A COMPARISON OF COMMISSIONING SAVINGS DETERMINATION METHODOLOGIES AND THE PERSISTENCE OF COMMISSIONING SAVINGS IN THREE BUILDINGS

A Thesis

by

KENNETH PAUL ENGAN

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

August 2007

Major Subject: Mechanical Engineering

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Chair of Committee, David Claridge
Committee Members, W. Dan Turner
Charles Culp
Head of Department, Dennis O'Neal

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ABSTRACT

A Comparison of Commissioning Savings Determination Methodologies and the
Persistence of Commissioning Savings in Three Buildings. (August 2007)
Kenneth Paul Engan, B.S., Brigham Young University
Chair of Advisory Committee: Dr. David Claridge

This thesis compares the variability of commissioning savings and the persistence of savings from the Normalized Annual Consumption (NAC) and standard International Performance Measurement and Verification Protocol (IPMVP) weather normalization approaches and from Option C and Option D of the IPMVP. Twenty-nine different weather years were used to obtain a set of savings results under each method.

Variability of savings was quantified by the average standard deviation of the 29 percent savings results across all post-commissioning periods for each method. For the combined chilled and hot water savings, the average standard deviation is 0.39% savings for Option D using the NAC weather normalization approach, 0.57% savings for Option D using the standard IPMVP weather normalization approach, 0.71% savings for Option C with regression models using the NAC weather normalization approach, and 0.98% savings for Option C with regression models using the standard IPMVP weather normalization approach.

The variability of savings persistence results deviate a little from variability of savings results. For the combined chilled and hot water persistence of savings, the average standard deviation across all post-commissioning periods is 0.48% persistence for Option D using the NAC weather normalization approach, 0.55% persistence for Option D using the standard IPMVP weather normalization approach, 0.52% persistence for Option C with regression models using the NAC weather normalization approach, and

1.26% persistence for Option C with regression models using the standard IPMVP weather normalization approach.

Overall, the NAC weather normalization approach shows less variability in savings and persistence than the standard IPMVP weather normalization approach. Additionally, Option D of the IPMVP generally shows less variability in savings and persistence of savings than Option C with regression models.

This thesis also determines the savings and persistence of savings from commissioning for three Texas A&M University buildings. Aggregate site savings averaged 11.4%, 16.5%, and 19.0% for the three buildings over differing periods of available data.

Persistence results for the three buildings are quite favorable, as each building shows an increase in aggregate site savings between the first and last post-commissioning periods. Follow-up commissioning restored and prevented degradation of savings in two of the buildings.

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TABLE OF CONTENTS

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

TABLE Page

CHAPTER I
INTRODUCTION

1.1 Background

In recent years there has been steady progress to improve existing building energy efficiency through a process known as commissioning. Commissioning can also be applied to new buildings but this study focuses on the commissioning of existing buildings. The purpose of commissioning as detailed by ASHRAE is to ensure proper operation of a building according to the design intent (1996). Several existing building commissioning processes exist, including retro-commissioning (RCx) and Continuous Commissioning® (CC®). Retro-commissioning is a one-time, systematic investigation of a building to improve and optimize the building's operations and maintenance (O&M). The process is intended not only to optimize how equipment and systems operate, but also to optimize how the systems function together (Herbst 2003). The CC® process focuses on optimizing HVAC system operation and control for existing building conditions. Common CC® measures in buildings include shutting systems down during unoccupied periods and/or slowing them down during lightly occupied periods, optimizing supply air temperatures, and improving static pressure set points and schedules to name a few. CC® maintains long-term savings by ongoing monitoring of energy savings with follow-up commissioning, as needed (Liu et al. 2002). While there are variations in the different types of existing building commissioning processes, they are collectively referred to as commissioning in this study.

The commissioning process has been performed on hundreds of buildings and has been shown to provide cost-effective energy savings. Savings have generally tended to

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This thesis follows the style of *ASHRAE Transactions.*

degrade over time but have sometimes remained fairly constant over time (Mills et al. 2004, Mills et al. 2005). The means used to determine these savings vary in both complexity and ease of performance. The International Performance Measurement and Verification Protocol (IPMVP) defines acceptable approaches for determining energy savings in buildings that have undergone energy conservation measures (ECMs) such as those carried out during commissioning (IPMVP 2002). Under the IPMVP there are four separate savings determination methods, Options A-D. Option A and Option B are not appropriate for determining whole building commissioning savings and are thus not applicable to this study.

Option C of the IPMVP uses whole building data to develop consumption models such as regression models while Option D uses calibrated simulations to determine building energy consumption. Regression models are a quick way to relate heating and cooling consumption to the outside dry bulb temperature for a specific time period using that period's consumption data. Calibrated simulations require a series of inputs to a simulation tool that are adjusted, or calibrated, until the simulated consumption closely matches the heating and cooling data as a function of the outside dry bulb temperature. Calibrated simulations are valuable because they can identify and verify potential causes for changes in consumption from year to year but are much more time consuming than regression models.

Once an energy consumption model (regression model or calibrated simulation) that determines consumption as a function of outside dry bulb temperature has been obtained for baseline and post-commissioning periods, commissioning savings can be determined by two different weather normalization approaches, the standard International Performance Measurement and Verification Protocol (IPMVP) weather normalization approach (IPMVP 2002) or by the Normalized Annual Consumption (NAC) weather normalization approach (Fels 1986). The standard IPMVP weather normalization approach calculates actual savings as the difference between the post-commissioning energy consumption determined by the pre-commissioning baseline model when using the post-commissioning weather data and the measured energy consumption during the post-commissioning period. In contrast, energy consumption models can be weather-normalized to "normal" or average weather conditions to mitigate the effects of varying weather from year to year. The common term for the annual consumption under the "normal" weather year is Normalized Annual Consumption or NAC (Fels 1986). Under the NAC weather normalization approach, each of the energy consumption models uses the "normal" weather year and savings are determined by the difference in the baseline and post-commissioning consumption.

Since the reported savings from commissioning are essential in telling the success of a commissioned building, it is important to know in some terms how the savings and persistence of savings results of one savings determination procedure compare to the other. In particular, it is useful to know whether use of the NAC weather normalization approach provides less variability in the persistence of commissioning savings than use of the standard IPMVP weather normalization approach when using a set of different weather years. Likewise, it is valuable to identify whether use of Option C of the IPMVP with regression modeling provides less variability in the persistence of commissioning savings than use of Option D of the IPMVP when using a set of different weather years. Persistence of savings refers to the degree to which post-commissioning savings are maintained from year-to-year. Specifically, the persistence of savings is the absence of change in savings between the first post-commissioning period and any later subsequent post-commissioning period.

Using the weather normalization approaches and IPMVP savings determination methods mentioned above, about 30 existing buildings have been analyzed in previous studies to quantify savings persistence and identify reasons for changes in savings from year to year after commissioning has been performed. Similarly, over 100 buildings that have undergone major retrofits have been analyzed to quantify savings persistence.

Additional commissioned and retrofitted buildings have been previously analyzed where savings results are given without persistence results. Further research on additional buildings is important because a larger set of buildings documenting savings persistence can help identify ways to make commissioning savings persist longer and encourage more to take advantage of the benefits of this energy saving process.

1.2 Objectives

This thesis aims to study and compare the variability of the NAC and standard IPMVP weather normalization approaches and of Option C with regression modeling and Option D of the IPMVP in determining the energy savings of a commissioned building. In addition, energy savings persistence results will be shown and analyzed for several specific buildings that have undergone commissioning. The objectives of this thesis are to determine:

- Whether use of the NAC weather normalization approach provides less variability in commissioning savings and the persistence of commissioning savings than use of the standard IPMVP weather normalization approach, and to quantify any difference observed.
- Whether use of Option C of the IPMVP with regression modeling provides less variability in commissioning savings and the persistence of commissioning savings than use of Option D of the IPMVP, and to quantify any difference observed.
- The persistence of savings from commissioning and possible reasons for savings degradation or increase over time for three buildings that have been commissioned.

CHAPTER II
LITERATURE REVIEW

2.1 Energy Savings Determination Methodologies

2.1.1 IPMVP Savings Methods and Weather Normalization Approach

In order to establish a standardized, reliable, and accurate methodology for determining energy savings, the U.S. Department of Energy (DOE) has established the International Performance Measurement and Verification Protocol (IPMVP 2002). IPMVP contains 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 identifies four Measurement and Verification (M&V) options (A-D) and gives a general procedure for each to determine reliable savings values. These options include partially measured retrofit isolation (Option A), retrofit isolation (Option B), whole facility (Option C), and calibrated simulation (Option D). Option A and Option B are not discussed further since they are not applicable to whole building commissioning savings.

Option C uses whole building data as opposed to data from an isolated portion of a building. This method of savings determination is useful when measuring the combined savings of multiple commissioning measures and when measuring interaction effects such as the impact of a lighting retrofit on the cooling consumption as well as savings in lighting energy. In order to use Option C, the size of the savings must be large enough to be discernible from the random or unexplained energy variations normally found at the level of the whole facility meter. Periodic inspections should be made to confirm systems and equipment are operating as intended after commissioning. It can be difficult sometimes to account for changes in equipment or building operation not made as part of the commissioning process and unknown to those monitoring savings. With

Option C, whole building data is used to develop a model for the baseline period. Many models appropriate for Option C are possible but statistical evaluation indices should be considered when selecting the appropriate model. Regression models that determine energy consumption as a function of ambient temperature are common under Option C.

Option D determines savings through simulation of energy use of components or the whole facility. Measured data is used to verify that the simulations adequately model the actual building energy performance. A calibration must be performed that involves modifying simulation inputs till the error between measured data and simulated output is minimized. For commissioning applications, it is recommended that calibration be to daily or hourly data. Simulation analysis should be conducted by one who is experienced with the appropriate software selected and simulation analyses must be well documented with electronic and hard copies of the input and output. Where possible, it is helpful to have access to information on actual building characteristics and operating data used for simulation inputs such as actual building ventilation and infiltration rates. As with the other M&V options, periodic inspections should occur to identify any changes made to equipment and operations after commissioning has taken place. Option D is particularly useful when baseline energy data do not exist or are unavailable. In such cases, calibrated simulations from post-commissioning data can be altered to reflect the baseline consumption by changing those inputs corresponding to implemented commissioning measures to a documented pre-commissioning value.

The IPMVP gives what this study refers to as the standard IPMVP weather normalization approach, which is used to determine actual savings from commissioning activities. Each of the four IPMVP options determines savings, S_{IPMVP}, according to the following equation:

$$S_{IPMVP}=E_{pre}-E_{meas,post} \tag{2.1}$$

where E_{pre} is the baseline or pre-commissioning energy consumption and $E_{meas,post}$ is the measured consumption during the post-commissioning period. This savings determination procedure calculates the difference between post-commissioning energy consumption determined by the baseline model with the post-commissioning period weather, E_{pre}, and the measured energy consumption from the post-commissioning period, $E_{post,meas}$.

2.1.2 Regression Models and NAC Weather Normalization Approach

An energy savings determination approach developed in the 1980s at Princeton University called PRISM (PRInceton Scorekeeping Method) uses both weather normalization and regression modeling (Fels 1986). PRISM is an accurate and straightforward method of determining energy savings from energy conservation measures and NAC is its associated weather normalization approach.

PRISM has been applied mainly to heating-dominated residential buildings but the principle of normalizing consumption to a typical weather year is important for buildings of all types. The PRISM method determines the daily consumption of a house's heating system, f, by the equation

$$f = \alpha + \beta(\tau - T_{out})_+ \tag{2.2}$$

where $\acute{\alpha}$ is a fixed base level of heating consumption per day, β is a proportional constant that represents the house's effective heat-loss rate, τ is the house's reference temperature, a reflection of the interior temperature settings, T_{out} is the outside air temperature, and the "+" indicates the expression $\beta(\tau - T_{out})$ is set to zero if the term inside the parentheses is negative. The term $(\tau - T_{\text{out}})$ represents the heating degree-days h to base τ, $h(\tau)$.

The two data requirements for the PRISM method are metered consumption and local daily averaged outdoor temperatures, from which heating degree-days to different reference temperatures are computed in exact correspondence to the consumption periods. The average daily consumption in the time interval i, F_i, is the consumption in the time interval (generally one year periods) *i* divided by N_i, the number of days in that interval. The heating degree-days per day computed to the reference temperature τ in time interval *i* are given by $H_i(\tau)$. $H_i(\tau)$ is computed from T_{ij}, the average daily outdoor temperature for the *j*th day of interval *i*, over N_i days:

$$H_i(\tau) = \sum_{j=1}^{N_i} (\tau - T_{ij})_+ / N_i \tag{2.3}$$

The set of data points $\{F_i\}$ and $\{H_i\}$ for the time interval is then fit to a linear model:

$$F_i = \alpha + \beta H_i(\tau) + \varepsilon_i \tag{2.4}$$

where ε_i is the random error. As mentioned above, τ has a variable value and must be solved for iteratively till the plot of F_i vs. $H_i(\tau)$ is most nearly a straight line.

The PRISM method determines a weather-adjusted index of consumption, Normalized Annual Consumption or NAC for each period that provides a measure of what energy consumption would be during a year under typical weather conditions. NAC is obtained from the model parameters ά, β, and τ, applied to a long-term annual average of heating degree-days. NAC is calculated by the following equation:

$$\text{NAC} = 365\acute{\alpha} + \beta H_o(\tau) \tag{2.5}$$

where $H_o(\tau)$ is the heating degree-days (base τ) in a "typical" year.

NAC is a reliable and stable index of consumption. The variables ά and β are much more sensitive to variations in τ than is NAC. Even in extreme cases when one or more of the parameters is poorly determined, the standard error of NAC is usually only 2-4% of the determined consumption, making NAC a very stable tool of weather normalization to determine energy consumption and savings.

The NAC weather normalization approach applied to data from commissioned buildings compares pre- and post-commissioning model consumption during a "normal" weather year. The PRISM method suggests using 10 or more years of average daily temperature data to estimate “normal” weather. By using the same weather across all models, the variation in the consumption due to different weather patterns from year to year is minimized.

Energy savings from commissioning under the NAC weather normalization approach is calculated using the following equation:

$$S_{NAC} = NAC_{pre} - NAC_{post} \tag{2.6}$$

where NAC_{pre} = normalized annual consumption determined by the pre-commissioning model

NAC_{post} = normalized annual consumption determined by the post-commissioning model

Further study was done by Ruch and Claridge (1993) to develop NAC for different types of regression models, namely the two-parameter linear regression and four-parameter change-point models (4P CP). Accompanying error diagnostics were also developed. The development of these models is significant because it gives more choices for fitting a physically meaningful model to data and determining a reliable NAC value. In general, 4P CP models provide better goodness-of-fit than the two-parameter linear regression and PRISM (which is a three-parameter change point model) models. This is particularly true for commercial buildings which experience simultaneous heating and cooling year round.

All of the above mentioned regression models—two-parameter linear regression, three-parameter change point (3P CP or PRISM), and four-parameter change point (4P CP)—use ambient temperature as the sole independent variable. These models have been shown to describe commercial building heating and cooling energy use with root mean square error (RMSE) values of about 15 percent of the mean energy consumption even with data time-intervals as short as a day. Using a model that relies on ambient temperature as its sole independent variable is also advantageous because it eliminates statistical problems due to multicollinearity and reduces data collection requirements to a single, accurately-measured, and widely available parameter (Kissock et al. 1998).

In addition to the NAC weather normalization approach, the regression models discussed above can also be applied to the standard IPMVP weather normalization approach referred to in the IPMVP. These regression models can be used with Option C of the IPMVP that utilizes whole building data to determine energy consumption.

2.1.3 Calibrated Simulations

Calibrated simulations can also be utilized in conjunction with the standard IPMVP and NAC weather normalization approaches. Calibrated simulations make up Option D of the IPMVP.

Simulation tools come in a wide variety of complexity level and user friendliness from whole building modeling programs such as DOE 2 (LBL 1979) and BLAST (Hittle 1977) to simplified air-side modeling programs like AirModel (Liu 1995). Knebel (1983) developed a simplified energy analysis method using the modified bin method to provide a procedure to model building energy consumption that is simple enough for a manual application and which accounts for the significant parameters affecting the energy usage of buildings. This simplified energy analysis method significantly reduces user inputs because it uses time averaging, steady-state techniques for building loads. The method is generally useful when the building mass is not a primary issue in the analysis. In buildings where the heat losses/gains, internal loads, and HVAC systems are simple the method provides reasonable results. AirModel adapts these simplified techniques to use with hourly averaged temperature data rather than bin data and is the simulation tool of choice in this study. Daily averaged temperature data can also be used for further simplification under steady-state assumptions. Using AirModel over a more complex simulation tool is advantageous because it allows the user to focus more on the major contributions to energy consumption and less time on simulation. The assumptions necessary to use AirModel for this study apply to the buildings that are investigated and it is used for calibrated simulation.

Calibrated simulation requires a general knowledge of building parameters and HVAC system characteristics and settings such as conditioned floor area, room temperature, cold deck temperature, total and outside air flow settings, and night-time setback schedules to name a few. Many of these values are taken from building design data, which can often result in output errors of as much as 50% or more when compared with actual building performance (Claridge et al. 2003). A means of calibrating the simulation is thus necessary to correct for this error. Wei et al. (1998) developed a method for calibrating simulations that is based on a graphical representation of the difference between the simulated and measured building consumption, referred to as a "calibration signature". This method was subsequently modified slightly by Claridge et al. (2003). The calibration signature is compared to a published "characteristic signature" to give the analyst clues regarding the errors in the simulation inputs. The calibration signature method is used in this study because it is relatively quick and reliable.

2.1.4 Other Savings Determination Models

While regression models and calibrated simulations are two important energy consumption models given in the IPMVP for determining building energy consumption, there are also many other models for determining energy consumption. A list of these is given by Chen et al. (2003), who compared five different savings models using the standard IPMVP weather normalization approach where actual savings are calculated as the difference between the baseline model energy usage using post-retrofit weather data and the actual post-retrofit usage. The five models used to determine savings were the degree-day method, bin method, linear change-point regression, neural networks, and genetic programming. Two buildings, the Ankeny Elementary School and the Town Engineering Building, were selected that underwent no retrofits or operational changes so that the energy changes were known to be zero. For both buildings, the collected data were divided into two groups: pre-retrofit data from the first half of each month and the post-retrofit data from the second half of each month. Each model was then applied to predict the known value of zero post-retrofit energy savings using models developed with the pre-retrofit data. The five models were compared by their abilities to predict the post-retrofit energy use using data from the second half of the month. The percent error, the difference between actual consumption and consumption determined by the model as a percent of the actual consumption, was calculated for each month. The overall performance of each method, represented by the coefficient of variation of the root mean square error (CV-RMSE), was calculated. CV-RMSE is defined as

$$CV - RMSE = \frac{1}{\bar{y}}\sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-1}} \tag{2.7}$$

where y is the dependent variable of the data set, n is the number of observations, $\bar{y}$ is the arithmetic mean value, and $\hat{y}$ is the model-predicted value of y.

Tables 2.1 and 2.2 show the results for the two buildings. The results for the Ankeny Elementary School data in Table 2.1 show the CV-RMSE for the energy use predictions varied from 18.0% for the neural network to 25.8% for the 65°F-base degree-day method. The CV-RMSE for the genetic programming, bin, and linear change-point methods varied from 21.5% to 22.9%. The results for the Town Engineering Building in Table 2.2 are similar to those for the Ankeny School except that all of the CV-RMSE values are lower. The neural network method had the lowest CV-RMSE at 11.0%, followed by genetic programming at 14.7%, linear change-point regression at 15.0%, the bin method at 16.8%, and the 65°F-base degree-day method at 20.2%.

Table 2.1: Comparison of methods for predicted half-month energy use and prediction errors (Ankeny Elementary School) (Chen et al. 2003).

		Energy Use Predicted by the Models (kWh)/Percent Error				
Post-Retrofit Period (2nd half)	**Actual Energy Use (kWh)**	**Degree-Day Method**	**Bin Method**	**Linear Regression**	**Neural Networks**	**Genetic Programming**
Jul-98	3063	2261 26.2%	4064 32.7%	4188 36.8%	4352 42.1%	4831 57.7%
Aug-98	6833	3692 46.0%	3905 42.9%	3826 44.0%	4446 34.9%	4820 29.5%
Sep-98	3713	3509 5.5%	3736 0.6%	3673 1.1%	4342 16.9%	4534 22.1%
Oct-98	4381	4735 8.1%	4532 3.5%	4469 2.0%	4770 8.9%	5666 29.3%
Nov-98	4912	5051 2.8%	4739 3.5%	4714 4.0%	4765 3.0%	5680 15.6%
Dec-98	7979	6077 23.8%	6832 14.4%	6799 14.8%	7107 10.9%	7309 8.4%
Jan-99	7423	6067 18.3%	6852 7.7%	6901 7.0%	6842 7.8%	7355 0.9%
Feb-99	5342	5806 8.7%	5673 6.2%	5694 6.6%	5591 4.7%	5834 9.2%
Mar-99	4639	5627 21.3%	5945 28.2%	6061 30.7%	5041 8.7%	6664 43.7%
Apr-99	4381	4862 11.0%	4434 1.2%	4407 0.6%	4113 6.1%	5227 19.3%
May-99	4374	3809 12.9%	3810 12.9%	3756 14.1%	4371 0.1%	5417 23.8%
Jun-99	4323	3231 25.3%	3603 16.7%	3558 17.7%	4352 0.7%	5067 17.2%
CV(RMSE)		25.8%	22.0%	22.9%	18.0%	21.5%

Table 2.2: Comparison of methods for predicted half-month energy use and prediction errors (Town Engineering Building) (Chen et al. 2003).

		Energy Use Predicted by the Models (kWh)/Percent Error				
Post-Retrofit Period (2nd half)	**Actual Energy Use (kWh)**	**Degree-Day Method**	**Bin Method**	**Linear Regression**	**Neural Networks**	**Genetic Programming**
Oct-99	410	324 20.9%	386 5.9%	381 7.0%	424 3.5%	372 9.3%
Dec-99	377	348 7.7%	305 19.2%	387 2.6%	359 5.0%	369 2.2%
Feb-00	321	329 2.5%	323 0.7%	320 0.3%	319 0.6%	309 3.9%
Mar-00	336	329 2.3%	372 10.5%	370 10.0%	366 8.8%	358 6.4%
Apr-00	474	319 32.6%	532 12.3%	412 13.1%	411 13.3%	411 13.4%
May-00	656	584 11.0%	532 18.9%	535 18.5%	581 11.4%	539 17.8%
CV(RMSE)		20.2%	16.8%	15.0%	11.0%	14.7%

2.2 Data Screening

In order to determine savings with Option C and Option D of the IPMVP, consumption data is used to model energy consumption during different time periods. Regression models and calibrated simulations used to determine energy consumption require accurate data (electricity, cooling, and heating) over a wide temperature range for each time period of interest. Thus, the amount and quality of the data available to the analyst are major limiting factors in the accuracy of the savings that are determined. The most important data errors in energy consumption measurements tend to be software errors that result in a scaling error (e.g., 2.0 or 2.5) and meter failures on heating data (i.e., zero values) that will not be noticed during summer months when reheat occurs (Shao and Claridge 2006, Shao 2005). Without an effective data screening method, it is difficult to tell whether a building's data meters function properly during a given time period.

There are different tools used to assess the quality of building energy consumption data. Time series plots and x-y scatter plots showing consumption versus outside air temperature are common tools used to check for good data quality (Haberl et al. 1993). While spreadsheets can be used to make such plots, programs such as EMODEL (Kissock 1993) have been developed to simplify and speed up this process. Although time series and x-y scatter plots can be effective in detecting poor data, data fault detection is oftentimes not readily apparent when viewing these plots. Displaying too much data on the same plot may hide certain trends in static time series and x-y plots because data points become overlaid upon each other, masking the central tendency behind a cloud of data points (Haberl et al. 1993). The ability to quickly diagnose a problem may further be complicated by a lack of experience by the viewer to notice subtle trends in the data.

While means of graphically enhancing time series and x-y scatter plots have aided in detecting poor data (Haberl et al. 1993, Kissock 1993), meter scaling errors and heating data meter failures are still difficult to detect. A method that employs the first law of thermodynamics, or energy balance, has been developed to allow one to evaluate all three streams (electricity, cooling, and heating) of energy data at once and cross check them against each other (Shao and Claridge 2006, Shao 2005).

The energy balance is the sum of the electricity and hot water consumption minus the chilled water consumption. Simulation of four different HVAC system types in a commercial building over a range of important HVAC system parameters shows that when plotted versus outside air temperature, the energy balance generally intersects the x-axis somewhere between 55°F and 70°F. If the entire curve trend is outside this range, it may suggest bad data in one or more of the three energy streams. It is also common for the energy balance curve to be somewhat linear in nature and to be steeper at high temperatures because of the additional latent cooling load present at these temperatures. When using daily averaged data, points that deviate significantly from the main trend of data should be investigated more thoroughly to see whether ignoring the use of those data points is warranted. The energy balance plot in Figure 2.1 shows a well defined data trend with no points significantly deviating from the overall curve, signifying the data is accurate. The energy balance plot in Figure 2.2, however, has multiple data points that do not follow the overall data trend and should be considered as potentially resulting from at least one channel of bad data. Energy balance plots are an effective method for screening consumption data to ensure the consumption data used for regression models and calibrated simulations is of good quality. This study uses energy balance plots for this purpose.

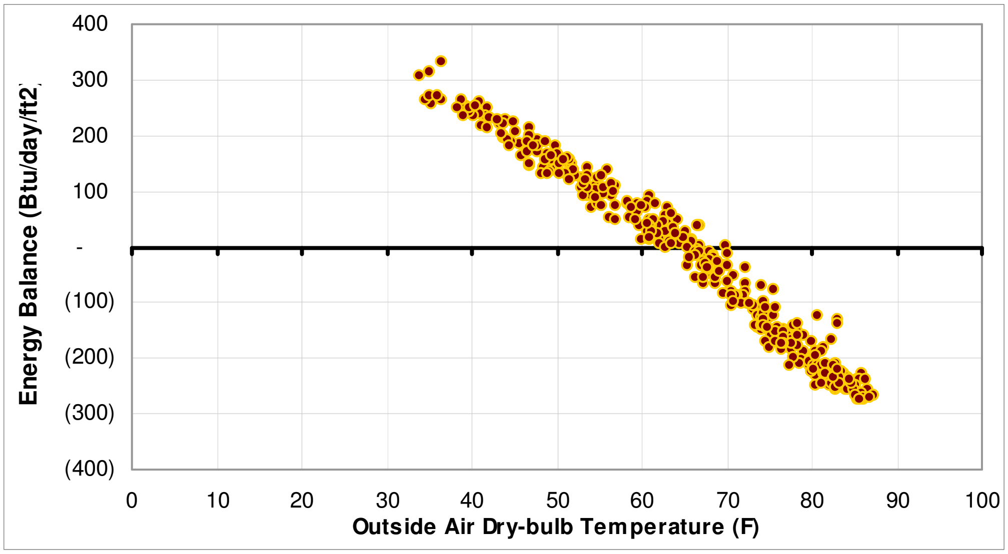


Figure 2.1: Energy balance plot showing fairly good energy (chilled water, hot water, and electricity) data.

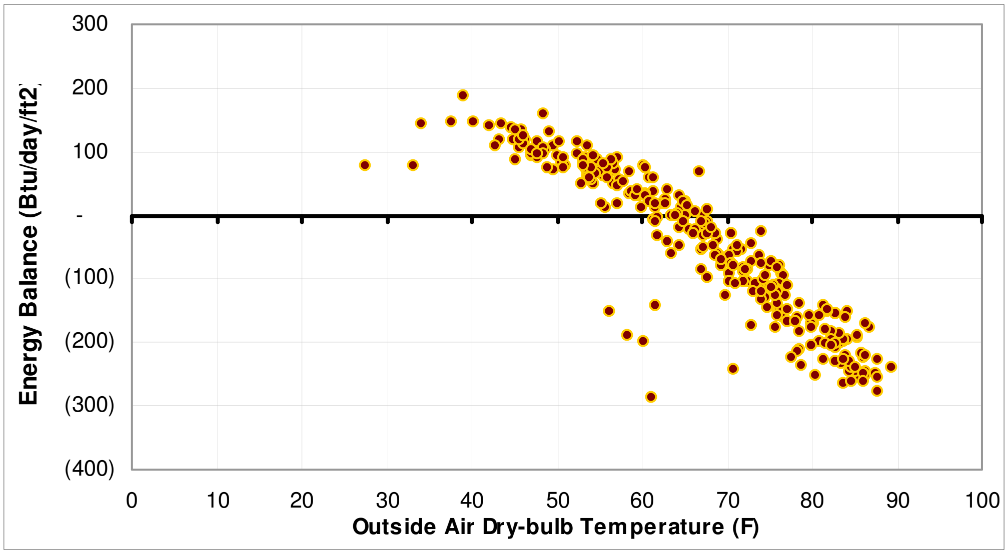


Figure 2.2: Energy balance plot indicating the presence of multiple bad data points.

2.3 Persistence of Commissioning Savings in Existing Buildings

It is useful to know the results of previous savings persistence studies when determining and analyzing savings persistence in additional buildings. This may help to identify similar savings persistence patterns and causes for degradation or increase in the savings of the buildings in the present study. The following section summarizes the findings of studies done several years after commissioning has taken place.

2.3.1 10 Buildings at Texas A&M University

A study was completed in 2002 that looked at the persistence of savings in 10 buildings on the Texas A&M University campus that had undergone commissioning in 1996 and 1997 (Turner et al. 2001, Cho 2002, Claridge et al. 2002, Claridge et al. 2004).

The energy savings from commissioning in this study were determined and normalized with the NAC weather normalization approach. Using Option C of the IPMVP, separate regression models for each year were developed as a function of that time period's own weather. The consumption for each year was then determined using 1995 weather data because that year's weather was determined to be close to the average for all of the years of the study (1996-2000).

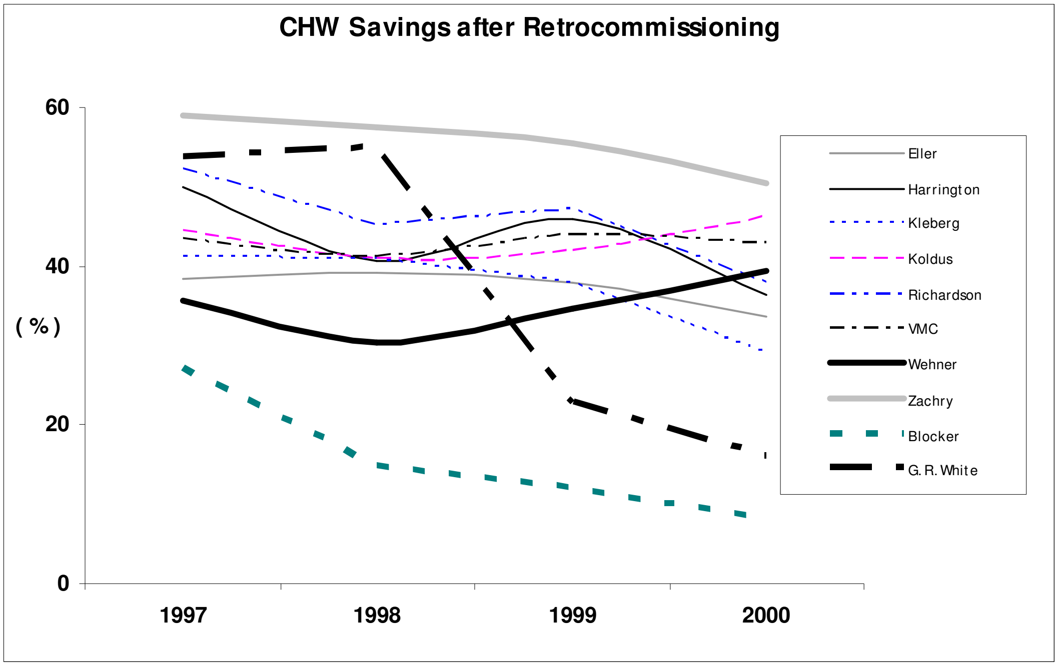


Figure 2.3: Chilled water savings trends from commissioning for 10 buildings at Texas A&M University (Cho 2002).

All 10 buildings showed significantly reduced chilled water and hot water energy consumption since commissioning, although the savings generally decreased somewhat with time. Figure 2.3 and Figure 2.4 show the chilled water and hot water savings trends for several years after commissioning. Overall, the chilled water savings for the three years following commissioning averaged 39.3% of the pre-commissioning baseline. Eight of the buildings showed good persistence of savings for chilled water (savings changed by less than 15 % during the 3-4 years after commissioning), while the other two displayed significant degradation. Hot water consumption was reduced significantly in the years following commissioning, but the savings fluctuated widely from year to year. The 10 buildings averaged hot water savings of 65.0 % after commissioning. Overall, the electricity consumption remained fairly constant, with three buildings showing small increases in consumption (negative savings). The average electricity savings for the 10 buildings from 1997 to 2000 were 10.8%.

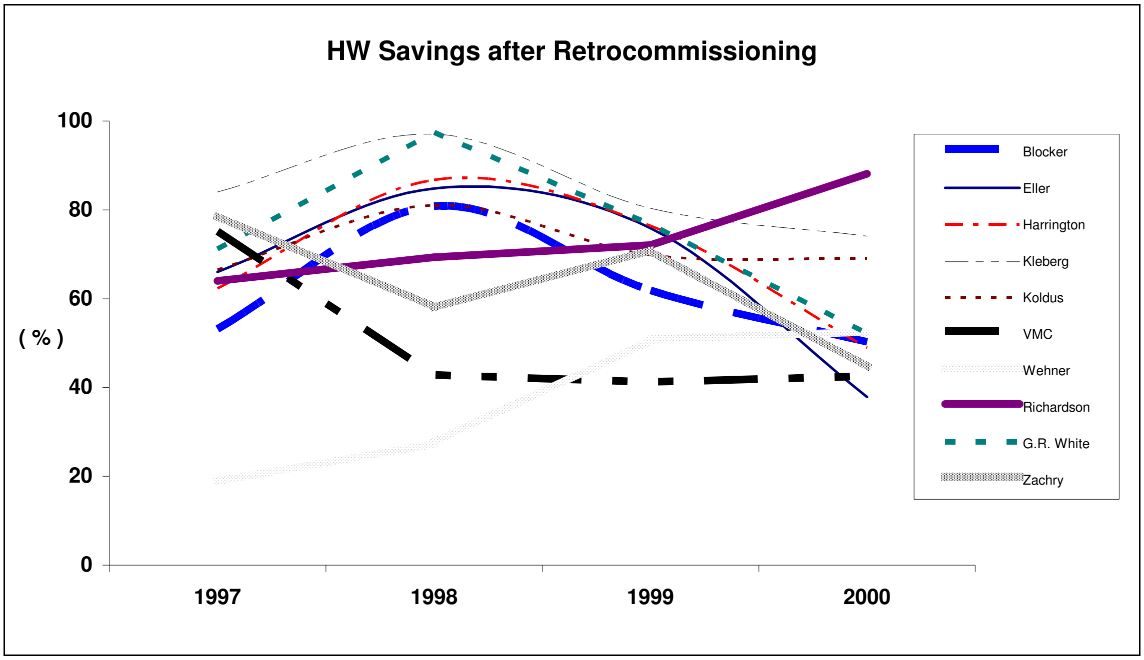


Figure 2.4: Hot water savings trends from commissioning for 10 buildings at Texas A&M University (Cho 2002).

It was found that the major reasons for savings degradation were equipment malfunction and HVAC control schedule changes made after commissioning. It was recommended that energy consumption in buildings be monitored closely for savings degradation in order to make adjustments and save energy.

2.3.2 Eight Buildings in SMUD Program in Sacramento

In 2003, a study was performed by Bourassa et al. on eight buildings which had undergone retrocommissioning through the Sacramento Municipal Utility District (SMUD) retrocommissioning program (2004).

Regression models were created from energy consumption data for the baseline pre-retrocommissioning period and post-retrocommissioning periods. The energy consumption data were normalized to a common weather year and to a common billing cycle of 30.5 days. This approach is similar to that done by Turner et al., with the exception that this study uses an average weather year for all the sites as opposed to selecting a representative year from the actual weather for each site. Savings were calculated as the difference between the normalized baseline model NAC and the post-retrocommissioning model NAC. The electrical savings observed for each building over the years following retrocommissioning are shown in Figure 2.5. Aggregate electricity savings for the sites are shown without the skewed effects of the most extreme building (Lab 1) in Figure 2.6. The savings peaked in the 2nd year after commissioning before beginning to degrade. The suspected reason for the savings peaking in the 2nd year after commissioning is the length of time for some of the commissioning measures to be implemented.

The average electricity savings for all the sites over all the years were 7.3% per year. Natural gas usage was only available for four of the buildings. The savings for natural gas were considerably lower, but since Sacramento is dominated by cooling needs, the lower natural gas savings only reduced the average total energy savings in these four buildings to 6.1% per year. The payback periods for the retrocommissioning projects all proved to be attractive, with the longest period being 2.3 years. It was shown that of the 48 commissioning measures that had been implemented among the eight buildings, 81% were still in place. Four of the measures had been abandoned altogether (all of these were related to air distribution components) and five of the measures were modified over time by building engineers because the original measures did not fully solve the problems.

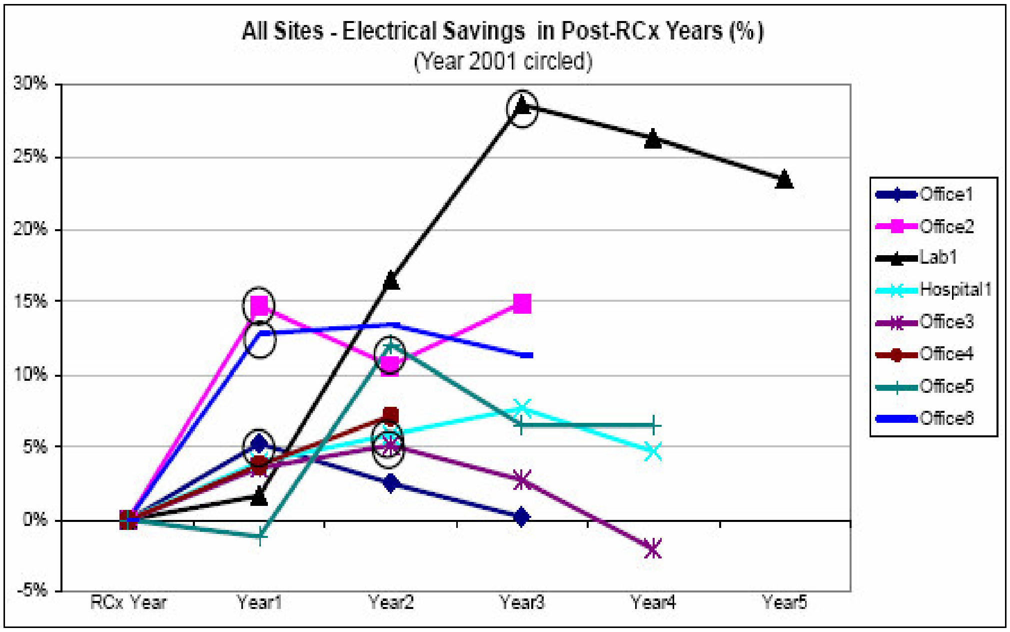


Figure 2.5: Electrical savings following retrocommissioning by SMUD for each of the buildings (Bourassa et al. 2004).

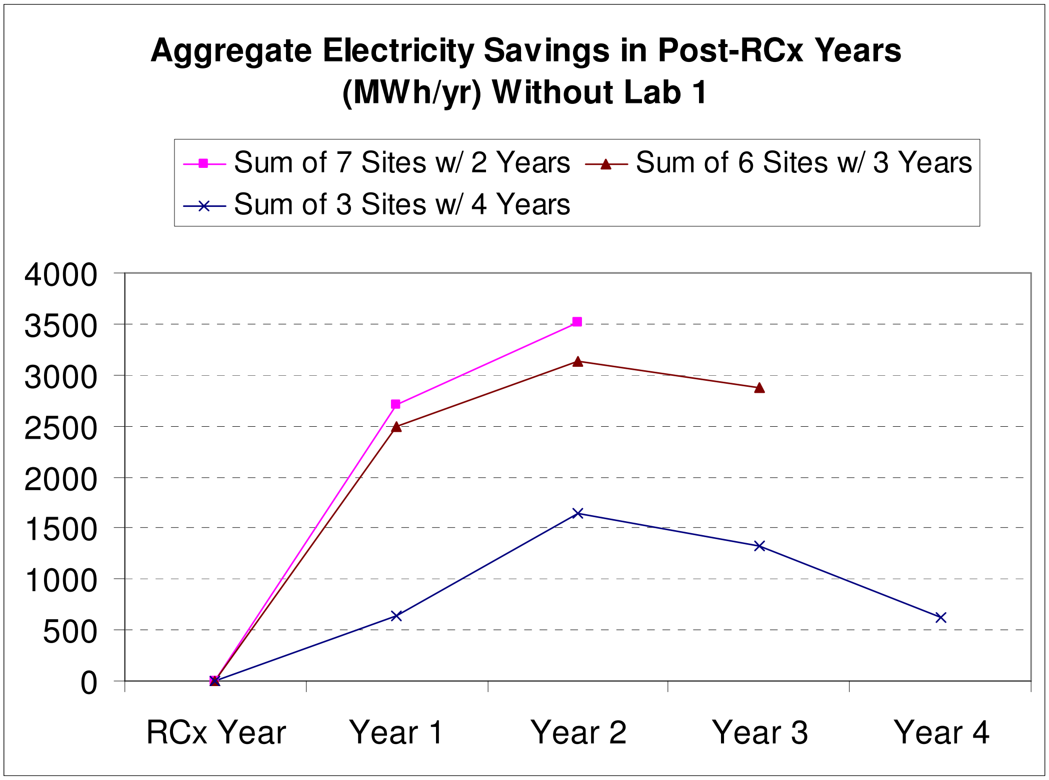


Figure 2.6: Aggregate post-retrocommissioning electricity savings without Lab 1 in SMUD project (Bourassa et al. 2004).

The SMUD retrocommissioning study recommended creating some way of tracking the implementation of measures, exploring methods to conduct a three year post-retrocommissioning energy consumption analysis, and developing simple performance tracking tools for the building operators.

2.3.3 Oregon Case Study

A study performed in Oregon in 2004 examined eight Intel buildings that had been retrocommissioned in 1999 and 2000 (Peterson 2005). The buildings were located on the Intel Jones Farm and Hawthorn Farm campuses.

Some of the retrocommissioning measures implemented were found to not have persisted. In one of the Hawthorn Farm campus buildings, a random sampling at the time of the study showed that 60% of terminal reheat units whose dampers were serviced during retrocommissioning showed no noticeable damper movement from full cooling to full heating mode. Additionally, the leaving condenser water setpoint for the Jones Farm campus chillers was lowered from 80°F to 67°F during retrocommissioning but was found at 71°F at the time of the study. While not as low as the original change (67°F), this temperature (71°F) is still significantly lower than the original temperature (80°F). For the Jones Farm campus buildings, a few control overrides were found at the time of this study for air handling units and terminal boxes that had been scheduled according to occupancy patterns (unoccupied hours were defined as 6 pm to 6 am on weekdays and all day on weekends), although many of the controls were still in place. Measures that were found to have persisted from the time of retrocommissioning to the time of this study include outside air intake control modifications that allowed the economizer cycle to function in the Hawthorn Farm campus buildings and Hawthorn Farm campus chiller optimizations. These optimizations had lowered the condenser water setpoint from 75°F to 70°F and increased the chilled water setpoint from 42°F to 45°F.

Overall, the energy conservation measures performed at the Hawthorn Farm campus were found to have been maintained, with the exception of the terminal unit reheat optimization in one of the buildings. Of the original projected savings at the Hawthorn Farm campus, 89% of the electric savings and 0% of the natural gas savings were still being achieved at the time of this study. At the Jones Farm campus, the results were more mixed and less quantifiable. The recommended scheduling changes were still programmed at a high level, but it appeared that numerous control overrides at a zone or box level had been made. Some overrides may have been due to changes in space use (such as conversion to a lab), but in many instances conference and training rooms were maintaining occupied modes around the clock.

2.3.4 Office Building in Colorado

A study completed in 2005 evaluated the persistence of recommissioning savings in a large office building in Colorado (Selch and Bradford 2005). Savings were determined using both Option B (individual measure evaluation) and Option C (whole building consumption) of the IPMVP. The office building was recommissioned in 1995, which resulted in verified savings of 14% in electrical demand, 25% in electrical use, and 74% in gas use. In 2003, the building was again recommissioned, at which time the status of the energy conservation measures implemented in the initial recommissioning effort was evaluated. It was calculated that 86% of the electrical demand savings had persisted, while 83% of the electrical use savings had persisted. A large majority of the energy savings measures implemented in the original recommissioning effort had persisted, as had their resultant energy savings. This was in spite of changing conditions in the building, including a complete change in operation staff. It was concluded that energy efficient measures of this nature can persist for at least eight years even with limited support from operators and staff.

2.3.5 224 Commissioned Buildings

Mills et al. analyzed the cost-effectiveness of the commissioning of 224 buildings across 21 states. 150 of these were existing buildings while 74 were new buildings (2004, 2005). For existing buildings, the median whole-building energy savings were 15% with a payback of 0.7 years. Median savings for existing buildings was $45,000 (in 2003 dollar terms), ranging as high as $1.8 million. Some of the IPMVP savings methods were used to determine the existing building commissioning savings while engineering estimates were also used. Whole facility measurement (Option C) was by far the most common method, although calibrated simulation (Option D) or sub-metering (Option A) were also used. For new buildings, the median payback was 4.8 years, which excluded non-energy savings. Addition of non-energy impacts could drastically reduce these payback times, to or below zero in many cases. Savings were generally more difficult to quantify for new buildings due to lack of baseline data.

Persistence data was available for 20 of the buildings. 18 of these 20 buildings are from the studies by Turner et al. and Bourassa et al. discussed in sections 2.3.1 and 2.3.2, respectively. Figure 2.7 combines and summarizes the results of these studies, with four years of savings persistence shown. Savings are compared by category (electricity, fuel, chilled water, and steam/hot water) and are shown as the fraction of post-commissioning consumption to the baseline consumption. The savings persistence show that savings often increase after the first post-commissioning year. This resulted from commissioning measure recommendations being implemented gradually by in-house personnel. In contrast, savings often eroded due to changing building conditions, operations, or aging. The degradation of savings was the least pronounced for electricity but much more noticeable for chilled water and steam/hot water.

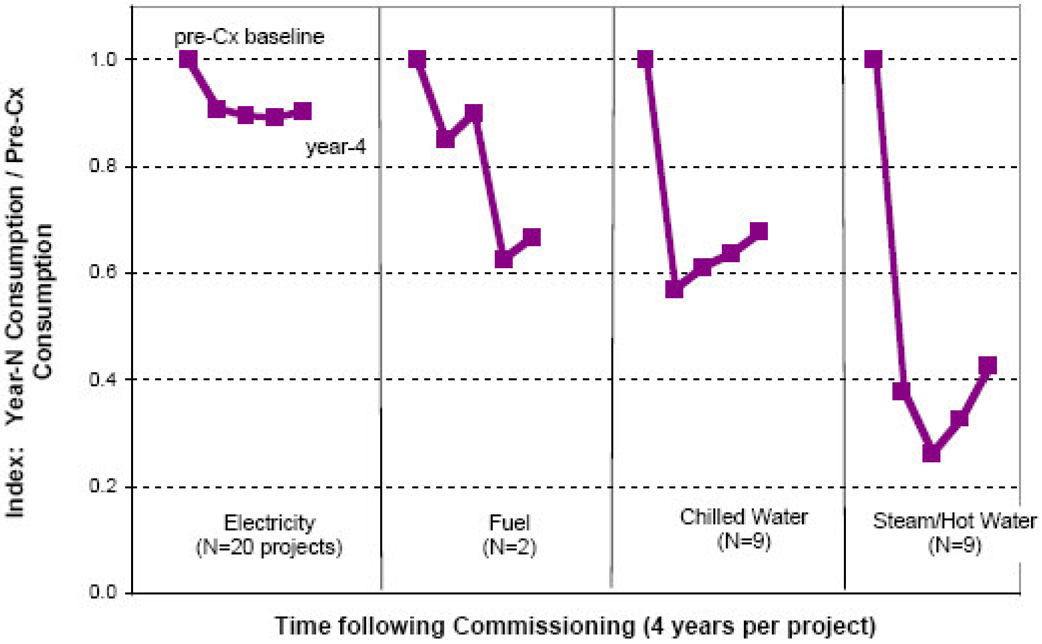


Figure 2.7: Emergence and persistence of weather normalized energy savings (Mills et al. 2003).

Mills et al. concluded that tracking consumption for evidence of significant consumption increases is the most important means of determining the need for follow-up commissioning. Additionally, hidden component failures are a major cause of persistence problems.

2.4 Strategies for Improving Persistence in Buildings

A report in 2003 by Friedman et al. (2003) summarized key conclusions from persistence studies, namely that many commissioning benefits tend to persist fairly well, but that significant opportunities still exist for improving overall savings persistence. Emphasis was placed on certain key elements of energy analysis and efficiency for long-term success in building operation and energy use. It was concluded that the top seven methods for improving the persistence of commissioning benefits in both new and existing buildings were design review, building documentation, operator training, building benchmarking, energy use tracking, trend data analysis, and recommissioning.

2.5 Persistence of Retrofit Measure Savings

While a large portion of the commissioning process involves changes in the operational schedule to a building, it is common that major retrofits are proposed and/or faulty equipment items are identified and changed. The persistence of savings due to building retrofits documented in previous studies is valuable to the present study as it is directly applicable. The following studies present savings results from different retrofit programs.

2.5.1 Seattle City Light Commercial Efficiency Program

Seattle City Light began the Energy Smart Design Program (ESDP) in 1988 to provide technical and financial assistance to commercial building owners and developers to design new and remodeled buildings (Coates and Lilly 1999). In 1991 the ESDP was expanded to include financial incentives for installing energy conservation measures in new, remodeled, and existing buildings. These measures included lighting, motors, heating, ventilating, and air conditioning systems, building envelope, energy management control systems, and other measures.

A study was performed in 94 buildings that participated in the ESDP conservation measures to determine the long-term success of the program. The buildings' conservation measures were implemented in 1992 and persistence of savings over a three-year period was determined. Site visits made to determine whether or not implemented measures were still in place showed that 84% had remained.

Several methods were used to determine savings. Each method involved comparing the energy consumption of the buildings that participated in the program measures versus the consumption of a stratified random sample of nonparticipant buildings that were stratified based on the commercial sector building type (e.g. office, lab, etc.) and the type of conservation measures installed in the building.

With one method, the Program Participation model, a regression analysis was performed on the energy consumption for program participants and nonparticipants. Energy savings for each of the post-program years were determined by interacting a program participation binary variable in each year with the pre-program energy consumption in 1991. Additional control of nonprogram factors was obtained by including in the analysis weather changes and load impacts for the outlier buildings.

With another method, the Statistically Adjusted Engineering (SAE) model, regression analyses were performed on the annual electricity consumption for program participants and nonparticipants. Models were created that both included and ignored the effects of weather changes.

Savings results from the methods described above are shown to vary and are presented in Table 2.3. The Program Participation (weather adjusted) method showed the most variation in energy savings, ranging from 47 to 155 MWh per year, or 2.4% to 8.0% of the pre-program consumption. In contrast, the SAE model showed savings ranging from 3.3% to 4.0% of the pre-program consumption when not weather adjusted and 3.7% to 4.0% of the pre-program consumption when weather adjusted.

Table 2.3: Mean annual megawatt-hour energy savings for program participants by savings method and year (Coates and Lilly 1999).

Savings Method	1993	1994	1995	All Years
Program Participation (weather adjusted)	47	79	155	94
% of pre-program	2.4%	4.1%	8.0%	4.9%
Statistically Adjusted Engineering	77	60	73	71
% of pre-program	4.0%	3.3%	3.8%	3.8%
Statistically Adjusted Engineering (weather adjusted)	77	72	75	74
% of pre-program	4.0%	3.7%	3.9%	3.7%

2.5.2 Bonneville Power Administration Residential Retrofit Programs

The Bonneville Power Administration undertook five separate residential retrofit programs in the Northwest during the 1980s (Brandis and Haeri 1992). Each of the programs was similar in that it offered monetary incentives for customers willing to make energy efficient retrofits in their homes but varied in the specifics. Savings from these retrofits two and three years after installation were determined using the PRISM method. Table 2.4 shows the average annual household savings achieved for each of the programs in the post-retrofit period.

The results varied in that two of programs experienced mostly steady persistence of savings while three of the programs showed a decline in savings over time. For the three programs showing decline, the average year 2 savings are 86.3% of year 1 savings and the average year 3 savings are 73.2% of year 1 savings. When considering all five programs together, the year 2 savings were 90.6% of year 1 savings and the year 3 savings were 82.0% of year 1 savings.

Table 2.4: Average annual energy savings during post-retrofit years for Bonneville Power Administration residential retrofit programs (Brandis and Haeri 1992).

Program	Energy Savings (kWh/yr)		
	Year 1	Year 2	Year 3
Pilot	4,130	4,160	3,750
Interim	4,515	3,870	2,690
Hood River	3,010	3,010	Not Estimated
Long-Term (1985)	2,800	2,760	2,800
Long-Term (1986)	3,290	2,270	2,300
Total	17,745	16,070	14,550*

* if year 3 is projected from the results for years 1 and 2 to remain at 3,010

2.5.3 Texas LoanSTAR Program

The Texas LoanSTAR Program implemented energy conservation retrofits in state-owned buildings throughout Texas starting in the early 1990s (Haberl et al. 1996). Data meters were also installed to track retrofit savings. In all, there were 203 Energy Cost Reduction Measures (ECRMs) in the design or construction phase or that had been implemented (52% had been implemented) in 74 buildings as of December 1993. The measured savings methodology utilized whole building (or main meter) before-after analysis. Implementing thermal storage systems was the most expensive measure to implement, costing $4.13/sqft, followed by constant volume to variable air volume air handler retrofits at $1.15/sqft. On average, the simple payback for this broad range of retrofits was 5.06 years. In general, those sites that had a combined pre-retrofit energy use of more than $1.5/sqft saw the greatest retrofit savings, while those sites that had a pre-retrofit energy use of less than $1.0/sqft showed generally less energy savings.

A detailed analysis was performed for 13 sites that received a constant volume to variable air volume air handler retrofit. Based on pre- and post-retrofit electricity data, it was shown that the degree of fan over-sizing plays a major role in the cost effectiveness of the retrofit. For sites where measured savings were 100%-200% of the audit estimate, the fan over-sizing was three to six times what is needed by the VAV system in the post-retrofit period. For sites where measured savings were less than 50% of the audit estimate, the fan over-sizing was about two times what the VAV system uses in the post-retrofit period. It was also concluded that the VAV system should be commissioned after the retrofit is installed to prevent the building operators from raising the static pressure to the point where the system no longer functions as a VAV.

Later analysis of the LoanSTAR Program showed results from 1991 through 2002 after additional retrofits had been performed (Kumar et al. 2002). In several of the buildings, a lack of savings in the first few years after the retrofit resulted in investigations that found the reason, fixed it, and subsequently improved the savings. Total program savings as of January 2002 were $75.7 million in 298 buildings, $5.6 million in savings from street light retrofits, $4.4 million in savings at K-12 schools, $26.6 million in Continuous Commissioning^{SM} savings, for a total program savings of $109.2 million for 298 buildings. Persistence results were not given.

2.5.4 Other Retrofit Savings Results

Kumar et al. also describes six retrofit programs, some of which highlight savings results without giving specifics of what measures were given and how the savings persisted from year to year (2002). The U.S. Army Energy Savings Performance Contracts (ESPC) program through 2001 had invested a total of approximately $290 million. At that time the present worth of total projected value of savings was $640 million. The U.S. Department of Energy Super ESPC Program invested approximately $238 million in retrofits. The total guaranteed cost savings was expected to be approximately $515 million, with $365 million in energy savings and $150 million in O&M cost reductions. Other retrofit programs were discussed that did not have adequate M&V data, which suggests the importance of further savings results from the buildings in this study that meet the M&V requirements.

2.6 Literature Review Summary

The results of the studies reviewed in this chapter give the background for how savings can accurately be determined using two different IPMVP savings determination methods and two weather normalization approaches. These include Option C and Option D of the IPMVP and the NAC weather normalization approach and standard IPMVP weather normalization approach, all of which are used in the present study. Each of these requires consumption data to be screened to make sure it is accurate. Energy balance plots are a quick and effective way to screen consumption data and are used in this study. Additionally, nine studies on savings and persistence of savings from commissioning and retrofits in existing buildings are given. Seven of these studies describe how savings and persistence of savings were determined. Six of them use Option C with regression models of the IPMVP to determine savings while two of them use Option D. Other methods are also used. Four of the studies specifically use the NAC weather normalization approach and two use the standard IPMVP weather normalization approach. None of these studies, however, specifically compares the variability in the persistence of savings results from the Option C and Option D savings methods or from the NAC and standard IPMVP weather normalization approaches. The variability in the persistence of savings between these savings methods and weather normalization approaches is a major part of this study.

In addition to documenting the savings determination methods and weather normalization approaches used, the studies on savings and persistence of savings also give the savings and persistence of savings results in various levels of detail for over 100 commissioned and retrofitted buildings. The results differ from building to building and from study to study and depend on many factors such as which measures were implemented, whether the measures themselves persisted, and whether follow-up commissioning was conducted. Overall, savings and persistence of savings results are quite favorable but savings and individual commissioning measures tend to degrade over time. Further-in depth study of savings persistence in other commissioned buildings is necessary to build a larger sample size. This study documents savings and persistence of savings results of three additional commissioned buildings. The previous studies of savings from commissioning and retrofits are useful in analyzing the savings of these three buildings because as a whole they give specific reasons for why savings increased or decreased over time and which factors tend to affect the success of the commissioning process.

CHAPTER III
METHODOLOGY

3.1 Building Selection

A preliminary screening of building energy data has been performed on buildings from the Texas A&M University campus that have been commissioned. Buildings were selected that could potentially be used for achieving all objectives of this paper—comparing the variability of the savings and persistence of savings of the NAC (Normalized Annual Consumption) and standard IPMVP (International Performance Measurement and Verification Protocol) weather normalization approaches, comparing the variability of the savings and persistence of savings of Option C and Option D of the IPMVP, and documenting the savings and persistence of savings in commissioned buildings. There are several requirements to consider in selecting buildings that could help achieve these objectives. First, there must be some form of documentation detailing when commissioning took place and what commissioning measures were implemented. Second, pre- and post-commissioning consumption data must be available for all of the energy types—electricity, chilled water, and hot water. If the pre-commissioning data is unavailable, then the commissioning report must clearly document key building and HVAC system parameters essential for creating a simulation for the pre-commissioning period by changing inputs of the calibrated simulation from the first post-commissioning period. Ideally, the post-commissioning data should be available for as many years as possible to track savings persistence, but there is no minimum requirement. Additionally, the available data in each period must span a temperature range wide enough to accurately model consumption using regression models and calibrated simulations. This requirement does not hold for electricity, which may be assumed to be mostly constant, independent of outside air temperature for the buildings on the Texas A&M campus chilled and hot water loops. If the temperature range for the available electricity data is too small to reasonably model with a two-parameter linear regression model then the average electricity data consumption is assumed constant for all temperatures during the period.

Hourly electricity, chilled water, and hot water data are used to calculate daily average consumption. For days in which 19 or more of the hours of data exist, the average from those hours is used as the daily average. This number is recommended by the Energy Systems Laboratory data analysis group based on their experience. For days in which 18 or fewer hours of data exist, the daily average is determined by linear interpolation from daily averages of prior and subsequent days. Energy balance plots are used to screen the daily consumption data. Data identified as potentially erroneous are discarded. If one or more of the three data streams has poor data quality for a particular day then the other streams of data are discarded since the energy balance data screening method can only indicate good data quality for all or none of the three streams.

