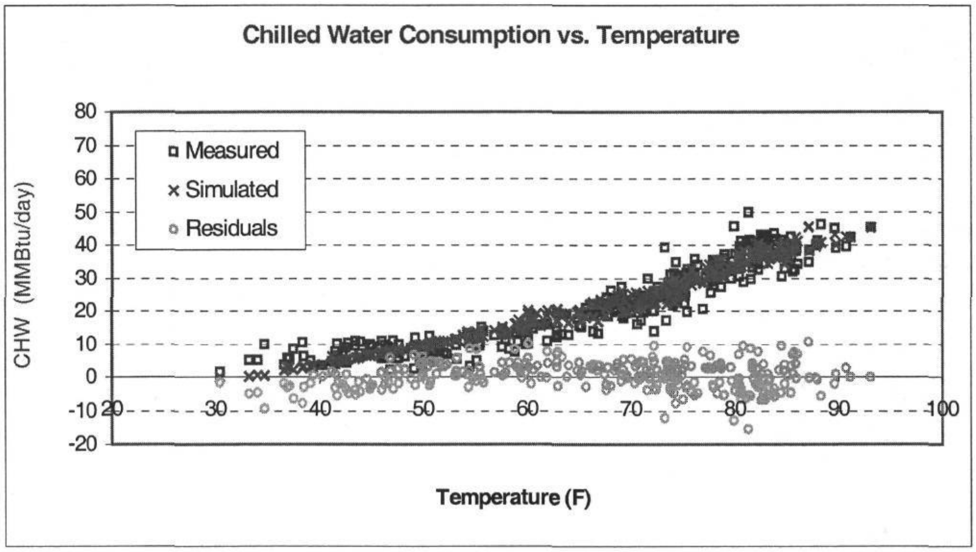
$T_{SET} = 145 - T_{OA}$, if T_{OA} is between $40\ ^{o}F$ and $70\ ^{o}F$

Calibrated: $T_{SET} = 105\ ^{o}F$, if T_{OA} is below $40\ ^{o}F$

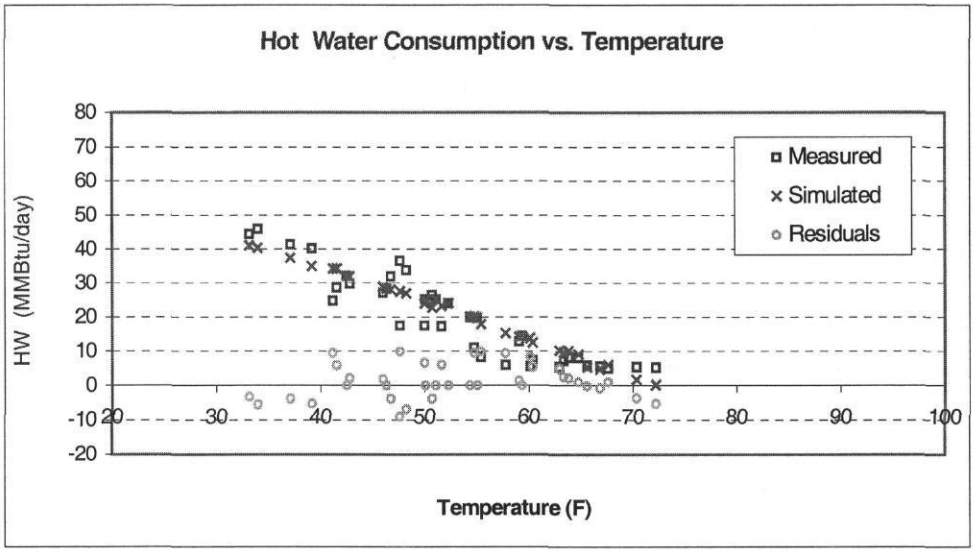
$T_{SET} = 75\ ^{o}F$, if T_{OA} is above $70\ ^{o}F$

$T_{SET} = 145 - T_{OA}$, if T_{OA} is between $40\ ^{o}F$ and $70\ ^{o}F$

Figures 6.22 and 6.23 show the result of calibrated simulation of the Harrington tower for year 2000. The hot water energy use data was available only for the period from 01/01/2000 to 02/07/2000 and the hot water data for the other days was missing in the year 2000.

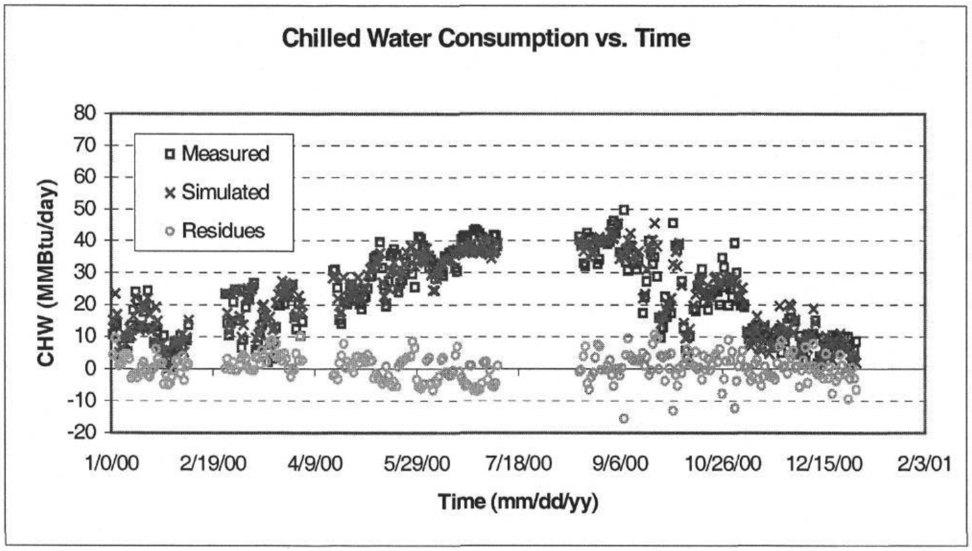


(a)

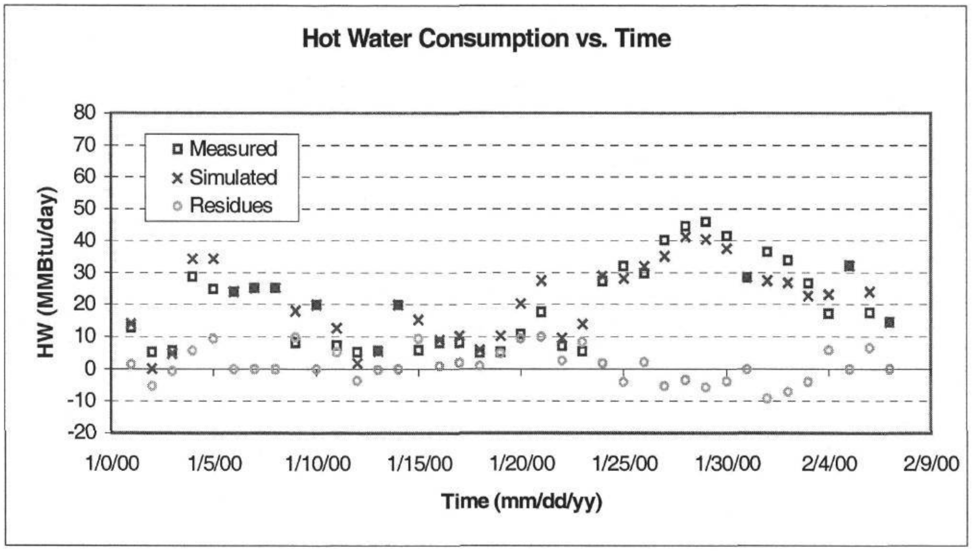


(b)

Figure 6.22 The Harrington Tower measured and simulated heating and cooling energy consumption as a function of ambient temperature after calibration for the period from 01/01/2000 to 12/31/2000 for CHW and to 02/07/2000 for HW



(a)



(b)

Figure 6.23 Time series plots of the Harrington Tower measured and simulated heating and cooling energy consumption for the period from 01/01/2000 to 12/31/2000 for CHW and to 02/07/2000 for HW

6.4.3 Calibrated Simulation with Pre- and Post-CC Data

During implementation of commissioning measures in 1996 the CC engineers found that the maximum supply air CFM (Cubic Feet per Minute) exceeded 2 CFM/sq-ft for the terminal boxes and at the same time to provide this much air flow the static pressure was set at 3-3.5 in H_2O. In reality, around one CFM/sq-ft was enough to satisfy the building needs. The minimum air flow rate was 1.0 cfm/sq-ft and outside air flow rate was 0.25 cfm/sq-ft. The cold deck temperatures did not vary with outside air temperature and had a constant value of 55 °F. The hot deck temperature schedules were not mentioned in the commissioning report; so the hot deck schedules were initially decided and calibrated based on the post-CC schedules. The input numbers were constant 55 °F for cold deck and 120 °F through 81 °F for hot deck based on the CC report. The hot deck settings are substantially higher than the post-CC schedule.

Here are input parameters that are different from those utilized in the simulation of year 2000.

Maximum air flow rate: 2.0 cfm/sq-ft

Outside air flow rate: 0.25 cfm/sq-ft

Minimum air flow: 1.0 cfm/sq-ft

Cold deck schedule: 55 °F (Constant)

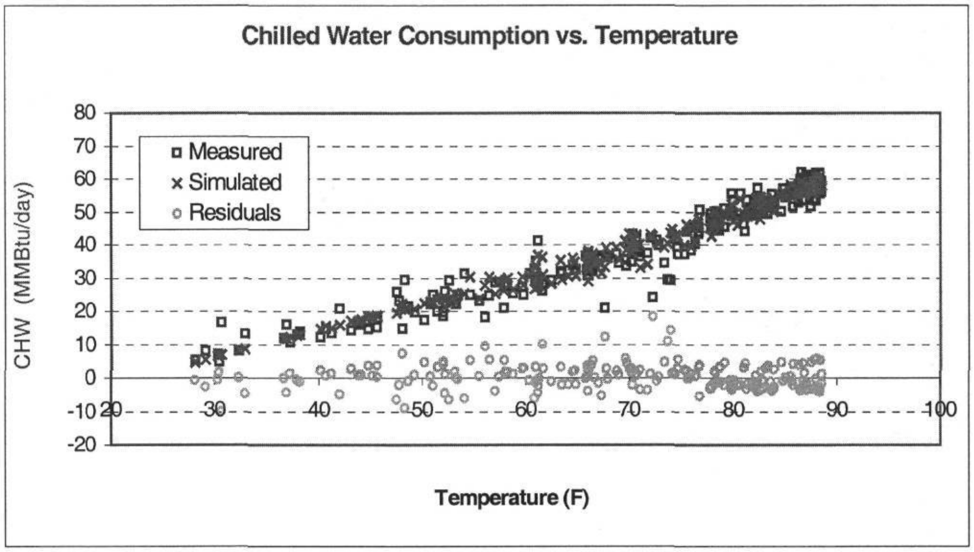
Hot deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

T_{SET} = 120 °F, if T_{OA} is below 30 °F

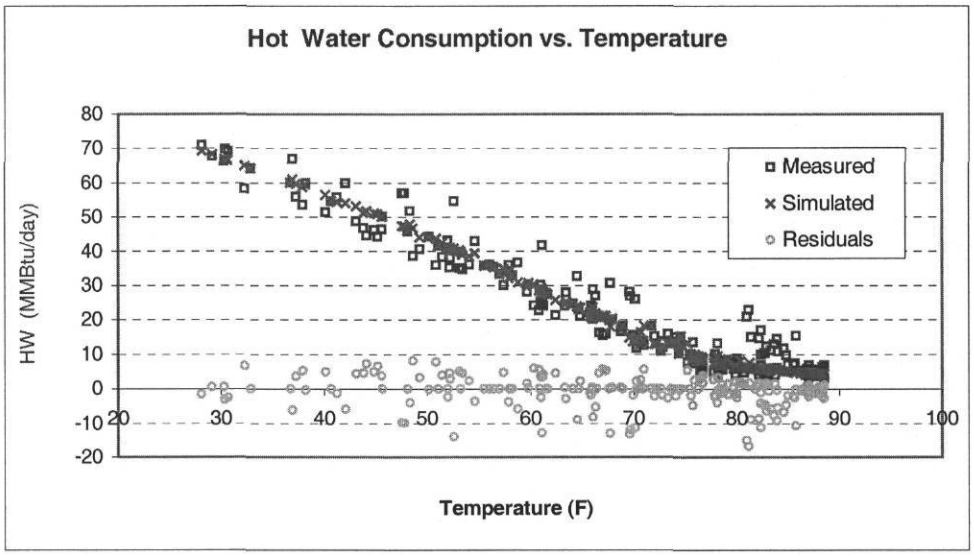
T_{SET} = 81 °F, if T_{OA} is above 73 °F

T_{SET} = 1/43*(6330 – 39*T_{OA}), if T_{OA} is between 30 °F and 73 °F

The calibrated simulation showed the CVRMSE values of 10% for chilled water and 22% for hot water. MBEs of chilled water and hot water energy use are 0.5 MMBtu/day and –0.7 MMBru/day, respectively. The measured and simulated thermal energy uses for the pre-CC period from 01/03/1996 to 07/20/1996 are shown in Figure 6.24 and Figure 6.25 as functions of temperature and time, respectively. The database involves the thermal and electrical energy use data starting from 11/15/1995 but the hot water use data was missing until 01/02/1996 so the simulation process for the pre-CC period was performed from 01/03/1996 to the date before commissioning.

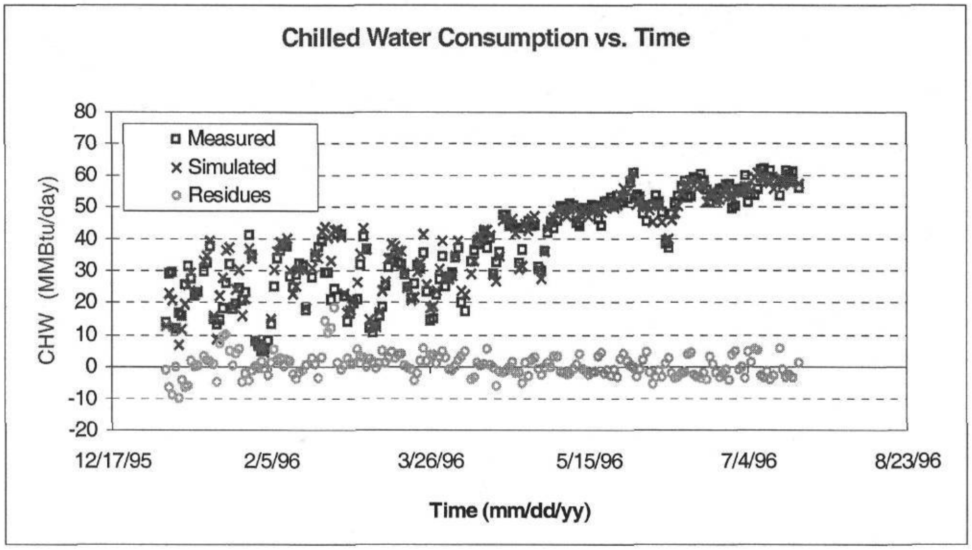


(a)

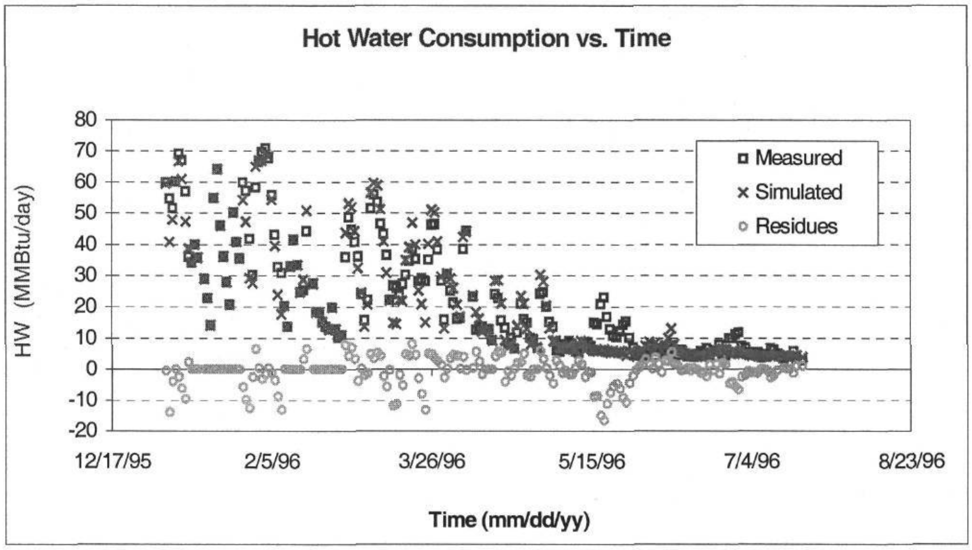


(b)

Figure 6.24 The Harrington Tower measured and simulated heating and cooling energy consumption as a function of ambient temperature after calibration for the pre-CC period from 01/03/1996 to 07/20/1996



(a)



(b)

Figure 6.25 Time series plots of the Harrington Tower measured and simulated heating and cooling energy consumption for the pre-CC period from 01/03/1996 to 07/20/1996

The CC process changed all major control schedules to optimized settings; maximum air flow rate was changed from 2.0 cfm/sq-ft to 1.1 cfm/sq-ft, outside air flow rate was changed from 0.25 cfm/sq-ft to 0.11 cfm/sq-ft, and minimum air flow was changed from 1.0 cfm/sq-ft to 0.61 cfm/sq-ft. The cold deck schedule was changed from a constant 55 ^{o}F to 60 ^{o}F at outside air temperatures of 40 ^{o}F or below increasing to 57 ^{o}F at outside air temperatures of 80 ^{o}F or higher. The hot deck temperatures were changed to vary from 100 ^{o}F to 70 ^{o}F as the outside air temperature rises from 40 ^{o}F to 70 ^{o}F.

These values were initially used to simulate the post-CC period from 08/16/1996 to 08/31/1997. The first results of the simulation showed quite good patterns for chilled water, but the simulated hot water consumption was lower than measured values during cold weather. The calibration process was performed by changing cold deck and hot deck schedules and finally reached CVRMSE values of 17% for chilled water and 27% for hot water. MBE was 1.7 MMBtu/day for chilled water and 0.5 MMBtu/day for hot water. The only change for the calibrated simulation is the cold deck schedule that is one degree lower at outside air temperatures of 40 ^{o}F or below. The initial and calibrated parameters are listed below.

Cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: T_{SET} = 60 ^{o}F, if T_{OA} is below 40 ^{o}F

T_{SET} = 57 ^{o}F, if T_{OA} is above 80 ^{o}F

$T_{SET} = 63 - 3/40*T_{OA}$, if T_{OA} is between 40 °F and 80 °F

Calibrated: $T_{SET} = 59$ °F, if T_{OA} is below 40 °F

$T_{SET} = 57$ °F, if T_{OA} is above 80 °F

$T_{SET} = 61 - 1/20*T_{OA}$, if T_{OA} is between 40 °F and 80 °F

Hot deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: $T_{SET} = 100$ °F, if T_{OA} is below 40 °F

$T_{SET} = 70$ °F, if T_{OA} is above 70 °F

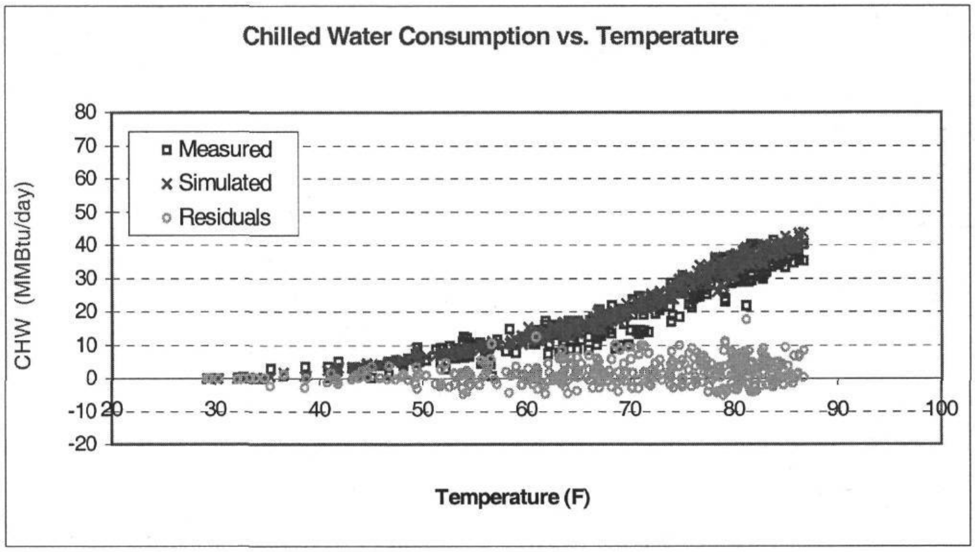
$T_{SET} = 140 - T_{OA}$, if T_{OA} is between 40 °F and 70 °F

Calibrated: $T_{SET} = 100$ °F, if T_{OA} is below 40 °F

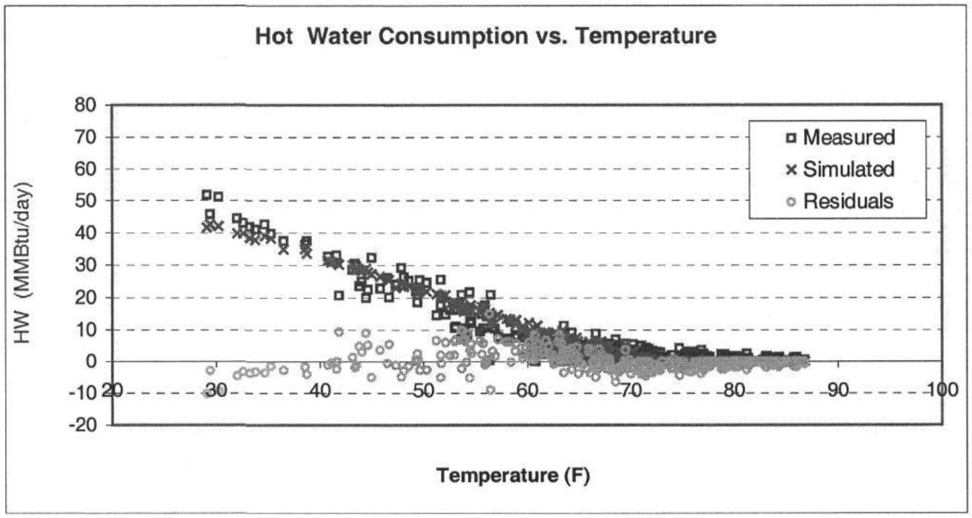
$T_{SET} = 70$ °F, if T_{OA} is above 70 °F

$T_{SET} = 140 - T_{OA}$, if T_{OA} is between 40 °F and 70 °F

The measured and simulated thermal energy uses for the post-CC period from 08/16/1996 to 08/31/1997 are shown in Figure 6.26 and Figure 6.27 as functions of temperature and time, respectively.

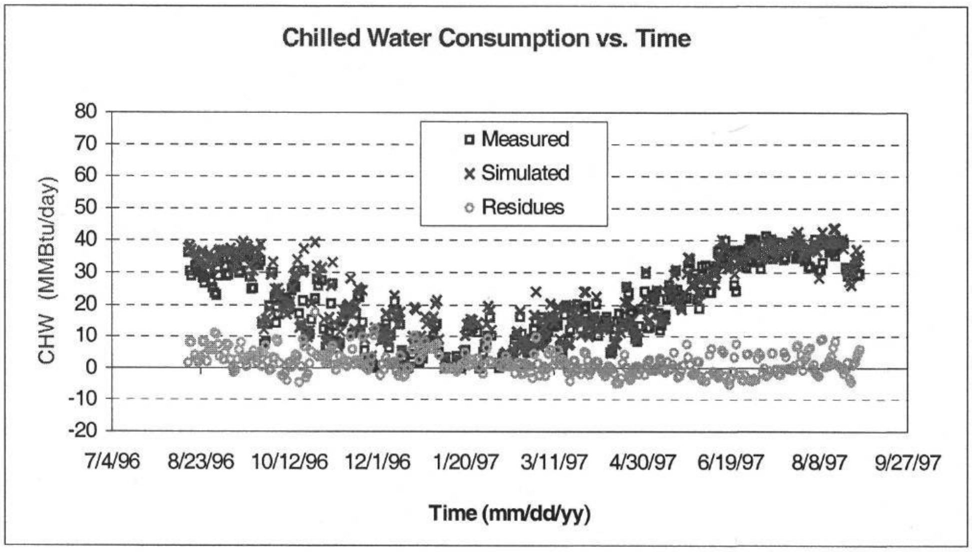


(a)

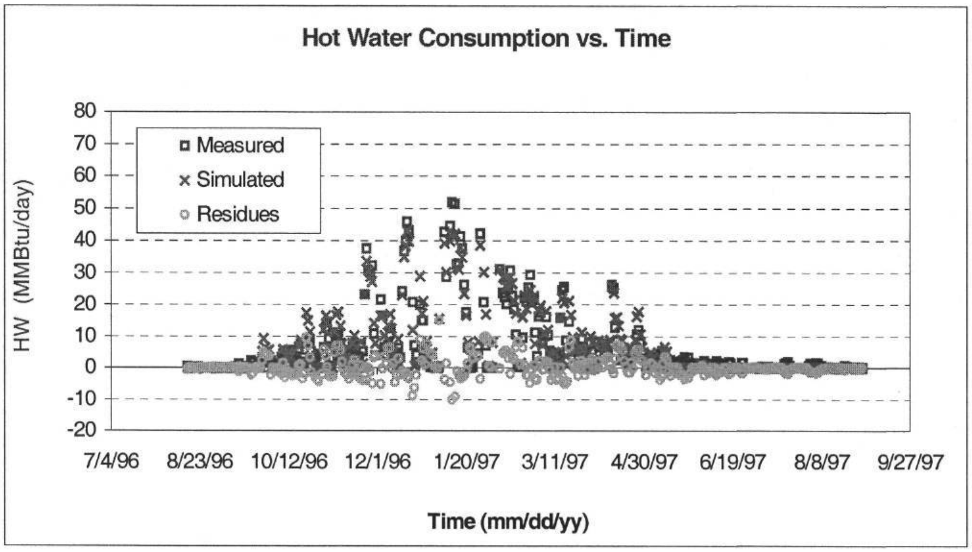


(b)

Figure 6.26 The Harrington Tower measured and simulated heating and cooling energy consumption as a function of ambient temperature after calibration for the post-CC period from 08/16/1996 to 08/31/1997



(a)



(b)

Figure 6.27 Time series plots of the Harrington Tower measured and simulated heating and cooling energy consumption for the post-CC period from 08/16/1996 to 08/31/1997

6.4.4 Simulation Comparison of Three Different Periods (Pre-CC, Post-CC and Year 2000)

The yearly thermal energy consumption of the pre-CC period was around twice the post-CC period for cooling and three times for heating. The chilled water use, as shown in Table 6.3, was 14092 MMBtu/yr before commissioning and then decreased to 7851 MMBtu/yr after commissioning so that savings were 44.3 %. The cooling energy savings degraded to 35.4 % in the year 2000. The hot water energy savings for the first year after commissioning were 69.8 % and then decreased to 65.9 % in the year 2000.

The savings of thermal energy in post-CC period came from decreasing the flow rates of maximum air, outside air, and minimum air and rescheduling the cold deck settings from a constant low temperature to variable temperatures. In the year 2000 the savings have degraded by 8.9 % for chilled water and 3.9 % for hot water. Decreasing cold deck temperatures by 2 degrees and increasing hot deck temperatures by 5 degrees resulted in the degradation of thermal energy savings.

Table 6.3 shows detailed results of the different simulations and the input parameters.

Table 6.3 The Harrington Tower Energy Consumption Results from Calibrated Simulation and Input Parameter Comparisons for the Pre-CC, Post-CC and Year 2000 Periods

	Type	Baseline (Pre-CC) (MMBtu/yr)	Post-CC Use (MMBtu/yr)	Post-CC Savings (%)	2000 Use (MMBtu/yr)	2000 Savings (%)
Calibrated	CHW	14269	8484	**40.5%**	9284	**34.9%**
Calibrated	HW	7391	2497	66.2%	3035	58.9%
Calibrated	CHW (MBE applied)	14092	7851	**44.3%**	9105	**35.4%**
Calibrated	HW (MBE applied)	7663	2313	**69.8%**	2609	**65.9%**
(Scheduled)	CHW (MBE applied)	14092	7843	44.3%	9118	35.3%
(Scheduled)	HW (MBE applied)	7663	2344	69.4%	2685	65.0%
(Scheduled)	CHW	14269	8409	41.1%	9232	35.3%
(Scheduled)	HW	7391	2423	67.2%	2982	59.7%

	Parameter	Pre-CC	Post-CC	2000
1	Room Temperature (Heating/Cooling)	72 75	72 75	72 75
2	Total Air Flow Rate (cfm/sq-ft)	2.00	1.10	1.10
3	Outside Air Flow Rate (cfm/sq-ft)	0.25	0.15	0.15
4	Min. Air Flow Rate (cfm/sq-ft)	1.00	0.61	0.61
5	Cold Deck Calibrated (Scheduled)	55 (55)	**59** 40 57 80 (60 40 57 80)	**57** 60 55 80 (58 60 55 80)
6	Hot Deck Calibrated (Scheduled)	120 30 81 73 (n/a)	100 40 70 70 (100 40 70 70)	105 40 75 70 (105 40 75 70)
7	Pre-heat Schedule	no	no	no

6.5 Calibrated Simulation 4: VMC (Veterinary Medical Center) Addition

6.5.1. Site Description

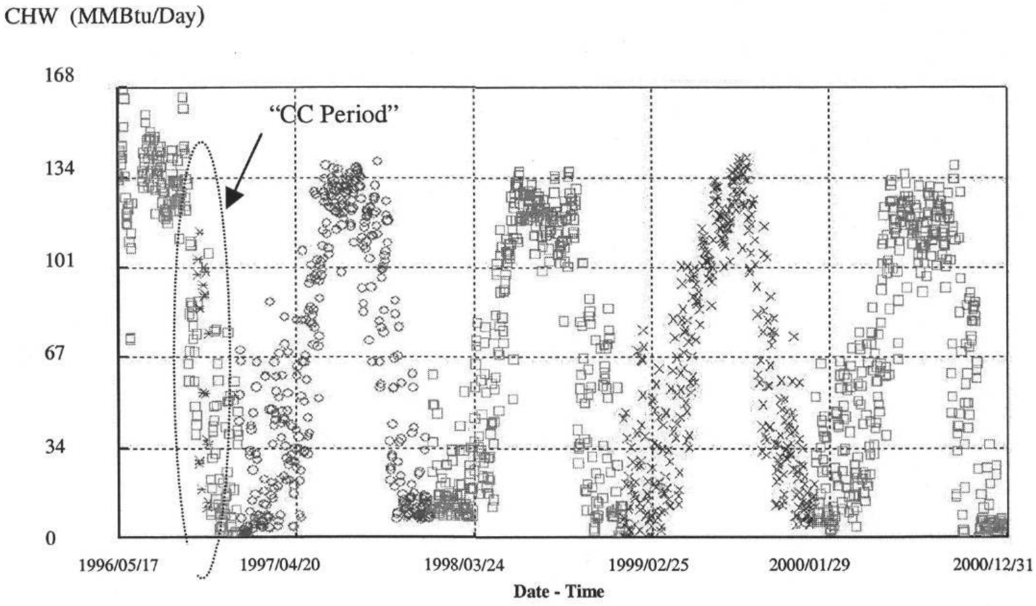
The VMC research facility is located on the west campus of Texas A&M University in College Station. This building consists of five stories with a conditioned floor area of 114,666 square feet. As a research tower, this building is composed of laboratories and classrooms as well as offices.

There are a total of five air handling units, four of which are using 100% outside air with ethylene glycol heat recovery coils between exhaust and intake. The central plant on campus provides this building with chilled water and hot water. The AHUs are single duct variable air volume (SDVAV) systems with terminal reheat and have variable frequency drives (VFDs).

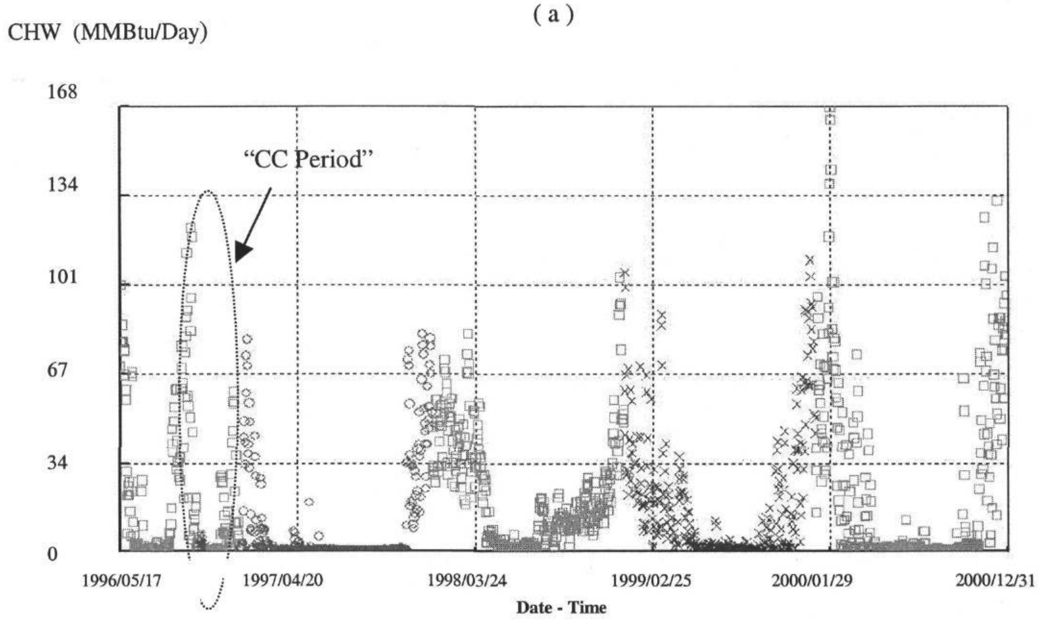
The heat recovery coils start working as a preheat system when the outside air temperature falls below 55 ^{o}F and when the ambient temperature rises above 75 ^{o}F they are utilized for pre-cooling. Although the heat recovery coils are working, there will be cases when the air temperature after the heat recovery coils drops below 50 ^{o}F. In these cases the preheat coils will come on to increase the air temperature to 50 ^{o}F for the purpose of freeze protection.

Implementation of CC measures for the VMC facility was completed in November of 1996. The main measures were optimization of cold deck, preheat, and heat recovery schedules. The economizer cycle capability in the system was put into operation and chilled water and hot water control sequences were optimized.

Figure 6.28 shows chilled water and hot water energy use of the VMC building for five years. The pattern of chilled water consumption has been maintained in a good shape for the four years since CC was finished, while hot water use has increased over time.



(a)



(b)

Figure 6.28 The VMC building daily chilled water and hot water energy use from 1996 to 2000

6.5.2 Calibrated Simulation with Year 2000 Data

Here are the major simulation input parameters for the VMC building.

HVAC system type: SDRHOA (Single Duct with Reheat & Outside Air Preheat)

Air supply: VAV (Variable Air Volume)

Conditioned floor area: 117,666 sq-ft

Internal zone fraction: 0.5

Exterior wall area / U value: 33560 sq-ft / 0.10 Btu/sq-ft hr F

Exterior window area / U value: 22370 sq-ft / 0.81 Btu/sq-ft hr F

Supply air fan HP / control model: 165 HP / VFD (Variable Frequency Drive)

Return air fan HP / control model: 130 HP / VFD

Room temperature (heating and cooling): 70 ^{o}F 73 ^{o}F

Total air flow rate: 1.15 cfm/sq-ft

Outside air flow rate: 0.86 cfm/sq-ft

Minimum air flow: 0.64 cfm/sq-ft

Cold deck schedule (T_{SET}): 56 ^{o}F

Hot deck schedule (T_{SET} T_{OA}): n/a

Preheat schedule: 50 ^{o}F

Internal heat gain: 2.75 W/sq-ft

Space conditioning in this building is provided by single duct variable air volume systems so there are only cold decks. Only one out of five AHUs uses return air and the others use 100 % outside air but utilize heat recovery coils to precondition the outside air.

The control program had schedules for cold deck discharge temperatures of 62 °F through 64 °F at outside air temperatures of 55 °F or below and 53 °F through 57 °F at outside air temperatures of 85 °F or higher. But the actual working status was overridden to manual operation at constant temperature of 56 °F. Both of the cases above were simulated, and it appears likely that this building has been operated based on the manual mode with fixed cold deck temperature of 56 °F, since when the variable settings were used in the simulation, the simulated chilled water and hot water energy use was much lower than the measured values for cold weather conditions, while the simulated chilled water and hot water consumption patterns with constant 56 °F cold deck agreed with measured use patterns.

The simulation with a constant cold deck temperature of 56 °F resulted in MBE of –1.6 MMBtu/day for chilled water and –0.2 MMBtu/day for hot water.

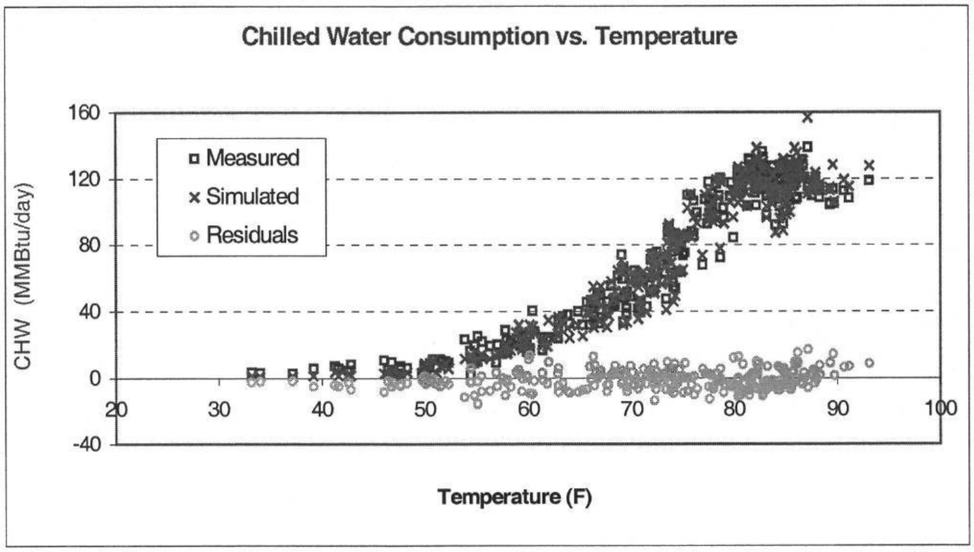
The cold deck setting was calibrated a little from 56.0 °F to 55.5 °F and the MBEs for chilled water and hot water changed to –0.7 MMBtu/day and 0.6 MMBtu/day, respectively. Here are the parameters initially used and after calibration.

Cold deck schedule (T_{SET}):

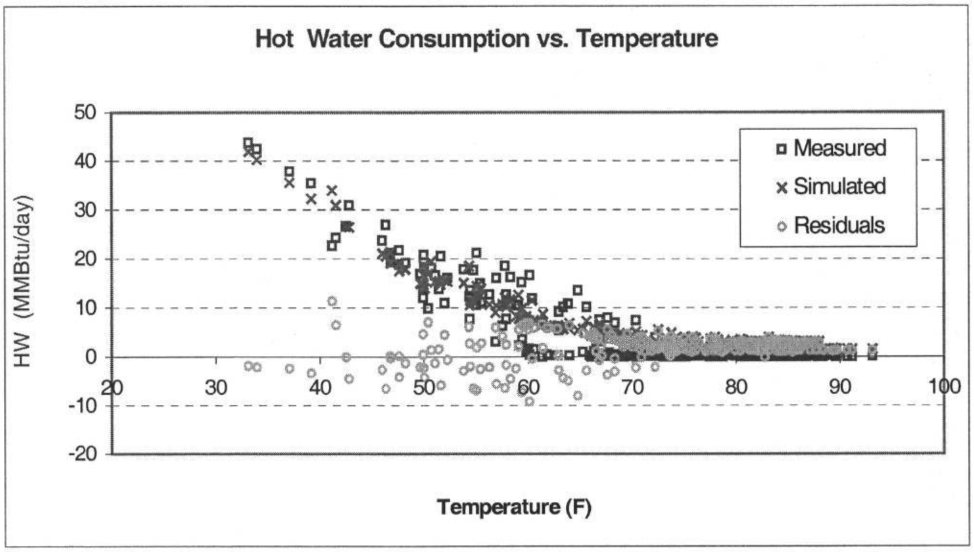
Scheduled: 56.0 (°F) - constant

Calibrated: 55.5 (°F) - constant

Figure 6.29 and Figure 6.30 show a scatter plot of measured and simulated thermal energy consumption and a time series plot, respectively.

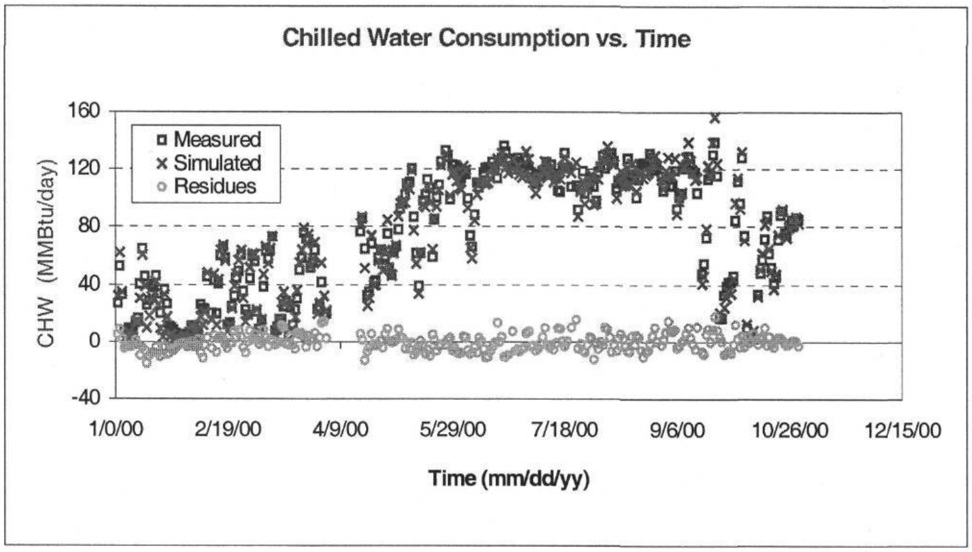


(a)

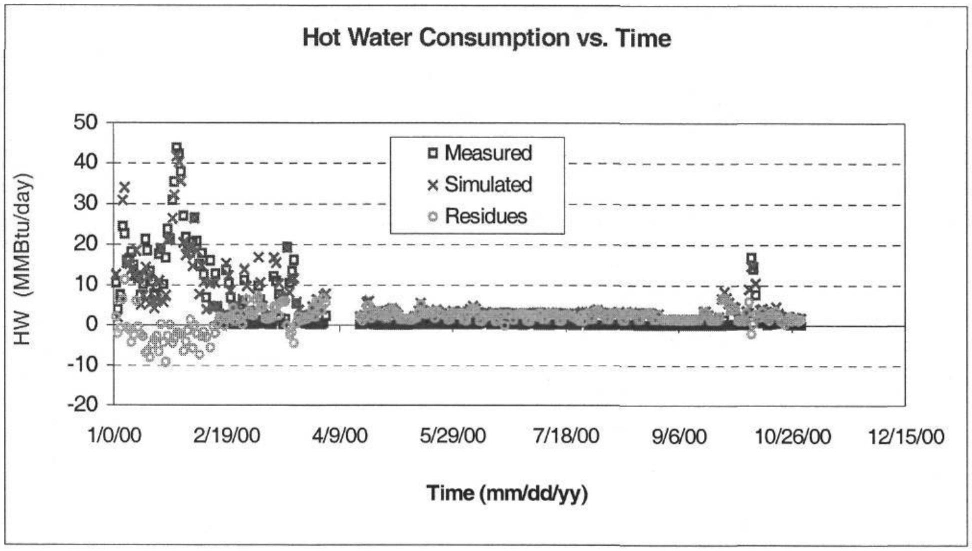


(b)

Figure 6.29 The VMC Addition measured and simulated heating and cooling energy consumption as a function of ambient temperature after calibration for the period from 01/01/2000 to 10/30/2000



(a)



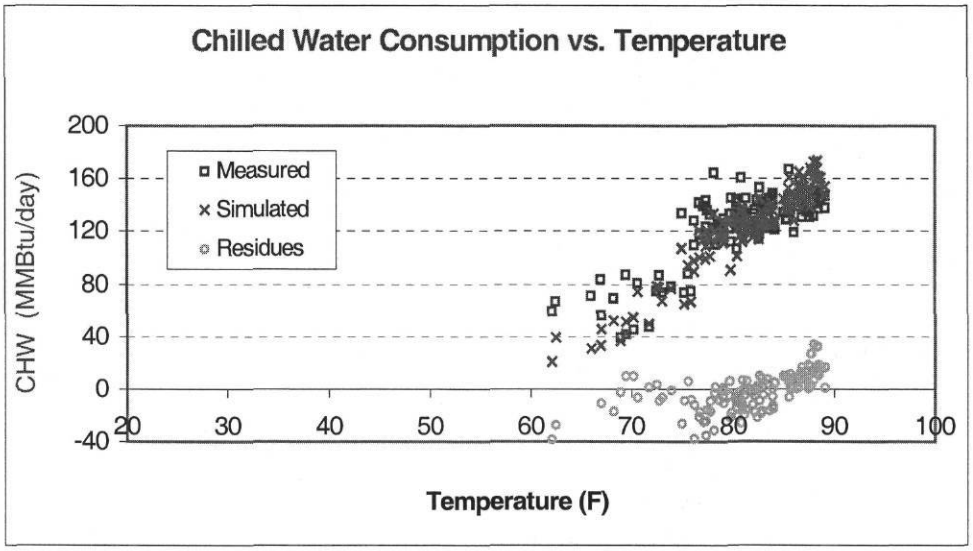
(b)

Figure 6.30 Time series plots of the VMC Addition measured and simulated heating and cooling energy consumption for the period from 01/01/2000 to 10/30/2000

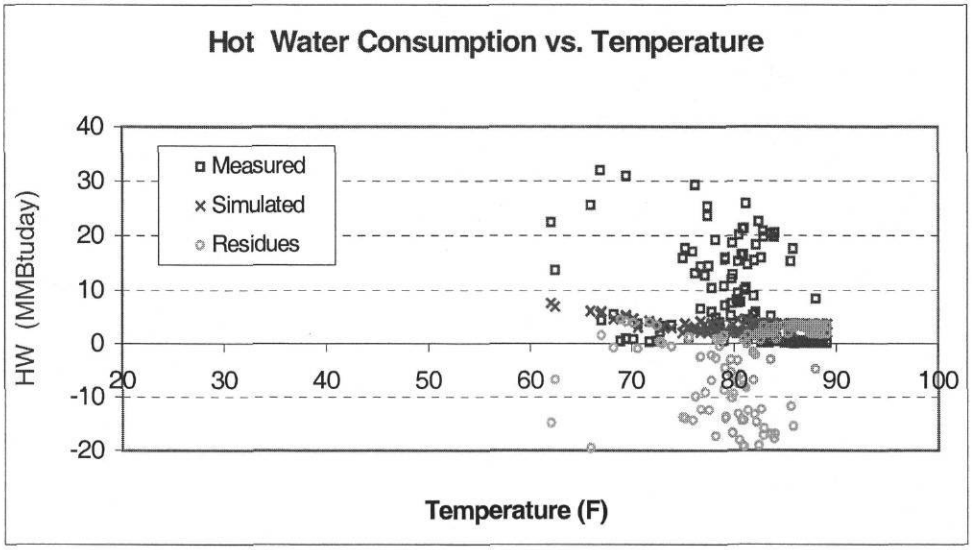
6.5.3 Calibrated Simulation with Pre- and Post-CC Data

The CC measures for this building were performed in the period from 10/16/2996 to 11/05/1996 and the metered data available for the pre-CC period is from 5/17/1996. Figures 6.31 and 6.32 show the initial simulation results with the same input parameters used in the year 2000 simulation except for the cold deck schedule of constant temperature, 55 °F. As shown in Figure 6.31, the data we have for the pre-CC period simulation is only in the outside air temperatures of 62 °F or higher and the hot water data fluctuates so widely that it looks like there was a metering or operation malfunction. In Figure 6.32 there are 16 days missing data from 6/13/1996 to 6/30/1996. The MBE values are –3.4 MMBtu/Day for chilled water and –4.3 MMBtu/Day for hot water.