Of the buildings screened for the sufficient documentation and data requirements, there are three that can be used for this study. These buildings are the Civil Engineering/Texas Transportation Institute Building (CE/TTI), the Heep Center, and the Memorial Student Center (MSC). CE/TTI is used to compare the savings variability of the NAC and the standard IPMVP weather normalization approaches, and to compare the savings variability of Option C with regression modeling and Option D of the IPMVP. This portion of the study uses results only from chilled and hot water. CE/TTI, Heep Center, and MSC are all used to further document the savings and persistence of savings from commissioning. This portion of the study analyzes chilled water, hot water, and electricity savings results. Both CE/TTI and Heep Center have limited baseline data available and the means discussed above to create baseline models in such cases are used for these two buildings.

3.2 IPMVP Savings Methods

Once consumption data has been screened, Option C with regression models and Option D of the IPMVP can be used to determine savings. These savings methods use regression models and calibrated simulations to obtain a relationship for energy consumption as a function of the outside air dry bulb temperature. Two-parameter linear, three-parameter change-point (3P CP or PRISM), and four-parameter change-point regression models are used to model electricity, cooling, and heating consumption. Using AirModel, calibrated simulations are created that model chilled and hot water consumption.

Data for each of the three buildings are separated into pre- and post-commissioning periods. Where possible, consumption data periods are divided into full calendar years. In many cases, however, periods are modified to be either shorter or longer than one calendar year where large periods of data are missing or of poor quality, or when the commissioning process takes place in the middle of a year. Katipamula et al. (1995) concluded that regression modeling of large commercial buildings can be accurate and reliable with at least three to six months of daily data. This data length requirement is met for all models and care is given to ensure that data spans a broad temperature range when less than a year of data is available. This process maximizes the amount of data that can be used for the study. As a result, each building has different pre- and post-commissioning period lengths. Consumption from each model is annualized by using a full weather year's temperature data, making comparison between periods of different lengths possible. A description of the weather data used in conjunction with the weather normalization approaches utilized is given in section 3.3.1 and again in Chapter V.

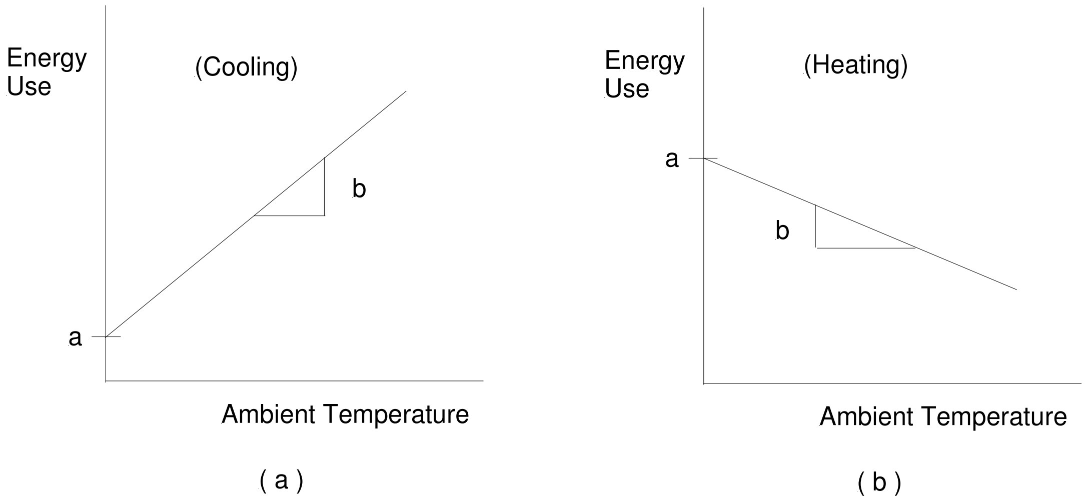
Regression models are created for each of the pre- and post-commissioning periods using data from each of the three buildings. Calibrated simulations are performed for each of CE/TTI's pre- and post-commissioning periods using AirModel. For buildings where insufficient pre-commissioning data is available to adequately model building chilled and hot water consumption, the first post-commissioning period consumption is simulated according to building and system characteristics stated in the commissioning report. After calibrating this simulation, the inputs are adjusted to reflect the pre-commissioning operation of the HVAC systems as documented in the commissioning report. In this manner, baseline consumption models are obtained for chilled and hot water when insufficient pre-commissioning data are available. A regression model is also created from the calibrated simulation baseline output for both chilled and hot water to determine savings with Option C of the IPMVP. The baseline electricity consumption in these cases is assumed to be mostly independent of outside weather conditions. The average of the limited pre-commissioning electricity data available is used as a constant daily consumption value.

3.2.1 Option C with Regression Models

The regression models used under Option C of the IPMVP to determine consumption in this study are a direct extension of the PRISM model development. While the original PRISM model was developed using variable-based degree-days, similar expressions using daily average temperature also exist for two-parameter linear regression, three-parameter change-point, and four-parameter change-point models. Equation 3.1 gives the expression for the two-parameter model and Figure 3.1 shows the graphical representation.

$$E = a + b * T_{OA} \tag{3.1}$$

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



(a) (b)

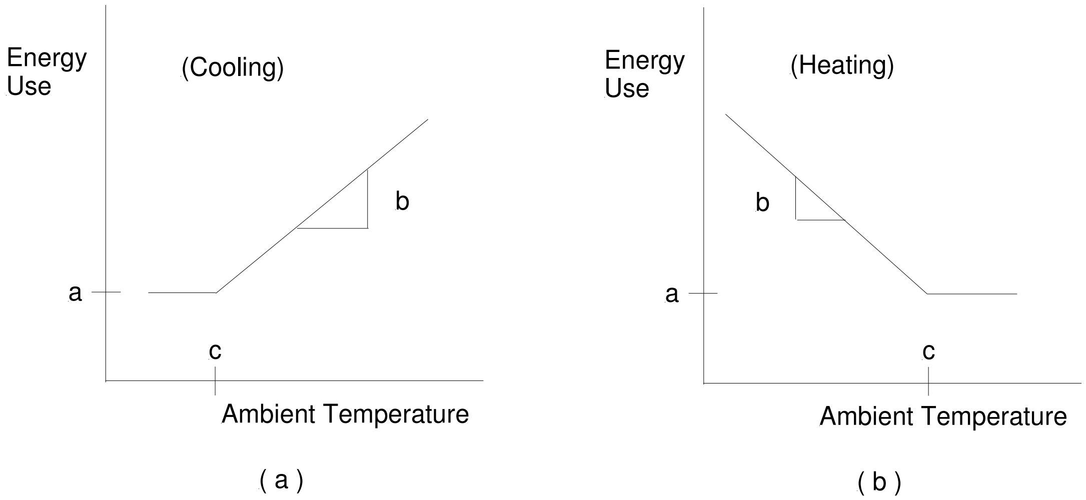
Figure 3.1: Two-parameter linear regression models for cooling and heating (Cho 2002).

Equations 3.2 and 3.3 express the functional form of three-parameter models, and Figure 3.2 shows the relationship graphically.

Cooling: $E = a + b * (T_{OA} - T_{CP})^{+}$ (3.2)

Heating: $E = a + b * (T_{OA} - T_{CP})^{-}$ (3.3)

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



(a) (b)

Figure 3.2: Three-parameter change point (3P CP) models for cooling and heating (Cho 2002).

Equation 3.4 expresses the functional form of four parameter models, and Figure 3.3 shows the relationship graphically.

$$E = a + b_1 * (T_{OA} - T_{CP})^- + b_2 * (T_{OA} - T_{CP})^+ \quad (3.4)$$

where the notation follows that of the 3P CP models.

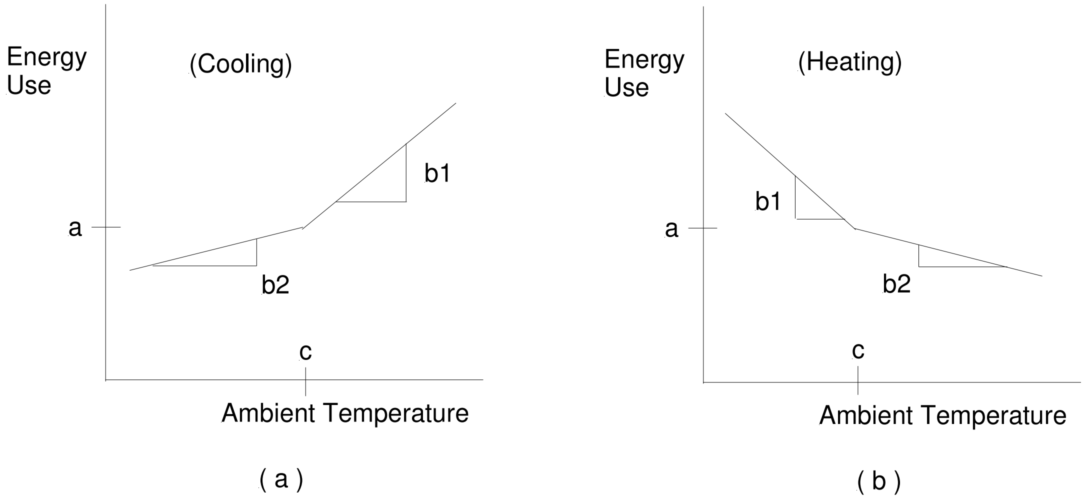


Figure 3.3: Four-parameter change point (4P CP) models for cooling and heating (Cho 2002).

Since Texas A&M University uses a central plant and chilled and heating hot water loops to provide for its heating and cooling, the electricity consumption in each of the buildings is fairly constant and a straight line regression model is used to form a relationship based on the outside air temperature. This excludes baseline pre-commissioning periods when limited available data makes it necessary to use the average consumption as a constant consumption value. Chilled and hot water typically employ a three- or four-parameter change point model in commercial buildings but in some instances may more closely follow a two-parameter linear regression model.

3.2.2 Option D

Option D of the IPMVP uses calibrated simulations to determine energy savings. When using AirModel to simulate building energy consumption, the user must specify two files, the input file and the weather source file. The input file includes specific quantities for the building and system parameters and characteristics such as conditioned floor area, room temperature, cold deck temperature, total and outside air flow settings, and night-time setback schedules. For this study, the weather file includes daily averaged values for dry bulb temperature and dew point temperature, although AirModel has the option of entering hourly values.

After running the AirModel simulation, the simulated output must be calibrated to the measured consumption data. A brief description of the calibration process is given here. A more detailed procedure of the simulation calibration process is given by Claridge et al. (2003) and Wei et al. (1998).

The term "calibration signature" (Claridge et al. 2003) is defined as follows:

$$CalibrationSignature = \frac{-residual}{MaxiumumMeasuredEnergy} \times 100\% \tag{3.5}$$

where

$$residual = SimulatedConsumption - MeasuredConsumption \tag{3.6}$$

The maximum measured energy is the maximum heating or cooling energy use recorded over the temperature range of the particular data file being used. The calibration signature is a normalized plot of the difference between measured energy use and simulated energy use over a specified temperature range. For each temperature, a measured energy use value and a simulated energy value exist. The difference in these values for each point is divided by the maximum measured energy use and multiplied by 100%. These values are then plotted versus temperature.

The calibration signature is now compared to published characteristic signatures of the given HVAC system type in the given climate. A characteristic signature is identical to a calibration signature, except that instead of comparing simulated and measured values, it compares two simulations. One simulation is taken to be the baseline or "measured" value. Then, by varying parameters one by one, signatures can be plotted and compared. Characteristic signatures (Claridge et al. 2003) are defined as:

$$CharacteristicSignature = \frac{ChangeInEnergyConsumption}{MaximumEnergyConsumption} \times 100\% \tag{3.7}$$

As mentioned, the baseline model is treated as the “measured” case, and maximum energy consumption comes from this model.

Characteristic signatures can be generated for each HVAC system type. The majority of the CE/TTI building’s HVAC systems are single-duct variable-air-volume (SDVAV), thus making it most practical to refer to SDVAV characteristic signatures when calibrating simulations. The parameters of major importance for which characteristic signatures should be generated include cold deck temperature, supply air flow rate (constant-volume systems), minimum air flow rate (VAV systems), floor area, preheat temperature, internal gains, outside air flow rate, room temperature, envelope U-value, and economizer.

Two indices used for evaluating the accuracy of a simulation are the “Root Mean Square Error” and the “Mean Bias Error.” The Root Mean Square Error (RMSE) is defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} residual_i^2}{n-2}} \tag{3.8}$$

where n is the number of total data points. The RMSE is a good measure of the overall magnitude of the errors, but does not give any reflection of bias, since no indication is made as to whether the errors are positive or negative. A good simulation minimizes the RMSE and can achieve 10-20% CV-RMSE (IPMVP 2002). It is generally difficult to reduce this to smaller than 5-10% CV-RMSE (Claridge et al. 2003). The Mean Bias Error (MBE) is defined as:

$$MBE = \frac{\sum_{i=1}^{n} residual_i}{n} \tag{3.9}$$

where n is the number of data points. The MBE is an overall measure of how biased the data is, since positive and negative errors cancel each other out. The MBE should be minimized in calibrating a simulation and should be less than ±20% of the mean consumption (IPMVP 2002).

Calibration signatures combined with characteristic signatures are used to quickly calibrate a simulation. The calibration signatures for heating and cooling generated for the simulation are compared with the characteristic signatures from the corresponding system and climate type, to see which change of parameter or parameters most closely resembles the calibration signature. Normally one parameter is changed at a time in the correct direction and according to the magnitude needed. For example, if the calibration signature is in the range of 20% for low temperatures, and a similar characteristic signature shows the same trend, but is in the range of only 5%, the parameter adjustment would need to be significantly greater than what was done to get the characteristic signature in order to increase the magnitude. The adjustment is of course limited by reasonable values – a cold deck set point would not be 38 degrees, for example. Once the parameter has been decided on, it is changed and the simulation is run again. The RMSE is calculated again, and calibration signatures are again generated and compared with the characteristic signatures. This process is repeated until the RMSE is minimized, and the calibration signature is flat and settled around zero. At this point, the simulation can be considered to be calibrated to the measured data. In most cases, however, it is difficult to obtain a completely flat calibration signature for both cooling and heating consumption. As stated above, a well calibrated simulation has a CV-RMSE of 10-20% (Claridge et al. 2003) and the MBE should be less than 20% of the mean consumption (IPMVP 2002).

3.3 Weather Normalization Approaches

The energy consumption models are now used to determine savings with two weather normalization approaches—NAC and standard IPMVP. In order to obtain a measure of variability in commissioning savings between the two weather normalization approaches, a set of different weather years is obtained to drive the energy consumption models. A set of different savings results is then obtained with both the NAC and standard IPMVP weather normalization approaches.

3.3.1 Weather Years Data

The weather years data used to create a set of savings results for the NAC and standard IPMVP weather normalization approaches are retrieved from the National Climatic Data Center (NCDC) weather database (2006). Hourly weather data for College Station, TX from the Easterwood Airport weather station is obtained for the years of 1973-2005.

For the years 1997 through June of 2004, NCDC data is used in conjunction with weather data within the Energy Systems Laboratory (ESL) database to fill in any missing data points. The vast majority of the data from the two sources is the same and NCDC weather is given precedence over the ESL weather in cases where there is a discrepancy. In cases where only one of the two data sources exists, the available data source is used. When neither of the data sources is available, interpolation between the previous and next available data is used. In this manner, all missing hourly weather data points are filled from 1997 through June of 2004. The remaining years (1973-1996, July 2004 - December 2005) are not cross checked with another database and have some missing hourly data.

As with the energy consumption data, hourly dry bulb and dewpoint temperature data are used to calculate daily average values. For days in which 19 or more of the hours of data exist, the average from those hours is used as the daily average. For days in which 18 or fewer hours of data exist, the daily average is determined by linear interpolation from daily averages of prior and succeeding days.

Additionally, daily average weather data from all available weather years are averaged to form a long-term average weather year. Each day's data of this long-term average weather year represents the average of all weather years' data for that day. For example, the daily average data for January 21 of the long-term average weather year is the average of all January 21 data from the existing weather years' data.

3.3.2 NAC Weather Normalization Approach

The NAC weather normalization approach determines savings as the difference between pre- and post-commissioning model consumption during a "normal" weather year. By using the same weather across all pre- and post-commissioning models, the variation in the consumption due to different weather patterns from year to year is minimized. Generally, long-term average weather data is used as the "normal" weather year when using the NAC weather normalization approach. This study, however, uses each of the 29 weather years obtained from NCDC as the "normal" weather year. Each of these 29 weather years is used with every one of CE/TTI's pre- and post-commissioning energy consumption models (both regression models and calibrated simulations) to obtain 29 sets of normalized annual consumption. The savings are then determined in each of the post-commissioning periods for each weather year used.

3.3.3 Standard IPMVP Weather Normalization Approach

The standard IPMVP weather normalization approach employed to determine actual savings from commissioning activities calculates the difference between post-commissioning energy consumption determined by the baseline model with the post-commissioning period weather and the measured energy consumption taken from the post-commissioning period. In order to annualize the measured energy consumption, the model created from consumption data is used to determine the annual measured energy consumption by using the full weather year's ambient temperature data to drive the model. A more typical procedure in cases where there is missing data in a post-commissioning time period is to use the post-commissioning model to generate any missing data to add to the actual measured data. This approach is not used in this study, however, due to the necessity of using post-commissioning time periods of less or greater than one year in several instances.

Since the standard IPMVP weather normalization approach uses the measured post-commissioning energy consumption to determine savings, there is just one set of savings for each post-commissioning period. In order to form a larger sample size of savings results from the standard IPMVP weather normalization approach to compare to the NAC weather normalization approach, a method is employed that randomly selects a College Station weather year from the NCDC weather years retrieved as the 1st post-commissioning year, another as the 2nd post-commissioning year, yet another as the 3rd post-commissioning year, and so forth. As an example of this methodology, assume that a random run of weather years selected to find savings for the six CE/TTI post-commissioning periods are 1984, 1976, 1999, 1998, 1993, and 1974. The 1st post-commissioning period savings under the standard IPMVP weather normalization approach would be determined by subtracting the "measured" 1st post-commissioning period consumption determined by the period's model normalized to 1984 weather from the consumption of the baseline model normalized to 1984 weather. The 2nd post-commissioning period savings under the standard IPMVP weather normalization approach would be determined by subtracting the "measured" 2nd post-commissioning period consumption determined by the period's model normalized to 1976 weather from the consumption of the baseline model normalized to 1976 weather. The 1999, 1998, 1993, and 1974 weather years would similarly be used to determine the savings of the

Table 3.1: Sequence of College Station weather years for 29 different random runs used with both Option D and Option C with regression models in conjunction with the standard IPMVP weather normalization approach.

Run	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04
1	1993	1993	1980	1985	1984	2001
2	1984	1976	1999	1998	1993	1974
3	1977	1998	2001	1984	1991	1999
4	1979	2005	1978	2005	1978	1991
5	1992	1981	2003	2005	1998	1998
6	1980	1996	1975	1979	1985	2004
7	1976	2000	1992	1981	1990	2000
8	1990	1973	1999	2004	2002	Avg Yr
9	Avg Yr	Avg Yr	1996	2002	1985	Avg Yr
10	1990	1983	1997	1999	1978	1990
11	2000	1997	1994	1977	1983	1999
12	2004	1993	1996	1973	1984	2001
13	1991	1985	1990	2005	1994	2003
14	1991	2000	2000	1984	1985	2001
15	1973	1998	1990	1999	1997	1997
16	1993	1975	2003	2002	1975	2004
17	1974	1978	2001	2000	1985	Avg Yr
18	1975	1981	1973	1997	2004	1984
19	1999	Avg Yr	1996	1999	2002	2000
20	2004	1973	2004	1998	2002	1990
21	Avg Yr	1985	1979	1985	1996	1984
22	1992	1985	2002	2001	1989	1992
23	1994	1989	1989	1976	1991	1981
24	1981	Avg Yr	1999	2001	1978	2001
25	2004	1990	1977	1999	2000	1979
26	1979	1996	1980	1998	1977	1978
27	2004	1993	1979	2003	1978	2000
28	1994	2000	1997	1981	1999	2003
29	1999	1983	1973	1996	1975	1996

3rd, 4th, 5th, and 6th post-commissioning periods, respectively. Other sets of random runs of weather years are used to obtain a set of savings results to determine whether the NAC weather normalization approach provides less variability in the persistence of commissioning savings than the standard IPMVP weather normalization approach. The 29 specific sets of random runs are given in Table 3.1. It should be reemphasized that the baseline regression model for CE/TTI used here is created from the synthetic "data" of the baseline calibrated simulation output. The baseline calibrated simulation is obtained by altering the inputs of the 1st post-commissioning period's calibrated simulation based on the commissioning report because limited baseline data is available for CE/TTI.

3.4 Detailed Procedure

In order avoid any confusion on the exact procedure used to obtain a larger sample size of savings results used to compare the savings variability of both IPMVP savings determination methods and both weather normalization approaches, a detailed, step-by-step description is given here for how each of the four different sets of savings results is obtained. Separate descriptions are given for each of the methods referred to throughout this chapter—Option D using the NAC weather normalization approach, Option C with regression models using the NAC weather normalization approach, Option D using the standard IPMVP weather normalization approach, and Option C with regression models using the standard IPMVP weather normalization approach. For each approach, numbered procedure steps are followed by a paragraph giving a brief explanation of the step listed. While some of the material may be repetitive, this section gives the reader a clearer understanding of how savings and persistence results are obtained in order to compare the variability among the four different methods.

3.4.1 Option D Using the NAC Weather Normalization Approach

Step 1. Calibrate an AirModel simulation to each of CE/TTI’s post-commissioning periods using the post-commissioning chilled and hot water consumption data.

Figure 3.4 compares the 1997 CE/TTI simulated output and the measured data for both chilled water and hot water. Similarly, five other calibrated simulations exist for the remaining CE/TTI post-commissioning periods. Plots showing the simulated chilled water and hot water output and measured consumption data for all of CE/TTI’s post-commissioning periods are found in Appendix A.

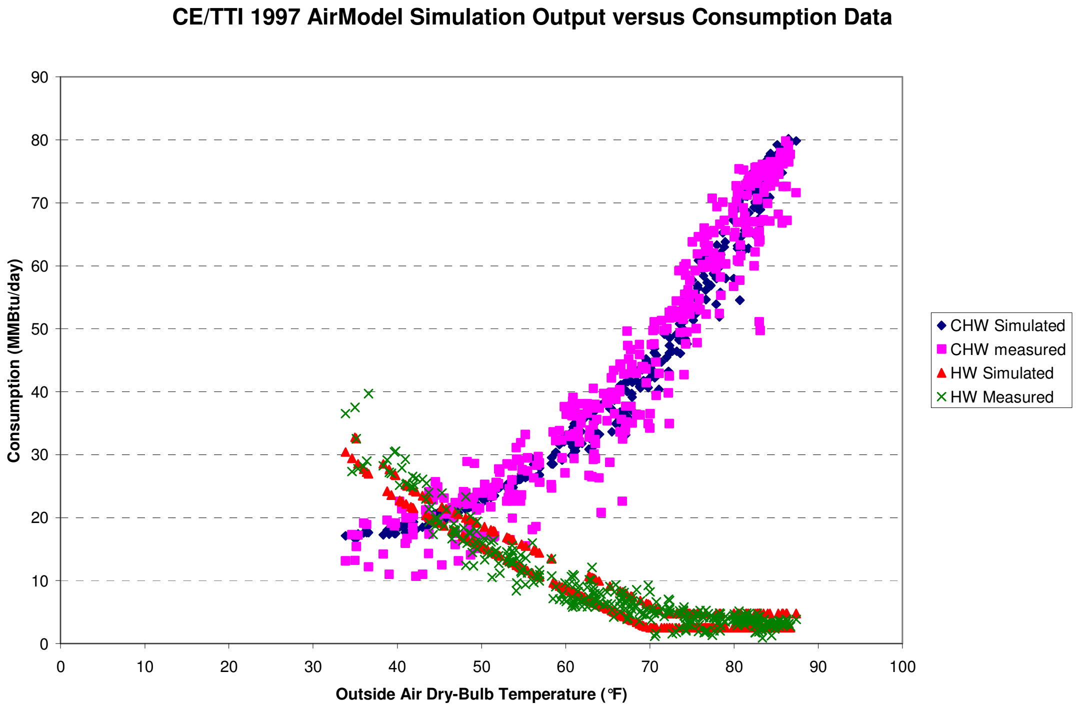


Figure 3.4: Comparison of CE/TTI 1997 calibrated simulation and consumption data.

Step 2. Adjust the inputs of 1997 CE/TTI calibrated simulation according to documented pre-commissioning conditions to simulate the baseline chilled and hot water consumption.

Since very little pre-commissioning consumption data is available, the pre-commissioning baseline consumption is simulated by altering the inputs from the first post-commissioning period's (1997) calibrated simulation according to pre-commissioning building conditions documented in the commissioning report. The simulated chilled water and hot water output for this baseline period is shown in Figure 3.5.

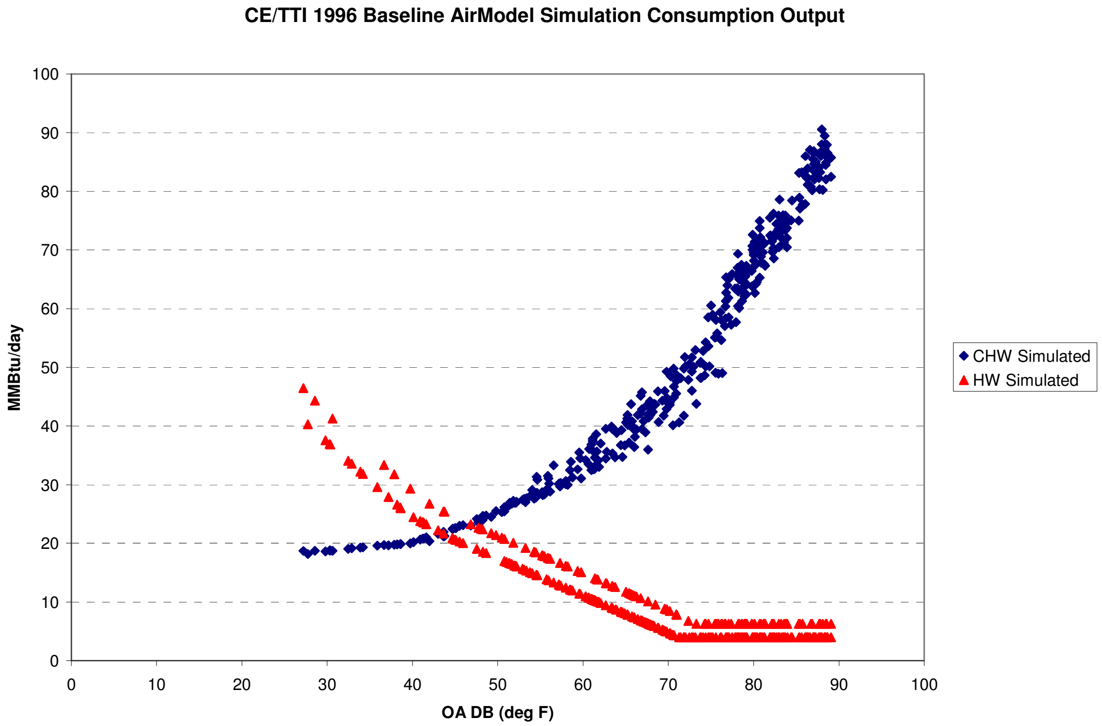


Figure 3.5: CE/TTI baseline simulated chilled and hot water obtained by altering the 1997 CE/TTI calibrated simulation inputs to pre-commissioning conditions.

Step 3. Use 29 different College Station weather years as the "normal" year to drive the baseline and each of the post-commissioning period calibrated simulations.

The 29 weather years include the weather data for each year from 1973-2005 except 1982, 1986, 1987, 1988, and 1995. The long-term average weather year formed as the average of these 28 weather years is also used as the "normal" weather year. This step should result in 29 different annual baseline consumption values and 29 different annual consumption values for each of the six post-commissioning periods.

Step 4. Determine chilled and hot water savings with the NAC weather normalization approach for each of the 29 "normal" weather years used.

Using the annual consumption determined by the pre- and post-commissioning period calibrated simulations, the NAC weather normalization approach is employed to determine savings in each of the post-commissioning periods for each of the 29 years used as the “normal” weather year. This procedure gives 29 sets of savings for six post-commissioning periods, making it possible to assess the variability of savings and persistence of savings using Option D in conjunction with the NAC weather normalization approach. The entire procedure for obtaining 29 sets of savings results for the six post-commissioning CE/TTI periods using Option D with the NAC weather normalization approach is given as a process diagram in Figure 3.6.

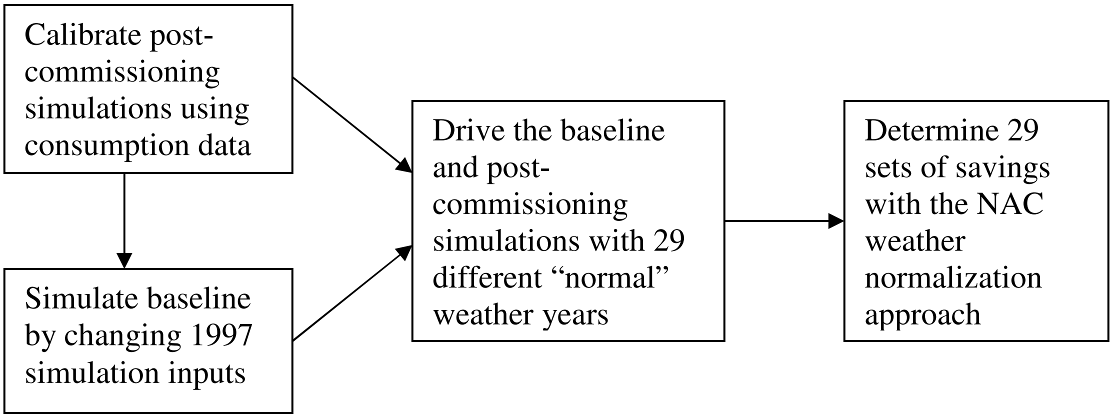


Figure 3.6: Process diagram for obtaining savings sets with Option D using the NAC weather normalization approach.

3.4.2 Option C with Regression Models Using the NAC Weather Normalization Approach

Step 1. Create regression models for each of CE/TTI’s post-commissioning periods using the post-commissioning chilled and hot water consumption data.

Regression models are created from CE/TTI’s available consumption data for each of the six post-commissioning periods. Four-parameter change-point regression models are used for each of CE/TTI's chilled and hot water post-commissioning models. Figure 3.7 shows the 1997 chilled water regression model created from this period's consumption data. Graphs showing regression models created from consumption for all other time periods are given in Appendix A.

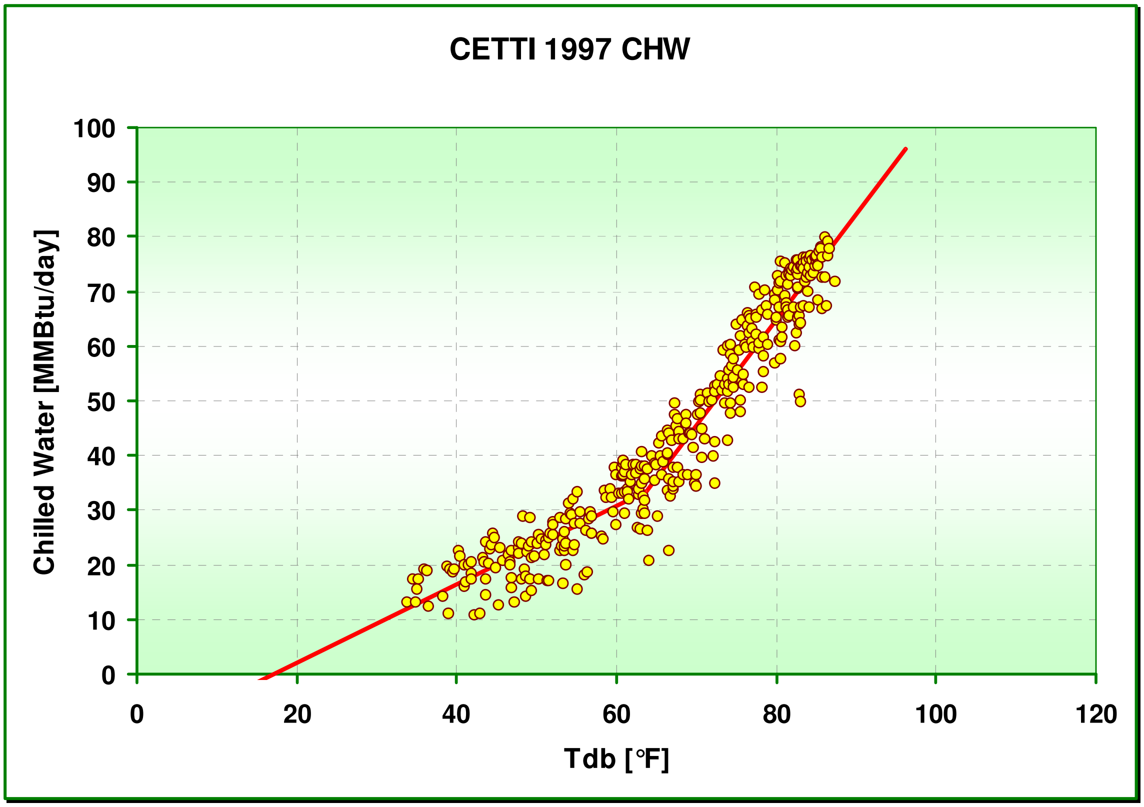


Figure 3.7: 1997 CE/TTI four-parameter change-point regression model created from the 1997 CE/TTI chilled water consumption data.

Step 2. Use the output from the AirModel simulated baseline year described in section 3.4.1 as "data" to create a baseline regression model.

Limited pre-commissioning data for CE/TTI prevents creating accurate chilled and hot water regression models. As a solution, the chilled and hot water output from the pre-commissioning period calibrated simulation is treated as synthetic consumption data with which chilled and hot water regression models are created. Figure 3.8 shows the baseline chilled water regression model created from the output of the baseline calibrated simulation.

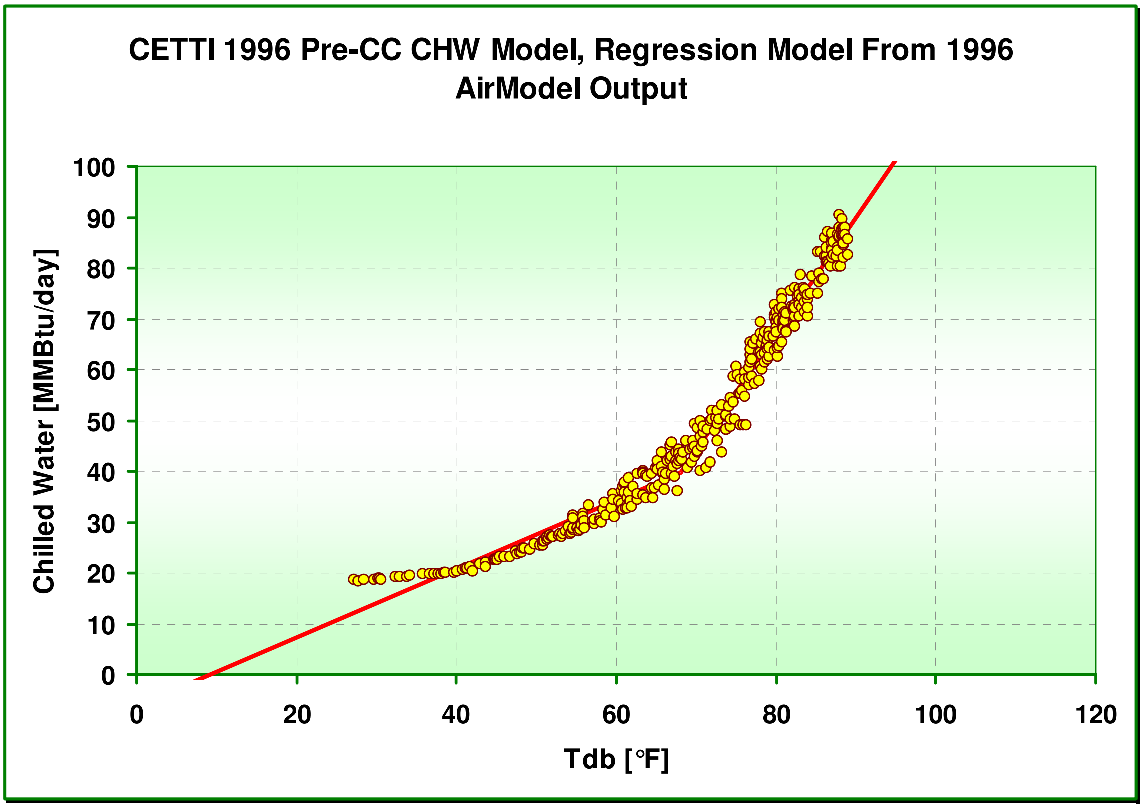


Figure 3.8: CE/TTI baseline four-parameter change-point regression model created from chilled water output of the baseline calibrated simulation.

Step 3. Use 29 different College Station weather years as the "normal" year to drive the baseline and each of the post-commissioning period regression models.

The 29 weather years include the weather data for each year from 1973-2005 except 1982, 1986, 1987, 1988, and 1995. The long-term average weather year formed as the average of these 28 weather years is also used as a "normal" weather year. This step results in 29 different annual baseline consumption values and 29 different annual consumption values for each of the six post-commissioning periods.

Step 4. Determine chilled and hot water savings with the NAC weather normalization approach for each of the 29 "normal" weather years used.

Using the annual consumption determined by the pre- and post-commissioning period calibrated simulations, the NAC weather normalization approach is employed to determine savings in each of the post-commissioning periods for each of the 29 years used as the "normal" weather year. This procedure gives 29 sets of savings for six post-commissioning periods, making it possible to assess the variability of savings and persistence of savings using Option C with regression models in conjunction with the NAC weather normalization approach. The entire procedure for obtaining 29 sets of savings results for the six post-commissioning CE/TTI periods using Option C with regression models using the NAC weather normalization approach is given as a process diagram in Figure 3.9.

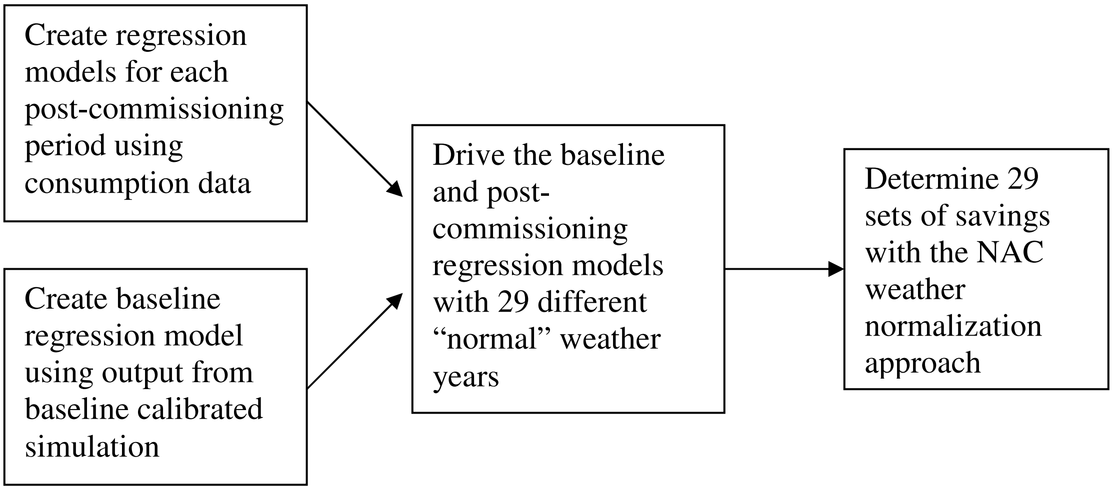


Figure 3.9: Process diagram for obtaining savings sets with Option C with regression models using the NAC weather normalization approach.

3.4.3 Option D Using the Standard IPMVP Weather Normalization Approach

Step 1. Calibrate an AirModel simulation to for each of CE/TTI's post-commissioning periods using the post-commissioning chilled and hot water consumption data.

Simulations for all six of the CE/TTI post-commissioning periods are created using the post-commissioning data for chilled and hot water. The comparison of the 1997 CE/TTI simulated output and measured data was previously shown in Figure 3.4 for both chilled and hot water. Plots showing the simulated chilled and hot water output and measured consumption data for all of CE/TTI's post-commissioning periods are found in Appendix A.

Step 2. Adjust the inputs of 1997 CE/TTI calibrated simulation according to documented pre-commissioning conditions to simulate the baseline chilled and hot water consumption.

Since very little pre-commissioning consumption data is available, the pre-commissioning baseline consumption is simulated by altering the inputs from the first post-commissioning period's (1997) calibrated simulation according to pre-commissioning building conditions documented in the commissioning report. The simulated chilled water and hot water output for this baseline period was previously shown in Figure 3.5.

Step 3. Substitute random College Station weather years in place of each of the six actual post-commissioning weather years. Use these random weather years to drive both the baseline simulation and the post-commissioning calibrated simulation corresponding to the actual weather being replaced.

In order to form a larger sample size of savings results from the standard IPMVP weather normalization approach, a method is employed that randomly selects a College Station weather year from the NCDC weather years retrieved as the 1st post-commissioning year, another as the 2nd post-commissioning year, yet another as the 3rd post-commissioning year, and so forth. Table 3.2 illustrates a sequence of random weather years substituted in place of the actual weather.

Table 3.2: Example of random run of weather years to substitute for the actual post-commissioning weather years.

Actual Post-Commissioning Weather	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04
Example of Random Weather Years Substituted for Actual Weather	1992	1981	2003	2005	1998	1998

Step 4. Use the random substituted weather years to drive both the baseline simulation and the post-commissioning calibrated simulation corresponding to the actual weather being replaced. Determine the chilled and hot water savings with the standard IPMVP weather normalization for this random run of substituted weather years.

Using the example of the random run of weather years to substitute for the actual weather in Table 3.2, the 1997 savings using the standard IPMVP weather normalization approach are determined by the difference in the consumption of the baseline simulation driven with 1992 weather data and the consumption of the 1997 post-commissioning calibrated simulation driven with 1992 weather. The 1998 savings are determined by the difference in the consumption of the baseline simulation driven with 1981 weather data and the consumption of the 1998 calibrated simulation driven with 1981 weather data. This procedure is carried out for the remaining four post-commissioning periods for this particular random run of weather years.

Step 5. Repeat steps three and four 28 additional times, each time substituting the actual post-commissioning weather with a different run of random College Station weather years.

All 29 random runs of weather data substituted for the actual weather data were given in Table 3.1. There are 29 random runs for simplicity in comparing results from the NAC weather normalization approach. Savings from all random runs are determined with the standard IPMVP weather normalization approach, thereby giving 29 sets of savings for six post-commissioning CE/TTI periods. These savings sets are used to ascertain the variability of savings and persistence of savings when using Option D in conjunction with the standard IPMVP weather normalization approach. The entire procedure for obtaining 29 sets of savings results for the six post-commissioning CE/TTI periods using Option C with regression models with the standard IPMVP weather normalization approach is given as a process diagram in Figure 3.10.

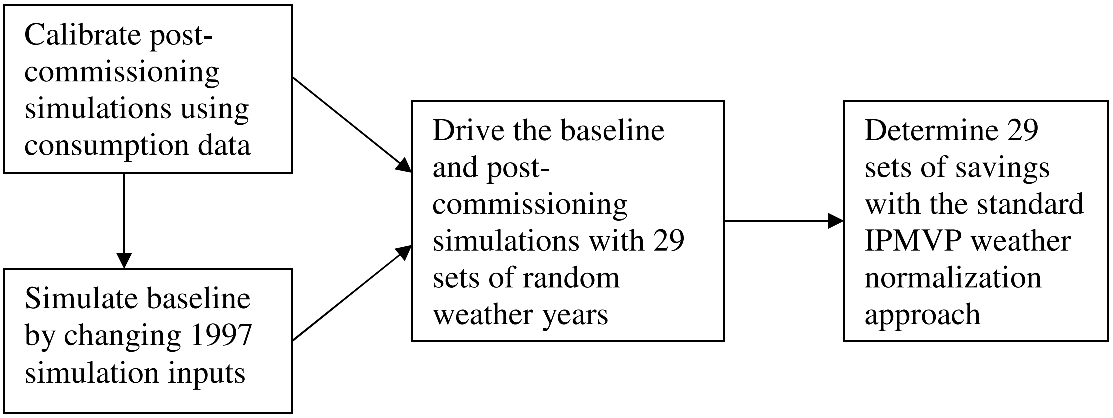


Figure 3.10: Process diagram for obtaining savings sets with Option D using the standard IPMVP weather normalization approach.

3.4.4 Option C with Regression Models Using the Standard IPMVP Weather Normalization Approach

Step 1. Create regression models for each of CE/TTI's post-commissioning periods using the post-commissioning chilled and hot water consumption data.

Regression models are created from CE/TTI's available consumption data for each of the six post-commissioning periods. Four-parameter change-point regression models are used for each of CE/TTI's chilled and hot water post-commissioning models. The 1997 chilled water regression model created from this period's consumption data has been shown in Figure 3.7. Graphs showing regression models created from consumption for all other time periods are given in Appendix A.

Step 2. Use the output from the AirModel simulated baseline year described in section 3.4.3 as “data” to create a baseline regression model.

Limited pre-commissioning data for CE/TTI prevents creating accurate chilled and hot water regression models. As a solution, the chilled and hot water output from the pre-commissioning period calibrated simulation is treated as synthetic consumption data with which chilled and hot water regression models are created. The baseline chilled water regression model created from the output of the baseline calibrated simulation has been shown in Figure 3.8.

Step 3. Substitute random College Station weather years in place of each of the six actual post-commissioning weather years. Use these random weather years to drive both the baseline simulation and the post-commissioning calibrated simulation corresponding to the actual weather being replaced.

In order to form a larger sample size of savings results from the standard IPMVP weather normalization approach, a method is employed that randomly selects a College Station weather year from the NCDC weather years retrieved as the 1st post-commissioning year, another as the 2nd post-commissioning year, yet another as the 3rd post-commissioning year, and so forth. Table 3.2 has been shown to illustrate a sequence of random weather years substituted in place of the actual weather.

Step 4. Use the random substituted weather years to drive both the baseline simulation and the post-commissioning calibrated simulation corresponding to the actual weather being replaced. Determine the chilled and hot water savings with the standard IPMVP weather normalization for this random run of substituted weather years.

Using the example of the random run of weather years to substitute for the actual weather in Table 3.2, the 1997 savings using the standard IPMVP weather normalization approach are determined by the difference in the consumption of the baseline simulation driven with 1992 weather data and the consumption of the 1997 post-commissioning calibrated simulation driven with 1992 weather. The 1998 savings are determined by the difference in the consumption of the baseline simulation driven with 1981 weather data and the consumption of the 1998 calibrated simulation driven with 1981 weather data. This procedure is carried out for the remaining four post-commissioning periods for this particular random run of weather years.

Step 5. Repeat steps three and four 28 additional times, each time substituting the actual post-commissioning weather with a different run of random College Station weather years.

All 29 random runs of weather data substituted for the actual weather data were given in Table 3.1. There are 29 random runs for simplicity in comparing results from the NAC weather normalization approach. Savings from all random runs are determined with the standard IPMVP weather normalization approach, thereby giving 29 sets of savings for six post-commissioning CE/TTI periods. These savings sets are used to ascertain the variability of savings and persistence of savings when using Option D in conjunction with the standard IPMVP weather normalization approach. The entire procedure for obtaining 29 sets of savings results for the six post-commissioning CE/TTI periods using Option C with regression models with the standard IPMVP weather normalization approach is given as a process diagram in Figure 3.11.

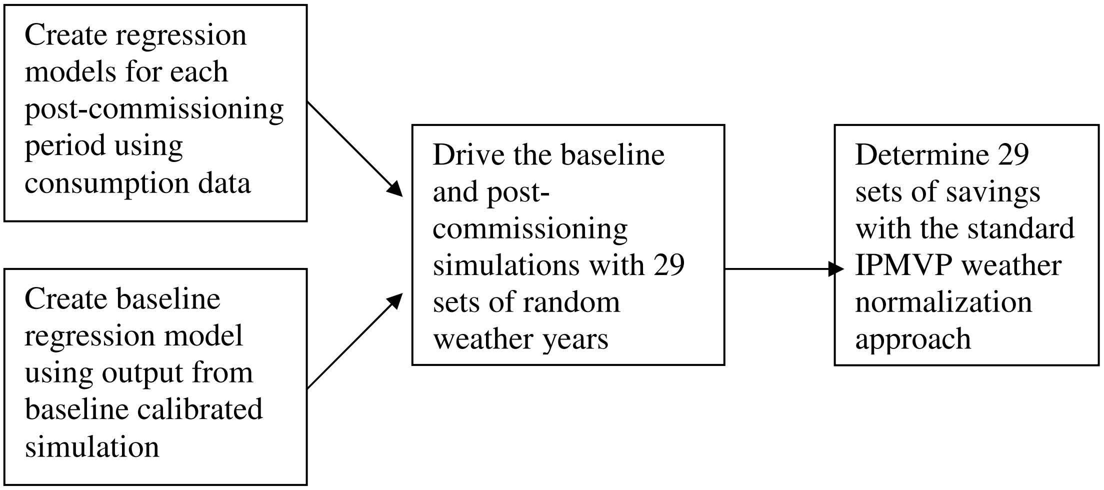


Figure 3.11: Process diagram for obtaining savings sets with Option C with regression models using the standard IPMVP weather normalization approach.

3.5 Savings and Persistence of Savings Analysis

Energy savings and savings persistence from commissioning for CE/TTI, Heep Center, and MSC are compared using the NAC weather normalization approach. Using the NAC weather normalization approach, the long-term average College Station weather year is used as the "normal" weather year. The normalized annual consumption for each of the models is determined by Option C of the IPMVP with regression models. Chilled water, hot water, electricity, and aggregate site savings results are obtained. The results are analyzed to determine reasons for degradation or increases of savings from year to year. This is done by examining commissioning reports and other documentation of operational changes made and retrofits installed in the buildings. The results are compared to general trends in the prior studies mentioned in Chapter II to check for both similarities and differences.

CHAPTER IV

SAVINGS AND PERSISTENCE ANALYSIS OF CE/TTI, HEEP CENTER, AND MSC

4.1 Introduction

The Civil Engineering/Texas Transportation Institute Building (CE/TTI), Heep Center, and Memorial Student Center (MSC) are all buildings on the Texas A&M University campus that have been commissioned multiple times. Each of the buildings uses the campus chilled and hot water loop to meet cooling and heating demands. The first commissioning for each of the buildings took place in either 1996 or 1997 and subsequent commissioning activities took place at different times. The Normalized Annual Consumption (NAC) for the baseline and post-commissioning periods is determined using Option C of the IPMVP (International Performance Measurement and Verification Protocol) with regression models. Savings are determined for each of the three buildings using the NAC weather normalization approach and the long-term average College Station weather year is used as the “normal” weather year. Chilled water, hot water, electricity, and aggregate site savings and persistence of savings are analyzed. Each of the post-commissioning savings are shown based on the original baseline, even for post-commissioning periods that occur after subsequent commissioning activities have taken place.

For each of the three buildings, information on the building and its HVAC systems is given, consumption data quality is verified, regression model parameters are given, commissioning measures are described, and savings and persistence results are analyzed. The savings and persistence of the three buildings as a whole are then discussed and compared to previous persistence studies.

4.2 CE/TTI

4.2.1 CE/TTI Building Description

The Civil Engineering and Texas Transportation Institute (CE/TTI) Building, shown in Figure 4.1, is comprised of two separate buildings connected by a second story skywalk with a total floor area of 157,844 ft^2 (Chen et al. 2004). The first of these buildings, the "tower" side, is an eight-story office building with a basement used solely for electrical and mechanical equipment. The tower side houses a student café, administrative and faculty offices, and the Texas Transportation Institute. The second building, referred to as the "lab" side, consists of four floors and houses several Civil Engineering computer labs, classrooms, and laboratories.

Figure 4.1: CE/TTI Building.

The tower side of the complex contains eleven air-handling units (AHU), among which are eight variable air volume (VAV) units and 3 constant volume units (CV). The first floor has three air-handling units (AHU), of which one services the first floor offices, and the other two service the first floor café. The rest of the building has one AHU per floor. There is also an outside air-handling unit located at the penthouse on the roof of the tower. This unit preconditions outside air before it is distributed to air-handling units in floors two through eight. The first floor gets its outside air supply from two outdoor air fans.

The lab side of the complex contains nine AHUs among which are six VAV units and three CV units. In addition to the AHUs, the lab side building contains twelve supplemental fan coil units (FCU).

Three variable frequency drive (VFD) chilled water pumps, one constant speed chilled water pump, three VFD hot water pumps, one constant speed hot water pump, and a constant speed freeze protection hot water pump supply the AHUs throughout the CE/TTI complex from the main campus loop. The freeze protection pump is only in use when it receives a low outside air temperature signal from the low temperature sensor.

The CE/TTI Building has been commissioned twice. The first commissioning took place between August 1996 and September 1996. The second commissioning took place between December 2002 and August 2003.

4.2.2 CE/TTI Consumption Data Quality Verification

Hourly chilled water, hot water, and electricity post-commissioning consumption data for CE/TTI is obtained from the Energy Systems Laboratory (ESL) database from January 1, 1997 through June 22, 2004. Reliable pre-commissioning data is limited to data from July 23, 1996 through July 31, 1996. Time series data plots found in Appendix B show overall good cyclical behavior for the CE/TTI hourly data. The period between April 25, 2000 and April 23, 2001, however, has no available hot water data and is thus not included in this study.

The hourly data is converted to daily average data and energy balance plots are created for five different time periods throughout the period of available data where it is known from the time series plots that reasonable data of all types exists. Shorter time periods are used with the energy balance plots in order to recognize potential bad data points more easily. The energy balance plots show overall good data quality. However, some data points are identified as poor because they lie far outside the main energy balance curve. Table 4.1 lists the days of data omitted for which the energy balance plots give reasonable doubt as to their accuracy. In addition to the five points listed in Table 4.1, there are many potentially bad data points during the second commissioning period (December 2002-August 2003). None of the data in this period are used in this study regardless of the data quality, however, since commissioning activities were being performed.

Table 4.1: Omitted CE/TTI data points.

6/4/2001	2/26/2002	6/15/2002
7/4/2002	9/28/2003	

4.2.3 CE/TTI Regression Models and Calibrated Simulations

Regression models are created using macros developed by the Energy Systems Laboratory for time periods where consumption data is available. Post-commissioning time periods are divided into full calendar years when possible. The period of missing hot water data, however, as well as the nine-month second commissioning period make this difficult to follow and consumption data period lengths are altered to lengths both shorter and longer than 12 months. As stated above in section 4.1, the regression models use the long-term average College Station weather year in conjunction with the NAC weather normalization approach. The following is a list of the post-commissioning time periods for which regression models are created:

1. 1997
2. 1998
3. January 1, 1999-April 24, 2000
4. April 24, 2001-December 31, 2001

5. January 1, 2002-November 30, 2002
6. September 24, 2003-June 22, 2004

As mentioned in section 4.2.2, pre-commissioning data for the first commissioning of the building is very limited for CE/TTI. This data is insufficient for creating chilled and hot water regression models because a much wider temperature range is needed than is available. For the electricity, however, it is assumed that consumption has little dependence on outside air temperature and is mostly constant since cooling and heating systems rely on the chilled and hot water campus loops. The electricity baseline consumption for CE/TTI, therefore, is assumed to be the mean of the available pre-commissioning data. A potential problem with this method of obtaining the electricity baseline is that the short period of available data is from the summer when campus operations in many buildings at Texas A&M University are reduced. In order to determine whether the average of the pre-commissioning electricity data adequately reflects a whole year's average, average electricity consumption from similar time periods in the first and second post-commissioning periods are compared to the annual electricity consumption. The results are detailed in Table 4.2, which shows the short period's average, the annual average, and the percent difference between the two. The differences obtained from this exercise are 4.08% for 1997 and 1.83% for 1998. Since the normal fluctuation in building use and plug load can cause electricity consumption to vary between 5-10% from year-to-year, it is assumed that these differences are small enough to not modify the average of the available CE/TTI pre-commissioning electricity data.

Table 4.2: Comparison of average of short period of available pre-commissioning electricity data to the annual average for CE/TTI.

Pre-Commissioning Data Period	Post Commissioning Data Period	Post Commissioning Short Period Average (kWh)	Annual Post Commissioning Average (kWh)	Percent Difference
7/23/96 (Tues) - 7/31/96 (Wed)	7/22/97 (Tues) – 7/30/97 (Wed)	9,271	8,908	4.08
7/23/96 (Tues) - 7/31/96 (Wed)	7/21/98 (Tues) – 7/29/98 (Wed)	8,768	8,610	1.83

For chilled and hot water, Measurement & Verification Option D of the IPMVP (2002) is necessary as the means of determining baseline consumption for the building. This is made possible by the availability of the 1996 commissioning report, which documents the commissioning measures implemented. By altering the inputs of the first post-commissioning period (1997) calibrated simulation to match the pre-commissioning building conditions as documented in the commissioning report, simulated chilled and hot water baseline consumption is found using AirModel. This simulated AirModel output is treated as consumption data and used to create baseline regression models for chilled and hot water.

Additionally, calibrated simulations are performed for all of the five other CE/TTI post-commissioning periods. The same time periods used to separate the data for the regression models are also used to separate the data for the calibrated simulations. These calibrated simulations offer possible reasons for savings persistence or lack thereof when limited documentation is available. They are also used to compare the variability of savings persistence with Option D of the IPMVP against Option C with regression models in Chapter VI. The simulated AirModel output is compared with measured data in Appendix A for all post-commissioning periods and specific AirModel inputs are given in Appendix C.

The basis of the simulation inputs comes mainly from commissioning reports, building blue prints, and trips to the building for assessment. Unfortunately, little documentation can be found describing changes to the building operation for the 1998, January 1, 1999-April 24, 2000, and April 24, 2001-December 31, 2001 time periods. Simulations were calibrated in chronological order, starting with the 1997 post-commissioning period. Many of this period's inputs are readily obtained from the 1996 commissioning report. The 1997 calibrated simulation's inputs were then used as the starting point for the 1998 calibrated simulation. Inputs were adjusted using the method outlined in the procedure section, according to the method given by Claridge et al. (2003) until the calibration signatures were as flat as possible and until the RMSE and MBE were minimized. The 1998 calibrated simulation's inputs were then used as the starting point for the January 1, 1999-April 24, 2000 calibrated simulation, and this process was continued through the last calibrated simulation. Information from the 2003 (second) commissioning report that documented both pre- and post-commissioning settings and parameter was then used for final two calibrated simulations, and the inputs were again adjusted to minimize the RMSE and MBE. Each simulation included inputs for two different system types—the single-duct with reheat air handling units (AHU) and the single zone AHUs.

Table 4.3 summarizes the goodness-of-fit measures for each time period's calibrated simulation. The 1996 pre-commissioning simulation has no goodness-of-fit measures because it has no measured consumption data to be compared to.

Table 4.3: Goodness-of-fit measures for CE/TTI AirModel calibrated simulations.