From the initial simulation results, it was concluded that the pre-CC simulation needs to be performed in two different periods; the first simulation (Case I) is from 7/01/1996 to 8/18/1996 and the second simulation (Case II) consists of the periods from 5/17/1996 to 6/12/1996 and from 8/19/1996 to 10/15/1996.

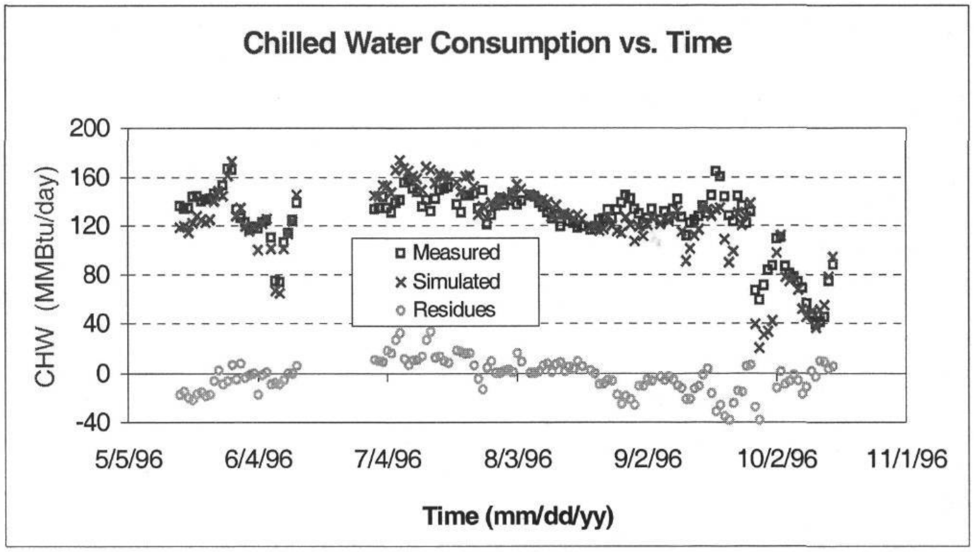


(a)

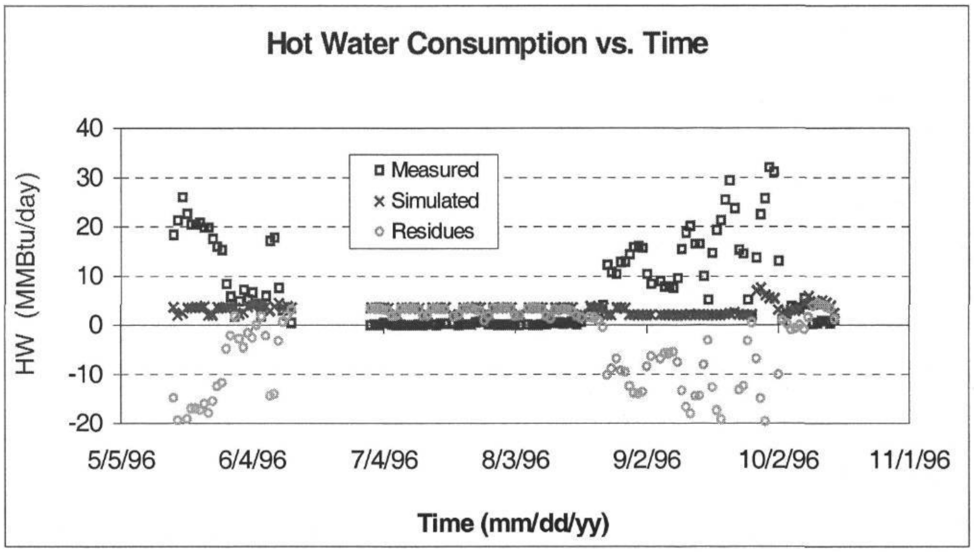


(b)

Figure 6.31 The VMC Addition measured and simulated heating and cooling energy consumption as a function of ambient temperature after calibration for the pre-CC period



(a)



(b)

Figure 6.32 The VMC Addition measured and simulated heating and cooling energy consumption as a function of time after calibration for the pre-CC period

The Case I simulation for the pre-CC period was performed with the same parameters used earlier for the pre-CC simulation and then was calibrated by changing mainly outside air flow rate, minimum air flow rate and cold deck schedule. The initial and calibrated parameters are shown below.

Initially used parameters:

Outside air flow rate: 0.86 cfm/sq-ft

Minimum air flow rate: 0.64 cfm/sq-ft

Cold deck schedule (T_{SET}): 55 °F – Constant

Calibrated Parameters:

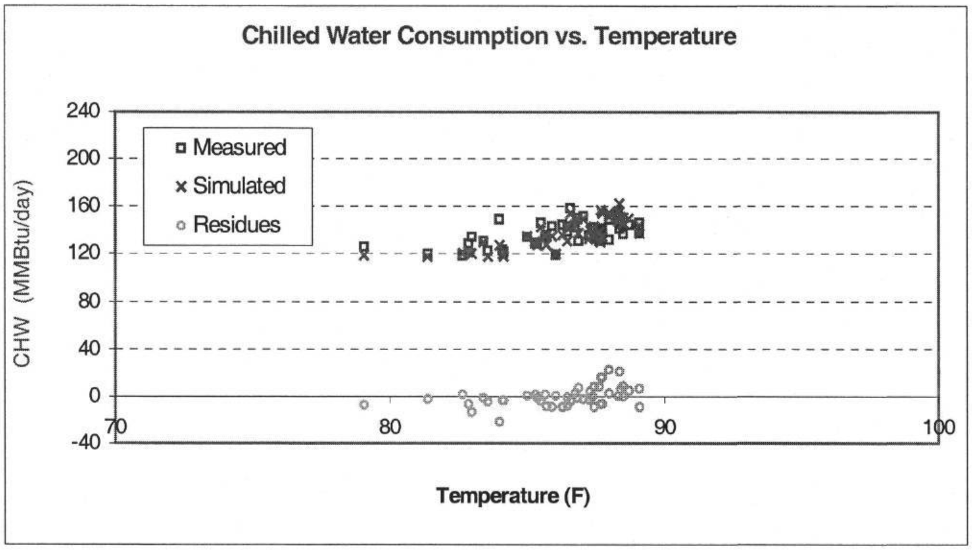
Outside air flow rate: 0.81 cfm/sq-ft

Minimum air flow rate: 0.60 cfm/sq-ft

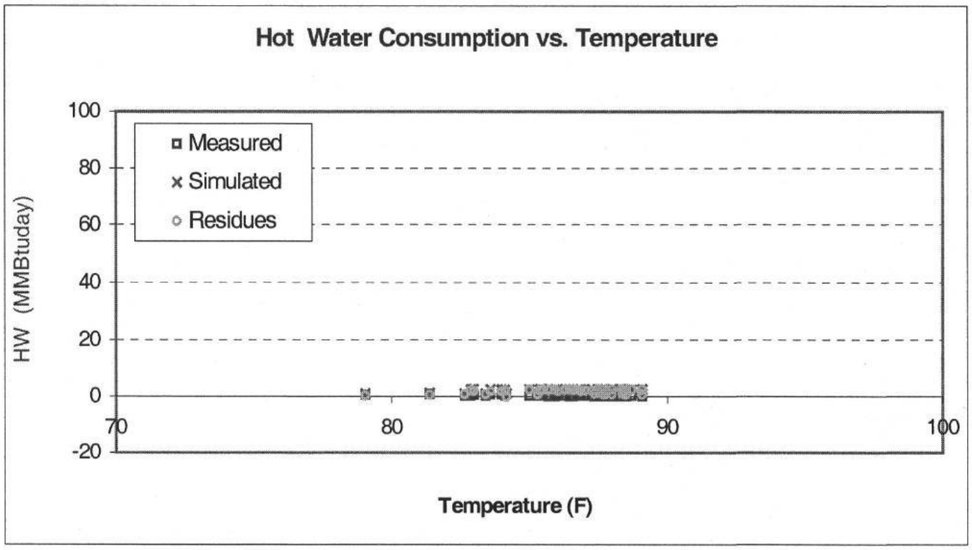
Cold deck schedule (T_{SET}): 55 °F - Constant

The calibrated parameters for outside air flow and minimum air flow rates decreased by 0.05 cfm/sq-ft and 0.04 cfm/sq-ft, respectively. It is not likely that these values were actually used for this building operation in that period since the Case II simulation used higher values and these values are not likely to change in the short period without major tasks like commissioning measures. As seen in Figures 6.33 and 6.34, it looks as if there was no hot water energy consumption, but no report was available to see if maintenance people turned the hot water valves off or if any other problems happened.

The simulation with the calibrated parameters above was the best results with the MBE values of –0.2 MMBtu/Day for chilled water and 1.8 MMBtu/Day for hot water. Figure 6.33 shows the daily measured values of chilled water and hot water and predictions of the calibrated simulation as a function of outside air temperature and the differences (simulated – measured) between these values or residues. Figure 6.34 gives time series plots of the same quantity.

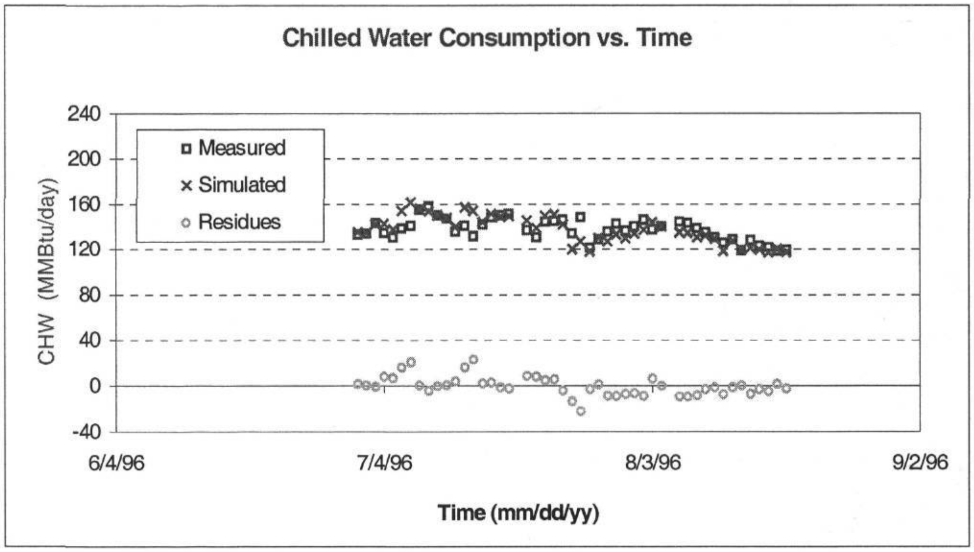


(a)

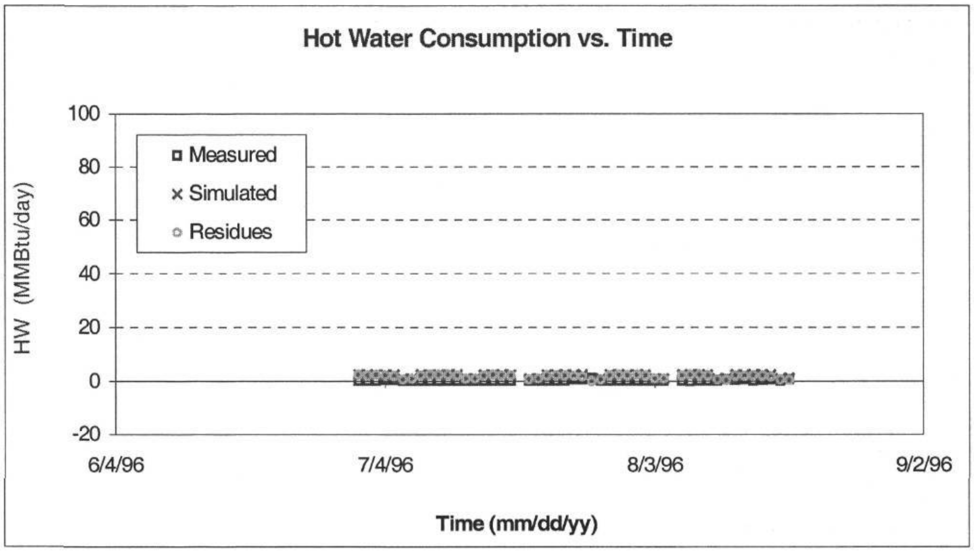


(b)

Figure 6.33 The VMC Addition measured and simulated heating and cooling energy consumption as a function of ambient temperature after calibration for the pre-CC period (Case I: 7/01/1996 – 8/18/1996)



(a)



(b)

Figure 6.34 The VMC Addition measured and simulated heating and cooling energy consumption as a function of time after calibration for the pre-CC period (Case I: 7/01/1996 – 8/18/1996)

The Case II simulation for the pre-CC period started with the same parameters used in the initial simulation of the Case I. The comparisons of the initial and calibrated parameters are listed below.

Initially used parameters:

Outside air flow rate: 0.86 cfm/sq-ft

Minimum air flow rate: 0.64 cfm/sq-ft

Cold deck schedule (T_{SET}): 55 ^{o}F – Constant

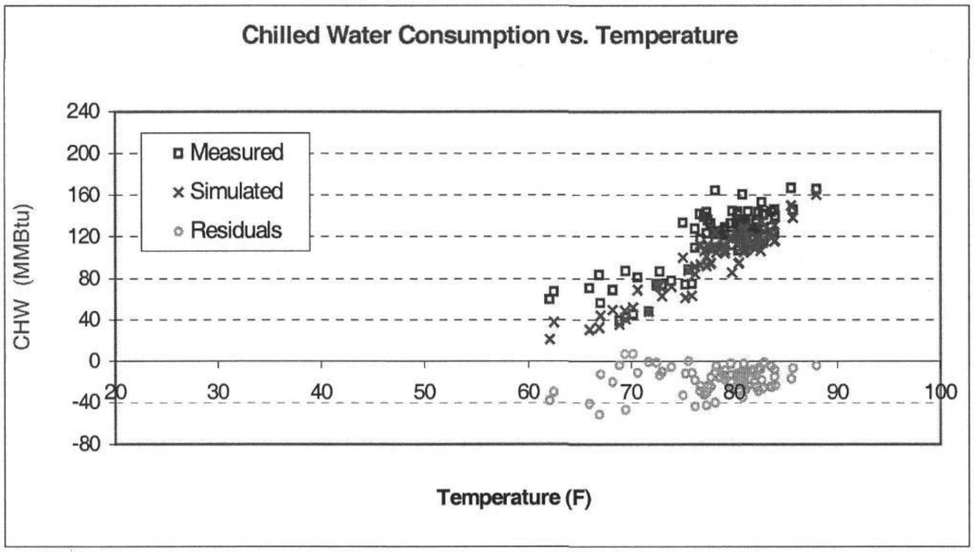
Calibrated Parameters:

Outside air flow rate: 0.86 cfm/sq-ft

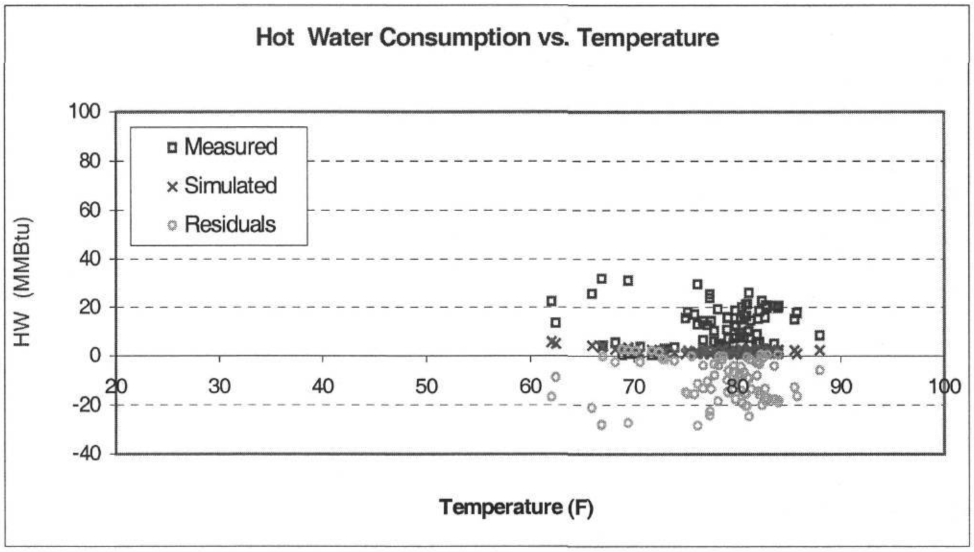
Minimum air flow rate: 0.70 cfm/sq-ft

Cold deck schedule (T_{SET}): 52 ^{o}F - Constant

Minimum air flow rate increased by 0.06 cfm/sq-ft and cold deck temperature decreased by 3 ^{o}F. Both these changes made chilled water and hot water energy consumption increase. As shown in Figures 6.35 and 6.36, the simulated chilled water use matched the measured use well, but the hot water part did not match since the measured hot water use data was fluctuating even for the same outside air temperatures. Figure 6.35 and Figure 6.36 show a scatter plot of measured and simulated thermal energy consumption and a time series plot, respectively.

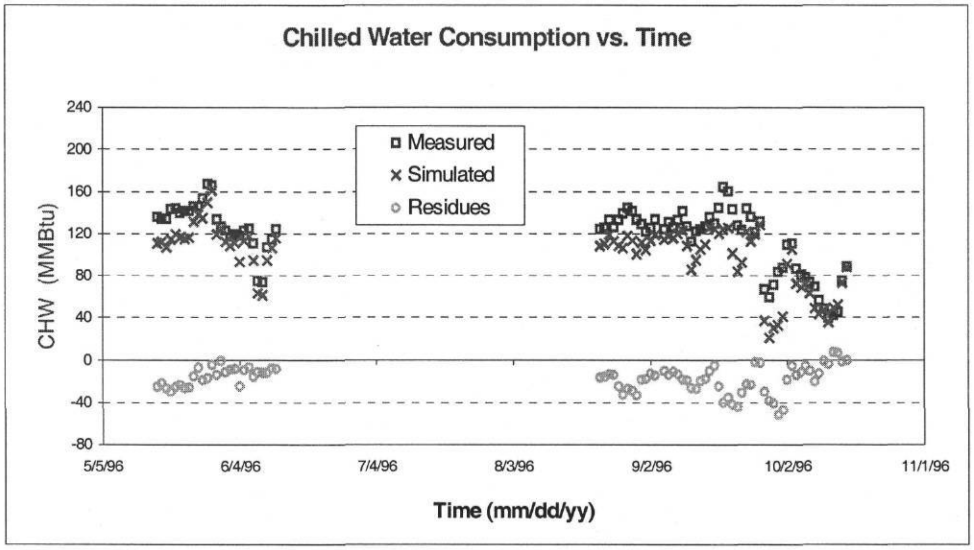


(a)

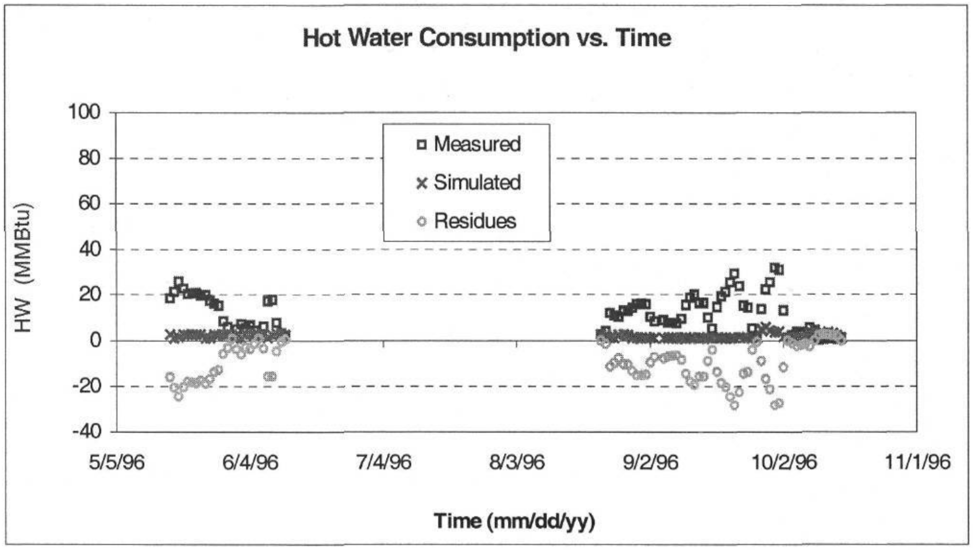


(b)

Figure 6.35 The VMC Addition measured and simulated heating and cooing energy consumption as a function of ambient temperature after calibration for the pre-CC period (Case II: 5/17/1996 – 6/12/1996 and 8/19/1996 – 10/15/1996)



(a)



(b)

Figure 6.36 The VMC Addition measured and simulated heating and cooling energy consumption as a function of time after calibration for the pre-CC period (Case II: 5/17/1996 – 6/12/1996 and 8/19/1996 – 10/15/1996)

To simulate the post-CC period, the 1997 data was used first, but there was insufficient measured data to compare with simulated results because only 21 days of hot water energy consumption data were available. So the energy use data for the period from 01/01/1998 to 10/29/1998 was utilized in the simulation.

After commissioning was completed, the cold deck schedule changed from a constant temperature of 55 °F to variable temperatures of 57 °F when the outside air temperature is 55 °F or below and 53 °F at outside air temperatures of 85 °F or higher. The outside air flow rate decreased from 0.86 cfm/sq-ft to 0.75 cfm/sq-ft. All other parameters are the same as those used in the other simulations. Here are the parameters used in the simulation of the post-CC period.

Outside air flow rate (cfm/sq-ft):

Scheduled: 0.75

Calibrated: 0.75

Cold deck schedule:

(T_{SET} = set temperature, T_{OA} = outside air temperature)

Scheduled: $T_{SET} = 57\ ^{o}F$, if T_{OA} is below 55 ^{o}F

$T_{SET} = 53\ ^{o}F$, if T_{OA} is above 85 ^{o}F

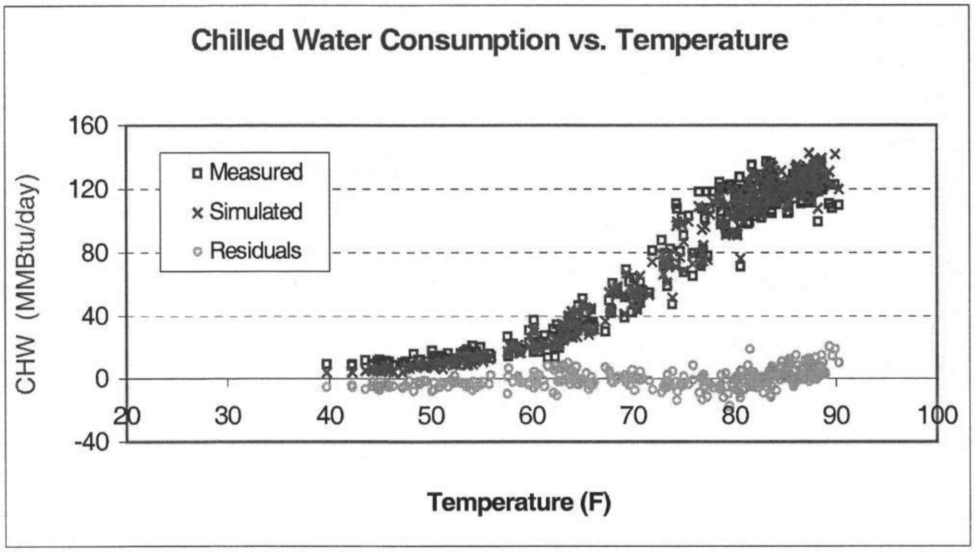
$T_{SET} = 193/3 - 2/15 * T_{OA}$, if T_{OA} is between 55 ^{o}F and 85 ^{o}F

Calibrated: $T_{SET} = 57\ ^{o}F$, if T_{OA} is below 55 ^{o}F

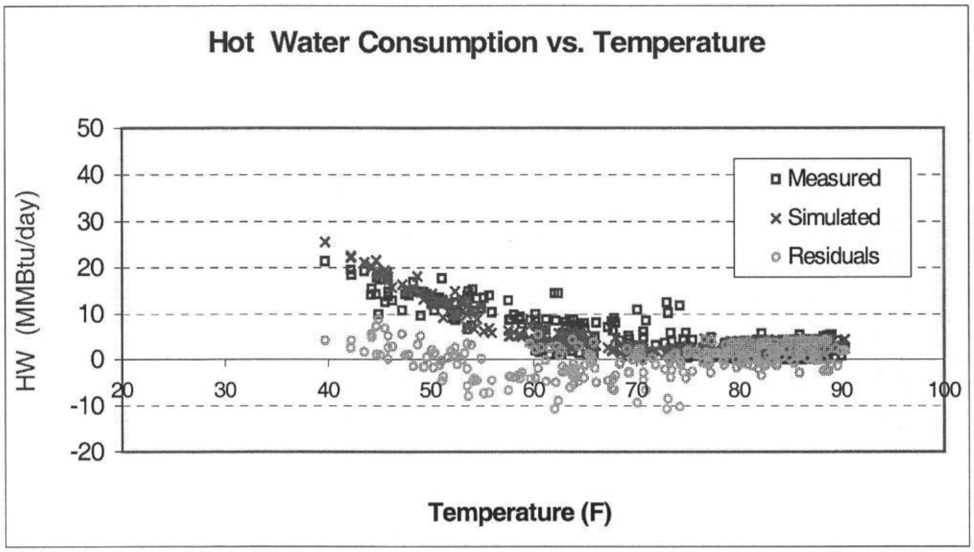
$T_{SET} = 53\ ^{o}F$, if T_{OA} is above 85 ^{o}F

$T_{SET} = 193/3 - 2/15 * T_{OA}$, if T_{OA} is between 55 ^{o}F and 85 ^{o}F

The comparison of measured and simulated energy consumption is shown in Figure 6.37 and Figure 6.38.

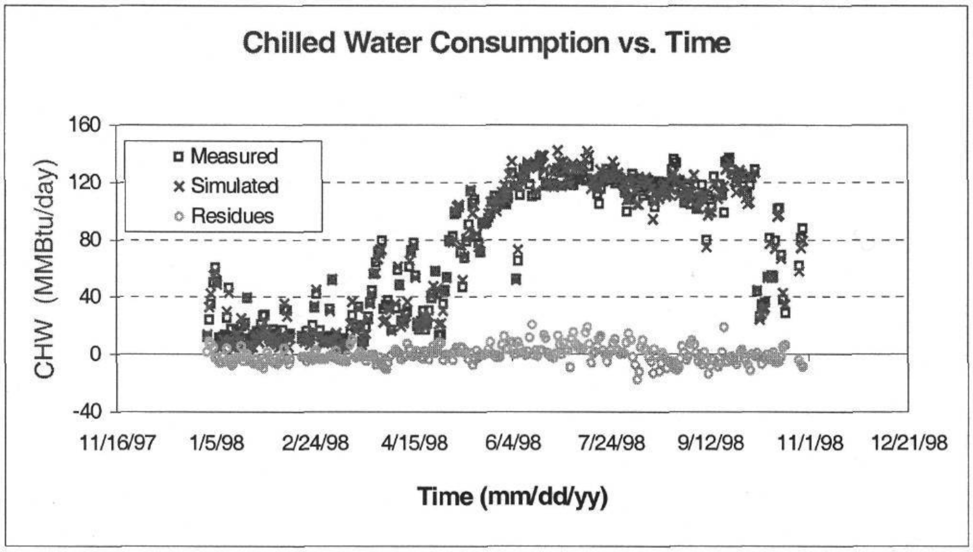


(a)

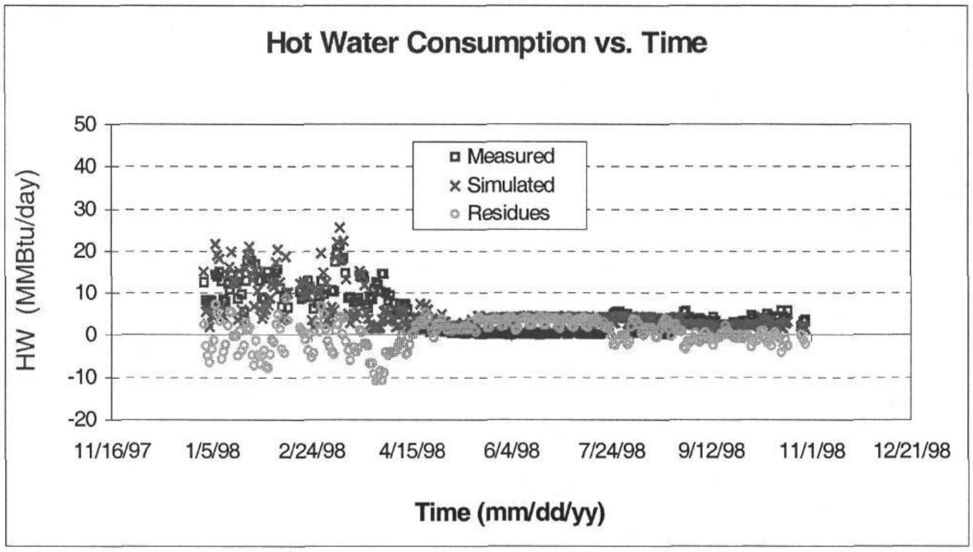


(b)

Figure 6.37 The VMC Addition measured and simulated heating and cooling energy consumption as a function of ambient temperature after calibration for the post-CC period from 01/01/1998 to 10/29/1998



(a)



(b)

Figure 6.38 Time series plots of the VMC Addition measured and simulated heating and cooling energy consumption for the period from 01/01/1998 to 10/29/1998

6.5.4 Simulation Comparison of Three Different Periods (Pre-CC, Post-CC and Year 2000)

The chilled water and hot water savings in 1998 after commissioning, as shown in Table 6.4, was 12.8 % and 64.6 % respectively. The operating changes were mainly in the cold deck schedule, outside airflow setting and minimum airflow rate.

To calculate the yearly chilled water and hot water consumption of the pre-CC period, there were two simulation cases. The two different simulations (Case I and Case II) were combined using two months energy use (6/18 – 8/18) for the Case I simulation and 10 months energy use (1/1 – 6/17, 8/19 – 12/31) for the Case II simulation.

The energy savings degraded to 8.9 % for chilled water and 58.8 % for hot water in year 2000, which are decreases of 3.9 % and 5.8 % respectively.

The major impact on the consumption rise was because of increasing the outside airflow from 0.75 cfm/sq-ft to 0.86 cfm/sq-ft. When we compare the cold deck schedules between 1998 and 2000, the setting for 1998 is likely to require more energy than that of 2000 since the cold deck temperature for 1998 starts dropping below 55.5 °F at outside air temperatures of 66.25 °F or higher and there were much more days of outside air temperatures of 66.25 °F or higher in 1998 and 2000 as well.

So the cold deck setting for 1998 requires more thermal energy consumption, but outside airflow rate increased from 0.75 cfm/sq-ft to 0.86 cfm/sq-ft at the same time. As a result, the energy consumption increase from increased outside airflow rate exceeded the consumption decrease from cold deck setting in 2000 compared to 1998 control settings.

Detailed information for savings and input parameter changes are shown in Table 6.4.

Table 6.4 The VMC Addition Energy Consumption Results from Calibrated Simulation and Input Parameter Comparisons for the Pre-CC, Post-CC and Year 2000 Periods

	Type	Baseline (Pre-CC) (MMBtu/yr)	Post-CC (1998) Use (MMBtu/yr)	Post-CC (1998) Savings (%)	2000 Use (MMBtu/yr)	2000 Savings (%)
Calibrated	CHW	28822	24556	14.8%	25587	11.2%
Calibrated	HW	5308	2155	59.4%	2604	50.9%
Calibrated	CHW (MBE applied)	28347	24723	12.8%	25832	8.9%
Calibrated	HW (MBE applied)	5779	2045	64.6%	2378	58.8%
(Scheduled)	CHW (MBE applied)	28145	24723	12.2%	25849	8.2%
(Scheduled)	HW (MBE applied)	5836	2045	65.0%	2422	58.5%
(Scheduled)	CHW	25904	24556	5.2%	25282	2.4%
(Scheduled)	HW	2867	2155	24.8%	2345	18.2%

	Parameter	Case I 7/01 - 8/18	Case II 5/17 - 6/12 8/19 - 10/15	Post-CC (1998)	2000
1	Room Temperature (Heating/Cooling)	70 73	70 73	70 73	70 73
2	Total Air Flow Rate (cfm/sq-ft)	1.15	1.15	1.15	1.15
3	Outside Air Flow Rate (cfm/sq-ft)	0.81	0.86	0.75	0.86
4	Min. Air Flow Rate (cfm/sq-ft)	0.60	0.70	0.64	0.64
5	Cold Deck Schedule (CC report)	55 (55)	**52** (55)	57 55 53 85 (57 55 53 85)	**55.5** (56)
6	Pre-heat Schedule (CC Report)	50	50	50	50

6.6 Calibrated Simulation 5: Wehner Building

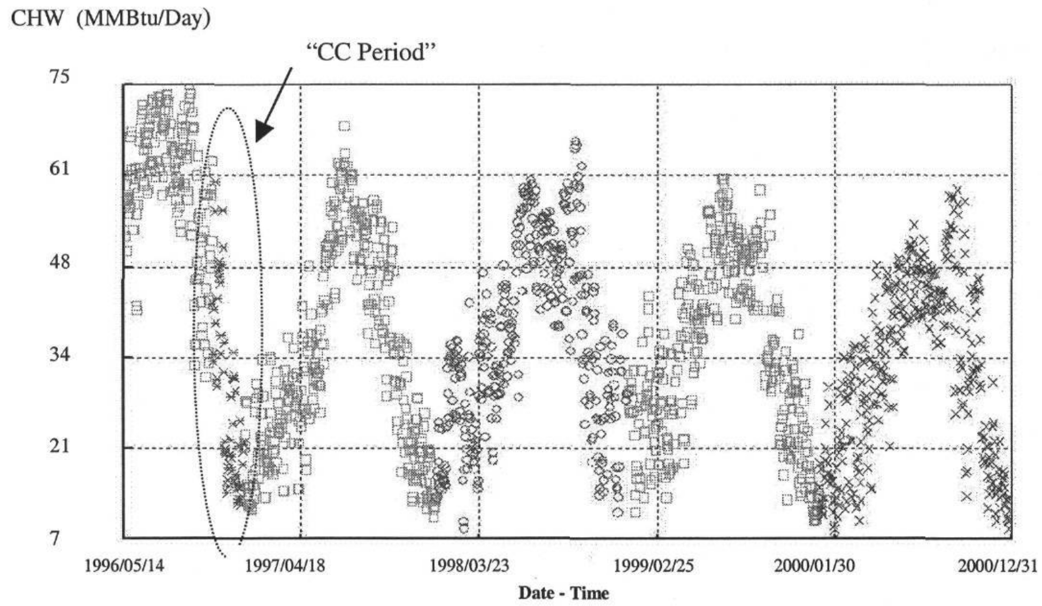
6.6.1 Site Description

The Wehner building is a four-story building located on the west campus of Texas A&M University in College Station. The total floor area is 192,000 square feet, and this building consists of classrooms and offices. The control program for this building is implemented by the Landis & Gyr energy management and control system (EMCS).

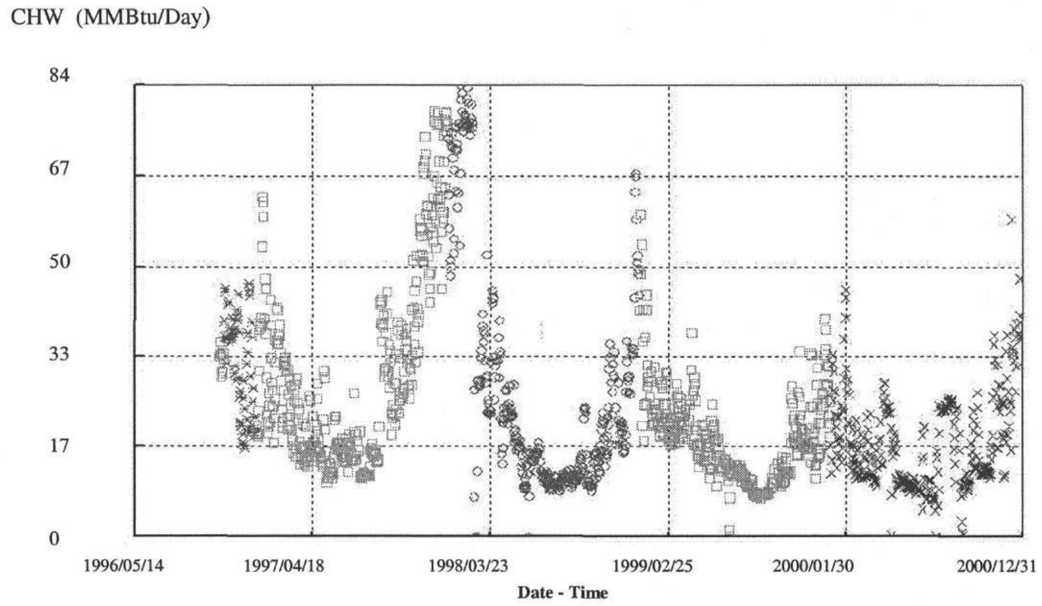
Chilled water and hot water are supplied by the central plant on the Texas A&M University campus. There are nine air-handling units. Three units are single duct variable air volume (SDVAV) systems and the other six AHUs are dual duct VAV (DDVAV) systems. The six DDVAV AHUs are the main units serving the 2nd floor through 4th floor, and the three SDVAV AHUs supply the first floor with conditioned air.

The CC work on this building was completed in December of 1996. Cold deck, hot deck, and static pressure schedules were reset to optimize the performance of the HVAC system during the commissioning process. Temperature set points for rooms were also changed to day and night modes.

Figure 6.39 shows energy consumption of the Wehner building over time.



(a)



(b)

Figure 6.39 Daily chilled water and hot water energy use for the Wehner building from 1996 to 2000

6.6.2 Calibrated Simulation with Year 2000 Data

The Wehner building has two major AHU systems. Six DDVAV AHUs serve the 2nd through the 4th floors and three SDVAV AHUs provide conditioned air to the 1st floor. So this building simulation assumes two different subsystems. Here are the major simulation input parameters for the two systems, with common parameters listed once in the dual duct system list.

Subsystem 1;

HVAC system type: DDPOA (Dual Duct with Preheat Outside Air)

Air supply: VAV (Variable Air Volume)

Conditioned floor area: 192,001 sq-ft

Internal zone fraction: 0.5

Exterior wall area / U value: 45,000 sq-ft / 0.20 Btu/sq-ft hr F

Exterior window area / U value: 30,000 sq-ft / 0.92 Btu/sq-ft hr F

Supply air fan HP / control model: 170 HP / VFD (Variable Frequency Drive)

Return air fan HP / control model: 0 HP / n/a

Room temperature (heating and cooling): 71 °F 73 °F (71°F 78°F: Night)

Total air flow rate: 1.00 cfm/sq-ft

Outside air flow rate: 0.10 cfm/sq-ft

Minimum air flow: 0.60 cfm/sq-ft

Cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

T_{SET} = 63 °F, if T_{OA} is below 50 °F

T_{SET} = 56 °F, if T_{OA} is above 80 °F

$T_{SET} = 224/3 - 7/30 * T_{OA}$, if T_{OA} is between 50 °F and 80 °F

Hot deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

T_{SET} = 110 °F, if T_{OA} is below 40 °F

T_{SET} = 75 °F, if T_{OA} is above 70 °F

$T_{SET} = 470/3 - 7/6 * T_{OA}$, if T_{OA} is between 40 °F and 70 °F

Preheat schedule: 50 °F

Internal heat gain: 0.84 W/sq-ft

Subsystem 2;

HVAC system type: SDRHOA (Single Duct Reheat with Preheat Outside Air)

Outside air flow rate: 0.10 cfm/sq-ft

Minimum air flow: 0.60 cfm/sq-ft

Cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

T_{SET} = 62 °F, if T_{OA} is below 60 °F

T_{SET} = 55 °F, if T_{OA} is above 80 °F

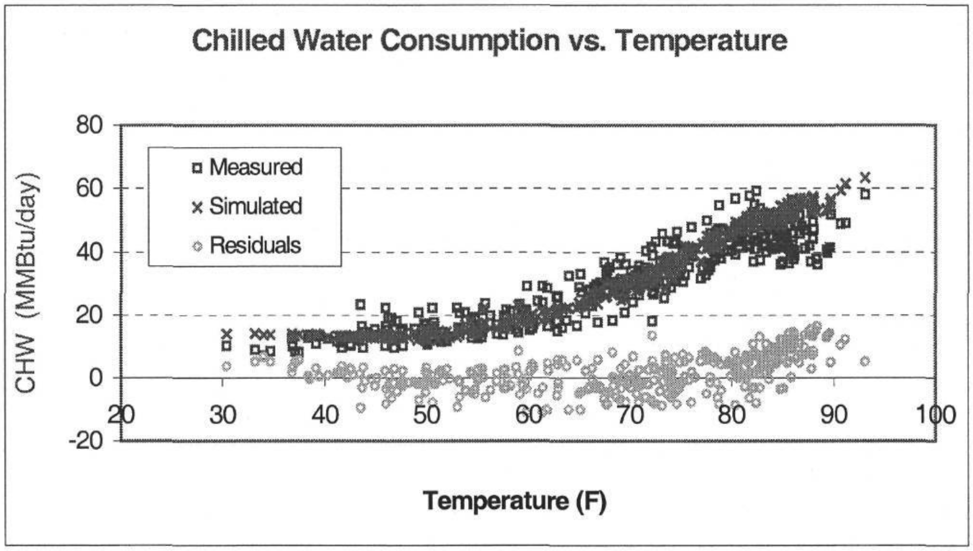
$T_{SET} = 83 - 7/20 * T_{OA}$, if T_{OA} is between 60 °F and 80 °F

The simulation results using the parameters above agreed quite well with measured energy use. The CVRMSE values are 19.0 % for chilled water and 17.1 % for hot water and the MBEs are 1.7 MMBtu/day for chilled water and –0.8 MMBtu/day for hot water.