RMSE (MMBtu/day)	**1996 Pre-Comm.**	**1997**	**1998**	**1/99-4/24/00**	**4/24/01-12/31/01**	**1/02-11/02**	**9/03-6/04**
CHW	n/a	4.4687	4.6170	4.2340	4.6359	4.4325	3.9846
HW	n/a	2.0499	2.3970	2.3941	2.0091	2.7280	4.0636
MBE (MMBtu/day)							
CHW	n/a	-0.0381	-0.1636	0.4876	-0.0088	-0.6075	-0.1620
HW	n/a	-0.2631	-0.4496	-0.0782	0.5751	0.2108	0.9088
CV-MBE							
CHW	n/a	-0.09%	-0.35%	1.23%	-0.02%	-1.32%	-0.49%
HW	n/a	-2.96%	-6.13%	-1.05%	8.45%	2.12%	9.52%
CV-RMSE							
CHW	n/a	10.04%	9.78%	10.67%	9.65%	9.66%	12.10%
HW	n/a	23.03%	32.66%	32.02%	29.51%	27.42%	42.56%

Each of the regression models' slope parameters are given in Appendix A. All of the baseline and post-commissioning chilled and hot water models are four parameter change point models (4P CP). All of the electricity regression models are two-parameter linear regression models, with the exception of the baseline period where the mean value is used. Plots of the regression models fit to the corresponding consumption data for chilled water, hot water, and electricity are also found in Appendix A. Regression model goodness-of-fit measures are found in Table 4.4.

Table 4.4: Goodness-of-fit measures for CE/TTI regression models.

CHW (MMBtu/day)	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04
MBE	n/a	-0.0002	-0.0002	0.0000	0.0938	0.0001	-0.0692
RMSE	n/a	4.9755	5.2263	5.0009	4.7574	4.7104	4.1297
CV-RMSE	n/a	11.17%	11.07%	12.61%	9.90%	10.27%	12.54%
HW (MMBtu/day)	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04
MBE	n/a	0.0005	-0.0003	0.0000	0.0063	0.0000	-0.2100
RMSE	n/a	1.7554	2.4857	2.0631	1.5637	2.2109	3.4344
CV-RMSE	n/a	19.72%	33.87%	27.60%	22.97%	22.22%	35.97%
Elec (kWh/day)	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04
MBE	n/a	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RMSE	n/a	1276.8098	1169.1626	1093.6882	1080.9003	1059.9627	1186.7167
CV-RMSE	n/a	14.3%	13.3%	13.0%	13.3%	12.3%	13.0%

4.2.4 CE/TTI Commissioning Measures

During the first commissioning of CE/TTI in 1996, several documented commissioning measures were implemented. These include the following:

1. The cold deck temperature was reset from 50°F to 52°F for all single-duct variable air volume AHUs.
2. The static pressure setpoint was reduced from 1.0" of water to a variable of 0.5" to 0.3" of water, corresponding to fan speeds of 70% to 30%.

3. The outside air supply air setpoint from the pre-treat AHU was changed from 50°F to 55°F.
4. The VAV box fans for the fourth floor were shut off and the VAV box fans on all the other fans were turned to low speed.

The 1996 commissioning report also mentions that at the time of commissioning only two of the eight main AHUs on the tower side of the building had VFDs that were operational. The other six VFDs were either in bypass mode or not working properly. The 2003 commissioning report does not mention any problems associated with the VFDs for these AHUs and the commissioning engineer from the second commissioning has confirmed that these VFDs were operational at the time of the second commissioning. Due to lack of documentation between commissioning reports, however, it is not known when exactly these repairs took place. Based on commissioning report documentation, it can only be concluded that the VFDs were repaired sometime between September 1996 and December 2002. A second set of calibrated simulations, however, was performed that focused on identifying when any VFD problems were fixed and what percentage of the AHUs in need of repair were still acting as constant volume systems. These simulations are discussed in the savings results and persistence analysis section below, section 4.2.5.

The 2003 commissioning report also documents several important measures that were implemented. The following is a list of the major changes made:

1. A nighttime/weekend shutdown schedule was implemented on multiple AHUs.
2. A nighttime/weekend discharge temperature setback was implemented on multiple AHUs.
3. A nighttime/weekend shutdown schedule was implemented on multiple laboratory fan coil units (FCU).
4. The outside air supply fans were rescheduled to coincide with the new AHU schedule.

4.2.5 CE/TTI Savings Results and Persistence Analysis

The chilled water, hot water, electricity, and aggregate site consumption, savings, percent savings, and change in percent savings are listed below in Table 4.5 and percent savings are shown in Figure 4.2. These values are determined with Option C of the IPMVP using regression the models from above and the NAC weather normalization approach. The long-term average College Station weather year is used as the "normal" weather year.

Table 4.5 and Figure 4.2 show favorable savings results for chilled water, hot water, and electricity. Figure 4.2 also notes several post-commissioning activities that play a role in the energy savings and persistence achieved. Each of these activities is discussed in this section (section 4.2.5). The chilled water, hot water, and electricity each experience savings increases from the first to second and from the second to third post-commissioning periods. Overall, aggregate site savings decline sharply between the 2001 and 1/02-11/02 periods, dropping from 14.6% to 7.1%. Hot water savings show an especially sharp drop between these two periods, dropping from 13.7% to -5.6%. The second commissioning of the building, performed after the 1/02-11/02 period, appears to be worthwhile, as the hot water and aggregate site savings increase to 19.4% and 15.6%, respectively, based on the 1996 pre-commissioning baseline. While only the first year of post-commissioning data is available for the second building commissioning, the aggregate site savings return to a level similar to the peak achieved before the 2nd commissioning occurred. Over six post-commissioning periods, CE/TTI averages 12.5% chilled water savings, 17.2% hot water savings, 7.9% electricity savings, and 11.4% aggregate site savings.

Table 4.5: CE/TTI chilled water, hot water, electricity, and aggregate site consumption, savings, percent savings, and change in percent savings using the NAC weather normalization approach and Option C with regression models.

Year/Period	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04
CHW Use (MMBtu/yr)	17356	16491	15849	14890	14767	15822	13256
CHW Savings (MMBtu/yr)	Baseline	864	1507	2466	2589	1534	4100
CHW % Savings	Baseline	5.0%	8.7%	14.2%	14.9%	8.8%	23.6%
CHW Change in % Savings	n/a	n/a	3.7%	5.5%	0.7%	-6.1%	14.8%
HW Use (MMBtu/yr)	3625	2804	2770	2553	3127	3828	2923
HW Savings (MMBtu/yr)	Baseline	821	856	1072	498	-203	702
HW % Savings	Baseline	22.7%	23.6%	29.6%	13.7%	-5.6%	19.4%
HW Change in % Savings	n/a	n/a	0.9%	6.0%	-15.9%	-19.3%	24.9%
Elec Use (MMBtu/yr)	11682	11105	10910	10472	9995	10705	11374
Elec Savings (MMBtu/yr)	Baseline	577	772	1210	1687	977	308
Elec % Savings	Baseline	4.9%	6.6%	10.4%	14.4%	8.4%	2.6%
Elec Change in % Savings	n/a	n/a	1.7%	3.8%	4.1%	-6.1%	-5.7%
Aggregate Site Use (MMBtu/yr)	32663	30400	29528	27915	27889	30355	27553
Aggregate Site Savings (MMBtu/yr)	Baseline	2263	3135	4748	4774	2308	5109
Aggregate Site % Savings	Baseline	6.9%	9.6%	14.5%	14.6%	7.1%	15.6%
Aggregate Site Change in % Savings	n/a	n/a	2.7%	4.9%	0.1%	-7.5%	8.6%

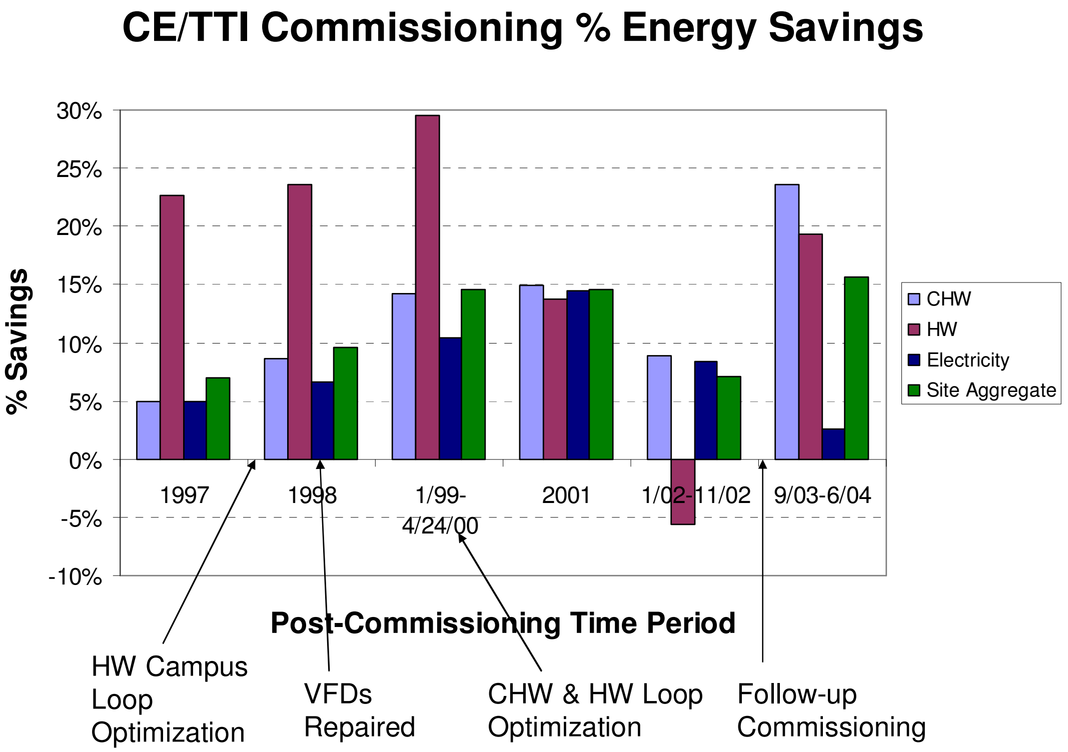


Figure 4.2: CE/TTI chilled water, hot water, electricity, and aggregate site percent savings and timeline of post-commissioning activities that affect energy savings (savings are determined using Option C with regression models of IPMVP using the NAC weather normalization approach and a long-term average College Station weather year).

To have a better understanding on the persistence nature of each of the energy types, it is useful to look at the specific changes in percent savings from post-commissioning period to post-commissioning period. Table 4.5 shows the change in percent savings (the percent savings of a given post-commissioning period minus the percent savings of the previous post-commissioning period). The change in percent electricity savings seem to be erratic and unrelated to commissioning activities or the change in percent savings trends of chilled and hot water. After each of the three energy types steadily increase during the second and third post-commissioning periods, the chilled water savings in 2001 level off, increasing slightly by 0.7%, and the hot water savings decrease by 15.9%. The electricity, however, has an even bigger increase in savings between 1/99-4/24/00 and 2001 than it does between 1998 and 1/99-4/24/00 (4.1% versus 3.8%). This trend is reversed after the second commissioning of the building. After all energy types show a decrease in savings during 1/02-11/02, the second commissioning helps the chilled water and hot water rebound during 9/03-6/04 by 14.8% and 24.9%, respectively, compared to the previous post-commissioning period. The electricity savings, however, decrease by 5.7% between 1/02-11/02 and 9/03-6/04. Thus, it can be concluded that the commissioning measures had a large effect on the chilled and hot water consumption but little effect on electricity consumption.

Overall from the first post-commissioning period in CE/TTI, 1997, through the last post-commissioning period, 9/03-6/04, the chilled water savings increase 18.6%, hot water savings degrade 3.3%, electricity savings degrade 2.3%, and aggregate site savings increase 8.7%.

A second set of calibrated simulations were performed that focused on identifying when any VFD problems were fixed and what percentage of the AHUs in need of repair were still acting as constant volume systems. These calibrated simulations were performed up through the 1999-4/24/00 post-commissioning period just before aggregate site savings begin to decrease. The original simulations include two subsystems, one for all AHUs that have just a cooling coil and one for all AHUs that have a cooling coil and a heating coil in series. The subsystem for the AHUs with just a cooling coil represents around 85% of the total building HVAC capacity and is further subdivided in the second set of calibrated simulations into a subsystem that identifies the area of the HVAC system operating as a constant volume system and the area of the HVAC system operating as a variable air volume system. Table 4.6 summarizes the results of the second set of calibrated simulations that focused on identifying when and how many of the VFD repairs were completed. The results show that most of the VFD repairs were completed after the commissioning report was written (September 1996) and prior to the 1997 post-commissioning period. In 1997 only nine percent of the floor area served by variable air volume air handlers was operating as a constant volume system. By the 1999-4/24/00 post-commissioning period, this number reduced to zero. This implies that there were one or two air handlers whose VFD problems had not been fixed as of 1997 that were subsequently repaired prior to the 1999-4/24/00 period. The other VFDs were apparently either repaired or switched out of the bypass mode between October and December 1996. Unfortunately, the first commissioning report does not specify how many of the six nonfunctioning VFDs were being bypassed and how many needed repairing. Switching the VFDs out of bypass mode is much less time consuming than repairing an existing VFD or installing a new VFD.

Table 4.6: Area fractions of HVAC system operating as constant volume and variable air volume systems according to second set of calibrated simulations aimed at identifying when and what proportion of VFD repairs were implemented in CE/TTI.

	1997	**1998**	**1999-4/24/00**
Constant Volume Area Fraction	0.09	0.06	0.00
Variable Air Volume Area Fraction	0.91	0.94	1.00

The ascending savings between 1997 and the 1999-4/24/00 post-commissioning period is most likely due to several factors. As discussed in the previous paragraph, there appears to have been one or two VFDs that were repaired between 1997 and 1999-4/24/00 that could have caused an increase in chilled water, hot water, and electricity savings. Additionally, there was a hot water campus loop optimization performed in 1997 (Cho 2002). Discussions with commissioning engineers revealed that a further campus loop optimization was done for both chilled and hot water at the end of 1999 and in 2000. All of these activities may explain why the savings in the first year after commissioning increase in both the second and third year after commissioning for both chilled water and hot water. In the fourth period after commissioning, the chilled water savings continue to increase, albeit slightly, while the hot water savings begin to decrease. Both decrease in the fifth post-commissioning period, the period directly before the second building commissioning.

The calibrated simulation cold deck temperature setpoints may help explain the decrease in chilled and hot water savings between 2001 and 1/02-1/02, as well as the increase in savings between 1/02-11/02 and 9/03-6/04 due to the second commissioning of the building. Table 4.7 shows the cold deck temperature setpoint inputs for the calibrated simulations. The cold deck temperature setpoint drops from 58°F to 57°F when the outside temperature is 45°F and from 51°F to 49°F when the outside temperature is 70°F between 2001 and 1/02-11/02. This corresponds to large decreases in both chilled (6.1% decrease) and hot water (5.6% decrease) savings. This problem is corrected during the second building commissioning and the cold deck temperature setpoint is raised to 55°F when the outside temperature is 45°F and 52°F when the outside temperature is 70°F. As a result, chilled and hot water savings both rebound. The chilled water savings increase 23.6% and the hot water savings increase 19.4% between 1/02-11/02 and 6/03-9/04. Additional measures from the second building commissioning that helped achieve these favorable savings during 6/03-9/04 include the nighttime/weekend AHU shutdowns and setbacks.

Table 4.7: Calibrated simulation cold deck temperature setpoint inputs. Setpoints vary linearly between the high and low setpoints when outside air temperature is between 45°F and 70°F; setpoints are constant below 45°F and above 70°F.

T_outside	45°F	70°F
Period	**T_setpoint**	
1996 Pre-CC	53	50
1997	55	52
1998	55	52
1999-4/24/00	58	51
2001	58	51
1/02-11/02	57	49
9/03-6/04	55	52

The decrease in cold deck temperature implemented during the first building commissioning appears to have a significant impact on the initial savings experienced in 1997. The change of the cold deck temperature setpoint during the 1999-4/24/00 post-commissioning period to 58°F when the outside temperature is 45°F and 51°F when the outside temperature is 70°F appears to potentially have some effect on both chilled and hot water savings. The chilled water savings increase 5.5% and hot water savings increase 6.0% between 1998 and 1999-4/24/00.

4.3 Heep Center

4.3.1 Heep Center Building Description

The Heep Center, pictured in Figure 4.3, was constructed in 1977 and is located on the West Campus of Texas A&M University (Powell and Deng 1999, Liu 2006). It is home to the Soil and Crop Sciences and Entomology departments, and consists primarily of offices and labs. The north side of the building has 6 floors while the south side has 5 floors for a total area of 158,979 square feet. It is generally occupied 24 hours a day, 7 days a week.

Figure 4.3: Heep Center.

The HVAC system in the building is a single-duct VAV system, and consists of 2 main air handling units that serve the whole building and 8 small air handling units that serve part of the 1st floor. The control system is direct digitally controlled (DDC) with pneumatic components. The total design supply flow in the building is 212,770 cfm, of which 21,200 cfm is outside air. The total design exhaust flow from the building is 74,940 cfm, and is achieved with 3 exhaust fans and 81 fume hoods. There are 63 make-up air fans which supply air directly to many of the fume hoods. Some of this make-up is drawn from the conditioned atrium air. Table 4.8 below gives an overview of the building HVAC system, including design information for air handling units, makeup fans, and exhaust fans.

Table 4.8: Heep Center HVAC design information.

Building Name:		Heep Center		**Total Area:**	158,979 ft^2
Unit	**Function**	**Service**	**Supply cfm**	**Outside Air cfm**	**Exhaust cfm**
AHU 1	Supply	North side of bldg.	110,000	15,400	0
AHU 2	Supply	South side of bldg.	84,000	11,700	0
AHU P4	Supply	1st floor	1930	190	0
AHU P5	Supply	1st floor	2230	220	0
AHU P6	Supply	1st floor	2010	200	0
AHU P7	Supply	1st floor lecture hall	1730	430	0
AHU P8	Supply	1st floor lecture hall	2180	550	0
AHU P9	Supply	1st floor	1650	170	0
AHU P10	Supply	1st floor lecture hall	5460	1,360	0
AHU P11	Supply	1st floor	1580	160	0
All Makeup Fans	Supply	Total	0	32,430	0
All Exhaust Fans	Exhaust	Total	0	0	74,940

The Heep Center has two chilled water pumps, each of which are direct digitally controlled. There are no hot water pumps; the building uses the hot water campus loop for pressure.

The Heep Center has been commissioned three times. The first commissioning took place between September 1996 and October 1996, the second commissioning took place between August 1999 and October 1999, and the third commissioning took place between October 2005 and February 2006. Pre- and post-commissioning data for the third commissioning of the Heep Center are not available.

4.3.2 Heep Center Consumption Data Quality Verification

Hourly chilled water, hot water, and electricity consumption data for the Heep Center is obtained from the Energy Systems Laboratory (ESL) database. Time series data plots can be found in Appendix B. Similar to CE/TTI, there is little pre-commissioning data available for Heep Center. Pre-commissioning data is available from June 20, 1996 through August 31, 1996 and post-commissioning data is available from January 1, 1997 through June 22, 2004. The time series plots show overall good electric and chilled water data trends for most of the available data period but the hot water data has several periods with no consumption readings. Specifically, there are several months of missing hot water data in 2003 and 2004 that are not used in creating regression models. In addition to time series plots, energy balance plots are used to identify bad data. Appendix B contains energy balance plots both before and after data identified as poor has been removed. Table 4.9 below lists the daily average data points either missing or identified as being of poor quality.

Table 4.9: List of Heep Center consumption data periods either missing or identified as poor data through energy balance plots.

Start Date	End Date	# Days/Period
3/9/1997	3/12/1997	4
3/14/1997	3/14/1997	1
3/18/1997	3/19/1997	2
3/25/1997	3/27/1997	3
4/12/1997	4/14/1997	3
4/26/1997	4/27/1997	2
5/6/1997	5/9/1997	4
6/19/1997	6/23/1997	5
1/26/1998	1/29/1998	4
11/18/1998	11/18/1998	1
11/21/1998	11/21/1998	1
12/9/1998	12/13/1998	5
12/18/1998	12/20/1998	3
1/21/1999	1/21/1999	1
1/30/1999	1/30/1999	1
3/13/1999	3/15/1999	3
4/3/1999	4/3/1999	1
4/8/1999	4/11/1999	4
5/19/1999	6/3/1999	16
6/10/1999	6/11/1999	2
6/18/1999	6/22/1999	5
11/3/1999	11/3/1999	1
3/17/2000	3/17/2000	1
4/26/2000	4/26/2000	1
5/14/2000	5/14/2000	1
6/24/2000	6/24/2000	1
7/19/2000	8/2/2000	15
8/18/2000	8/19/2000	2
10/7/2000	10/10/2000	4
12/26/2000	1/1/2001	7
8/25/2002	8/25/2002	1
10/2/2002	10/3/2002	2
12/9/2002	12/10/2002	2
12/30/2002	12/30/2002	1
7/20/2003	11/24/2003	128
2/26/2004	4/27/2004	62
5/1/2004	5/6/2004	6
5/10/2004	5/26/2004	17
6/3/2004	6/7/2004	5

4.3.3 Heep Center Regression Models

Post-commissioning regression models are created from chilled and hot water consumption data for the following time periods:

1. 1997
2. 1998
3. January 1, 1999-July 31, 1999
4. November 1, 1999-December 31, 2000
5. 2001
6. 2002
7. 2003
8. January 1, 2004-June 22, 2004

Due to the second commissioning of the building from August through October of 1999, the third and fourth time periods are not able to be full calendar years.

As with CE/TTI, Heep Center's pre-commissioning data is from summer months and does not cover a large enough temperature range to create accurate chilled and hot water regression models. The pre-commissioning electricity consumption data is again assumed to be mostly constant with outside air temperature and the mean value is used as a uniform daily consumption value. Similar to Table 4.2 for CE/TTI, the average electricity consumption from a shortened post-commissioning period is compared to the annual average for Heep Center in Table 4.10 to determine whether modification of the average of the pre-commissioning electricity data is necessary. Results in Table 4.10 again show a small difference (1.15%) and it is assumed that the average from the available pre-commissioning electricity data accurately reflects the annual pre-commissioning average.

Table 4.10: Comparison of average of short period of available pre-commissioning electricity data to the annual average for Heep Center.

Pre-Commissioning Data Period	Post Commissioning Data Period	Post Commissioning Short Period Average (kWh)	Annual Post Commissioning Average (kWh)	Percent Difference
6/20/96 (Thur) – 8/31/96 (Sat)	6/26/97 (Thur) – 9/6/97 (Sat)	13,984	13,824	1.15

Option D of the IPMVP is again employed in conjunction with Option C to create baseline chilled and hot water models. The 1997 data are used to calibrate a simulation based on HVAC system parameters documented in the 1996 commissioning report for post-commissioning conditions. Goodness-of-fit parameters for this 1997 simulation are shown below in Table 4.11. Appendix A shows the calibrated simulation output against the consumption data versus outside dry-bulb temperature for both chilled water and hot water for the 1997 period. Using the 1997 calibrated simulation, the pre-commissioning baseline consumption is simulated by changing the input parameters to the pre-commissioning values as detailed in the commissioning report. Specific inputs are found in Appendix C for both the 1997 and pre-commissioning time periods. With the simulated pre-commissioning consumption output from AirModel, chilled and hot water regression models are created that serve as baseline regression models. Post-commissioning regression models are created using the post-commissioning consumption data. Each of the regression models' slope parameters are given in Appendix A. Plots of the regression models fit to the corresponding consumption data for both chilled water and hot water can also be found in Appendix A. Regression model goodness-of-fit measures are found in Table 4.12.

Table 4.11: Goodness-of-fit measures for 1997 Heep Center calibrated simulation.

	Chilled Water	**Hot Water**
RMSE (MMBtu/day)	6.64	2.40
MBE (MMBtu/day)	-1.28	0.80
CV-RMSE	9.08%	17.68%

Table 4.12: Goodness-of-fit measures for Heep Center regression models.

CHW (MMBtu/day)	1997	1998	1/99-7/99	11/99-12/00	2001	2002	2003	1/1/04-6/22/04
MBE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RMSE	7.6584	8.3828	6.2234	7.7960	7.9215	9.1384	10.3759	5.9339
CV-RMSE	10.47%	10.69%	8.85%	11.59%	11.05%	12.76%	17.12%	11.49%
HW (MMBtu/day)	**1997**	**1998**	**1/99-7/99**	**11/99-12/00**	**2001**	**2002**	**2003**	**1/1/04-6/22/04**
MBE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RMSE	1.7503	2.5728	1.7417	1.9942	2.3937	2.6212	2.5926	2.6924
CV-RMSE	12.87%	21.98%	14.45%	17.53%	18.46%	19.37%	22.01%	22.98%
Electricity (kWh/day)	**1997**	**1998**	**1/99-7/99**	**11/99-12/00**	**2001**	**2002**	**2003**	**1/1/04-6/22/04**
MBE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RMSE	1684.19	1528.42	1369.05	1705.94	1685.33	1591.86	1569.55	1243.72
CV-RMSE	12.2%	11.2%	10.5%	13.2%	13.1%	12.0%	12.7%	10.9%

4.3.4 Heep Center Commissioning Measures

The commissioning team implemented several key measures during the initial 1996 commissioning of the building. The supply duct static pressure setpoint was reduced from 3.0” to 1.5”. Additionally, the supply duct temperature setpoint was changed from a fixed 55°F to a variable 62°F at 55°F ambient temperature to 53°F at 85°F ambient temperature. The return chilled water temperature setpoint was changed from 56°F to 54°F and the flow rate was raised from 1000 gpm to 1250 gpm. This measure’s purpose was to ensure a low chilled water supply temperature and sufficient flow to the air handling units to satisfy building loads. The total supply air flow was reduced from 164,000 cfm to 142,000 cfm and outside air flow was reduced from approximately 43% to 16% of the supply air flow. It should be noted that the outside air flow input for the 1997 AirModel simulation is calibrated to a value of 30%. This value is probably more realistic than the 16% stated in the commissioning report since outside air flow measurements are often difficult to accurately make. This is particularly true for the Heep Center, where each of the two outside air intake louvers stand nine feet tall by eight feet wide.

The follow-up commissioning in 1999 found that the outside air had increased to 59% of the total supply air flow. Steps were taken to reduce this level to 36% by increasing the return air flow. For the hot summer months, this measure reduces the amount of hot air coming in from outside and increases the amount of cool return air returning to the air handling units, thus reducing chilled water consumption. Additionally, the domestic hot water temperature setpoint was changed to a fixed temperature of 110°F from a variable 125°F at 40°F ambient temperature to 70°F at 70°F ambient temperature. The follow-up commissioning report also mentions that all sensors, control valves, and dampers in the entire building were checked for functionality and that some faulty devices had been replaced while others were awaiting replacement. The commissioning report also mentions that area maintenance workers were at the time in the process of either repairing or replacing all building thermostats and checking all terminal units. This action had been recommended during the initial building commissioning in 1996.

4.3.5 Heep Center Savings Results and Persistence Analysis

Energy consumption, savings, percent savings, and change in percent savings for Heep Center are listed in Table 4.13 and percent savings are shown in Figure 4.4. Figure 4.4 also notes post-commissioning activities that play a role in the savings achieved. These include the hot water campus loop optimization at the end of 1997 and in 1998, as well as the follow-up commissioning from August through October 1999 and significant maintenance work done during 2002 and 2003.

Overall, the savings persistence is quite stable. In particular, the persistence of the chilled water savings appears to be mostly steady. These savings range from as low as 7.2% to as high as 15.7%. The biggest change in chilled water percent savings occurs between the first and second post-commissioning periods, 1997 and 1998, and is 4.6%. The biggest subsequent change from one post-commissioning period to the next for chilled water is 2.7%. Electricity percent savings range from 10.7% to 26.2% and hot

Table 4.13: Heep Center chilled water, hot water, electricity, and aggregate site consumption, savings, and change in percent savings using the NAC weather normalization approach and Option C with regression models.

Year/Period	Sim'd Pre-CC	1997	1998	1/99-7/99	11/99-12/00	2001	2002	2003	1/1/04-6/22/04
CHW Use (MMBtu/yr)	29310	27191	25856	25253	24695	25126	25359	25547	24757
CHW Savings (MMBtu/yr)	Baseline	2119	3454	4058	4615	4184	3952	3763	4554
CHW % Savings	Baseline	7.2	11.8	13.8	15.7	14.3	13.5	12.8	15.5
CHW Change in % Savings	n/a	n/a	4.6%	2.1%	1.9%	-1.5%	-0.8%	-0.6%	2.7%
HW Use (MMBtu/yr)	6430	4855	4380	4375	4106	4728	4942	4268	4075
HW Savings (MMBtu/yr)	Baseline	1575	2050	2056	2325	1702	1489	2163	2355
HW % Savings	Baseline	24.5	31.9	32.0	36.2	26.5	23.1	33.6	36.6
HW Change in % Savings	n/a	n/a	7.4%	0.1%	4.2%	-9.7%	-3.3%	10.5%	3.0%
Elec Use (MMBtu/yr)	19334	17256	16863	16159	16092	15942	16459	15484	14273
Elec Savings (MMBtu/yr)	Baseline	2078	2471	3175	3242	3392	2875	3850	5062
Elec % Savings	Baseline	10.7%	12.8%	16.4%	16.8%	17.5%	14.9%	19.9%	26.2%
Elec Change in % Savings	n/a	n/a	2.0%	3.6%	0.3%	0.8%	-2.7%	5.0%	6.3%
Aggregate Site Use (MMBtu/yr)	55075	49303	47099	45786	44893	45797	46759	45298	43104
Aggregate Site Savings (MMBtu/yr)	Baseline	5772	7975	9288	10182	9278	8316	9776	11970
Aggregate Site % Savings	Baseline	10.5%	14.5%	16.9%	18.5%	16.8%	15.1%	17.8%	21.7%
Aggregate Site Change in % Savings	n/a	n/a	4.0%	2.4%	1.6%	-1.6%	-1.7%	2.7%	4.0%

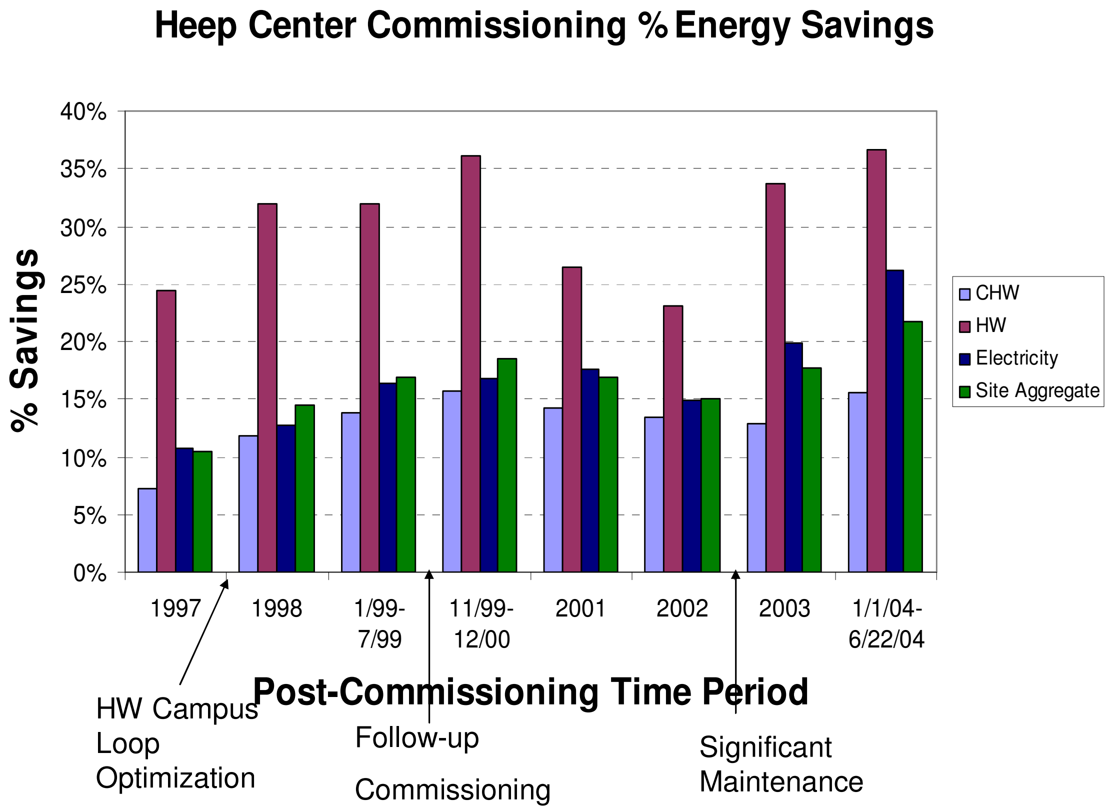


Figure 4.4: Heep Center chilled water, hot water, electricity, and aggregate site percent savings and timeline of post-commissioning activities that affect energy savings (savings are determined using Option C with regression models of IPMVP using the NAC weather normalization approach and a long-term average College Station weather year).

water percent savings range from 23.1% to 36.6%. Unlike CE/TTI, the Heep Center's electricity savings appear to be related to commissioning activities since they generally increase or decrease with chilled and hot water savings. The biggest change in electricity percent savings from one post-commissioning period to the next is 6.3%, taking place during 1/1/04-6/22/04. Hot water savings are the most erratic, decreasing 9.7% between 11/99-12/00 and 2001 just two years after the second commissioning took place, and increasing by 10.5% between 2002 and 2003.

Chilled water, hot water, and electricity percent savings all show savings increases from post-commissioning period to post-commissioning period between the first and second building commissioning. The biggest of these increases, 7.4%, occurs in hot water from

1997 to 1998. This increase is most likely due to the hot water campus loop optimization performed on the Texas A&M University campus during 1997. Chilled water also increased by 4.6% over this same period, the largest increase from one post-commissioning period to the next over all periods. The increases in chilled water, hot water, and electricity savings may be linked to the gradual repairing/replacement of the building thermostats and terminal units as mentioned in section 4.3.4.

Since calibrated simulations were not performed over all post-commissioning periods for Heep Center, an attempt to explain savings behavior from year-to-year is made by creating what this thesis calls quasi-calibration signatures. Quasi-calibration signatures are based on the regression model output from a given year and the regression model output from the subsequent year, each model being driven with the long-term average College Station weather year. Quasi-calibration signatures are calculated similarly to calibration signatures (refer to equation 3.5 and 3.6) except that the regression model output of a given year is treated as "measured consumption" and the regression model output of the subsequent year is treated as "simulated consumption." Quasi-calibration signatures represent an attempt to determine specific operational changes from year to year since most of these details are not available. The quasi-calibrated signatures, given in Appendix D, unfortunately do not indicate any obvious changes in building performance when comparing them to published characteristic signatures.

The savings results show the first commissioning yielded higher results than the second commissioning. Based on the savings results for both chilled and hot water, the end result of the follow-up commissioning is more of maintaining savings and preventing degradation than increasing savings. Chilled water, hot water, and electricity savings all reach their pre-second building commissioning peak during the 1/99-7/99 period at 13.8%, 32.0%, and 16.4% respectively. During the first period following the second building commissioning (11/99-12/00), the savings only increase 1.9%, 4.2%, and 0.3% respectively for chilled water, hot water, and electricity. After this period, chilled water savings stay mostly constant, not dropping below 12.8%. The electricity savings also stay very steady for the first three periods after the second commissioning before increasing by 5.0% between 2002 and 2003, and by 6.3% between 2003 and 1/1/04-6/22/04. The hot water savings are the least steady of the three energy types after the second building commissioning. After reaching 36.2% hot water savings (based on the original baseline) during 11/99-12/00, the hot water savings experience two consecutive decreases of 9.7% and 3.3%, followed by two consecutive increases of 10.5% and 3.0%. These increases raise the savings to 36.6% during 1/1/04-6/22/04, which is just 0.4% different than the 36.2% hot water savings achieved before the decline. As mentioned in Figure 4.4, there was significant maintenance work done during 2002 and 2003 on Heep Center. According to commissioning engineers, this maintenance addressed some of the recommendations from the follow-up commissioning in 1999. Unfortunately the extent and details of the maintenance work are unclear. After this maintenance work was performed, hot water savings were brought back to their previous levels before the decline in savings.

Overall, there is an increase in aggregate site savings from post-commissioning period to post-commissioning period from 1997 through the 11/99-12/00 period, the first period after the follow-up commissioning of Heep Center. This is followed by two periods of decline and then two periods of increase.

Over eight post-commissioning periods, Heep Center averages 13.1% chilled water savings, 30.5% hot water savings, 16.9% electricity savings, and 16.5% aggregate site savings.

Overall from the first post-commissioning period in Heep Center, 1997, through the last post-commissioning period, 1/1/04-6/22/04, the chilled water savings increase 8.3%, hot water savings increase 12.1%, electricity savings increase 15.5%, and aggregate site savings increase 11.2%.

4.4 MSC

4.4.1 MSC Building Description

The Memorial Student Center Complex, pictured in Figure 4.5, is a two-story building with a basement and a total gross area of 348,000 ft^2 (Veteto et al. 1998, Liu et al. 2005). Located on the main campus of Texas A&M University, this building was originally constructed in 1950. The MSC complex includes MSC Main, which is the original construction of the complex, Food Services, Board of Regents, the MSC Hotel, and the MSC Annex. Data is available for the combined consumption for MSC Main, Food Services, Board of Regents, and the MSC Hotel. Data for the MSC Annex, however, is not available.

Figure 4.5: Memorial Student Center (MSC).

The MSC Main consists of multiple offices and student organization areas, as well as ballrooms, a food service area, food courts, bookstores, and meeting areas. The MSC Main has been renovated multiple times since its original construction in order to accommodate the needs and desires of the student body and faculty. The MSC Hotel was constructed 1950 as part of the MSC Main building and has three floors, two floors of rooms and a first floor reception area.

The MSC Main is a two-story building with a basement and has a total conditioned floor area of 200,460 square feet. The HVAC (Heating, Ventilation, and Air Conditioning) system for this building consists of 37 air handling units (AHUs). These units are located in mechanical rooms throughout the building and a few are located in the ceilings of multiple floors. All but two of these units are pneumatically controlled to maintain the space temperature setpoint. The other two units are equipped with Direct Digital Control (DDC).

There are three chilled water pumps for the MSC. Each is equipped with a VFD to control the pump speed. The pump speeds are maintained to control the loop differential pressure (DP) at its setpoint, which is constant as set by the user. Additionally, there are two constant speed hot water pumps. The DP setpoint for these two loops is maintained by modulating the building control valve located in the return line of the two loops.

The MSC has been commissioned twice. The first commissioning took place between September 1997 and November 1997 and the second commissioning took place between December 2003 and February 2005. Pre- and post-commissioning data for the second commissioning of MSC is not available.

4.4.2 MSC Consumption Data Quality Verification

Hourly chilled water, hot water, and electricity consumption data for MSC is obtained from the Energy Systems Laboratory (ESL) database from January 1, 1997 through June 22, 2004. Time series plots of the data can be found in Appendix B. There is no available data at all after the middle of 2001. The time series plots show overall good chilled water and electricity data for most of the available data period but the hot water data has multiple periods with no consumption readings.

Table 4.14: List of MSC consumption data periods identified as poor data through energy balance plots.

Start Date	End Date	# Days/Period
12/4/1997	12/4/1997	1
12/19/1997	12/20/1997	2
1/5/1998	1/5/1998	1
1/11/1998	1/12/1998	2
1/14/1998	1/14/1998	1
1/21/1998	1/21/1998	1
2/19/1998	2/19/1998	1
3/5/1998	3/5/1998	1
4/30/1998	5/7/1998	8
5/9/1998	5/9/1998	1
5/13/1998	5/13/1998	1
7/15/1998	7/15/1998	1
8/11/1998	8/11/1998	1
9/5/1998	9/5/1998	1
12/11/1998	12/13/1998	3
12/19/1998	12/19/1998	1
1/1/1999	3/25/1999	84
4/2/1999	4/3/1999	2
4/6/1999	10/14/1999	192
10/16/1999	10/21/1999	6
2/8/2000	2/14/2000	7
2/17/2000	2/23/2000	7
2/25/2000	4/5/2000	41
4/7/2000	4/21/2000	15
4/25/2000	5/1/2000	7
5/21/2000	5/28/2000	8
12/9/2000	12/9/2000	1
12/13/2000	12/13/2000	1
12/19/2000	12/31/2000	13

Due to the abundance of poor hot water data, energy balance plots are used to identify many poor consumption data points. Upon inspection of the energy balance plots for all periods, days of erroneous data are eliminated from consideration as part of this study. Table 4.14 lists all of the data periods removed. Energy balance plots used to identify bad data points are found in Appendix B.

4.4.3 MSC Regression Models

Regression models are generated from the accurate chilled and hot water consumption data for the following time periods:

1. January 1, 1997-August 31, 1997
2. December 1, 1997-December 31, 1998
3. 1999
4. 2000

Consumption data prior to 1997 is unavailable, thus making it necessary for the baseline pre-commissioning period (1/1/97-8/31/97) to be shorter than one full year. Each of the regression model's slope parameters are given in Appendix A. Plots of the regression models fit to the corresponding consumption data for chilled water, hot water, and electricity can also be found in Appendix A. Regression model goodness-of-fit measures are found in Table 4.15.

Table 4.15: Goodness-of-fit measures for MSC regression models.

CHW (MMBtu/day)	1/97-8/97	12/97-12/98	1999	2000
MBE	0.0000	0.0000	0.0000	0.0000
RMSE	10.3492	15.2111	7.6551	13.5900
CV-RMSE	6.38%	10.51%	6.72%	10.30%
HW (MMBtu/day)	**1/97-8/97**	**12/97-12/98**	**1999**	**2000**
MBE	0.0000	0.0000	0.0000	0.0000
RMSE	6.0209	7.9014	8.4799	10.5978
CV-RMSE	8.63%	13.56%	12.66%	26.60%
Electricity (kWh/day)	**1/97-8/97**	**12/97-12/98**	**1999**	**2000**
MBE	0.0000	0.0000	0.0000	0.0000
RMSE	1212.3319	1451.4406	1643.6213	1454.4502
CV-RMSE	5.81%	7.13%	10.33%	9.04%

4.4.4 MSC Commissioning Measures

There were many commissioning measures implemented in the MSC that were performed multiple times on different AHUs and the respective zones they serve. Common energy savings measures performed during commissioning include resetting the cold deck temperature, optimizing the supply air flow rate, calibrating and resetting room thermostats, and performing air balances.

Additionally, the commissioning report from the first commissioning of the building (9/97-11/97) lists several important measures whose implementation were recommended. These recommendations were not able to be performed during the official commissioning period and it was left up to the area maintenance of Texas A&M University to implement the recommendations sometime after the documented commissioning report was written.

The major recommended measures detailed in the first commissioning report deal with an overall negative pressurization problem that was causing excessive outside air to be drawn through doors, windows, and other openings in the building. One problem noticed during commissioning was a bad outside air fan (SF 1) that serves AHUs 1, 3, MB5, 12, 13, 17, and 18. It was recommended that this fan be replaced. Additionally, makeup air fans in the kitchen had been turned off, causing conditioned air to be exhausted and uncomfortable conditions to occur in the kitchen during the summer. It was recommended that the makeup air fans be interlocked with the kitchen exhaust fans and to run both exhaust and makeup fans only during cooking and service hours rather than all day long. This was to be implemented through the control system. The commissioning report also recommended cleaning the reheat coils for the kitchen AHUs. Additional recommendations were also made. The complete list of recommendations not implemented during the official commissioning period can be found in Appendix E.

There is unfortunately no documentation available regarding these recommendations after the first commissioning took place. It is therefore difficult to determine if and when the recommended commissioning measures were actually implemented due to unavailable documentation between the first and second commissioning period (12/03-2/05). However, the second commissioning report does not mention problems dealing with negative pressurization as described above, suggesting these problems may have been resolved. Of all the recommended measures listed in Appendix E, the only one that is referred to again in the second commissioning report is to repair a manual valve in the hot water loop. That said, a commissioning technician from the second building commissioning reported that the make-up and exhaust fans were not interlocked in 2004. Thus, if control changes had been made, they were subsequently overridden.

4.4.5 MSC Savings Results and Persistence Analysis

Of the three buildings discussed in this chapter, MSC has the least amount of post-commissioning periods (three) to analyze for savings and persistence of savings. MSC also has the least amount of documentation to explain the changes seen in the years after commissioning was completed. The limited MSC savings results, however, appear to be quite favorable in terms of positive savings achieved and the lack of degradation shown. Similar to results seen in the CE/TTI building and Heep Center, the MSC experiences positive first year post-commissioning savings that continue to increase in the second and third post-commissioning periods for both chilled and hot water. Table 4.16 lists the consumption, savings, percent savings, and change in percent savings and Figure 4.6 shows the percent savings for the MSC. Values shown are based on normalized annual consumption (NAC) determined with the regression models detailed above and the NAC weather normalization approach, normalized to the long-term average College Station weather year. Campus chilled and hot water loop optimizations are also noted in Figure 4.6.

The chilled water percent savings jump from 13.5% during the 12/97-12/98 period to 16.4% in 1999 to 23.2% in 2000. The hot water percent savings jump from 17.7% during the 12/97-12/98 period to 21.0% in 1999 to 38.6% in 2000. The electricity percent savings jump from 2.6% during the 12/97-12/98 period to 20.2% in 1999 to 22.7% in 2000. While savings increase from post-commissioning period to post-commissioning period for chilled water, hot water, and electricity, the increases of one energy type are not always consistent with the other two energy types. For example, electricity percent savings increase 17.6% from 12/97-12/98 to 1999, yet only 2.5% from 1999 to 2000. Hot water percent savings, on the other hand, increase just 3.3% from 12/97-12/98 to 1999 but then jump 17.6% from 1999 to 2000. Chilled water percent savings are more constant, increasing 2.9% from 12/97-12/98 to 1999 and 6.8% from 1999 to 2000.

Table 4.16: MSC chilled water, hot water, electricity, and aggregate site consumption, savings, percent savings, and change in percent savings using the NAC weather normalization approach and Option C with regression models.

Year/Period	1/97-8/97	12/97-12/98	1999	2000
CHW Use (MMBtu/yr)	58712	50814	49110	45090
CHW Savings (MMBtu/yr)	Baseline	7898	9602	13622
CHW % Savings	Baseline	13.5%	16.4%	23.2%
CHW Change in % Savings	n/a	n/a	2.9%	6.8%
HW Use (MMBtu/yr)	25791	21237	20365	15842
HW Savings (MMBtu/yr)	Baseline	4554	5427	9949
HW % Savings	Baseline	17.7%	21.0%	38.6%
HW Change in % Savings	n/a	n/a	3.4%	17.5%
Elec Use (MMBtu/yr)	26009	25331	20762	20107
Elec Savings (MMBtu/yr)	Baseline	678	5247	5902
Elec % Savings	Baseline	2.6%	20.2%	22.7%
Elec Change in % Savings	n/a	n/a	17.6%	2.5%
Aggregate Site Use (MMBtu/yr)	110512	97383	90237	81039
Aggregate Site Savings (MMBtu/yr)	Baseline	13130	20276	29473
Aggregate Site % Savings	Baseline	11.9%	18.3%	26.7%
Aggregate Site Change in % Savings	n/a	n/a	6.5%	8.3%

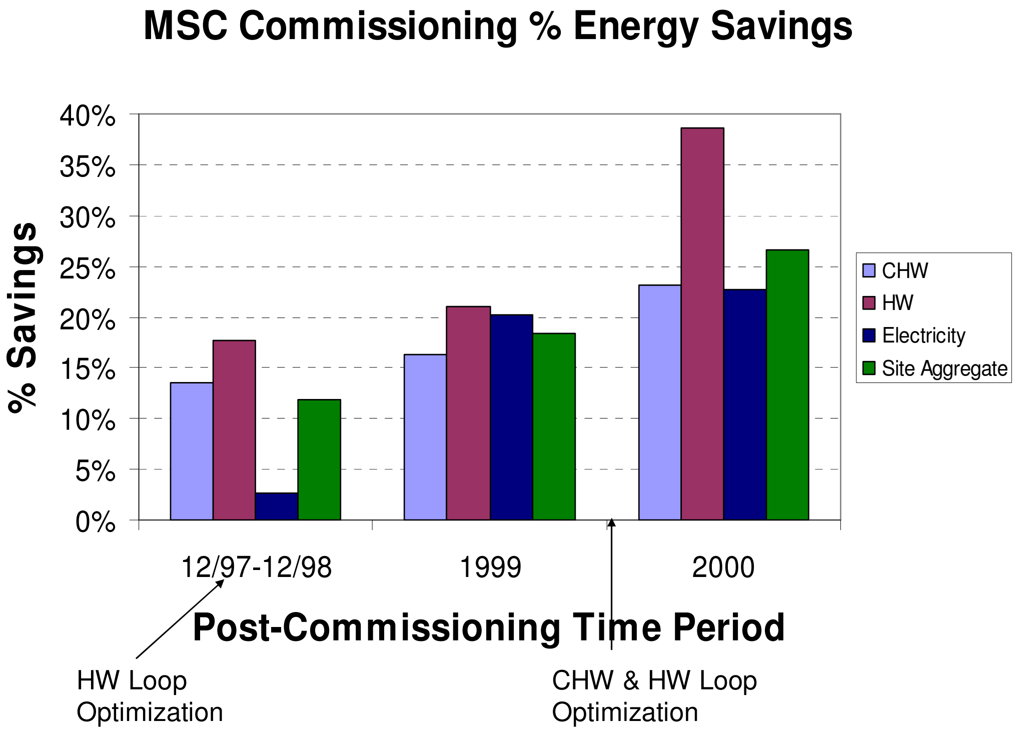


Figure 4.6: MSC chilled water, hot water, electricity, and aggregate site percent savings and timeline of post-commissioning activities that affect energy savings (savings are determined using Option C with regression models of IPMVP using the NAC weather normalization approach and a long-term average College Station weather year).

Over three post-commissioning periods, MSC averaged 17.7% chilled water savings, 25.8% hot water savings, 15.2% electricity savings, and 19.0% aggregate site savings.

Overall from the first post-commissioning period in MSC, 12/97-12/98, through the last post-commissioning period, 2000, the chilled water savings increase 9.7%, hot water savings increase 20.9%, electricity savings increase 20.1%, and aggregate site savings increase 14.8%.

Due to the increase in savings for chilled water, and hot water, and electricity, it appears likely that at least some of the recommended commissioning measures were indeed implemented during the post-commissioning periods. The campus hot water loop optimization that took place at the end of 1997 and in 1998 may also help to explain savings increases over time. A subsequent campus chilled and hot water loop optimization at the end of 1999 and in 2000 seems to have a large role in the savings increases during 2000. Similar to Heep Center, quasi-calibration signatures are given in Appendix D for MSC in attempt to further explain savings behavior from year-to-year. As with Heep Center, however, it is difficult to determine any specific operational changes made in MSC by comparing the quasi-calibration signatures to published characteristic signatures.

4.5 Combined Persistence Results Analysis

Overall, the savings achieved in CE/TTI, Heep Center, and MSC show mixed results. The chilled water, hot water, electricity, and aggregate site percent savings for these buildings are shown together in Figure 4.7, 4.8, 4.9, and 4.10 below. Similar figures for buildings from other studies are shown in the literature review chapter (Chapter II). While CE/TTI, Heep Center, and MSC were commissioned at different times and have different post-commissioning period times and lengths, Figure 4.7, 4.8, 4.9, and 4.10 generically show savings versus post-commissioning period number. Table 4.17 gives the specific dates of the post-commissioning period numbers for each of the three buildings. The savings in these figures are all determined with Option C of the IPMVP using regression models and the NAC weather normalization approach, normalized to the long-term average College Station weather year.

Table 4.17: Specific dates of post-commissioning period numbers for CE/TTI, Heep Center, and MSC.

Post-Commissioning Period Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
CE/TTI	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04		
Heep Center	1997	1998	1/99-7/99	11/99-12/00	2001	2002	2003	1/1/04-6/22/04
MSC	12/97-12/98	1999	2000					

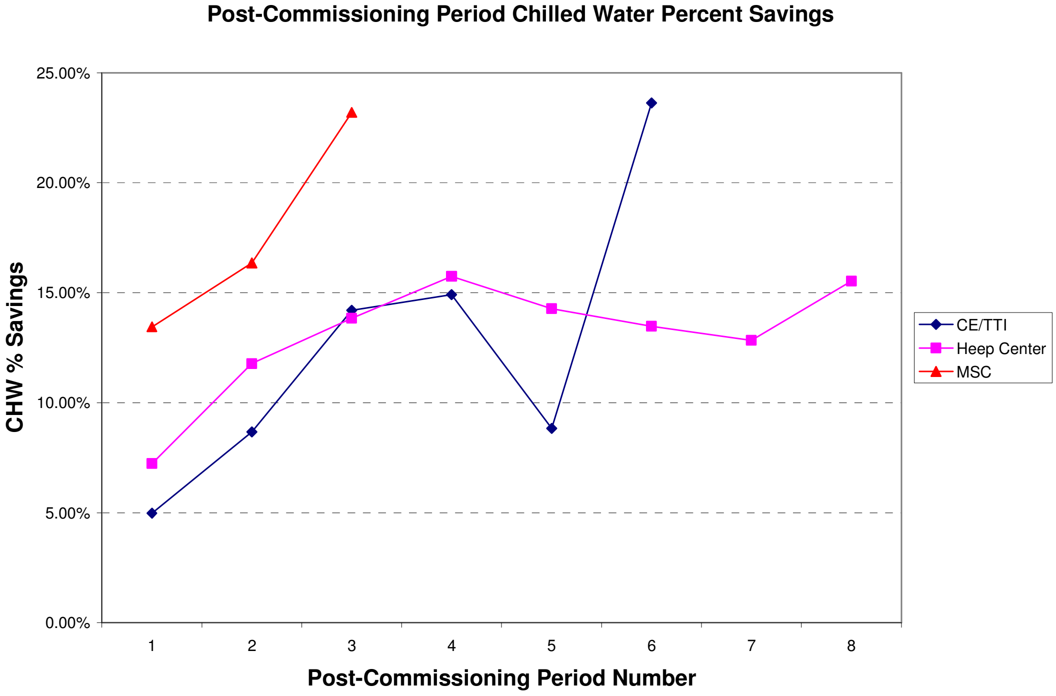


Figure 4.7: Post-commissioning chilled water percent savings for CE/TTI, Heep Center, and MSC.

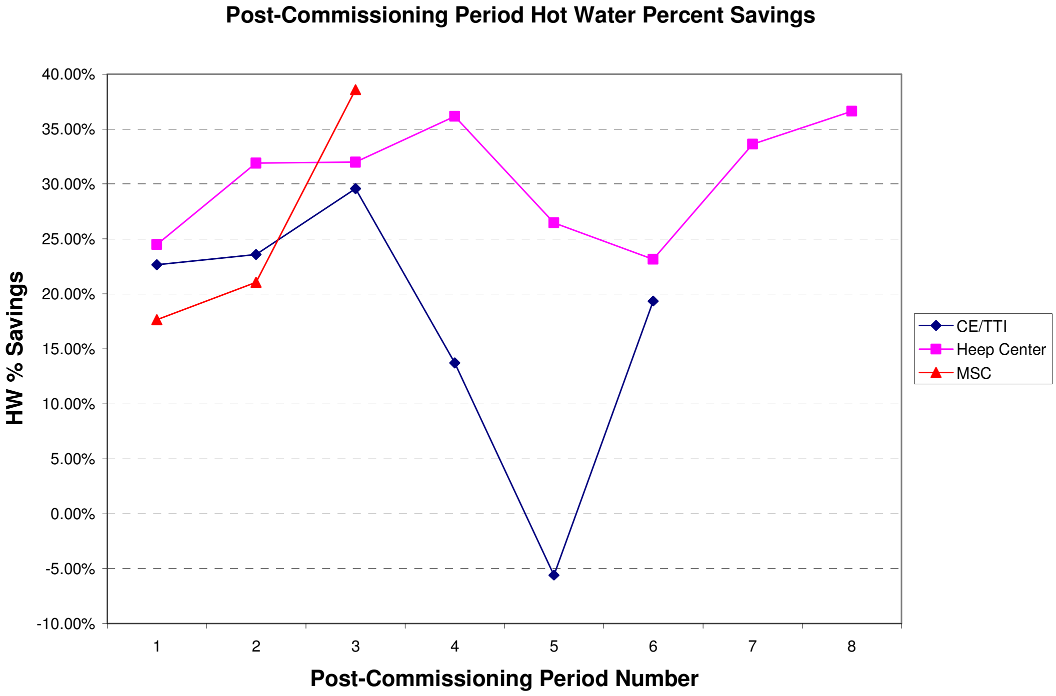


Figure 4.8: Post-commissioning hot water percent savings for CE/TTI, Heep Center, and MSC.

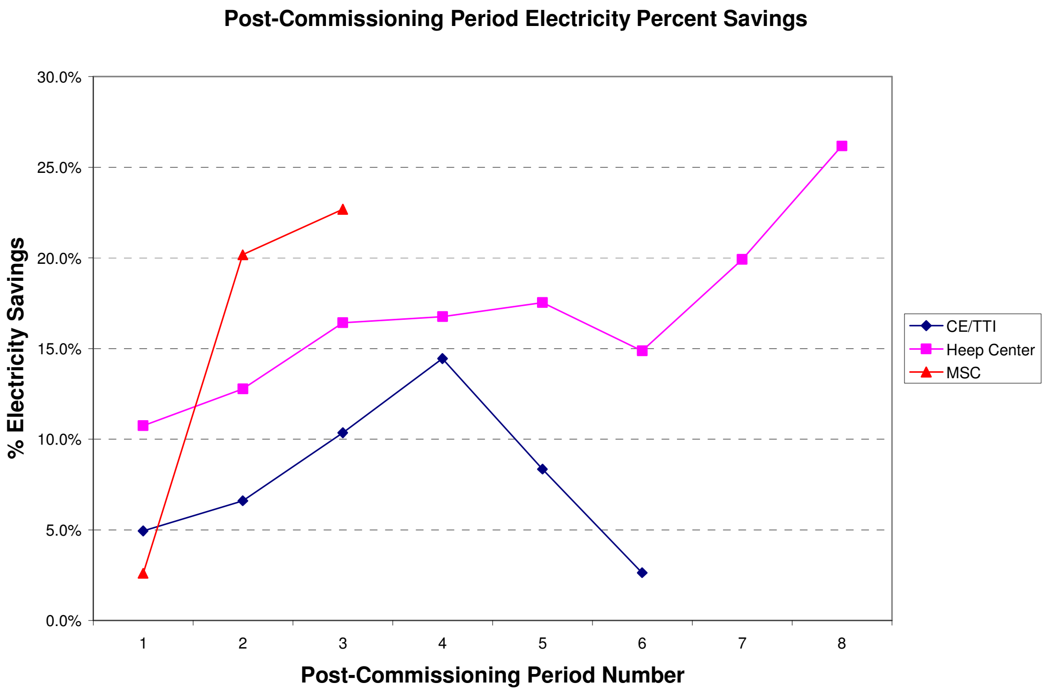


Figure 4.9: Post-commissioning electricity percent savings for CE/TTI, Heep Center, and MSC.

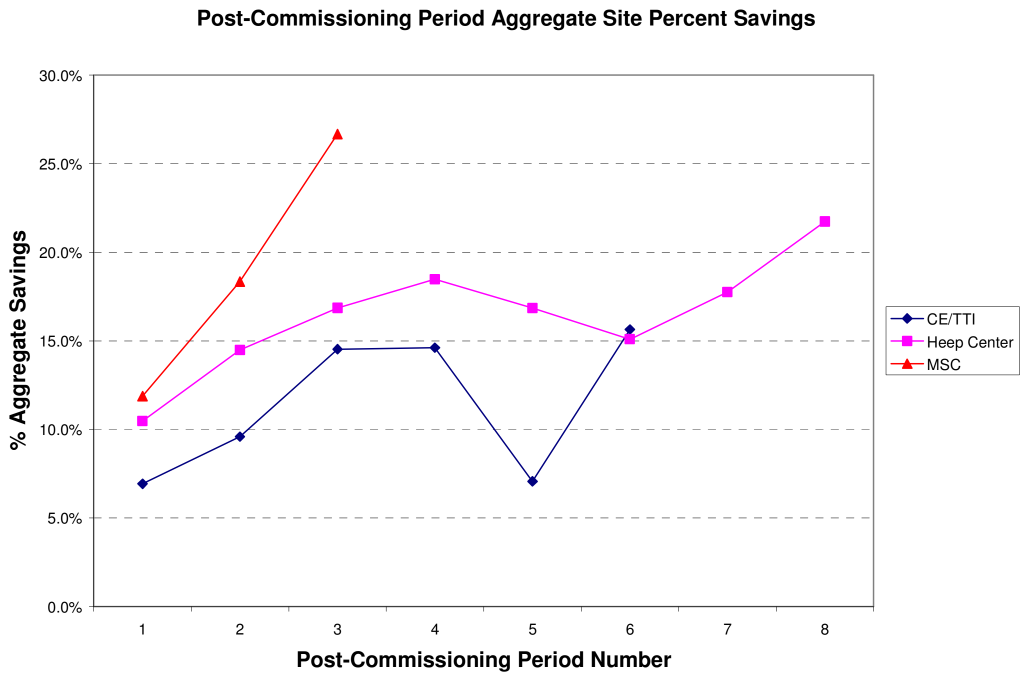


Figure 4.10: Post-commissioning aggregate site percent savings for CE/TTI, Heep Center, and MSC.

Of the three buildings presented in Figure 4.7, 4.8, 4.9, and 4.10, Heep Center displays the steadiest behavior in terms of percent savings for each energy type. The follow-up commissioning performed on Heep Center between the third and fourth post-commissioning periods is particularly noteworthy as it is likely responsible for preventing a large decline in savings. CE/TTI, on the other hand, experiences the largest drop in savings of the three buildings over time. In fact, the hot water consumption during the fifth post-commissioning period is more than the baseline consumption (negative savings). CE/TTI also underwent a follow-up second commissioning which results in significant savings increases for both chilled and hot water during the one post-commissioning period of available data. Had this second commissioning of CE/TTI occurred a couple of years earlier, a more steady savings pattern similar to that of Heep Center may have resulted. This suggests the importance of follow-up commissioning about three years after an initial commissioning to ensure savings persistence. The persistence of savings for the MSC is more difficult to analyze since there are only three post-commissioning periods but this building shows the biggest increases in aggregate site percent savings.

All three buildings experience savings increases in chilled water, hot water, and electricity from post-commissioning period one to two and from period two to three. Of the two buildings in this study with more than three post-commissioning periods available (CE/TTI and Heep Center), the aggregate site percent savings continue to experience savings increases through the fourth post-commissioning period before both decrease the following period. Each, however, rebound and achieve their peak aggregate site percent savings during the last post-commissioning period.

Some of the persistence and savings characteristics shown in CE/TTI, Heep Center, and MSC are also seen in the literature review. Like the majority of the buildings in the literature review, the commissioning savings shown in this study are quite favorable and reflect well upon the effectiveness of building commissioning. Additionally, the trend of increasing savings during the first several years after commissioning is seen in buildings in the literature review. For example, three of the buildings studied by Turner et al. and also on the Texas A&M University campus experienced increases in savings not related to a further commissioning of the building after the first post-commissioning period (Turner et al. 2001, Cho 2002, Claridge et al. 2002, Claridge et al. 2004). Table 4.18 summarizes the consumption and savings results for these buildings. Wehner CBA reaches its lowest post-commissioning chilled water savings in 1998 at 31% before reaching its maximum savings two years later at 40%. This is the largest increase for chilled water percent savings among these three buildings. Richardson Petroleum and VMC Addition also experience increases in chilled water savings, although the savings are markedly smaller than those in Wehner CBA. Richardson Petroleum has a maximum change in percent chilled water savings of 2% from 1998 to 1999 and VMC has a maximum change in percent chilled water savings of 3% over this same period. These two increases are not large enough to consider significant. Hot water savings increases among these buildings, on the other hand, are significantly higher than chilled water savings increases, although the VMC Addition actually drops from 75% in 1997 to 43% in 2000. The hot water savings increase steadily from 64% in 1997 to 88% in 2000 for Richardson Petroleum, and from 19% in 1997 to 53% in 2000 for Wehner CBA. Electricity savings for Richardson Petroleum, VMC Addition, and Wehner CBA seem to be unrelated to the commissioning measures or chilled and hot water savings trends and show random variability in their behavior, increasing and decreasing in usually small increments. Electricity savings in CE/TTI similarly show little relation to commissioning measures or chilled and hot water savings trends.

Table 4.18: Buildings at Texas A&M University from Cho's study (2002) that experienced increased savings some time after the first post-commissioning year.

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 (%)**
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**

*The baseline energy use for this building is estimated from the average savings of other buildings because insufficient data is available to create a reliable baseline.

Savings increases between post-commissioning periods are also shown by Bourassa et al. (2003). In fact, five of the eight buildings in the SMUD Program experienced savings increases at some point after the first post-commissioning year. Two of these buildings had maximum savings increases from one post-commissioning period to the next of over 10 percent while the other three experienced a maximum increase of three percent or less.

CHAPTER V
WEATHER DATA QUALITY VERIFICATION

5.1 Introduction

As stated in the procedure, the College Station weather years from 1973 through 2005 are available to populate a set of savings results for the NAC (Normalized Annual Consumption) and standard IPMVP (International Performance Measurement and Verification Protocol) weather normalization approaches using both Option C with regression models and Option D of the IPMVP. This makes it possible to see which of the two weather normalization approaches and which of the two IPMVP savings options has less variability. Since the weather years themselves are important in deciding the outcome of this study, it is necessary to use accurate weather data to avoid potentially misleading energy savings results. Given that the weather data years obtained from NCDC and ESL databases for the present study have many missing hourly data points, it is important to check for any resulting temperature bias that could skew consumption and savings results. A means of quantifying the bias of each weather year compared to the others is necessary to evaluate the weather data. Weather years where a bias is suspected are not used in this study.

5.2 Missing Weather Data

As mentioned in section 3.3.1, the College Station weather data used in this study is obtained solely from NCDC for 1973 through 1996 and July 2004 through 2005. The weather years from 1997 through June 2004 are obtained using both the ESL database and NCDC to cross check against each other and fill in any missing data points. Table 5.1 summarizes the number of hourly data missing per weather year and gives the percent of missing data. Table 5.1 shows that there are three years with more than 20 percent of the data missing (1982, 1986, and 1987). The other years all have fewer than

10 percent of the data missing and just six of those years (1978, 1979, 1980, 1983, 1988, and 1995) have between five and 10 percent missing.

Table 5.1: Missing hourly College Station weather data summary.

Weather Year	# Hourly Missing Data	% Data Missing
1973	291	3.32
1974	328	3.74
1975	277	3.16
1976	315	3.59
1977	295	3.37
1978	491	5.61
1979	487	5.56
1980	551	6.27
1981	310	3.54
1982	1847	21.08
1983	512	5.84
1984	383	4.36
1985	348	3.97
1986	1981	22.61
1987	2667	30.45
1988	561	6.39
1989	360	4.11
1990	259	2.96
1991	219	2.50
1992	186	2.12
1993	193	2.20
1994	371	4.24
1995	761	8.69
1996	0	0.00
2005	84	0.96

Knowing simply how much missing data exists does not sufficiently describe a potential bias in temperature. For example, the missing data could have occurred mostly during the coldest month of the year rather than being equally distributed throughout the year. Another possible scenario may include much of the missing data from a certain part of each day such as between 12am and 4am. Table 5.2 and Table 5.3 show the number of annual missing hourly weather data points for each hour of the day for the College Station weather years. Table 5.4 and Table 5.5 show the distribution of the number of days with a given amount of missing hours of weather data for each College Station weather year. The years from 1997 through 2004 are not shown in these tables since all of the data points were filled using the two databases.

Table 5.2: Annual number of missing weather data for each hour of the day for each College Station weather year (1973-1985).

Hour of day	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**
0	14	12	12	18	9	19	19	28	15	11	15	13	9
1	9	14	10	11	13	21	32	28	8	25	14	16	20
2	16	9	15	13	11	22	21	25	13	20	22	23	10
3	11	16	10	3	10	15	12	21	15	24	26	14	15
4	9	14	13	14	16	20	15	22	11	94	23	13	12
5	16	7	8	10	8	19	17	20	18	181	13	12	14
6	9	10	8	17	10	15	14	13	12	229	26	13	25
7	7	9	9	14	17	22	25	24	14	233	21	18	14
8	9	15	11	15	15	14	19	29	11	233	28	20	18
9	11	14	15	9	13	28	25	24	16	228	24	15	17
10	11	17	8	13	14	27	23	22	17	227	27	14	6
11	12	20	9	8	19	24	20	27	15	86	24	19	9
12	18	14	13	7	8	15	16	20	13	8	21	21	8
13	13	16	8	7	9	17	27	16	12	29	28	16	18
14	17	21	14	18	14	23	13	11	7	24	19	13	17
15	8	18	14	17	11	20	15	19	11	21	27	16	11
16	14	16	15	10	18	19	23	17	16	14	29	17	20
17	9	11	12	23	14	24	23	23	12	22	20	18	15
18	10	12	12	7	11	22	24	29	9	22	10	18	20
19	16	17	14	24	11	23	20	29	18	23	25	16	14
20	12	10	18	13	14	20	22	28	13	28	15	19	18
21	10	14	11	8	13	19	18	30	10	22	14	16	11
22	12	10	9	21	5	24	25	20	11	22	15	11	14
23	18	12	9	15	12	19	19	26	13	21	26	12	13

Table 5.3: Annual number of missing weather data for each hour of the day for each College Station weather year (1986-1996, 2005).

Hour of day	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	2005
0	14	18	13	13	12	10	11	8	14	28	0	2
1	16	19	16	16	19	9	10	8	15	41	0	2
2	7	16	11	16	11	13	9	11	9	25	0	0
3	12	24	12	18	8	7	8	12	12	31	0	2
4	187	67	13	12	5	12	3	6	15	23	0	3
5	250	313	23	12	4	12	7	8	14	29	0	3
6	247	363	45	19	8	12	11	3	12	29	0	3
7	250	365	43	12	4	5	3	4	11	27	0	5
8	253	365	43	16	4	7	6	6	10	33	0	6
9	251	365	40	12	11	8	7	3	12	24	0	4
10	251	365	46	9	8	8	11	6	13	28	0	3
11	73	170	47	12	15	4	13	5	19	34	0	2
12	9	11	18	16	6	6	6	7	20	25	0	5
13	10	23	18	24	11	9	10	5	25	53	0	2
14	22	22	20	10	8	11	5	17	21	37	0	1
15	12	16	21	22	9	15	8	4	21	35	0	4
16	14	17	20	17	15	8	5	9	20	42	0	7
17	16	17	16	16	9	12	4	9	22	42	0	3
18	20	17	14	14	19	11	10	15	20	41	0	3
19	20	23	24	17	14	10	11	10	11	34	0	1
20	17	24	19	14	16	11	8	13	18	24	0	1
21	14	14	9	16	12	2	4	12	17	24	0	1
22	9	18	15	14	16	8	10	8	10	28	0	3
23	7	15	15	13	15	9	6	4	10	24	0	18

Table 5.4: Breakdown of the number of days per College Station weather year with a certain number of missing hours (1973-1985).

# Hours Missing Per Day	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
0	202	202	233	180	170	112	122	112	178	36	141	155	163
1	93	105	95	114	122	125	106	109	114	44	112	115	114
2	37	32	25	42	48	63	75	71	47	28	50	53	51
3	21	15	3	20	23	41	37	32	15	17	28	32	24
4	8	2	1	3	2	9	13	19	4	13	13	4	7
5	2	3	2	2	0	11	8	14	4	4	8	3	5
6	0	1	0	2	0	3	1	5	1	57	3	0	1
7	0	0	1	2	0	0	2	4	1	93	2	1	0
8	1	0	0	0	0	1	1	0	1	48	2	2	0
9	0	0	0	1	0	0	0	0	0	12	2	0	0
10	0	0	0	0	0	0	0	0	0	9	1	0	0
11	1	0	0	0	0	0	0	0	0	1	0	0	0
12	0	0	0	0	0	0	0	0	0	2	1	1	0
13	0	0	1	0	0	0	0	0	0	0	0	0	0
14	0	1	0	0	0	0	0	0	0	1	1	0	0
15	0	1	0	0	0	0	0	0	0	0	0	0	0
16	0	1	0	0	0	0	0	0	0	0	0	0	0
17	0	0	1	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	1	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	2	3	0	0	0	0	0	0	0	0	0	0

Table 5.5: Breakdown of the number of days per College Station weather year with a certain number of missing hours (1986-1996, 2005).

# Hours Missing Per Day	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	2005
0	56	0	131	151	193	218	222	224	178	109	366	306
1	36	0	117	134	118	101	108	110	112	103	0	44
2	19	0	53	47	36	31	31	20	40	56	0	10
3	2	0	25	17	7	7	4	7	14	37	0	2
4	3	0	6	9	9	5	1	2	8	18	0	1
5	3	0	3	4	1	3	0	0	4	9	0	1
6	1	98	9	0	0	0	0	1	2	8	0	0
7	133	145	13	2	1	0	0	0	2	4	0	0
8	85	72	6	0	0	0	0	1	1	4	0	1
9	19	30	2	0	0	0	0	0	1	3	0	0
10	4	12	0	0	0	0	0	0	0	3	0	0
11	3	2	0	1	0	0	0	0	0	2	0	0
12	0	3	0	0	0	0	0	0	0	3	0	0
13	1	2	1	0	0	0	0	0	2	0	0	0
14	0	1	0	0	0	0	0	0	0	1	0	0
15	0	0	0	0	0	0	0	0	0	2	0	0
16	0	0	0	0	0	0	0	0	1	2	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	1	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.2 and Table 5.3 show that the weather years with the most missing data, particularly 1982, 1986, and 1987, are missing much more morning hours than other hours of the day. As a result, these three years most likely have a bias in their average temperatures. For the other weather years, it is more difficult to determine if a similar bias is present by using the tables above. On the other hand, the above tables show that most weather years have only several days with more than three or four hours of data missing.

5.3 Temperature Bias Calculation

While the results in Tables 5.2-5.5 are helpful, the resulting bias in the temperature from the missing data is still not quantified. While a precise measure of temperature bias cannot be determined, two methods of measuring a weather year's temperature bias due to missing data are introduced here.

The first method divides the year into two-week periods to determine the impact of the missing weather data within those two-week periods on the whole weather year's data. This method indicates a larger bias when a large amount of data is missing from a relatively small number of two-week periods and indicates a smaller bias when missing points are more equally distributed over the course of the year's two-week periods.

The second method looks at each weather year's days separated into four quarters of each day (12am-5am, 6am-11am, 12pm-5pm, 6pm-11pm) to ascertain the impact of the missing weather data within those four quarters on the whole weather year's data. This method indicates a larger bias when missing data tend to come from one or more of the same day quarters and a smaller bias when the missing data are more evenly distributed across the four quarters. The equations used for the second method incorporate the hourly ASHRAE design day temperatures (in this case the peak hourly temperature is 95 °F and the minimum hourly temperature is 74 °F) for each of the day's quarters to essentially find a weighted average temperature bias based on how many data points from each quarter are missing throughout the year (ASHRAE 2001). This value is then compared to the ASHRAE daily average design temperature to find the annual temperature bias.

Under the first method that breaks the weather years' data down into two-week periods, the measure of annual temperature bias, $T_{bias,annual,2\text{-}Wk}$, is found using the following equations:

$$T_{avg,daily} = \frac{\sum_{i=1}^{n_{avail,day}} T_{i,hourly}}{n_{avail,day}} \tag{5.1}$$

$$T_{avg,2-Wk} = \frac{\sum_{i=1}^{14} T_{i,avg,daily}}{14} \tag{5.2}$$

$$T_{avg,avail,hr,2-Wk} = \frac{\sum_{i=1}^{n_{avail,2-Wk}} T_{i,hourly}}{n_{avail,2-Wk}} \tag{5.3}$$

$$T_{annual,miss} = \frac{\sum_{i=1}^{26} (n_{i,miss,2-Wk} \times T_{i,TrueAvg,2-Wk})}{\sum_{i=1}^{26} n_{i,miss,2-Wk}} \tag{5.4}$$

$$T_{annual,exist} = \frac{\sum_{i=1}^{n_{avail,yr}} T_{i,hourly}}{n_{avail,yr}} \tag{5.5}$$

$$T_{bias,annual,2-Wk} = (T_{annual,exist} - T_{annual,miss}) \times n_{miss,yr} \div 8760 \tag{5.6}$$

In these equations,

$n_{avail,day}$=Number of hours of data available on a given day

$n_{avail,2\text{-}Wk}$=Number of hours of data available in a given 2-week period

$n_{miss,2\text{-}Wk}$=Number of hours of data missing in a given 2-week period

$n_{miss,yr}$=Number of hours of data missing in a given weather year

$n_{avail,yr}$=Number of hours of data available in a given weather year

$T_{avg,daily}$=Average of all available hourly temperatures in a given day

$T_{avg,2\text{-}wk}$=Average of 14 values of $T_{avg,daily}$ in a given 2-week period

$T_{avg,avail,hr,2\text{-}Wk}$=Average of all available hourly temperature data in a given 2-week period

$T_{annual,miss}$=Annual weighted average temperature of missing data

$T_{annual,exist}$=Annual weighted average temperature of existing data

$T_{bias,annual,2\text{-}Wk}$=Annual average temperature bias analyzed with 2-week periods of data

For the second method, the following equations are used in order to find the measure of temperature bias, $T_{bias,annual,4\ Quarters}$, found by separating each day into four quarters:

$$T_{annual,miss} = (T_{Design,12am-5am} \times n_{miss,yr,12am-5am} + T_{Design,6am-11am} \times n_{miss,yr,6am-11am} + T_{Design,12pm-5pm} \times n_{miss,12pm-5pm} + T_{Design,6pm-11pm} \times n_{miss,6pm-11pm}) \div n_{miss,yr} \tag{5.7}$$

$$T_{bias,annual,4Quarters} = (T_{Design,daily} - T_{annual,miss}) \times n_{miss,yr} \div 8760 \tag{5.8}$$

In these equations,

$T_{Design,12am-5am}$=Average ASHRAE design temperature for 12am-5am

$T_{Design,6am-11am}$=Average ASHRAE design temperature for 6am-11am

$T_{Design,12pm-5pm}$=Average ASHRAE design temperature for 12pm-5pm

$T_{Design,6pm-11pm}$=Average ASHRAE design temperature for 6pm-11pm

$T_{Design,daily}$=Daily average ASHRAE design temperature

$n_{miss,yr,12am-5am}$=Number of hours of data missing from 12am-5am in a given weather year

$n_{miss,yr,6am-11am}$= Number of hours of data missing from 6am-11am in a given weather year

$n_{miss,yr,12pm-5pm}$= Number of hours of data missing from 12pm-5pm in a given weather year

$n_{miss,yr,6pm-11pm}$= Number of hours of data missing from 6pm-11pm in a given weather year

$T_{bias,annual,4\ Quarters}$=Annual average temperature bias analyzed with data from 4 quarters of each day

Using the first method, the temperature bias for both the dry-bulb and dewpoint temperatures for each of the weather years are calculated. Under the second method, the temperature bias was calculated just for the dry-bulb temperature. Results are shown in Table 5.6.

Table 5.6: Calculated average annual temperature biases in College Station weather years due to missing data points.

Weather Year	DB Bias Using 2-Wk Av Temps (°F)	Dpt Bias Using 2-Wk Av Temps (°F)	DB Bias Using Design Air Temp Quarters (°F)
1973	-0.0037	0.0167	-0.0062
1974	-0.1472	-0.0959	-0.0263
1975	-0.1378	-0.0479	-0.0098
1976	-0.0480	-0.0615	-0.0122
1977	0.0243	0.0441	-0.0059
1978	0.0147	0.0234	0.0006
1979	0.0526	0.0461	0.0014
1980	0.1353	0.1186	0.0462
1981	-0.0848	-0.0700	0.0105
1982	-1.2603	-0.9966	0.3573
1983	-0.3116	-0.3905	-0.0330
1984	0.0147	0.0433	-0.0107
1985	-0.0647	-0.0393	-0.0083
1986	-1.1047	-1.2695	0.5261
1987	0.0678	0.0917	0.5535
1988	0.5367	0.5568	-0.0077
1989	-0.0319	-0.0296	-0.0219
1990	0.0264	0.0151	0.0040
1991	0.0442	0.0374	-0.0013
1992	-0.0051	-0.0028	0.0122
1993	0.0456	0.0429	0.0003
1994	0.0800	0.0379	-0.0582
1995	-0.3039	-0.3097	-0.0675
1996	0.0000	0.0000	0.0000
2005	-0.0121	-0.0062	-0.0087

Since the two methods to measure temperature bias are not exact or proven methods, arbitrary criteria are used to determine which weather years should not be used in this study when they appear to have a relatively large bias compared to other weather years. Weather years are not used if the absolute value of the annual dry bulb temperature bias using two-week average temperatures is greater than 0.32 °F, if the absolute value of the dewpoint temperature bias using two-week average temperatures is greater than 0.39 °F, or if the absolute value of the dry bulb temperature bias using the design air temperature quarters is greater than 0.05 °F. If any one of these criteria is violated then the corresponding weather year is discarded and not used in the variability of persistence of savings portion of this study. In many cases the weather years have much smaller biases for each of these three criteria. Thus it is determined from the results in Table 5.6 that the College Station weather years of 1982, 1986, 1987, and 1988 will not be used in this study in order to minimize introducing any potential bias into consumption and savings results. Additionally, 1995 will not be used because it has an abnormally high number of days missing between three or more hours of data (26.5% of its days are missing three or more hours while weather years determined to have a sufficiently low temperature bias typically have fewer than 10% of its days with three or more missing hours). These five weather years also have the most missing data of all the weather years. It is assumed that the biases from the other weather years are not significant enough to greatly drastically alter consumption and savings results even though all but one of the weather years have some data missing.

CHAPTER VI

SAVINGS AND VARIABILITY OF SAVINGS RESULTS COMPARISON FROM DIFFERENT SAVINGS METHODOLOGIES

6.1 Introduction

The Civil Engineering/Texas Transportation Institute Building (CE/TTI) is used to compare the variability in the savings and persistence of energy savings results using different methodologies. These methodologies include two different IPMVP (International Performance Measurement and Verification Protocol) savings methods—Option C with regression modeling and Option D—and two different weather normalization approaches—NAC (Normalized Annual Consumption) and standard IPMVP. CE/TTI is used for this purpose because it has cleaner data than both Heep Center and the Memorial Student Center (MSC) and is easier to simulate over all post-commissioning periods. Due to the inability of AirModel to accurately simulate electricity consumption, only chilled and hot water results are compared in this portion of the study.

Information on CE/TTI regarding building use, HVAC systems, consumption data quality, regression models created from consumption data, and the commissioning measures performed is detailed in Chapter IV. The energy consumption models (calibrated simulations and regression models) are compared in section 6.2 before variability of savings and persistence of savings results are presented.

6.2 CE/TTI Energy Consumption Model Comparison

Information on the calibrated simulations for CE/TTI's pre- and post-commissioning periods has been given in Chapter IV. Calibrated simulation goodness-of-fit measures are again given in Table 6.1. The 1996 pre-commissioning simulation has no goodness-of-fit measures because it has no measured consumption data to be compared to. Specific inputs can be found in Appendix C for the pre- and each post-commissioning period. Appendix A shows the calibrated simulation output against the consumption data versus outside dry-bulb temperature for both chilled water and hot water for each of the calibrated simulations.

Table 6.1: CE/TTI goodness-of-fit measures for AirModel calibrated simulations.

RMSE (MMBtu/day)	**1996 Pre-Comm.**	**1997**	**1998**	**1/99-4/24/00**	**4/24/01-12/31/01**	**1/02-11/02**	**9/03-6/04**
CHW	n/a	4.4687	4.6170	4.2340	4.6359	4.4325	3.9846
HW	n/a	2.0499	2.3970	2.3941	2.0091	2.7280	4.0636
MBE (MMBtu/day)							
CHW	n/a	-0.0381	-0.1636	0.4876	-0.0088	-0.6075	-0.1620
HW	n/a	-0.2631	-0.4496	-0.0782	0.5751	0.2108	0.9088
CV-MBE							
CHW	n/a	-0.09%	-0.35%	1.23%	-0.02%	-1.32%	-0.49%
HW	n/a	-2.96%	-6.13%	-1.05%	8.45%	2.12%	9.52%
CV-RMSE							
CHW	n/a	10.04%	9.78%	10.67%	9.65%	9.66%	12.10%
HW	n/a	23.03%	32.66%	32.02%	29.51%	27.42%	42.56%

For ease of comparison with the calibrated simulations, regression model goodness-of-fit measures are again shown (see Table 6.2). It is interesting to note that the goodness-of-fit measures results of the calibrated simulations and regression models in Table 6.1 and Table 6.2 show that the calibrated simulations generally have a smaller RMSE and CV-RMSE than the regression models for chilled water. The results for hot water, however, show the opposite occurs—regression models generally have lower RMSE and CV-RMSE values than calibrated simulations. The significance of this result, however, is difficult to ascertain because AirModel links the chilled water and hot water consumption together while chilled water and hot water regression models are created independent of each other.

Table 6.2: CE/TTI goodness-of-fit measures for regression models.

RMSE (MMBtu/day)	**1996 Pre-Comm.**	**1997**	**1998**	**1/99-4/24/00**	**4/24/01-12/31/01**	**1/02-11/02**	**9/03-6/04**
CHW	n/a	4.9755	5.2263	5.0009	4.7574	4.7104	4.1297
HW	n/a	1.7554	2.4857	2.0631	1.5637	2.2109	3.4344
MBE (MMBtu/day)							
CHW	n/a	-0.0002	-0.0002	0.0000	0.0938	0.0001	-0.0692
HW	n/a	0.0005	-0.0003	0.0000	0.0063	0.0000	-0.2100
CV-RMSE							
CHW	n/a	11.17%	11.07%	12.61%	9.90%	10.27%	12.54%
HW	n/a	19.72%	33.87%	27.60%	22.97%	22.22%	35.97%

Two statistical measures are used to compare the overall closeness of the post-commissioning calibrated simulations and regression models in fitting to the data. These measures include a pooled variance t-test and a match pairs t-test. These statistical measures were recommended by statisticians from the Texas A&M Statistics Department after consultations where project details were discussed.

A pooled variance t-test is performed to obtain a statistical measure that either rejects or fails to reject the assumption, or null-hypothesis, of equal root mean square error between the calibrated simulation and regression model populations (Montgomery and Runger 2003). This test is done for both chilled and hot water and uses ά=0.05. For this case, the null hypothesis is as follows:

$$H_0 : \mu_{simulation} - \mu_{regression} = \Delta_0 = 0 \text{ or } H_0 : \mu_{simulation} = \mu_{regression} \tag{6.1}$$

where $\mu_{simulation}$= average root mean square error determined by the calibrated simulations

$\mu_{regression}$= average root mean square error determined by the regression models

The test statistic, T_0, is given according to the following equation:

$$T_0 = \frac{\overline{X}_{simulation} - \overline{X}_{regression} - \Delta_0}{S_p \sqrt{\dfrac{1}{n_{simulation}} + \dfrac{1}{n_{regression}}}} \tag{6.2}$$

where $$S_p = \frac{(n_{simulation} - 1)S^2_{simulation} + (n_{regression} - 1)S^2_{regression}}{n_{simulation} + n_{regression} - 2} \qquad (6.3)$$

$\overline{X}_{simulation}$ =average calibrated simulation RMSE value

$\overline{X}_{regression}$ =average regression model RMSE value

$S^2_{simulation}$ =sample variance of calibrated simulation RMSE values

$S^2_{regression}$ =standard variance of regression model RMSE values

S_p=pooled or weighted average standard deviation of the calibrated simulations and regression models

$n_{simulation}$=number of calibrated simulations

$n_{regression}$=number of regression models

Results from the pooled variance t-test are shown in Table 6.3. The t-test on both the chilled and hot water models produces the same result: the null hypothesis of equal means fails to be rejected. Since both of the p-values are greater than 0.05, the test statistic is not significant. In other words, at the 0.05 level of significance, there is not strong evidence to conclude that mean RMSE results from the calibrated simulations differ from mean RMSE results of the regression models.

Table 6.3: Pooled variance t-test results.

	S_p	T_0	P-value (with 10df)
Chilled Water	0.4748	1.4758	0.088
Hot Water	1.2914	-0.4757	0.326

The match pairs t-test is similar to the pooled variance t-test in that it tests whether or not there is equal root mean square error between the calibrated simulation and regression model populations. The same assumption (e.g. ά=0.05) is used and the same null hypothesis, as given in Equation 6.1, is tested. The match pairs t-test differs from the pooled variance t-test in how the test statistic, T_0, is calculated. Rather than using a pooled standard deviation, the standard deviation of the differences between the RMSE of the calibrated simulations and regression models for each of the post-commissioning periods is calculated. T_0 is found according to the following equation:

$$T_0 = \frac{\overline{X}_{simulation-regression}}{S_{simulation-regression}\sqrt{\frac{1}{n}}} \tag{6.4}$$

where $\overline{X}_{simulation-regression}$=average of the differences between calibrated simulation and regression model RMSE values

$S_{simulation-regression}$=standard deviation of the differences between calibrated simulation and regression model RMSE values

n=number of calibrated simulations/regression models

Results from the match pairs t-test are given in Table 6.4. Interestingly, the match pairs t-test has opposite results of the pooled variance t-test. Since the p-values for both chilled and hot water are less than 0.05, the null hypothesis of equal RMSE means is rejected.

Table 6.4: Match pairs t-test results.

	T_0	P-value (with 5df)
Chilled Water	3.761093	0.0367
Hot Water	-3.48562	0.018

6.3 Variability Results

6.3.1 Option D MBE Adjustment

Each of the calibrated simulations has an associated mean bias error (MBE) that if left unadjusted may significantly affect the post-commissioning savings depending on the magnitude of the MBE and its sign (positive or negative). The regression models created have essentially no MBE and consequently are not adjusted. In order to avoid biased savings and persistence results, adjustments are made to each of the annual consumption values determined by the calibrated simulations to offset the MBE of the calibrated simulation. Table 6.5 shows the MBE of the calibrated simulations from the pre-commissioning period and each of the post-commissioning periods. The annual adjustment given to each period's consumption determined with the calibrated simulations is also shown. The annual adjustment represents the opposite (positive or negative) of the MBE expressed as a daily value multiplied by 365 (days/yr).

Table 6.5: Calibrated simulation MBE and corresponding annual consumption adjustment for chilled and hot water.

	1996 Pre-Comm	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04
CHW MBE (MMBtu/day)	-0.0381	-0.0381	-0.1636	0.4876	-0.0088	-0.6075	-0.1620
Annual CHW Adjustment (MMBtu/yr)	13.90	13.90	59.70	-177.96	3.23	221.75	59.14
HW MBE (MMBtu/day)	-0.2631	-0.2631	-0.4496	-0.0782	0.5751	0.2108	0.9088
Annual HW Adjustment (MMBtu/yr)	96.031	96.031	164.1	28.53543	-209.925	-76.9577	-331.702

6.3.2 NAC Versus Standard IPMVP Weather Normalization Approach

The percent savings results from the NAC weather normalization approach generally show good agreement with the percent savings results from the standard IPMVP weather normalization approach. Chilled water consumption and savings results are shown for both the NAC and standard IPMVP weather normalization approaches in Table 6.6 with Option C using regression models and Table 6.7 with Option D (MBE adjusted). The NAC weather normalization approach in these tables uses the long-term average College Station weather year. The differences in percent savings between the two weather normalization approaches shown in the tables for each post-commissioning period vary but there are only two post-commissioning periods where the difference is greater than 1% and one post-commissioning period where the difference is greater than 2%. However, some of these differences are relatively large compared to the percent savings of these post-commissioning periods. For example, the average 1997 percent savings between the two weather normalization approaches using Option D (MBE adjusted) are 4.34% (see Table 6.6). The difference in savings, 0.58%, represents 13.4% of the average savings. In other words, while percent savings differences shown in Table 6.6 and Table 6.7 may seem small, a small difference may be significant if the overall savings is not that large. The chilled water percent savings differences between the NAC and standard IPMVP weather normalization approaches using Option D (MBE adjusted) average 0.78% over all post-commissioning periods while the differences using Option C with regression models average 0.64%.

Table 6.6: Chilled water consumption and savings results using Option D (MBE adjusted) of IPMVP to compare NAC and standard IPMVP weather normalization approaches. The long-term average weather year is used for the NAC weather normalization approach.

	Year/Period	1996 Pre-Comm	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04
NAC Weather Normalization Approach								
Normalized to Long-Term Avg Weather	CHW Use (MMBtu/yr)	16800	16024	15409	14745	14469	15639	13069
	CHW Savings (MMBtu/yr)	Baseline	777	1392	2056	2331	1161	3732
	CHW % Savings	Baseline	4.62%	8.28%	12.24%	13.87%	6.91%	22.21%
Standard IPMVP Weather Normalization Approach								
Baseline Consumption with Post-Commiss. Weather	CHW Use (MMBtu/yr)	18874	17017	18610	17571	17839	17685	17983
Post-Commissioning Consumption with Own Period's Weather	CHW Use (MMBtu/yr)	18874	16253	17066	15685	15305	16164	13819
	CHW Savings (MMBtu/yr)	Baseline	764	1544	1886	2534	1522	4164
	CHW % Savings	Baseline	4.05%	8.18%	9.99%	13.43%	8.06%	22.06%
	CHW % Savings Difference	Baseline	0.58%	0.10%	2.24%	0.45%	1.15%	0.15%

Table 6.7: Chilled water consumption and savings results using Option C of IPMVP with regression models to compare NAC and standard IPMVP weather normalization approaches. The long-term average weather year is used for the NAC weather normalization approach.

	Year/Period	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04
NAC Weather Normalization Approach								
Normalized to Long-Term Avg Weather	CHW Use (MMBtu/yr)	17356	16491	15849	14890	14767	15822	13256
	CHW Savings (MMBtu/yr)	Baseline	864	1507	2466	2589	1534	4100
	CHW % Savings	Baseline	4.98%	8.68%	14.21%	14.92%	8.84%	23.62%
Standard IPMVP Weather Normalization Approach								
Baseline Consumption with Post-Commiss. Weather	CHW Use (MMBtu/yr)	18860	17142	18840	18034	18058	17841	18094
Post-Commissioning Consumption with Own Period's Weather	CHW Use (MMBtu/yr)	18860	16253	17059	15685	15298	16125	13734
	CHW Savings (MMBtu/yr)	Baseline	889	1780	2349	2760	1716	4360
	CHW % Savings	Baseline	4.71%	9.44%	12.45%	14.64%	9.10%	23.12%
	CHW % Savings Difference	Baseline	0.27%	0.76%	1.76%	0.28%	0.26%	0.50%

While the results in Tables 6.6 and 6.7 do not show any striking differences in savings between the NAC and standard IPMVP weather normalization approaches, they do not show which approach has less variability. Figure 6.1 compares chilled water percent savings quantiles of the NAC and standard IPMVP weather normalization approaches side by side when using the 29 different College Station weather years and random runs. Consumption and savings obtained with each weather year using the NAC weather normalization approach and with each random run using the standard IPMVP weather normalization approach are found in Appendix F. Option D (MBE adjusted) of the IPMVP is used for both weather normalization approaches in Figure 6.1. Various quantiles are shown, including the 0th (minimum), 10th, 25th, 50th, 75th, 90th, and 100th (maximum). Figure 6.1 is significant in that it shows a much smaller variability in savings for the NAC weather normalization approach than the standard IPMVP approach for many of the post-commissioning time periods. It shows that depending on the weather years used for the standard IPMVP weather normalization approach, there may be much less persistence in savings over time than there would be if the NAC weather normalization approach is used. For hot water, the results are more mixed (see Figure 6.2). Some of the hot water post-commissioning periods have more similar percent savings ranges when comparing the two weather normalization approaches. Three of the post-commissioning periods (1997, 1/02-11/02, and 9/03-6/04) show a greater variability in hot water percent savings with the NAC weather normalization approach than with the standard IPMVP approach, although the 1997 savings range is only 0.12% greater for the NAC weather normalization approach and the 9/03-6/04 savings range is only 0.06% greater for the NAC weather normalization approach. The standard IPMVP weather normalization approach, however, shows much more variability in hot water savings than the NAC weather normalization approach during the 1/99-4/24/00 post-commissioning period.

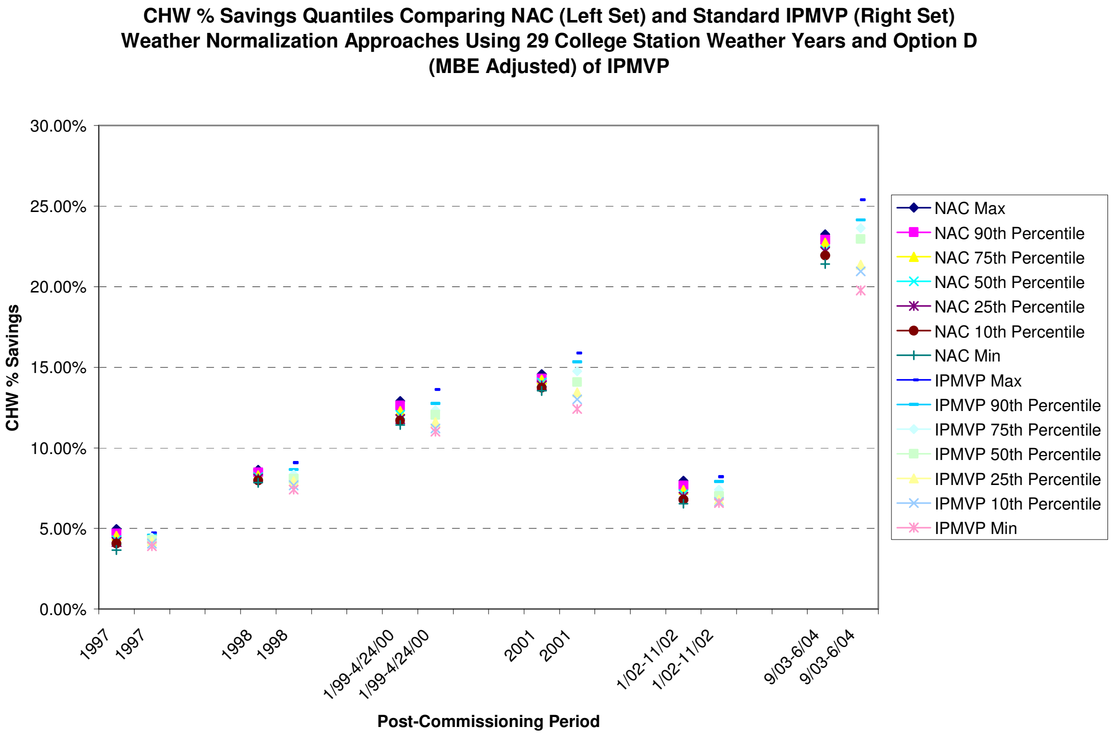


Figure 6.1: Chilled water percent savings variability comparison between NAC (left set) and standard IPMVP (right set) weather normalization approaches when using Option D (MBE adjusted) of IPMVP.

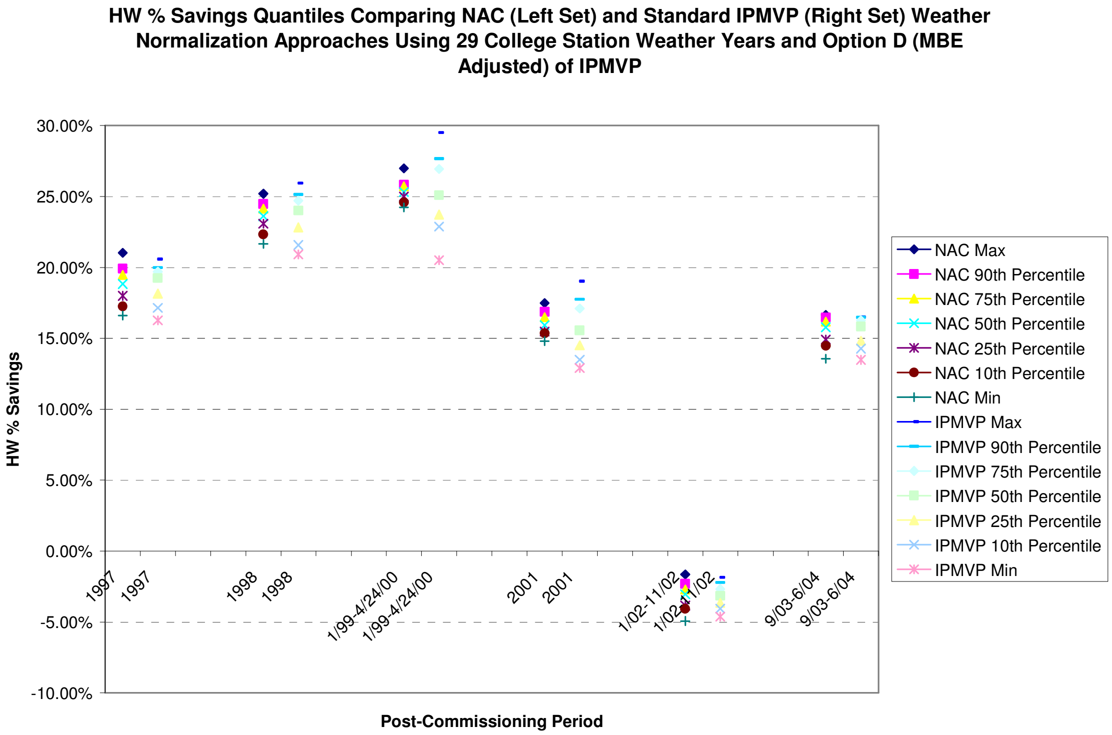


Figure 6.2: Hot water percent savings variability comparison between NAC (left set) and standard IPMVP (right set) weather normalization approaches when using Option D (MBE adjusted) of IPMVP.

The quantiles of the sum of the chilled and hot water percent savings for the NAC and standard IPMVP weather normalization approaches are shown in Figure 6.3. Option D (MBE adjusted) of the IPMVP is again utilized. Generally, the variability in savings persistence from one post-commissioning period to another is greater for the standard IPMVP weather normalization approach than the NAC weather normalization approach. There are two periods (1997 and 1/02-11/02) for which this is not the case, however.

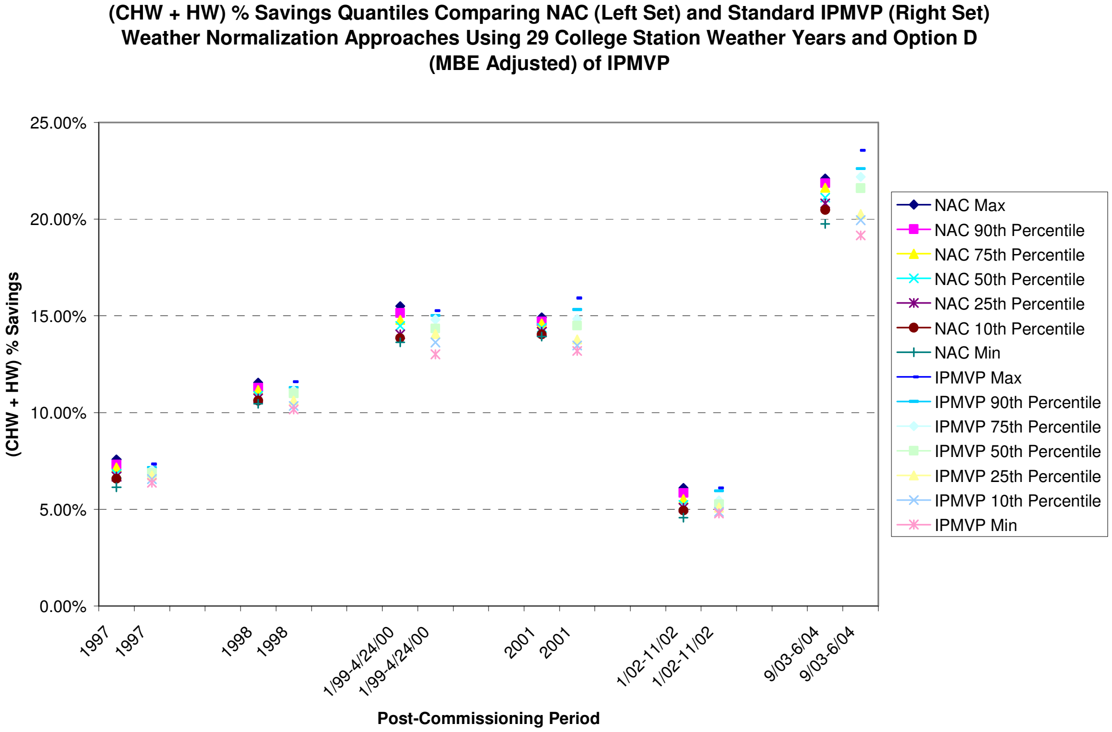


Figure 6.3: Sum of chilled and hot water percent savings variability comparison between NAC (left set) and standard IPMVP (right set) weather normalization approaches when using Option D (MBE adjusted) of IPMVP.

Chilled and hot water savings ranges and averages across all weather years with the NAC weather normalization approach and all random runs with the standard IPMVP weather normalization approach are listed in Table 6.8. Option D (MBE adjusted) of the IPMVP is used for both weather normalization approaches in this table. The results show that the NAC weather normalization approach has a smaller average range in savings across all post-commissioning periods than the standard IPMVP weather normalization approach for both chilled and hot water. For chilled water, the mean percent savings range is 1.32% for the NAC weather normalization approach and 2.64% for the standard IPMVP weather normalization approach. For hot water, the mean percent savings range is 3.30% for NAC and 5.04% for standard IPMVP. Despite these differences, the mean of the post-commissioning period average savings is quite similar. For chilled water, the mean of the average percent savings is 11.38% for the NAC weather normalization approach versus 11.40% for the standard IPMVP weather normalization approach. For hot water, the mean of the average percent savings is 15.99% for both the NAC and standard IPMVP weather normalization approaches. The differences between the two weather normalization approaches in average percent savings across each of the post-commissioning periods are also relatively small. For chilled water, the largest difference in average savings between the two weather normalization approaches in a post-commissioning period is 0.25%, occurring in the 9/03-6/04 period. For hot water, it is 0.28%, occurring in 2001.

Table 6.8: Chilled and hot water percent savings range and average across all College Station weather years under NAC weather normalization approach and across all random runs under standard IPMVP weather normalization approach. Both approaches use Option D (MBE adjusted).

CHW % Savings Range	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
NAC	1.30%	0.81%	1.49%	1.04%	1.42%	1.84%	1.32%
Standard IPMVP	0.82%	1.67%	2.62%	3.47%	1.64%	5.62%	2.64%
HW % Savings Range	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
NAC	4.43%	3.53%	2.76%	2.70%	3.29%	3.09%	3.30%
Standard IPMVP	4.31%	5.02%	9.00%	6.11%	2.77%	3.03%	5.04%
CHW % Savings Average	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
NAC	4.33%	8.21%	12.12%	14.02%	7.18%	22.41%	11.38%
Standard IPMVP	4.32%	8.14%	12.03%	14.12%	7.16%	22.66%	11.40%
HW % Savings Average	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
NAC	18.71%	23.50%	25.36%	16.04%	-3.20%	15.53%	15.99%
Standard IPMVP	18.87%	23.77%	25.19%	15.76%	-3.18%	15.52%	15.99%

Similar to the results in Table 6.8 comparing the average and range in savings for the two weather normalization approaches using Option D (MBE adjusted), Table 6.9 compares the average and range in savings for the two weather normalization approaches using Option C with regression models. The results using Option C with regression models are similar to those found with Option D (MBE adjusted) except that the mean range in hot water savings across all post-commissioning periods is higher for the NAC weather normalization approach (7.16%) than the standard IPMVP weather normalization approach (6.86%). The average range in chilled water savings across all post-commissioning periods is still lower for the NAC weather normalization approach (2.14%) than the standard IPMVP weather normalization approach (4.07%). The mean of the post-commissioning period average chilled water savings for the NAC weather normalization approach is 12.57% versus 12.65% for the standard IPMVP weather normalization approach. The difference is higher for hot water savings; the hot water mean of the post-commissioning period average savings for the NAC weather normalization approach is 15.39% versus 15.67% for the standard IPMVP weather normalization approach.

Table 6.9: Chilled and hot water percent savings range and average across all College Station weather years under NAC weather normalization approach and across all random runs under standard IPMVP weather normalization approach. Both approaches use Option C with regression models.

CHW % Savings Range	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
NAC	1.33%	1.82%	1.82%	2.59%	2.69%	2.60%	2.14%
Standard IPMVP	1.45%	2.58%	4.16%	5.42%	3.92%	6.89%	4.07%
HW % Savings Range	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
NAC	9.65%	7.14%	8.97%	4.49%	6.01%	6.70%	7.16%
Standard IPMVP	8.31%	6.25%	9.64%	4.95%	6.17%	5.82%	6.86%
CHW % Savings Average	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
NAC	4.81%	8.79%	13.82%	14.91%	9.00%	24.08%	12.57%
Standard IPMVP	4.60%	8.91%	13.66%	15.14%	9.26%	24.32%	12.65%
HW % Savings Average	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
NAC	18.16%	20.07%	26.87%	12.56%	-4.20%	18.87%	15.39%
Standard IPMVP	18.49%	20.66%	26.67%	12.54%	-3.59%	19.22%	15.67%

6.3.3 Option C with Regression Models Versus Option D of IPMVP

The previous section compares the variability in savings persistence between the NAC and standard IPMVP weather normalization approaches. It is also valuable to know whether Option C with regression models or Option D of the IPMVP shows less variability in the persistence of savings and by how much. Knowing this may influence how much time one is willing to invest calibrating simulations under Option D when one could quickly create regression models.

Figure 6.4 compares the chilled water percent savings across all post-commissioning periods for Option C with regression models and Option D (MBE adjusted) for certain weather years. These weather years include the hottest (1996) of the 29 available College Station weather years, the coolest (1979), the median (1991), and the long-term average weather year. Figure 6.5 shows the same for hot water percent savings. The variability in chilled water percent savings between the four different weather years shown from one post-commissioning period to another appears to be less than the variation in hot water percent savings. There is also less variability in persistence of savings from post-commissioning period to post-commissioning period using Option D (MBE adjusted) than Option C with regression models for both chilled and hot water, although this is much more noticeable for hot water.

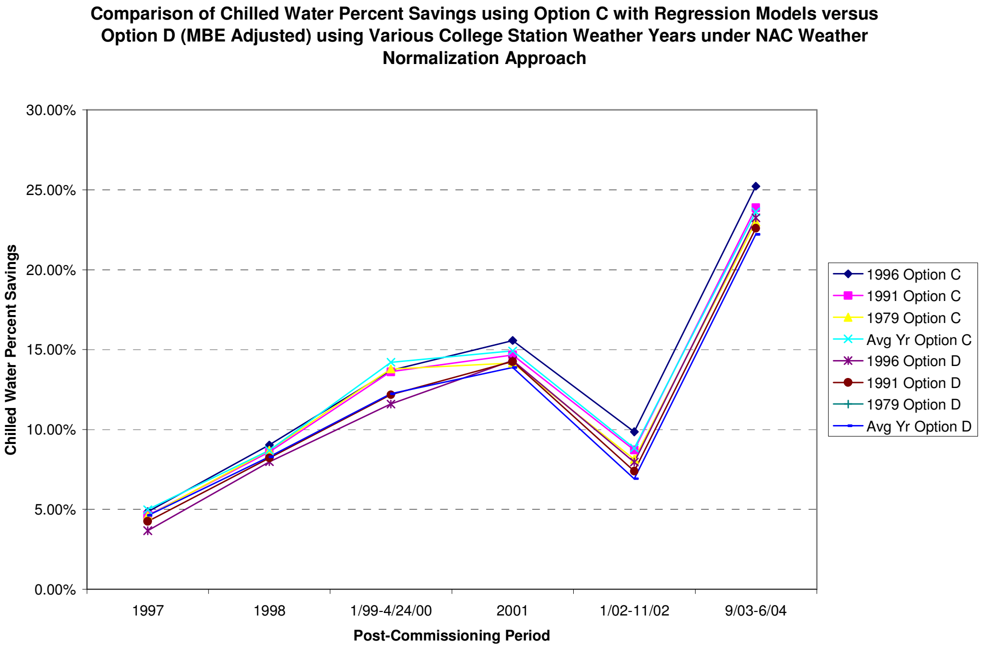


Figure 6.4: Chilled water percent savings comparison of Option C with regression models and Option D (MBE adjusted) using NAC weather normalization approach. Extreme (maximum and minimum), median, and long-term average weather years are shown.

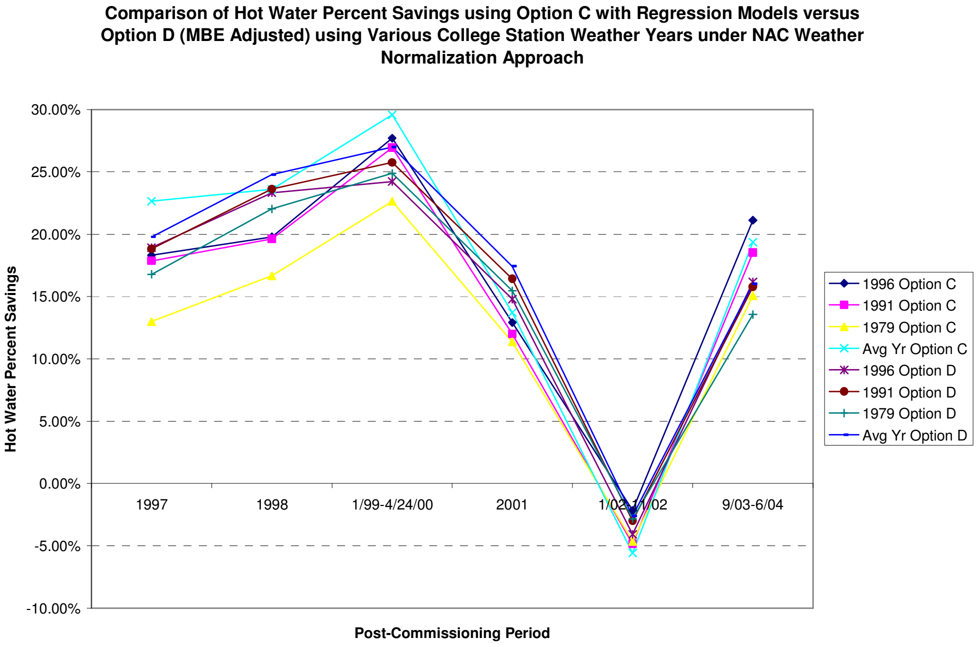


Figure 6.5: Hot water percent savings comparison of Option C with regression models and Option D (MBE adjusted) using NAC weather normalization approach. Extreme (maximum and minimum), median, and long-term average weather years are shown.

Table 6.10 quantifies the variation in percent savings across the different weather years using the NAC weather normalization approach for both Option C with regression models and Option D (MBE adjusted) of the IPMVP. The range and average percent savings across all 29 College Station weather years for each post-commissioning period are shown. Specific consumption and savings values for the pre-commissioning period and each of the post-commissioning periods using both weather normalization approaches and both Option C and Option D of the IPMVP are found in Appendix F. Table 6.10 shows that each of the post-commissioning period calibrated simulations (Option D, MBE adjusted) has less variation (smaller range) than the corresponding regression models (Option C) for both chilled and hot water, although some of the chilled water post-commissioning periods are quite similar. The smallest chilled water range difference between Option C and Option D is 0.03% (1997) while the largest is 1.56% (2001). The average chilled water savings range over all post-commissioning periods for Option D (MBE adjusted) is 1.32% while the average for Option C with regression models is 2.14%. The hot water range differences are larger, the smallest being 1.80% (2001) and the largest being 6.22% (1/99-4/24/00). The mean hot water savings range over all post-commissioning periods for Option D (MBE adjusted) is 3.30% and 7.16% for Option C with regression models. Even though Option D (MBE adjusted) exhibits an overall lower savings range than Option C with regression models across all weather years when using the NAC weather normalization approach, the average chilled water savings from the different weather years over all post-commissioning periods are somewhat similar for Option D (MBE adjusted) and Option C with regression models. The differences for average chilled water percent savings vary from 0.48% in 1997 to 1.81% in 1/02-11/02. For hot water, the differences for average savings during the post-commissioning periods vary as two of the periods show differences between Option D (MBE adjusted) and Option C with regression models of less than 1% (1997 and 1/02-11/02) and three show differences greater than 3% (1998, 2001, and 9/03-6/04). The differences for average hot water percent savings vary from 0.54% in 1997 up to 3.48% in 2001.

Table 6.10: Chilled and hot water percent savings range and average across all College Station weather years under NAC weather normalization approach for Option D (MBE adjusted) and Option C with regression models.

CHW % Savings Range	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
Option D	1.30%	0.81%	1.49%	1.04%	1.42%	1.84%	1.32%
Option C with Regression	1.33%	1.82%	1.82%	2.59%	2.69%	2.60%	2.14%
HW % Savings Range	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
Option D	4.43%	3.53%	2.76%	2.70%	3.29%	3.09%	3.30%
Option C with Regression	9.65%	7.14%	8.97%	4.49%	6.01%	6.70%	7.16%
CHW % Savings Average	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
Option D	4.33%	8.21%	12.12%	14.02%	7.18%	22.41%	11.38%
Option C with Regression	4.81%	8.79%	13.82%	14.91%	9.00%	24.08%	12.57%
HW % Savings Average	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
Option D	18.71%	23.50%	25.36%	16.04%	-3.20%	15.53%	15.99%
Option C with Regression	18.16%	20.07%	26.87%	12.56%	-4.20%	18.87%	15.39%

Figure 6.6 and 6.7 present various chilled water percent savings quantiles from using the 29 different College Station weather years for both Option C with regression models and Option D (MBE adjusted) of the IPMVP. In order to better visualize the variability in the persistence of savings, the post-commissioning periods are arranged so that the savings decrease from left to right in both figures. Figure 6.6 compares Option C with regression models and Option D (MBE adjusted) using the NAC weather normalization approach while Figure 6.7 compares Option C with regression models and Option D (MBE adjusted) using the standard IPMVP weather normalization approach. In both figures, the variability in the persistence of chilled water savings is greater for Option C with regression models than Option D (MBE adjusted). This is especially true in Figure

6.7 when the standard IPMVP weather normalization approach is employed. These figures confirm what has already been shown; the range in each of the post-commissioning period savings quantiles is higher using the standard IPMVP weather normalization approach than the NAC weather normalization approach for both Option C with regression models and Option D (MBE adjusted).