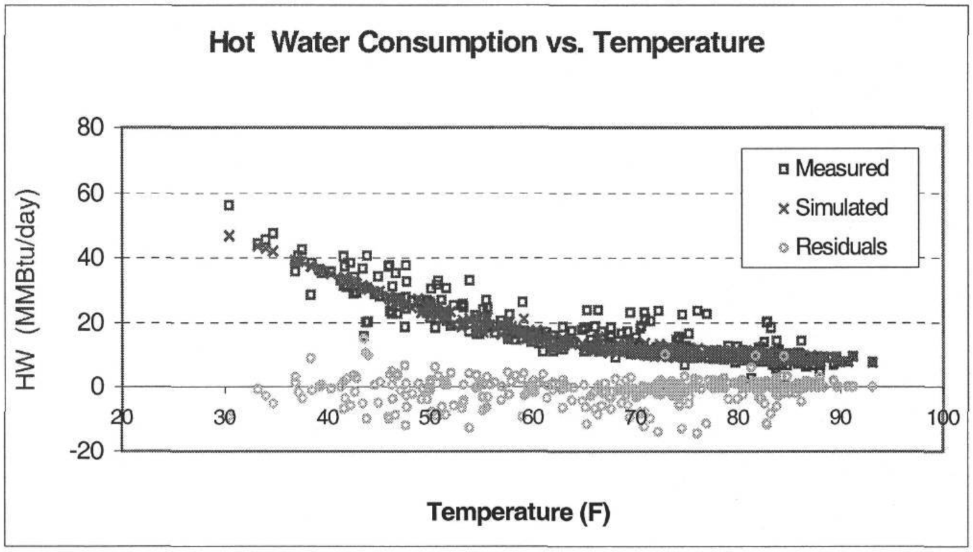
But as seen in Figure 6.41 (a) there were many days during the summer with lower measured energy consumption than simulated, which means that less chilled water energy was consumed than expected based on the indicated control settings. Work orders from the Energy Office revealed that this building experienced 58 hot calls from occupants in the year 2000.

For the subsystem 1, the cold deck settings in EMCS were one-degree lower values than the schedule used in this simulation based on the temperature sensor readings for all outside air temperatures. It means that this building was supposed to have one-degree lower cold deck temperatures but actually operated with one-degree higher cold deck temperatures than scheduled. It is possible that occupants made the hot calls under this operating scenario. Unfortunately, no specific details or troubleshooting results are available. The simulation results agreed well with calibrated cold deck settings for relatively low outside air temperatures but not in high outside air temperatures. It appears that there was either temperature sensor problems or a failure in chilled water supply due to the chilled water valve problems or some related problems.

Figures 6.40 and 6.41 show the Wehner building measured and simulated heating and cooling energy consumption as functions of ambient temperature and time after calibration for the period from 01/01/2000 to 12/31/2000.

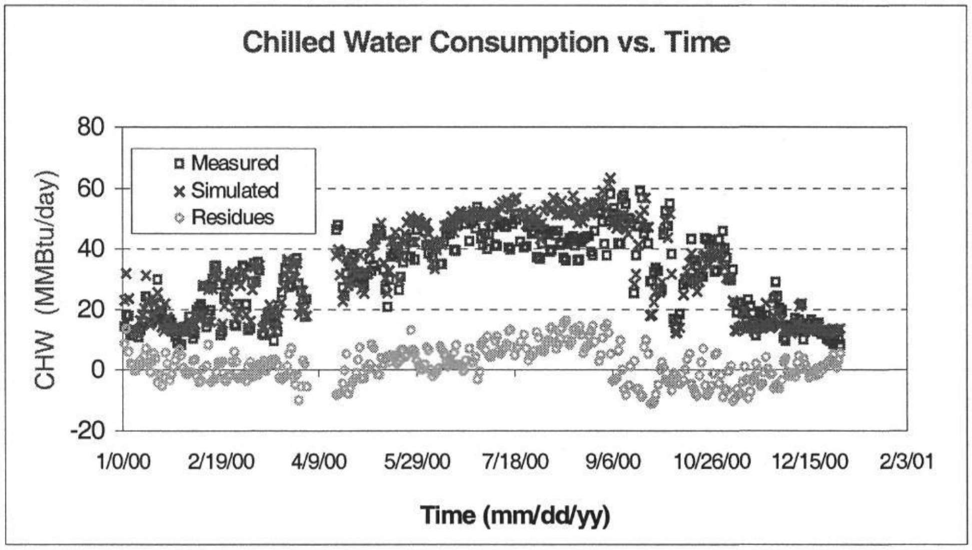


(a)

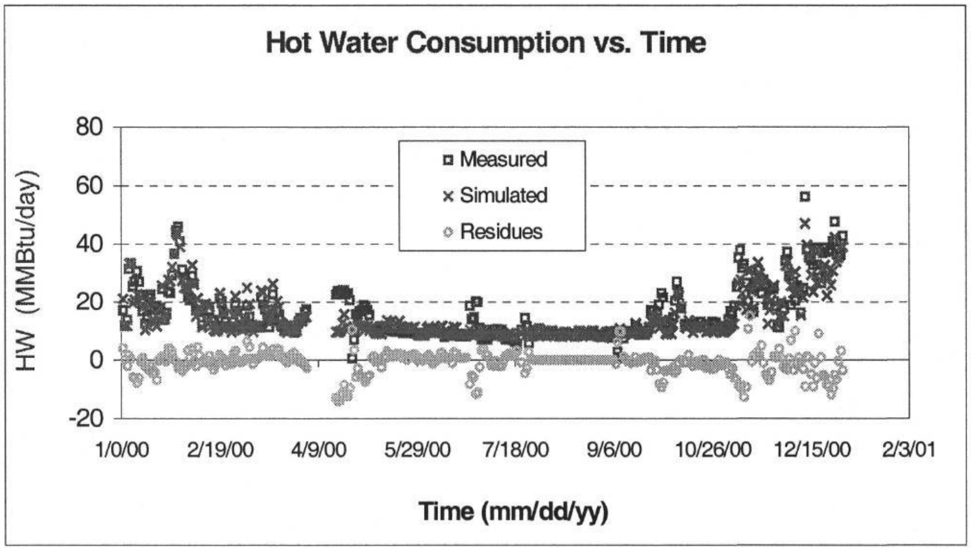


(b)

Figure 6.40 The Wehner building measured and simulated heating and cooling energy consumption as a function of ambient temperature after calibration for the period from 01/01/2000 to 12/31/2000



(a)



(b)

Figure 6.41 Time series plots of the Wehner building measured and simulated heating and cooling energy consumption for the period from 01/01/2000 to 12/31/2000

6.6.3 Calibrated Simulation with Pre- and Post-CC Data

Before commissioning was performed, the hot deck temperature schedule was so high that this building consumed a lot of thermal energy. The hot deck maintained a temperature of 140 °F at outside air temperatures of 20 °F or below and decreased to 100 °F at outside air temperatures of 80 °F or higher. The chilled water energy consumption data for the pre-CC period is available from the database after 05/15/1996, but the hot water data is available from 10/23/1996 due to the missing data so only 30 days data before commissioning were used for the pre-CC simulation process. Here are the pre-CC simulation that differ from those used in the year 2000 simulation.

Minimum Air Flow: 0.67 cfm/sq-ft

Cold Deck Schedule: 55 °F

Hot deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

T_{SET} = 140 °F, if T_{OA} is below 20 °F

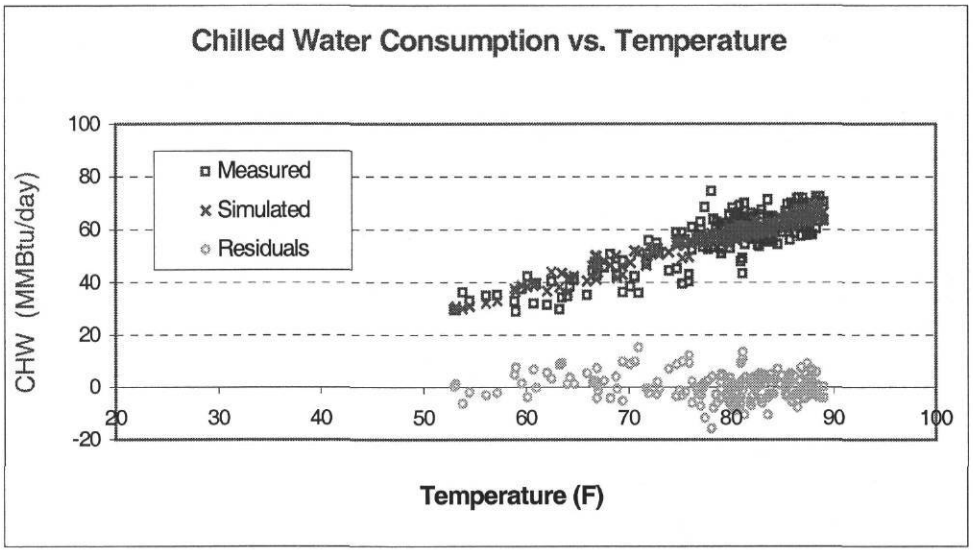
T_{SET} = 100 °F, if T_{OA} is above 80 °F

$T_{SET} = 460/3 - 2/3 * T_{OA}$, if T_{OA} is between 20 °F and 80 °F

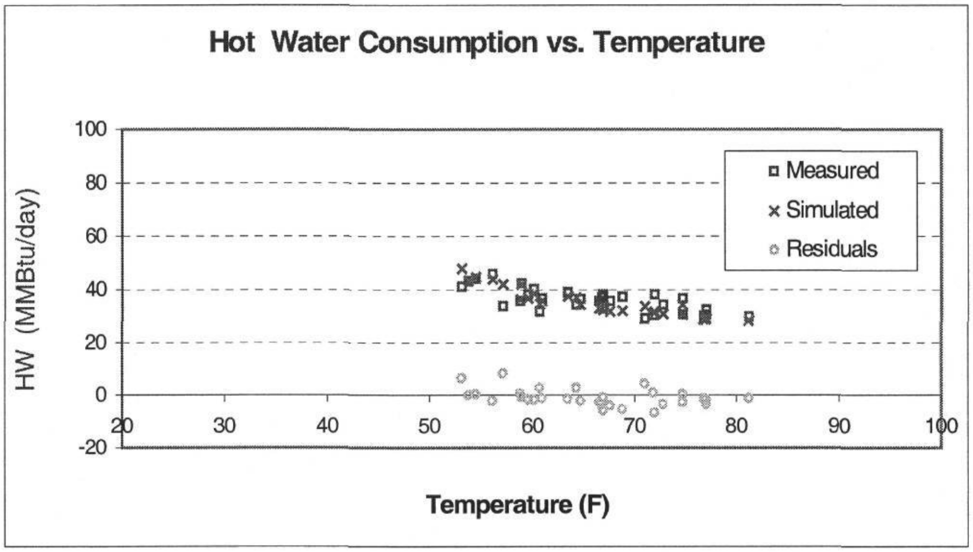
The simulation results using the parameters above showed a good match with measured data for chilled water consumption, but the simulated hot water consumption was much lower than measured use with an MBE of –6.1 MMBtu/day. The hot deck schedule was calibrated and increased by 10 degrees in the high outdoor weather condition. This building has hot water data only from 10/23/1996 to 11/23/1996 during the pre-CC period. Various combinations of input parameters were applied for calibrated simulation, but no combinations were available to match, except dropping internal heat gains. When the internal heat gain decreased to 0.30 W/sq-ft, the simulation obtained the MBE values of 0.3 MMBtu/day for cooling and –0.9 MMBtu/day for heating. Figures 6.38 and 6.39 show the measured and simulated consumption and residues as well as functions of ambient temperature and time, respectively.

The results with the heat gain of 0.3 W/sq-ft, however, is not acceptable since this input value, which is only 20% of the electric energy use in this building, is out of range. Internal heat gain values used in simulation are around 70 % of the whole building electricity consumption and are mainly from lighting and office equipment. The whole building electricity consumption does not 100 % convert into heat gain because some portion is consumed in the mechanical and electrical equipment rooms that may not be conditioned and another portion is exhausted to the outside directly by exhaust air.

Figures 6.42 and 6.43 show the Wehner building measured and simulated heating and cooling energy consumption as functions of ambient temperature and time after calibration (internal heat gain: 0.3 W/sq-ft) for the period from 05/15/1996 to 11/23/1996 for CHW and from 10/23/1996 to 11/23/1996 for HW.

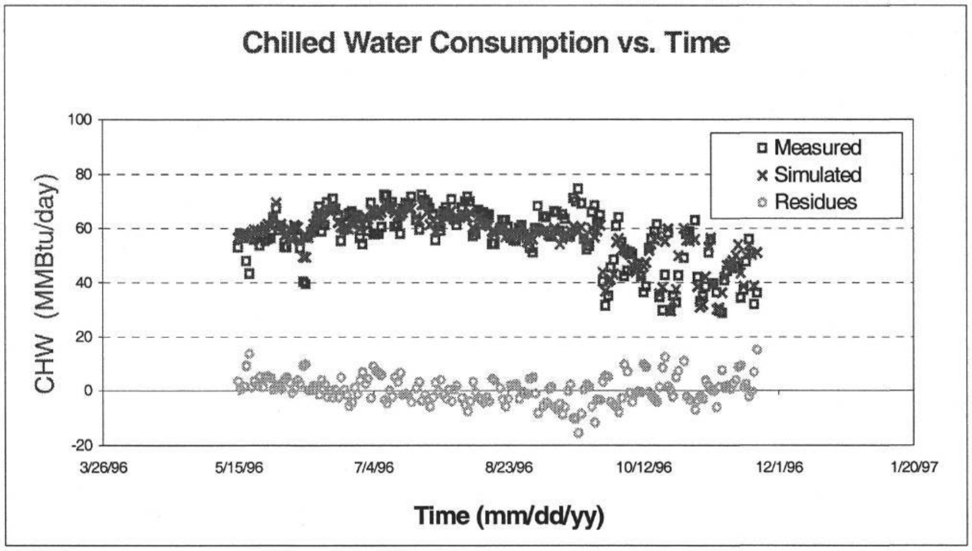


(a)

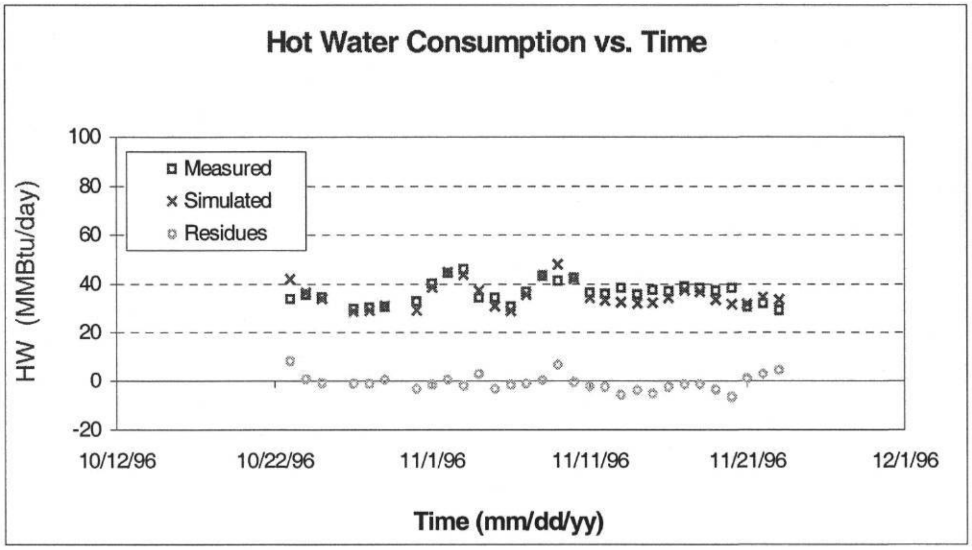


(b)

Figure 6.42 The Wehner building measured and simulated heating and cooling energy consumption as a function of ambient temperature after calibration (internal heat gain: 0.3 W/sq-ft) for the period from 05/15/1996 to 11/23/1996 for CHW and from 10/23/1996 to 11/23/1996 for HW



(a)



(b)

Figure 6.43 The Wehner building measured and simulated heating and cooling energy consumption as a function of time after calibration (internal heat gain: 0.3 W/sq-ft) for the period from 05/15/1996 to 11/23/1996 for CHW and from 10/23/1996 to 11/23/1996 for HW

The simulation for the pre-CC period, therefore, was done with the input data from the commissioning report and internal heat gain values of 70 % of this building electricity consumption. The initial and calibrated hot deck schedules are shown below.

Hot Deck Settings (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: T_{SET} = 140 °F, if T_{OA} is below 20 °F

T_{SET} = 100 °F, if T_{OA} is above 80 °F

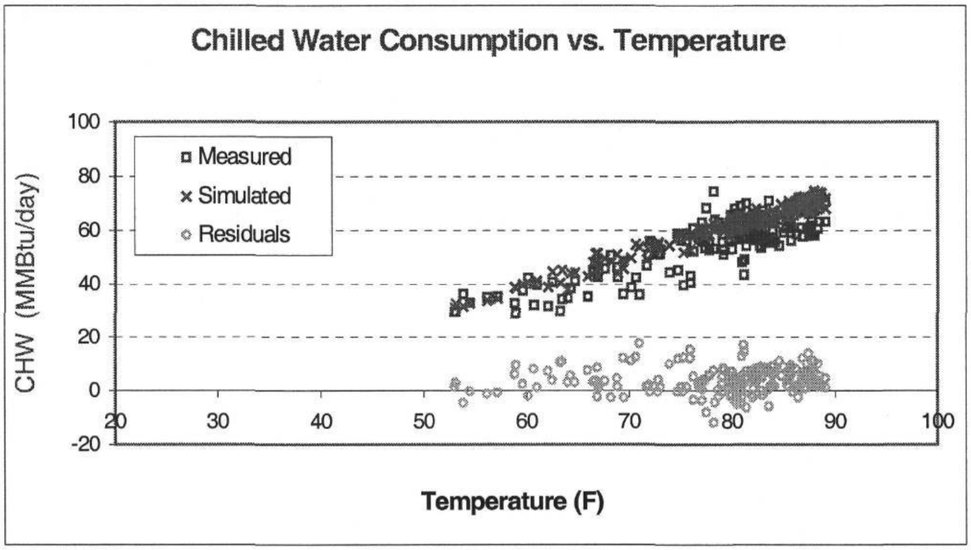
$T_{SET} = 460/3 - 2/3 * T_{OA}$, if T_{OA} is between 20 °F and 80 °F

Calibrated: T_{SET} = 140 °F, if T_{OA} is below 20 °F

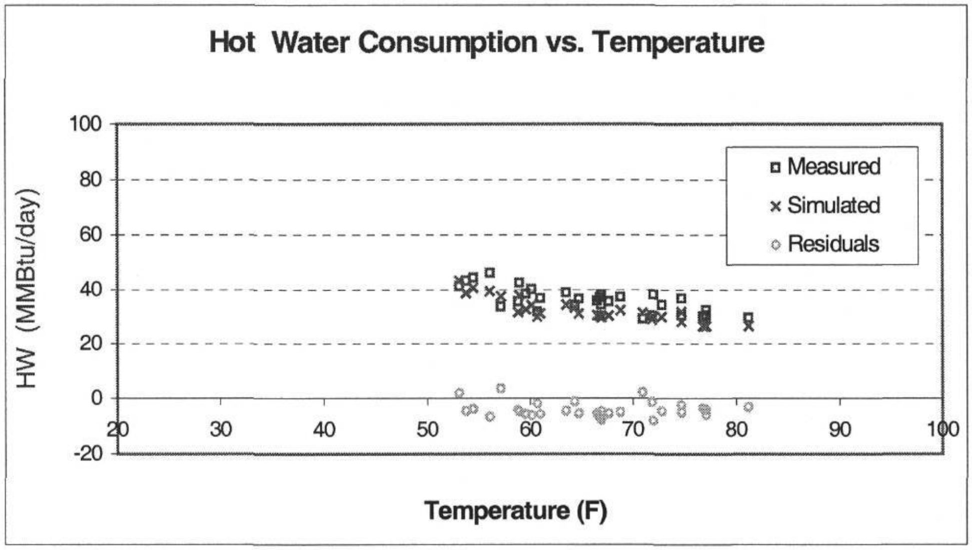
T_{SET} = 110 °F, if T_{OA} is above 80 °F

$T_{SET} = 150 - 1/2 * T_{OA}$, if T_{OA} is between 20 °F and 80 °F

Figure 6.44 and Figure 6.45 show a scatter plot of measured and simulated thermal energy consumption and a time series plots, respectively.

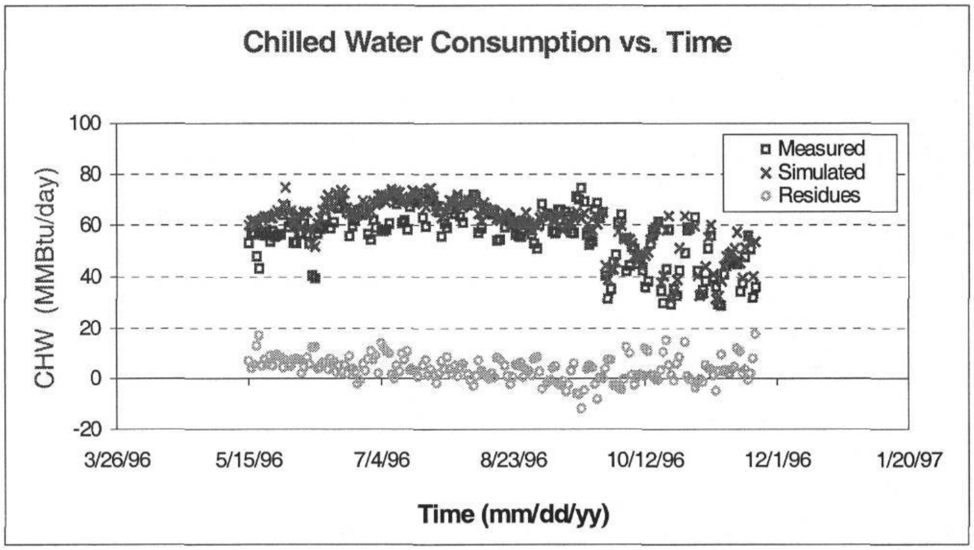


(a)

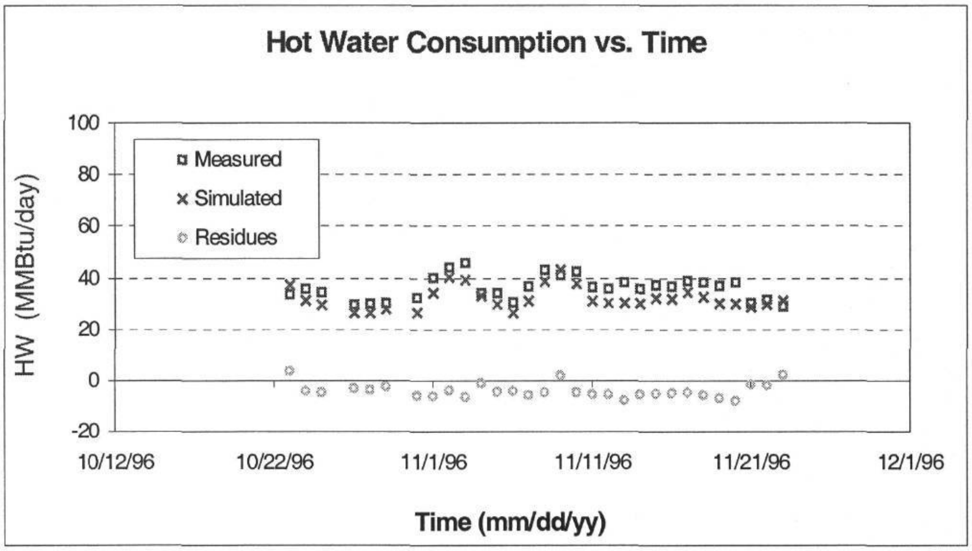


(b)

Figure 6.44 The Wehner building measured and simulated heating and cooling energy consumption as a function of ambient temperature for the period from 05/15/1996 to 11/23/1996 for CHW and from 10/23/1996 to 11/23/1996 for HW



(a)



(b)

Figure 6.45 The Wehner building measured and simulated heating and cooling energy consumption as a function of time for the period from 05/15/1996 to 11/23/1996 for CHW and from 10/23/1996 to 11/23/1996 for HW

The CC process changed three parameters. Minimum air flow decreased from 0.67 cfm/sq-ft to 0.60 cfm/sq-ft, cold deck temperature varied from 60 °F to 53 °F, and hot deck temperature decreased by around 30 °F. Here are the initial input parameters for the post-CC simulation.

Minimum Air Flow: 0.60 cfm/sq-ft

Cold deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

Subsystem 1: T_{SET} = 62 °F, if T_{OA} is below 55 °F

T_{SET} = 55 °F, if T_{OA} is above 80 °F

$T_{SET} = 387/5 - 7/25*T_{OA}$, if T_{OA} is between 55 °F and 80 °F

Subsystem 2: T_{SET} = 58 °F, if T_{OA} is below 50 °F

T_{SET} = 53 °F, if T_{OA} is above 80 °F

$T_{SET} = 199/3 - 1/6*T_{OA}$, if T_{OA} is between 50 °F and 80 °F

Hot deck schedule (T_{SET} = set temperature, T_{OA} = outside air temperature):

T_{SET} = 110 °F, if T_{OA} is below 40 °F

T_{SET} = 75 °F, if T_{OA} is above 70 °F

$T_{SET} = 470/3 - 7/6 * T_{OA}$, if T_{OA} is between 40 °F and 70 °F

The initial simulation produced thermal energy values lower than measured. So the schedules were calibrated and finally the cold deck temperature was decreased by 2 °F for the entire range of outside air temperatures. CVRMSEs are 15.1 % for chilled water and 19.9 % for hot water, and MBEs are 1.0 MMBtu/day for chilled water and –1.1 MMBtu/day for hot water. Here is the comparison of initial and calibrated parameters.

Cold deck schedule for subsystem 1 (T_{SET} = set temperature, T_{OA} = outside air temperature):

Scheduled: $T_{SET} = 62\ ^{o}F$, if T_{OA} is below $55\ ^{o}F$

$T_{SET} = 55\ ^{o}F$, if T_{OA} is above $80\ ^{o}F$

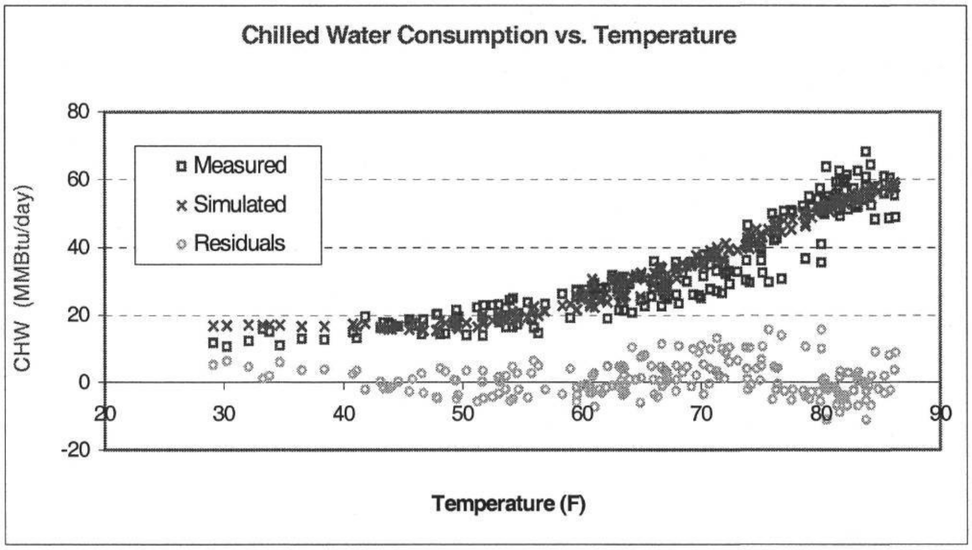
$T_{SET} = 387/5 - 7/25 * T_{OA}$, if T_{OA} is between $55\ ^{o}F$ and $80\ ^{o}F$

Calibrated: $T_{SET} = 60\ ^{o}F$, if T_{OA} is below $55\ ^{o}F$

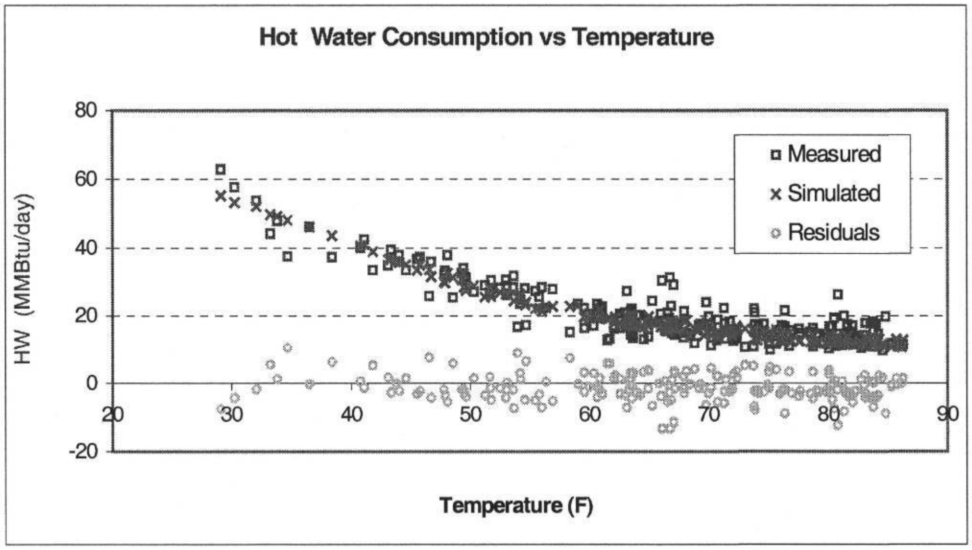
$T_{SET} = 53\ ^{o}F$, if T_{OA} is above $80\ ^{o}F$

$T_{SET} = 377/5 - 7/25 * T_{OA}$, if T_{OA} is between $55\ ^{o}F$ and $80\ ^{o}F$

Figures 6.46 and 6.47 show the measured and calibrated simulation energy consumption for cooling and heating as functions of ambient temperature and time, respectively.

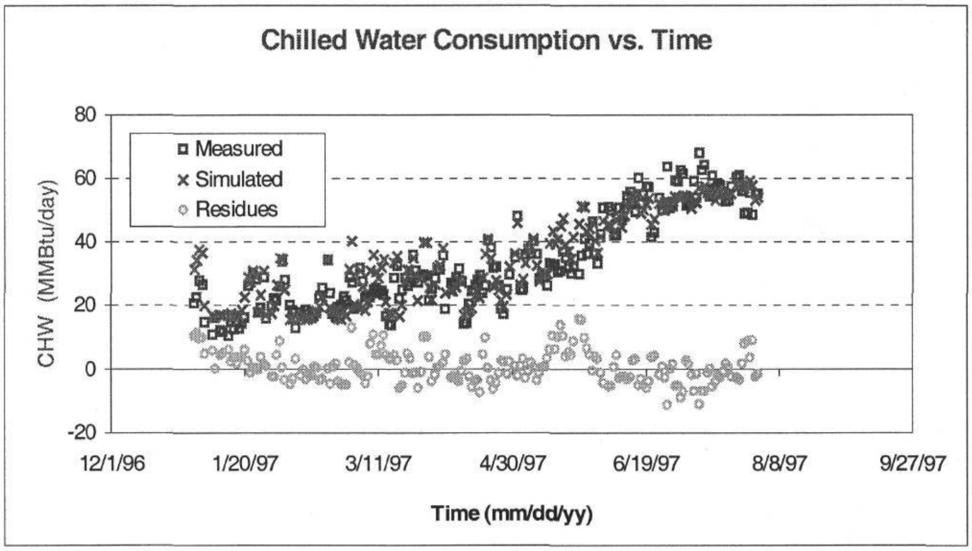


(a)

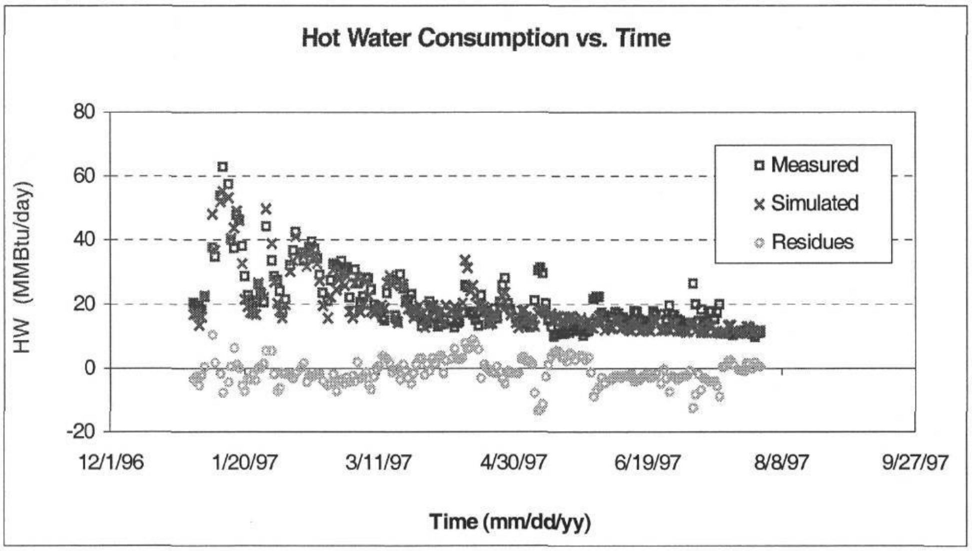


(b)

Figure 6.46 The Wehner building measured and simulated heating and cooling energy consumption as a function of ambient temperature after calibration for the post-CC period from 01/01/1997 to 07/31/1997



(a)



(b)

Figure 6.47 The Wehner building measured and simulated heating and cooling energy consumption as a function of time after calibration for the post-CC period from 01/01/1997 to 07/31/1997

6.6.4 Simulation Comparison of Three Different Periods (Pre-CC, Post-CC and Year 2000)

Thermal energy savings were 20.3 % for cooling and 45.8 % for heating in 1997 compared to baseline or pre-CC energy consumption. These savings were made by decreasing minimum air flow and hot deck temperature settings. The savings then increased by 10.9 % for cooling and 11.9 % for heating in 2000. The Wehner building is the only one in the five simulated buildings that shows increase of savings over time after commissioning. The additional energy savings in 2000 were due to an increase in cold deck temperatures of 2 ^{o}F - 3 ^{o}F in 2000 compared to 1997 as shown in Table 6.5.

Table 6.5 The Wehner Building Energy Consumption Results from Calibrated Simulation and Input Parameter Comparisons for the Pre-CC, Post-CC and Year 2000 Periods

	Type	Baseline Use (MMBtu/yr)	1997		2000	
			Use (MMBtu)	Savings (%)	Use (MMBtu)	Savings (%)
Calibrated	CHW	17601	13914	20.9%	12230	30.5%
Calibrated	HW	12472	6649	46.7%	5128	58.9%
Calibrated	CHW (MBE applied)	17003	13552	20.3%	11701	31.2%
Calibrated	HW (MBE applied)	12987	7039	45.8%	5499	57.7%
(Scheduled)	CHW (MBE applied)	17329	13585	21.6%	11701	32.5%
(Scheduled)	HW (MBE applied)	12880	7052	45.3%	5499	57.3%
(Scheduled)	CHW	16625	13748	17.3%	12230	26.4%
(Scheduled)	HW	11565	6517	43.6%	5128	55.7%

No.	Parameter	Pre-CC		Post-CC		2000	
		System 1 (DDPOA)	System 2 (SDRHOA)	System 1 (DDPOA)	System 2 (SDRHOA)	System 1 (DDPOA)	System 2 (SDRHOA)
1	Room Temperature Occ/Unocc (Heating/Cooling)	71 73 71 78	71 75 71 82	71 73 71 78	71 75 71 82	71 73 71 78	71 75 71 82
2	Total Air Flow Rate (cfm/sq-ft)	1.00	1.00	1.00	1.00	1.00	1.00
3	Outside Air Flow Rate (cfm/sq-ft)	0.10	0.10	0.10	0.10	0.10	0.10
4	Min. Air Flow (cfm/sq-ft)	0.67	0.67	0.60	0.60	0.60	0.60
5	Cold Deck Calibrated (Scheduled)	55 (55)	55 (n/a)	**60** 55 **53** 80 (62 55 55 80)	58 50 53 80 (n/a)	63 50 56 80 (63 50 56 80)	62 60 55 80 (62 60 55 80)
6	Hot Deck Calibrated (Scheduled)	140 20 **110** 80 (140 20 100 80)	n/a	110 40 75 70 (110 40 75 70)	n/a	110 40 75 70 (110 40 75 70)	n/a
7	Pre-heat Deck Schedule	50	50	50	50	50	50

6.7 Summary

In this chapter, calibrated simulation using the Airmodel program has been utilized to investigate reasons for heating and cooling use changes following commissioning in five buildings on the Texas A&M University campus. Various input parameters were calibrated based on information in the CC reports combined with recent EMCS data to fit simulated energy consumption to the measured energy consumption patterns of buildings.

Each of the five buildings was simulated for three periods: one before CC activities (pre-CC), one after CC implementation (post-CC) and for the year 2000. The simulations were initially performed using a combination of information obtained from the EMCS and from the CC reports; these simulations will be referred to as using "scheduled" input parameters. Subsequently the input parameters were adjusted to provide a better fit to the measured consumption; these simulations will be referred to as using "calibrated" input parameters. As shown in Table 6.6, the thermal energy savings of four of the simulated buildings have degraded between the post-CC period and the year 2000.

Table 6.6 also shows that in several cases, the energy consumption for the calibrated simulation exactly equals the energy consumption for the corresponding simulation with the scheduled input parameters; for example, this is true for the baseline CHW and HW energy use for the Kleberg building. This means that the "calibrated" input parameters are the same as the "scheduled" input parameters.

The average savings for the post-CC period were 30.1% for chilled water and 62.2% for hot water. In the year 2000 these average savings decreased to 24.2% for chilled water and 57.2% for hot water. However, the savings increased in the Wehner building from 20.3% to 31.2% for chilled water and from 45.8% to 57.7% for hot water. The savings in the other four buildings decreased on average from 32.6% to 22.5% for CHW and from 66.3% to 57.1% for HW during the same period.

It was determined during the simulation process that one building, Kleberg, out of the five simulated buildings experienced control settings changes and significant HVAC component malfunctions as well. The other four buildings simulated did not appear to experience significant HVAC equipment malfunctions.

If the Kleberg building is excluded due to the component problems, examining and comparing the savings based on the calibrated inputs with those based on the scheduled inputs, the Root Mean Square (RMS) differences between 'Calibrated' and 'Scheduled' savings values for four buildings are 1.5% for the post-CC period and 1.5% for 2000. Perhaps more significantly, the RMS difference between the changes in savings occurring between the "post-CC" periods and year 2000 is only 0.3% for the four buildings. This result suggests that the changes in savings for the four buildings were almost entirely due to the control changes identified.

Overall, changes made in cold deck and hot deck temperature settings following commissioning were the major reasons for changes in chilled water and hot water energy consumption and savings after commissioning.

Table 6.6 A Summary of MBE-Applied Chilled Water and Hot Water Energy Savings for Five Buildings from Simulation Using both Calibrated and Scheduled Input Parameters for the Periods of Post-CC and Year 2000

Buildings	Type		Baseline (Pre-CC) (MMBtu/yr)	Post-CC Savings		2000 Savings	
				Use (MMBtu/yr)	Savings (%)	Use (MMBtu/yr)	Savings (%)
Kleberg	CHW	Calibrated	72935	29392	59.7%	45431	37.7%
		Scheduled	72935	29392	59.7%	43888	39.8%
	HW	Calibrated	43296	5024	88.4%	16351	62.2%
		Scheduled	43296	5024	88.4%	15199	64.9%
Eller O&M	CHW	Calibrated	22487	19444	13.5%	20703	7.9%
		Scheduled	22389	19349	13.6%	20609	7.9%
	HW	Calibrated	6099	3503	42.6%	3571	41.5%
		Scheduled	5561	3409	38.7%	3462	37.7%
Harrington Tower	CHW	Calibrated	14092	7851	44.3%	9105	35.4%
		Scheduled	14092	7843	44.3%	9118	35.3%
	HW	Calibrated	7663	2313	69.8%	2609	65.9%
		Scheduled	7663	2344	69.4%	2685	65.0%
VMC Addition	CHW	Calibrated	28347	24723	12.8%	25832	8.9%
		Scheduled	28145	24723	12.2%	25849	8.2%
	HW	Calibrated	5779	2045	64.6%	2378	58.8%
		Scheduled	5836	2045	65.0%	2422	58.5%
Wehner	CHW	Calibrated	17003	13552	20.3%	11701	31.2%
		Scheduled	17329	13585	21.6%	11701	32.5%
	HW	Calibrated	12987	7039	45.8%	5499	57.7%
		Scheduled	12880	7052	45.3%	5499	57.3%

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

This thesis has investigated the persistence of thermal and electrical energy savings from commissioning in ten buildings on the Texas A&M University campus that were commissioned by the Continuous Commissioning group between 1996 and 1997. Savings were determined using the measured consumption data and the Emodel program for multiple periods during the first 3-4 years after commissioning. CC reports, examination of EMCS settings, maintenance logs, and interviews with CC engineers and operating personnel were used to investigate changes in operating practice since the CC measures were originally implemented. Calibrated simulation was subsequently used to quantitatively investigate the impact of these operating changes.

The cumulative measured savings from the 10 buildings studied for the period from 1997 to 2000 after continuous commissioning were $4,439,000, of which 50.4% were cooling energy savings, 39.2% were heating energy savings, and 10.4% were electricity savings. Energy cost savings were calculated by using the historic campus energy costs of $4.67/MMBtu for chilled water, $4.75/MMBtu for hot water, and $0.02788/KWh for electricity.

The electric energy savings have degraded by only 0.8 % from 1997 to 2000. Lighting, plug loads and motors that operate fans and pumps are the main sources of electric energy consumption. Electricity use increases of this size can readily occur in campus buildings due to increasing plug loads from computers and research equipment, and increasing enrollment. Increased plug loads lead to increased air flow requirements which in turn requires more fan power to supply the conditioned air to the buildings.

The cooling energy savings obtained from commissioning have degraded by 9.7 % from 44.8% to 35.1% during the period from 1997 to 2000. Although the heating energy savings have decreased by 17.6 % from 67.3 % in 1997 to 49.7 % in year 2000, the hot water loop work performed on campus between 1997 and 1998 raised hot water savings to 79.7 % in 1998. The hot water savings decrease from 1998 to 2000 is 30.0 %. In spite of these decreases, savings of both money and energy from the commissioning are still substantial.

Preliminary investigation of the reasons for the decline in savings identified numerous changes in control parameters and a significant controls malfunction. The reason for the dramatic savings decrease in the G. R. White Coliseum was clearly due to a malfunction in the AHU controls in this building that appeared to occur in 1999.

To further understand reasons for the observed degradation in savings, operating changes and equipment problems were investigated in some detail. Using CC reports, interviews of CC engineers and operators, and retrieval of current working data from energy management control systems, it was found that the EMCS schedules have been changed since CC was originally implemented. Only the Koldus building had not had any apparent control changes since commissioning. The other buildings have experienced significant HVAC control schedule changes, which were generally consistent with the observed changes in energy consumption.

To verify the impact of the EMCS changes on energy consumption, the calibrated simulation process was performed on the five buildings with the most complete data sets. Simulation was conducted for a pre-CC period, a post-CC period soon after commissioning and for the year 2000 for each building. While performing the simulation process, it was learned that the Kleberg building experienced both control changes and significant component malfunctions, as identified by the CC engineers. The changes in consumption observed following commissioning in the other four buildings were consistent with those due to the identified controls changes, with an RMS difference of only 0.3%. The control changes accounted for the savings increase observed in the Wehner building as well as the decreases observed in the other three buildings. This suggests that the changes in savings for these four buildings were almost entirely due to the control changes. One might then conclude that control settings must continue to be optimum for the savings obtained from commissioning to persist.

Based on the results of this research, it is recommended that energy use data from commissioned buildings be monitored, a baseline established for the post-commissioning behavior and that CC engineers examine building operation again whenever consumption deviates from the post-CC baseline by some set amount. Research is needed to determine this amount. The examination of the building would determine reasons for the observed changes and provide a new optimized set of control settings as necessary. Changes in control will be necessary in some cases, but it is recommended that access to the control program for more than a temporary override be limited to some specific personnel who are able to determine the energy and comfort impact of proposed control changes and consider that impact as part of the decision to change control settings.

REFERENCES

ASHRAE 1996. *1996 ASHRAE Guideline (The HVAC Commissioning Process)*. Atlanta, GA, The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE 1997. Chapter 30 – Energy Estimating and Modeling Methods. *1997 ASHRAE Handbook: Fundamentals*, Atlanta, GA, The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE 1999. Chapter 41 – Building Commissioning. *1999 ASHRAE Applications Handbook*. Atlanta, GA, The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Bou-Saada, Tarek, E. and J.S. Haberl. 1994. An Improved Procedure for Developing Calibrated Hourly Simulation Models, IBPSA. *Fourth International Conference Proceedings*, Madison, WI, August 14-16, 475-484.

Bronson, D.J., S.B. Hinchey, J.S. Haberl, and D.L. O'Neal. 1992. A Procedure for Calibrating the DOE-2 Simulation Program to Non-Weather-Dependent Measured Loads. *ASHRAE Transactions*, 98, Part I: 636-652.

Chen, H., 2001. CC Verification and Results for Kleberg Building. Internal Report. Energy Systems Laboratory, Texas A&M University, College Station, TX.

Chen, H., D. E. Claridge, S. Deng, W. D. Turner, and H. L Bruner. 2002. Continuous Commissioning Results Verification and Follow-Up for an Institutional Building – A Case Study. *Proceedings of the Thirteenth Annual Symposium on Improving Building Systems in Hot and Humid Climates,* Houston, TX, May 20-23, (To be Published).

Claridge, D.E., J. S. Haberl, S. Katipamula, D. O'Neal, L.Chen, T. Henneghan, S. Hinchey, K.Kissock, and J. Wang. 1990. Analysis of the Texas LoanSTAR Data. *Proceedings of the Seventh Annual Symposium on Improving Building Systems in Hot and Humid Climates,* Texas A&M University, College Station, TX, Oct. 9-10, 53-60.