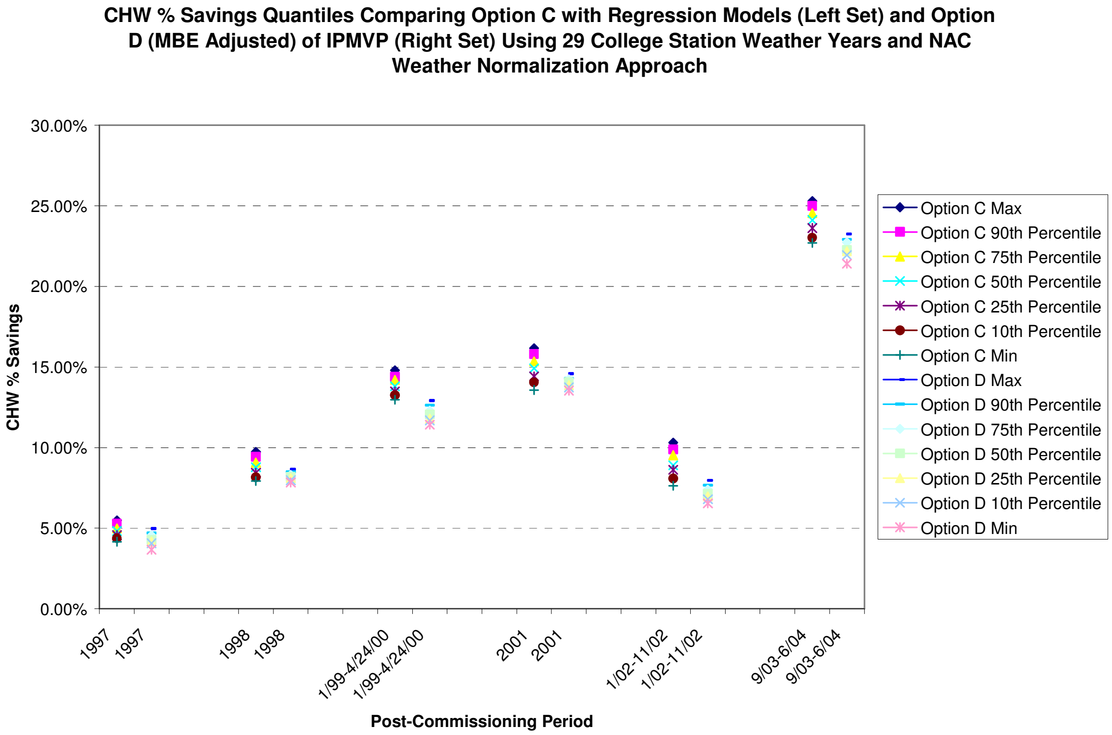


Figure 6.6: Chilled water percent savings variability comparison between Option C with regression models (left set) and Option D (MBE adjusted) (right set) when using NAC weather normalization approach.

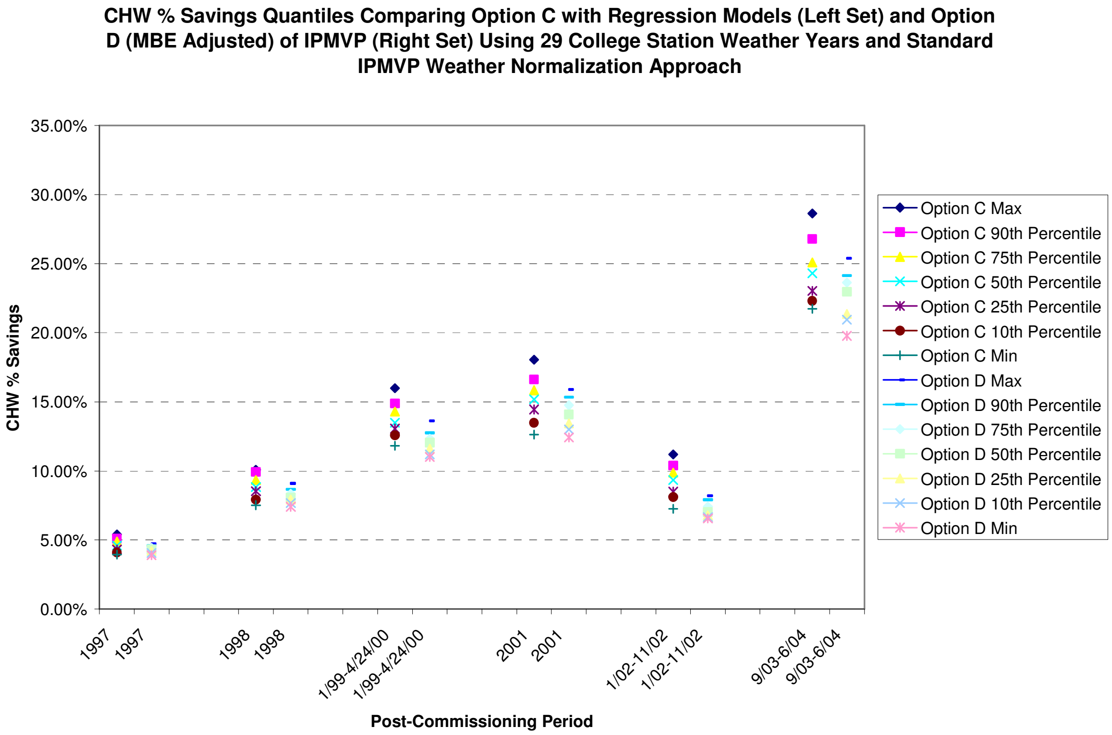


Figure 6.7: Chilled water percent savings variability comparison between Option C with regression models (left set) and Option D (MBE adjusted) (right set) when using standard IPMVP weather normalization approach.

Similar to the chilled water savings, the hot water savings using Option D (MBE adjusted) show less variability in persistence of savings from post-commissioning period to post-commissioning period than the hot water savings using Option C with regression models for both the NAC weather normalization approach (see Figure 6.8) and the standard IPMVP weather normalization approach (see Figure 6.9). Unlike the chilled water savings, however, the hot water savings show little noticeable difference in variability between the NAC and the standard IPMVP weather normalization approaches. Adjusting for the MBE with Option D proved to be quite necessary for the hot water savings quantiles shown in both Figure 6.8 and Figure 6.9 as some of the results for Option C with regression models would have been much different than those for Option D (MBE unadjusted). Despite the adjustment there are still noticeable differences in hot water savings, variability of savings, and variability of persistence of savings between Option C with regression models and Option D (MBE adjusted).

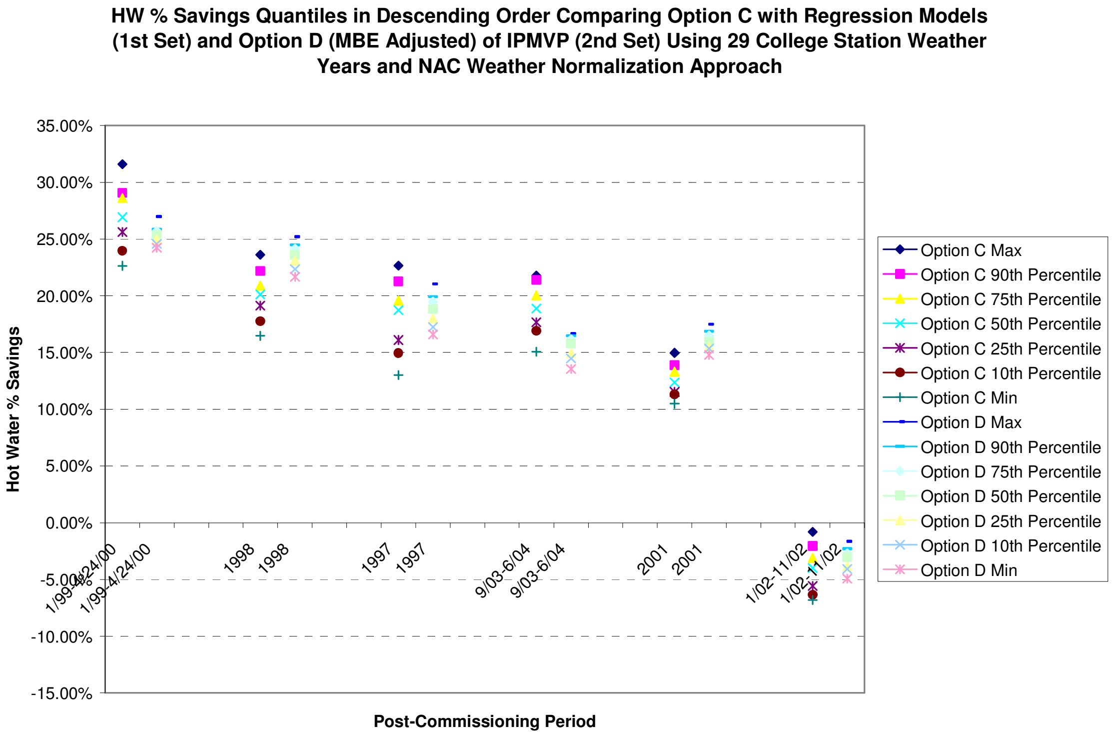


Figure 6.8: Hot water percent savings variability comparison between Option C with regression models (left set) and Option D (MBE adjusted) (right set) when using NAC weather normalization approach.

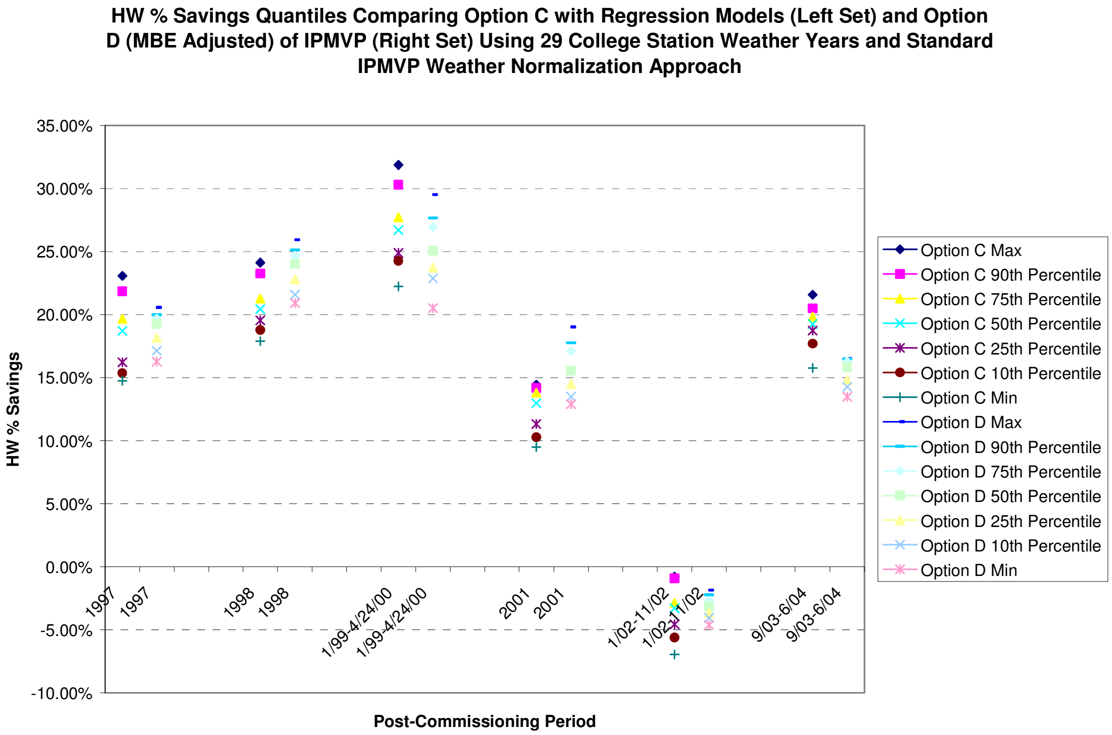


Figure 6.9: Hot water percent savings variability comparison between Option C with regression models (left set) and Option D (MBE adjusted) (right set) when using standard IPMVP weather normalization approach.

Since CE/TTI is in a hot and humid climate and cooling consumption is quite large compared to heating consumption, the percent savings quantiles for the sum of chilled and hot water show similar results to those of the chilled water percent savings quantiles. The variability in persistence of the sum of chilled and hot water savings from post-commissioning period to post-commissioning period is less for Option D (MBE adjusted) than Option C with regression models using both the NAC weather normalization approach (see Figure 6.10) and the standard IPMVP weather normalization approach (see Figure 6.11). As with the chilled water results, the variability in the persistence of the sum of chilled and hot water savings is less for the NAC weather normalization approach than the standard IPMVP as a whole for both Option C with regression models and Option D (MBE adjusted). This can be seen by comparing Figure 6.10 with Figure 6.11.

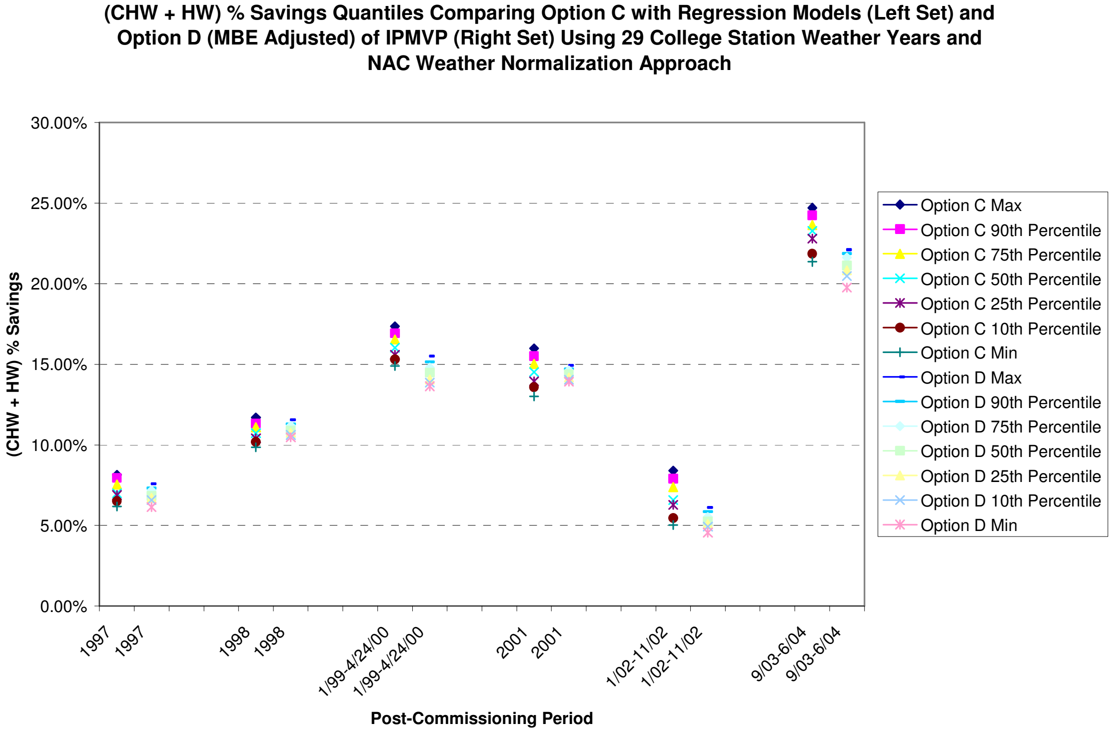


Figure 6.10: Sum of chilled and hot water percent savings variability comparison between Option C with regression models (left set) and Option D (MBE adjusted) (right set) when using NAC weather normalization approach.

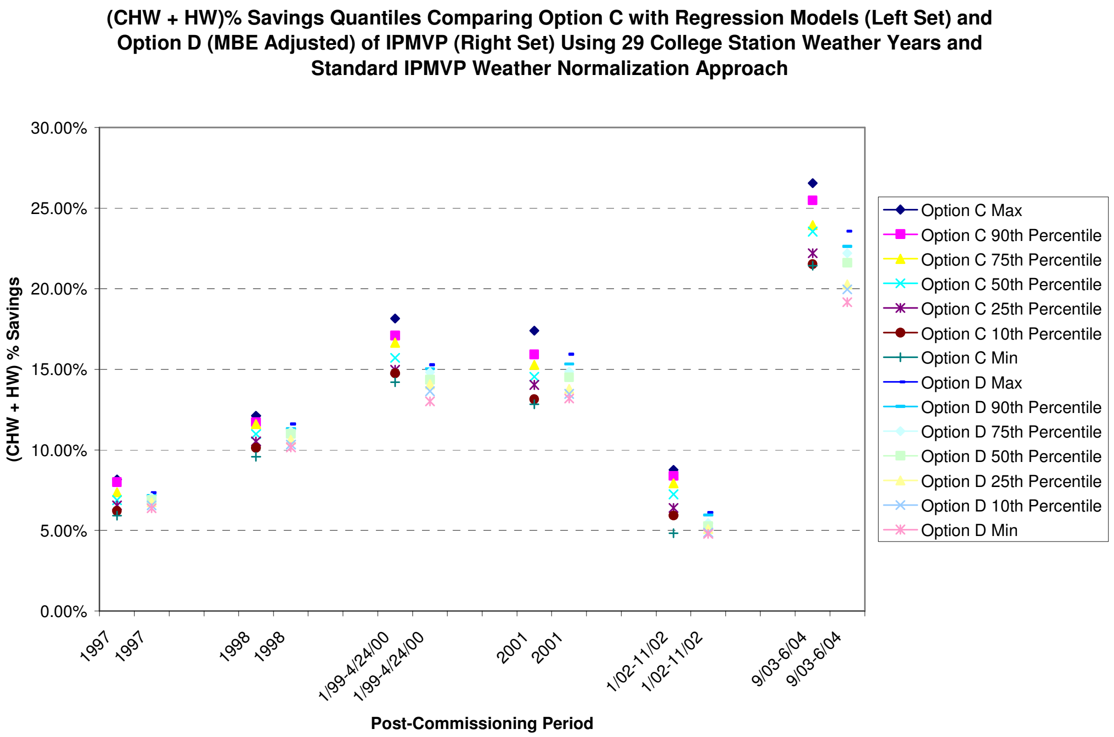


Figure 6.11: Sum of chilled and hot water percent savings variability comparison between Option C with regression models (left set) and Option D (MBE adjusted) (right set) when using standard IPMVP weather normalization approach.

To further illustrate the dominance of the chilled water on the overall variability in persistence of savings, it is helpful to see the chilled and hot water quantiles from the different College Station weather years for consumption (see Figure 6.12) and savings (see Figure 6.13) on the same graph. The NAC weather normalization approach and Option D (MBE adjusted) of the IPMVP are used for both figures. The chilled water consumption variability across different weather years is larger than the hot water variability across different weather years. This is mainly due to the chilled water consumption being around four to five times as large as the hot water consumption. This trend is also apparent in the savings, although variability in chilled water savings during post-commissioning periods is similar to variability in hot water savings when the chilled and hot water savings are similar in magnitude such as in 1997. As chilled water savings increase, the range in chilled water savings across all weather years during these post-commissioning periods also increases.

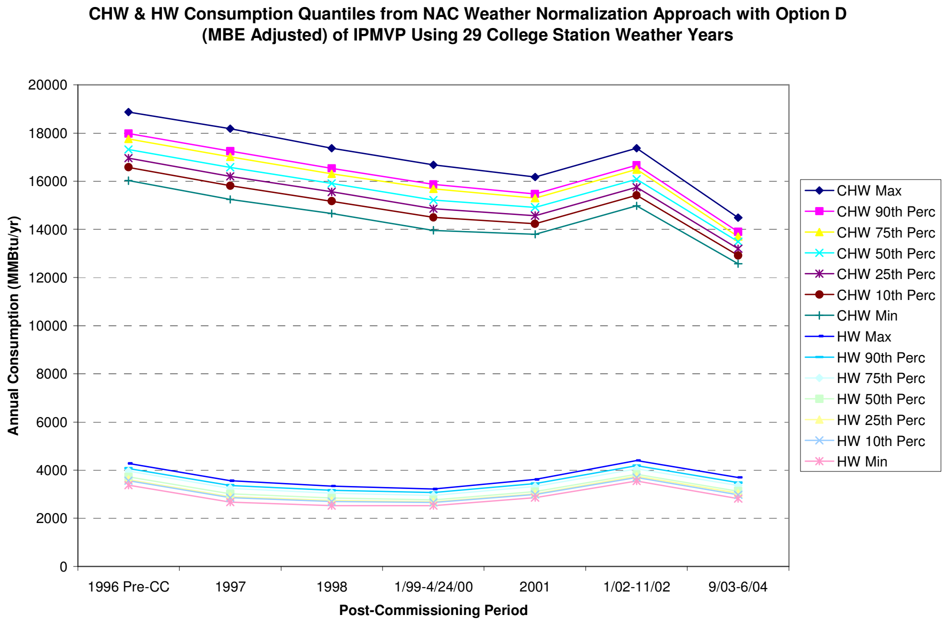


Figure 6.12: Consumption variability between chilled and hot water across pre- and post-commissioning periods using NAC weather normalization approach and Option D (MBE adjusted) of IPMVP.

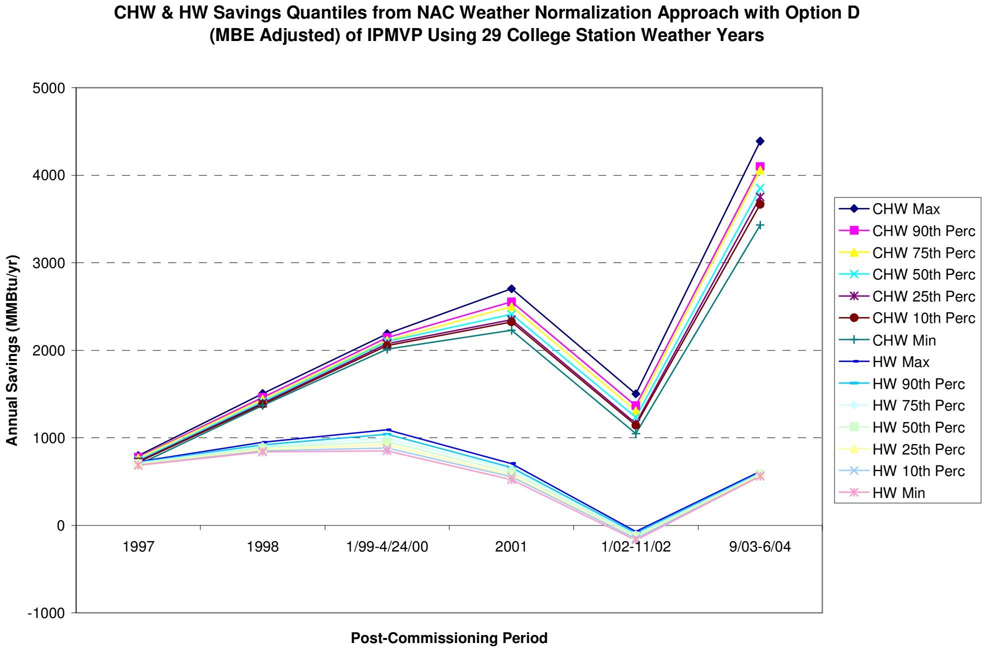


Figure 6.13: Savings variability between chilled and hot water across pre- and post-commissioning periods using NAC weather normalization approach and Option D (MBE adjusted) of IPMVP.

6.4 Statistical Variability Measures

6.4.1 Variability of Savings Statistical Measures

Section 6.3.2 and 6.3.3 have given a visual representation of the differences in savings and persistence of savings variability both between the NAC and standard IPMVP weather normalization approaches and between Option C with regression models and Option D (MBE adjusted) of the IPMVP savings determination methods. This section presents two statistical measures to quantify the variability of savings for each of the four different combinations of savings determination methods and weather normalization approaches (Option D using the NAC weather normalization approach, Option C with regression models using the NAC weather normalization approach, Option D using the standard IPMVP weather normalization approach, and Option C with regression models using the standard IPMVP weather normalization approach). This allows for simple comparison of savings variability between the four different combinations of sets of savings obtained from the 29 different College Station weather years and random runs for the NAC and standard IPMVP weather normalization approaches, respectively. The two statistical measures used here are the standard deviation and the coefficient of variation of the percent savings.

Chilled water savings variability results are listed in Table 6.11. Both the standard deviation and coefficient of variation results show Option D (MBE adjusted) with the NAC weather normalization approach to have the least amount of savings variability (0.32% savings average standard deviation and 3.50% average coefficient of variation for chilled water savings across all post-commissioning periods) while Option C with regression models using the standard IPMVP weather normalization approach has the most amount of savings variability (1.01% savings average standard deviation and 8.36% average coefficient of variation for chilled water savings across all post-commissioning periods). The average chilled water savings variability measures are similar for Option D (MBE adjusted) with the standard IPMVP weather normalization approach (0.68% savings average standard deviation and 5.78% average coefficient of variation for chilled water savings across all post-commissioning periods) and Option C with regression models with the NAC weather normalization approach (0.57% savings average standard deviation and 5.29% average coefficient of variation for chilled water savings across all post-commissioning periods). Thus the NAC weather normalization approach shows less variability in chilled water savings than the standard IPMVP weather normalization approach when comparing results using the same IPMVP savings determination method. Additionally, Option D (MBE adjusted) shows less variability in chilled water savings than Option C with regression models when comparing results using the same weather normalization approach.

Table 6.11: Chilled water savings variability quantification for each of the four combinations of the NAC and standard IPMVP weather normalization approaches and Option C and Option D (MBE adjusted) savings determination methods.

Option D (MBE Adjusted) with NAC Weather Normalization Approach							
	1997	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	0.29%	0.20%	0.39%	0.25%	0.36%	0.43%	0.32%
coeff var	6.76%	2.41%	3.19%	1.76%	4.95%	1.92%	3.50%
Option D (MBE Adjusted) with Standard IPMVP Weather Normalization Approach							
	1997	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	0.20%	0.41%	0.61%	0.93%	0.49%	1.46%	0.68%
coeff var	4.70%	5.06%	5.08%	6.57%	6.82%	6.44%	5.78%
Option C with Regression Models with NAC Weather Normalization Approach							
	1997	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	0.35%	0.47%	0.48%	0.70%	0.73%	0.71%	0.57%
coeff var	7.20%	5.37%	3.46%	4.68%	8.06%	2.96%	5.29%
Option C with Regression Models with Standard IPMVP Weather Normalization Approach							
	1997	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	0.40%	0.69%	0.97%	1.27%	1.02%	1.74%	1.01%
coeff var	8.75%	7.79%	7.09%	8.41%	10.97%	7.14%	8.36%

Figure 6.14 shows the standard deviation of the chilled water percent savings for each of the post-commissioning periods. This figure shows that Option D (MBE adjusted) with the NAC weather normalization approach has the least variability in all but one of the

post-commissioning periods and that Option C with regression models using the standard IPMVP weather normalization approach has the most variability in all of the post-commissioning periods. The standard deviation about the mean for Option D (MBE adjusted) with the standard IPMVP weather normalization approach and for Option C with regression models with the NAC weather normalization approach alternate multiple times over the course of the post-commissioning periods.

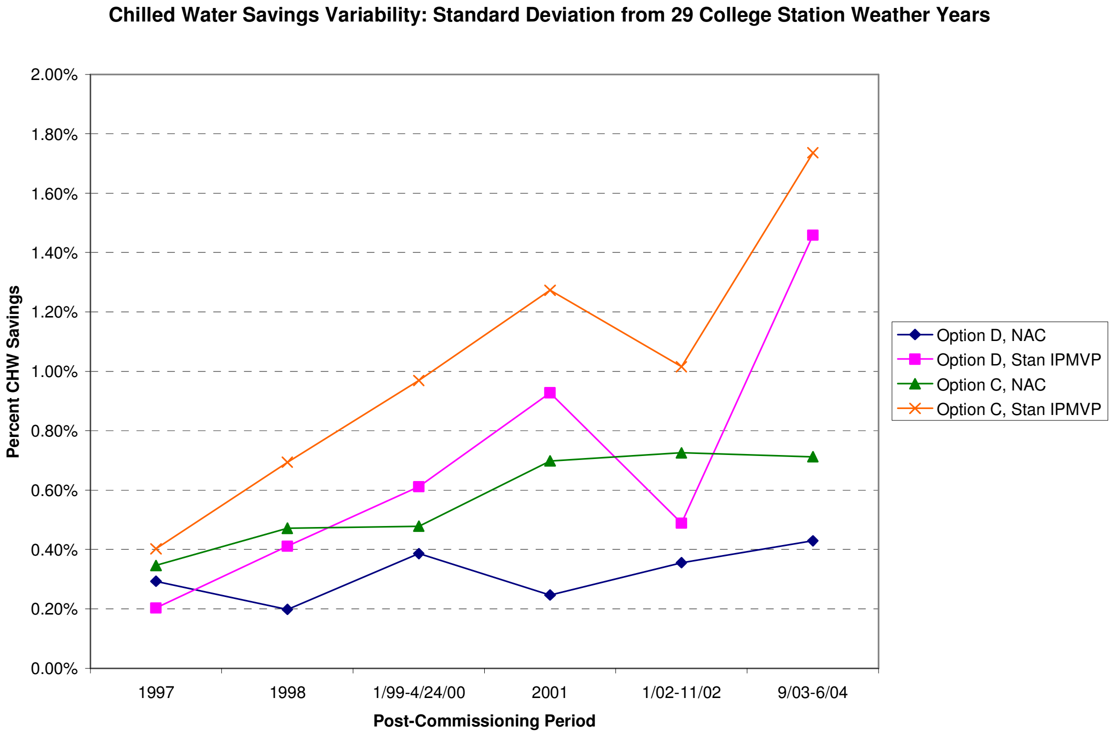


Figure 6.14: Standard deviation of chilled water percent savings.

Hot water savings variability results are listed in Table 6.12. When not considering the coefficient of variation of the 1/02-11/02 where negative savings occur, hot water savings variability results are similar to those of the chilled water except that the savings variability measures are much closer for the NAC and standard IPMVP weather normalization approaches when using Option C with regression models. The average standard deviation across all post-commissioning periods is 1.83% savings for Option C with regression models using the NAC weather normalization approach versus 1.85%

savings for Option C with regression models using the standard IPMVP weather normalization approach. When using Option D (MBE adjusted), however, the NAC weather normalization approach clearly shows less savings variability than the standard IPMVP weather normalization approach. The average standard deviation across all post-commissioning periods is 0.79% savings for Option D (MBE adjusted) using the NAC weather normalization approach versus 1.32% savings for Option D (MBE adjusted) using the standard IPMVP weather normalization approach. When considering the average of the coefficient of variation across all post-commissioning periods excluding the 1/02-11/02 period, the same pattern seen with the standard deviation exists. The NAC weather normalization approach (4.20% average coefficient of variation) shows less variability in savings than the standard IPMVP weather normalization approach (7.36% average coefficient of variation) when using Option D (MBE adjusted) of the IPVMP. Also, the NAC weather normalization approach (9.83% average coefficient of variation) shows similar variability in savings to the standard IPMVP weather normalization approach (9.92% average coefficient of variation) when using Option C with regression models of the IPMVP.

Table 6.12: Hot water savings variability quantification for each of the four combinations of the NAC and standard IPMVP weather normalization approaches and Option C and Option D (MBE adjusted) savings determination methods.

Option D (MBE Adjusted) with NAC Weather Normalization Approach

	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Average	Avg without 1/02-11/02
stdev	1.06%	0.82%	0.62%	0.67%	0.76%	0.80%	0.79%	0.80%
coeff var	5.69%	3.50%	2.46%	4.18%	-23.74%	5.15%	-0.46%	4.20%

Option D (MBE Adjusted) with Standard IPMVP Weather Normalization Approach

	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Average	Avg without 1/02-11/02
stdev	1.14%	1.34%	2.11%	1.70%	0.69%	0.93%	1.32%	1.44%
coeff var	6.05%	5.62%	8.39%	10.76%	-21.82%	5.96%	2.49%	7.36%

Option C with Regression Models with NAC Weather Normalization Approach

	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Average	Avg without 1/02-11/02
stdev	2.54%	1.80%	2.09%	1.13%	1.61%	1.78%	1.83%	1.87%
coeff var	14.00%	8.95%	7.79%	8.96%	-38.48%	9.46%	1.78%	9.83%

Option C with Regression Models with Standard IPMVP Weather Normalization Approach

	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Average	Avg without 1/02-11/02
stdev	2.49%	1.72%	2.38%	1.58%	1.70%	1.22%	1.85%	1.88%
coeff var	13.45%	8.31%	8.91%	12.60%	-47.54%	6.32%	0.34%	9.92%

Figure 6.15 shows the standard deviation of the hot water percent savings for each of the post-commissioning periods. This figure shows that Option D (MBE adjusted) with the NAC weather normalization approach has the least variability in all but one of the post-commissioning periods. Other results are more mixed as the standard deviation of the other three combinations of IPMVP savings determination methods and weather normalization approaches vary over the post-commissioning periods. Overall, Option D (MBE adjusted) using the standard IPMVP shows less variability in savings than either weather normalization approach using Option C with regression models.

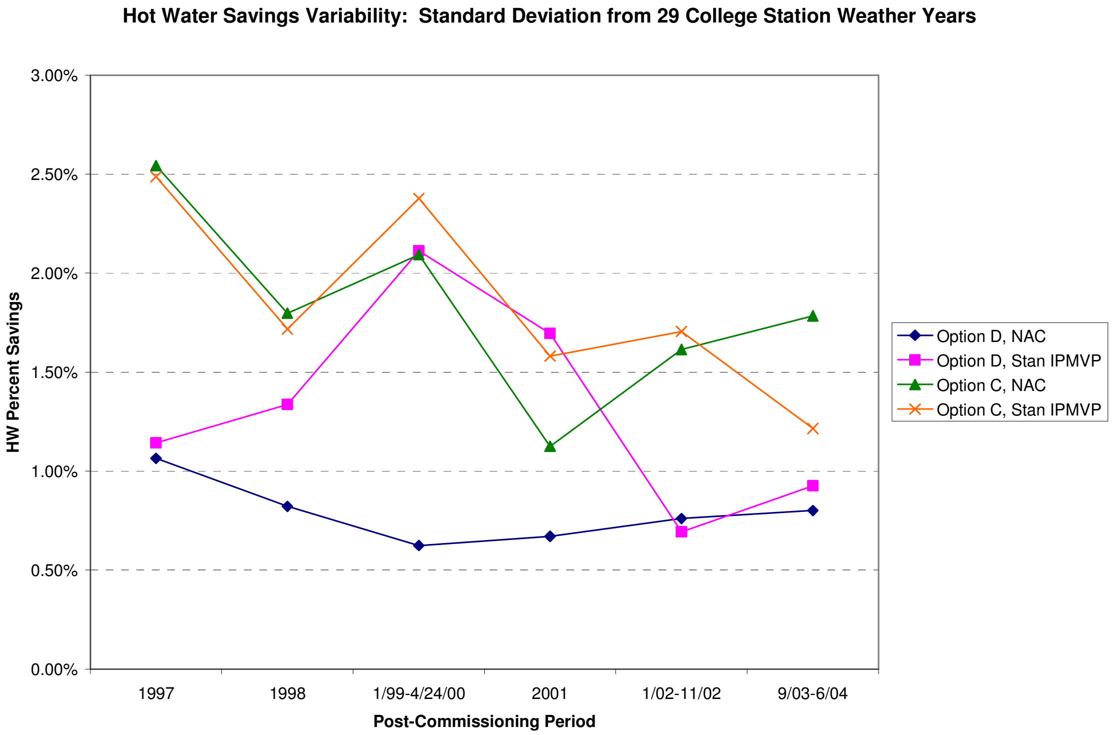


Figure 6.15: Standard deviation of hot water percent savings.

The variability of the sum of chilled and hot water savings shows a pattern more similar to the variability of chilled water savings than to the variability of hot water savings. The combined chilled and hot water savings variability results are listed in Table 6.13. The average savings variability across all post-commissioning periods with Option D (MBE adjusted) using the NAC weather normalization approach is again the lowest (0.39% savings average standard deviation and 3.74% average coefficient of variation for the sum of chilled and hot water savings across all post-commissioning periods) while the average savings variability with Option C with regression models using the standard IPMVP weather normalization approach is the highest (0.98% savings average standard deviation and 8.35% average coefficient of variation for the sum of chilled and hot water savings across all post-commissioning periods). Option D (MBE adjusted) using the standard IPMVP weather normalization approach has a 0.57% savings average standard deviation and a 4.73% average coefficient of variation over all post-commissioning periods. Option C with regression models using the NAC weather normalization approach has a 0.71% savings average standard deviation and a 6.49% average coefficient of variation over all post-commissioning periods. Thus, the NAC weather normalization approach shows less overall savings variability than the standard IPMVP weather normalization approach when using the same IPMVP savings determination method. Also, Option D (MBE adjusted) shows less savings variability than Option C with regression models when using the same weather normalization approach.

Table 6.13: Sum of chilled and hot water savings variability quantification for each of the four combinations of the NAC and standard IPMVP weather normalization approaches and Option C and Option D (MBE adjusted) savings determination methods.

<table>
<tr><th colspan="8">Option D (MBE Adjusted) with NAC Weather Normalization Approach</th></tr>
<tr><th></th><th>1997</th><th>1998</th><th>1/99-4/24/00</th><th>2001</th><th>1/02-11/02</th><th>9/03-6/04</th><th>Average</th></tr>
<tr><td>stdev</td><td>0.32%</td><td>0.27%</td><td>0.51%</td><td>0.27%</td><td>0.38%</td><td>0.58%</td><td>0.39%</td></tr>
<tr><td>coeff var</td><td>4.66%</td><td>2.51%</td><td>3.53%</td><td>1.89%</td><td>7.15%</td><td>2.72%</td><td>3.74%</td></tr>
<tr><th colspan="8">Option D (MBE Adjusted) with Standard IPMVP Weather Normalization Approach</th></tr>
<tr><th></th><th>1997</th><th>1998</th><th>1/99-4/24/00</th><th>2001</th><th>1/02-11/02</th><th>9/03-6/04</th><th>Average</th></tr>
<tr><td>stdev</td><td>0.24%</td><td>0.38%</td><td>0.57%</td><td>0.74%</td><td>0.38%</td><td>1.12%</td><td>0.57%</td></tr>
<tr><td>coeff var</td><td>3.42%</td><td>3.48%</td><td>3.98%</td><td>5.15%</td><td>7.11%</td><td>5.26%</td><td>4.73%</td></tr>
<tr><th colspan="8">Option C with Regression Models with NAC Weather Normalization Approach</th></tr>
<tr><th></th><th>1997</th><th>1998</th><th>1/99-4/24/00</th><th>2001</th><th>1/02-11/02</th><th>9/03-6/04</th><th>Average</th></tr>
<tr><td>stdev</td><td>0.53%</td><td>0.49%</td><td>0.65%</td><td>0.76%</td><td>0.93%</td><td>0.88%</td><td>0.71%</td></tr>
<tr><td>coeff var</td><td>7.43%</td><td>4.52%</td><td>4.04%</td><td>5.25%</td><td>13.87%</td><td>3.81%</td><td>6.49%</td></tr>
<tr><th colspan="8">Option C with Regression Models with Standard IPMVP Weather Normalization Approach</th></tr>
<tr><th></th><th>1997</th><th>1998</th><th>1/99-4/24/00</th><th>2001</th><th>1/02-11/02</th><th>9/03-6/04</th><th>Average</th></tr>
<tr><td>stdev</td><td>0.63%</td><td>0.67%</td><td>1.03%</td><td>1.11%</td><td>1.05%</td><td>1.41%</td><td>0.98%</td></tr>
<tr><td>coeff var</td><td>9.02%</td><td>6.17%</td><td>6.47%</td><td>7.58%</td><td>14.85%</td><td>6.02%</td><td>8.35%</td></tr>
</table>

Figure 6.16 shows the standard deviation of the combined chilled and hot water percent savings for each of the post-commissioning periods. As seen in the figure, Option D (MBE adjusted) using the NAC weather normalization approach has the lowest combined chilled and hot water savings variability in all of the post-commissioning periods but one and Option C with regression models using the standard IPMVP weather normalization approach has the most combined chilled and hot water savings variability in all of the post-commissioning periods. Option D (MBE adjusted) using the standard

IPMVP weather normalization approach and Option C with regression models using the NAC weather normalization approach show similar savings variability results but have more overall savings variability than Option D (MBE adjusted) using the standard IPMVP weather normalization approach.

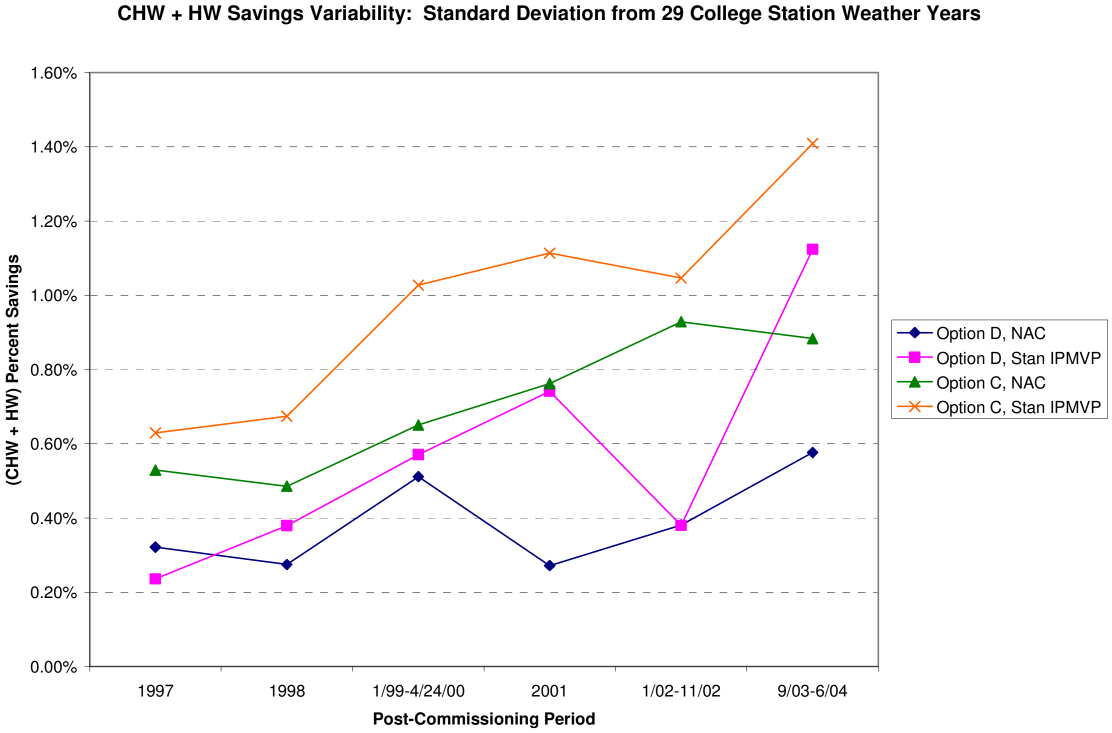


Figure 6.16: Standard deviation of combined chilled and hot water percent savings.

6.4.2 Variability of Persistence of Savings Statistical Measures

Just as it is important to have some quantifiable measure of the variability of commissioning savings for each of the four different combinations of savings determination methods and weather normalization approaches, it is also valuable to quantify the variability of commissioning persistence of savings for each of these four different combinations. Persistence of savings in this case is defined as the percent savings difference between a post-commissioning period after 1997 (the first post-commissioning period) and the 1997 post-commissioning period.

Table 6.14 shows the chilled water savings and persistence of savings for both the NAC and standard IPMVP weather normalization approaches using Option D (MBE adjusted) of the IPMVP. The long-term average College Station weather year is used for the NAC weather normalization approach. The normal procedure for the standard IPMVP weather normalization approach is employed that uses the actual weather data of the post-commissioning periods. Table 6.14 indicates that persistence of savings results do vary depending on the weather normalization approach used just as savings results do. For two of the post-commissioning periods (1/99-4/24/00 and 1/02-11/02), chilled water persistence of savings differs by more than 1.5% between the NAC and standard IPMVP weather normalization approaches.

Table 6.14: Chilled water savings and persistence of savings results using Option D (MBE adjusted) of IPMVP for both NAC and standard IPMVP weather normalization approaches. The long-term average weather year is used for the NAC weather normalization approach.

	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04
NAC Weather Normalization Approach						
CHW % Savings	4.62%	8.28%	12.24%	13.87%	6.91%	22.21%
CHW Persistence	n/a	3.66%	7.62%	9.25%	2.29%	17.59%
Standard IPMVP Weather Normalization Approach						
CHW % Savings	4.05%	8.18%	9.99%	13.43%	8.06%	22.06%
CHW Persistence	n/a	4.13%	5.94%	9.38%	4.01%	18.01%
CHW % Savings Difference	0.57%	0.10%	2.25%	0.44%	1.15%	0.15%
CHW Persistence Difference	n/a	0.47%	1.68%	0.13%	1.72%	0.42%

To quantify the variability of persistence of savings, sets of savings from the 29 different College Station weather years and 29 different random runs are again used for the NAC and standard IPMVP weather normalization approaches, respectively. From these sets of persistence of savings results, the standard deviation and the coefficient of variation of the persistence are found. Table 6.15 quantifies the chilled water variability of persistence of savings. Results of the variability of chilled water persistence of savings differ somewhat from the results of the variability of chilled water savings. Option C with regression models using the NAC weather normalization approach (0.38% persistence average standard deviation and 5.12% average coefficient of variation across all post-commissioning periods) shows slightly less overall variability than Option D (MBE adjusted) using the NAC weather normalization approach (0.42% persistence average standard deviation and 7.37% average coefficient of variation across all post-commissioning periods). Option D (MBE adjusted) with the standard IPMVP weather normalization approach (0.68% persistence average standard deviation and 9.04% average coefficient of variation across all post-commissioning periods), however, still shows less variability than Option C with regression models using the standard IPMVP weather normalization approach (1.20% persistence average standard deviation and 15.03% average coefficient of variation across all post-commissioning periods). As with chilled water variability of savings results, the NAC weather normalization approach shows less chilled water variability of persistence than the standard IPMVP weather normalization approach when comparing results using the same IPMVP savings determination method (both Option C with regression models and Option D).

Table 6.15: Chilled water persistence of savings variability quantification for each of the four combinations of the NAC and standard IPMVP weather normalization approaches and Option C and Option D (MBE adjusted) savings determination methods.

Option D (MBE Adjusted) with NAC Weather Normalization Approach						
	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Average
stdev	0.17%	0.22%	0.42%	0.61%	0.70%	0.42%
coeff var	4.38%	2.84%	4.29%	21.49%	3.87%	7.37%
Option D (MBE Adjusted) with Standard IPMVP Weather Normalization Approach						
	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Average
stdev	0.30%	0.46%	0.80%	0.45%	1.38%	0.68%
coeff var	7.78%	6.02%	8.21%	15.65%	7.53%	9.04%
Option C with Regression Models with NAC Weather Normalization Approach						
	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Average
stdev	0.18%	0.17%	0.44%	0.49%	0.60%	0.38%
coeff var	4.61%	1.85%	4.37%	11.68%	3.10%	5.12%
Option C with Regression Models with Standard IPMVP Weather Normalization Approach						
	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Average
stdev	0.84%	1.01%	1.38%	1.07%	1.71%	1.20%
coeff var	19.39%	11.12%	13.07%	22.91%	8.65%	15.03%

Figure 6.17 shows the standard deviation of the chilled water persistence of savings for each of the post-commissioning periods. When using the standard deviation of the chilled water persistence of savings to measure variability of persistence, Option D (MBE adjusted) using the NAC weather normalization approach has similar variability over the different post-commissioning periods to Option C with regression models using the NAC weather normalization approach. Option D (MBE adjusted) using the NAC weather normalization approach has the least variability of persistence of all four combinations in two of the post-commissioning periods (1998 and 2001) and Option C with regression models using the NAC weather normalization approach has the least variability of persistence of savings in two of the post-commissioning periods (1/99-4/24/00 and 9/03-6/04). Option D (MBE adjusted) using the standard IPMVP weather normalization approach has the least amount of variability of chilled water persistence of savings in one of the post-commissioning periods (1/02-11/02), although it has greater variability of chilled water persistence of savings than both Option D (MBE adjusted) using the NAC weather normalization approach and Option C with regression models

using the NAC weather normalization approach in all of the other post-commissioning periods. Option C with regression models using the standard IPMVP weather normalization approach consistently shows the greatest variability of chilled water persistence of savings.

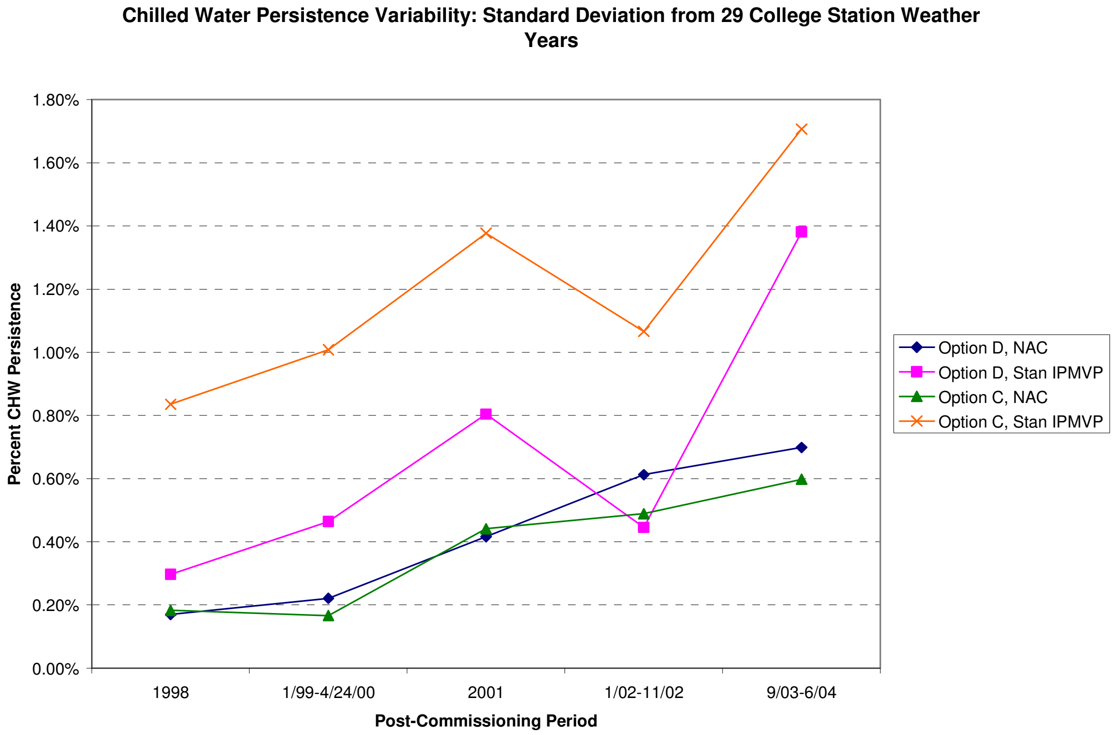


Figure 6.17: Standard deviation of chilled water persistence of savings.

When assessing hot water variability of persistence of savings results (see Table 6.16), the coefficient of variation should not be considered. Due to very small average persistence values in multiple post-commissioning periods, many of the results for the coefficient of variation cannot accurately assess the variability of hot water persistence of savings. The standard deviation appears better suited as a measure of variability of hot water persistence of savings. When only considering the average value across all post-commissioning periods of the standard deviation for hot water persistence of savings, Option D (MBE adjusted) using the NAC weather normalization approach has the least variability (0.98% persistence average standard deviation across all post-commissioning periods). This is followed by Option D (MBE adjusted) using the standard IPMVP weather normalization approach (1.12% persistence average standard deviation across all post-commissioning periods), Option C with regression models using the NAC weather normalization approach (1.75% persistence average standard deviation across all post-commissioning periods), and Option C with regression models using the standard IPMVP weather normalization approach (2.61% persistence average standard deviation across all post-commissioning periods).

Table 6.16: Hot water persistence of savings variability quantification for each of the four combinations of the NAC and standard IPMVP weather normalization approaches and Option C and Option D (MBE adjusted) savings determination methods.

Option D (MBE Adjusted) with NAC Weather Normalization Approach						
	1998	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	0.32%	1.09%	1.24%	1.69%	0.56%	0.98%
coeff var	6.78%	16.43%	-46.25%	-7.71%	-17.61%	-9.67%
Option D (MBE Adjusted) with Standard IPMVP Weather Normalization Approach						
	1998	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	0.80%	1.59%	1.16%	1.61%	0.44%	1.12%
coeff var	16.30%	25.21%	-37.33%	-7.30%	-12.98%	-3.22%
Option C with Regression Models with NAC Weather Normalization Approach						
	1998	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	0.83%	1.31%	2.10%	2.98%	1.51%	1.75%
coeff var	43.68%	15.09%	-37.40%	-13.31%	214.89%	44.59%
Option C with Regression Models with Standard IPMVP Weather Normalization Approach						
	1998	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	2.42%	3.03%	2.36%	3.25%	1.98%	2.61%
coeff var	111.63%	37.05%	-39.69%	-14.71%	271.96%	73.25%

While Option D (MBE adjusted) using the NAC weather normalization approach shows the least overall standard deviation for hot water persistence of savings, Option D (MBE adjusted) using the standard IPMVP weather normalization approach has the least standard deviation in more post-commissioning periods (three) than Option D (MBE adjusted) using the NAC weather normalization approach does (two). Figure 6.18 shows the standard deviation of the hot water persistence of savings for each of the post-commissioning periods. Option C with regression models using the standard IPMVP weather normalization approach has the greatest standard deviation in each of the post-commissioning periods. Option C with regression models using the NAC weather normalization approach has greater hot water persistence of savings variability than both Option D (MBE adjusted) using the NAC weather normalization approach and Option D (MBE adjusted) using standard IPMVP weather normalization approach in all but one of the post-commissioning periods.

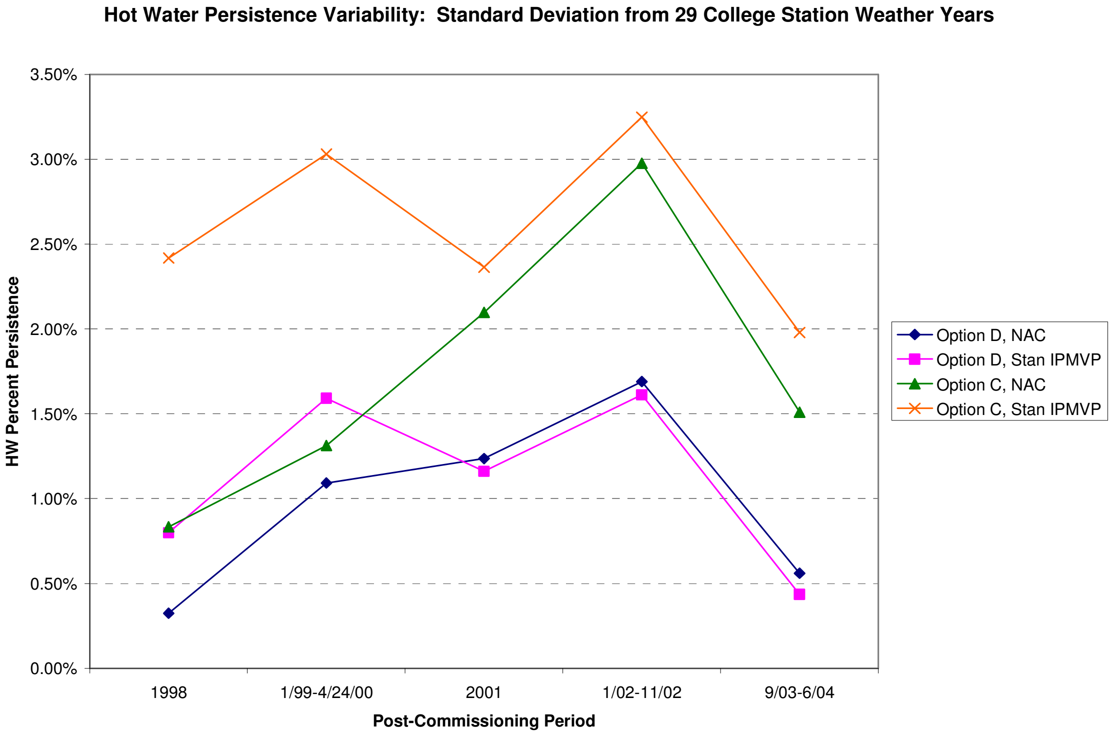


Figure 6.18: Standard deviation of hot water persistence of savings.

As with the hot water persistence of savings, the coefficient of variation for persistence of savings for the sum of chilled and hot water is skewed by low average persistence values, making the standard deviation of the combined chilled and hot water persistence of savings the only reasonable variability of persistence measure available for comparison purposes (see Table 6.17). There is only a 0.07% persistence of savings range in average standard deviation over all post-commissioning periods between Option D (MBE adjusted) using the NAC weather normalization approach (0.48% persistence average standard deviation), Option D (MBE adjusted) using the standard IPMVP weather normalization approach (0.55% persistence average standard deviation), and Option C with regression models using the NAC weather normalization approach (0.52% persistence average standard deviation). Option C with regression models using the standard IPMVP weather normalization approach has the most variability of combined chilled and hot water persistence of savings (1.26% persistence average standard deviation).

Table 6.17: Sum of chilled and hot water persistence of savings variability quantification for each of the four combinations of the NAC and standard IPMVP weather normalization approaches and Option C and Option D (MBE adjusted) savings determination methods.

Option D (MBE Adjusted) with NAC Weather Normalization Approach						
	1998	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	0.13%	0.34%	0.43%	0.65%	0.84%	0.48%
coeff var	3.30%	4.47%	5.69%	-41.79%	5.88%	-4.49%
Option D (MBE Adjusted) with Standard IPMVP Weather Normalization Approach						
	1998	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	0.26%	0.41%	0.61%	0.42%	1.06%	0.55%
coeff var	6.45%	5.47%	8.17%	-27.07%	7.29%	0.06%
Option C with Regression Models with NAC Weather Normalization Approach						
	1998	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	0.21%	0.31%	0.49%	0.76%	0.81%	0.52%
coeff var	5.92%	3.41%	6.69%	-175.22%	5.03%	-30.83%
Option C with Regression Models with Standard IPMVP Weather Normalization Approach						
	1998	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Average**
stdev	0.98%	1.24%	1.36%	1.23%	1.47%	1.26%
coeff var	24.88%	13.88%	17.70%	1796.61%	8.96%	372.41%

Figure 6.19 shows the standard deviation of the persistence of savings for the sum of chilled and hot water. Option D (MBE adjusted) using the NAC weather normalization approach and Option C with regression models using the NAC weather normalization approach have the lowest overall standard deviation of persistence of savings and alternate several times over the course of all the post-commissioning periods. One or the other has the least standard deviation in all of the post-commissioning periods except

one (1/02-11/02), when Option D (MBE adjusted) using the standard IPMVP weather normalization approach has the least standard deviation of persistence of savings.

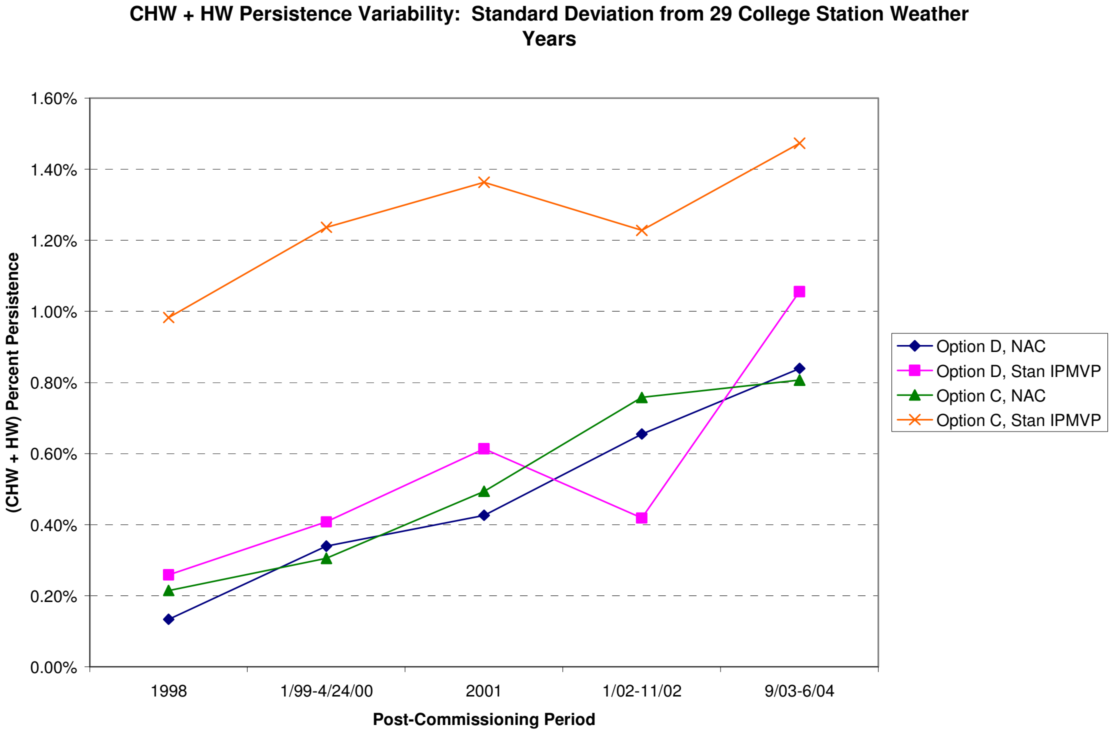


Figure 6.19: Standard deviation of sum of chilled and hot water persistence of savings.

6.5 Summary

The variability of savings and persistence of savings results from the commissioning of CE/TTI using the NAC and standard IPMVP weather normalization approaches, as well as Option C with regression models and Option D of the IPMVP are presented in this chapter. It has been shown that the savings and persistence of savings may vary greatly depending on which weather normalization approach, IPMVP Option, and weather year used as the “normal” weather year are used. Overall, the NAC weather normalization approach shows less variability in savings and persistence of savings than the standard IPMVP weather normalization approach. Additionally, Option D of the IPMVP generally shows less variability in savings and persistence of savings than Option C with regression models. These statements are true when considering chilled water savings and the savings for the sum of chilled and hot water. For hot water savings, however, results for the variability in the persistence of savings are more mixed. These statements are also true when considering hot water persistence of savings and the sum of chilled and hot water persistence. Chilled water persistence of savings results differ in that Option C with regression models using the NAC weather normalization approach shows slightly less overall variability of persistence than Option D using the NAC weather normalization approach.

For chilled water savings, the average standard deviation across all post-commissioning periods is 0.32% savings for Option D (MBE adjusted) using the NAC weather normalization approach, 0.68% savings for Option D (MBE adjusted) using the standard IPMVP weather normalization approach, 0.57% savings for Option C with regression models using the NAC weather normalization approach, and 1.01% savings for Option C with regression models using the standard IPMVP weather normalization approach.

For hot water savings, the average standard deviation across all post-commissioning periods is 0.79% savings for Option D (MBE adjusted) using the NAC weather normalization approach, 1.32% savings for Option D (MBE adjusted) using the standard IPMVP weather normalization approach, 1.83% savings for Option C with regression models using the NAC weather normalization approach, and 1.85% savings for Option C with regression models using the standard IPMVP weather normalization approach.

For the sum of chilled and hot water savings, the average standard deviation across all post-commissioning periods is 0.39% savings for Option D (MBE adjusted) using the NAC weather normalization approach, 0.57% savings for Option D (MBE adjusted) using the standard IPMVP weather normalization approach, 0.71% savings for Option C with regression models using the NAC weather normalization approach, and 0.98%

savings for Option C with regression models using the standard IPMVP weather normalization approach.

For chilled water persistence of savings, the average standard deviation across all post-commissioning periods is 0.42% persistence for Option D (MBE adjusted) using the NAC weather normalization approach, 0.68% persistence for Option D (MBE adjusted) using the standard IPMVP weather normalization approach, 0.38% persistence for Option C with regression models using the NAC weather normalization approach, and 1.20% persistence for Option C with regression models using the standard IPMVP weather normalization approach.

For hot water persistence of savings, the average standard deviation across all post-commissioning periods is 0.98% persistence for Option D (MBE adjusted) using the NAC weather normalization approach, 1.12% persistence for Option D (MBE adjusted) using the standard IPMVP weather normalization approach, 1.75% persistence for Option C with regression models using the NAC weather normalization approach, and 2.61% persistence for Option C with regression models using the standard IPMVP weather normalization approach.

For the sum of chilled and hot water persistence of savings, the average standard deviation across all post-commissioning periods is 0.48% persistence for Option D (MBE adjusted) using the NAC weather normalization approach, 0.55% persistence for Option D (MBE adjusted) using the standard IPMVP weather normalization approach, 0.52% persistence for Option C with regression models using the NAC weather normalization approach, and 1.26% persistence for Option C with regression models using the standard IPMVP weather normalization approach.

CHAPTER VII
CONCLUSIONS AND RECOMMENDATIONS

This thesis has determined the savings and persistence of savings from commissioning for three buildings (Civil Engineering/Texas Transportation Institute Building (CE/TTI), Heep Center, and the Memorial Student Center (MSC)) located on the Texas A&M University campus. The first commissioning for each of the buildings took place in either 1996 or 1997 and subsequent commissioning activities took place at different times in CE/TTI and Heep Center. Chilled water, hot water, and electricity savings were determined for these buildings using Option C with regression models of the IPMVP (International Performance Measurement and Verification Protocol) and the NAC (Normalized Annual Consumption) weather normalization approach. A long-term average College Station weather year was used as the "normal" year to drive regression models. Consumption data was used to create regression models.

Over six post-commissioning periods, CE/TTI averaged 12.5% chilled water savings, 17.2% hot water savings, 7.9% electricity savings, and 11.4% aggregate site savings. Over eight post-commissioning periods, Heep Center averaged 13.1% chilled water savings, 30.5% hot water savings, 16.9% electricity savings, and 16.5% aggregate site savings. Over three post-commissioning periods, MSC averaged 17.7% chilled water savings, 25.8% hot water savings, 15.2% electricity savings, and 19.0% aggregate site savings.

Overall from the first post-commissioning period in CE/TTI, 1997, through the last post-commissioning period, 9/03-6/04, the chilled water savings increased 18.6%, hot water savings degraded 3.3%, electricity savings degraded 2.3%, and aggregate site savings increased 8.7%. From the first post-commissioning period in Heep Center, 1997, through the last post-commissioning period, 1/1/04-6/22/04, the chilled water savings increased 8.3%, hot water savings increased 12.1%, electricity savings increased 15.5%, and aggregate site savings increased 11.2%. From the first post-commissioning period in MSC, 12/97-12/98, through the last post-commissioning period, 2000, the chilled water savings increased 9.7%, hot water savings increased 20.9%, electricity savings increased 20.1%, and aggregate site savings increased 14.8%.

Limited documentation of building operations after commissioning takes places makes it difficult to precisely determine causes for the favorable increases in savings over time seen in the three buildings. For CE/TTI, gradual VFD repair, increases in the cold deck temperature setpoint, an AHU shutdown/setback schedule, and the campus chilled and hot water loop optimizations likely contributed to energy savings over time. For Heep Center, the hot water campus loop optimization, follow-up commissioning, and significant maintenance work several years after the follow-up commissioning played a role in the favorable persistence results. Due to limited documentation, the MSC is the most difficult to determine causes of increased energy savings after initial commissioning, although the chilled and hot water campus loop optimizations most likely contributed.

It is recommended that measures implemented after the official commissioning period be well documented for at least the first year or two after commissioning, if not longer. Often it is difficult to determine if and when commissioning measures recommended by the commissioning team and left up to the maintenance staff to implement are performed. It is important to be able to determine exact reasons for energy savings increases or degradation. Another common problem encountered when determining energy savings is the lack of quality consumption data available. It is thus recommended that data consumption data be continuously monitored to become aware of both poor data quality and unexpected increases in energy consumption. A large decrease in savings in CE/TTI that was subsequently remedied by follow-up commissioning might have been prevented had it been noticed earlier. It is also important for future persistence studies to make sure that consumption data meters are regularly calibrated to avoid any systematic bias. Consumption data quality is also difficult to assess when old, non-calibrated data meters are replaced with new data meters. In such cases it may be impossible to accurately combine both meters' data together for persistence of savings analysis.

This thesis has also compared the variability of savings and persistence of savings of two weather normalization approaches, the NAC and standard IPMVP weather normalization approaches. The variability of savings and persistence of savings of Option C with regression models and Option D of the IPMVP have also been compared. CE/TTI was used for this portion of the study. For the NAC weather normalization approach, a set of savings results was obtained by using 29 different College Station weather years as the "normal" weather year. For the standard IPMVP weather normalization approach, a set of savings results was obtained from 29 different runs that selected random College Station weather years for each of the different post-commissioning periods' weather year. Variability was quantified by the average standard deviation of the percent savings across all post-commissioning periods.

For the combined chilled and hot water savings variability, the average standard deviation across all post-commissioning periods is 0.39% savings for Option D (MBE adjusted) using the NAC weather normalization approach, 0.57% savings for Option D (MBE adjusted) using the standard IPMVP weather normalization approach, 0.71% savings for Option C with regression models using the NAC weather normalization approach, and 0.98% savings for Option C with regression models using the standard IPMVP weather normalization approach.

The variability of persistence of savings yields similar results to the variability of savings. For the combined chilled and hot water persistence of savings, the average standard deviation across all post-commissioning periods is 0.48% persistence for Option D (MBE adjusted) using the NAC weather normalization approach, 0.55%

persistence for Option D (MBE adjusted) using the standard IPMVP weather normalization approach, 0.52% persistence for Option C with regression models using the NAC weather normalization approach, and 1.26% persistence for Option C with regression models using the standard IPMVP weather normalization approach.

In general, the NAC weather normalization approach shows less variability in savings and persistence of savings than the standard IPMVP weather normalization approach. Additionally, Option D of the IPMVP generally shows less variability in savings and persistence of savings than Option C with regression models.

It is recommended that future research on the variability of savings and persistence of savings of the NAC and standard IPMVP weather normalization approaches and Option C and Option D of the IPMVP concentrate on developing more measures of variability quantification. Additionally, it is recommended that a similar study be performed on commissioned buildings in a colder climate to specifically compare the contributions of chilled and hot water savings variability to the combined chilled and hot water savings variability.

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APPENDIX A

REGRESSION MODELS AND CALIBRATED SIMULATIONS SHOWN WITH CONSUMPTION DATA

CE/TTI Regression Models

Table A.1: CE/TTI chilled water regression model parameters (MMBtu/day).

Year/Period	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**4/24/01-12/31/01**	**1/02-11/02**	**9/03-6/04**
Model Type	4P CP	4P CP	4P CP	4P CP	4P CP	4P CP	4P CP
Y_cp	39.6862	33.5589	33.1021	26.2907	26.3787	31.7617	31.9449
change point	68.0455	63.8167	63.5258	60.3542	58.36	61.12	66.3117
left slope	0.6735	0.7175	0.8124	0.6723	0.6669	0.7578	0.6075
right slope	2.2859	1.9333	1.7535	1.6917	1.4009	1.5088	1.2205

Table A.2: CE/TTI hot water regression model parameters (MMBtu/day).

Year/Period	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**4/24/01-12/31/01**	**1/02-11/02**	**9/03-6/04**
Model Type	4P CP	4P CP	4P CP	4P CP	4P CP	4P CP	4P CP
Y_cp	5.2608	8.5117	6.8944	12.2482	8.8062	8.9024	4.6356
change point	69.2830	57.3917	60.0183	49.9517	60.5133	66.8367	67.315
left slope	-0.7611	-1.0458	-0.8847	-0.9147	-0.6877	-0.6415	-0.8006
right slope	-0.0414	-0.2169	-0.1452	-0.3071	-0.2109	-0.3014	-0.1732

Table A.3: CE/TTI electricity regression model parameters (kWh/day).

Year/Period	**7/23/96-7/31/96**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**
Model Type	Mean	2P Linear	2P Linear	2P Linear	2P Linear	2P Linear	2P Linear
Y_cp	9380.4444	8373.8270	8131.6145	6386.5666	6890.0242	8378.2977	8163.4166
change point	0	0	0	0	0	0	0
left slope	0.0000	8.0526	9.3254	29.9905	16.8424	3.2304	14.3817
right slope	0.0000	8.0526	9.3254	29.9905	16.8424	3.2304	14.3817

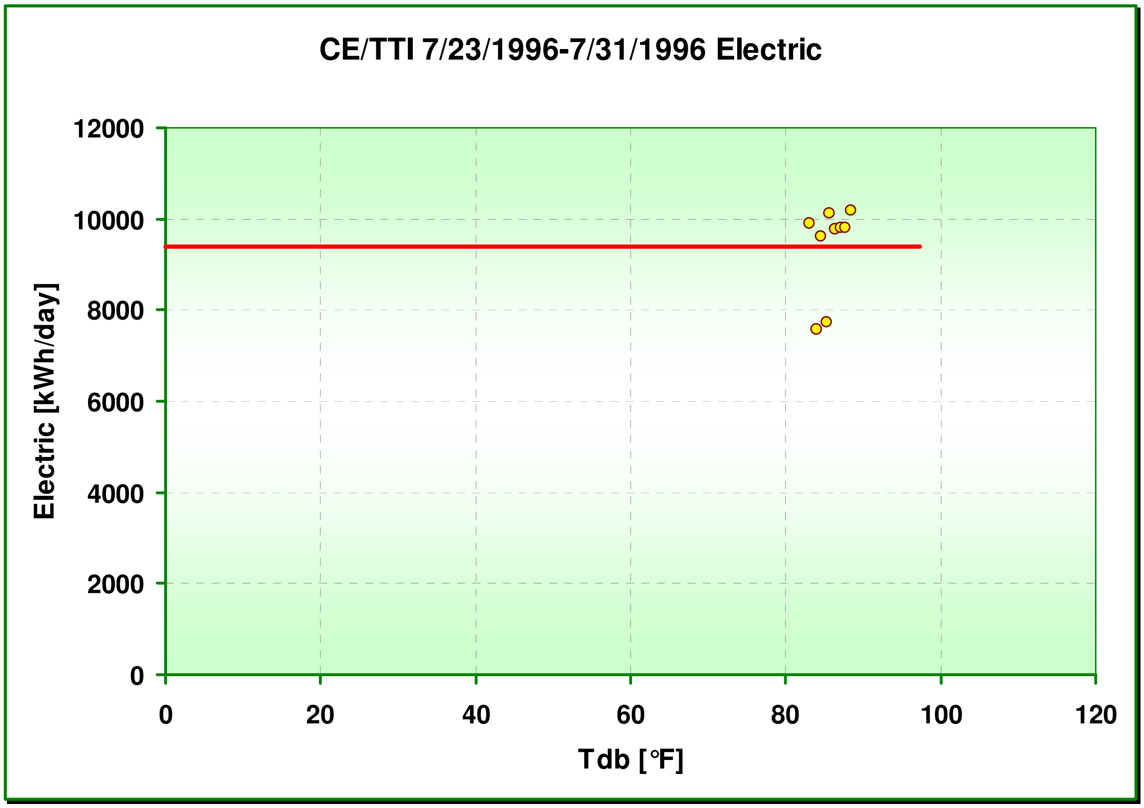

Figure A.1: CE/TTI 7/23/96-7/31/96 pre-commissioning period electricity mean regression model.

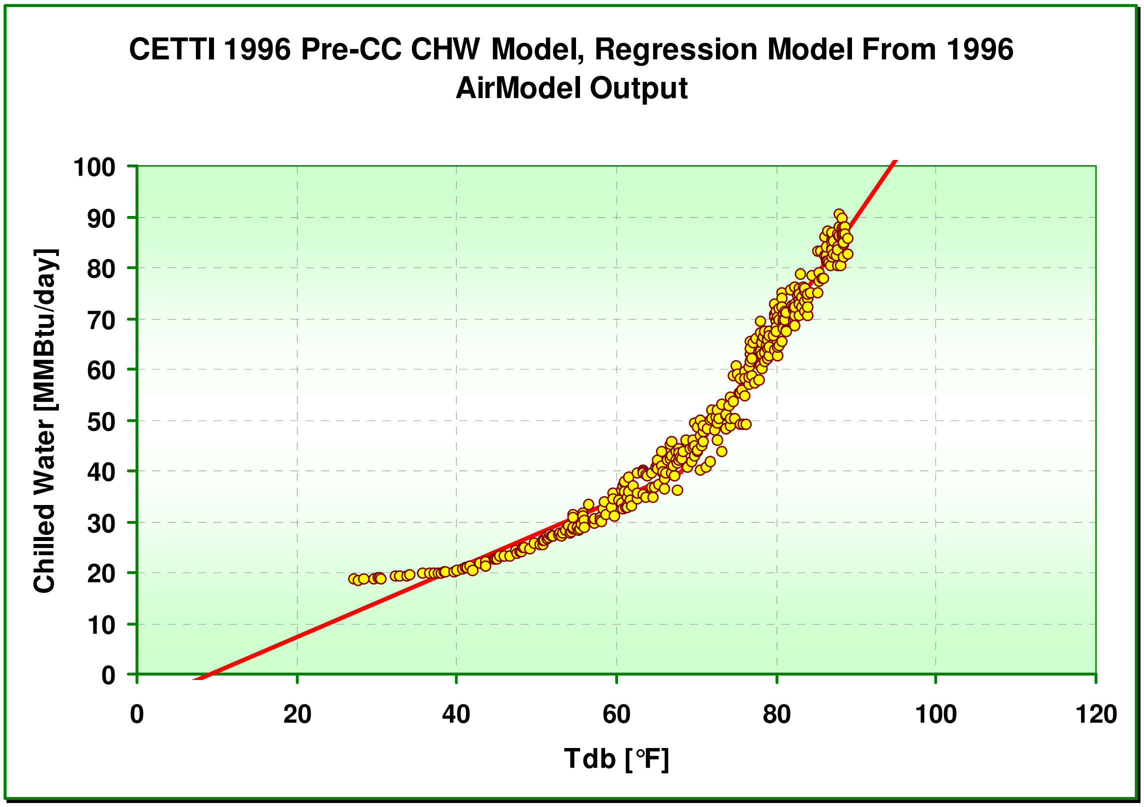

Figure A.2: CE/TTI 1996 pre-commissioning period chilled water 4P CP regression model.

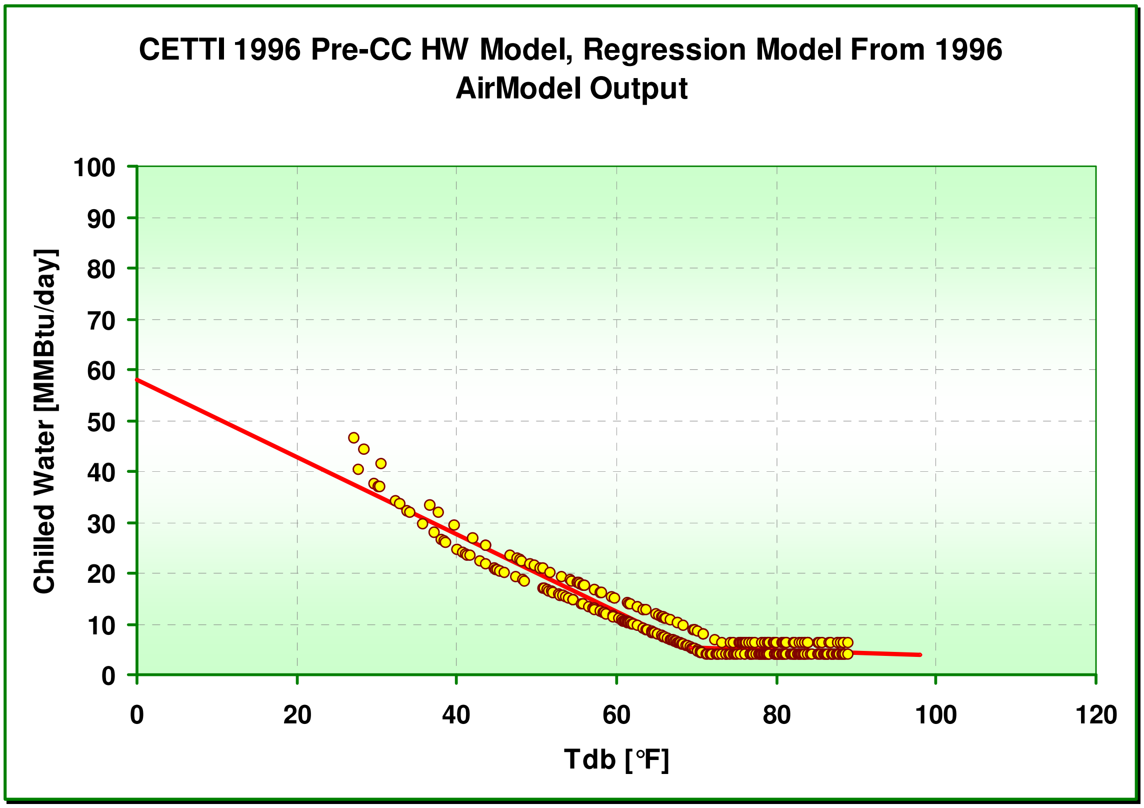

Figure A.3: CE/TTI 1996 pre-commissioning period hot water 4P CP regression model.

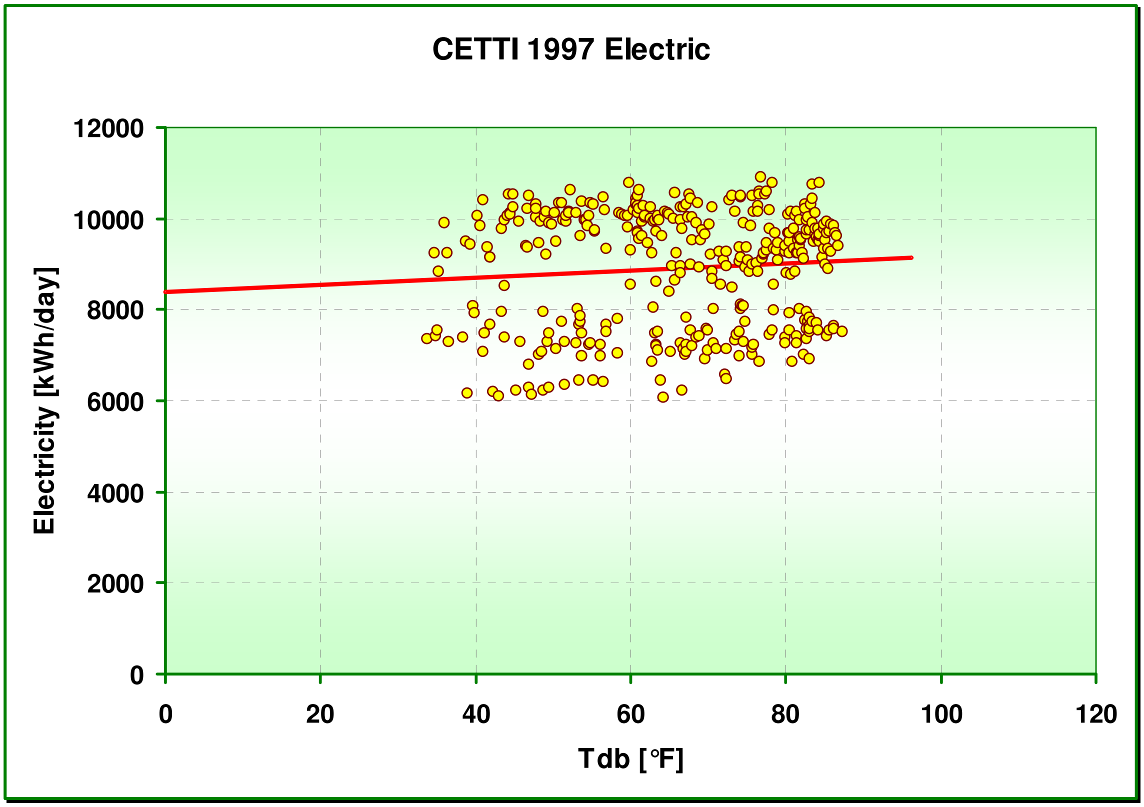

Figure A.4: CE/TTI 1997 period electricity straight line regression model.

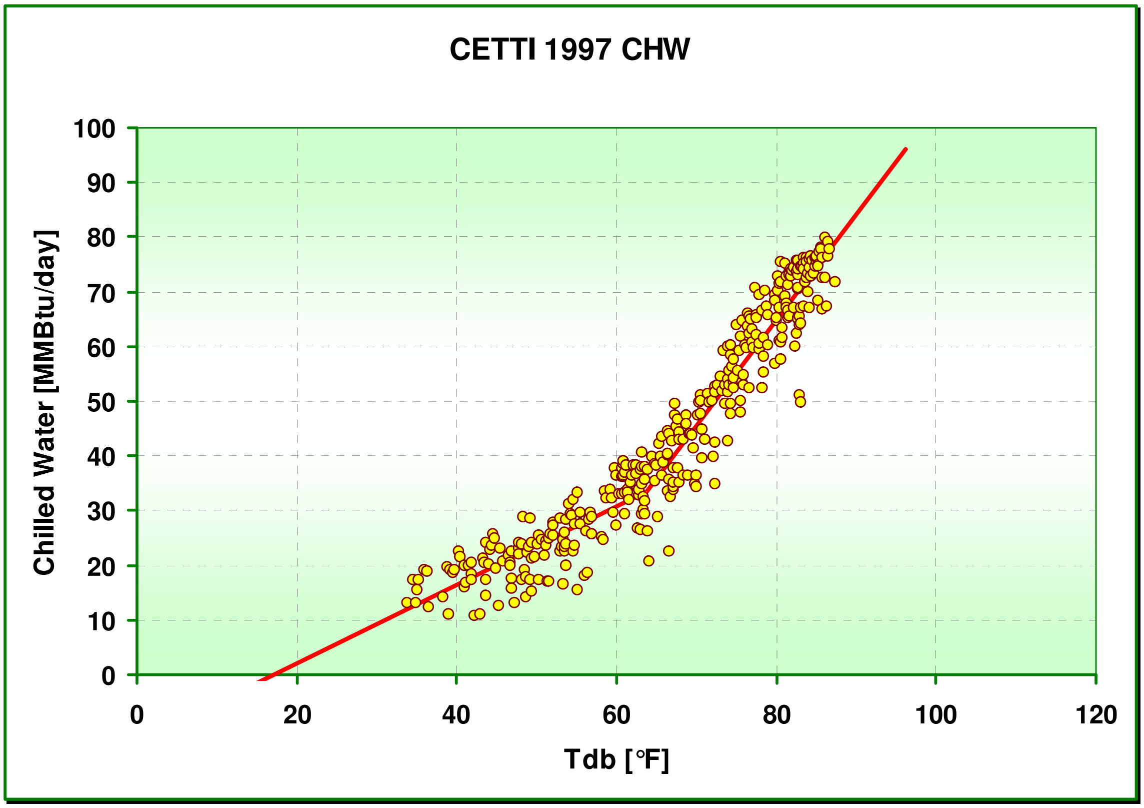

Figure A.5: CE/TTI 1997 period chilled water 4P CP regression model.

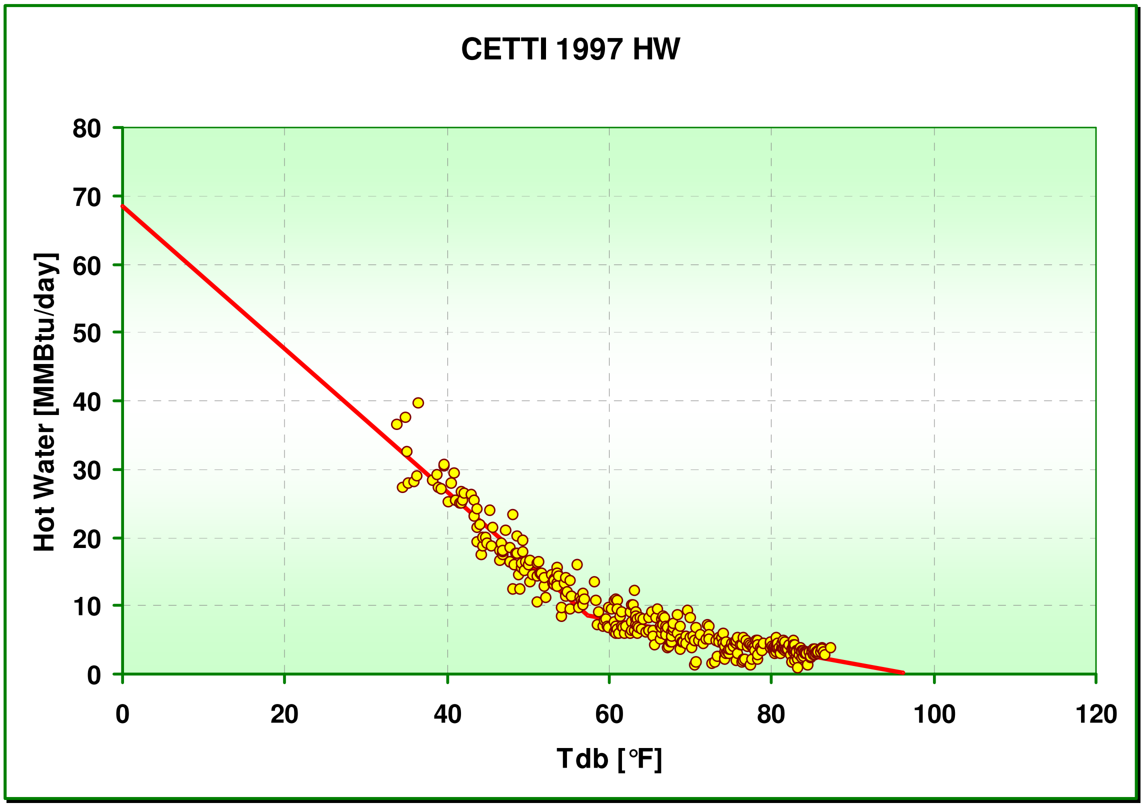

Figure A.6: CE/TTI 1997 period hot water 4P CP regression model.

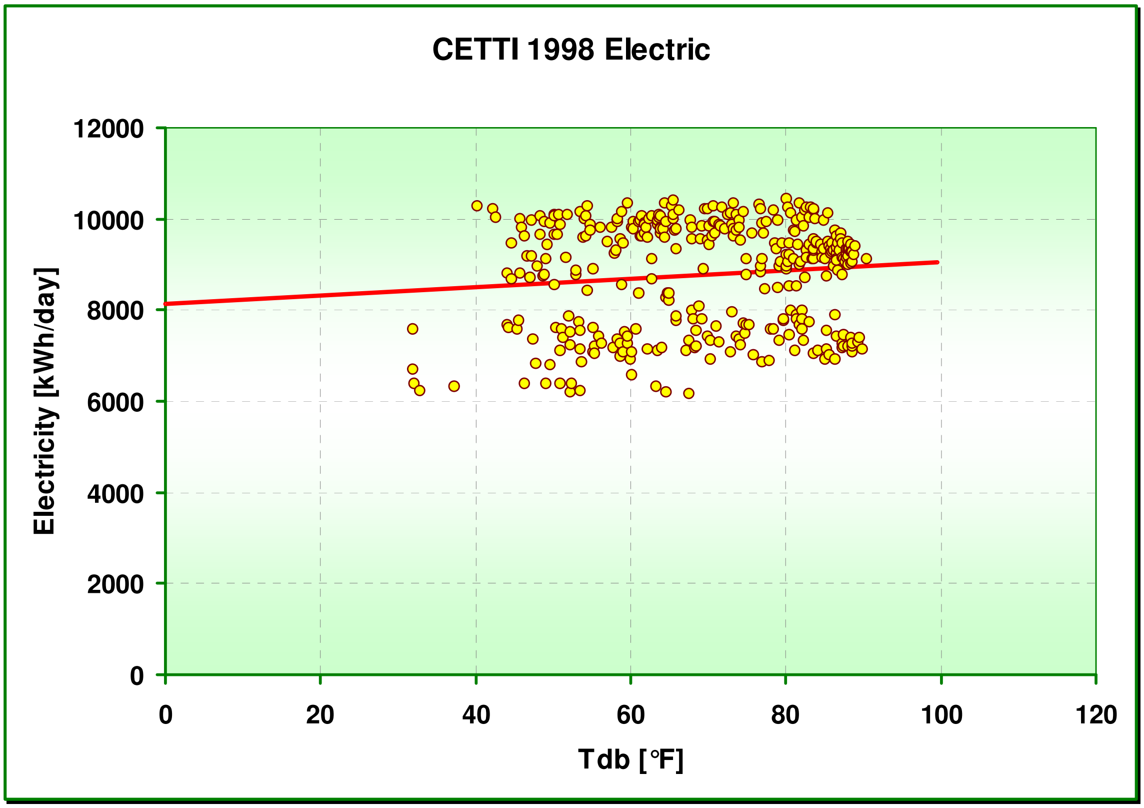

Figure A.7: CE/TTI 1998 period electricity straight line regression model.

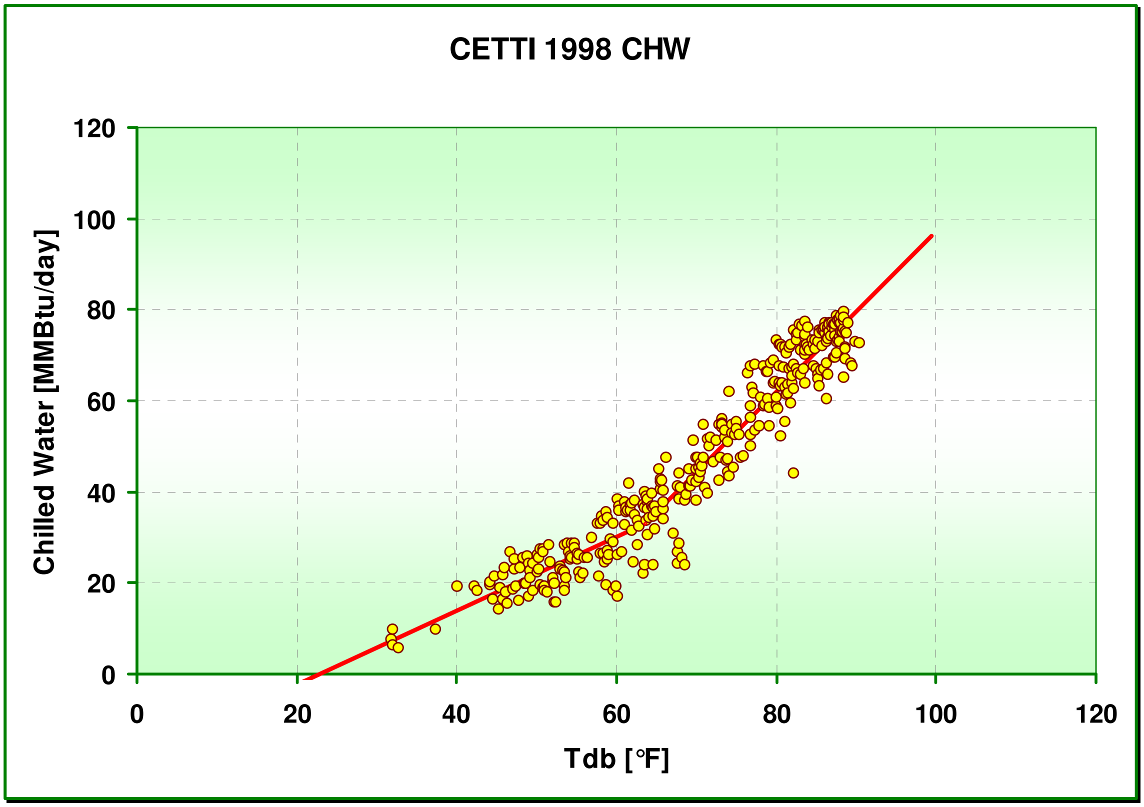

Figure A.8: CE/TTI 1998 period chilled water 4P CP regression model.

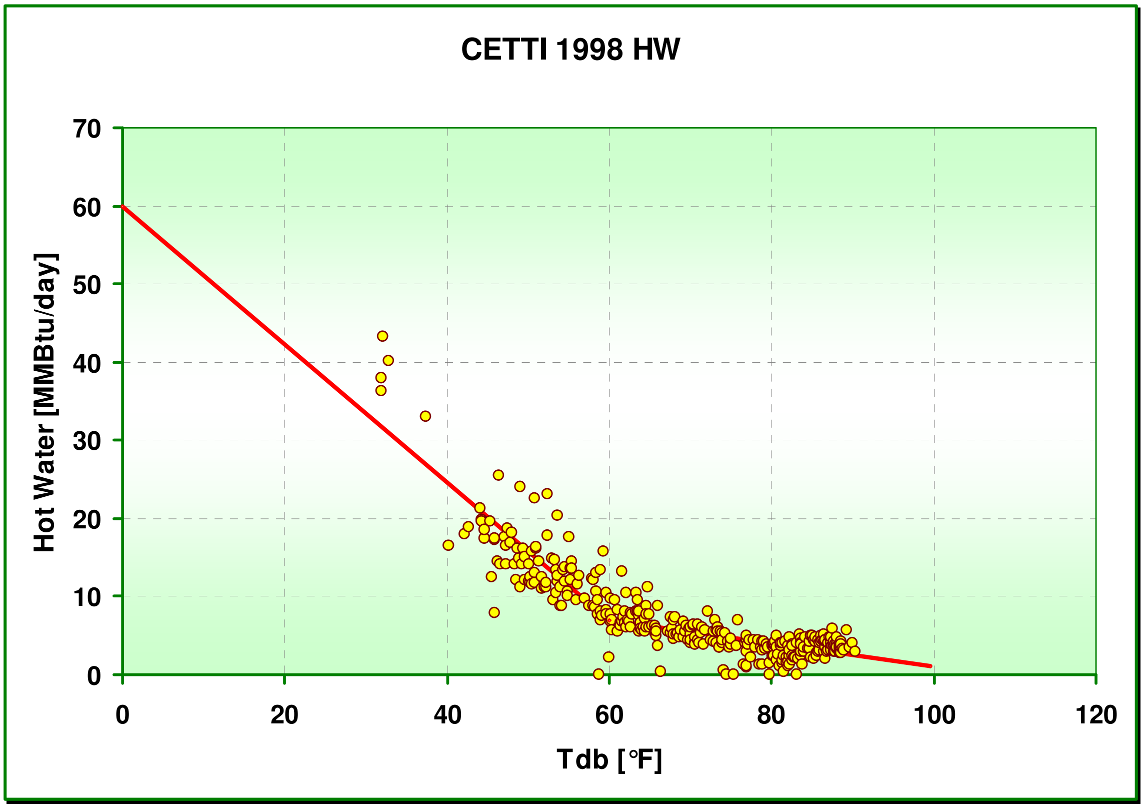

Figure A.9: CE/TTI 1998 period hot water 4P CP regression model.

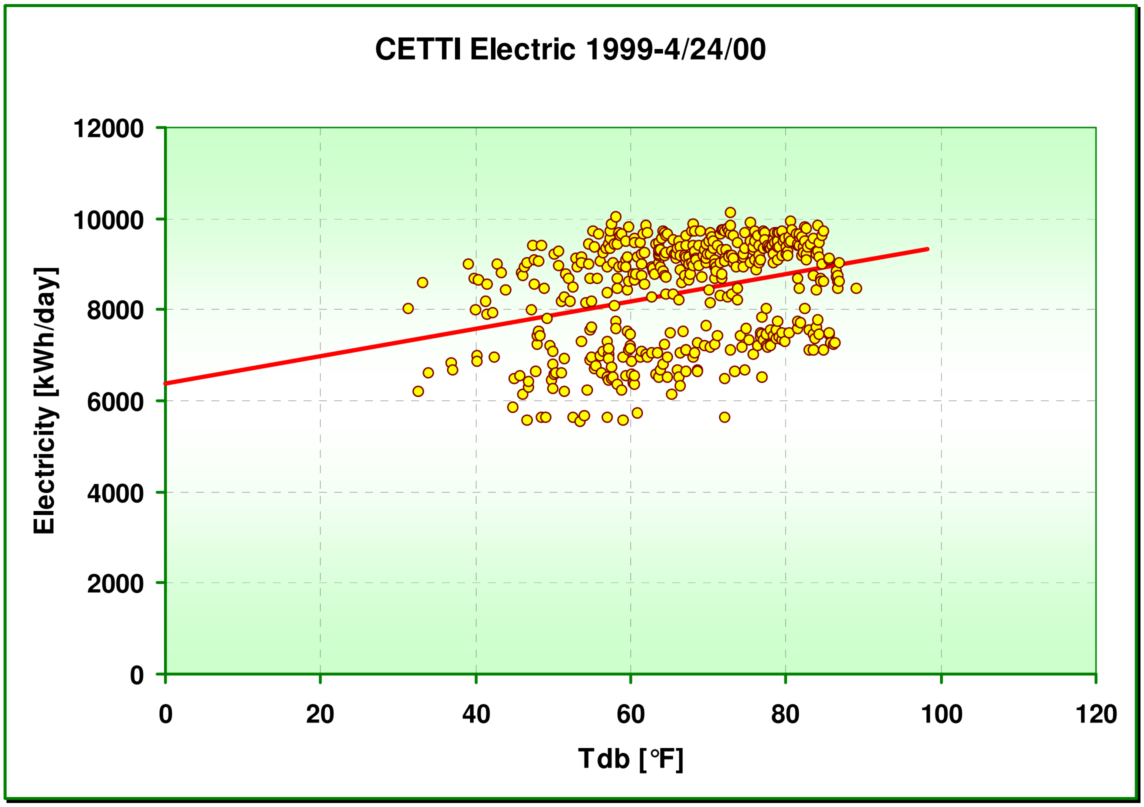

Figure A.10: CE/TTI 1999-4/24/00 period electricity straight line regression model.

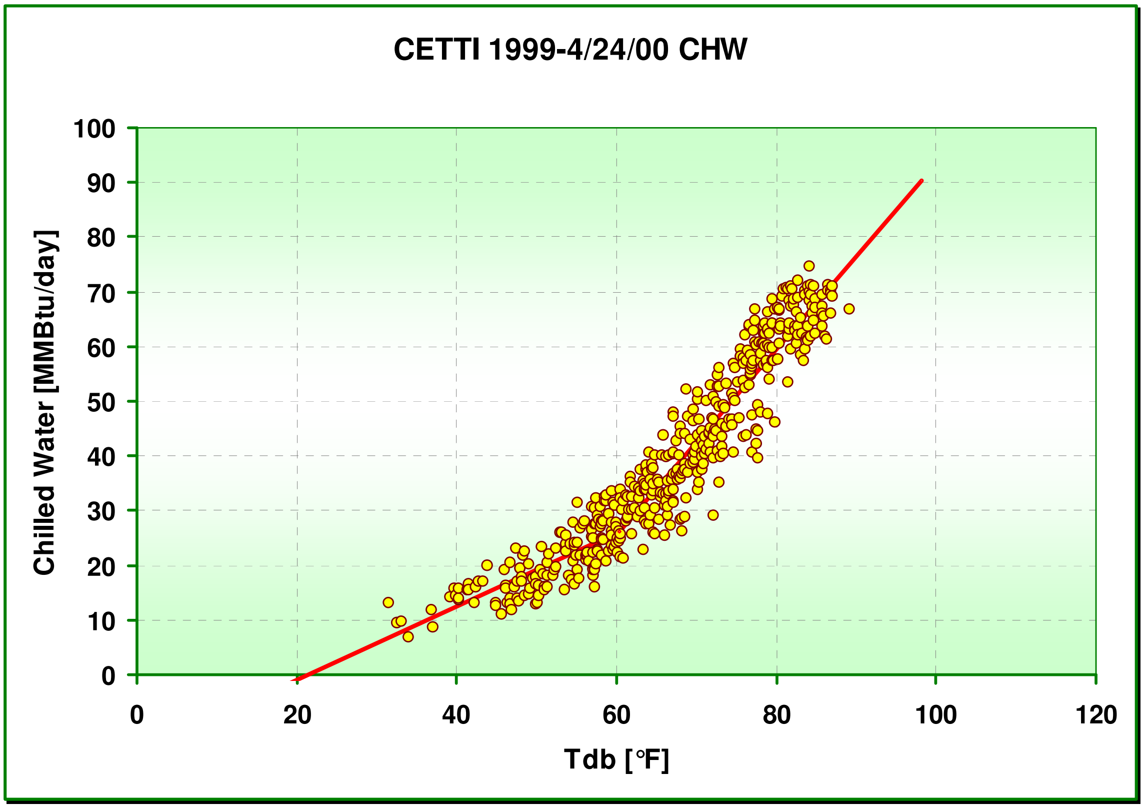

Figure A.11: CE/TTI 1999-4/24/00 period chilled water 4P CP regression model.

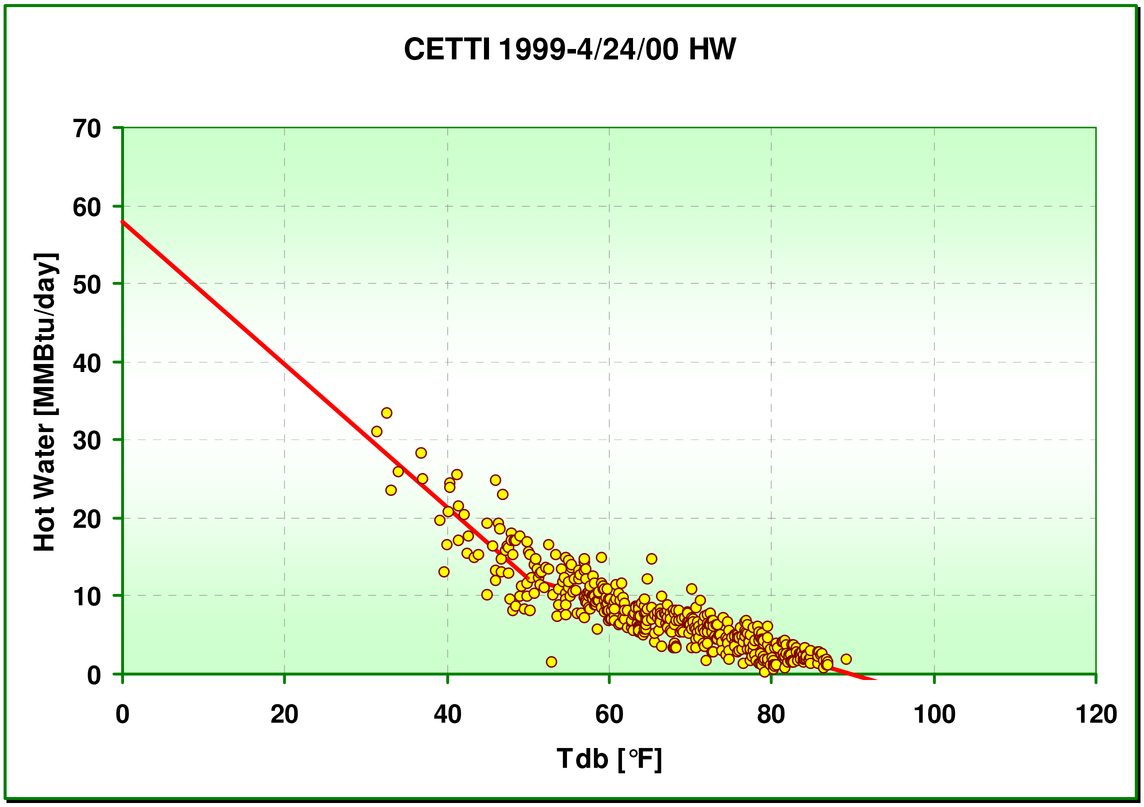

Figure A.12: CE/TTI 1999-4/24/00 period hot water 4P CP regression model.

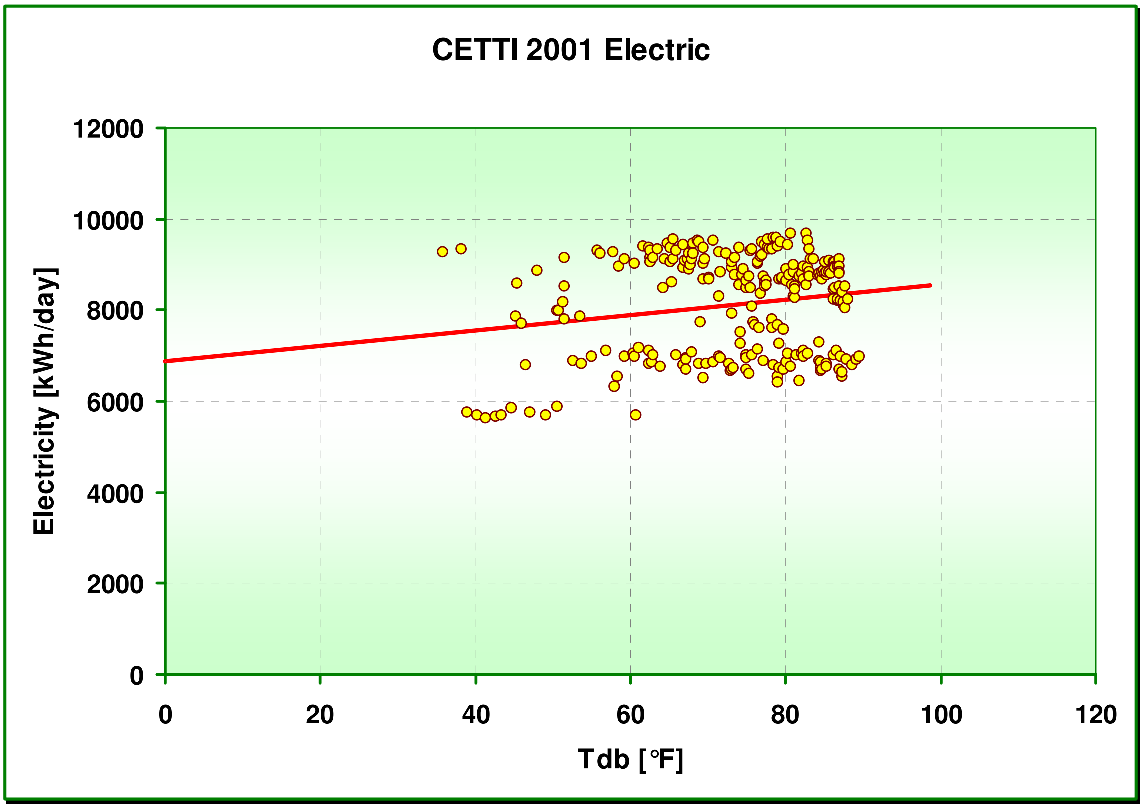

Figure A.13: CE/TTI 4/24/01-12/31/01 period electricity straight line regression model.

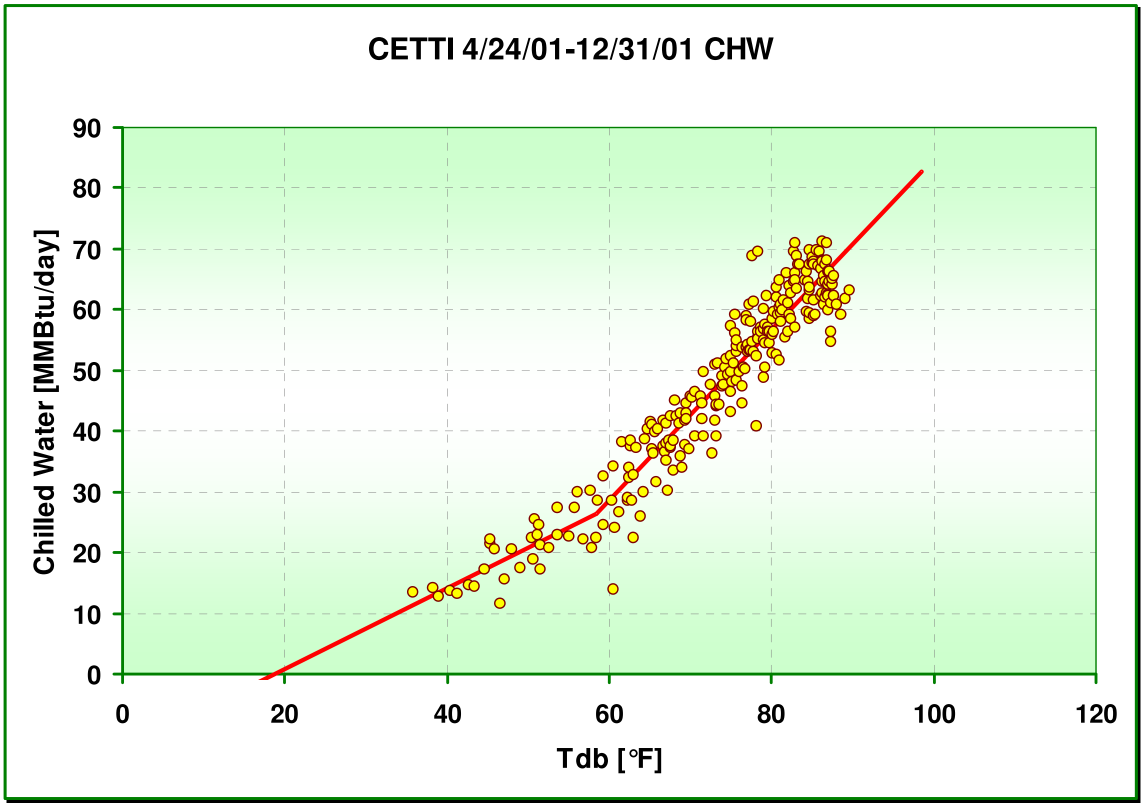

Figure A.14: CE/TTI 4/24/01-12/31/01 period chilled water 4P CP regression model.

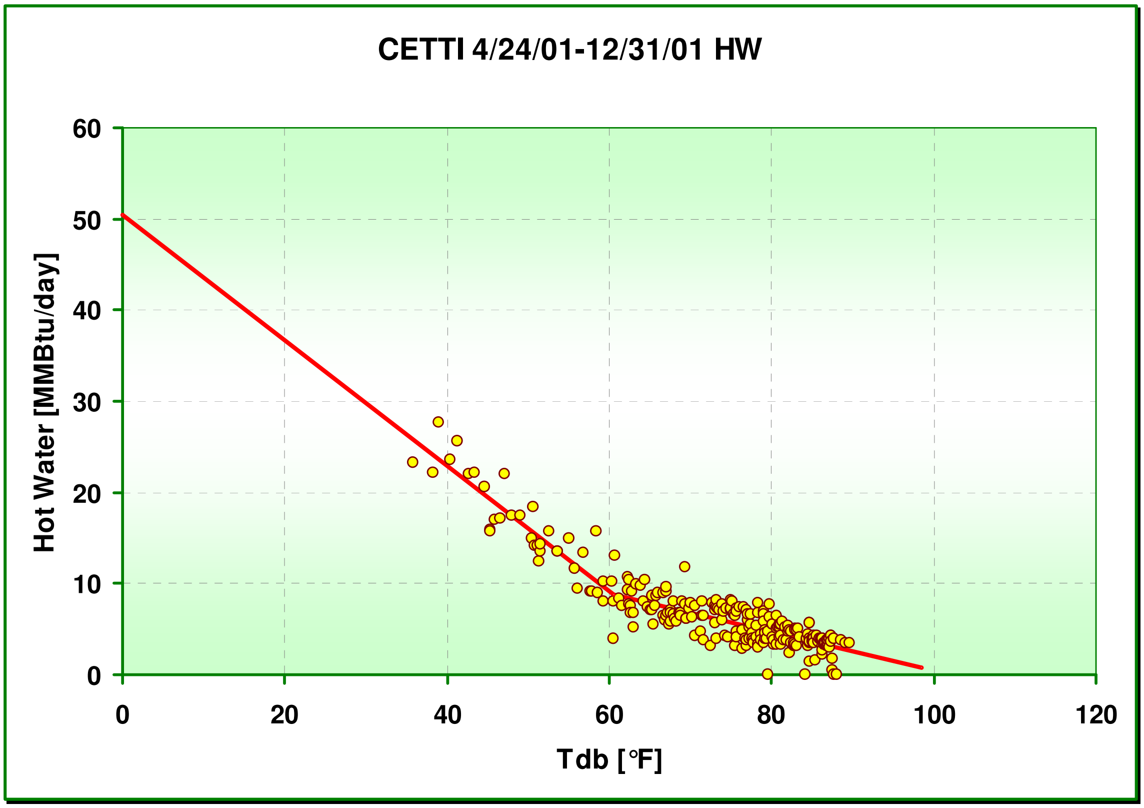

Figure A.15: CE/TTI 4/24/01-12/31/01 period hot water 4P CP regression model.

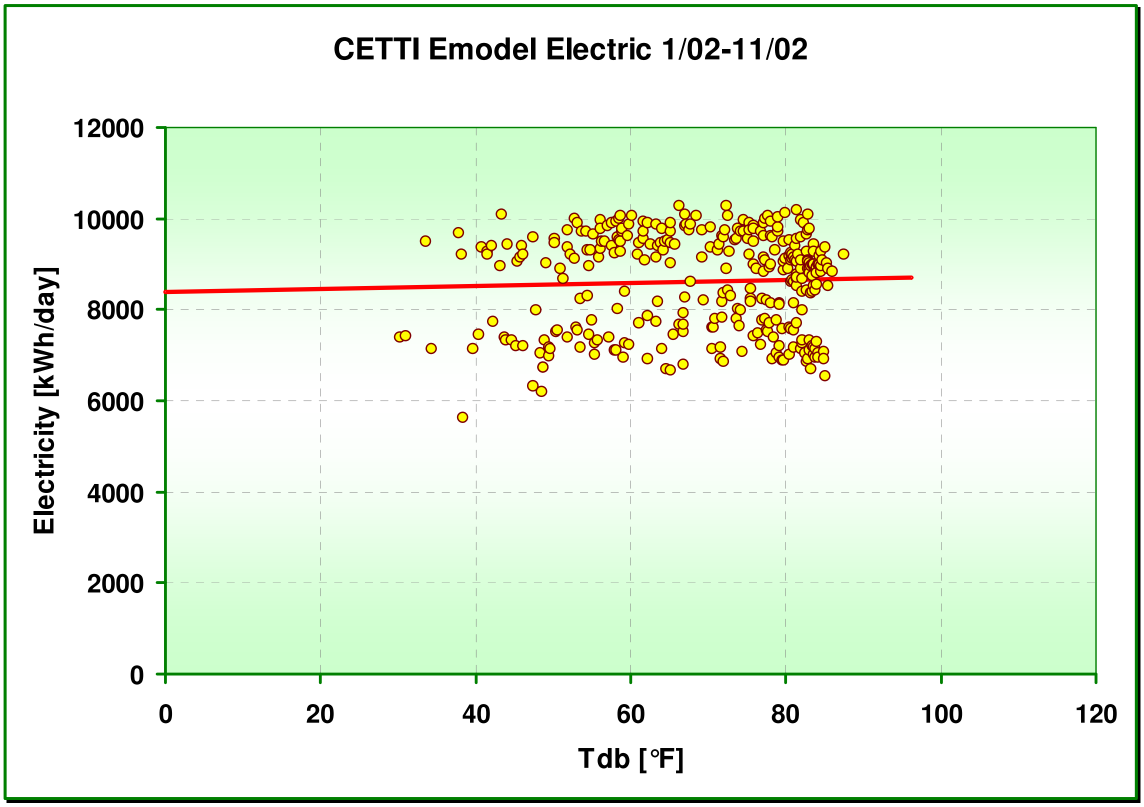

Figure A.16: CE/TTI 1/02-11/02 period electricity straight line regression model.