Claridge, D.E, J.S. Haberl, R. Sparks, R. Poyner, and J. Bryan. 1992. Use of Energy Management and Control Systems for Performance Monitoring of Retrofit Projects. ESL-TR-91/09-02, Energy Systems Laboratory, Mechanical Engineering Department, Texas A&M University, College Station, TX.

Claridge, D.E., J.S. Haberl, M. Liu, J. Houcek, and A. Athar. 1994. Can You Achieve 150% of Predicted Retrofit Savings? Is It Time for Recommissionings? *ACEEE 1994 Summer Study on Energy Efficiency In Buildings Proceedings: Commissioning,* *Operation and Maintenance*, Vol. 5, American Council for an Energy Efficient Economy, Washington, DC, 73-87.

Claridge, D.E., M. Liu, Y. Zhu, M. Abbas, A. Athar, and J. Haberl. 1996. Implementation of Continuous Commissioning in the Texas LoanSTAR Program: 'Can You Achieve 150% of Predicted Retrofit Savings?' Revisited. *Proceedings 4, Commercial Buildings: Technologies, Design, and Performance Analysis. ACEEE 1996 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy Efficient Economy, Washington, DC, 4.59-4.67.

Claridge, D.E., C.H. Culp, S. Deng, W.D. Turner, J.S. Haberl, and M. Liu. 2000a. Continuous Commissioning of a University Campus. *Proc. of 8th National Conference on Building Commissioning*, Kansas City, MO, May 3-5, 12.1 - 12.9.

Claridge, D.E., C.H. Culp, M. Liu, S. Deng, W.D. Turner, and J.S. Haberl. 2000b. Campus-Wide Continuous Commissioning^{SM} of University Buildings. *Proc. of ACEEE 2000 Summer Study on Energy Efficiency in Buildings*, Pacific Grove, CA, Aug. 20-25, 3.101-3.112.

Fels, M. 1986. Special Issue Devoted to Measuring Energy Savings, the Scorekeeping Approach. *Energy and Buildings*, Vol. 9: 9.5 – 9.18.

Fels, M. F. and Cathy L. Reynolds. 1988. The Two-Third House Revisited. *ACEEE 1988 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy Efficient Economy, Pacific Grove, CA, Aug. 28 – Sep. 3, C1–C10.

Fels, M. and C. Reynolds. 1991. Towards Standardizing the Measurement of Whole-Building Energy Savings in DSM Programs. *Proceedings of the 1991 Energy Program Evaluation Conference,*Chicago, IL, 75-85.

Fels, M., K. Kissok, and M. Marean. 1994. Model Selection Guidelines for PRISM: Now That I Know That HC PRISM Is Coming How Will I Know When To Use It? *Proceedings of the 1994 ACEEE Summer Study on Energy Efficiency in Buildings*, Asilomar, CA (August), Vol. 8: 8.49-8.62.

Fels, M., K. Kissok, M. Marean, and C. Reynolds. 1995. Advancing the Art of PRISM Analysis. *Home Energy* 12(4): 19-23.

Gregerson, Joan, 1997. Cost Effectiveness of Commissioning 44 Existing Buildings. *Fifth National Conference on Building Commissioning*, Huntington Beach, CA, April 28-30, 15.1-15.11.

Haasl, T. and T. Sharp. 1999. *A Practical Guide for Commissioning Existing Buildings*. ORNL/TM-1999/34, Portland Energy Conservation, Inc. and Oak Ridge National Laboratory for the U.S. Department of Energy, April 1999, 1-8.

Haberl, J. and D. Claridge. 1987. An Expert System for Building Consumption Analysis: Prototype Results. *ASHRAE Transactions* 93(1): 979-998.

Haberl, J. 1988. Persistence of Energy Savings. *ACEEE 1988 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy Efficient Economy, Pacific Grove, CA, Aug. 28 – Sep. 3, C11–C19.

Haberl, J. and E. James Vajda. 1988. Use of Metered Data Analysis to Improve Operation and Maintenance: Early Results from Two Federal Complexes. *ACEEE 1988 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy Efficient Economy, Pacific Grove, CA, Aug. 28 – Sep. 3, 4.1–4.13.

Haberl, J. and P. Komer. 1990a. Improving Energy Audits: How Annual and Monthly Consumption Data Can Help. *ASHRAE Journal* 32(8): 26-33.

Haberl, J. and P. Komer. 1990b. Improving Energy Audits: How Daily and Hourly Consumption Data Can Help. *ASHRAE Journal* 32(9): 26-36.

Haberl, J. and T. E. Bou-Saada. 1998. Procedures for Calibrating Hourly Simulation Models to Measured Building Energy and Environmental Data. *Journal of Solar Energy Engineering,* Vol. 120: 193-204.

Heinz, S. 1996. Give Your Utility Bills a Checkup! *Energy Engineering* 93(3): 27-43.

Hsieh, E. 1988. Calibrated Computer Models of Commercial Buildings and Their Role in Building Design and Operation. *MS Thesis*, Princeton University, Princeton, NJ.

Kats, G.H, A.H. Rosenfeld, T.A. McIntosh, and S.A. McGaragham. 1996. Energy Efficiency as a Commodity: The Emergence of an Efficiency Secondary Market for Savings in Commercial Buildings. *Proc. of 4th National Conference on Building Commissioning*. St. Pete Beach, FL, April 29 – May 6, 5.111-5.122.

Kissock, J.K., T.A. Reddy, and D.E. Claridge. 1992. A Methodology for Identifying Energy Savings in Commercial Buildings. *Proceedings of the Eighth Symposium on Improving Building Systems in Hot and Humid Climates*, Dallas, TX, May 12-13, 234-246.

Kissock, J.K. 1993. A Methodology to Measure Retrofit Energy Savings in Commercial Buildings. *Ph.D. Dissertation*, Department of Mechanical Engineering, Texas A&M University.

Kissock, K., E. Wu, R. Sparks, D. Claridge, J. Mahoney, and J. Haberl. 1994. Users Manual for Emodel Version 1.4, ESL-SW-94/12-01, Energy Systems Laboratory, Texas A&M University, College Station, TX.

Liu, M., J. Houcek, A. Athar, A. Reddy, and D.E. Claridge. 1994. Identifying and Implementing Improved Operation and Maintenance Measures in Texas LoanSTAR Buildings. A*CEEE 1994 Summer Study on Energy Efficiency in Buildings Proceedings: Commissioning, Operation and Maintenance*, American Council for an Energy Efficient Economy, Washington, DC, 5.153-5.165.

Liu, M., and D.E. Claridge. 1995. Manual for AirModel. Energy Systems Laboratory, Texas A&M University, College Station, TX.

Liu, M., Y. Zhu and D.E. Claridge. 1996. Use of EMCS Recorded Data to Identify Potential Savings Due to Improved Operations & Maintenance (O&M). *Proceedings of 10th Symposium on Improving Building Systems in Hot and Humid Climates*, Fort Worth, TX, May 13-14, 28-37.

Liu, M., D.E. Claridge and W.D. Turner. 1999. Advancement of Continuous Commissioning in the Energy Systems Laboratory, Texas A&M. *Proc. of 7th National Conference on Building Commissioning*, Portland, OR, May 3-5, 10.1 - 10.16.

Liu, Y. 1993. Measuring Retrofit Savings in Commercial Buildings with Pre-Retrofit Utility Billing Data and Post-Retrofit Sub-Metered Data. *MS Thesis*. Mechanical Engineering Department, Texas A&M University, College Station, TX.

Reddy, T.A., N. Saman, D. Claridge, J. Haberl, and W. Turner. 1996. Development of Baseline Monthly Utility Models for Eight Army Installations around the United States. Energy Systems Laboratory Technical Report ESL-TR-96/03-1. Department of Mechanical Engineering, Texas A&M University, College Station, TX.

Ruch, D. and D. Claridge. 1991. A Four Parameter Change Point Model for Predicting Energy Consumption in Commercial Buildings. *Proceedings of the ASME-JSES-SSME International Solar Energy Conference,* Reno, NV, March 17-22, 433-439.

Ruch, D., L. Chen, J. Haberl, and D. Claridge. 1991. A Change Point Principle Component Analysis (CP/PCA) Method for Predicting Energy Usage in Commercial Buildings: the PCA Model. *Proceedings of the ASME-JSES-SSME International Solar Energy Conference*, Reno, NV, March 17-22, 457-467.

SRC. 1996. *Metrix User's Manual*. Berkeley, CA: SRC Systems, Inc.

Turner, W.D., M. Liu, D.E. Claridge, and J.S. Haberl. 1996. Improving Building Energy System Performance by Continuous Commissioning. ESL-TR-96/07-01, Energy Systems Laboratory Technical Report, Department of Mechanical Engineering, Texas A&M University.

Turner, W.D., D.E. Claridge, M. Liu, and J.S. Haberl. 1998. The Continuous Commissioning Process and Rebuild America (Brazos Valley Energy Conservation Coalition). *Proc. of 6th National Conference on Building Commissioning*, Disney's Coronado Springs Resort Lake Buena Vista, FL, May 18-20, 2.1 - 2.6.

Turner, W.D., D.E. Claridge, D.L. O'Neal, J.S. Haberl, W.M. Heffington, D. Taylor, and T. Sifuentes. 2000. Program Overview, The Texas LoanSTAR Program; 1989-1999, A 10-Year Experience. *Proc. of ACEEE 2000 Summer Study on Energy Efficiency in Buildings*, Pacific Grove, CA, Aug. 20-25, 4.365-4.376.

U.S. Department of Energy (DOE). 1996a. *ASEAM User's Manual*. Washington, DC: U.S. Government Printing Office.

U.S. Department of Energy (DOE). 1996b. *North American Energy Measurement and Verification Protocol*. DOE/EE-0081. Washington, DC: U.S. Government Printing Office.

U.S. Department of Energy (DOE). 1997. *International Performance Monitoring and Verification Protocol*. DOE/EE-0157. Washington, DC: U.S. Government Printing Office.

U.S. Department of Energy (DOE). 2001. *International Performance Monitoring and Verification Protocol*. DOE/GO-102000-1132 Revised. Washington, DC: U.S. Government Printing Office.

Wang, J. 1996. Comparison of the Prediction Accuracy of Daily and Monthly Regression Models for Energy Consumption in Commercial Buildings. *MS Thesis*. Mechanical Engineering Department, Texas A&M University, College Station, TX.

Wei, G., M. Liu, and D.E. Claridge. 1998. Signatures of Heating and Cooling Energy Consumption for Typical AHUs. *The Eleventh Symposium on Improving Building Systems in Hot and Humid Climates Proceedings*, Fort Worth, Texas, June 1-2, 387-402.

VITA

Name: Sool Yeon Cho

Address: 922 Willow Pond Street
College Station, TX 77845

Education: University of Ulsan
Ulsan, Korea (ROK)
B.S., 1995, Mechanical Engineering

Present Employment: Energy Systems Laboratory, Texas A&M University
College Station, TX

APPENDIX A

Building and HVAC System Information for 10 Buildings

Appendix A contains tables that have general building information, HVAC system types, and EMCS schedules, which were the current (January, 2001) schedules for the 10 buildings. The Energy Management Control Systems (EMCS) were installed for all 10 buildings, and CHW and HW are supplied from Central Plant Utilities. Cooling and heating set points for each zone or room in the buildings were retrieved from the Siemens APOGEE^{TM} program.

Table A.1: Building and HVAC System Information for the Blocker Building.

Building and HVAC System Information

I. Building Information

Building Name	***BLOCKER BUILDING***		
Building Number	# 524		
Building Type	Classrooms, Offices, Laboratories		
Number of Stories	6		
Total Floor Area (ft^2)	255,490		
Maintenance Area	# 4	Phone	845-4518

II. HVAC System Information

(1) General

Heating/Cooling Resources	CHW & HW Supplied From Central Plant Utilities			
HVAC System Types	10 DDVAV AHUs & 2 100% OA units serve 10 DDVAV AHUs 2 SDCV AHUs in the basement M/R, 1 Liebert unit for 6th floor c/r			
EMCS Installed ?	Yes	X	No	
EMCS Type(s)	Siemens DDC			

AHU #	Type					Control	Supply Fan HP	Comment
	DD	SD	VAV	CV	Reheat			
AHU 11,12,13,41	X		X			DDC	20 each	
AHU 14,42	X		X			DDC	25 each	
AHU 31,32,51,52	X		X			DDC	40 each	
OAHU 1,2		X		X		DDC	10 each	
AHU B-1		X		X		DDC	3	

(2) Control Schedule & Settings in EMCS Programs

1) Cold Deck (CD) Control Schedule

AHU #	Temperature (°F)				Remark
AHU 11,12	T_{OA}	40	60	60	
	$T_{setpoint}$	56	54	52	
AHU 13,14,31, 32,41,42,51,52	T_{OA}	40	60	75	
	$T_{setpoint}$	55	54	55	
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				

2) Hot Deck (HD) Control Schedule

AHU #	Temperature (^oF)				Remark
AHU 11,12	T_{OA}	45	70		
	$T_{setpoint}$	95	70		
AHU 13,14,31, 32,41,42,51,52	T_{OA}	30	75		
	$T_{setpoint}$	95	75		
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				

3) Static Pressure (SP) Control Schedule

AHU #	Temp (^oF) vs. $SP_{setpoint}$ (in H_2O)				Night Setback				Remark
AHU 11,12,13,14	T_{OA}	45	45		Time	21:00	23:00	5:00	
	SP	0.8	1.5		SP	0.7	0.5	end	
AHU 31,32,41,51	T_{OA}	40	40		Time	21:00	23:00	5:00	
	SP	1.0	1.5		SP	0.8	0.6	end	
AHU 42	T_{OA}	50	50		Time	21:00	23:00	5:00	
	SP	0.5	1.5		SP	0.4	0.2	end	
AHU 52	T_{OA}	50	50		Time	21:00	23:00	5:00	
	SP	0.5	1.5		SP	0.5	0.4	end	
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				

4) Building Differential Pressure (DP) Control Schedule

Pump System	Temp (^oF) vs. $DP_{setpoint}$ (psi)				Remark
CHWP	DP	$DP = GPM^2 * 0.124 / 1000 + 7$			
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				

5) Typical Zone / Room Thermostat Setpoints

	Occupied Setpoints (^{o}F)		Unoccupied Setpoints (^{o}F)		Remark
	Heating	Cooling	Heating	Cooling	
Range	64 ~ 74	68 ~ 78	64 ~ 74	68 ~ 82	Total # of Thermostats : 326
Mainly	68	73	65	76	
Average	68.4	72.8	66.4	74.8	

6) Control of Outside Air (Including Freeze Protection)

a. Outside air HWPs are "ON" when outside air is 38 ^{o}F and "OFF" when outside air is 45 ^{o}F.

b. Two OAHUs supply outside air into 10 AHUs.

(3) Existing System Operation Conditions (From EMCS & Field Visit)

1) Major Equipment Under Manual Operation Mode

:

2) Components With Problems

:

Table A.2: Building and HVAC System Information for the Eller O&M Building.

Building and HVAC System Information

I. Building Information

Building Name	***Eller O&M Building***		
Building Number	# 443		
Building Type	Classrooms, Offices, Laboratories		
Number of Stories	14		
Total Floor Area (ft^2)	180,316		
Maintenance Area	# 1	Phone	845-1917

II. HVAC System Information

(1) General

Heating/Cooling Resources	CHW & HW Supplied From Central Plant Utilities			
HVAC System Types	4 DD-Dual Fan VAV AHUs 2 CV MZ Units (one in the basement & one on the 14th floor)			
EMCS Installed ?	Yes	X	No	
EMCS Type(s)	Siemens DDC			

AHU #	Type					Control	Supply Fan HP	Comment
	DD	SD	VAV	CV	Reheat			
AHU 407,421	X		X			DDC		
AHU 907,921	X		X			DDC		
AHU 14	X			X		DDC		14th floor
FCU-1		X		X		DDC		

(2) Control Schedule & Settings in EMCS Programs

1) Cold Deck (CD) Control Schedule

AHU #		Temperature (°F)			Remark
AHU 407,421	T_{OA}	55	100		
	$T_{setpoint}$	60	52		
AHU 907,921	T_{OA}	55	70		
	$T_{setpoint}$	60	55		
AHU 14	$T_{setpoint}$	55 (Constant)			
FCU 1	$T_{setpoint}$	55 (Constant Discharge Temperature)			
	T_{OA}				
	$T_{setpoint}$				

2) Hot Deck (HD) Control Schedule

AHU #	Temperature (^oF)				Remark
AHU 407,421	T_{OA}	50	70		
	$T_{setpoint}$	90	80		
AHU 907,921	T_{OA}	50	70		
	$T_{setpoint}$	90	80		
AHU 14	$T_{setpoint}$	85 (Constant)			
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				

3) Static Pressure (SP) Control Schedule

AHU #	Temp (^oF) vs. $SP_{setpoint}$ (in H_2O)				Night Setback				Remark	
AHU 407,421	T_{OA}	60	90		Time					
	SP	1.5	2.25		SP					
AHU 907	T_{OA}	60	70		Time	20:01	21:00	22:00	23:00	5:30
	SP	1.5	2.25		SP	0.8	0.7	0.6	0.4	end
AHU 921	T_{OA}	60	70		Time	This AHU had same schedule with AHU 907, but currently the command is "comment" mode.				
	SP	1.0	1.8		SP					
	T_{OA}				Time					
	SP				SP					
	T_{OA}				Time					
	SP				SP					
	T_{OA}				Time					
	SP				SP					

4) Building Differential Pressure (DP) Control Schedule

Pump System	Temp (^oF) vs. $DP_{setpoint}$ (psi)				Remark
2 CHWPs	T_{OA}	Both CHW & HW pumps are modulated to maintain the DP of AHU 14 on the 14th floor at their setpoint of 5 psi.			
	DP				
2 HWPs	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				

5) Typical Zone / Room Thermostat Setpoints

	Occupied Setpoints (°F)		Unoccupied Setpoints (°F)		Remark
	Heating	Cooling	Heating	Cooling	
Range	66 ~ 75	70 ~ 78	65 ~ 70	70 ~ 82	Total # of Thermostats : 436
Mainly	70	74	66	78	
Average	70.3	74.0	66.0	78.0	

6) Control of Outside Air (Including Freeze Protection)

:

(3) Existing System Operation Conditions (From EMCS & Field Visit)

1) Major Equipment Under Manual Operation Mode

:

2) Components With Problems

:

Table A.3: Building and HVAC System Information for the G.R. White Coliseum.

Building and HVAC System Information

I. Building Information

Building Name	***G.R. White Coliseum***		
Building Number	# 453		
Building Type	Offices & Indoor basketball court		
Number of Stories	2 stories and basketball coliseum		
Total Floor Area (ft^2)	177,838		
Maintenance Area	# 3	Phone	845-1331

II. HVAC System Information

(1) General

Heating/Cooling Resources	CHW & HW Supplied From Central Plant Utilities			
HVAC System Types	13 CV AHUs on DDC controls 5 SDCV AHUs with reheat coil (Pneumatic)			
EMCS Installed ?	Yes	X	No	
EMCS Type(s)	Siemens DDC Pneumatic			

AHU #	Type					Control	Supply Fan HP	Comment
	DD	SD	VAV	CV	Reheat			
1,2,3		X		X		DDC	5	
4 ~ 13		X		X		DDC	7.5	
A,B,C		X		X	X	Pneumatic	3 each	
D		X		X	X	Pneumatic	2	
E		X		X	X	Pneumatic	5	

(2) Control Schedule & Settings in EMCS Programs

1) Cold Deck (CD) Control Schedule

AHU #	Temperature (°F)				Remark
AHU 1~13	$T_{average}$	70	76		
	$T_{setpoint}$	76	68		
	$T_{average}$				
	$T_{setpoint}$				
	$T_{average}$				
	$T_{setpoint}$				

2) Hot Deck (HD) Control Schedule

AHU #	Temperature (^oF)				Remark
AHU 1~13	$T_{average}$	63	71		
	$T_{setpoint}$	76	65		
	$T_{average}$				
	$T_{setpoint}$				
	$T_{average}$				
	$T_{setpoint}$				
	$T_{average}$				
	$T_{setpoint}$				
	$T_{average}$				
	$T_{setpoint}$				
	$T_{average}$				
	$T_{setpoint}$				

3) Building Differential Pressure (DP) Control Schedule

Pump System	Temp (^oF) vs. $DP_{setpoint}$ (psi)						Remark
CHWP 1	DP	$DP = GPM^2 / 210^2 + 2$				12 psi (Oper. Mode)	For Arena
CHWP 3	GPM	0	240	480	720	15 psi (Oper. Mode)	For AHU A-E
	DP	15	15.9	18.6	23.2		
CHWP 5	T_{return}	44		54		15 psi (Oper. Mode)	For Fan-Coil
	DP	15		40			
	T_{OA}						
	DP						
	T_{OA}						
	DP						
	T_{OA}						
	DP						

4) Typical Zone / Room Thermostat Setpoints

Zone / Room #	Occupied Setpoints (^oF)		Unoccupied Setpoints (^oF)		Remark
	Heating	Cooling	Heating	Cooling	
Total 13 Zones	70	74	65	82	Same Setpoints

5) **Control of Outside Air (Including Freeze Protection)**

: Manual damper control

(3) Existing System Operation Conditions (From EMCS & Field Visit)

1) **Major Equipment Under Manual Operation Mode**

:

2) **Components With Problems**

:

Table A.4: Building and HVAC System Information for the Harrington Tower.

Building and HVAC System Information

I. Building Information

Building Name	***Harrington Tower***		
Building Number	# 435		
Building Type	Classrooms & Offices		
Number of Stories	8		
Total Floor Area (ft^2)	130,844		
Maintenance Area	# 3	Phone	845-1331

II. HVAC System Information

(1) General

Heating/Cooling Resources	CHW & HW Supplied From Central Plant Utilities			
HVAC System Types	1 - 200 hp DDVAV AHU 3 smaller SD AHUs for 1st floor			
EMCS Installed ?	Yes	X	No	
EMCS Type(s)	Siemens DDC			

AHU #	Type					Control	Supply Fan HP	Comment
	DD	SD	VAV	CV	Reheat			
Main AHU	X		X			DDC	200	Terminal reheat ?
AHU-1		X		X		DDC		
AHU-2		X		X		DDC		
AHU-3		X		X		DDC		

(2) Control Schedule & Settings in EMCS Programs

1) Cold Deck (CD) Control Schedule

Days	Temperature (°F)				Remark
Odd days					For Main AHU
	$T_{setpoint}$	55			
Odd nighs					
	$T_{setpoint}$	55			
Even days	Local Variable = Function of T_{oa} & Dew-Point for Optimizing Cold-Deck Temperature				
	$T_{setpoint}$	60 ~ 55			
Even nights	Local Variable = Function of T_{oa} & Dew-Point for Optimizing Cold-Deck Temperature				
	$T_{setpoint}$	65 ~ 60			
AHU 1,2,3	T_{OA}				
	$T_{setpoint}$	55 (Constant Discharge Temperature)			

2) Hot Deck (HD) Control Schedule

Days	Temperature (^{o}F)				Remark
Odd days	T_{OA}	40	70		
	$T_{setpoint}$	110	80		
Even days	T_{OA}	40	70		
	$T_{setpoint}$	100	70		
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				

3) Static Pressure (SP) Control Schedule

Day / Night	Temp (^{o}F) vs. $SP_{setpoint}$ (in H_2O)				Night Setback				Remark
Day	T_{OA}				Time				Constant pressure
	SP	1.2			SP				
Night	T_{OA}				Time				Constant pressure
	SP	0.75			SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				

4) Building Differential Pressure (DP) Control Schedule

Pump System	Temp (^{o}F) vs. $DP_{setpoint}$ (psi)				Remark
CHWP	T_{OA}				
	DP				
HWP	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				

5) Typical Zone / Room Thermostat Setpoints

	Occupied Setpoints (^oF)		Unoccupied Setpoints (^oF)		Remark
	Heating	Cooling	Heating	Cooling	
Range	66 ~ 76	68 ~ 77	65 ~ 73	68 ~ 82	Total # of Thermostats : 157
Mainly	70	73	70	75	
Average	70.5	72.4	69.9	74.2	

6) Control of Outside Air (Including Freeze Protection)

: Economizer is working based on 6 days mode operation.

Mode 1 & 2 have no economizer cycle.

Mode 3 & 4 have temperature economizer.

Mode 3 : Occu.(4:00-24:00) - Economizer working in the range of Toa between 37 F ~ 58 F

: Unoccu.(24:00-4:00) - Economizer working in the range of Toa between 50F~60F

Mode 4 : Occu.(4:00-24:00) - Economizer working in the range of Toa between 37 F ~ 60 F

: Unoccu.(24:00-4:00) - Economizer working in the range of Toa between 50F~65F

Mode 5 & 6 have enthalpy economizer.

Mode 5 : Occu.(4:00-24:00) - Economizer working between Toa of 37F and return air enthalpy

: Unoccu.(24:00-4:00) - Economizer working between Toa of 50Fand return air enthalpy

Mode 6 : Occu.(4:00-24:00) - Economizer working between Toa of 37F and return air enthalpy

: Unoccu.(24:00-4:00) - Economizer working between Toa of 50Fand return air enthalpy

(3) Existing System Operation Conditions (From EMCS & Field Visit)

1) Major Equipment Under Manual Operation Mode

:

2) Components With Problems

:

Table A.5: Building and HVAC System Information for the Kleberg Building.

Building and HVAC System Information

I. Building Information

Building Name	***Kleberg Building***		
Building Number	# 1501		
Building Type	Classrooms, Offices, Laboratories		
Number of Stories	4		
Total Floor Area (ft^2)	165,031		
Maintenance Area	# 5	Phone	845-5544

II. HVAC System Information

(1) General

Heating/Cooling Resources	CHW & HW Supplied From Central Plant Utilities			
HVAC System Types	2 x 100 hp SDVAV AHUs with pr-heat and terminal box reheat 2 x 25 hp return air fans			
EMCS Installed ?	Yes	X	No	
EMCS Type(s)	Siemens DDC			

AHU #	Type					Control	Supply Fan HP	Comment
	DD	SD	VAV	CV	Reheat			
AHU-1		X	X			DDC	100	Fan-powered boxes with terminal reheat
AHU-2		X	X			DDC	100	
AHU-3		X		X	X	DDC	25	
AHU-4		X		X	X	DDC	25	

(2) Control Schedule & Settings in EMCS Programs

1) Cold Deck (CD) Control Schedule

AHU #	Temperature (^oF)				Remark
AHU-1	T_{OA}	40	70		
	$T_{setpoint}$	65	55		
AHU-2	T_{OA}	40	70		
	$T_{setpoint}$	65	55		
AHU-3	T_{OA}	CHW & HW Valves are controlled by Return Air Temperature Setpoint.			
	$T_{setpoint}$				
AHU-4	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				

2) Static Pressure (SP) Control Schedule

AHU #	Temp (^oF) vs. $SP_{setpoint}$ (in H_2O)				Night Setback				Remark
AHU-1	T_{OA}				Time				
	SP	1.8	1.8		SP				
AHU-2	T_{OA}				Time				
	SP	1.8	1.8		SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				

3) Building Differential Pressure (DP) Control Schedule

Pump System	Temp (^oF) vs. $DP_{setpoint}$ (psi)				Remark
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				Near Power Plant
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				

4) Typical Zone / Room Thermostat Setpoints

Zone / Room #	Occupied Setpoints (^oF)		Unoccupied Setpoints (^oF)		Remark
	Heating	Cooling	Heating	Cooling	

5) Control of Outside Air (Including Freeze Protection)

a. There is a CO_2 sensor in return air side, which gives the signal to open OA damper when the CO_2 level exceeds 1000 ppm.

b. If the mixing air temperature is less than 35 ^oF, then HWP-1 turns on.

c. If outside air temperature is lower than 40 ^oF, then preheat control valve is open.

(3) Existing System Operation Conditions (From EMCS & Field Visit)

1) Major Equipment Under Manual Operation Mode

:

2) Components With Problems

:

Table A.6: Building and HVAC System Information for the Koldus Building.

Building and HVAC System Information

I. Building Information

Building Name	***Koldus Building***		
Building Number	# 379		
Building Type	Offices		
Number of Stories	2		
Total Floor Area (ft^2)	97,920		
Maintenance Area	# 3	Phone	845-1331

II. HVAC System Information

(1) General

Heating/Cooling Resources	CHW & HW Supplied From Central Plant Utilities			
HVAC System Types	5 SDVAV AHUs 5 SDCV AHUs for kitchen and electrical room and other areas			
EMCS Installed ?	Yes	X	No	
EMCS Type(s)	Siemens DDC			

AHU #	Type					Control	Supply Fan HP	Comment
	DD	SD	VAV	CV	Reheat			
LB-1,2,3,4,5		X	X			DDC		Terminal Reheat
LB-6,7,8,9		X		X		DDC		Small Units
AHP 51		X		X		DDC		Small Unit

(2) Control Schedule & Settings in EMCS Programs

1) Cold Deck (CD) Control Schedule

AHU #	Temperature (°F)				Remark
LB 1,2,3,4,5	T_{OA}	55	85		
	$T_{setpoint}$	60	55		
LB 6,8,9					
	$T_{setpoint}$	65 (Constant Discharge Temperature)			
LB 7					
	$T_{setpoint}$	69 (Constant Discharge Temperature)			
AHP 51	T_{OA}				Failed on Apogee
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				

2) Static Pressure (SP) Control Schedule

AHU #	Temp (^oF) vs. $SP_{setpoint}$ (in H_2O)				Night Setback				Remark
LB 2,3,4,5	T_{OA}	55	85		Time				
	SP	0.6	0.9		SP				
LB 1	T_{OA}	55	85		Time				
	SP	1.0	1.5		SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				

3) Building Differential Pressure (DP) Control Schedule

Pump System	Temp (^oF) vs. $DP_{setpoint}$ (psi)				Remark
2 CHWPs	DP	CWSP = 0.0057*GPM^2/100+1			10 psi on Apogee
		Min CWSP = 9 psi			
2 HWPs					15 psi on Apogee
	DP				
	DP				
	DP				
	DP				
	DP				

4) Typical Zone / Room Thermostat Setpoints

Zone / Room #	Occupied Setpoints (^oF)		Unoccupied Setpoints (^oF)		Remark
	Heating	Cooling	Heating	Cooling	
All	70	74	65	82	

5) Control of Outside Air (Including Freeze Protection)

: If outside air temperature is lower than 62 °F, economizer is "ON" and OA damper starts moving.

(3) Existing System Operation Conditions (From EMCS & Field Visit)

1) Major Equipment Under Manual Operation Mode

:

2) Components With Problems

:

Table A.7: Building and HVAC System Information for the Richardson Building.

Building and HVAC System Information

I. Building Information

Building Name	***Richardson Petroleum Building***		
Building Number	# 387		
Building Type	Classrooms & Offices		
Number of Stories	10		
Total Floor Area (ft^2)	113,700		
Maintenance Area	# 2	Phone	845-1427

II. HVAC System Information

(1) General

Heating/Cooling Resources	CHW & HW Supplied From Central Plant Utilities			
HVAC System Types	7 SDVAV AHUs 2 SDCV AHUs			
EMCS Installed ?	Yes	X	No	
EMCS Type(s)	Siemens DDC			

AHU #	Type					Control	Supply Fan HP	Comment
	DD	SD	VAV	CV	Reheat			
AHU 2,3,4,6,8,9,10		X	X			DDC		
AHU 1		X		X	X	DDC		Computer Lab.
AHU B		X		X		DDC		

(2) Control Schedule & Settings in EMCS Programs

1) Cold Deck (CD) Control Schedule

AHU #	Temperature (°F)				Remark
AHU 2,3,4,6,8,9	SPD (mA)	4 ~ 9	12	18 ~ 20	Speed range is from 4 to 20 mA
	$T_{setpoint}$	60	55	54	
AHU 10	SPD (mA)	4 ~ 9	12	18 ~ 20	
	$T_{setpoint}$	60	57	58	
AHU 1					
	$T_{setpoint}$	55 (Constant Discharge Temperature)			
AHU B	T_{OA}				
	$T_{setpoint}$	62 (Constant Discharge Temperature)			
	T_{OA}				
	$T_{setpoint}$				

2) Static Pressure (SP) Control Schedule

AHU #	Speed (mA) vs. $SP_{setpoint}$ (in H_2O)				Night Setback				Remark
AHU 2,3,4,6,8,9	SPD	4~12	12~15	15~20	Time				Speed range is from 4 to 20 mA
	SP	0.4	0.5	0.6	SP				
AHU 10	SPD	4~12	12~15	15~20	Time				
	SP	1.2	1.2	1.2	SP				
	SPD				Time				
	SP				SP				
	SPD				Time				
	SP				SP				
	SPD				Time				
	SP				SP				
	SPD				Time				
	SP				SP				

3) Building Differential Pressure (DP) Control Schedule

Pump System	Temp (°F) vs. $DP_{setpoint}$ (psi)				Remark
CHWP	T_{OA}				
	DP	10 psi (Constant Setpoint)			
HWP	T_{OA}				
	DP	15 psi (Constant Setpoint)			
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				

4) Typical Zone / Room Thermostat Setpoints

Zone / Room #	Occupied Setpoints (°F)		Unoccupied Setpoints (°F)		Remark
	Heating	Cooling	Heating	Cooling	

5) Control of Outside Air (Including Freeze Protection)

: Pumps of AHUs 1,2,3,4,6,8,9 are On-line pumps, which are "ON" when Toa is 35 °F and "OFF" when Toa is 37 °F.

(3) Existing System Operation Conditions (From EMCS & Field Visit)

1) Major Equipment Under Manual Operation Mode

:

2) Components With Problems

:

Table A.8: Building and HVAC System Information for the VMC Addition.

Building and HVAC System Information

I. Building Information

Building Name	***V.M.C. Addition (Research Tower)***		
Building Number	# 1197		
Building Type	Classrooms, Offices, Laboratories		
Number of Stories	5		
Total Floor Area (ft^2)	114,666		
Maintenance Area	# 5	Phone	845-5544

II. HVAC System Information

(1) General

Heating/Cooling Resources	CHW & HW Supplied From Central Plant Utilities			
HVAC System Types	5 SDVAV AHUs 4 out of 5 AHUs are 100% OA with Heat Recovery Coils			
EMCS Installed ?	Yes	X	No	
EMCS Type(s)	*Siemens DDC*			

AHU #	Type					Control	Supply Fan HP	Comment
	DD	SD	VAV	CV	Reheat			
AHU 1,2,3,4,5		X	X			DDC		Terminal Reheat

(2) Control Schedule & Settings in EMCS Programs

1) Cold Deck (CD) Control Schedule

AHU #	Temperature (^oF)				Remark
AHU 1,3	T_{OA}	55	85		
	$T_{setpoint}$	62	53		
AHU 2	T_{OA}	55	85		
	$T_{setpoint}$	64	57		
AHU 4,5	T_{OA}	55	85		
	$T_{setpoint}$	62	55		
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				

2) Static Pressure (SP) Control Schedule

AHU #	Temp (°F) vs. $SP_{setpoint}$ (in H_2O)				Night Setback				Remark
AHU 1	T_{OA}				Time				
	SP		1.6		SP				
AHU 2	T_{OA}				Time				
	SP		1.8		SP				
AHU 3	T_{OA}				Time				
	SP		1.42		SP				
AHU 4	T_{OA}				Time				
	SP		1.35		SP				
AHU 5	T_{OA}				Time				
	SP		1.25		SP				
	T_{OA}				Time				
	SP				SP				

3) Building Differential Pressure (DP) Control Schedule

Pump System	Temp (°F) vs. $DP_{setpoint}$ (psi)				Remark
2 CHWPs	T_{OA}	70	90		
	DP	14	18		
2 HWPs	T_{OA}				
	DP	10 psi (Constant Setpoint)			
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				

4) Typical Zone / Room Thermostat Setpoints

	Occupied Setpoints (°F)		Unoccupied Setpoints (°F)		Remark
	Heating	Cooling	Heating	Cooling	
Range	51 ~ 72	65 ~ 74	56 ~ 65	70 ~ 82	Total # of Thermostats : 93
Mainly	70	72	65	82	
Average	68.8	72.4	64.9	81.7	

5) Control of Outside Air (Including Freeze Protection)

: For freeze protection, HWPs are "ON" when T_{oa} is 35 ^{o}F and "OFF" when T_{oa} is 40 ^{o}F.

(3) Existing System Operation Conditions (From EMCS & Field Visit)

1) Major Equipment Under Manual Operation Mode

:

2) Components With Problems

:

Table A.9: Building and HVAC System Information for the Wehner Building.

Building and HVAC System Information

I. Building Information

Building Name	***Wehner CBA***		
Building Number	# 1506		
Building Type	Classrooms & Offices		
Number of Stories	4		
Total Floor Area (ft^2)	192,001		
Maintenance Area	# 5	Phone	845-5544

II. HVAC System Information

(1) General

Heating/Cooling Resources	CHW & HW Supplied From Central Plant Utilities			
HVAC System Types	6 DDVAV AHUs 3 SDVAV AHUs with fan-powered terminal units			
EMCS Installed ?	Yes	X	No	
EMCS Type(s)	Siemens DDC			

AHU #	Type					Control	Supply Fan HP	Comment
	DD	SD	VAV	CV	Reheat			
AHU-1A,1E,1W		X	X			DDC		
AHU-2E,2W, 3E,3W,4E,4W	X		X			DDC		

(2) Control Schedule & Settings in EMCS Programs

1) Cold Deck (CD) Control Schedule

AHU #	Temperature (°F)				Remark
AHU-2E,2W, 3E,3W,4E,4W	T_{OA}	50	80		
	$T_{setpoint}$	62	55		
AHU 1A	Room Temp.	65	75		Discharge Temperature Settings
	$T_{setpoint}$	73	71		
AHU 1E	Room Temp.	60	80		
	$T_{setpoint}$	62	55		
AHU 1W	Room Temp.	60	80		
	$T_{setpoint}$	62	55		
	T_{OA}				
	$T_{setpoint}$				

2) Hot Deck (HD) Control Schedule

AHU #	Temperature (°F)				Remark
AHU-2E,2W, 3E,3W,4E,4W	T_{OA}	40	70		
	$T_{setpoint}$	100	70		
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				

3) Static Pressure (SP) Control Schedule

AHU #	Temp (°F) vs. $SP_{setpoint}$ (in H_2O)				Night Setback				Remark
AHU 1E,1W,2E,2W	T_{OA}				Time				
	SP	1.0			SP				
AHU 3E,3W,4E,4W	T_{OA}				Time				
	SP	2.0			SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				

4) Building Differential Pressure (DP) Control Schedule

Pump System	Temp (°F) vs. $DP_{setpoint}$ (psi)				Remark
2 CHWPs	T_{OA}				
	DP	8 psi			
2 HWPs	T_{OA}				
	DP	4 psi			
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				

5) Typical Zone / Room Thermostat Setpoints

	Occupied Setpoints (^oF)		Unoccupied Setpoints (^oF)		Remark
	Heating	Cooling	Heating	Cooling	
Range	66 ~ 73	68 ~ 75	65 ~ 68	70 ~ 82	Total # of Thermostats : 184
Mainly	70	73	65	82	
Average	69.5	71.7	65.1	80.7	

6) Control of Outside Air (Including Freeze Protection)

: Preheat pumps are "ON" when OA temperature is 36 ^oF or below and "OFF" when OA temperature is greater than 38 ^oF.

(3) Existing System Operation Conditions (From EMCS & Field Visit)

1) Major Equipment Under Manual Operation Mode

:

2) Components With Problems

:

Table A.10: Building and HVAC System Information for the Zachry Building.

Building and HVAC System Information

I. Building Information

Building Name	***Zachry Engineering Center***		
Building Number	# 518		
Building Type	Classrooms, Offices, Laboratories		
Number of Stories	5		
Total Floor Area (ft^2)	258,600		
Maintenance Area	# 2	Phone	845-1427

II. HVAC System Information

(1) General

Heating/Cooling Resources	CHW & HW Supplied From Central Plant Utilities			
HVAC System Types	12 DD-Dual Fan VAV AHUs 3 SDCV AHUs			
EMCS Installed ?	Yes	X	No	
EMCS Type(s)	Siemens DDC			

AHU #	Type					Control	Supply Fan HP	Comment
	DD	SD	VAV	CV	Reheat			
AHU 1,2,3,4,5, 6,7,8,9,10,11,12	X		X			DDC	40 each	
AHU 21,22,23		X		X		DDC		2nd Floor

(2) Control Schedule & Settings in EMCS Programs

1) Cold Deck (CD) Control Schedule

AHU #	Temperature (°F)				Remark
AHU 1,2,4,5, 6,7,8,9,10,11,12	T_{OA}	55	90		
	$T_{setpoint}$	60	54		
AHU 3	T_{OA}	55	80		
	$T_{setpoint}$	58	54		
AHU 21,22,23	T_{OA}				
	$T_{setpoint}$	70 (Constant Discharge Temperature)			
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				

2) Hot Deck (HD) Control Schedule

AHU #	Temperature (^oF)				Remark
AHU 1,2,3,4,5, 6,7,8,9,10,11,12	T_{OA}	55	70		
	$T_{setpoint}$	90	70		
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				
	T_{OA}				
	$T_{setpoint}$				

3) Static Pressure (SP) Control Schedule

AHU #	Temp (^oF) vs. $SP_{setpoint}$ (in H_2O)				Night Setback				Remark
AHU 2,4,5, 7,8,9,10,11,12,	T_{OA}	55	80		Time				
	SP	1.0	2.0		SP				
AHU 1	T_{OA}	55	73		Time				
	SP	1.0	2.0		SP				
AHU 3	T_{OA}	55	80		Time				
	SP	1.5	2.0		SP				
AHU 6	T_{OA}	55	80		Time				
	SP	1.0	2.5		SP				
	T_{OA}				Time				
	SP				SP				
	T_{OA}				Time				
	SP				SP				

4) Building Differential Pressure (DP) Control Schedule

Pump System	GPM vs. $DP_{setpoint}$ (psi)				Remark
2 CHWPs	DP	$DP = GPM^2 / 131^2$			
		15 psi on Apogee (Oper. Mode)			
2 HWPs	T_{OA}	55	58		
	ON / OFF	ON	OFF		
	T_{OA}				
	DP				
	T_{OA}				
	DP				
	T_{OA}				
	DP				

5) Typical Zone / Room Thermostat Setpoints

	Occupied Setpoints (^oF)		Unoccupied Setpoints (^oF)		Remark
	Heating	Cooling	Heating	Cooling	
Range	62 ~ 76	64 ~ 78	62 ~ 75	72 ~ 82	Total # of Thermostats : 370
Mainly	71	73	62	82	
Average	70.8	72.9	62.8	81.7	

6) Control of Outside Air (Including Freeze Protection)

:

(3) Existing System Operation Conditions (From EMCS & Field Visit)

1) Major Equipment Under Manual Operation Mode

:

2) Components With Problems

:

APPENDIX B

Chilled Water and Hot Water Energy Use Models

Appendix B contains each year's chilled water and hot water energy use models for the 10 buildings for the periods of pre-CC (Baseline) and post-CC through year 2000. Table B.1 shows a summary of each model and also explains some feasible reasons for trends. Table B.2 contains model parameters and statistics. Figures B.1 through B.20 show the chilled water and hot water energy use models for 10 buildings.

Table B.1: A Summry of CHW and HW Energy Use Models and Savings for 10 Buildings.

Building Name	Type	Model Types Used	Savings after CC (%)				Comments
			'97	'98	'99	'00	
Blocker building	CHW	4P-CP	27	15	12	8	No chilled water and hot water models for year 2000 due to missing data. This building has only three month data, January, November and December. These months of data do not show reasonable trends.
	HW	3P-CP	53	81	62	50	
Eller O&M Building	CHW	4P-CP	38	39	38	34	These models depict fairly good persistence since CC was completed.
	HW	3P-CP	66	85	76	38	The periods, 5/1997-10/1997, 5/1998-11/1998, 5/1999-10/1999, and 7/2000-10/2000, have "0" hot water energy use.
G.R.White Coliseum	CHW	3P-CP	54	55	23	16	Two years after CC the chilled water and hot water energy uses increased. This building was malfunctioning and currently cooling and heating are fighting. The trends of the chilled water models for year 1999 and 2000 are not acceptable but were used for savings calculation.
	HW	3P-CP	71	97	77	52	
Harrington Tower	CHW	4P-CP	50	41	46	36	Year 2000 model shows a little more chilled water energy use in the temperature range between 30 - 50 °F than the other year's models have.
	HW	3P-CP	62	87	76	49	The model for 2000 was made with only one month data, January 2000. The other month's data are missing.
Kleberg Building	CHW	3P-CP	41	41	38	29	Chilled water models show that the chilled water consumption has increased yearly since CC.
	HW	3P-CP	84	97	80	74	Hot water consumptions were zero in every summer of 1997, 1998, 1999, and 2000.
Koldus Building	CHW	4P-CP	45	41	42	46	No chilled water data before CC; so every model after CC was compared to the 1997 model.
	HW	3P-CP	67	81	70	69	Hot water consumptions were zero in every summer of 1997, 1998, 1999, and 2000.
Rich. Petroleum	CHW	3P-CP	52	45	47	38	Chilled water energy consumptions have increased over time, but the models show fairly good persistence.
	HW	3P-CP	64	69	72	88	No hot water data before CC; so every model after CC was compared to the 1997 model. The data from 8/2000 to 12/2000 were all "0"; so the 2000 model is unusual.
VMC Addition	CHW	3P-CP	43	41	44	43	The chilled water energy savings have persisted since CC was completed.
	HW	3P-CP	75	43	41	43	Hot water savings for 1997 were exceptionally high. Hot water use a day was ranging from 0.1 - 0.3 MMBtu/Day between 2/1997 and 11/1997.
Wehner CBA	CHW	3P-CP	36	31	35	40	Chilled water savings have increased since CC activity.
	HW	3P-CP	19	27	51	53	Hot water energy use has decreased after CC was finished.
Zachry Building	CHW	4P-CP	59	57	56	50	On the whole, chilled water has been saved over time, but hot water savings showed big fluctuation. In the summer of 1998 and 2000 this building consumed much more energy than the other year's summer period.
	HW	3P-CP	79	58	71	44	

Table B.2: A Table for the Information of Energy Use Models that Involves Model Types, Three-Parameter Change or Four-Parameter Change Point Models, Model Parameters , and Statistics.

Building Name	Energy Type	Model Type	Year	Ycp	LS	RS	Xcp	R^2	RMSE	CV RMSE
Blocker	CHW	4P-CP	Baseline	63.0061	0.6980	2.1238	75.3820	0.54	14.5412	24.2%
			1997	40.0913	0.3125	1.6082	71.0380	0.44	12.7551	25.2%
			1998	46.3349	0.6078	1.5567	67.7640	0.54	13.3120	24.1%
			1999	51.0292	0.4829	1.1565	68.8660	0.49	11.3215	20.5%
			2000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	HW	3P-CP	Baseline	20.7566	-0.1655	0.0000	88.4140	0.06	9.8100	40.1%
			1997	0.0000	-1.0047	0.0000	78.6400	0.43	9.8400	168.8%
			1998	2.6400	-0.8757	0.0000	58.8720	0.17	8.1500	200.7%
			1999	1.0332	-0.4462	0.0000	87.3280	0.28	9.8300	108.1%
			2000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Eller O&M	CHW	4P-CP	Baseline	70.0160	0.7716	1.9658	64.5220	0.42	24.0906	28.8%
			1997	42.6854	0.4331	2.4375	71.0380	0.57	14.9012	26.6%
			1998	37.2655	0.6276	2.4280	67.1560	0.68	14.8923	28.6%
			1999	43.9494	0.6145	2.2005	69.9520	0.61	13.8436	27.6%
			2000	41.1108	0.2551	1.9936	65.6080	0.58	14.9134	26.7%
	HW	3P-CP	Baseline	3.5820	-0.8960	0.0000	88.4140	0.34	16.1600	87.2%
			1997	0.0000	-0.3895	0.0000	87.3280	0.21	9.4100	160.4%
			1998	0.5225	-0.6505	0.0000	65.0280	0.23	7.9800	270.0%
			1999	0.0000	-0.3302	0.0000	84.0700	0.29	6.9000	131.4%
			2000	0.0728	-0.7960	0.0000	85.1560	0.33	15.3200	118.3%
G.R. White	CHW	3P-CP	Baseline	38.8635	0.0000	0.7286	52.6200	0.21	12.9600	27.4%
			1997	16.4654	0.0000	1.1226	67.7800	0.56	8.1000	30.8%
			1998	13.5198	0.0000	1.2391	65.6080	0.48	10.5500	44.8%
			1999	44.7645	0.0000	-0.2930	53.6620	0.03	19.1500	48.0%
			2000	44.4863	0.0000	-0.4304	76.7320	0.01	17.9800	41.5%
	HW	3P-CP	Baseline	54.4475	-0.4630	0.0000	72.8080	0.12	12.0300	20.4%
			1997	8.0351	-0.4508	0.0000	88.4140	0.30	9.5800	63.0%
			1998	0.5709	-0.4099	0.0000	59.0920	0.19	4.3300	288.8%
			1999	2.3353	-0.5812	0.0000	88.4140	0.16	18.3300	135.6%
			2000	10.0806	-0.9172	0.0000	88.4360	0.29	19.0100	74.1%
Harrington Tower	CHW	4P-CP	Baseline	18.4888	0.0556	1.1712	52.8460	0.70	8.7469	25.2%
			1997	13.8290	0.3095	1.0962	67.7800	0.63	7.4702	38.6%
			1998	16.8813	0.5158	1.2493	67.1560	0.64	9.2989	39.6%
			1999	17.1942	0.2715	1.5437	73.2100	0.59	8.4634	40.0%
			2000	16.4897	0.2716	1.5009	68.0458	0.62	9.5762	37.9%
	HW	3P-CP	Baseline	4.9804	-0.9599	0.0000	83.2120	0.41	13.9300	75.6%
			1997	0.4346	-0.3489	0.0000	88.4140	0.20	9.5700	133.4%
			1998	1.3976	-0.5710	0.0000	57.5800	0.17	5.5700	227.6%
			1999	3.0145	-1.4737	0.0000	52.5760	0.29	7.1700	153.0%
			2000	6.6921	-1.7171	0.0000	56.5417	0.75	6.9600	37.7%

Building Name	Energy Type	Model Type	Year	Ycp	LS	RS	Xcp	R^2	RMSE	CV RMSE
Kleberg	CHW	3P-CP	Baseline	129.7029	0.0000	1.5598	48.8320	0.15	31.6500	21.8%
			1997	80.5380	0.0000	3.4612	72.1240	0.24	34.4400	36.0%
			1998	76.2818	0.0000	3.7286	70.2840	0.32	36.1900	36.3%
			1999	71.1613	0.0000	4.4607	67.7800	0.44	37.0000	33.2%
			2000	83.4304	0.0000	2.5394	59.0920	0.28	42.2400	36.7%
	HW	3P-CP	Baseline	104.7819	-0.9946	0.0000	71.8360	0.07	36.2800	30.4%
			1997	0.1576	-1.0359	0.0000	86.2420	0.21	27.6400	155.2%
			1998	4.5778	0.1977	0.0000	71.3460	0.11	5.2400	155.9%
			1999	11.3633	-4.6660	0.0000	59.0920	0.35	25.9300	149.2%
			2000	5.5329	-1.2237	0.0000	88.4140	0.20	34.2500	117.8%
Koldus	CHW	4P-CP	Baseline	n/a	n/a	n/a	n/a	n/a	n/a	n/a
			1997	23.6651	0.1321	0.9319	61.2640	0.59	7.5280	20.6%
			1998	24.1391	0.1612	1.2409	62.9000	0.74	7.2738	20.0%
			1999	29.3635	0.3226	1.2273	68.8660	0.66	7.4427	21.4%
			2000	23.9536	0.1915	0.7649	60.1780	0.53	7.8763	24.3%
	HW	3P-CP	Baseline	5.6277	-0.0386	0.0000	63.2840	0.02	2.2400	37.4%
			1997	0.0000	-0.1621	0.0000	79.7260	0.44	2.0600	103.9%
			1998	0.0319	-0.0938	0.0000	78.8600	0.43	1.2600	125.4%
			1999	0.1004	-0.0853	0.0000	88.4140	0.35	1.6000	87.2%
			2000	0.1062	-0.0871	0.0000	88.4140	0.31	1.7900	100.6%
Rich. Pertoleum	CHW	3P-CP	Baseline	77.4038	0.0000	0.2230	74.3100	0.02	4.5800	5.7%
			1997	25.1161	0.0000	1.8736	67.7800	0.62	10.7300	27.9%
			1998	23.1531	0.0000	1.7634	60.7720	0.68	11.9500	27.5%
			1999	21.6462	0.0000	1.9596	62.3500	0.69	12.3200	29.2%
			2000	27.3230	0.0000	1.8251	60.1780	0.45	18.7100	33.8%
	HW	3P-CP	Baseline	n/a	n/a	n/a	n/a	n/a	n/a	n/a
			1997	8.1443	-0.7304	0.0000	81.8980	0.38	11.6900	73.1%
			1998	7.1159	-0.6807	0.0000	79.9240	0.40	10.0500	66.9%
			1999	8.5638	-0.3775	0.0000	82.9840	0.28	7.7500	56.7%
			2000	7.5316	0.3074	0.0000	67.7800	0.03	9.1400	132.3%
VMC Addition	CHW	3P-CP	Baseline	100.0292	0.0000	1.8944	68.2480	0.17	24.1200	19.3%
			1997	21.9141	0.0000	4.1272	62.3500	0.65	28.1900	44.4%
			1998	21.7759	0.0000	3.8092	60.1780	0.67	26.5500	39.7%
			1999	28.4349	0.0000	4.7382	66.6940	0.69	24.5600	39.4%
			2000	24.5845	0.0000	3.6338	61.2640	0.60	28.5600	44.7%
	HW	3P-CP	Baseline	4.5874	-0.2645	0.0000	88.8560	0.04	8.0600	122.0%
			1997	0.1557	-0.1689	0.0000	81.8980	0.20	4.3700	179.7%
			1998	1.8335	-0.2966	0.0000	80.8120	0.51	3.7000	66.8%
			1999	0.4659	-0.3122	0.0000	81.8980	0.42	4.7100	99.3%
			2000	0.3392	-0.3918	0.0000	81.8980	0.33	7.1800	127.2%
Wehner	CHW	3P-CP	Baseline	40.9478	0.0000	0.7765	55.8160	0.37	9.2000	15.9%
			1997	20.8922	0.0000	1.2837	62.3500	0.64	8.9700	26.6%
			1998	27.2346	0.0000	1.1774	65.6080	0.51	9.5000	25.8%
			1999	23.3629	0.0000	1.0929	62.3500	0.59	8.5900	25.1%
			2000	20.1977	0.0000	0.9345	59.0920	0.52	9.2500	29.1%
	HW	3P-CP	Baseline	56.6959	-0.2475	0.0000	64.9500	0.07	4.5400	12.3%
			1997	20.4127	-0.6176	0.0000	84.0700	0.22	15.5800	52.3%
			1998	11.4917	-1.1939	0.0000	80.8120	0.51	14.7800	56.0%
			1999	9.2251	-0.4588	0.0000	88.4140	0.52	6.1400	33.8%
			2000	13.9109	-0.2930	0.0000	79.7260	0.16	8.1700	46.9%

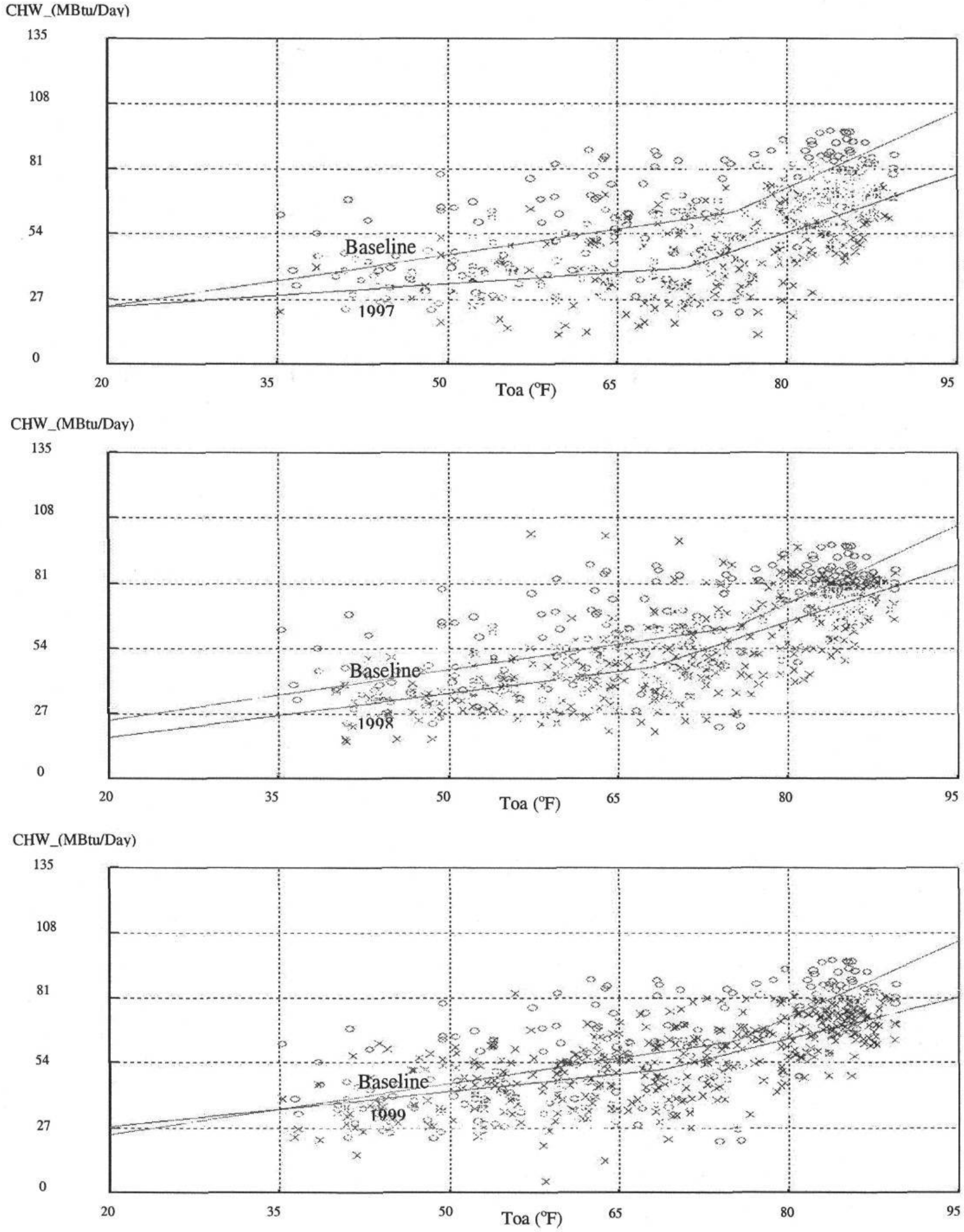


Figure B.1: The Blocker Building Chilled Water Use Models for the Periods of 1996 (Baseline) and 1997-1999.

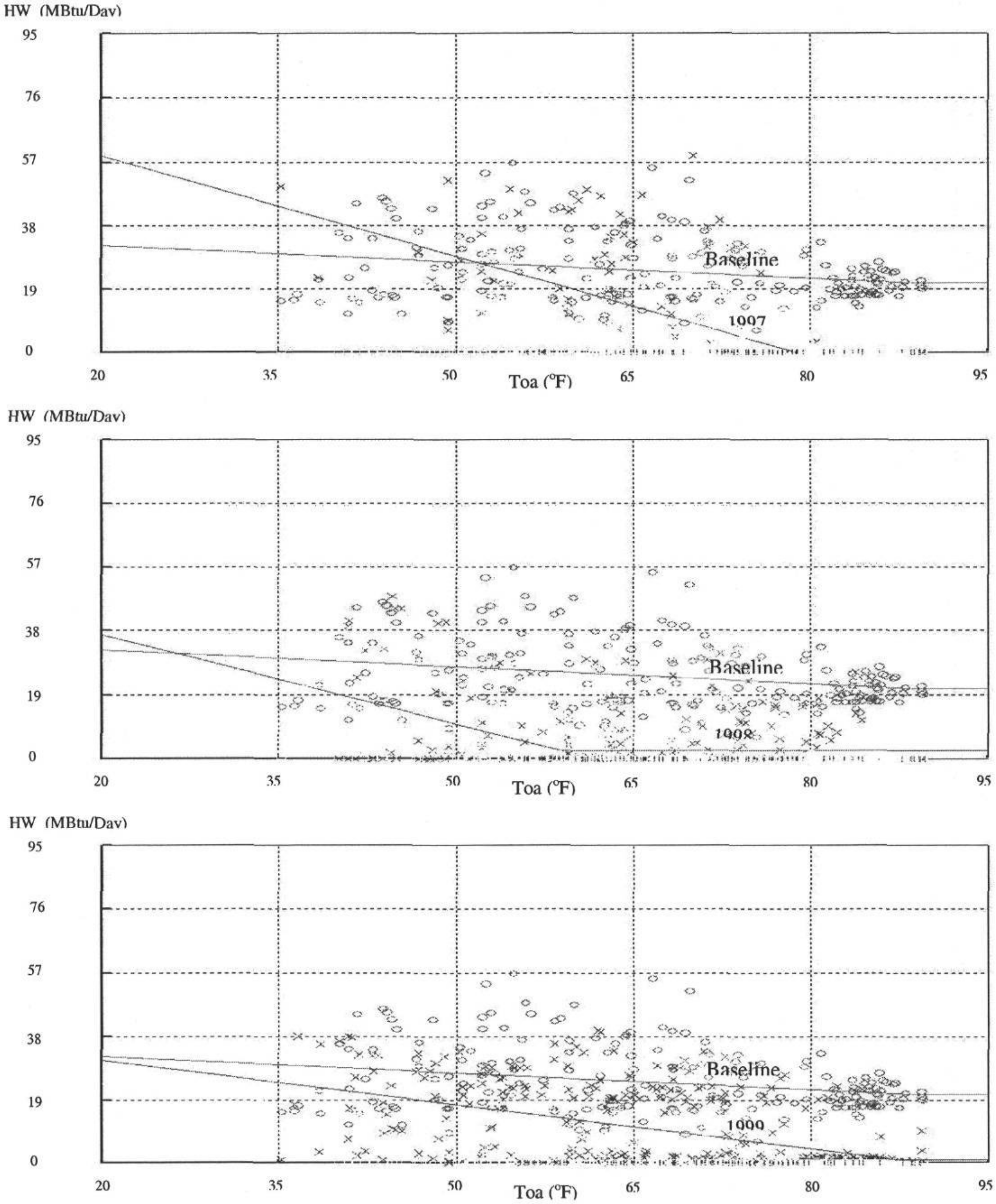


Figure B.2: The Blocker Building Hot Water Use Models for the Periods of 1996 (Baseline) and 1997-1999.

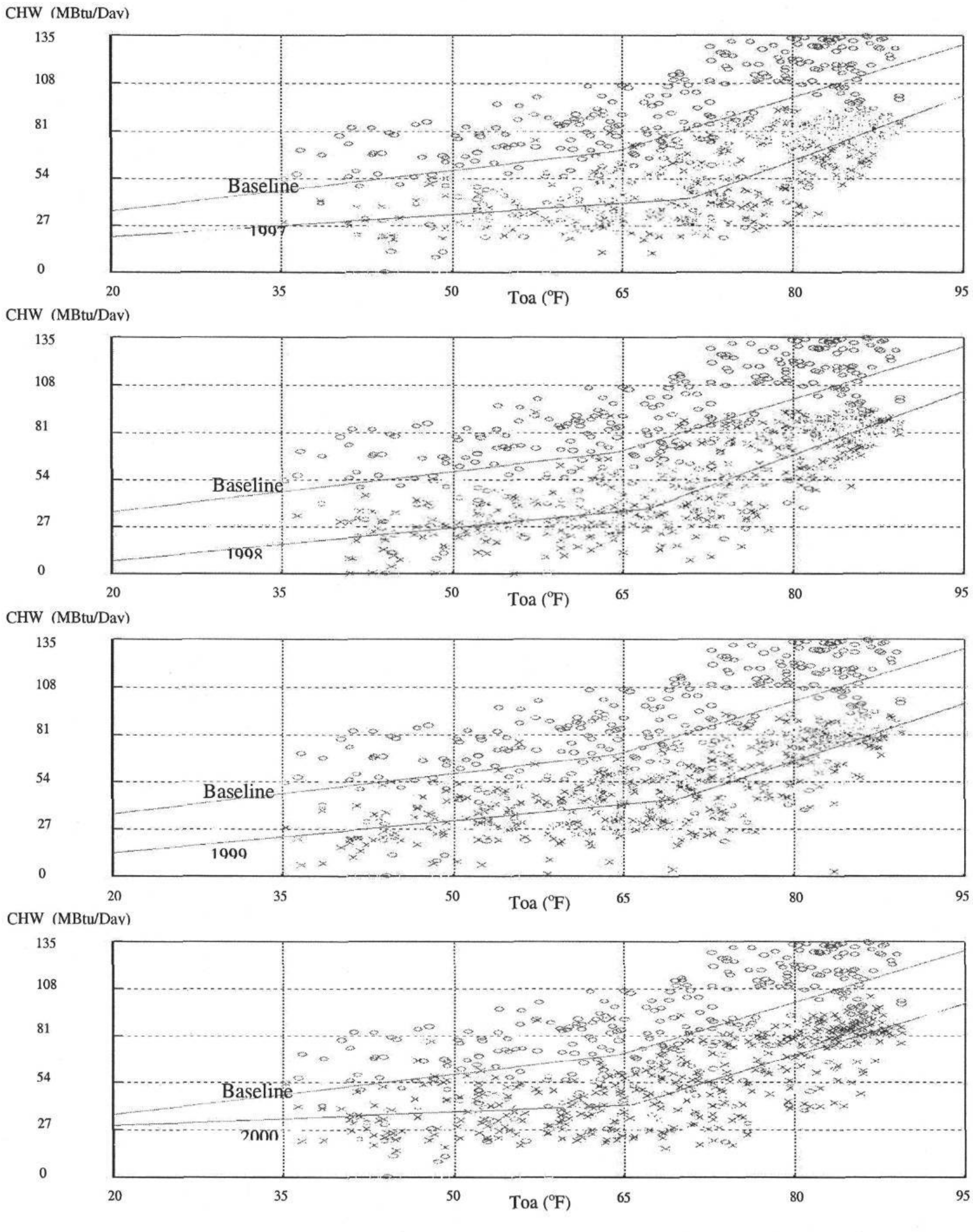


Figure B.3: The Eller O&M Building Chilled Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

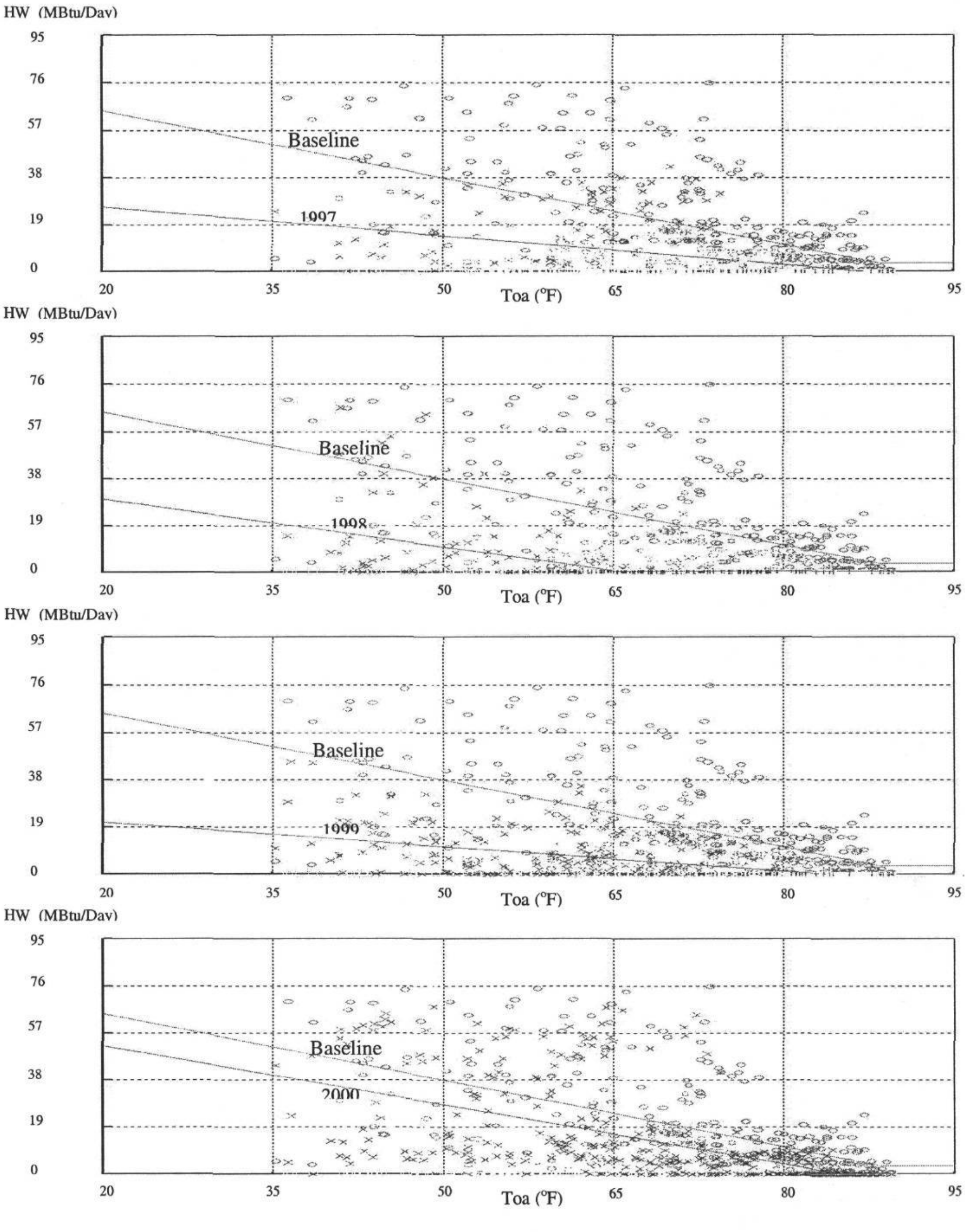


Figure B.4: The Eller O&M Building Hot Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

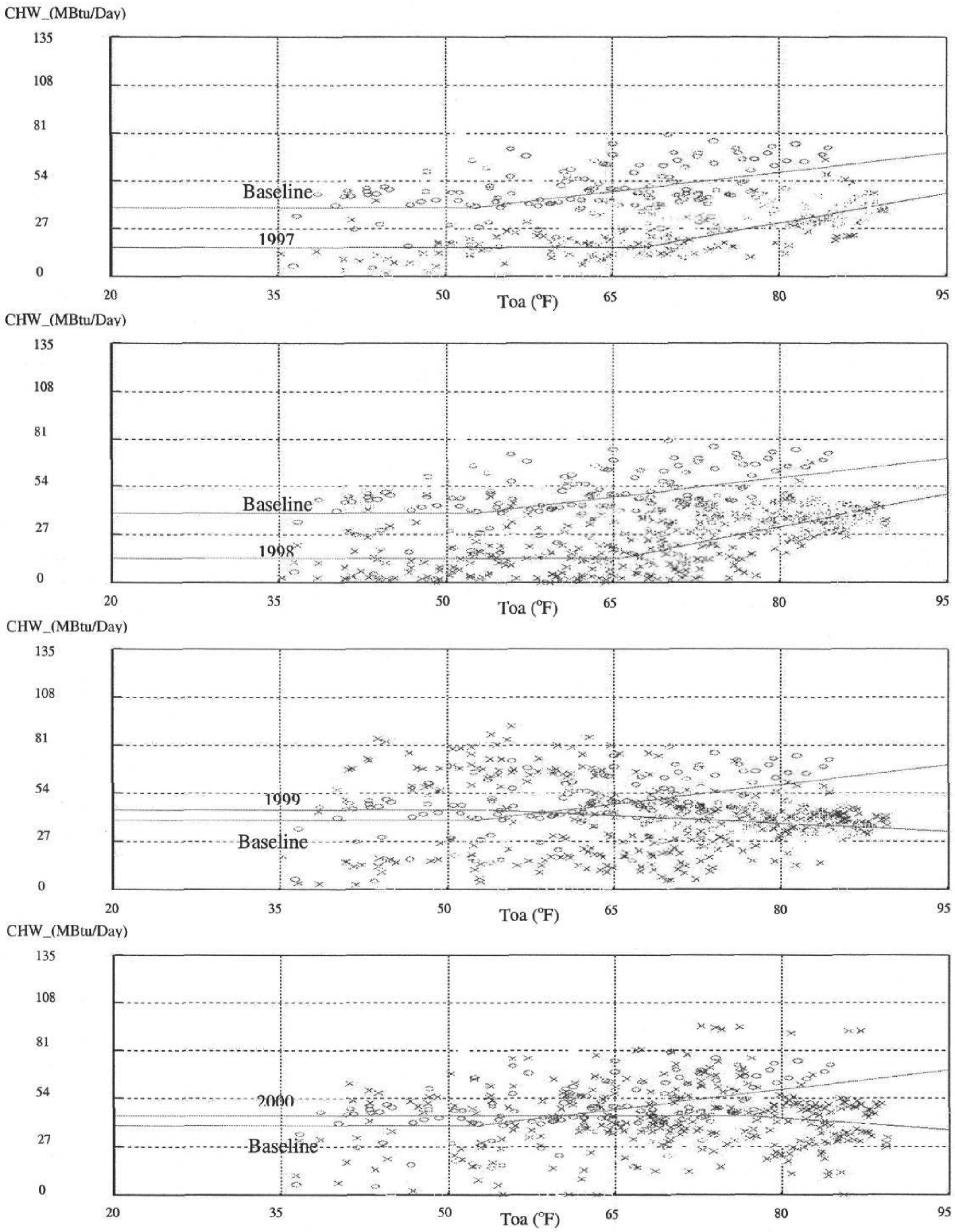


Figure B.5: The G.R. White Colleseum Chilled Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

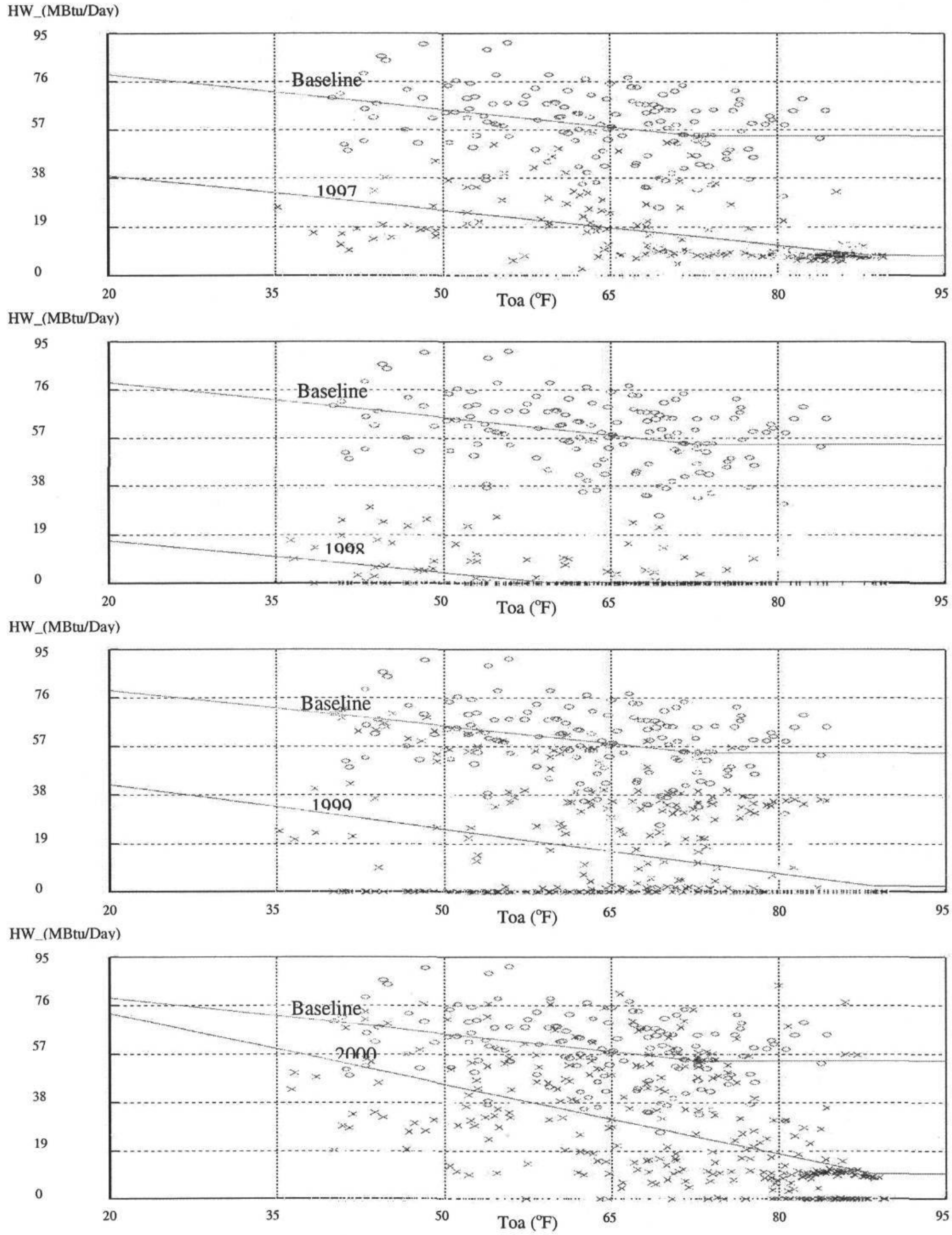


Figure B.6: The G.R. White Colleseum Hot Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

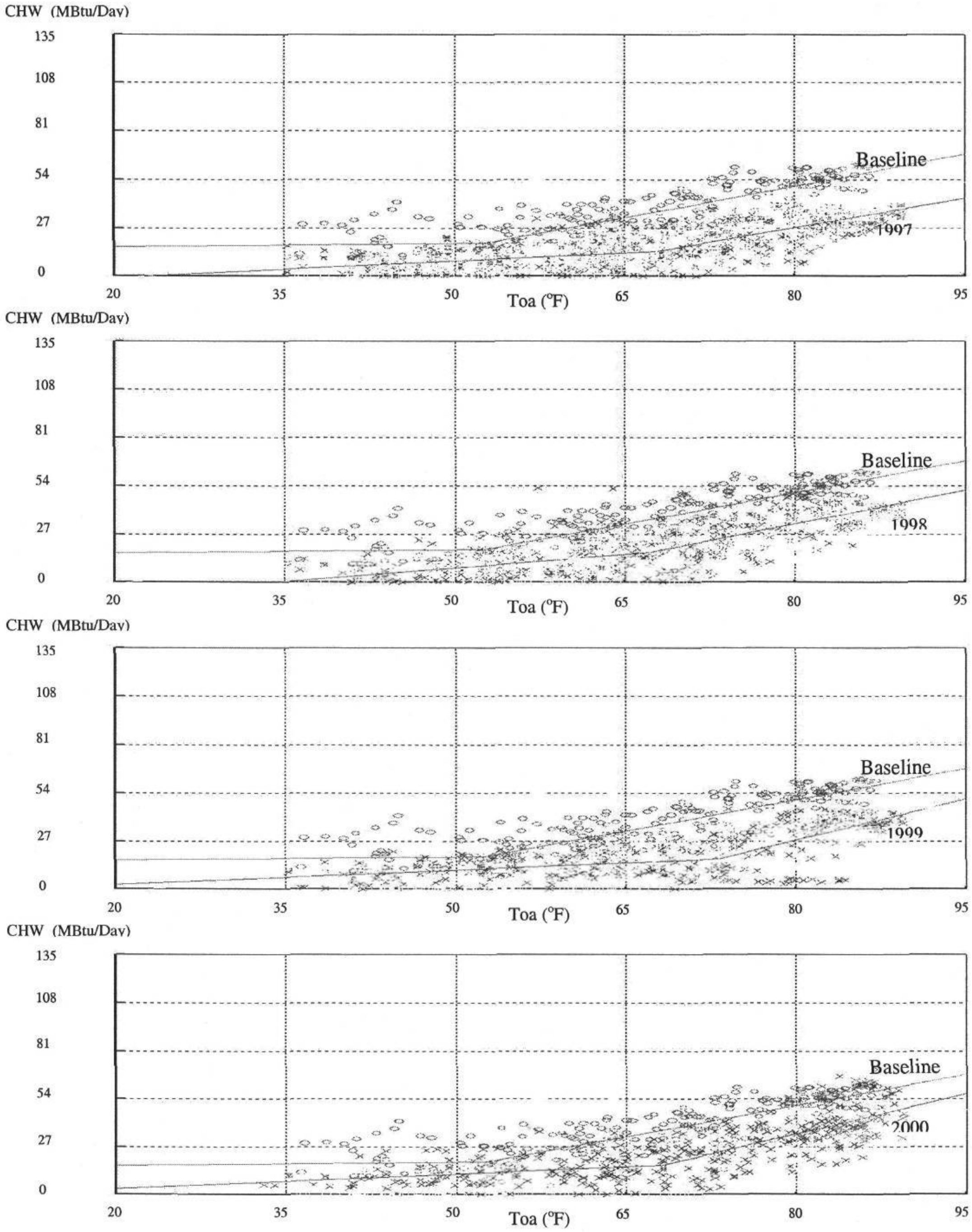


Figure B.7: The Harrington Tower Chilled Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

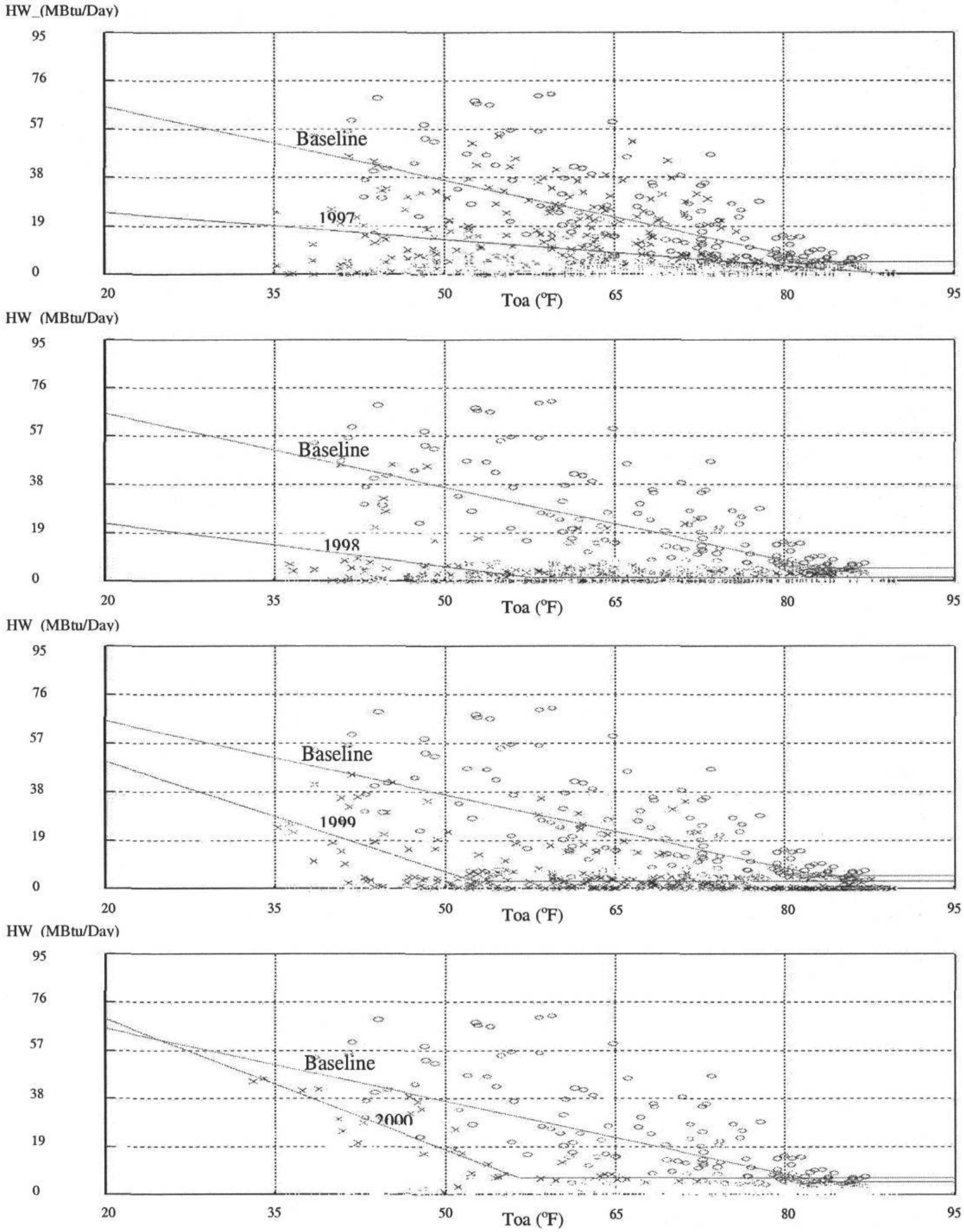


Figure B.8: The Harrington Tower Hot Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

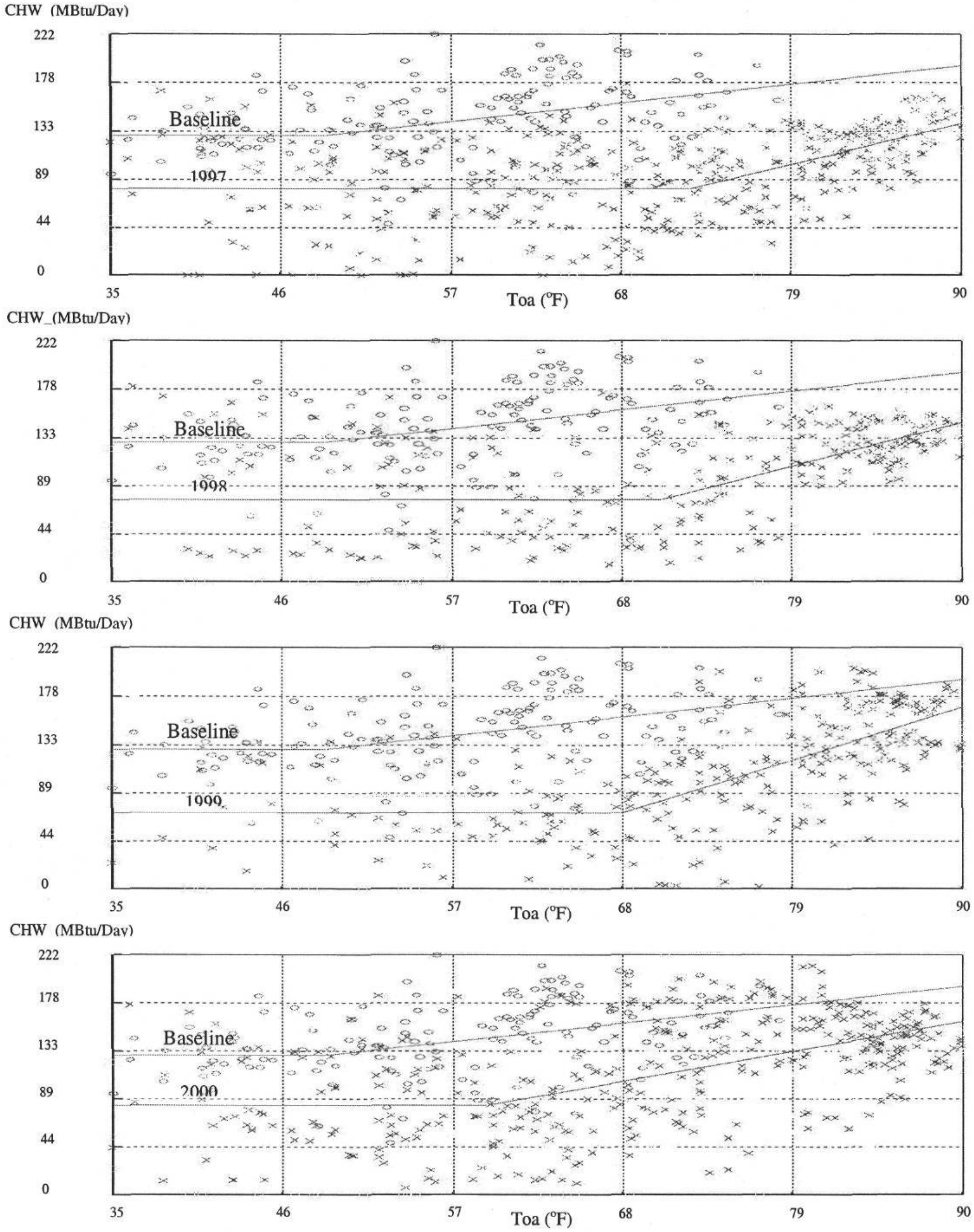


Figure B.9: The Kleberg Building Chilled Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

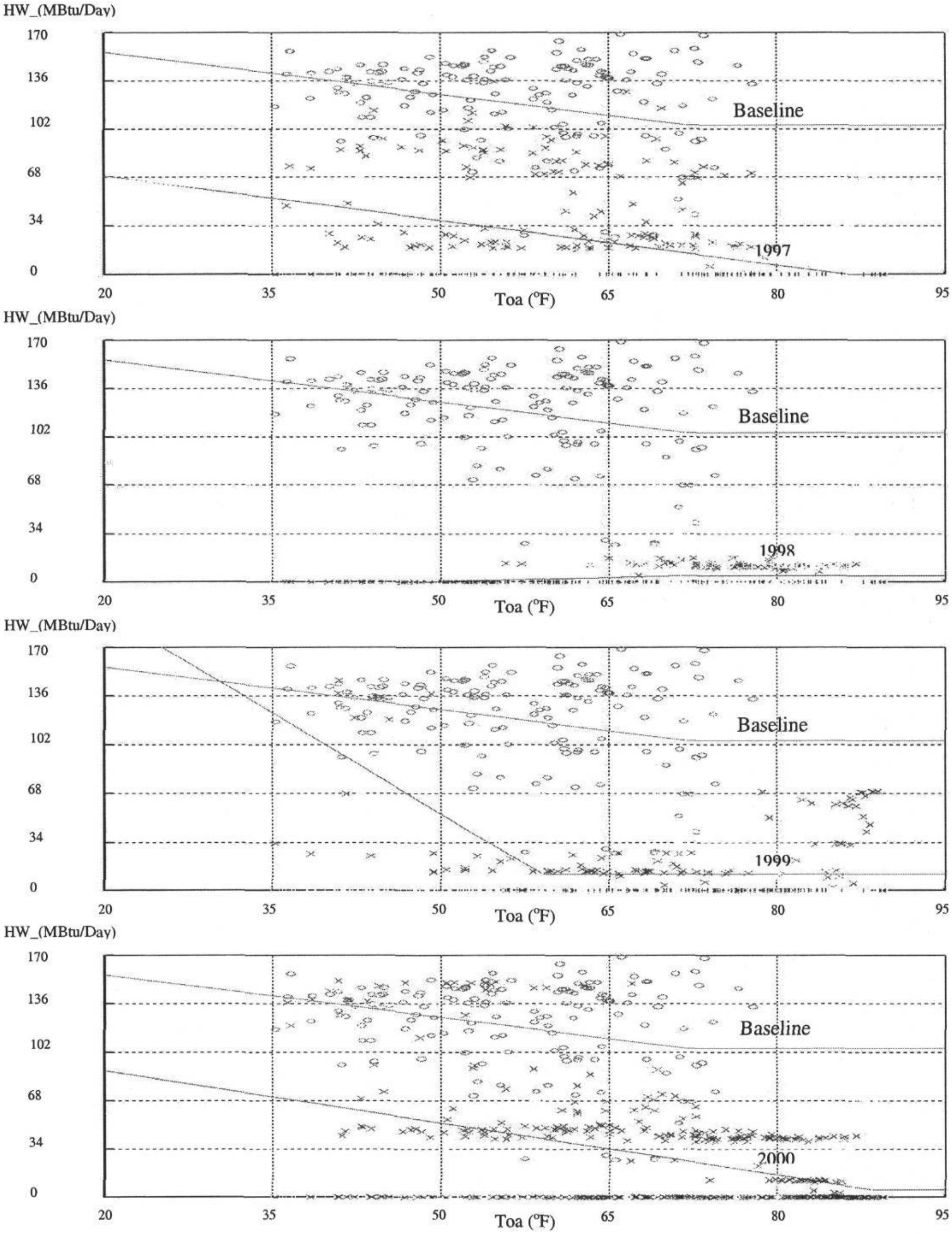


Figure B.10: The Kleberg Building Hot Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

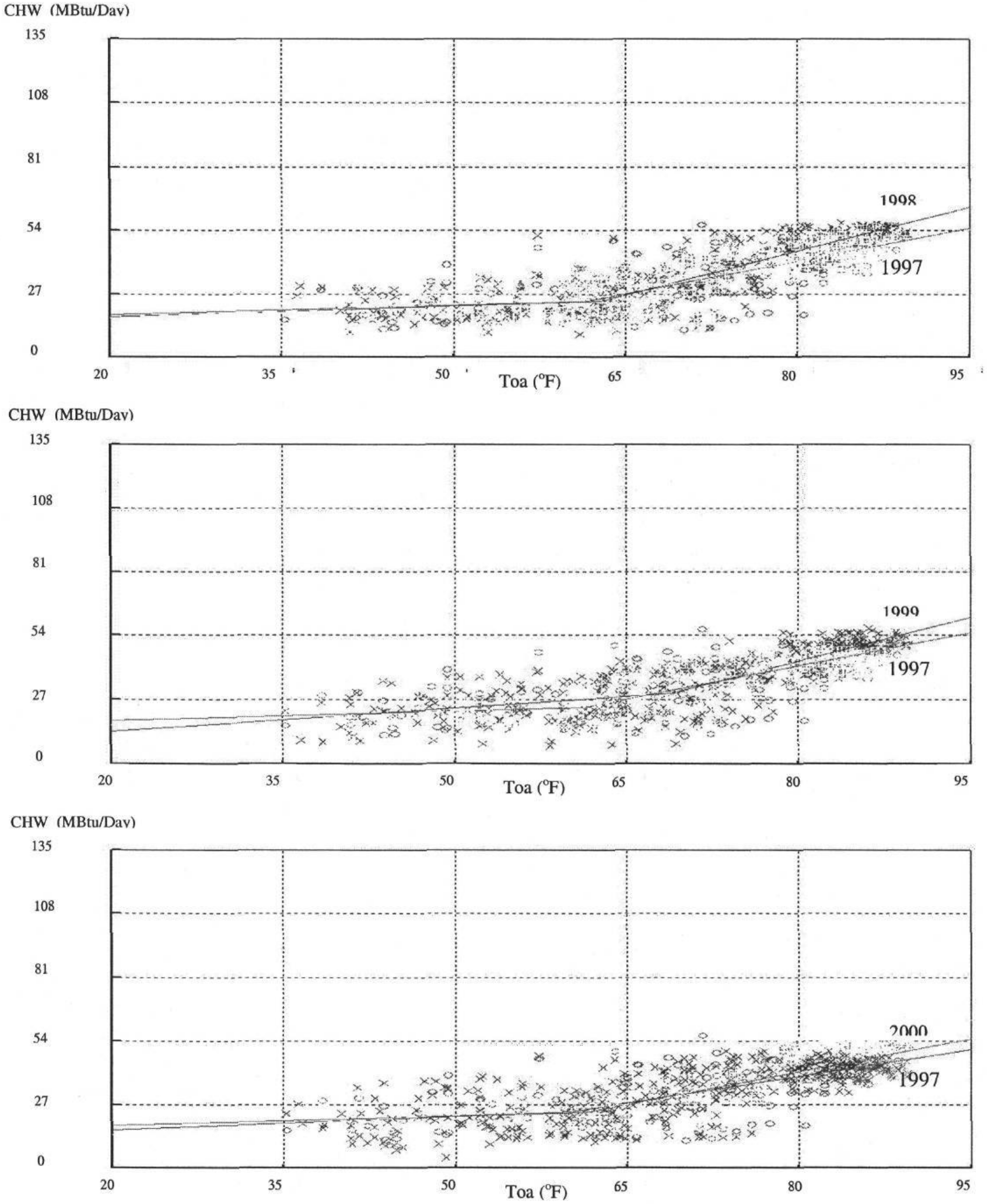


Figure B.11: The Koldus Building Chilled Water Use Models for the Periods of 1997-2000.