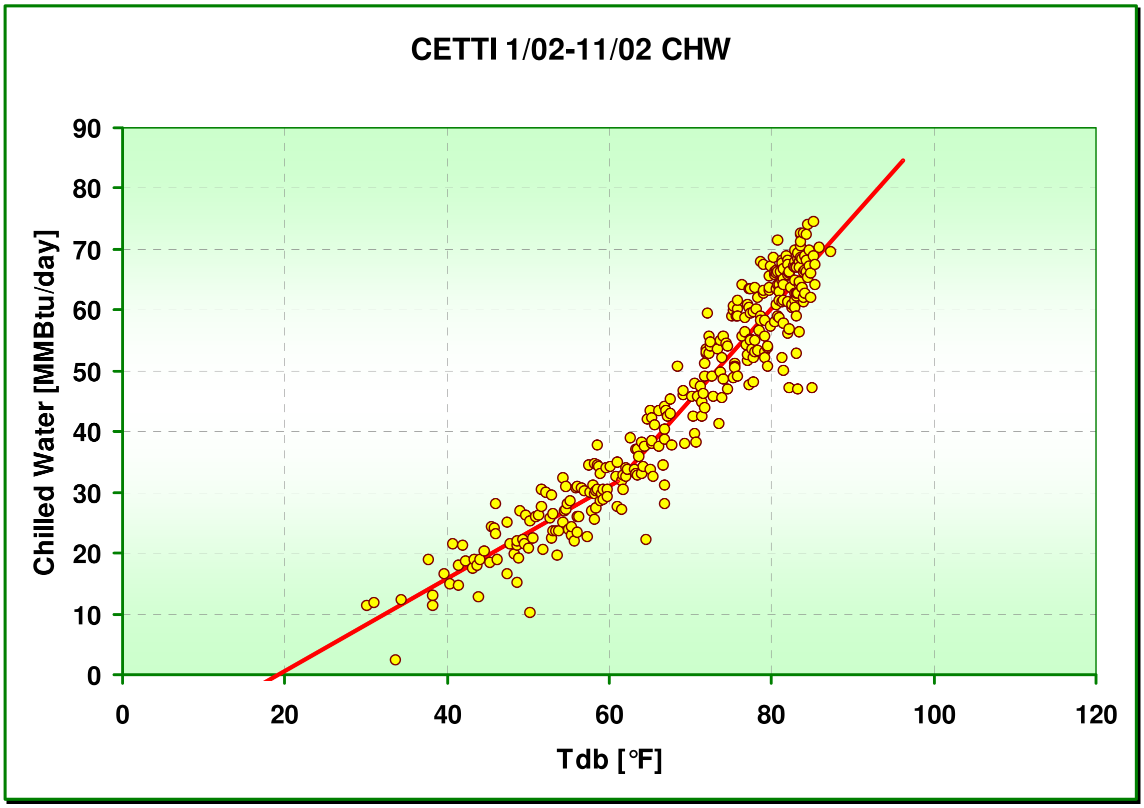

Figure A.17: CE/TTI 1/02-11/02 period chilled water 4P CP regression model.

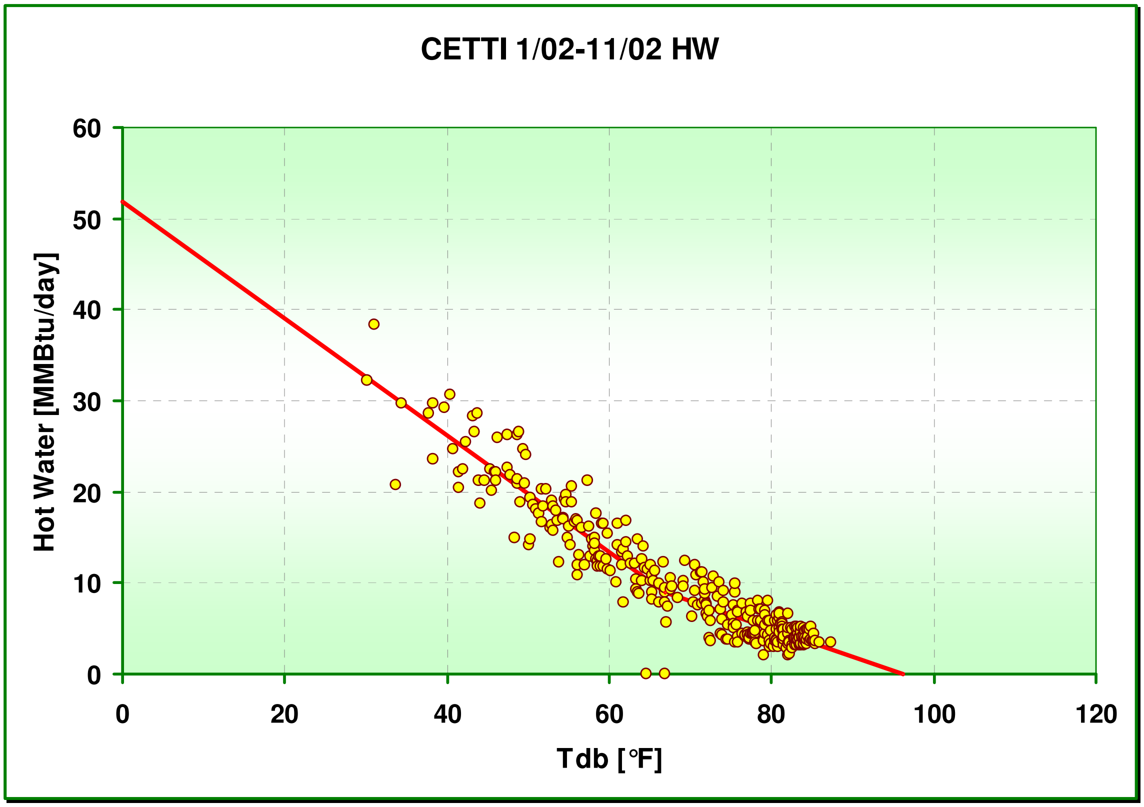

Figure A.18: CE/TTI 1/02-11/02 period hot water 4P CP regression model.

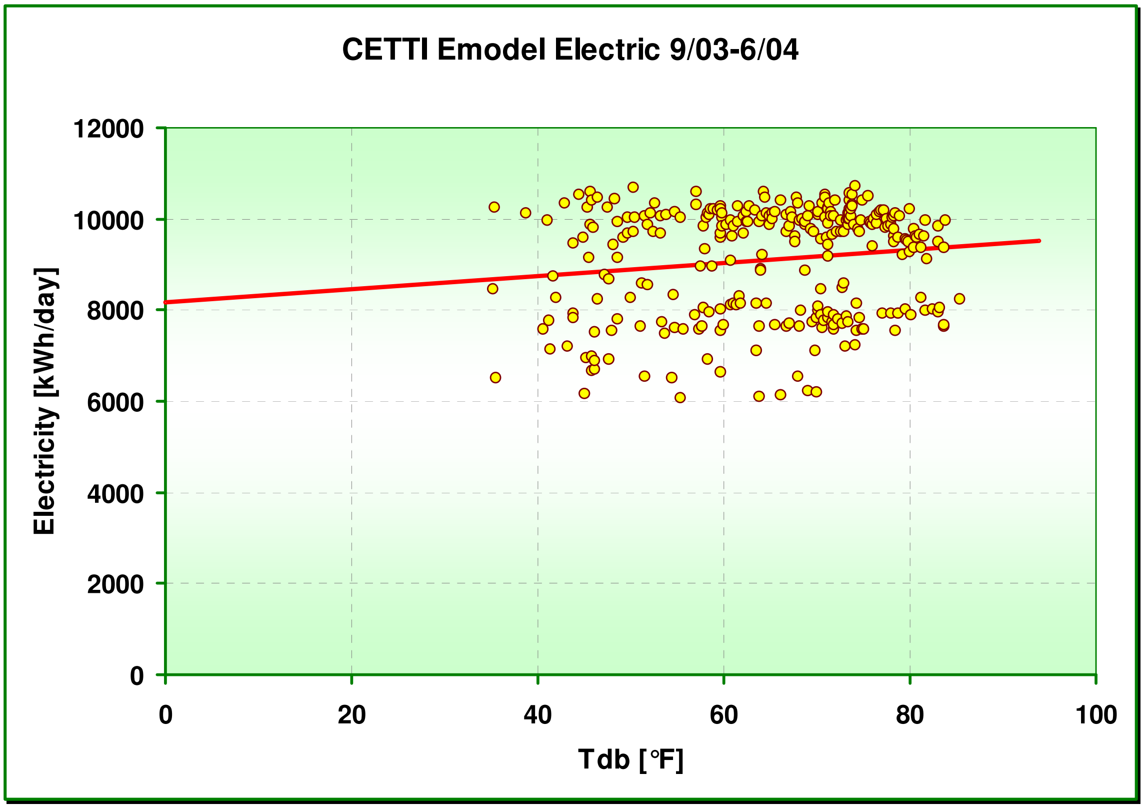

Figure A.19: CE/TTI 9/24/03-6/22/04 period electricity straight line regression model.

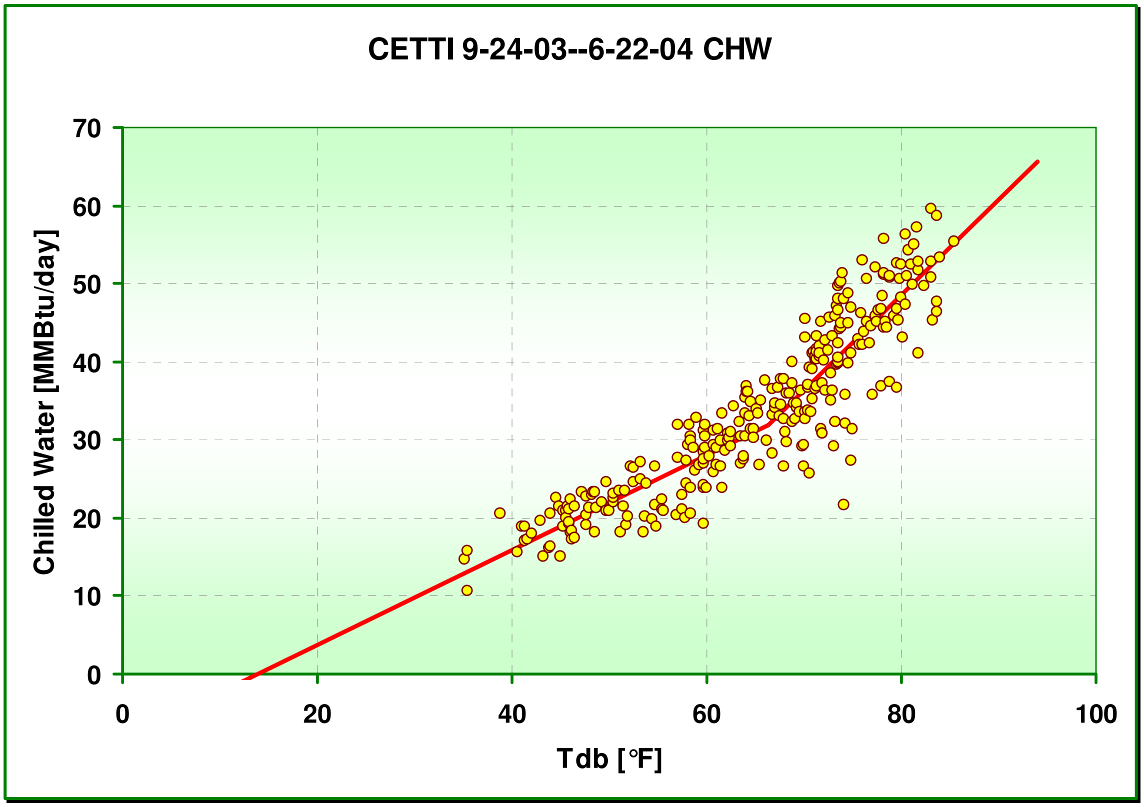

Figure A.20: CE/TTI 9/24/03-6/22/04 period chilled water 4P CP regression model.

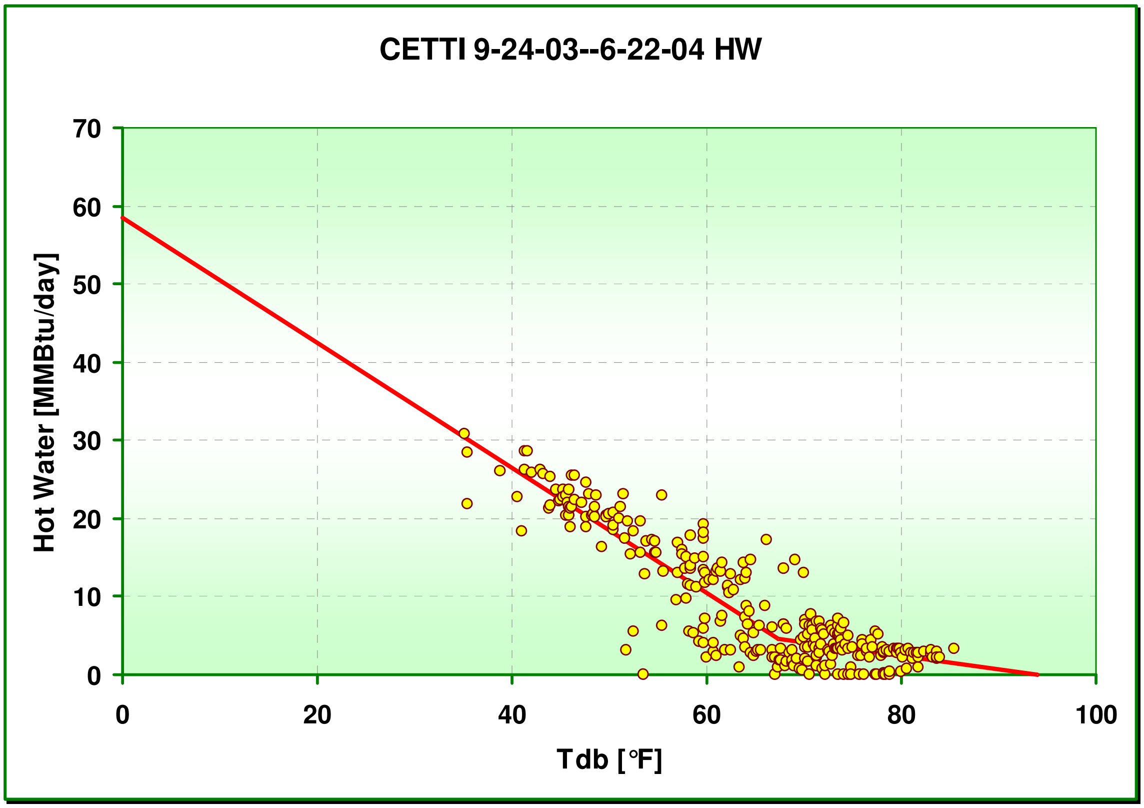

Figure A.21: CE/TTI 9/24/03-6/22/04 period hot water 4P CP regression model.

CE/TTI Calibrated Simulations

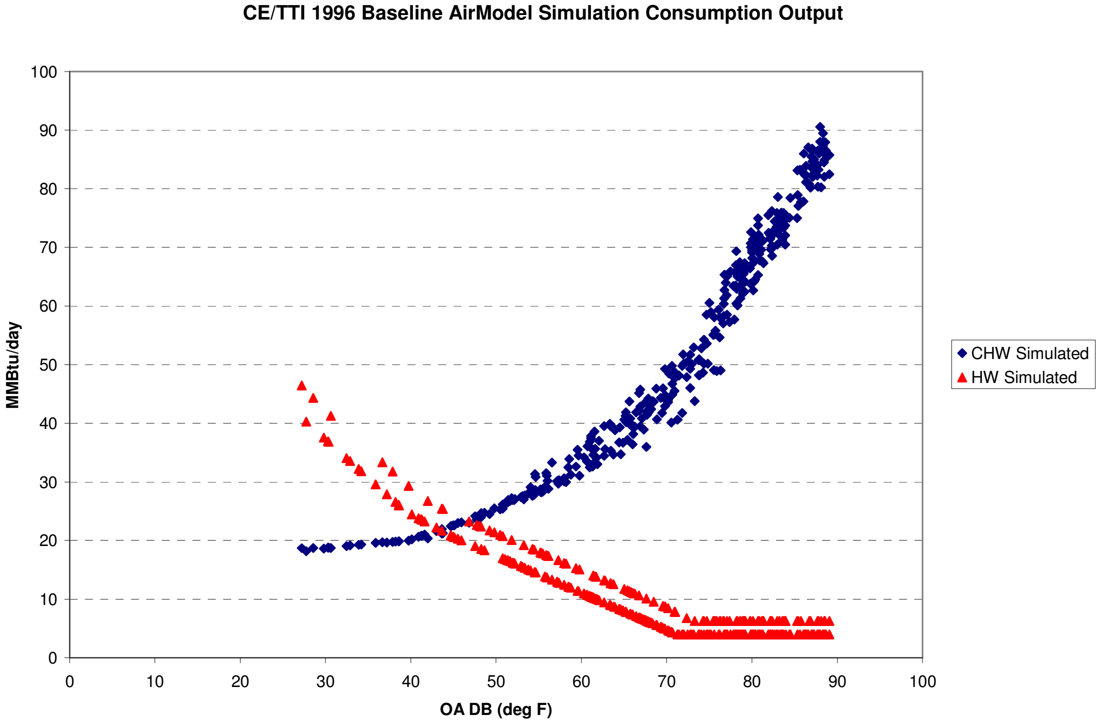

Figure A.22: CE/TTI 1996 baseline simulated consumption.

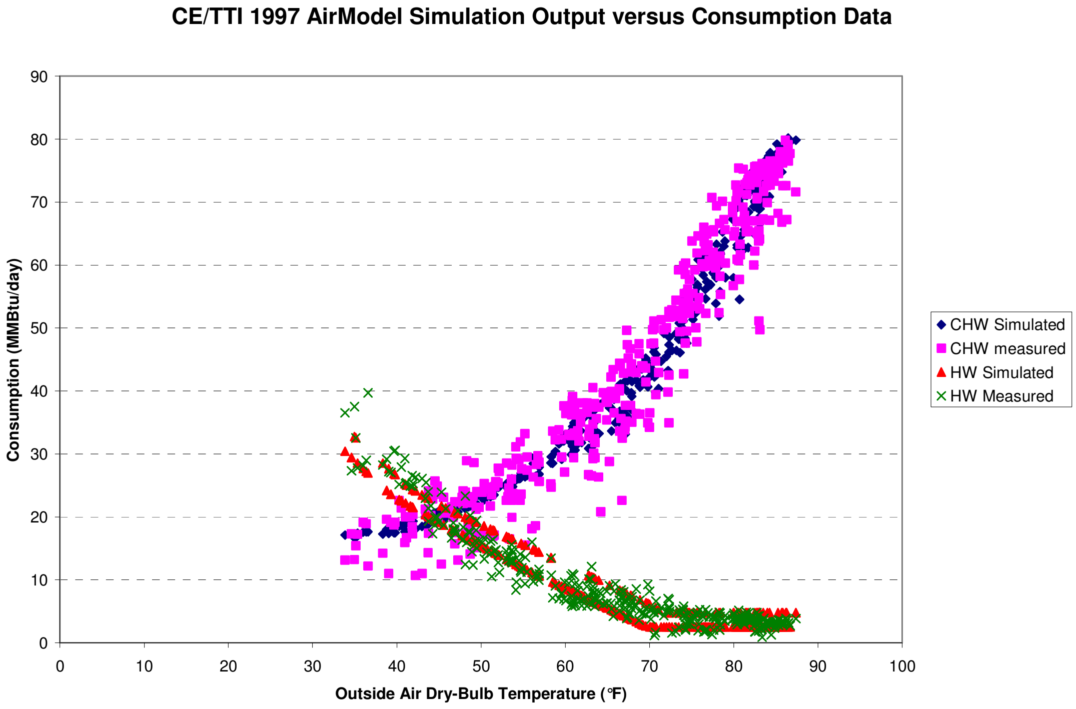

Figure A.23: Comparison of CE/TTI 1997 calibrated simulation and consumption data.

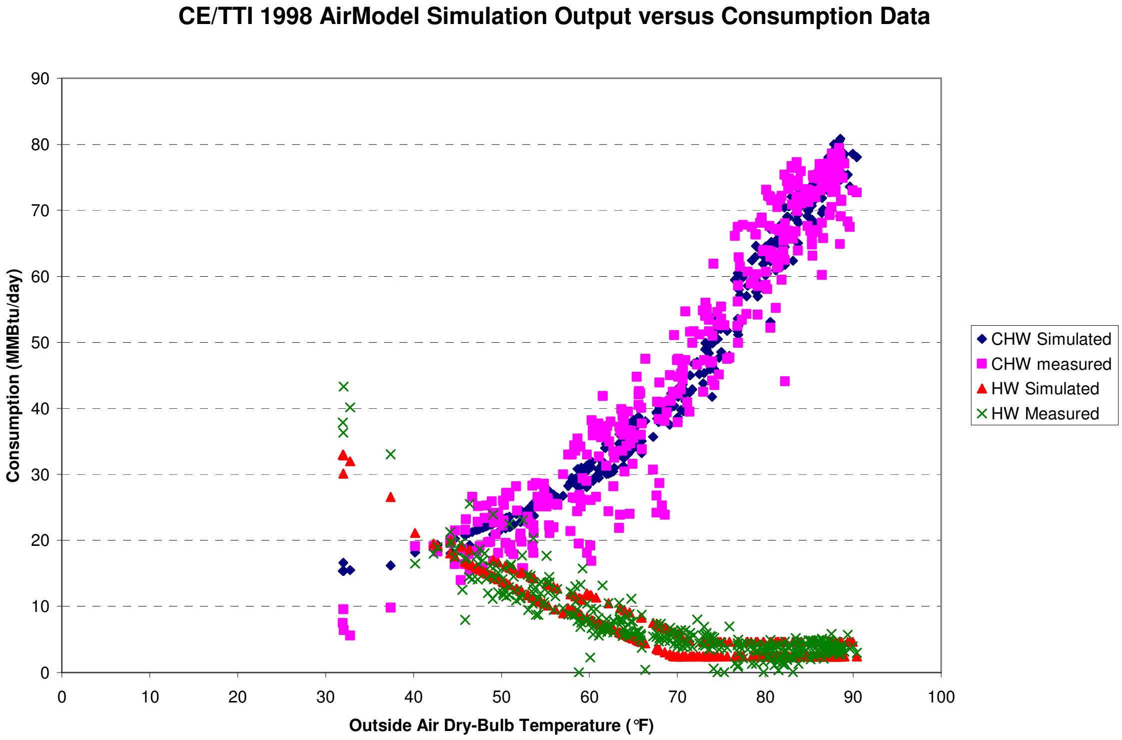

Figure A.24: Comparison of CE/TTI 1998 calibrated simulation and consumption data.

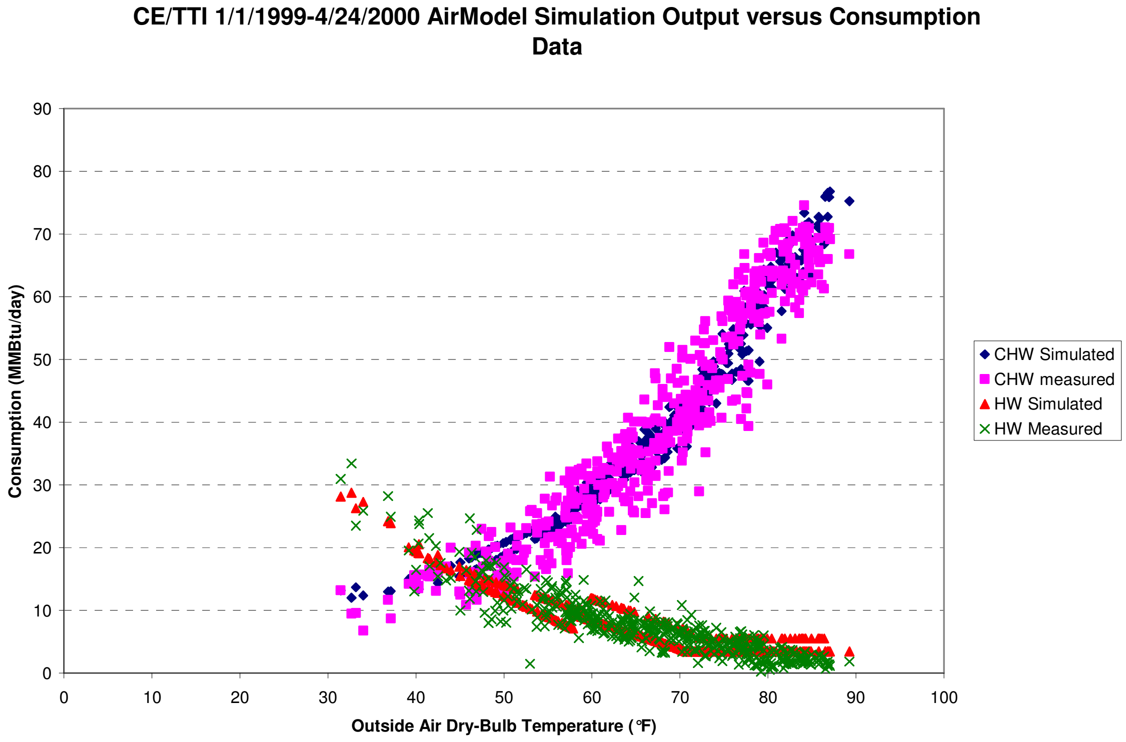

Figure A.25: Comparison of CE/TTI 1/1/99-4/24/00 calibrated simulation and consumption data.

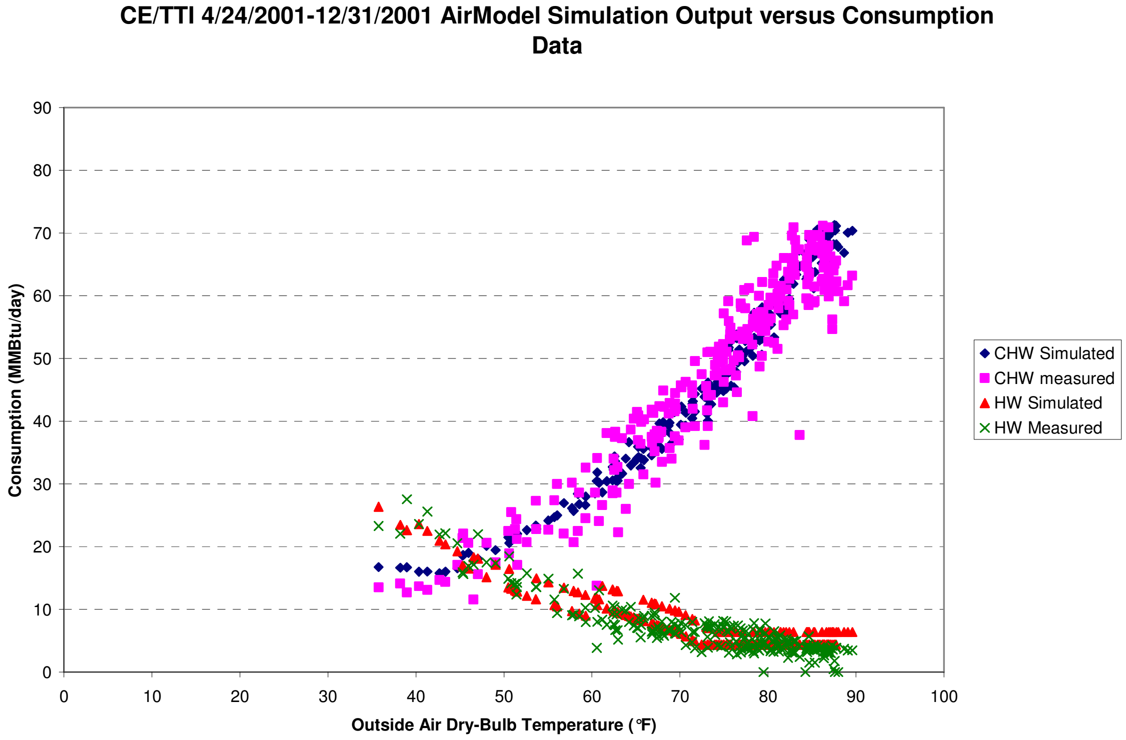

Figure A.26: Comparison of CE/TTI 4/24/01-12/31/01 calibrated simulation and consumption data.

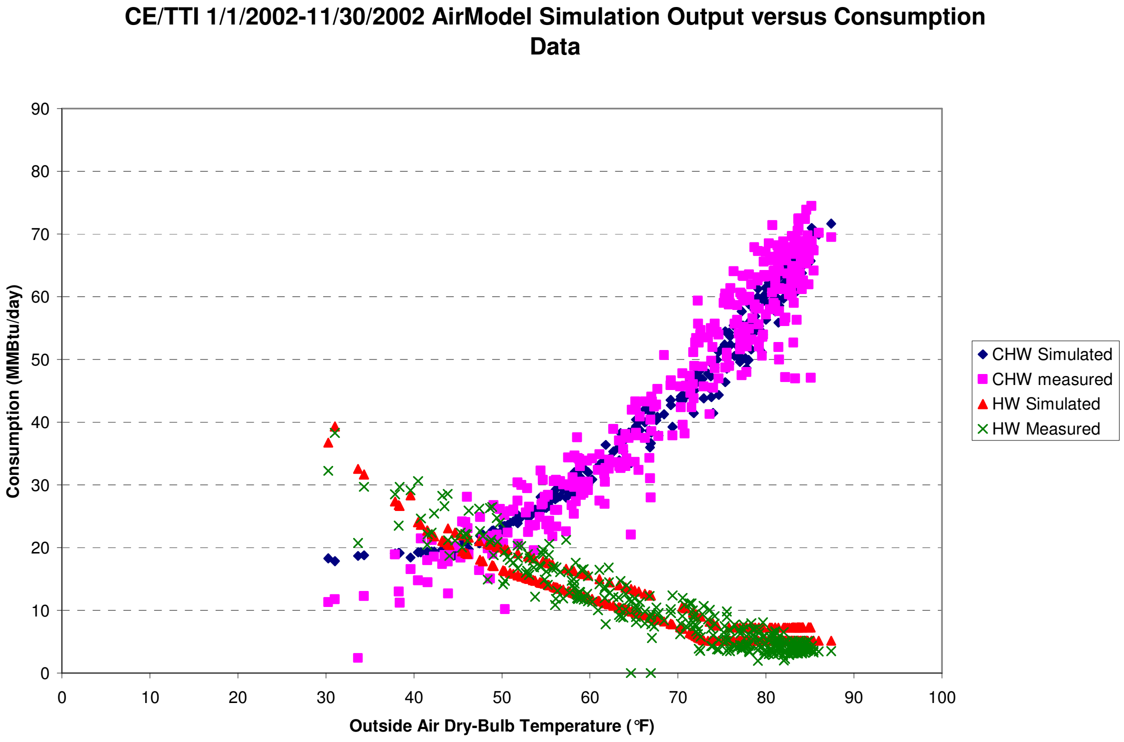

Figure A.27: Comparison of CE/TTI 1/1/02-11/30/02 calibrated simulation and consumption data.

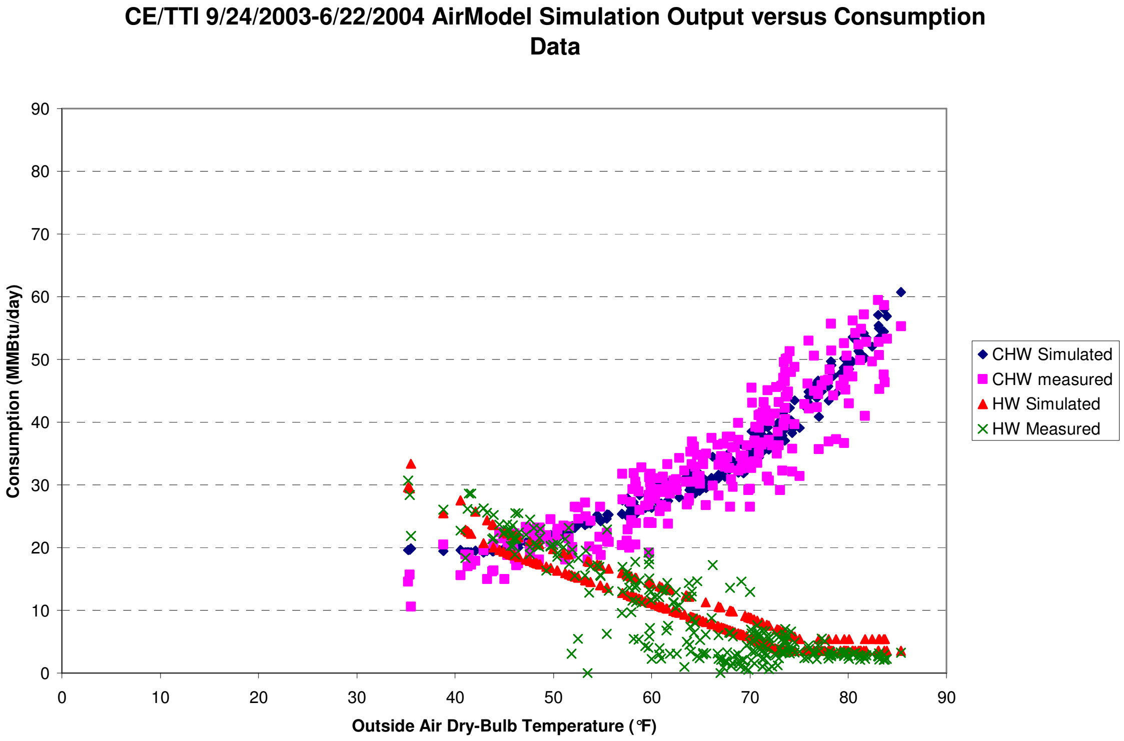

Figure A.28: Comparison of CE/TTI 9/24/2003-6/22/2004 calibrated simulation and consumption data.

Heep Center Regression Models

Table A.4: Heep Center chilled water regression model parameters (MMBtu/day).

Year/Period	Simulated Pre-Comm	1997	1998	1/99-7/99	11/99-12/00	2001	2002	2003	1/1/04-6/22/04
Model Type	4P CP	4P CP	4P CP	4P CP	4P CP	4P CP	4P CP	4P CP	4P CP
Y_cp	46.9229	53.8074	34.3085	47.2061	34.7848	44.2368	29.9256	44.4984	19.7028
change point	60.6205	62.7458	55.3417	62.3192	55.5250	59.4667	56.5467	64.9375	56.2783
left slope	1.4073	1.8281	1.3281	1.4617	1.1527	1.5260	1.2431	1.7780	0.8036
right slope	3.9421	3.3336	2.8787	3.2066	2.6186	2.7516	3.3623	4.8811	3.9398

Table A.5: Heep Center hot water regression model parameters (MMBtu/day).

Year/Period	Simulated Pre-Comm	1997	1998	1/99-7/99	11/99-12/00	2001	2002	2003	1/1/04-6/22/04
Model Type	4P CP	4P CP	SLR	4P CP	4P CP	4P CP	SLR	SLR	SLR
Y_cp	7.2487	17.4106	19.8517	13.1038	11.3072	13.2013	16.5423	13.3505	16.9379
change point	82.8955	43.4708	0.0000	69.7683	61.7917	59.4667	0.0000	0.0000	0.0000
left slope	-0.6691	-0.5594	-0.1165	-0.0785	-0.1706	-0.1361	-0.0445	-0.0246	-0.0856
right slope	-0.2882	-0.1716	-0.1165	-0.3828	-0.0664	-0.0540	-0.0445	-0.0246	-0.0856

Table A.6: Heep Center electricity regression model parameters (kWh/day).

Year/Period	**6/20/96-8/31/96**	**1997**	**1998**	**1/99-7/99**	**11/99-12/00**	**2001**	**2002**	**2003**	**1/1/04-6/22/04**
Model Type	Mean	SLR	SLR	SLR	SLR	SLR	SLR	SLR	SLR
Y_cp	15524.63	11654.91	11355.46	10448.24	10100.00	9735.10	9883.46	10714.68	11442.99
change point	0	0	0	0	0	0	0	0	0
left slope	0.0000	32.6517	32.4118	37.4809	41.8499	45.4745	49.4261	25.4840	0.2577
right slope	0.0000	32.6517	32.4118	37.4809	41.8499	45.4745	49.4261	25.4840	0.2577

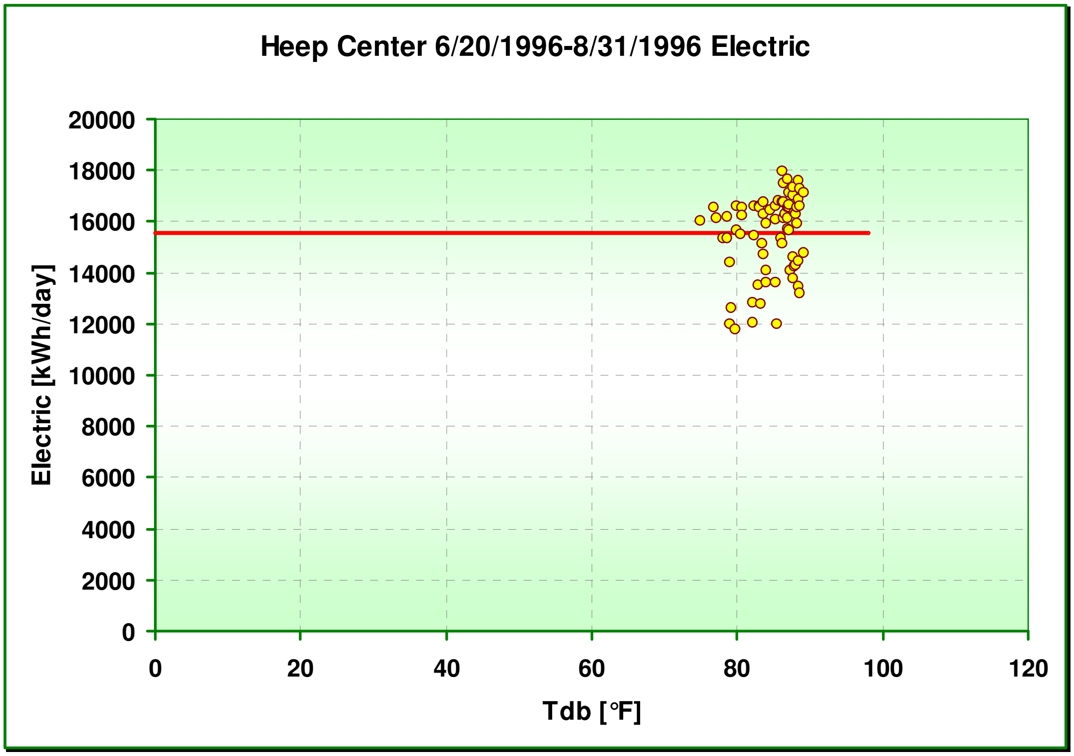

Figure A.29: Heep Center 6/20/96-8/31/96 pre-commissioning period electricity mean regression model.

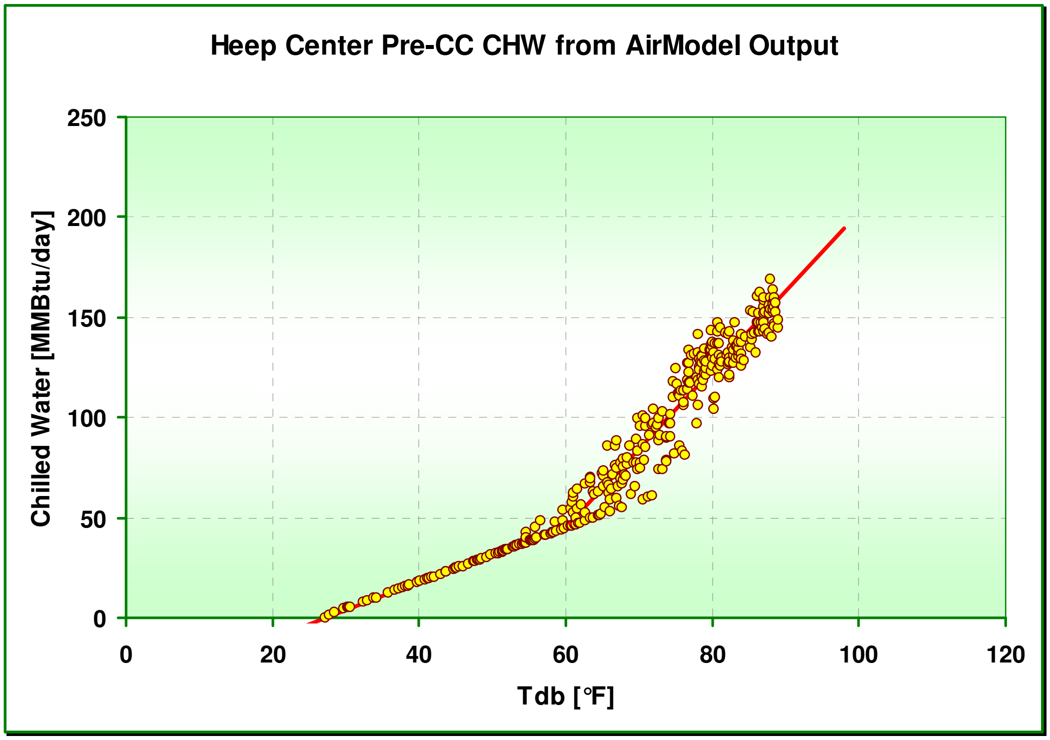

Figure A.30: Heep Center pre-commissioning period chilled water 4P CP regression model formed from AirModel output.

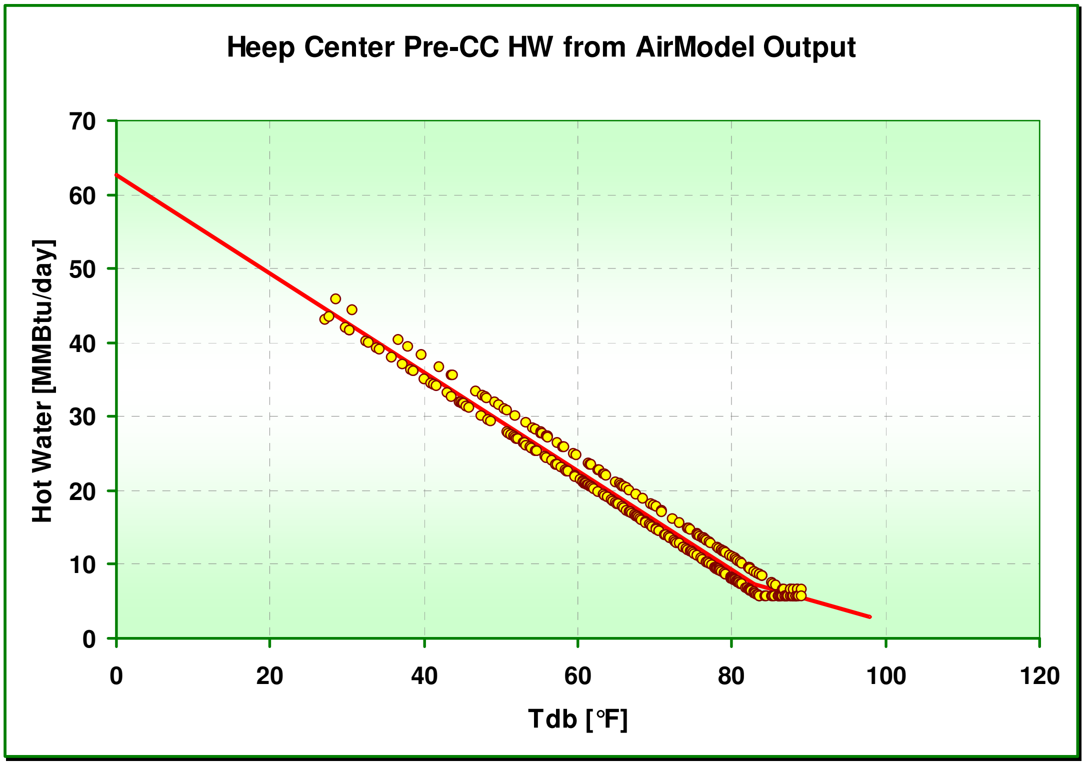

Figure A.31: Heep Center pre-commissioning period hot water 4P CP regression model formed from AirModel output.

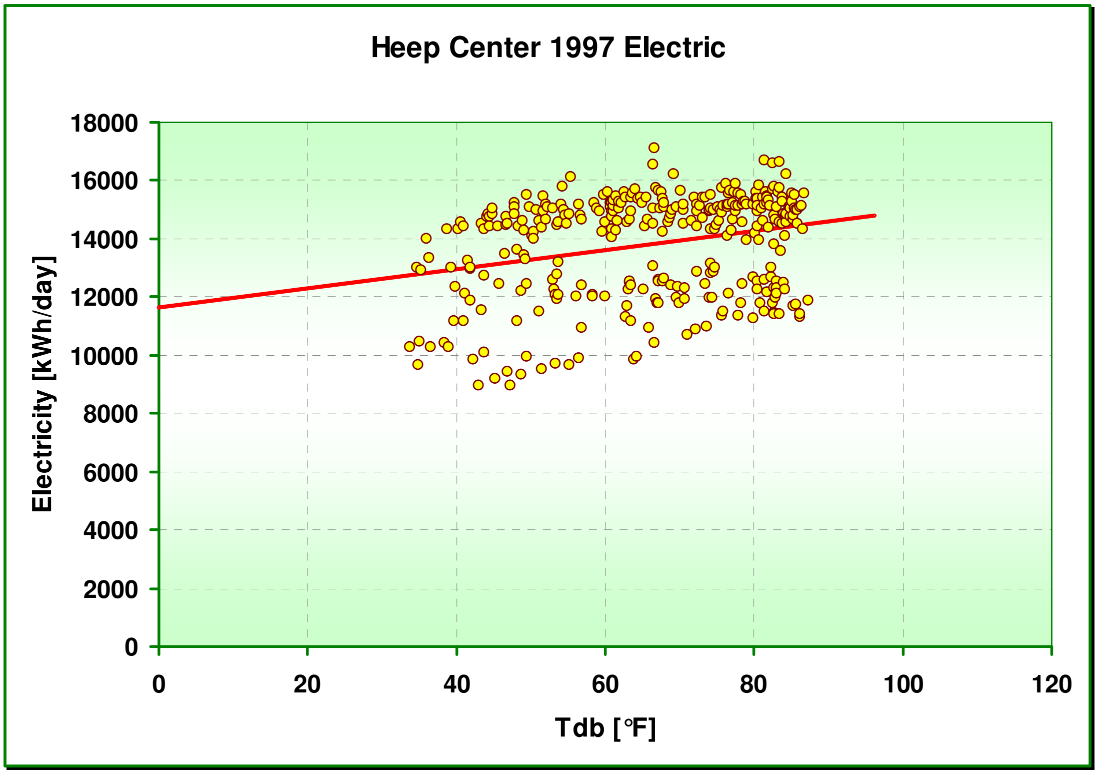

Figure A.32: Heep Center 1997 period electricity straight line regression model.

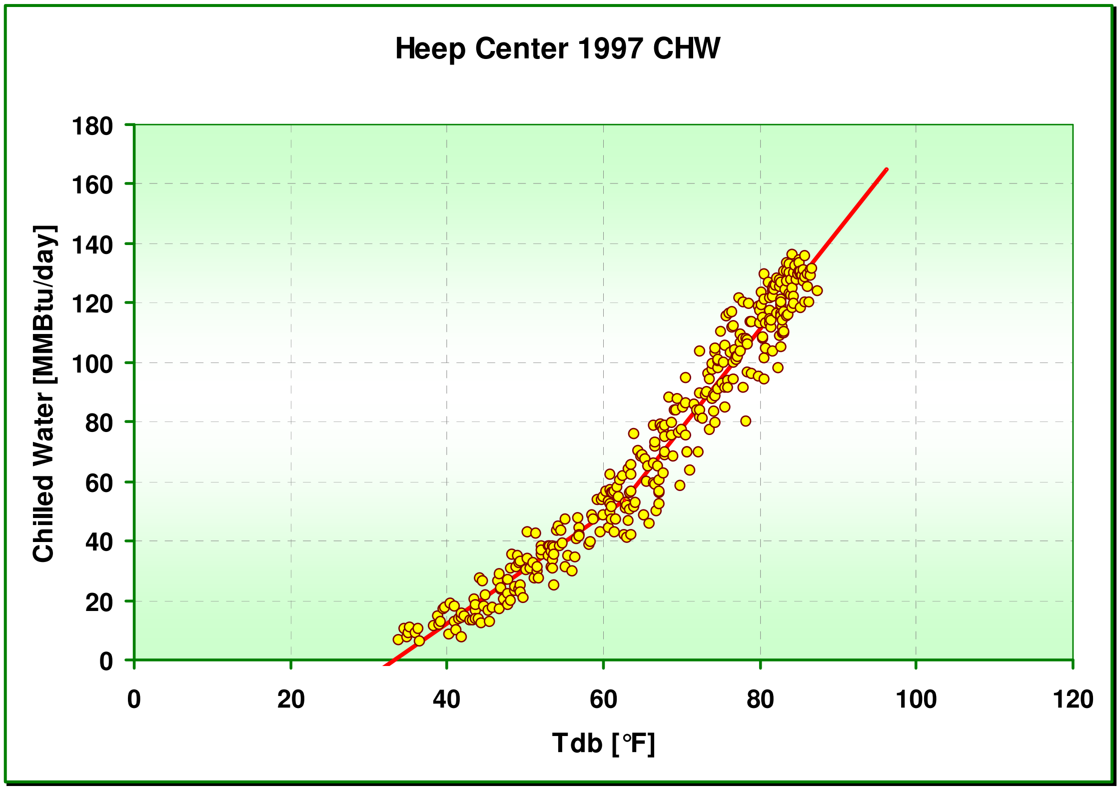

Figure A.33: Heep Center 1997 period chilled water 4P CP regression model.

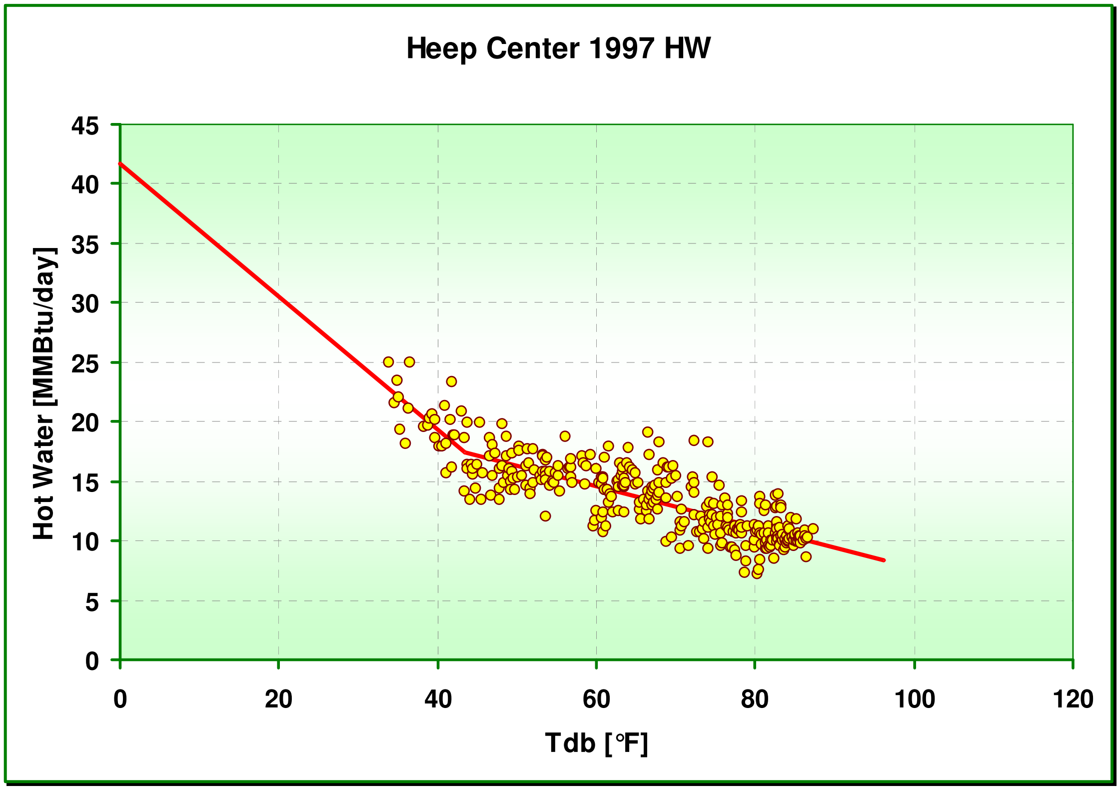

Figure A.34: Heep Center 1997 period hot water 4P CP regression model.

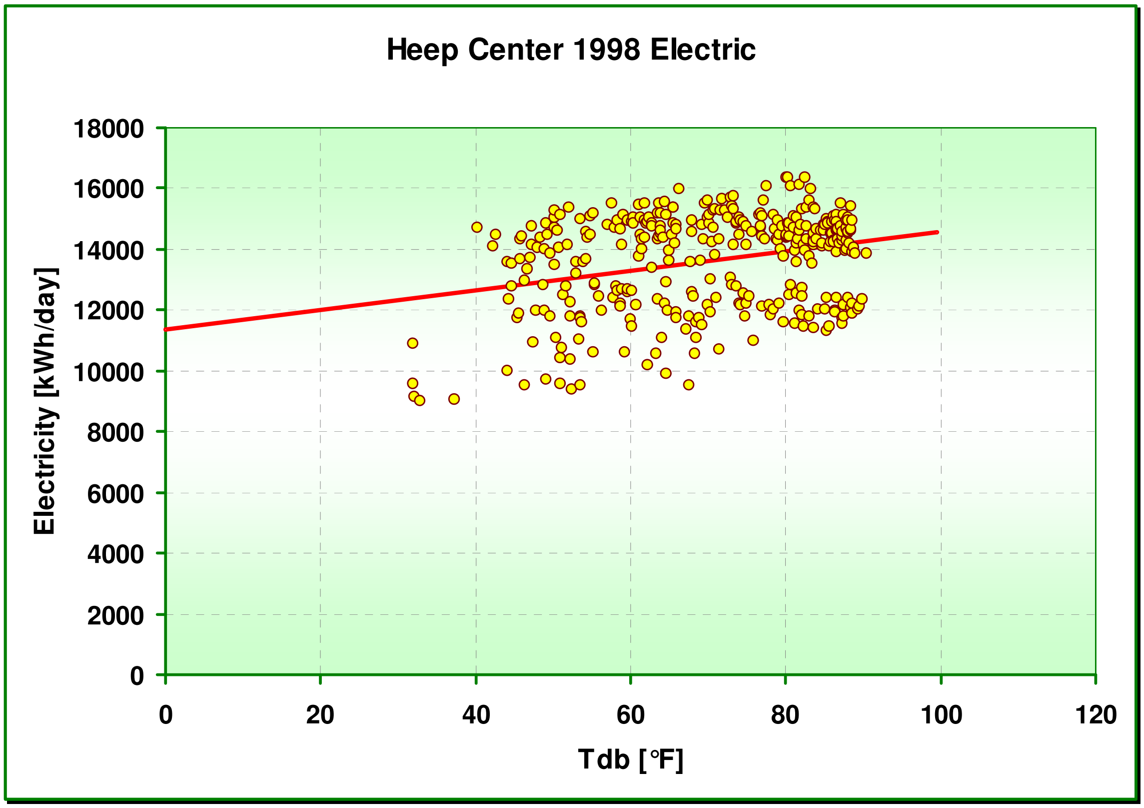

Figure A.35: Heep Center 1998 period electricity straight line regression model.

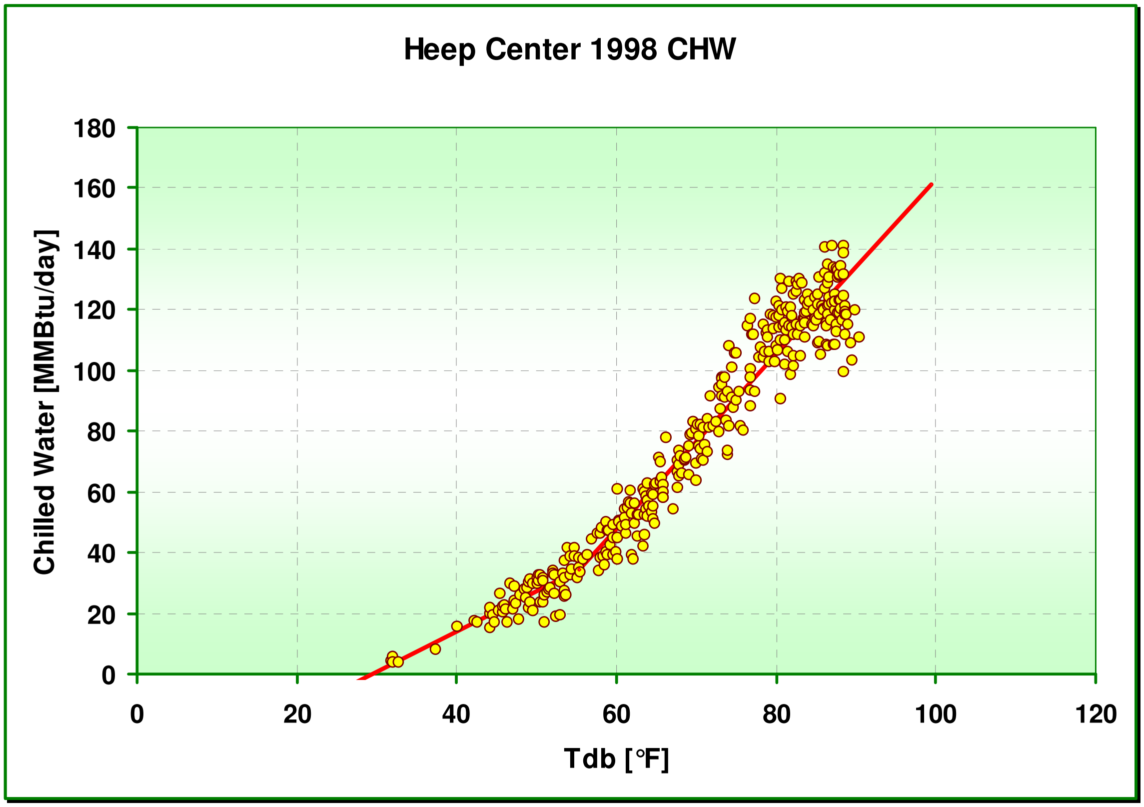

Figure A.36: Heep Center 1998 period chilled water 4P CP regression model.

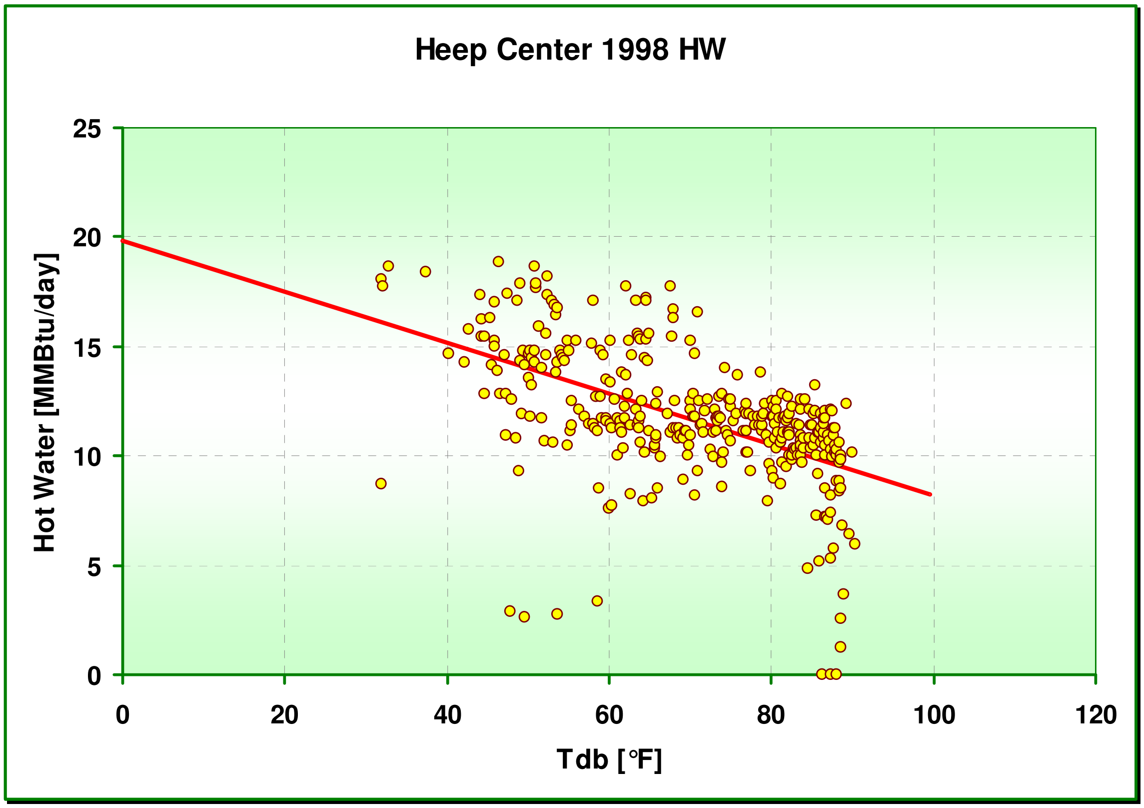

Figure A.37: Heep Center 1998 period hot water straight line regression model.