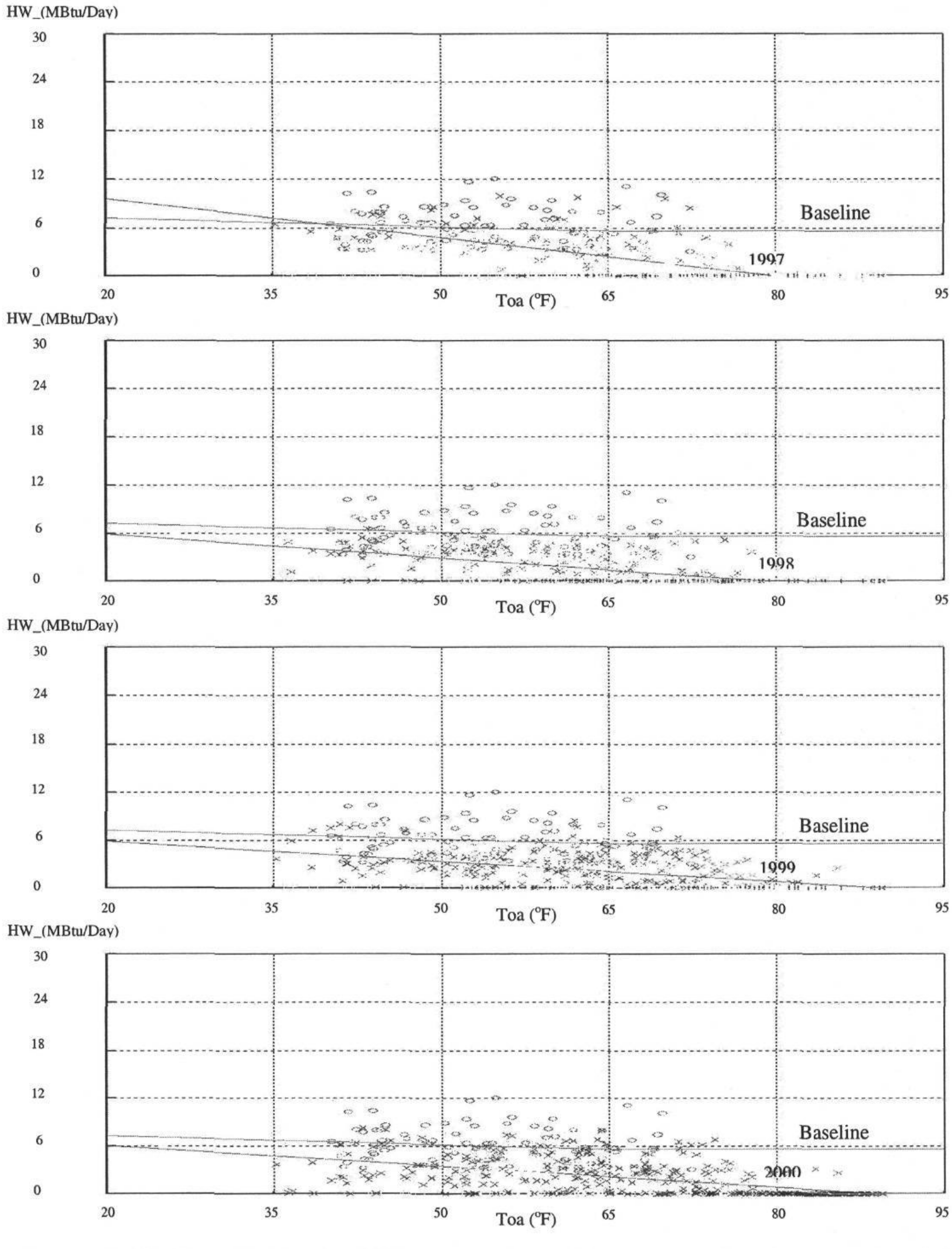


Figure B.12: The Koldus Building Hot Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

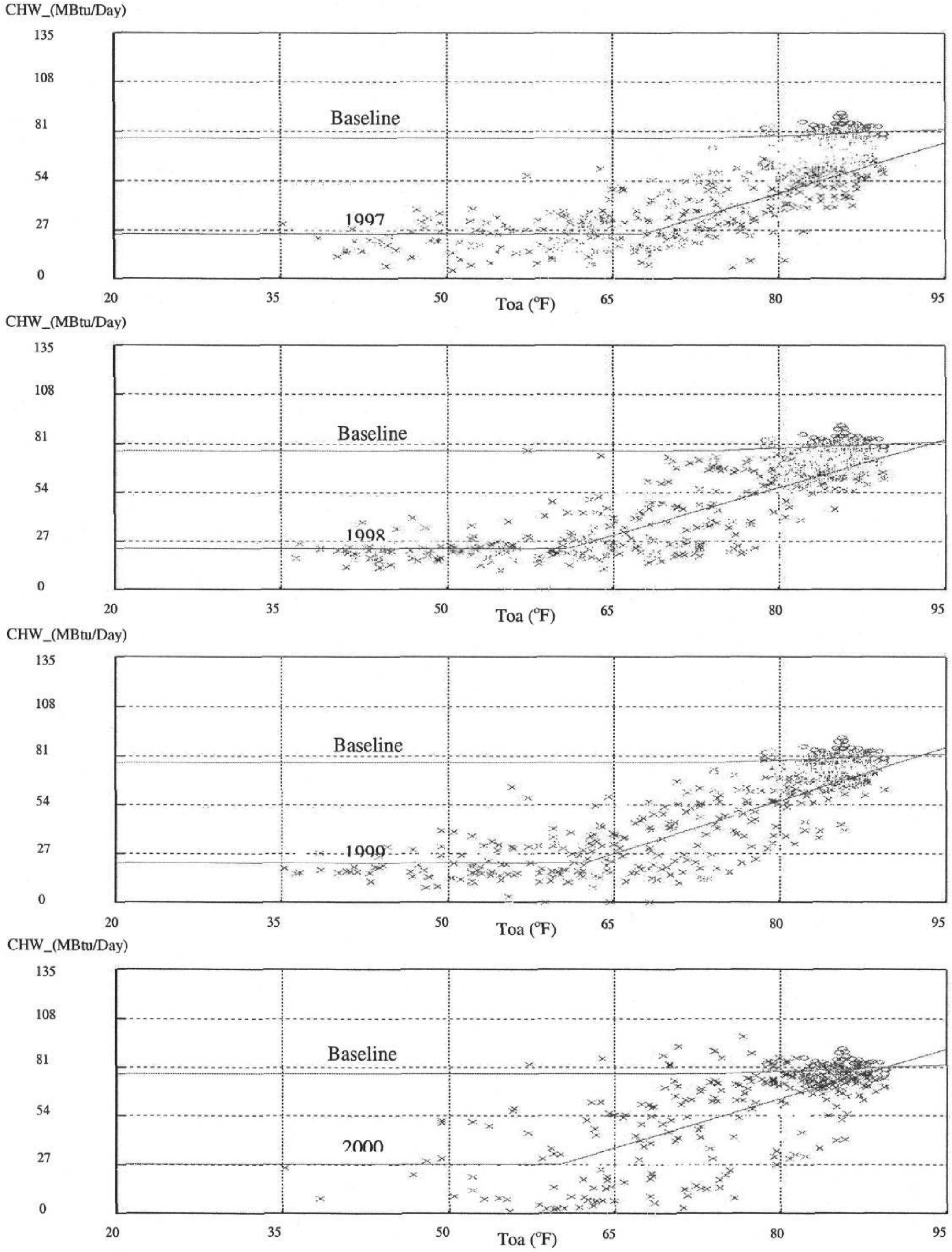


Figure B.13: The Richardson Building Chilled Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

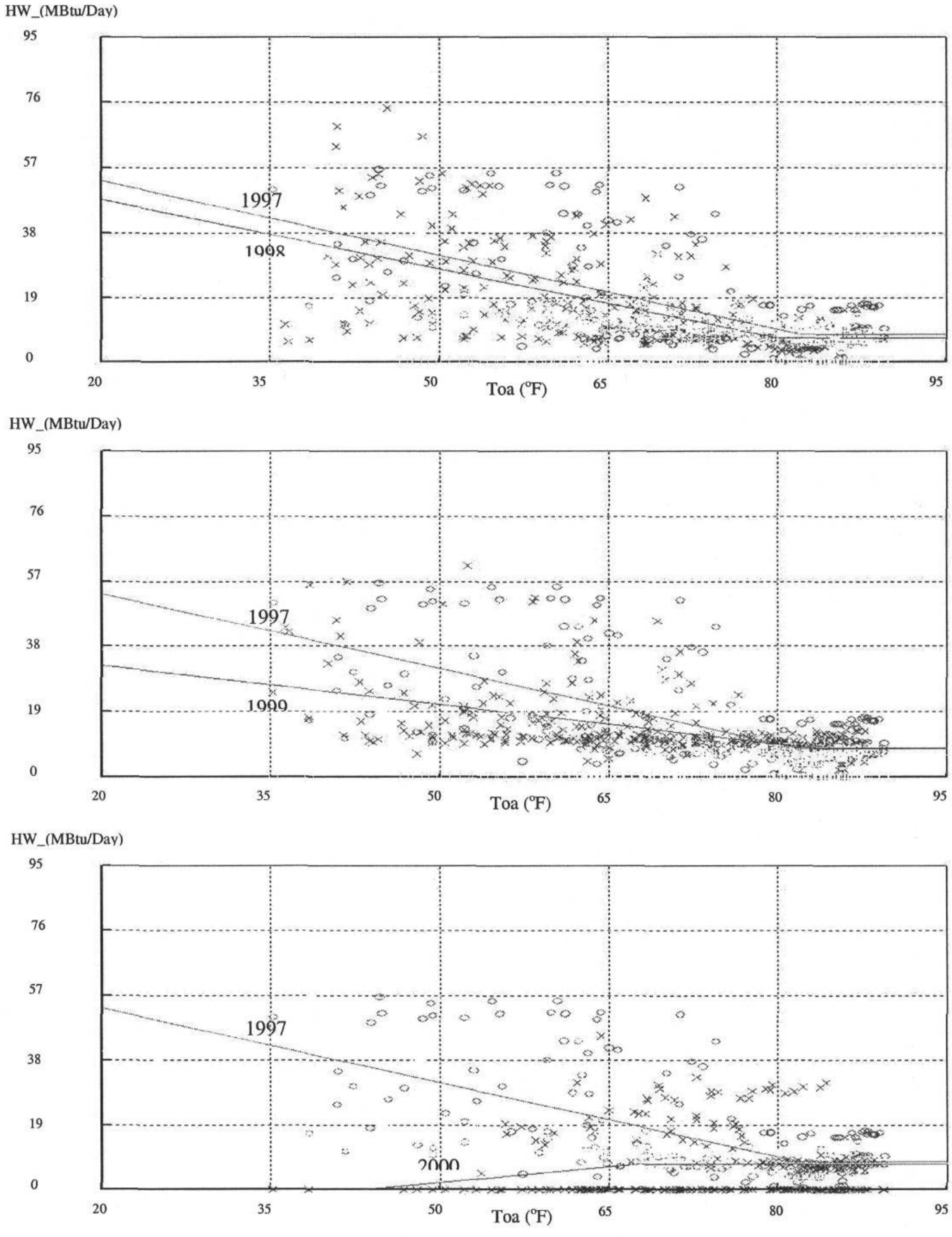


Figure B.14: The Richardson Building Hot Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

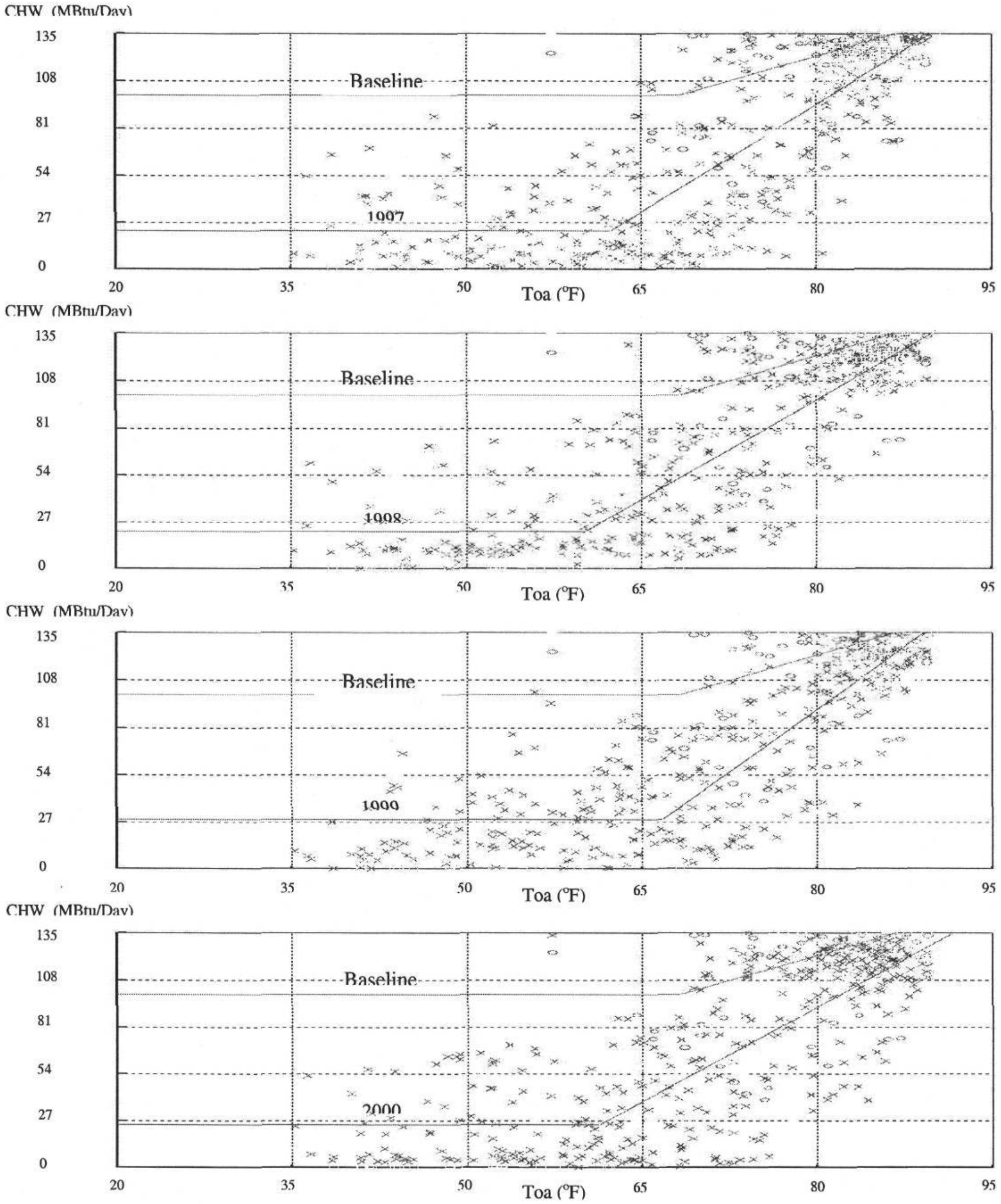


Figure B.15: The VMC Addition Chilled Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

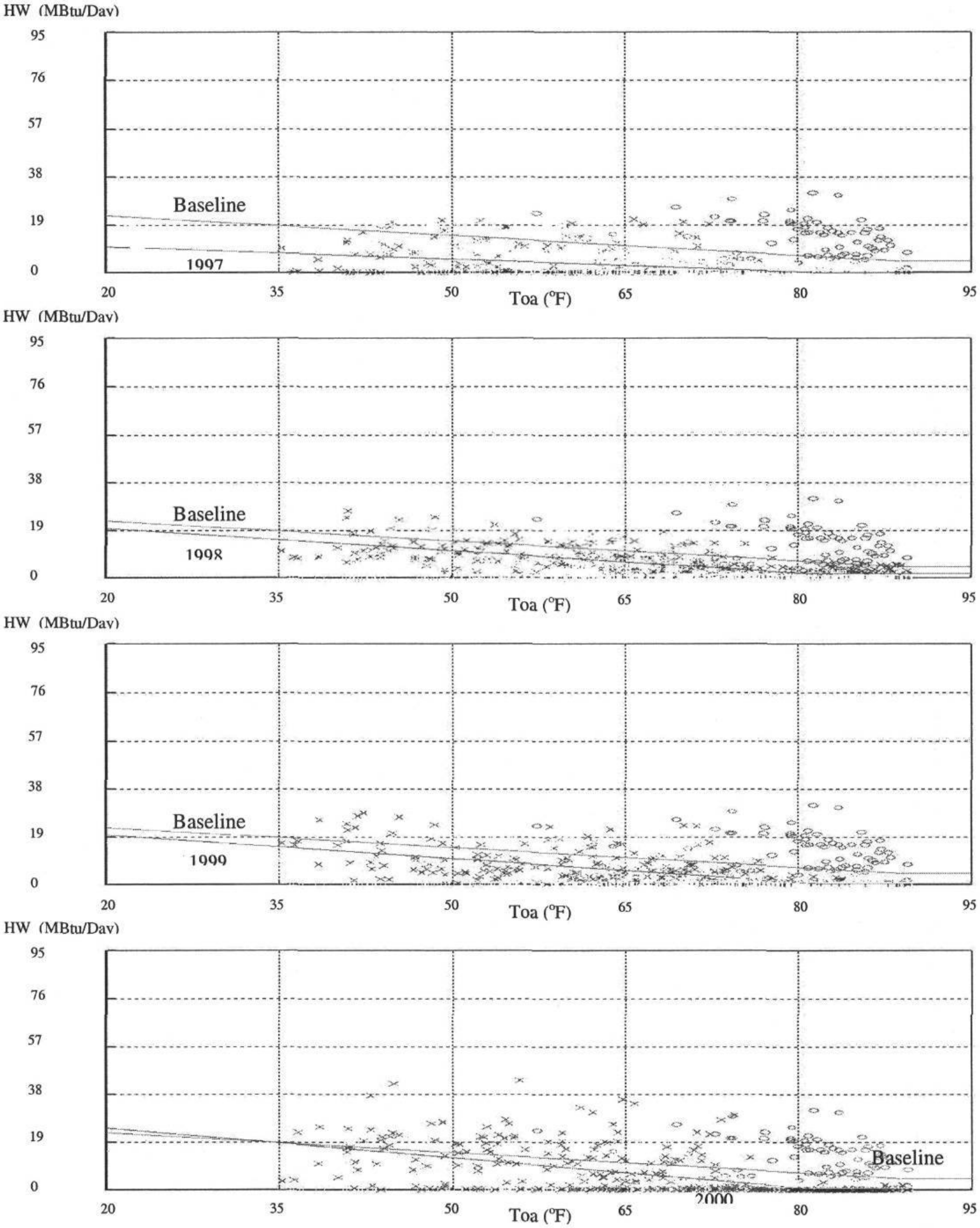


Figure B.16: The VMC Addition Hot Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

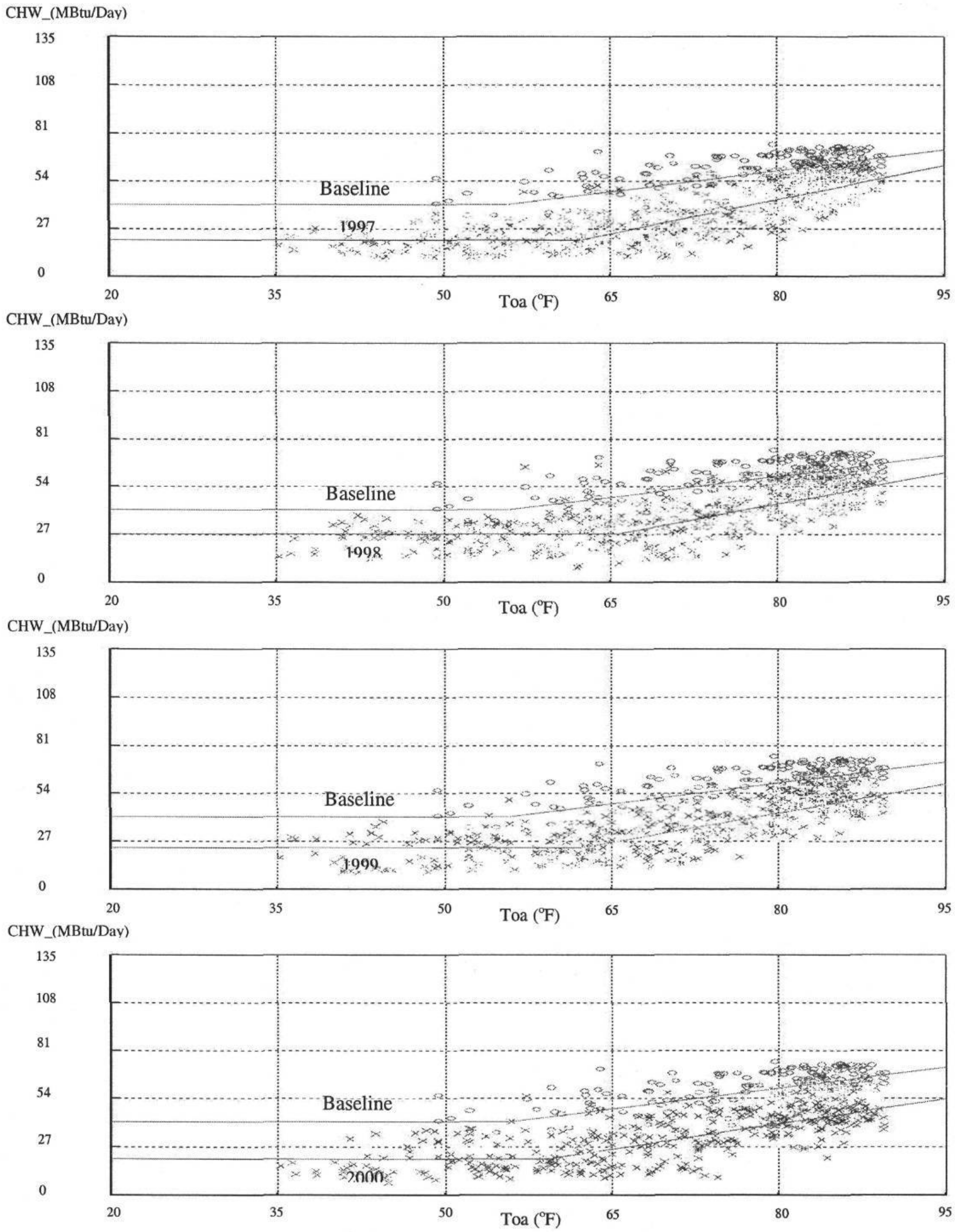


Figure B.17: The Wehner Building Chilled Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

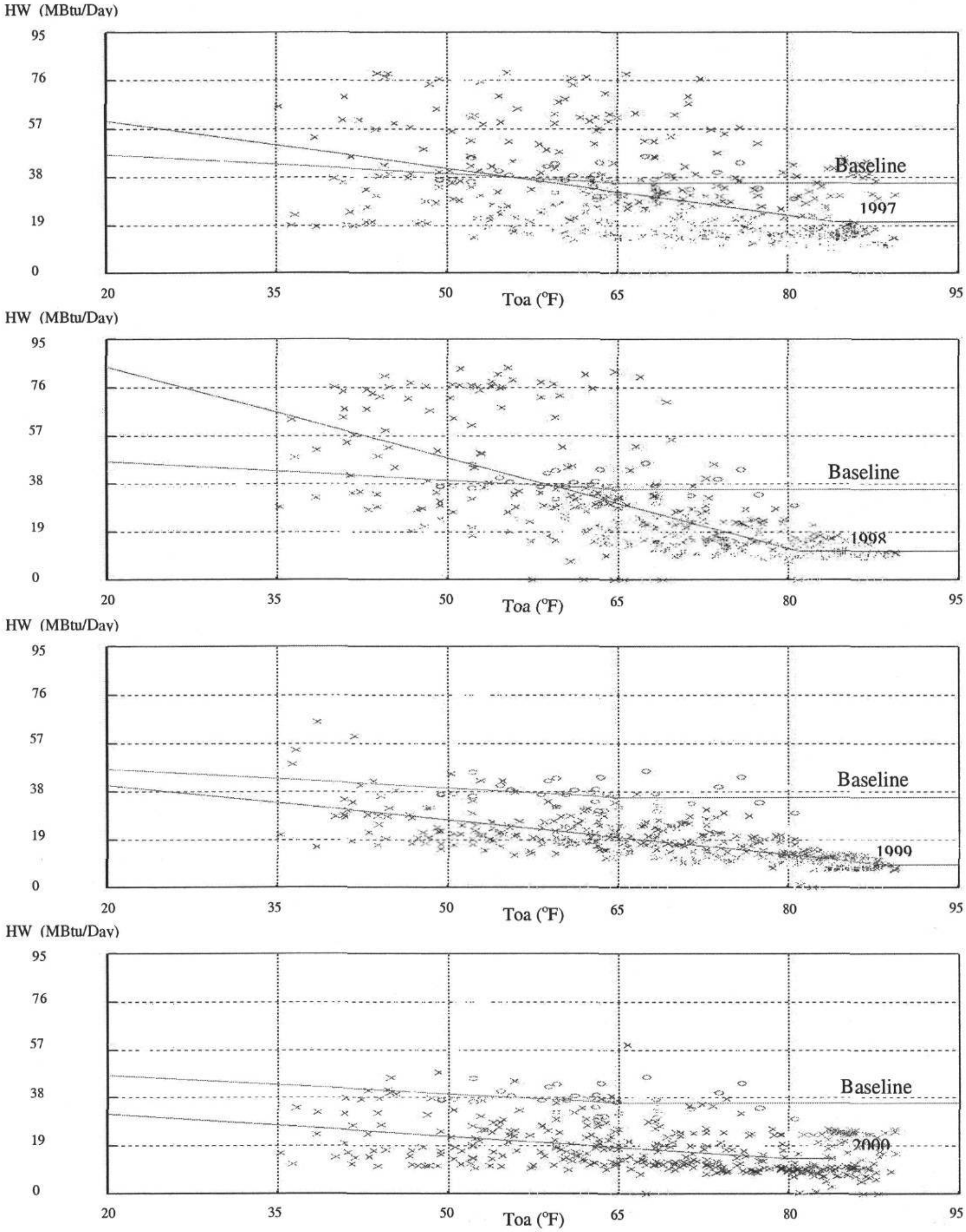


Figure B.18: The Wehner Building Hot Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

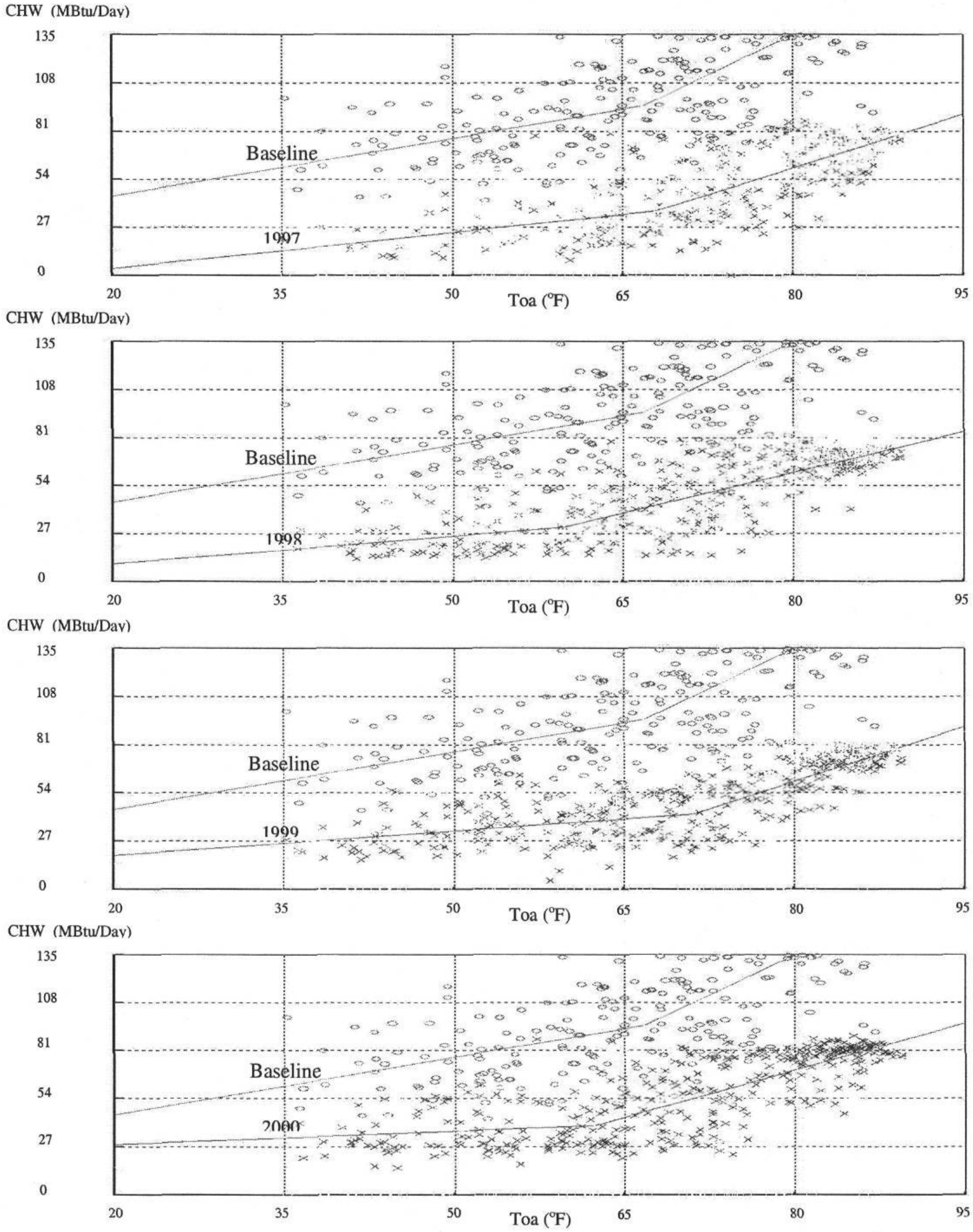


Figure B.19: The Zachry Building Chilled Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

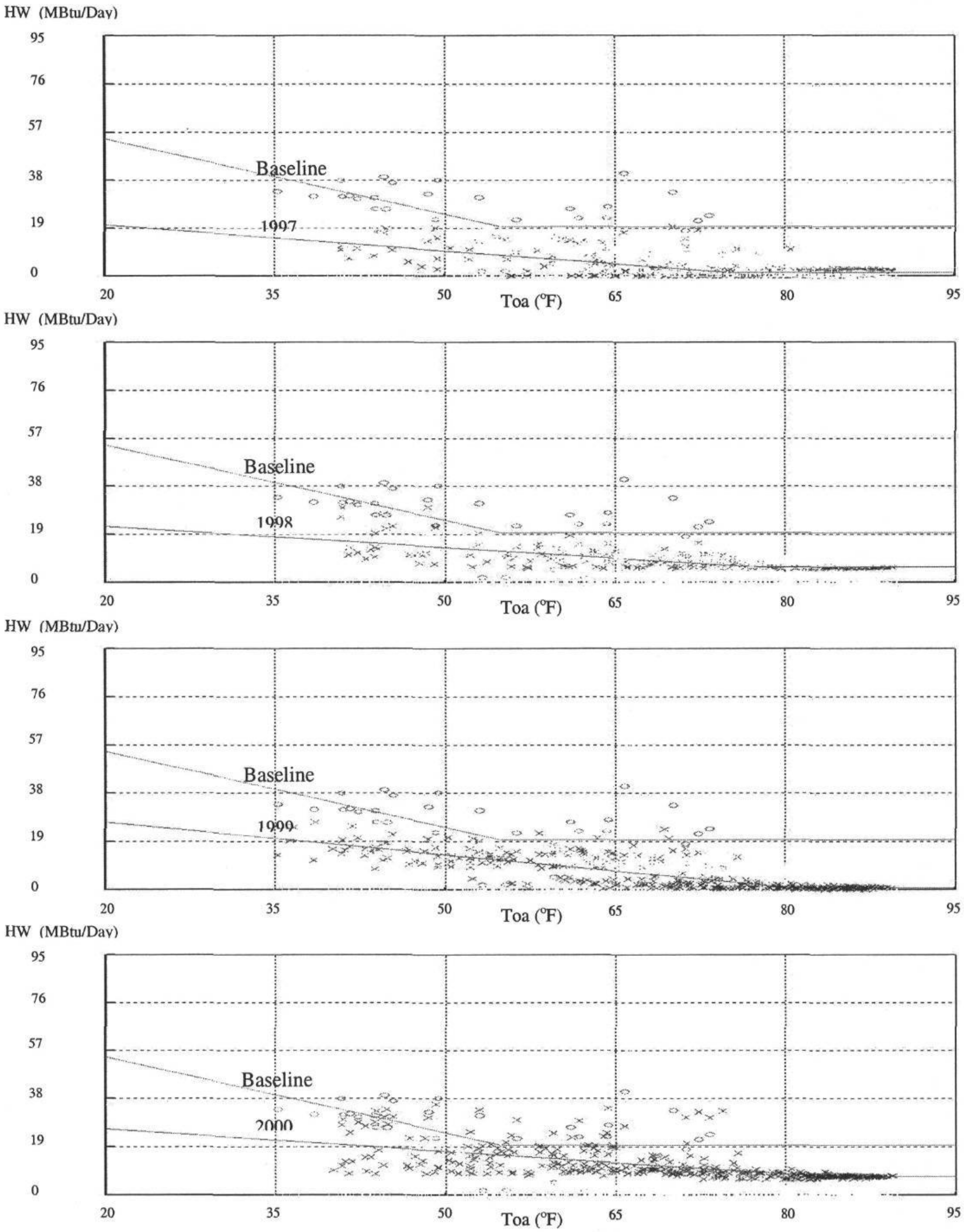


Figure B.20: The Zachry Building Hot Water Use Models for the Periods of 1996 (Baseline) and 1997-2000.

Appendix C

Electricity Energy Use

Appendix C shows the electricity energy use for 10 Buildings. Table C.1 is for reference to compare each year's electricity use after CC with baseline or pre-CC electric consumption. Figures C.1 through C.10 show electricity consumption for each building as a function of time for the periods of pre-CC (baseline) and post-CC (1997-2000).

Table C.1: Yearly Electricity Energy Consumption and Savings for 10 Buildings.

No.	Building Name	Type	Baseline Use	Year 1997	1998	1999	2000	4 years average savings
1	Blocker	Elec (MWh/yr)	4,832	3,773.0	3,882.8	3,935.5	3,859.0	**20.1**
		Savings (%)		**21.9**	**19.7**	**18.6**	**20.1**	
2	Eller O&M	Elec (MWh/yr)	4,891	3,697.9	3,674.6	3,823.0	3,874.2	**23.0**
		Savings (%)		**24.4**	**24.9**	**21.8**	**20.8**	
3	G.R.White Coliseum	Elec (MWh/yr)	1,480	1,297.4	1,168.0	1,171.4	1,291.2	**16.8**
		Savings (%)		**12.4**	**21.1**	**20.9**	**12.8**	
4	Harrington Tower	Elec (MWh/yr)	1,666	1,296.7	1,336.4	1,340.9	1,352.6	**20.1**
		Savings (%)		**22.2**	**19.8**	**19.5**	**18.8**	
5	Kleberg	Elec (MWh/yr)	5,511	5,458.5	5,066.5	4,778.3	4,683.8	**9.3**
		Savings (%)		**0.9**	**8.1**	**13.3**	**15.0**	
6	Koldus	Elec (MWh/yr)	2,850	2,511.2	2,596.7	2,624.1	2,592.3	**9.4**
		Savings (%)		**11.9**	**8.9**	**7.9**	**9.0**	
7	Rich. Petroleum	Elec (MWh/yr)	1,933	1,897.7	1,914.4	1,990.9	2,153.4	**-2.9**
		Savings (%)		**1.8**	**1.0**	**-3.0**	**-11.4**	
8	VMC Addition	Elec (MWh/yr)	4,186	3,995.6	4,139.7	4,236.5	4,056.5	**1.9**
		Savings (%)		**4.5**	**1.1**	**-1.2**	**3.1**	
9	Wehner CBA	Elec (MWh/yr)	2,555	2,410.5	2,446.2	2,552.3	2,580.8	**2.2**
		Savings (%)		**5.6**	**4.2**	**0.1**	**-1.0**	
10	Zachry	Elec (MWh/yr)	7,502	6,762.0	6,792.6	7,099.3	6,955.3	**8.0**
		Savings (%)		**9.9**	**9.5**	**5.4**	**7.3**	

Savings Calculation		Yearly Average Savings				Total Average Savings
	Year	1997	1998	1999	2000	
	Savings (%)	**11.5**	**11.7**	**10.3**	**10.7**	**11.1**

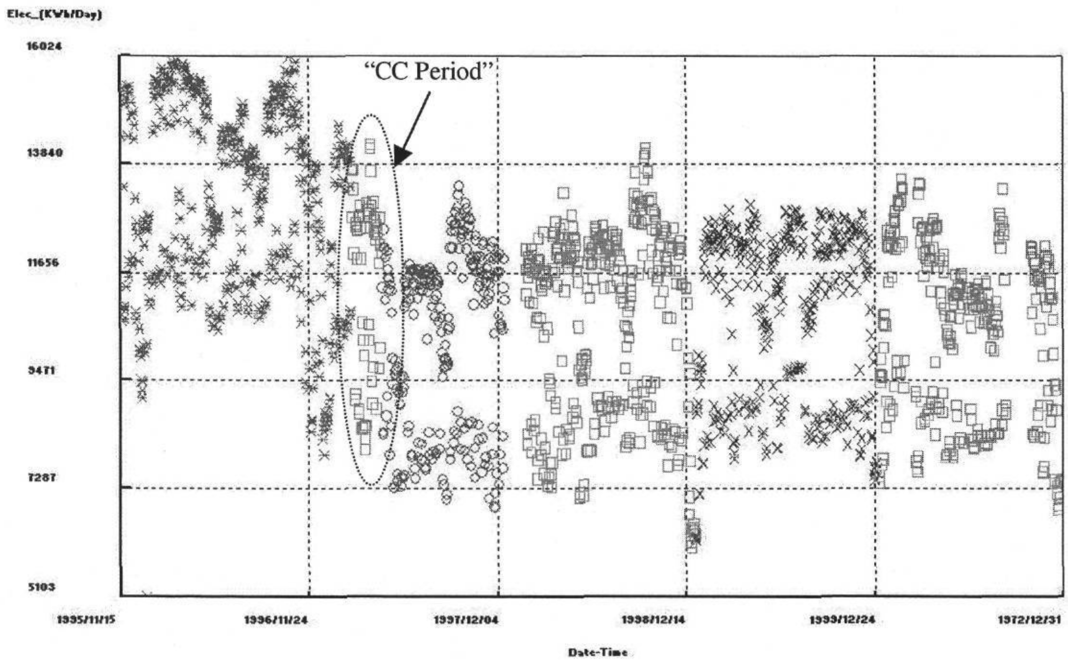


Figure C.1: The Blocker Building Electricity Use as a Function of Time for the Period from 11/15/1995 to 12/31/2000.

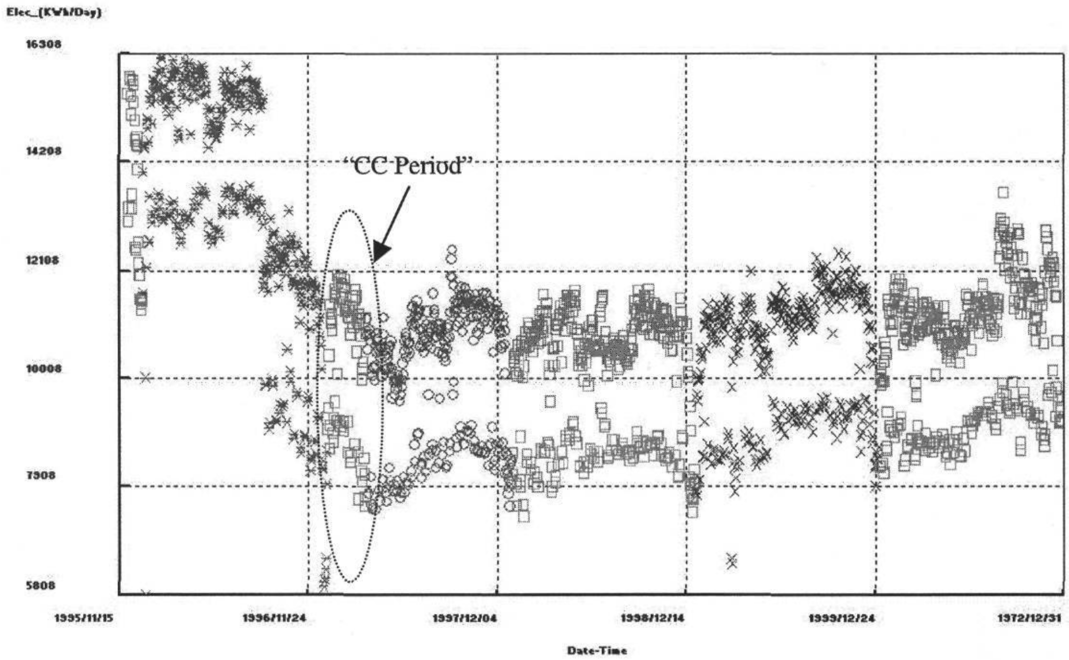


Figure C.2: The Eller O&M Building Electricity Use as a Function of Time for the Period from 11/30/1995 to 12/31/2000.

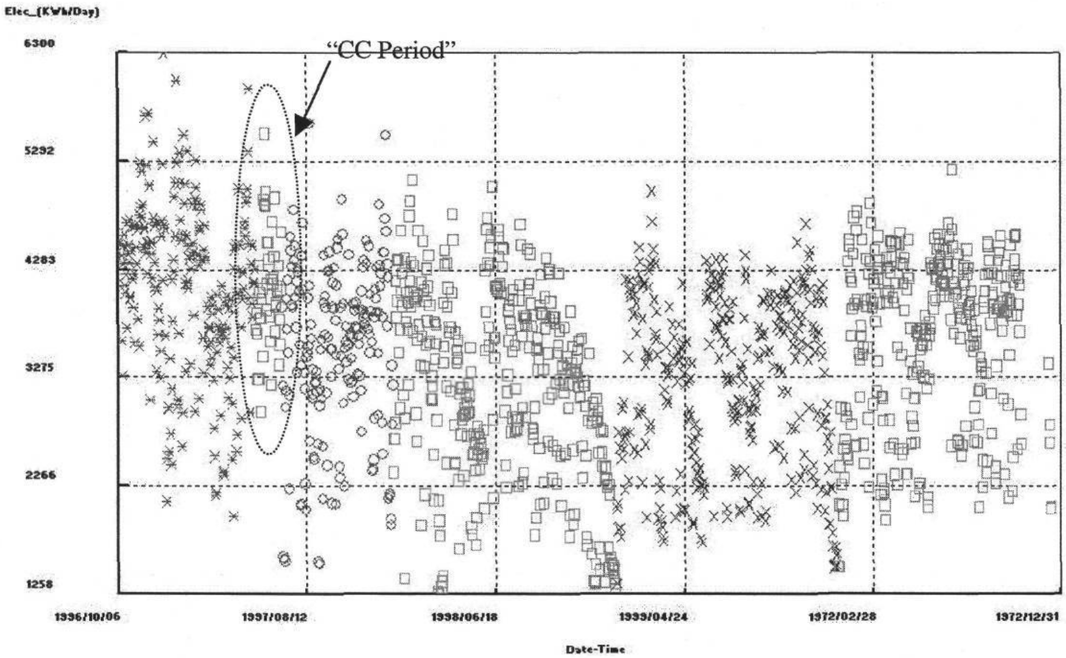


Figure C.3: The G.R. White Coliseum Electricity Use as a Function of Time for the Period from 10/06/1996 to 12/31/2000.

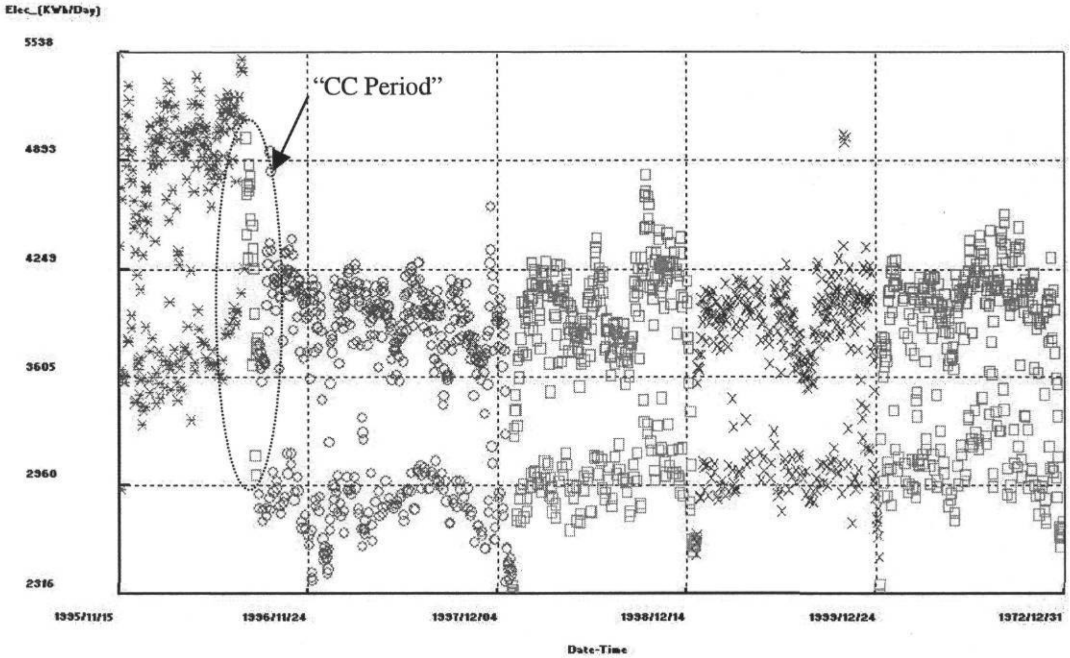


Figure C.4: The Harrington Tower Electricity Use as a Function of Time for the Period from 11/15/1995 to 12/31/2000.

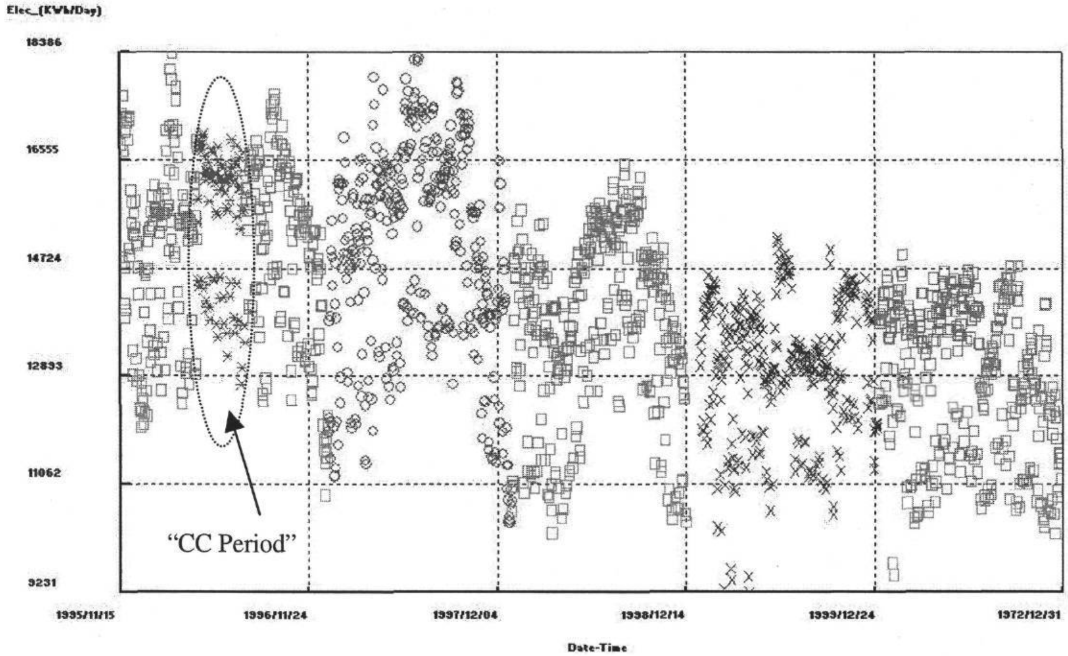


Figure C.5: The Kleberg Building Electricity Use as a Function of Time for the Period from 11/15/1995 to 12/31/2000.

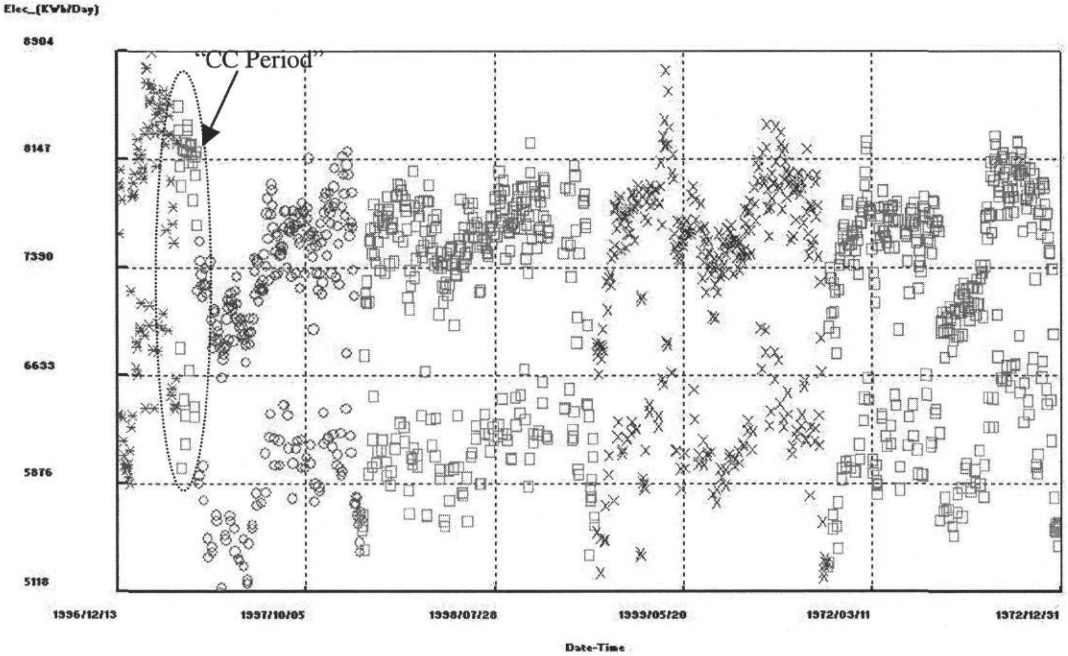


Figure C.6: The Koldus Building Electricity Use as a Function of Time for the Period from 12/13/1996 to 12/31/2000.

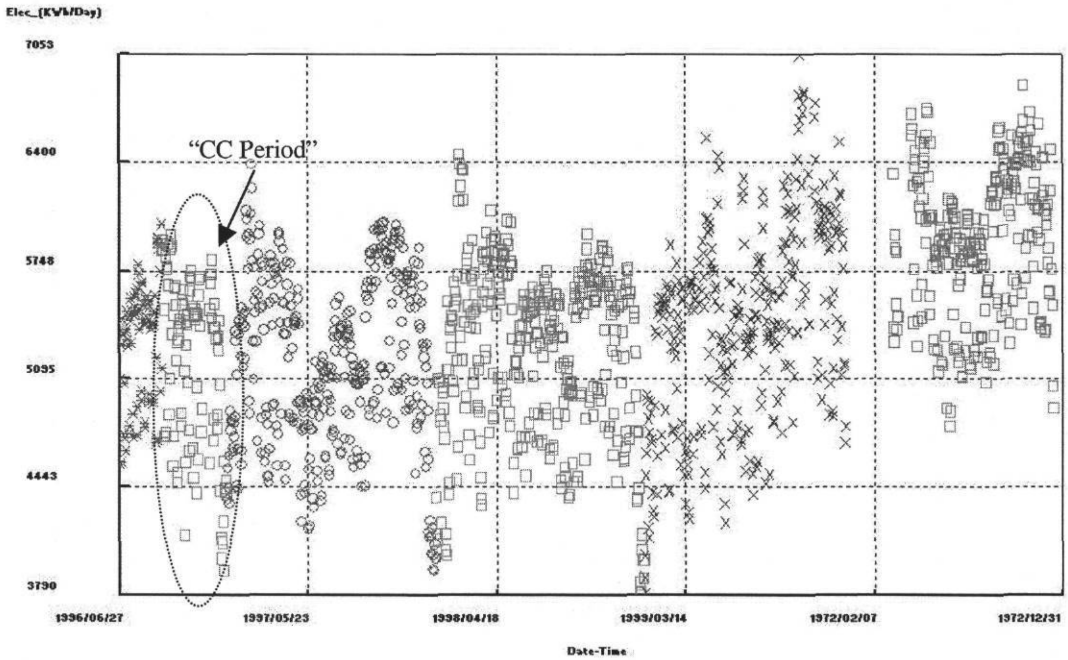


Figure C.7: The Richardson Building Electricity Use as a Function of Time for the Period from 06/27/1996 to 12/31/2000.

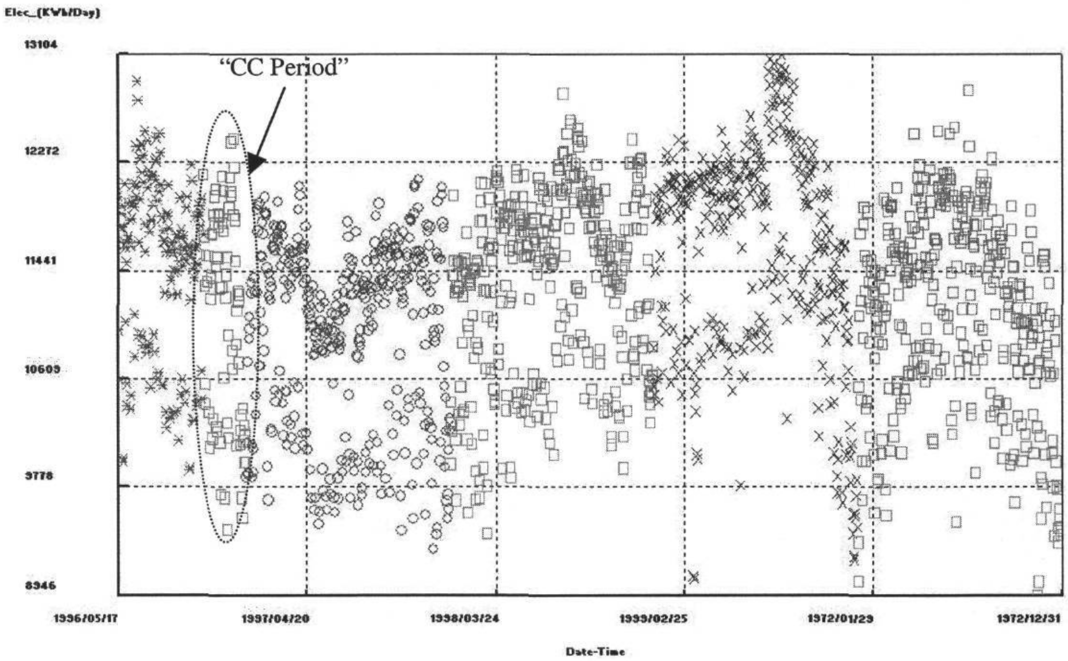


Figure C.8: The VMC Addition Electricity Use as a Function of Time for the Period from 05/17/1996 to 12/31/2000.

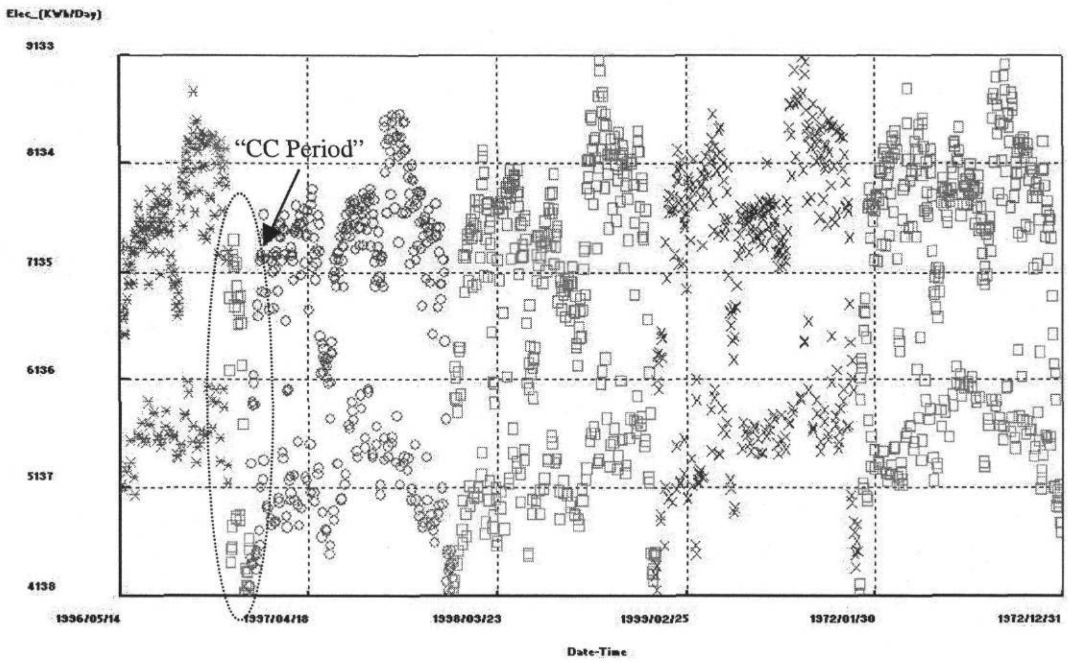


Figure C.9: The Wehner Building Electricity Use as a Function of Time for the Period from 05/14/1996 to 12/31/2000.

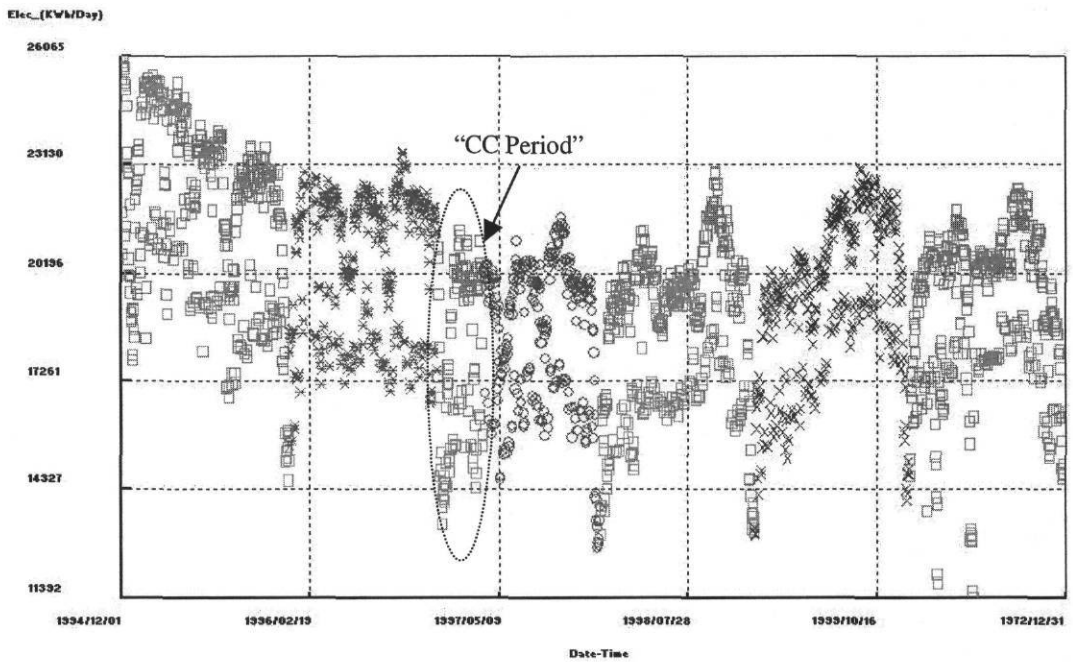


Figure C.10: The Zachry Building Electricity Use as a Function of Time for the Period from 12/01/1994 to 12/31/2000.

Appendix D

Comparison of EMCS Settings between Pre-CC, Post-CC and Year 2000 Periods

Appendix D contains a history of EMCS settings for the 10 buildings. Table D.1 shows what type of HVAC systems each building has and what major EMCS settings are programmed based on outside air temperature variation. Some observations for buildings are mentioned. Figures D.1 through D.10 show the control changes of cold deck, hot deck and static pressure for the pre-CC, post-CC and year 2000 periods.

Table D.1: A Summary of HVAC System Types and EMCS Settings for 10 Buildings.

No.	Building Name	CC Period	HVAC System Types				EMCS Settings			Remarks
			DD	SD	VAV	CAV	Cold Deck	Hot Deck	Static Press.	
1	Blocker	2 / 97 - 4 / 97	x		x		x	x	x	This building currently has the lowest cold deck settings compared to the other buildings.
2	Eller O&M	2 / 97 - 3 / 97	x		x		x	x	x	Static pressure settings were same for all AHUs but they are currently divided into three different groups for AHUs.
3	G.R.White Coliseum	5 / 97 - 7 / 97		x		x	x			Cold deck was set based on return air temperature.
4	Harrington Tower	7 / 96 - 8 / 96	x		x		x	x	x	Cold deck temp. depended on Toa and Dew-point.
5	Kleberg	4 / 96 - 7 / 96		x	x		x		x	Static pressure set points are all constant.
6	Koldus	3 / 97 - 4 / 97		x	x		x		x	Cold deck and static pressure settings have not changed since cc.
7	Rich. Petroleum	9 / 96 - 9 / 96		x	x		x		x	Cold deck and static pressure were dependent on the speed of supply VFD.
8	VMC Addition	10/ 96 - 11/ 96		x	x		x		x	No history for static pressure settings.
9	Wehner CBA	11/ 96 - 12/ 96	x		x		x	x	x	Hot deck discharge temperature settings have not changed since CC.
10	Zachry Building	12/ 96 - 3 / 97	x		x		x	x	x	Hot deck has had the same settings after CC was completed.

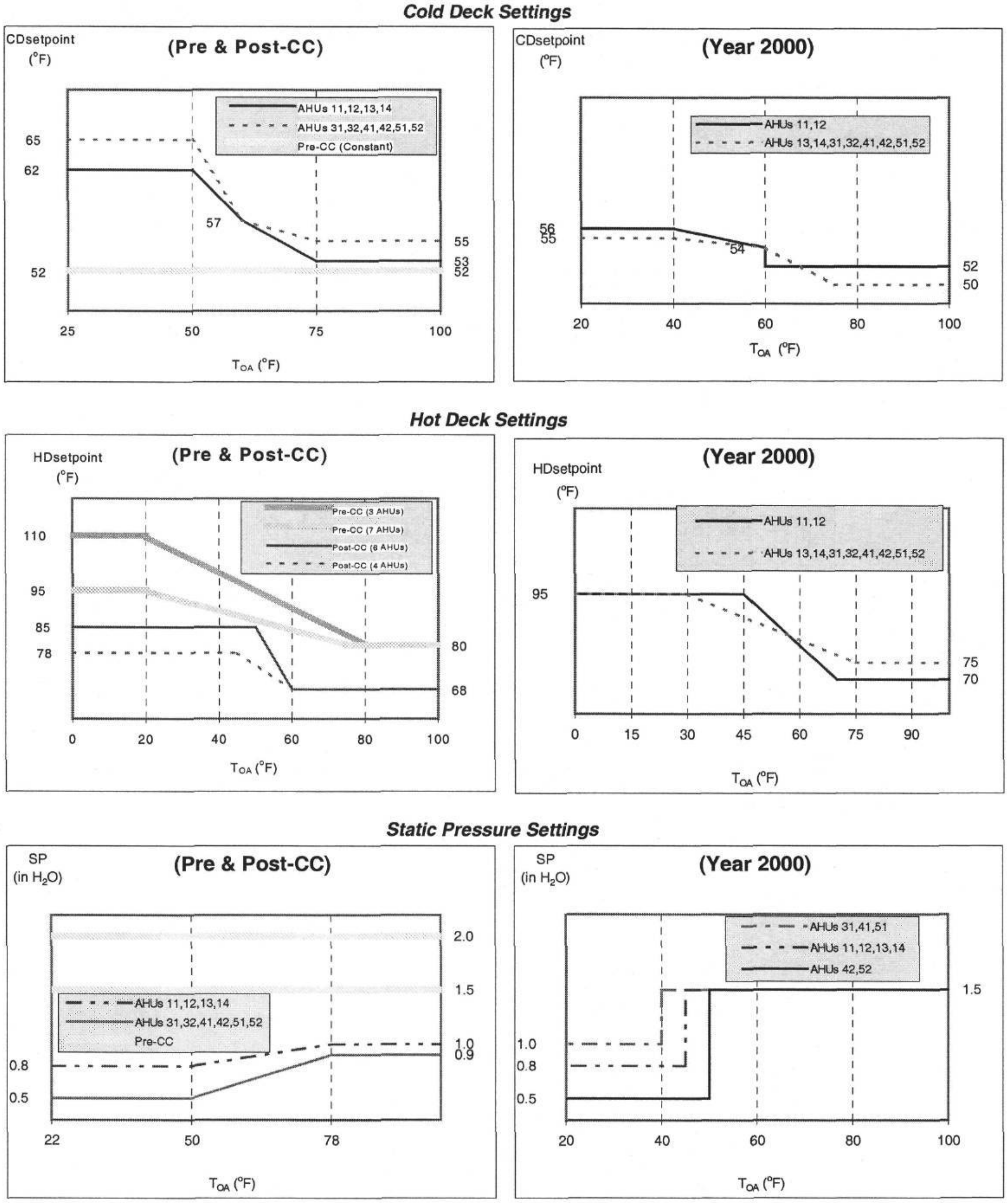


Figure D.1: Control Changes of Cold Deck, Hot Deck and Static Pressure for The Blocker Building as a Function of Outside Air Temperature for the Pre-CC, Post-CC and Year 2000 Periods.

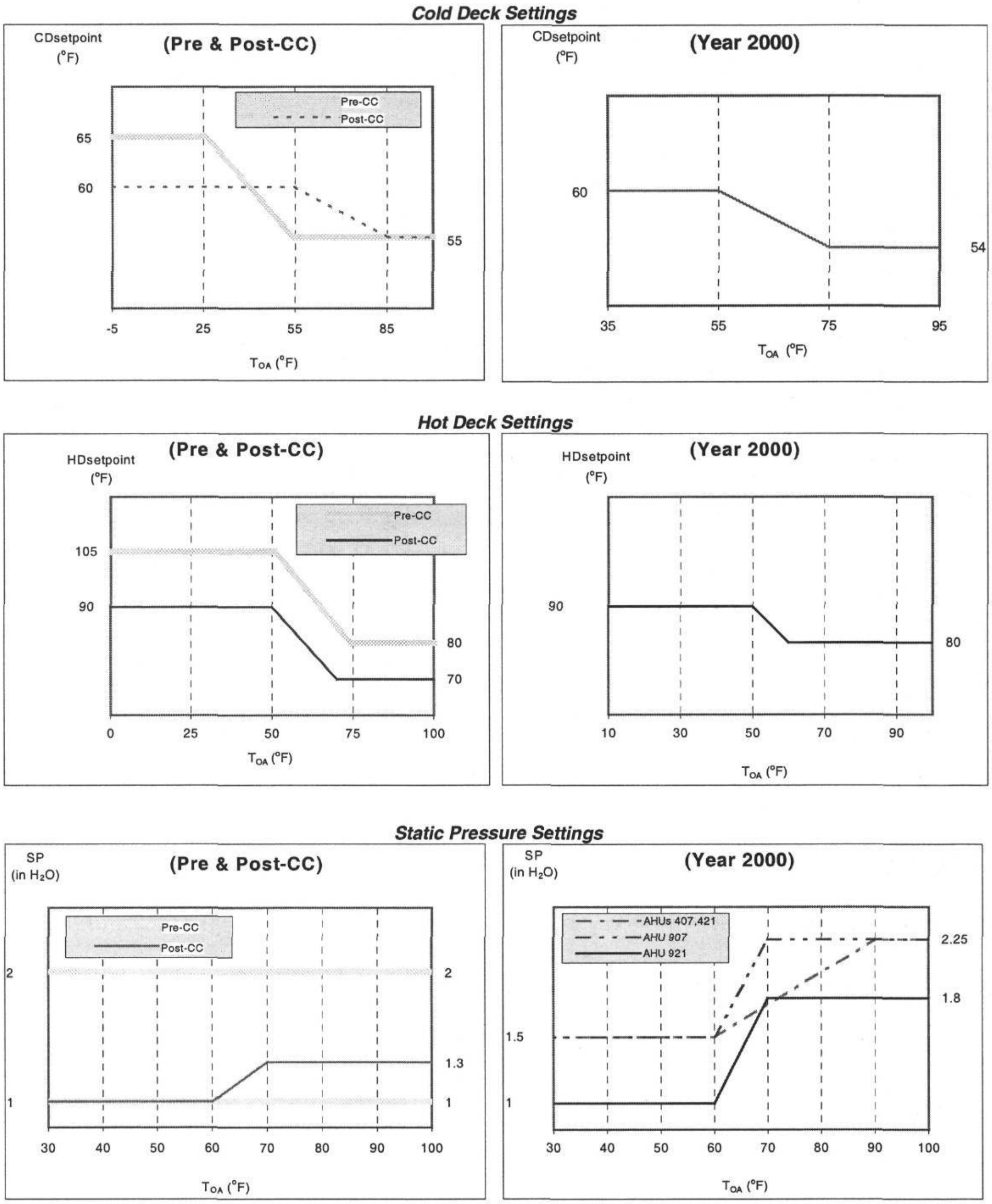


Figure D.2: Control Changes of Cold Deck, Hot Deck and Static Pressure for The Eller O&M Building as a Function of Outside Air Temperature for the Pre-CC, Post-CC and Year 2000 Periods.

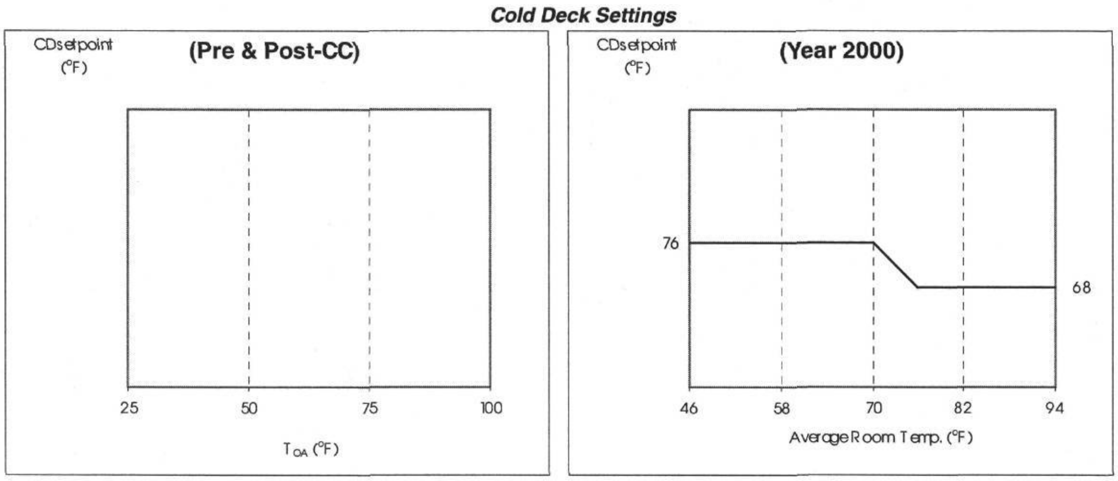


Figure D.3: Control Changes of Cold Deck for The G.R. White Coliseum as a Function of Average Room Air Temperature for the Pre-CC, Post-CC and Year 2000 Periods. (No Hot Deck Settings because This Building has Single Duct Air Handling Systems. Control Schedules are not available for the Pre-CC and Post-CC Periods.)

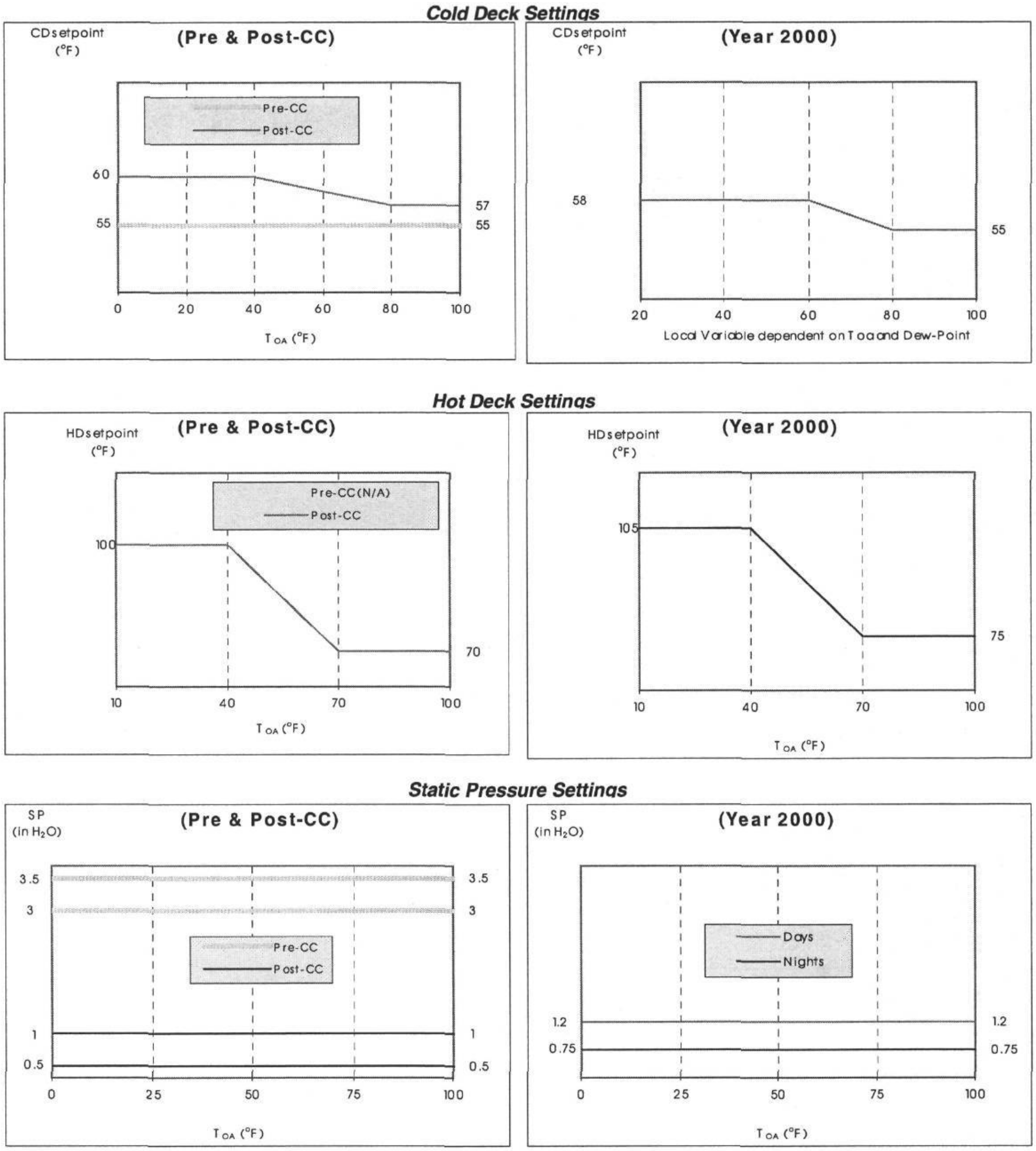


Figure D.4: Control Changes of Cold Deck, Hot Deck and Static Pressure for The Harrington Tower as a Function of Outside Air Temperature for the Pre-CC, Post-CC and Year 2000 Periods. (Cold Deck Settings for Year 2000 are based on the combined Function of Outside Air Temperature and Dew-Point Temperature.)

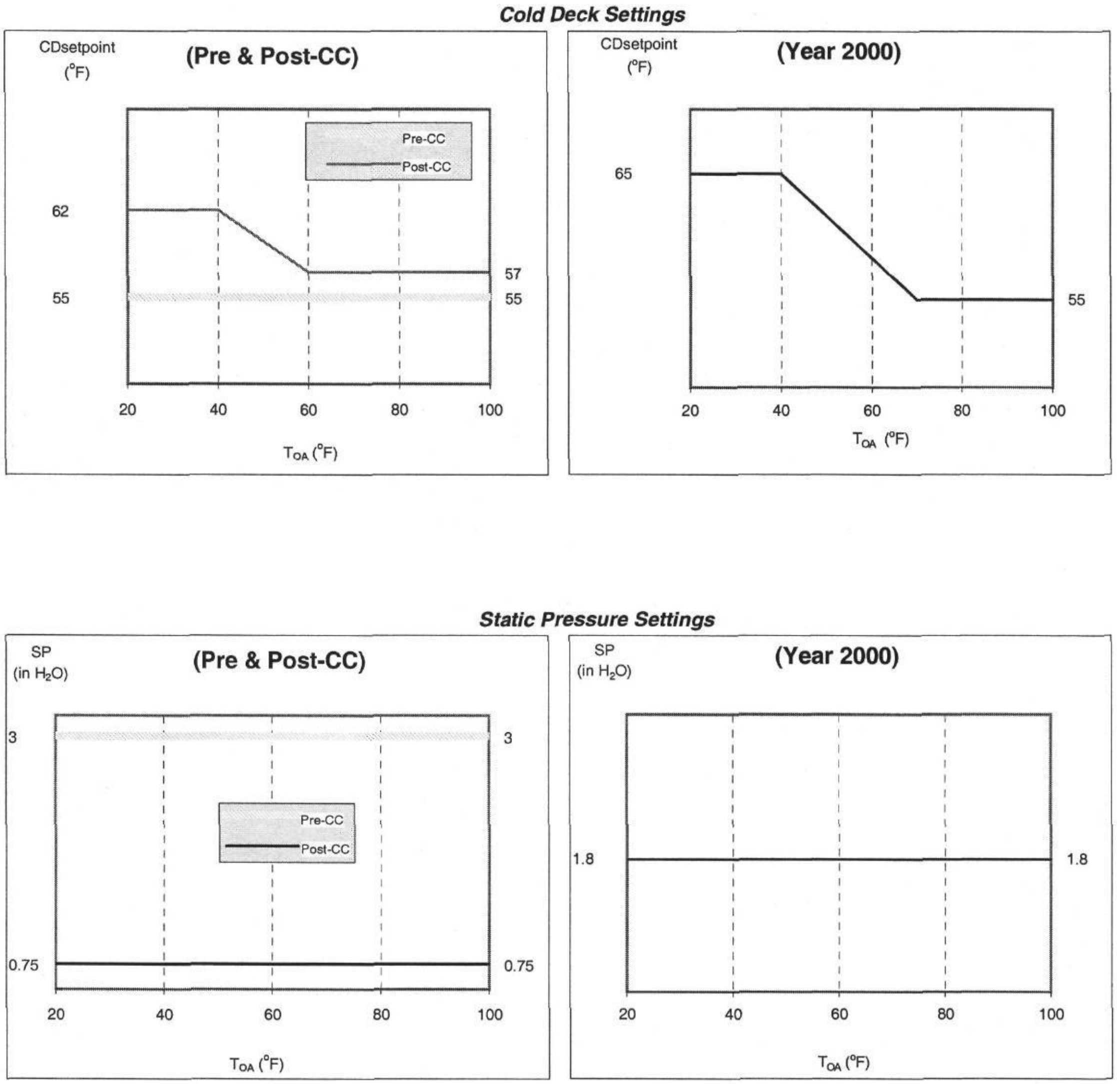


Figure D.5: Control Changes of Cold Deck and Static Pressure for The Kleberg Building as a Function of Outside Air Temperature for the Pre-CC, Post-CC and Year 2000 Periods. (No Hot Deck Settings because this Building has Single Duct Air Handling Systems.)

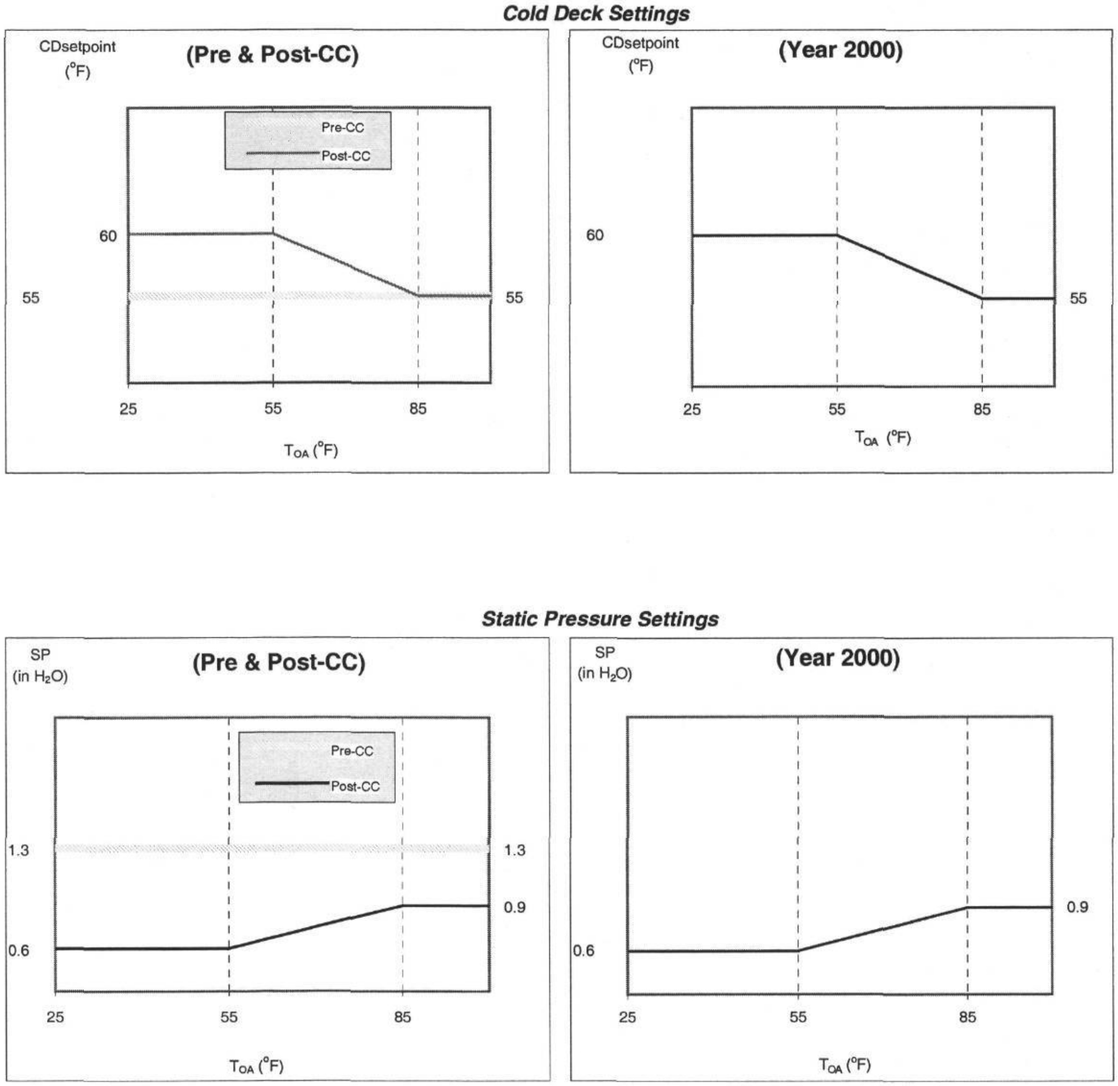


Figure D.6: Control Changes of Cold Deck and Static Pressure for The Koldus Building as a Function of Outside Air Temperature for the Pre-CC, Post-CC and Year 2000 Periods. (No Hot Deck Settings because this Building has Single Duct Air Handling Systems.)

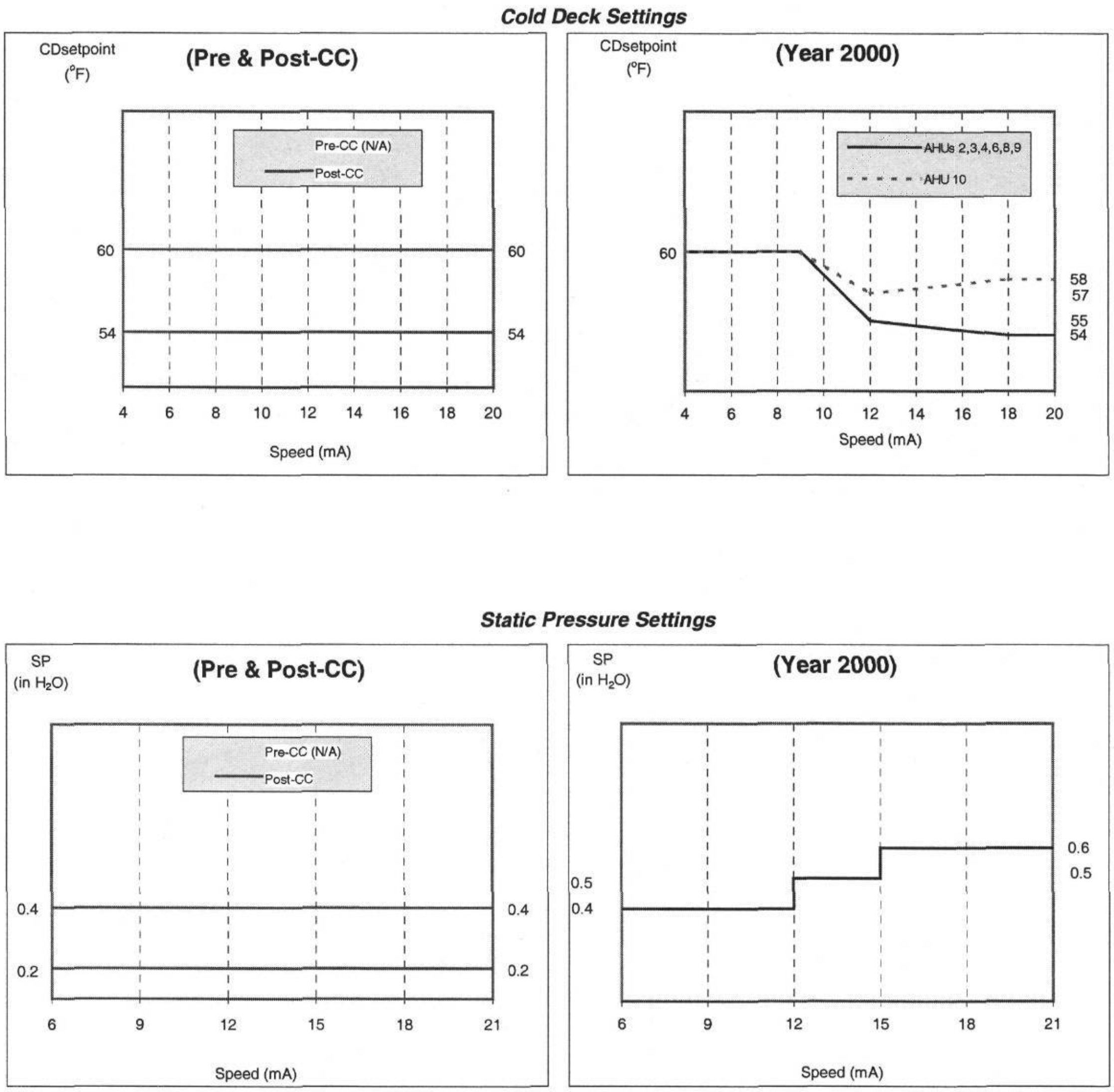


Figure D.7: Control Changes of Cold Deck and Static Pressure for The Richardson Building as a Function of Outside Air Temperature for the Pre-CC, Post-CC and Year 2000 Periods. (No Hot Deck Settings because this Building has Single Duct Air Handling Systems.)

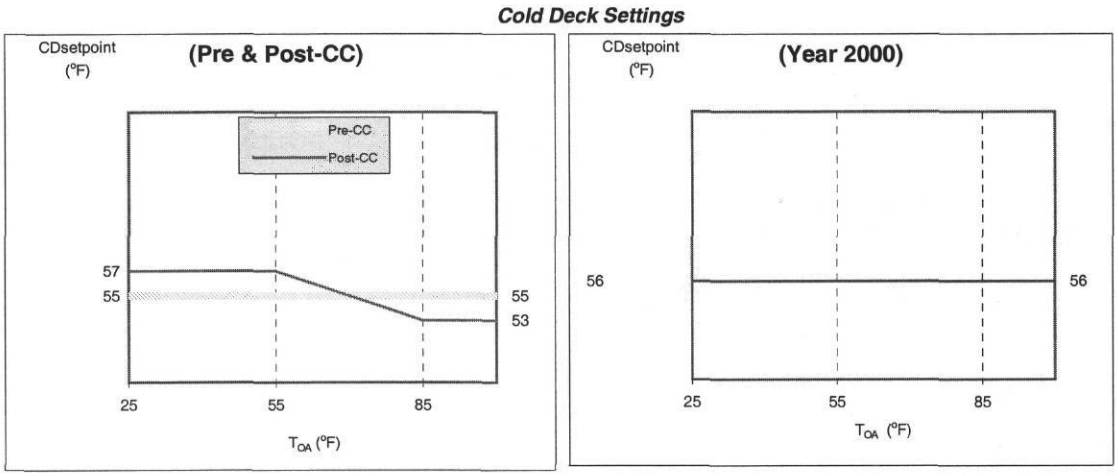


Figure D.8: Control Changes of Cold Deck for the VMC Addition as a Function of Outside Air Temperature for the Pre-CC, Post-CC and Year 2000 Periods. (No Hot Deck Settings because this Building has Single Duct Air Handling Systems. Static Pressure Schedules are not available.)

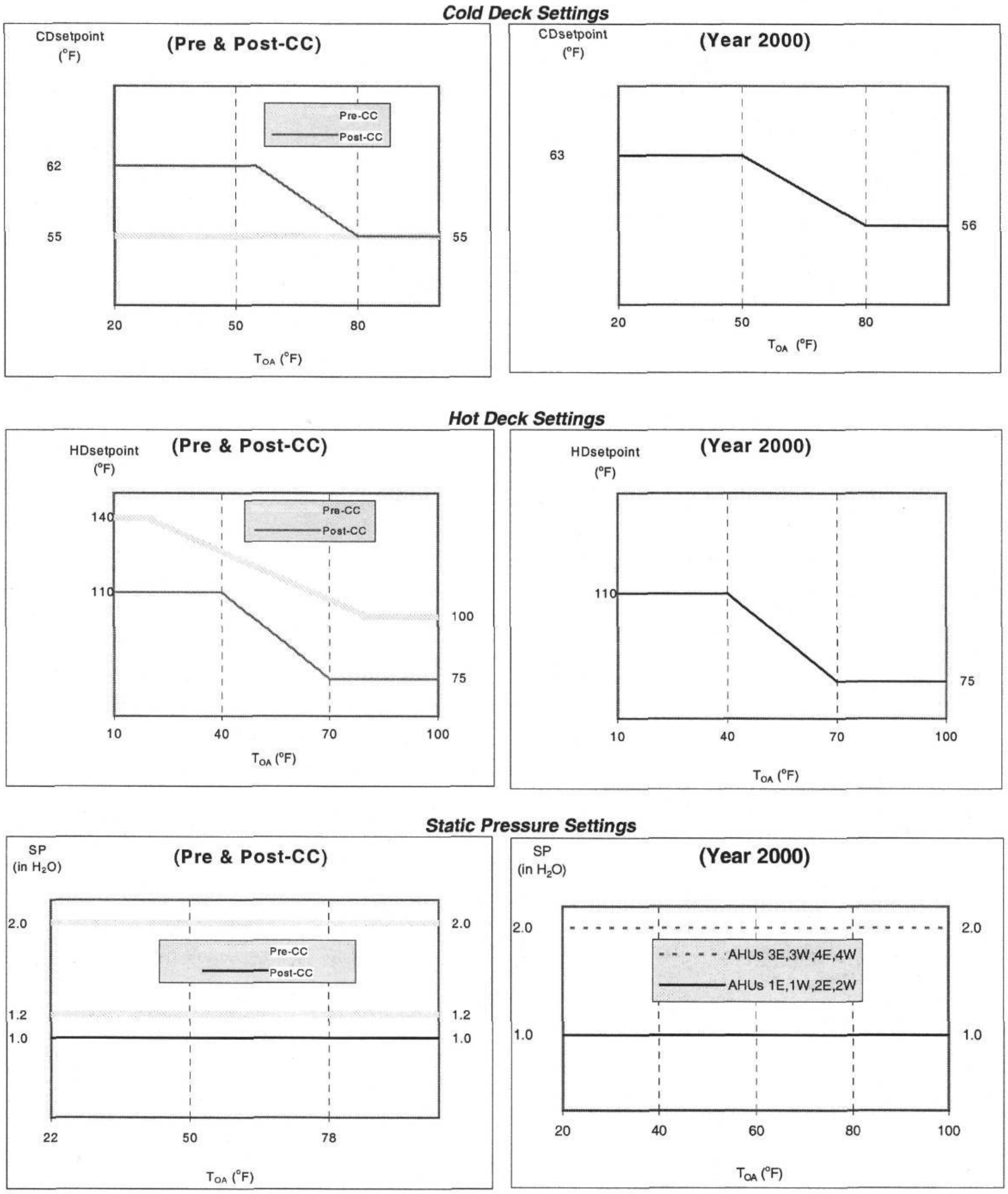


Figure D.9: Control Changes of Cold Deck, Hot Deck and Static Pressure for The Wehner Building as a Function of Outside Air Temperature for the Pre-CC, Post-CC and Year 2000 Periods.

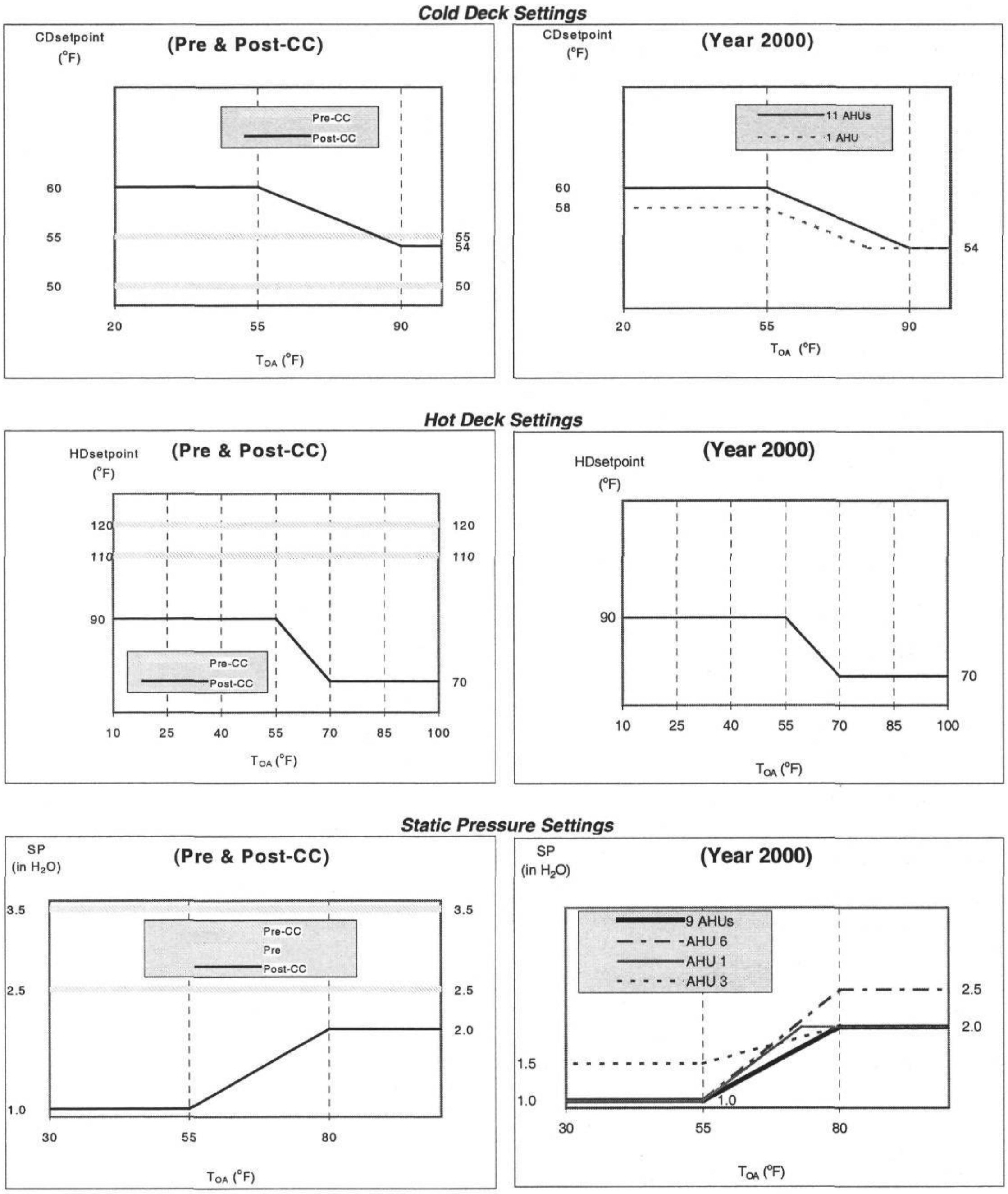


Figure D.10: Control Changes of Cold Deck, Hot Deck and Static Pressure for The Zachry Building as a Function of Outside Air Temperature for the Pre-CC, Post-CC and Year 2000 Periods.

APPENDIX E

Input Parameters Calibrated and Used in Simulation for 5 Buildings

Appendix E contains input files used in the simulations for a pre-CC period, a post-CC period and year 2000. To understand the meanings of the input numbers arranged, please refer to the user's manual for Air Side Simulation (AirModel) programs (Liu and Claridge, 1995) available.

E.1 The Eller O&M Building Input Parameters

E1.1 Input Parameters Used in the Pre-CC Period

Section 1: General Information
1.1 Relative humdity (1) or dew point (0)
0
1.2 Dry bulb temperature (F) range (low and high)
22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 1 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
1
1.6 The first Vacation period:month, day to month day
1 1 1 14
1.7 The second vacation period:month, day to month day
5 15 8 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
1
2. Conditioned floor area (sq-ft) and fraction of interior area
90158 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
70 74 70 78
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.3 1.3 0.19 0.19
6. Minimum air flow for occupied and unoccupied
0.75 0.75
7. Maximum room relative humidity

0.55
8. Minimum air flow through each duct (for DD system)
0.1
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
3
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3
13. Economizer Range Tmin, Tmax
10.00000 60.000000
14. Minimum and maximum outside air intake fraction
0.1 0.3
15. Internal Heat Gain W/sq-ft
1.40 1.40
16. Average Floor Area For Each Person sq-ft/person
150.000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
31624 0.20
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
13104 0.98
24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.11 37 0.23 102
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
200 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
0 0
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
55 25 55 55 55 85 55 90 55 110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
105 10 105 50 80 75 80 90 80 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
55 10 55 30 55 50 55 85 55 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
55 160 55 260 55 360 55 460 57 560

Section 3: Inputs for sub-system 2

1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
1
2. Conditioned floor area (sq-ft) and fraction of interior area
90158 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
70 74 70 78
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.3 1.3 0.19 0.19
6. Minimum air flow for occupied and unoccupied
0.75 0.75
7. Maximum room relative humidity
0.55
8. Minimum air flow through each duct (for DD system)
0.1
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
3
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3
13. Economizer Range Tmin, Tmax
10 70
14. Minimum and maximum outside air intake fraction

0.1 0.3

15. Internal Heat Gain W/sq-ft

1.40 1.40

16. Average Floor Area For Each Person sq-ft/person

150.0000

17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio

0.0

22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)

31624 0.2

23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)

13104 0.98

24. Air infiltration for interior and exterior zones (ACH)

0 0

25. Solar Gains (Solarmin, Toa; Solarmax, Toa)

0.11 37 0.23 102

26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
200 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
0 0
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
55 30 55 55 55 85 55 90 55 100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
110 10 110 50 80 75 80 85 80 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
55 10 55 30 55 50 55 85 55 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
55 160 55 260 55 360 55 460 57 560

E1.2 Input Parameters Used in the Post-CC Period

Section 1: General Information
1.1 Relative humdity (1) or dew point (0)
  0
1.2 Dry bulb temperature (F) range (low and high)
  22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
  1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
  1 1 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
  1
1.6 The first Vacation period:month, day to month day
  1 1 1 14
1.7 The second vacation period:month, day to month day
  5 15 8 28
1.8 The third vacation period:month, day to month day
  12 15 12 31
1.9 Energy price \$/kWh, \$/MMBtu-CHW \$/MMBtu-HW
  0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
  1
2. Conditioned floor area (sq-ft) and fraction of interior area
  90158 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
  8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
  70 74 70 78
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
  1.3 1.3 0.19 0.19
6. Minimum air flow for occupied and unoccupied
  0.75 0.75
7. Maximum room relative humidity
  0.55
8. Minimum air flow through each duct (for DD system)
  0.1
9. Excessive Air Leakage CFM/sq-ft

1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
3
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3
13. Economizer Range Tmin, Tmax
10.00000 60.000000
14. Minimum and maximum outside air intake fraction
0.1 0.3
15. Internal Heat Gain W/sq-ft
1.40 1.40
16. Average Floor Area For Each Person sq-ft/person
150.000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
 0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
 31624 0.20
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
 13104 0.98
24. Air infiltration for interior and exterior zones (ACH)
 0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
 0.11 37 0.23 102
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
 200 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
 0 0
28. Temp. Diff. Between Return and Room Air Temp F
 2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
60 25 60 55 55 85 55 90 55 110

34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
90 10 90 50 70 70 70 90 70 110

35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
55 10 55 30 55 50 55 85 55 110

36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
55 160 55 260 55 360 55 460 57 560

Section 3: Inputs for sub-system 2

1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
1

2. Conditioned floor area (sq-ft) and fraction of interior area
90158 0.5

3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0

4. Room temperature for occupied and unoccupied (heating and cooling)
70 74 70 78

5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.3 1.3 0.19 0.19

6. Minimum air flow for occupied and unoccupied
0.75 0.75

7. Maximum room relative humidity
0.55

8. Minimum air flow through each duct (for DD system)
0.1

9. Excessive Air Leakage CFM/sq-ft
1.000000E-01

10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000

11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
3

12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3

13. Economizer Range Tmin, Tmax
10 70

14. Minimum and maximum outside air intake fraction
0.1 0.3

15. Internal Heat Gain W/sq-ft
1.40 1.40

16. Average Floor Area For Each Person sq-ft/person

150.0000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
31624 0.2
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
13104 0.98
24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.11 37 0.23 102
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
200 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD

0 0
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
60 30 60 55 55 85 55 90 55 100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
100 10 100 50 70 70 70 85 70 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
55 10 55 30 55 50 55 85 55 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
55 160 55 260 55 360 55 460 57 560

E1.3 Input Parameters Used in the Year 2000 Period

Section 1: General Information
1.1 Relative humdity (1) or dew point (0)
0
1.2 Dry bulb temperature (F) range (low and high)
22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 1 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
1
1.6 The first Vacation period:month, day to month day
1 1 1 14
1.7 The second vacation period:month, day to month day
5 15 8 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
1
2. Conditioned floor area (sq-ft) and fraction of interior area
90158 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
70 74 70 78
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.3 1.3 0.19 0.19
6. Minimum air flow for occupied and unoccupied
0.75 0.75
7. Maximum room relative humidity
0.55
8. Minimum air flow through each duct (for DD system)
0.1
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm

380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin;
4:IAQ;5:IAQ+Occupancy
3
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3
13. Economizer Range Tmin, Tmax
10.00000 60.000000
14. Minimum and maximum outside air intake fraction
0.1 0.3
15. Internal Heat Gain W/sq-ft
1.40 1.40
16. Average Floor Area For Each Person sq-ft/person
150.000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0

22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
31624 0.20
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
13104 0.98
24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.11 37 0.23 102
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
200 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
0 0
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
60 25 60 55 54 75 54 90 54 110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
90 10 90 50 80 60 80 90 80 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
55 10 55 30 55 50 55 85 55 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
55 160 55 260 55 360 55 460 57 560

Section 3: Inputs for sub-system 2

1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
1
2. Conditioned floor area (sq-ft) and fraction of interior area
90158 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
70 74 70 78
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.3 1.3 0.19 0.19
6. Minimum air flow for occupied and unoccupied
0.75 0.75
7. Maximum room relative humidity
0.55
8. Minimum air flow through each duct (for DD system)
0.1
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
3
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3
13. Economizer Range Tmin, Tmax
10 70
14. Minimum and maximum outside air intake fraction
0.1 0.3
15. Internal Heat Gain W/sq-ft
1.40 1.40
16. Average Floor Area For Each Person sq-ft/person
150.0000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
31624 0.2
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
13104 0.98
24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.11 37 0.23 102
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
200 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
0 0
28. Temp. Diff. Between Return and Room Air Temp F

2.000000

29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5

60 30 60 55 54 75 54 90 54 100

34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5

110 10 110 50 80 60 80 85 80 110

35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5

55 10 55 30 55 50 55 85 55 110

36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5

55 160 55 260 55 360 55 460 57 560

E.2 The Harrington Tower Input Parameters

E2.1 Input Parameters Used in the Pre-CC Period

Section 1: General Information
1.1 Relative humdity (1) or dew point (0)
0
1.2 Dry bulb temperature (F) range (low and high)
22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 0 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
1
1.6 The first Vacation period:month, day to month day
1 1 1 14
1.7 The second vacation period:month, day to month day
5 15 8 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
1
2. Conditioned floor area (sq-ft) and fraction of interior area
130844 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
72 75 72 75
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
2.0 2.0 0.25 0.25
6. Minimum air flow for occupied and unoccupied
1.00 1.00
7. Maximum room relative humidity
0.50
8. Minimum air flow through each duct (for DD system)
0.10
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm

380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
2
13. Economizer Range Tmin, Tmax
20.00000 60.000000
14. Minimum and maximum outside air intake fraction
0.13 0.45
15. Internal Heat Gain W/sq-ft
0.82 0.82
16. Average Floor Area For Each Person sq-ft/person
200.000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0

22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
 41200 0.20
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
 19017 0.80
24. Air infiltration for interior and exterior zones (ACH)
 0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
 0.078 22 0.17 102
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
 230 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
 0 0
28. Temp. Diff. Between Return and Room Air Temp F
 2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
  55 30 55 40 55 80 55 90 55 110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
  120 20 120 30 81 73 81 90 81 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
  11 10 12 30 13 50 14 85 15 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
  55 160 55 260 55 360 55 460 55 560

E2.2 Input Parameters Used in the Post-CC Period

Section 1: General Information
1.1 Relative humdity (1) or dew point (0)
  0
1.2 Dry bulb temperature (F) range (low and high)
  22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
  1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
  1 0 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
  1
1.6 The first Vacation period:month, day to month day
  1 1 1 14
1.7 The second vacation period:month, day to month day
  5 15 8 28
1.8 The third vacation period:month, day to month day
  12 15 12 31
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
  0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
  1
2. Conditioned floor area (sq-ft) and fraction of interior area
  130844 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
  8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)

72 75 72 75

5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   1.1 1.1 0.15 0.15
6. Minimum air flow for occupied and unoccupied
   0.61 0.61
7. Maximum room relative humidity
   0.50
8. Minimum air flow through each duct (for DD system)
   0.10
9. Excessive Air Leakage CFM/sq-ft
   1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
    380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
    1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
    2
13. Economizer Range Tmin, Tmax
    20.00000 60.000000
14. Minimum and maximum outside air intake fraction
    0.13 0.45
15. Internal Heat Gain W/sq-ft
    0.82 0.82
16. Average Floor Area For Each Person sq-ft/person
    200.000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
41200 0.20
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
19017 0.80
24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.078 22 0.17 102
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
230 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
0 0
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
 59 30 59 40 57 80 57 90 57 110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
 100 20 100 40 70 70 70 90 70 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
 11 10 12 30 13 50 14 85 15 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
 55 160 55 260 55 360 55 460 55 560

E2.3 Input Parameters Used in the Year 2000 Period

Section 1: General Information
1.1 Relative humdity (1) or dew point (0)
 0
1.2 Dry bulb temperature (F) range (low and high)
 22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
 1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
 1 0 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
 1
1.6 The first Vacation period:month, day to month day
 1 1 1 14
1.7 The second vacation period:month, day to month day
 5 15 8 28
1.8 The third vacation period:month, day to month day

12 15 12 31

1.9 Energy price \$/kWh, \$/MMBtu-CHW \$/MMBtu-HW

0.02788 4.670 4.750

Section 2: Inputs for sub-system 1

1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)

   1

2. Conditioned floor area (sq-ft) and fraction of interior area

   130844 0.5

3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation

   8 17 0 0 0 0 0 0

4. Room temperature for occupied and unoccupied (heating and cooling)

   72 75 72 75

5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones

   1.1 1.1 0.15 0.15

6. Minimum air flow for occupied and unoccupied

   0.61 0.61

7. Maximum room relative humidity

   0.50

8. Minimum air flow through each duct (for DD system)

   0.10

9. Excessive Air Leakage CFM/sq-ft

   1.000000E-01

10. O.A. CO2 (350); Zone CO2 (1000) ppm

    380.000000 840.000000

11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy

    1

12. Economizer Type 1-Enth.; 2-Temp.; 3-None;

    2

13. Economizer Range Tmin, Tmax

    20.00000 60.000000

14. Minimum and maximum outside air intake fraction

    0.13 0.45

15. Internal Heat Gain W/sq-ft

    0.82 0.82

16. Average Floor Area For Each Person sq-ft/person

    200.000

17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

1.000000 1.000000 1.000000 1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
41200 0.20
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
19017 0.80
24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.078 22 0.17 102
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
230 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
0 0
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
57 30 57 40 57 60 55 80 55 110

34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
105 20 105 40 75 70 75 90 75 110

35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
11 10 12 30 13 50 14 85 15 110

36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
55 160 55 260 55 360 55 460 55 560

E.3 The Kleberg Input Parameters

E3.1 Input Parameters Used in the Pre-CC Period

Section 1: General Information
1.1 Relative humidity (1) or dew point (0)
0
1.2 Dry bulb temperature (F) range (low and high)
22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 0 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
1
1.6 The first Vacation period:month, day to month day
1 1 1 14
1.7 The second vacation period:month, day to month day
5 15 8 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price \$/kWh, \$/MMBtu-CHW \$/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA, 4 SDRHMA, 5 SDHC, and 6 SDHCH)
4
2. Conditioned floor area (sq-ft) and fraction of interior area
165031 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
70 74 70 74
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.1 1.1 0.51 0.51
6. Minimum air flow for occupied and unoccupied
0.92 0.92
7. Maximum room relative humidity
0.55
8. Minimum air flow through each duct (for DD system)
0.1
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
1

12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
 3
13. Economizer Range Tmin, Tmax
 10.00000 55.000000
14. Minimum and maximum outside air intake fraction
 0.46 0.46
15. Internal Heat Gain W/sq-ft
 2.40 2.40
16. Average Floor Area For Each Person sq-ft/person
 200.000000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
 0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
 36000 0.17
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
 14880 1.09

24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.099 32 0.215 102
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
200 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
50 1
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
55 20 55 40 55 70 55 80 55 100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
110 20 100 30 95 70 95 85 95 110

35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
75 30 98 55 98 65 98 70 98 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
60 160 60 260 57 360 57 460 57 560

E3.2 Input Parameters Used in the Post-CC Period

Section 1: General Information
1.1 Relative humidity (1) or dew point (0)
0
1.2 Dry bulb temperature (F) range (low and high)
22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 0 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
1
1.6 The first Vacation period:month, day to month day
1 1 1 14
1.7 The second vacation period:month, day to month day
5 15 8 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA, 4 SDRHMA, 5 SDHC, and 6 SDHCH)
4
2. Conditioned floor area (sq-ft) and fraction of interior area
180031 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
70 74 70 74
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.1 1.1 0.51 0.51
6. Minimum air flow for occupied and unoccupied
0.70 0.70
7. Maximum room relative humidity

0.55
8. Minimum air flow through each duct (for DD system)
0.1
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3
13. Economizer Range Tmin, Tmax
10.00000 60.000000
14. Minimum and maximum outside air intake fraction
0.46 0.46
15. Internal Heat Gain W/sq-ft
2.40 2.40
16. Average Floor Area For Each Person sq-ft/person
200.000000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
36000 0.17
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
14880 1.09
24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.099 32 0.215 102
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
200 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
50 1
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
62 20 62 40 57 60 57 70 57 80
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
110 20 100 30 95 70 95 85 95 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
52 20 52 30 52 40 47 60 47 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
60 160 60 260 57 360 57 460 57 560

E3.3 Input Parameters Used in the Year 2000 Period

Section 1: General Information
1.1 Relative humidity (1) or dew point (0)
0
1.2 Dry bulb temperature (F) range (low and high)
22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 0 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
1
1.6 The first Vacation period:month, day to month day
1 1 1 14
1.7 The second vacation period:month, day to month day
5 15 8 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price \$/kWh, \$/MMBtu-CHW \$/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA, 4 SDRHMA, 5 SDHC, and 6 SDHCH)

4
2. Conditioned floor area (sq-ft) and fraction of interior area
180031 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
70 74 70 74
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.1 1.1 0.33 0.33
6. Minimum air flow for occupied and unoccupied
0.92 0.92
7. Maximum room relative humidity
0.55
8. Minimum air flow through each duct (for DD system)
0.1
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin;
4:IAQ;5:IAQ+Occupancy
1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3
13. Economizer Range Tmin, Tmax
10.00000 60.000000
14. Minimum and maximum outside air intake fraction
0.30 0.30
15. Internal Heat Gain W/sq-ft
2.40 2.40
16. Average Floor Area For Each Person sq-ft/person
200.000000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
36000 0.17
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
14880 1.09
24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.099 32 0.215 102
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
200 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
50 1
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
63 20 63 40 53 70 53 80 53 100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
110 20 100 30 95 70 95 85 95 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
74 30 74 40 76 70 76 80 76 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
60 160 60 260 57 360 57 460 57 560

E.4 The VMC Addition Input Parameters

E4.1 Input Parameters Used in the Pre-CC Period

E4.1.1 Input Parameters (Case I: 7/01/1996 – 8/18/1996)

Section 1: General Information
1.1 Relative humidity (1) or dew point (0)

0
1.2 Dry bulb temperature (F) range (low and high)
22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 0 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
1
1.6 The first Vacation period:month, day to month day
1 1 1 14
1.7 The second vacation period:month, day to month day
5 15 8 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA, 4 SDRHMA, 5 SDHC, and 6 SDHCH)
3
2. Conditioned floor area (sq-ft) and fraction of interior area
117666 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
70 73 70 73
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.15 1.15 0.81 0.81
6. Minimum air flow for occupied and unoccupied
0.60 0.60
7. Maximum room relative humidity
0.50
8. Minimum air flow through each duct (for DD system)
0.1
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3

13. Economizer Range Tmin, Tmax
10.00000 70.000000
14. Minimum and maximum outside air intake fraction
0.705 0.705
15. Internal Heat Gain W/sq-ft
2.75 2.75
16. Average Floor Area For Each Person sq-ft/person
200.000000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
33560 0.10
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
22370 0.81
24. Air infiltration for interior and exterior zones (ACH)
0 0

25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.07 30 0.15 100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
165 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
130 1
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
55 20 55 45 55 85 55 90 55 110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
110 20 100 30 95 70 95 85 95 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
50 10 50 30 50 50 50 85 50 110

36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
60 160 60 260 57 360 57 460 57 560

E4.1.2 Input Parameters (Case II: 5/17/1996–6/12/1996 and 8/19/1996–10/15/1996)

Section 1: General Information
1.1 Relative humidity (1) or dew point (0)
0
1.2 Dry bulb temperature (F) range (low and high)
22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 0 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
1
1.6 The first Vacation period:month, day to month day
1 1 1 14
1.7 The second vacation period:month, day to month day
5 15 8 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA, 4 SDRHMA, 5 SDHC, and 6 SDHCH)
3
2. Conditioned floor area (sq-ft) and fraction of interior area
117666 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
70 73 70 73
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.15 1.15 0.86 0.86
6. Minimum air flow for occupied and unoccupied
0.70 0.70
7. Maximum room relative humidity
0.50
8. Minimum air flow through each duct (for DD system)

0.1

9. Excessive Air Leakage CFM/sq-ft

1.000000E-01

10. O.A. CO2 (350); Zone CO2 (1000) ppm

380.000000 840.000000

11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy

1

12. Economizer Type 1-Enth.; 2-Temp.; 3-None;

3

13. Economizer Range Tmin, Tmax

10.00000 70.000000

14. Minimum and maximum outside air intake fraction

0.75 0.75

15. Internal Heat Gain W/sq-ft

2.75 2.75

16. Average Floor Area For Each Person sq-ft/person

200.000000

17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
33560 0.10
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
22370 0.81
24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.07 30 0.15 100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
165 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
130 1
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
 52 20 52 45 52 85 52 90 52 110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
 110 20 100 30 95 70 95 85 95 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
 50 10 50 30 50 50 50 85 50 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
 60 160 60 260 57 360 57 460 57 560

E4.2 Input Parameters Used in the Post-CC Period

Section 1: General Information
1.1 Relative humidity (1) or dew point (0)
 0
1.2 Dry bulb temperature (F) range (low and high)
 22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
 1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
 1 0 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
 1
1.6 The first Vacation period:month, day to month day
 1 1 1 14
1.7 The second vacation period:month, day to month day
 5 15 8 28
1.8 The third vacation period:month, day to month day
 12 15 12 31
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
 0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA, 4 SDRHMA, 5 SDHC, and 6 SDHCH)
 3
2. Conditioned floor area (sq-ft) and fraction of interior area

117666 0.5

3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
   70 73 70 73
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   1.15 1.15 0.86 0.86
6. Minimum air flow for occupied and unoccupied
   0.64 0.64
7. Maximum room relative humidity
   0.50
8. Minimum air flow through each duct (for DD system)
   0.1
9. Excessive Air Leakage CFM/sq-ft
   1.000000E-01
10. O.A. CO_2 (350); Zone CO_2 (1000) ppm
    380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin;
4:IAQ;5:IAQ+Occupancy
    1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
    3
13. Economizer Range Tmin, Tmax
    10.00000 70.000000
14. Minimum and maximum outside air intake fraction
    0.75 0.75
15. Internal Heat Gain W/sq-ft
    2.75 2.75
16. Average Floor Area For Each Person sq-ft/person
    200.000000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
33560 0.10
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
22370 0.81
24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.07 30 0.15 100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
165 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
130 1
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000

31. Clock HVAC Operation Model for Sunday
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000

32. Clock HVAC Operation Model for Vacation
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000
1.000000 1.000000 1.000000 1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
57 20 57 45 57 55 53 85 53 110

34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
110 20 100 30 95 70 95 85 95 110

35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
50 10 50 30 50 50 50 85 50 110

36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
60 160 60 260 57 360 57 460 57 560

E4.3 Input Parameters Used in the Year 2000 Period

Section 1: General Information

1.1 Relative humidity (1) or dew point (0)
0

1.2 Dry bulb temperature (F) range (low and high)
22 110

1.3 Do you have decimal date in the input file (1=y or 0=n)
1

1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 0 0 0 0 0 0

1.5 The key system in this investigation (1 to 7)
1

1.6 The first Vacation period:month, day to month day

1 1 1 14
1.7 The second vacation period:month, day to month day
5 15 8 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA, 4 SDRHMA, 5 SDHC, and 6 SDHCH)
3
2. Conditioned floor area (sq-ft) and fraction of interior area
117666 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
70 73 70 73
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.15 1.15 0.86 0.86
6. Minimum air flow for occupied and unoccupied
0.64 0.64
7. Maximum room relative humidity
0.50
8. Minimum air flow through each duct (for DD system)
0.1
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin;
4:IAQ;5:IAQ+Occupancy
1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3
13. Economizer Range Tmin, Tmax
10.00000 70.000000
14. Minimum and maximum outside air intake fraction
0.75 0.75
15. Internal Heat Gain W/sq-ft
2.75 2.75
16. Average Floor Area For Each Person sq-ft/person
200.000000
17. Clock Internal Electrical gain Ratio for Weekdays
1.000000 1.000000 1.000000 1.000000

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000

21. Nighttime Base Electrical Gain Ratio
    0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
    33560 0.10
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
    22370 0.81
24. Air infiltration for interior and exterior zones (ACH)
    0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
    0.07 30 0.15 100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
    165 1

27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
    130 1

28. Temp. Diff. Between Return and Room Air Temp F
    2.000000

29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
55.5 20 55.5 45 55.5 85 55.5 90 55.5 110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
110 20 100 30 95 70 95 85 95 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
50 10 50 30 50 50 50 85 50 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
60 160 60 260 57 360 57 460 57 560

E.5 The WehnerBuilding Input Parameters

E5.1 Input Parameters Used in the Pre-CC Period

Section 1: General Information
1.1 Relative humdity (1) or dew point (0)
0
1.2 Dry bulb temperature (F) range (low and high)
22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 1 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
1
1.6 The first Vacation period:month, day to month day
3 8 3 14
1.7 The second vacation period:month, day to month day
5 14 5 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
1
2. Conditioned floor area (sq-ft) and fraction of interior area
104000 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
71 73 71 78
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.0 1.0 0.10 0.10
6. Minimum air flow for occupied and unoccupied
0.67 0.67
7. Maximum room relative humidity
0.50
8. Minimum air flow through each duct (for DD system)
0.05
9. Excessive Air Leakage CFM/sq-ft
1.100000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm

350.000000 1000.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3
13. Economizer Range Tmin, Tmax
10.00000 60.000000
14. Minimum and maximum outside air intake fraction
0.10 0.10
15. Internal Heat Gain W/sq-ft
0.84 0.84
16. Average Floor Area For Each Person sq-ft/person
200.000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

21. Nighttime Base Electrical Gain Ratio
0.00

22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
 35750 0.20
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
 24500 0.92
24. Air infiltration for interior and exterior zones (ACH)
 0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
 0.08 24 0.195 98
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
 186 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
 0 0
28. Temp. Diff. Between Return and Room Air Temp F
 2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
55 20 55 40 55 50 55 80 55 100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
140 20 110 80 110 85 110 90 110 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
50 10 50 36 50 50 50 85 50 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
55 160 55 260 55 360 55 460 57 560

Section 3: Inputs for sub-system 2

1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
3
2. Conditioned floor area (sq-ft) and fraction of interior area
35000 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
71 75 71 82
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.0 1.0 0.10 0.10
6. Minimum air flow for occupied and unoccupied
0.67 0.67
7. Maximum room relative humidity
0.55
8. Minimum air flow through each duct (for DD system)
0
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
2
13. Economizer Range Tmin, Tmax
10 70
14. Minimum and maximum outside air intake fraction
0.10 0.60
15. Internal Heat Gain W/sq-ft
0.84 0.84
16. Average Floor Area For Each Person sq-ft/person
200.0000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

20. Clock Internal Electrical Gain Ratio for Vacation

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

21. Nighttime Base Electrical Gain Ratio
  0.0

22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
  11250 0.20

23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
  7500 0.92

24. Air infiltration for interior and exterior zones (ACH)
  0 0

25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
  0.04 24 0.065 98

26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
  80 1

27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
  27.5 1

28. Temp. Diff. Between Return and Room Air Temp F

2.000000

29. Clock HVAC Operation Model for Weekdays

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

30. Clock HVAC Operation Model for Saturday

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

31. Clock HVAC Operation Model for Sunday

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

32. Clock HVAC Operation Model for Vacation

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5

55 30 55 50 55 80 55 90 55 100

34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5

105 20 105 40 75 70 75 85 75 110

35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5

50 10 50 30 50 50 50 85 50 110

36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5

55 160 55 260 55 360 55 460 57 560

E5.2 Input Parameters Used in the Post-CC Period

Section 1: General Information
1.1 Relative humdity (1) or dew point (0)
0
1.2 Dry bulb temperature (F) range (low and high)
22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 1 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
1
1.6 The first Vacation period:month, day to month day
3 8 3 14
1.7 The second vacation period:month, day to month day
5 14 5 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
1
2. Conditioned floor area (sq-ft) and fraction of interior area
104000 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
71 73 71 78
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.0 1.0 0.10 0.10
6. Minimum air flow for occupied and unoccupied
0.60 0.60
7. Maximum room relative humidity
0.50
8. Minimum air flow through each duct (for DD system)
0.05
9. Excessive Air Leakage CFM/sq-ft
1.100000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
350.000000 1000.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin;
4:IAQ;5:IAQ+Occupancy
1

12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
 3
13. Economizer Range Tmin, Tmax
 10.00000 60.000000
14. Minimum and maximum outside air intake fraction
 0.10 0.10
15. Internal Heat Gain W/sq-ft
 0.84 0.84
16. Average Floor Area For Each Person sq-ft/person
 200.000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

21. Nighttime Base Electrical Gain Ratio
 0.00
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
 35750 0.20
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
 24500 0.92

24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
0.08 24 0.195 98
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
186 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
0 0
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
60 20 60 40 60 55 53 80 53 100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
110 20 110 40 75 70 75 90 75 110

35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
50 10 50 36 50 50 50 85 50 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
55 160 55 260 55 360 55 460 57 560
Section 3: Inputs for sub-system 2
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
3
2. Conditioned floor area (sq-ft) and fraction of interior area
35000 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
71 75 71 82
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.0 1.0 0.10 0.10
6. Minimum air flow for occupied and unoccupied
0.60 0.60
7. Maximum room relative humidity
0.55
8. Minimum air flow through each duct (for DD system)
0
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
2
13. Economizer Range Tmin, Tmax
10 70
14. Minimum and maximum outside air intake fraction
0.10 0.60
15. Internal Heat Gain W/sq-ft
0.84 0.84
16. Average Floor Area For Each Person sq-ft/person
200.0000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

20. Clock Internal Electrical Gain Ratio for Vacation

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

21. Nighttime Base Electrical Gain Ratio

0.0

22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)

11250 0.20

23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)

7500 0.92

24. Air infiltration for interior and exterior zones (ACH)

0 0

25. Solar Gains (Solarmin, Toa; Solarmax, Toa)

0.04 24 0.065 98

26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD

80 1

27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD

27.5 1

28. Temp. Diff. Between Return and Room Air Temp F

2.000000

29. Clock HVAC Operation Model for Weekdays

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

30. Clock HVAC Operation Model for Saturday

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

31. Clock HVAC Operation Model for Sunday

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

32. Clock HVAC Operation Model for Vacation

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
58 30 58 50 53 80 53 90 53 100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
105 20 105 40 75 70 75 85 75 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
50 10 50 30 50 50 50 85 50 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
55 160 55 260 55 360 55 460 57 560

E5.3 Input Parameters Used in the Year 2000 Period

Section 1: General Information
1.1 Relative humdity (1) or dew point (0)
0

1.2 Dry bulb temperature (F) range (low and high)
22 110
1.3 Do you have decimal date in the input file (1=y or 0=n)
1
1.4 Job for each subsystem: 0-Not exist; 1 simulation; and 3 optimization
1 1 0 0 0 0 0
1.5 The key system in this investigation (1 to 7)
1
1.6 The first Vacation period:month, day to month day
3 8 3 14
1.7 The second vacation period:month, day to month day
5 14 5 28
1.8 The third vacation period:month, day to month day
12 15 12 31
1.9 Energy price \$/kWh, \$/MMBtu-CHW \$/MMBtu-HW
0.02788 4.670 4.750
Section 2: Inputs for sub-system 1
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
1
2. Conditioned floor area (sq-ft) and fraction of interior area
104000 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
71 73 71 78
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.0 1.0 0.10 0.10
6. Minimum air flow for occupied and unoccupied
0.60 0.60
7. Maximum room relative humidity
0.50
8. Minimum air flow through each duct (for DD system)
0.05
9. Excessive Air Leakage CFM/sq-ft
1.100000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
350.000000 1000.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
3
13. Economizer Range Tmin, Tmax

10.00000 60.000000

14. Minimum and maximum outside air intake fraction
0.10 0.10
15. Internal Heat Gain W/sq-ft
0.84 0.84
16. Average Floor Area For Each Person sq-ft/person
200.000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

20. Clock Internal Electrical Gain Ratio for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

21. Nighttime Base Electrical Gain Ratio
0.00
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
35750 0.20
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
24500 0.92
24. Air infiltration for interior and exterior zones (ACH)
0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)

0.08 24 0.195 98
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
186 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
0 0
28. Temp. Diff. Between Return and Room Air Temp F
2.000000
29. Clock HVAC Operation Model for Weekdays

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

30. Clock HVAC Operation Model for Saturday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

31. Clock HVAC Operation Model for Sunday

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

32. Clock HVAC Operation Model for Vacation

1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000
1.000000	1.000000	1.000000	1.000000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5
63 20 63 40 63 50 56 80 56 100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
110 20 110 40 75 70 75 90 75 110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
50 10 50 36 50 50 50 85 50 110
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5

55 160 55 260 55 360 55 460 57 560
Section 3: Inputs for sub-system 2
1. System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6 SDHCH)
3
2. Conditioned floor area (sq-ft) and fraction of interior area
35000 0.5
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
8 17 0 0 0 0 0 0
4. Room temperature for occupied and unoccupied (heating and cooling)
71 75 71 82
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
1.0 1.0 0.10 0.10
6. Minimum air flow for occupied and unoccupied
0.60 0.60
7. Maximum room relative humidity
0.55
8. Minimum air flow through each duct (for DD system)
0
9. Excessive Air Leakage CFM/sq-ft
1.000000E-01
10. O.A. CO2 (350); Zone CO2 (1000) ppm
380.000000 840.000000
11. O.A. control 1:bet=c; 2:CFMoa=c, 3:CFMoa>=CFMoamin; 4:IAQ;5:IAQ+Occupancy
1
12. Economizer Type 1-Enth.; 2-Temp.; 3-None;
2
13. Economizer Range Tmin, Tmax
10 70
14. Minimum and maximum outside air intake fraction
0.10 0.60
15. Internal Heat Gain W/sq-ft
0.84 0.84
16. Average Floor Area For Each Person sq-ft/person
200.0000
17. Clock Internal Electrical gain Ratio for Weekdays

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

18. Clock Internal Electrical Gain Ratio for Saturday

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

19. Clock Internal Electrical Gain Ratio for Sunday

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

20. Clock Internal Electrical Gain Ratio for Vacation

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

21. Nighttime Base Electrical Gain Ratio
 0.0
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
 11250 0.20
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
 7500 0.92
24. Air infiltration for interior and exterior zones (ACH)
 0 0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
 0.04 24 0.065 98
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
 80 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
 27.5 1
28. Temp. Diff. Between Return and Room Air Temp F
 2.000000
29. Clock HVAC Operation Model for Weekdays

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

1.00000	1.00000	1.00000	1.00000

30. Clock HVAC Operation Model for Saturday

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

31. Clock HVAC Operation Model for Sunday

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

32. Clock HVAC Operation Model for Vacation

1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000

33. Cold Deck Schedule: Tc1, Ta1;..... Tc5, Ta5

62 30 62 60 55 80 55 90 55 100

34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5

105 20 105 40 75 70 75 85 75 110

35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5

50 10 50 30 50 50 50 85 50 110

36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5

55 160 55 260 55 360 55 460 57 560