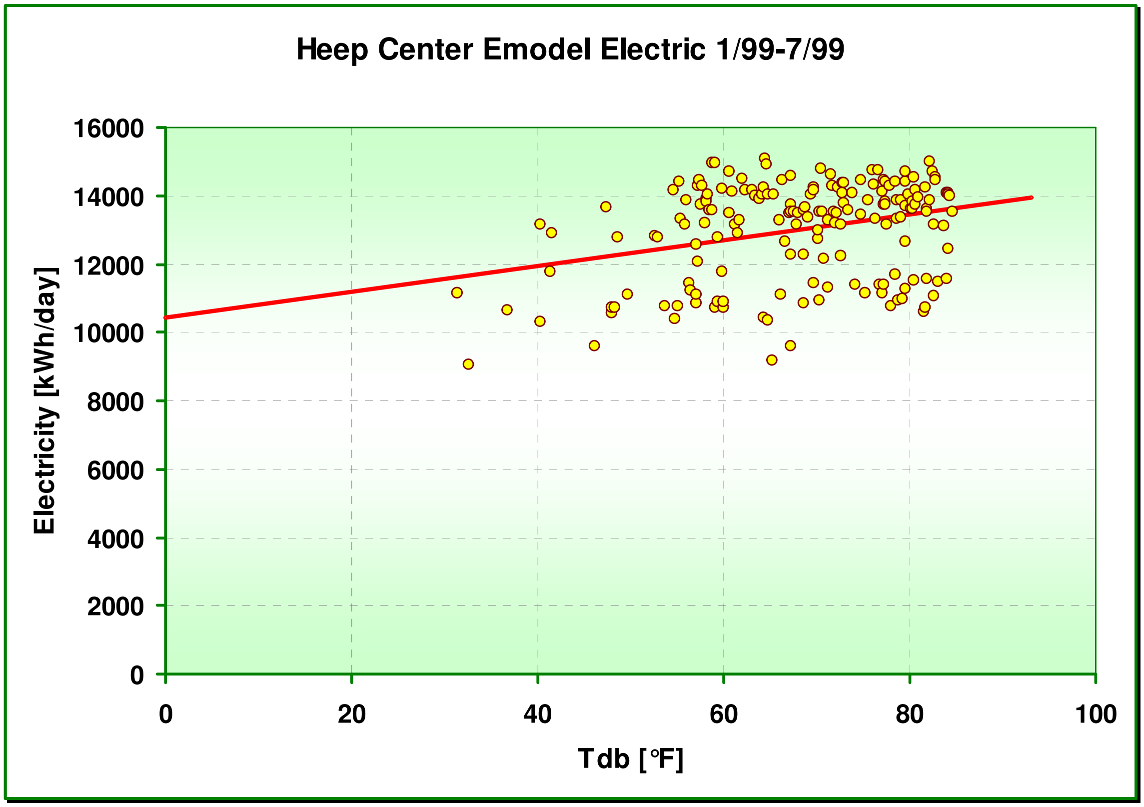

Figure A.38: Heep Center 1/99-7/99 period electricity straight line regression model.

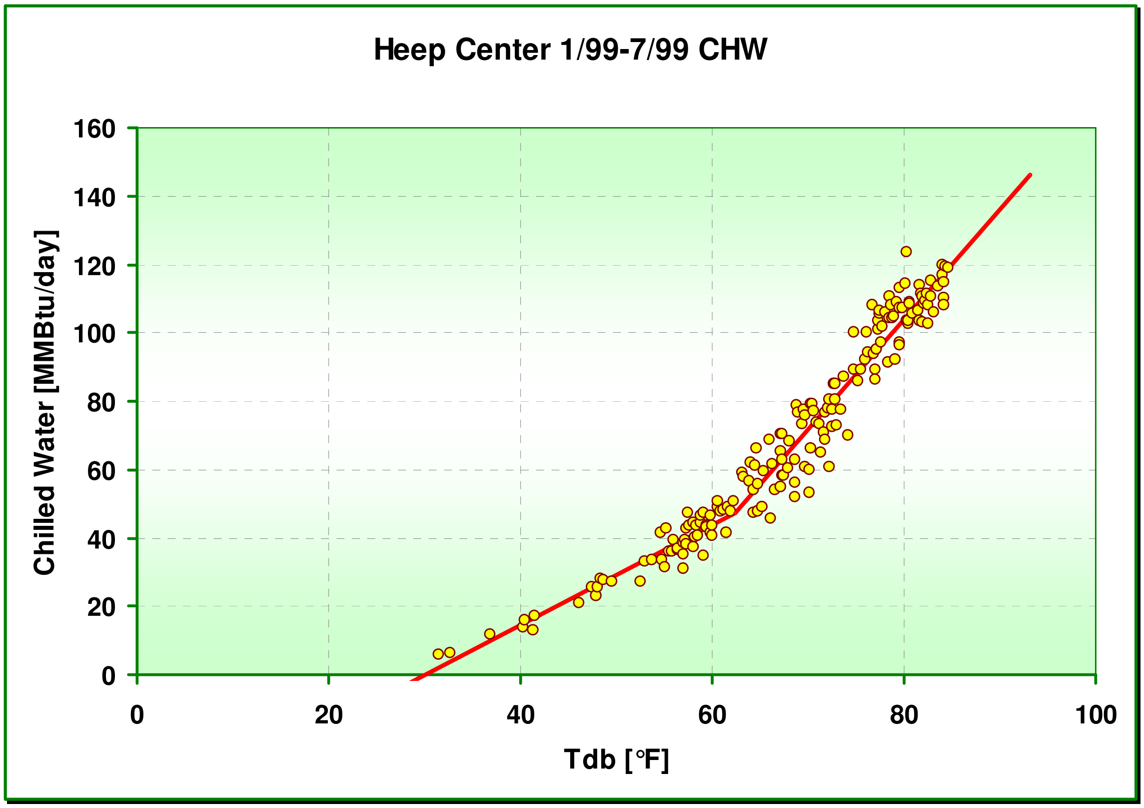

Figure A.39: Heep Center 1/99-7/99 period chilled water 4P CP regression model.

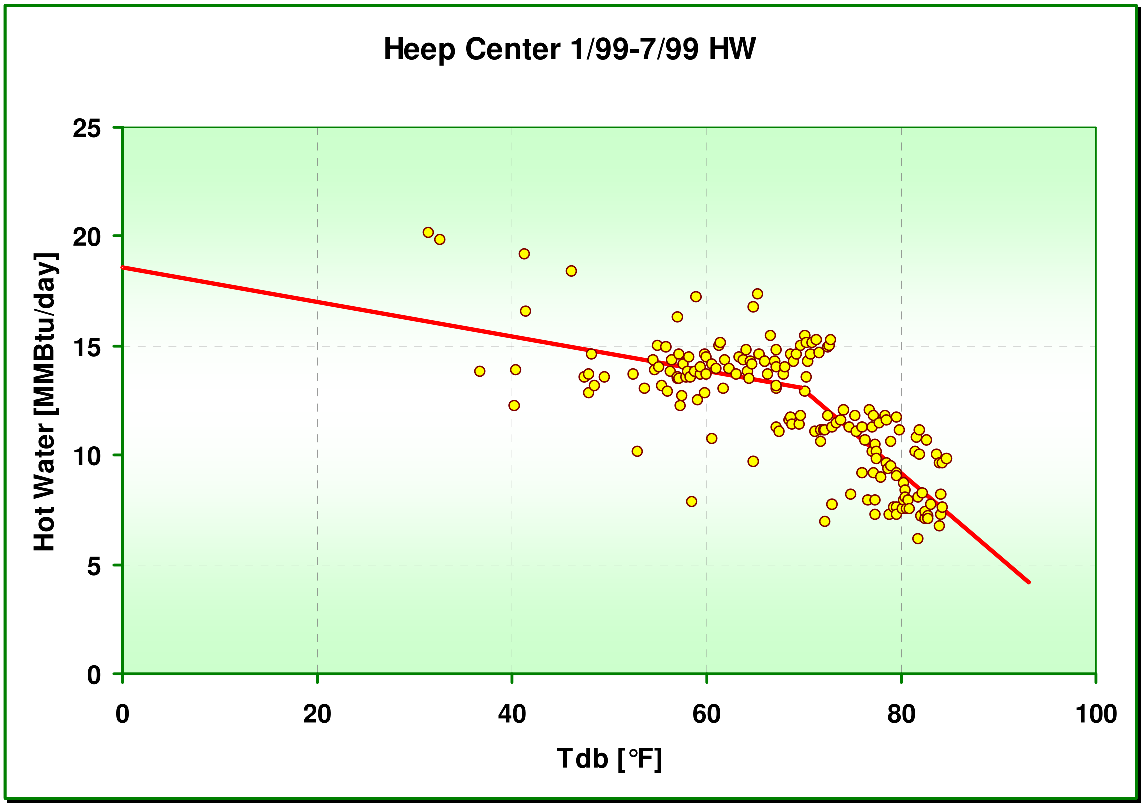

Figure A.40: Heep Center 1/99-7/99 period hot water 4P CP regression model.

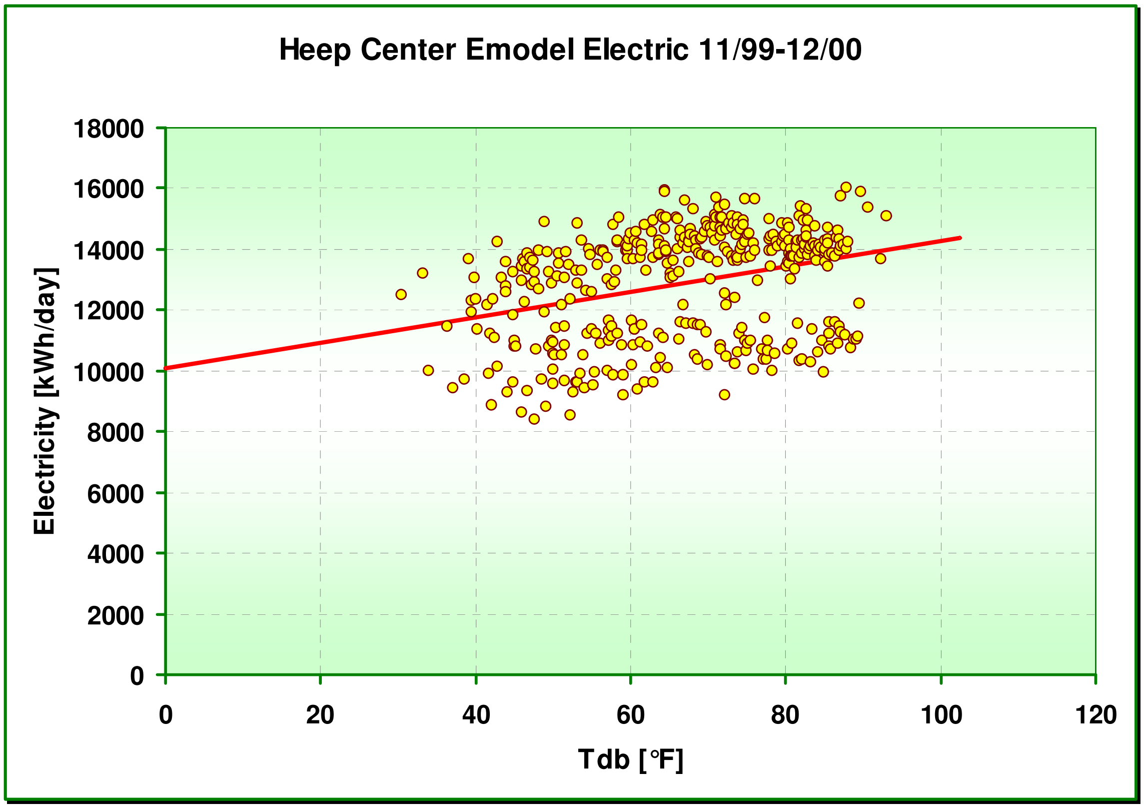

Figure A.41: Heep Center 11/99-12/00 period electricity straight line regression model.

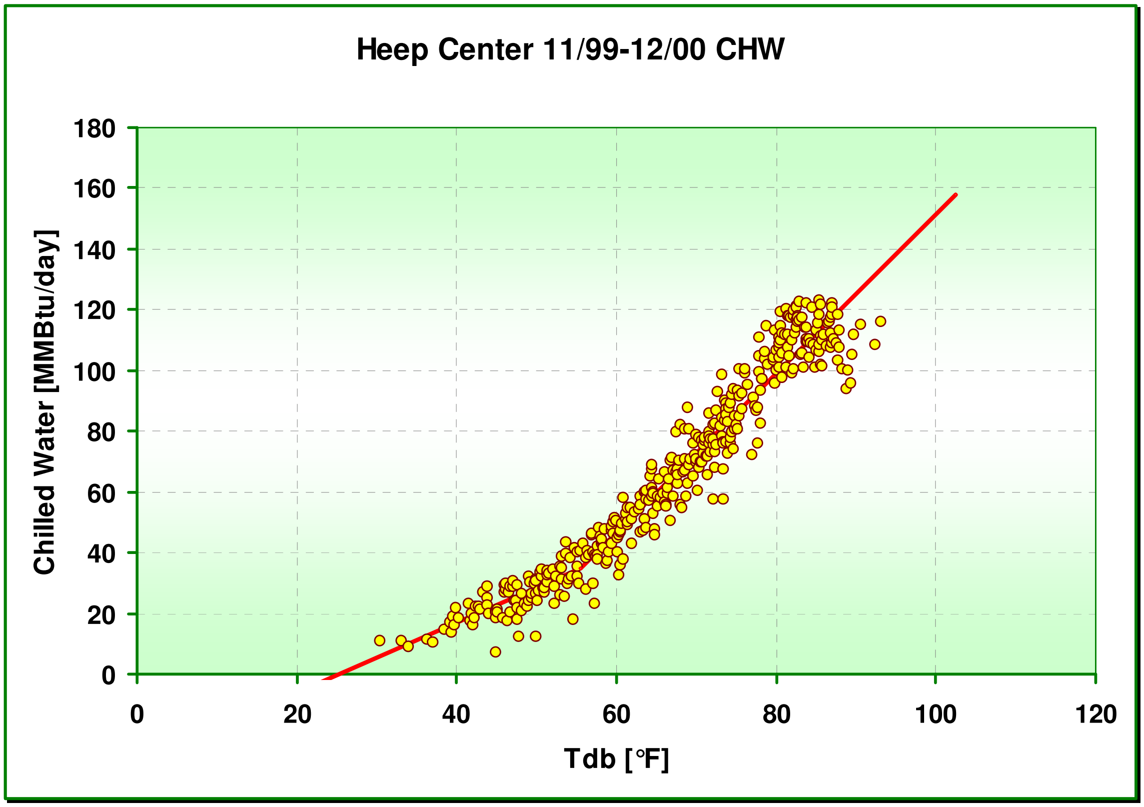

Figure A.42: Heep Center 11/99-12/00 period chilled water 4P CP regression model.

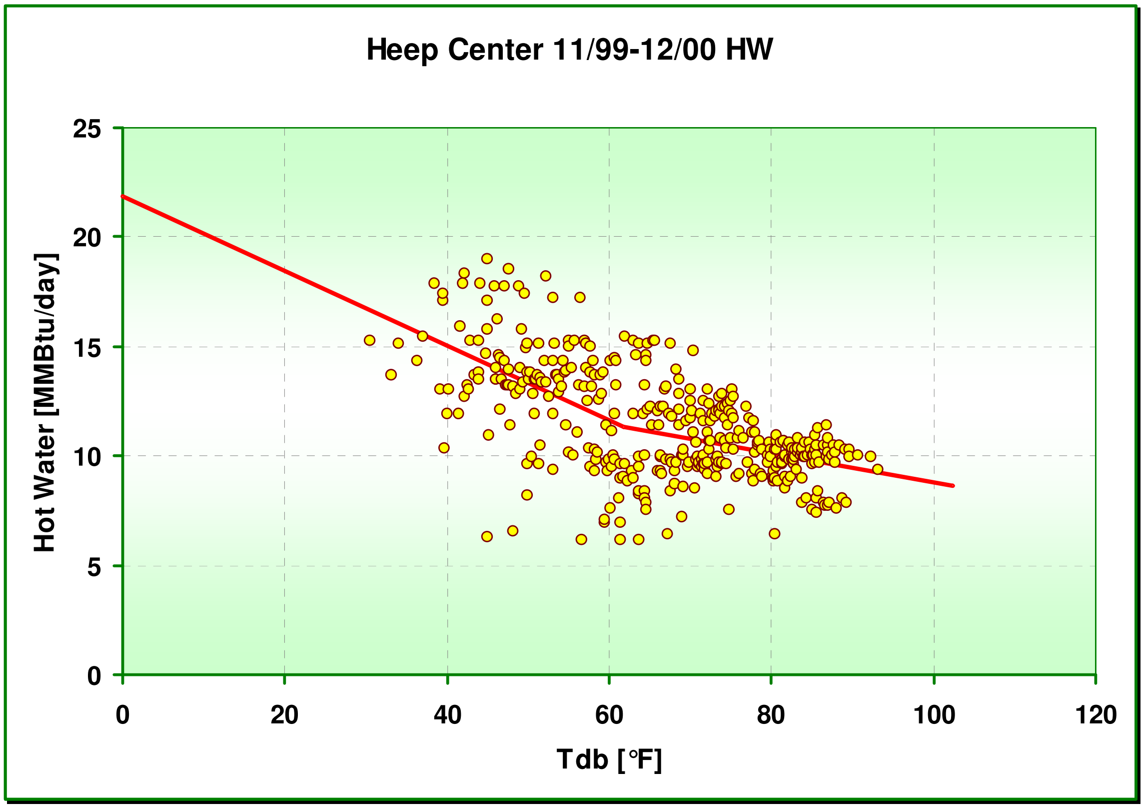

Figure A.43: Heep Center 11/99-12/00 period hot water 4P CP regression model.

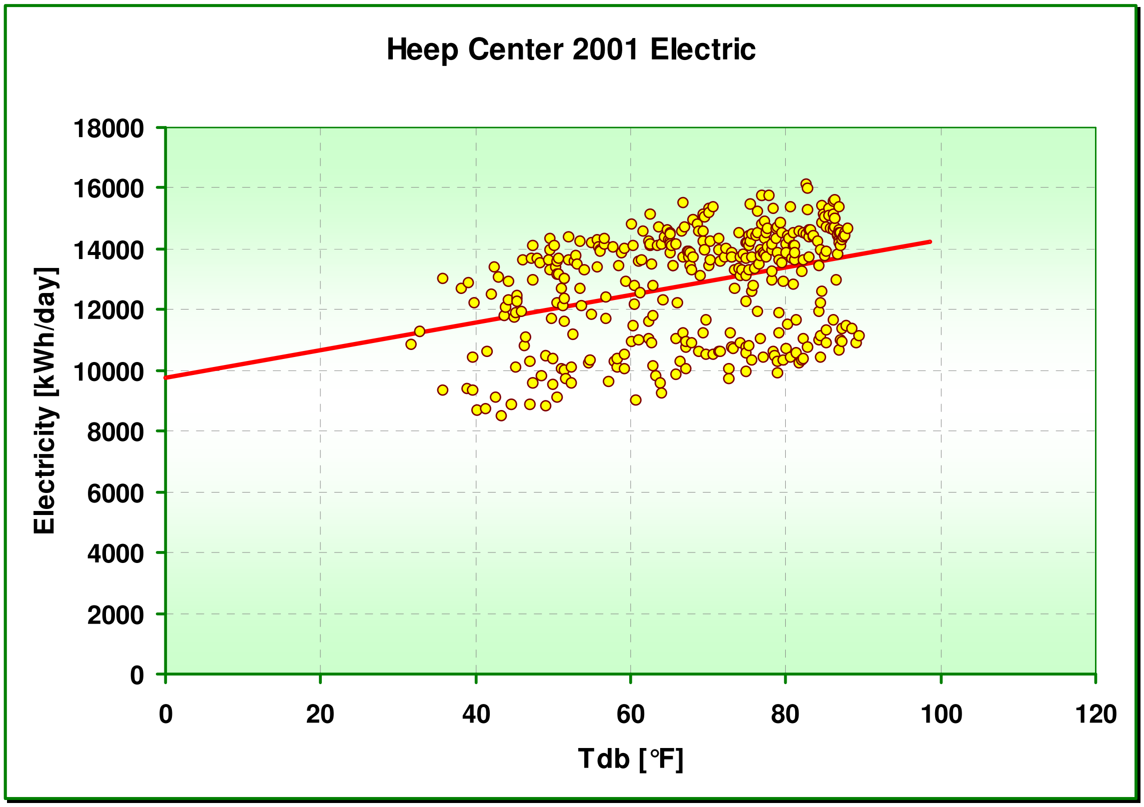

Figure A.44: Heep Center 2001 period electricity straight line regression model.

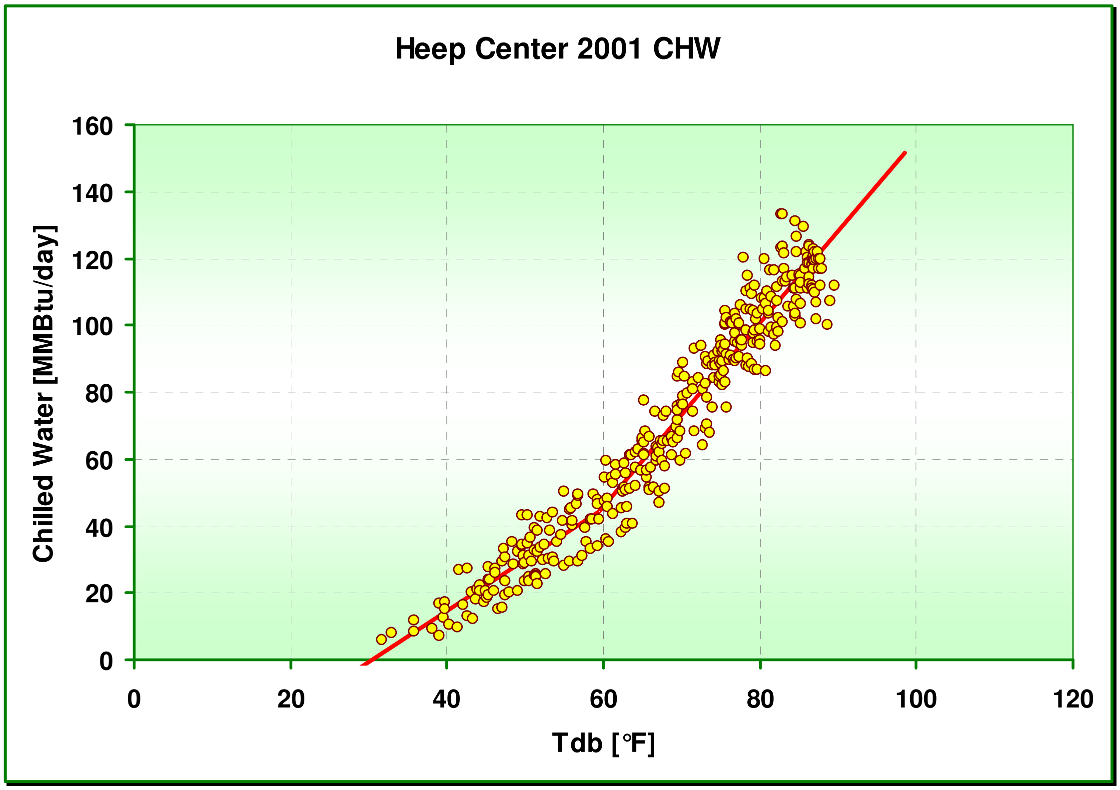

Figure A.45: Heep Center 2001 period chilled water 4P CP regression model.

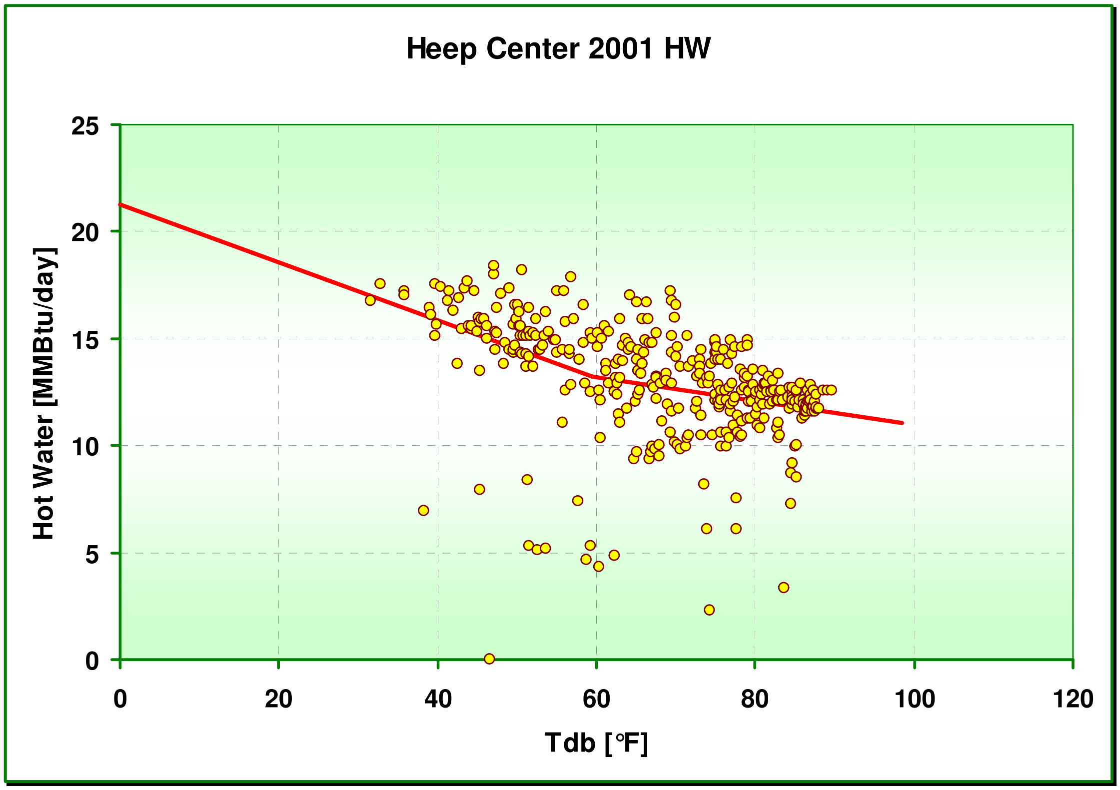

Figure A.46: Heep Center 2001 period hot water 4P CP regression model.

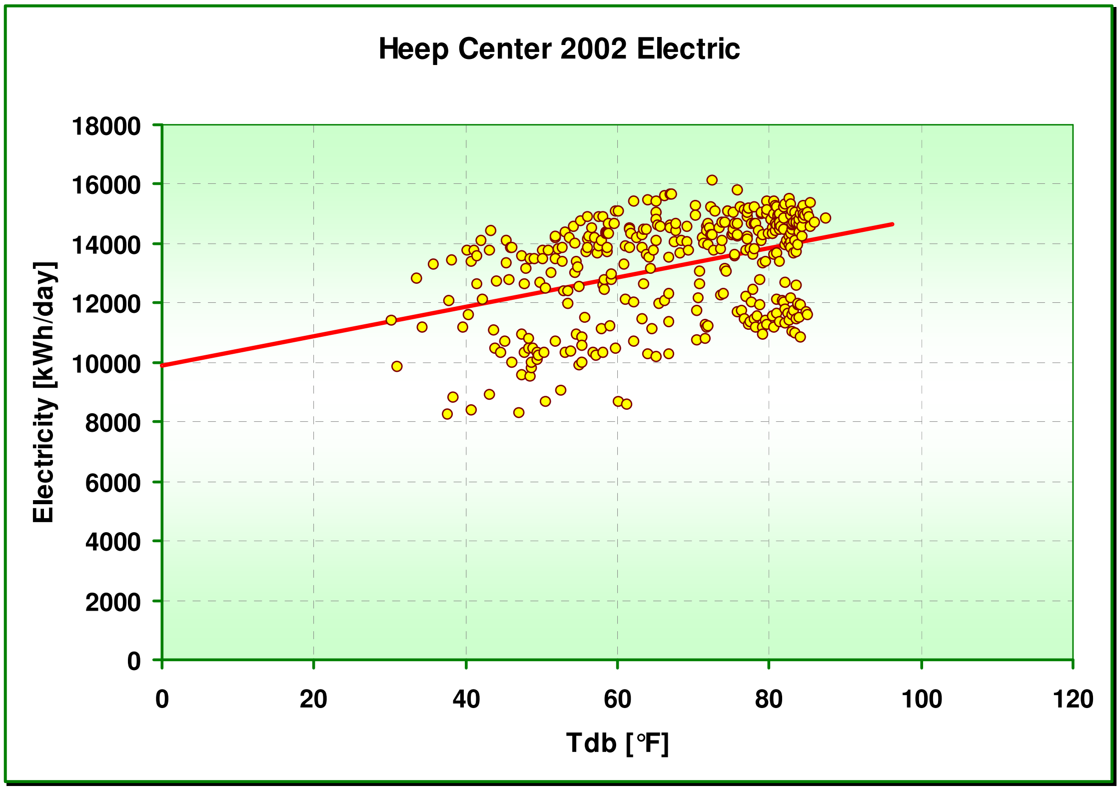

Figure A.47: Heep Center 2002 period electricity straight line regression model.

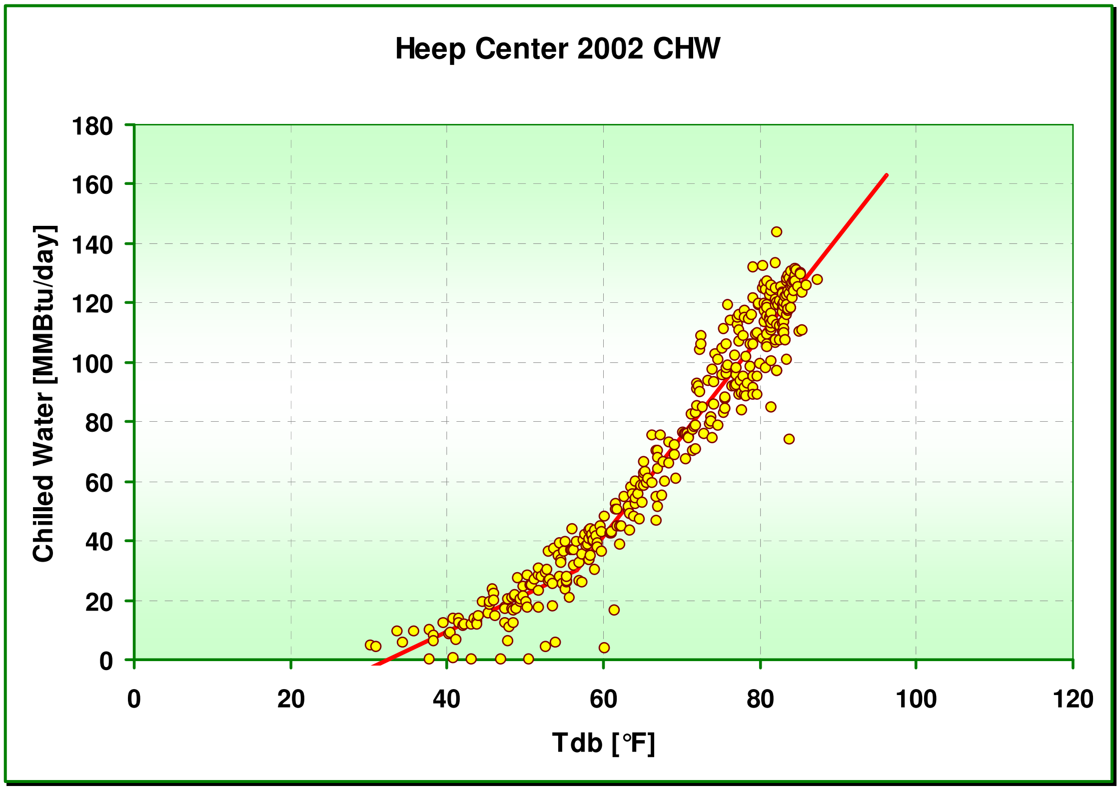

Figure A.48: Heep Center 2002 period chilled water 4P CP regression model.

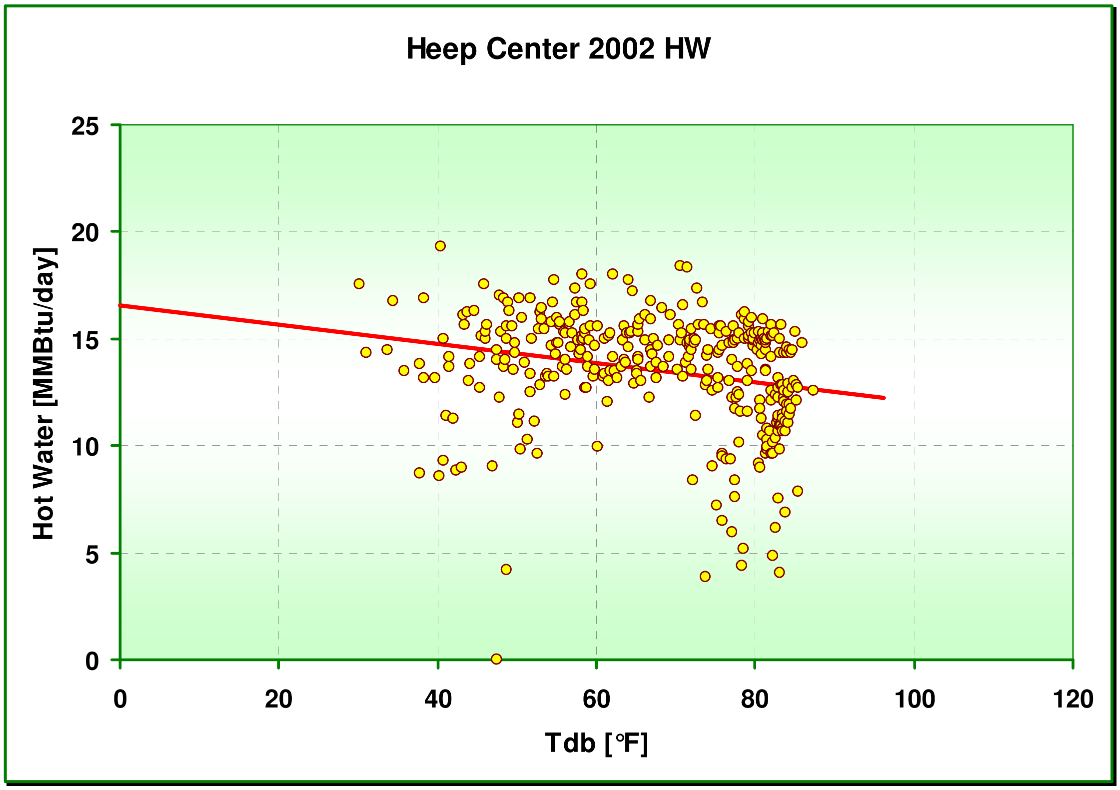

Figure A.49: Heep Center 2002 period hot water straight line regression model.

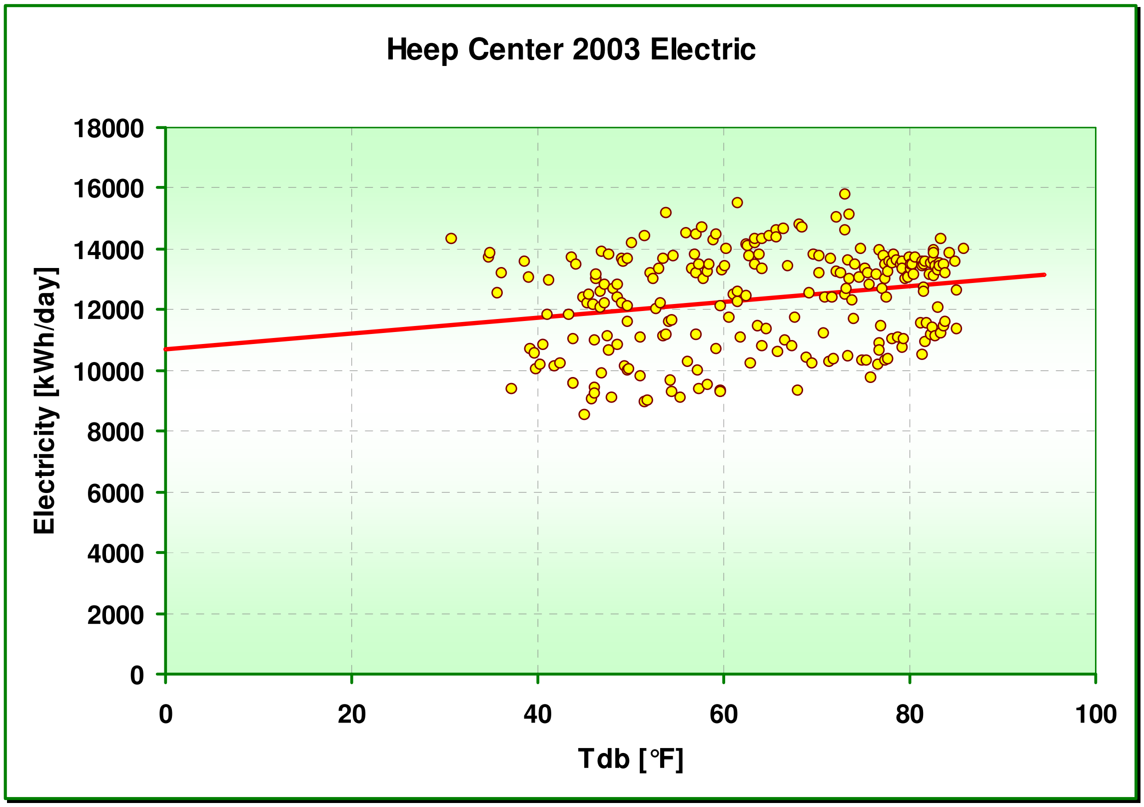

Figure A.50: Heep Center 2003 period electricity straight line regression model.

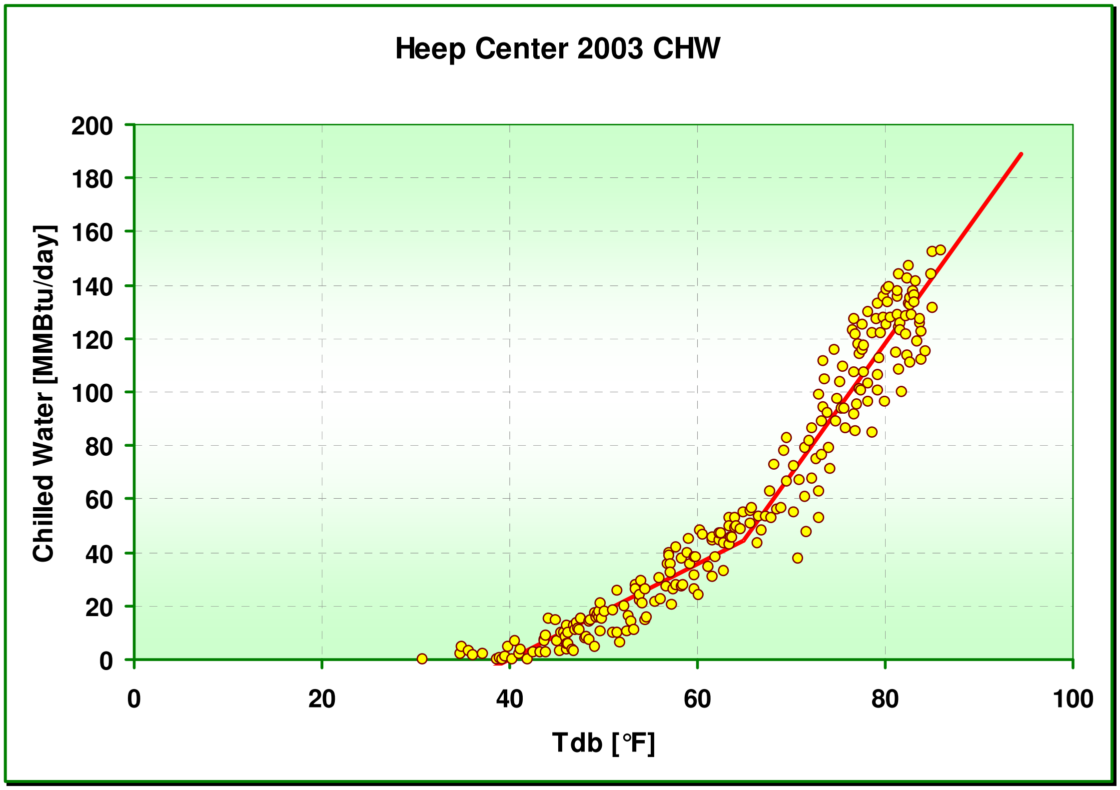

Figure A.51: Heep Center 2003 period chilled water 4P CP regression model.

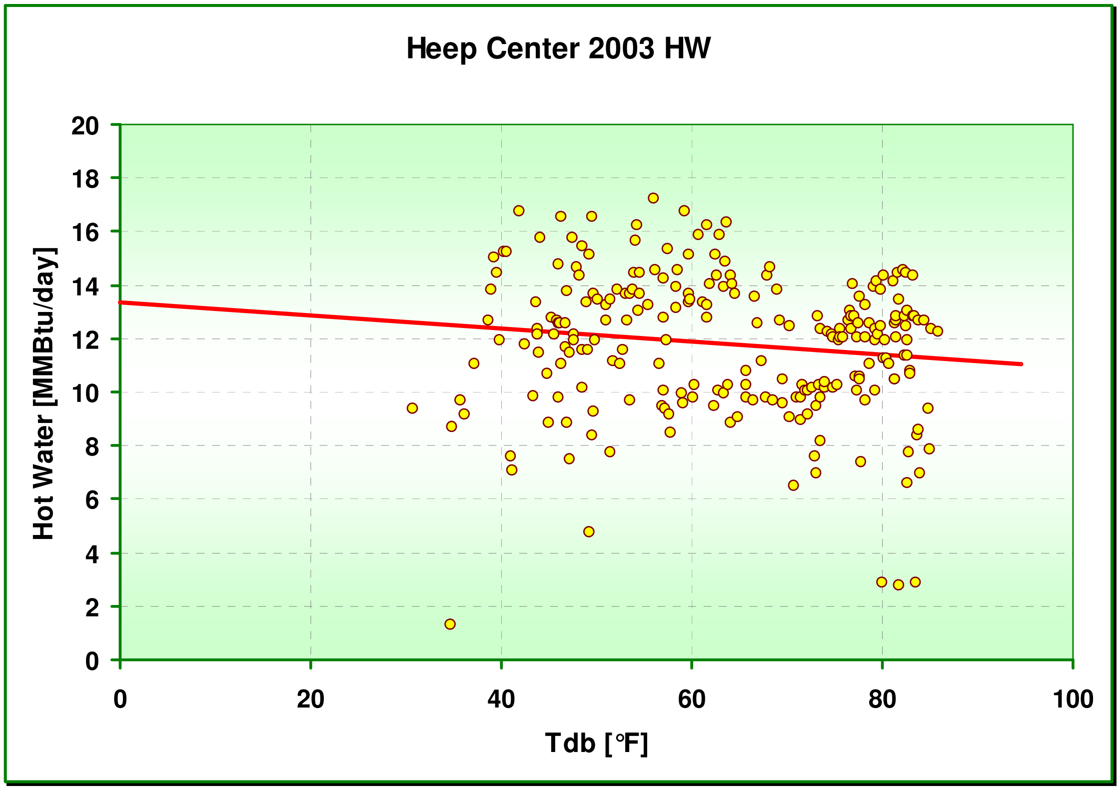

Figure A.52: Heep Center 2003 period hot water straight line regression model.

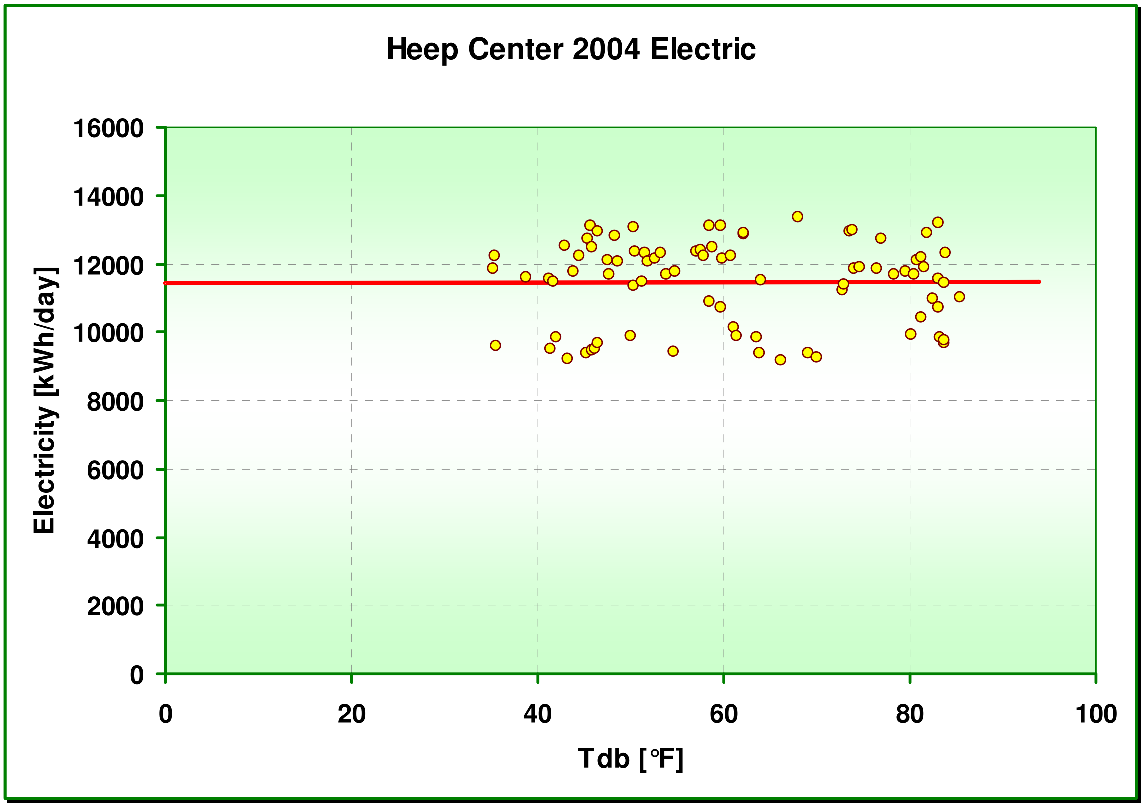

Figure A.53: Heep Center 2004 period electricity straight line regression model.

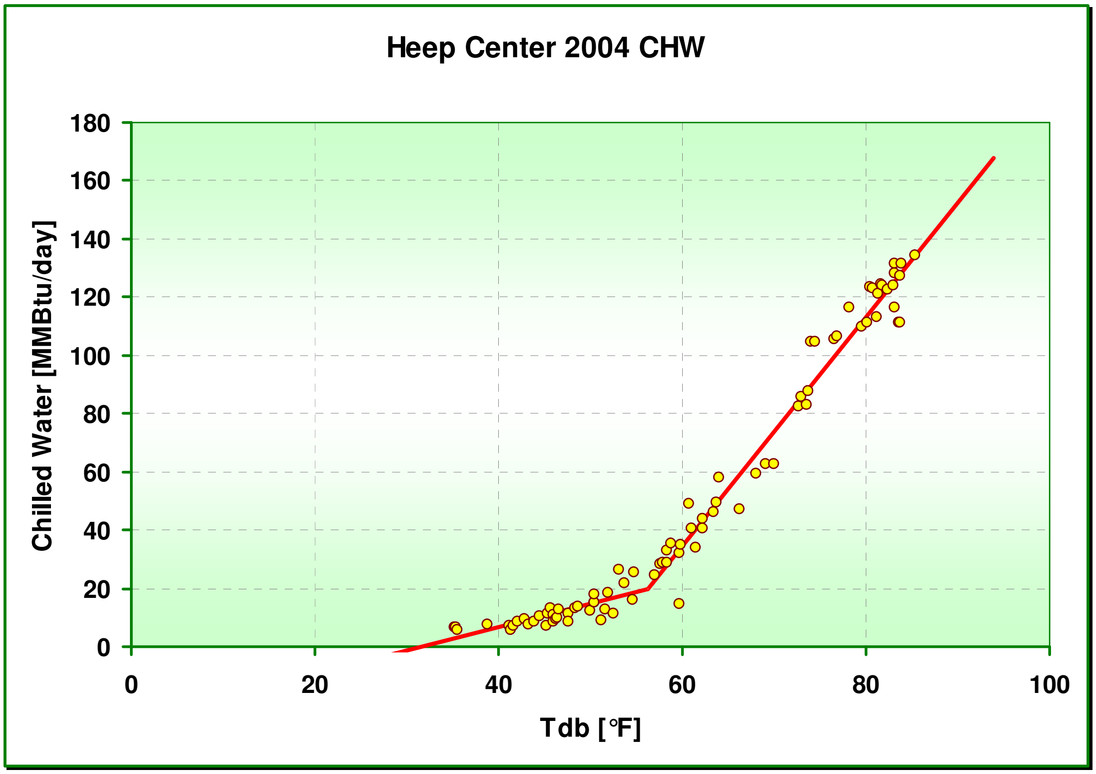

Figure A.54: Heep Center 2004 period chilled water 4P CP regression model.

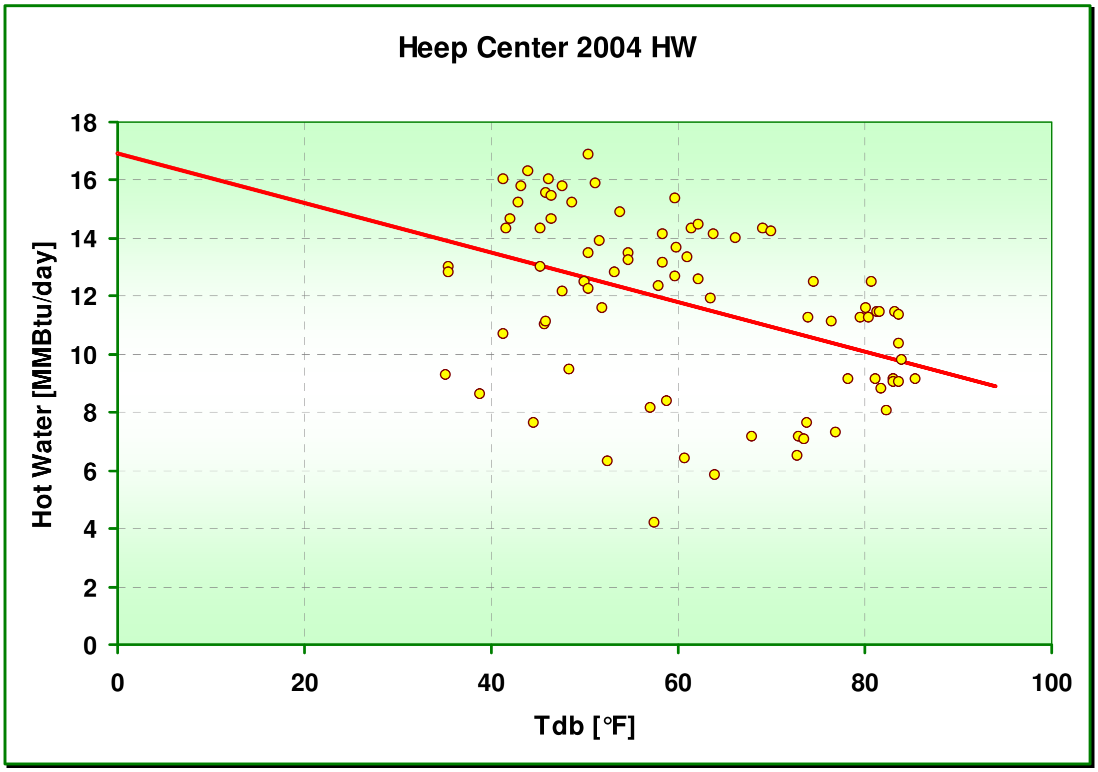

Figure A.55: Heep Center 2004 period hot water straight line regression model.

Heep Center Calibrated Simulations

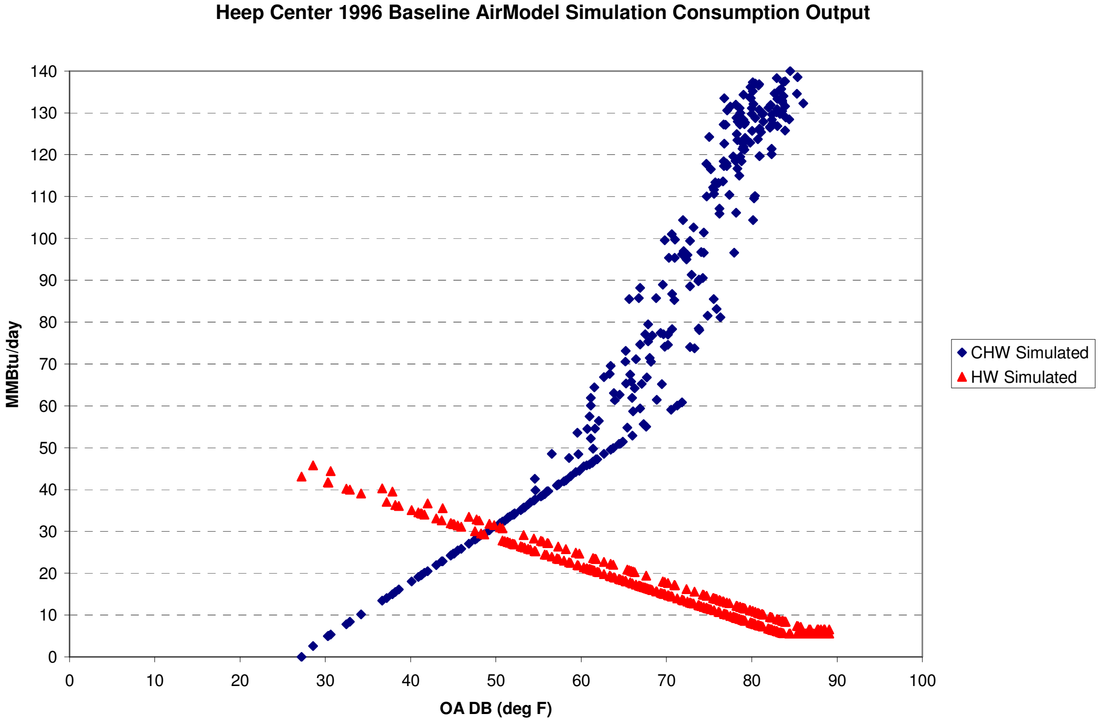

Figure A.56: Heep Center 1996 baseline simulated consumption.

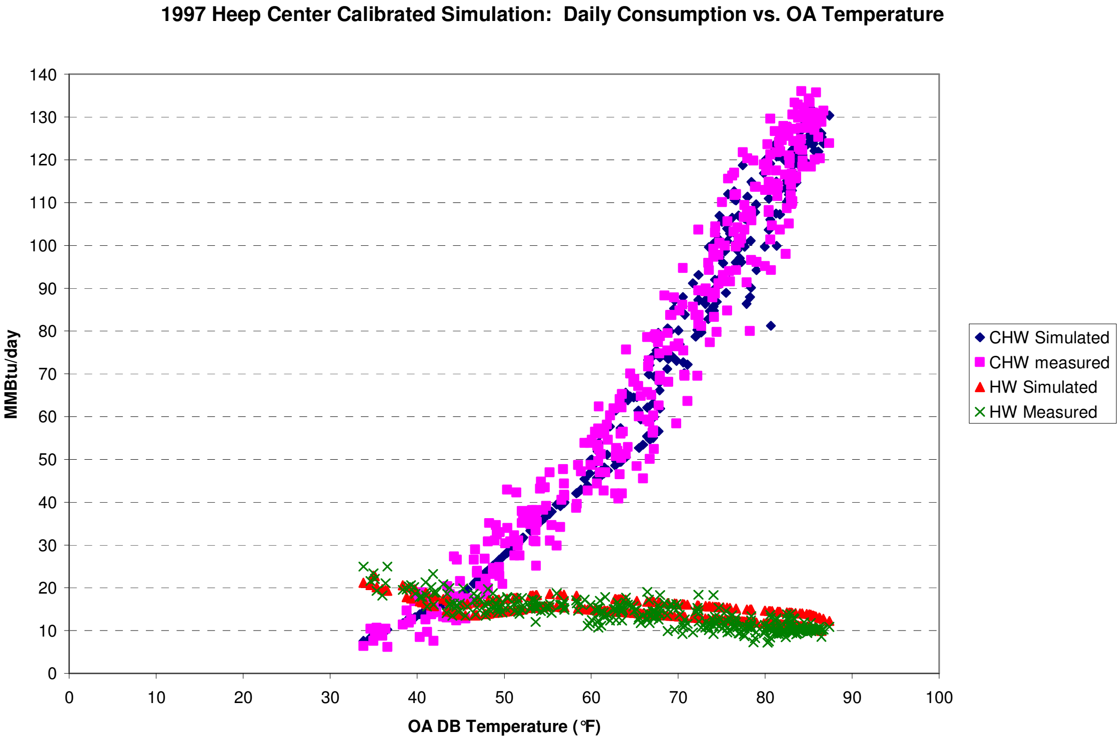

Figure A.57: Comparison of Heep Center 1997 calibrated simulation and consumption data.

MSC Regression Models

Table A.7: MSC chilled water regression model parameters (MMBtu/day).

Year/Period	1/97-8/97	12/97-12/98	1999	2000
Model Type	4P CP	4P CP	4P CP	3P Cooling
Y_cp	176.4476	113.7068	98.7949	72.0824
change point	76.6667	62.2917	53.8042	44.2450
left slope	1.8852	2.1648	0.6402	0.0000
right slope	3.0725	3.8925	2.5156	2.2199

Table A.8: MSC hot water regression model parameters (MMBtu/day).

Year/Period	1/97-8/97	12/97-12/98	1999	2000
Model Type	4P CP	4P CP	SLR	4P CP
Y_cp	76.4110	62.9028	140.3772	25.6301
change point	65.9583	46.6667	0.0000	83.0983
left slope	-1.1103	-1.3658	-1.2546	-1.1329
right slope	-1.7729	-0.2281	-1.2546	-0.5823

Table A.9: MSC electricity regression model parameters (kWh/day).

Year/Period	1/97-8/97	12/97-12/98	1999	2000
Model Type	SLR	SLR	SLR	SLR
Y_cp	21973.3814	18883.6480	10916.6806	17170.2156
change point	0	0	0	0
left slope	-16.1546	21.6036	85.3557	-15.2035
right slope	-16.1546	21.6036	85.3557	-15.2035

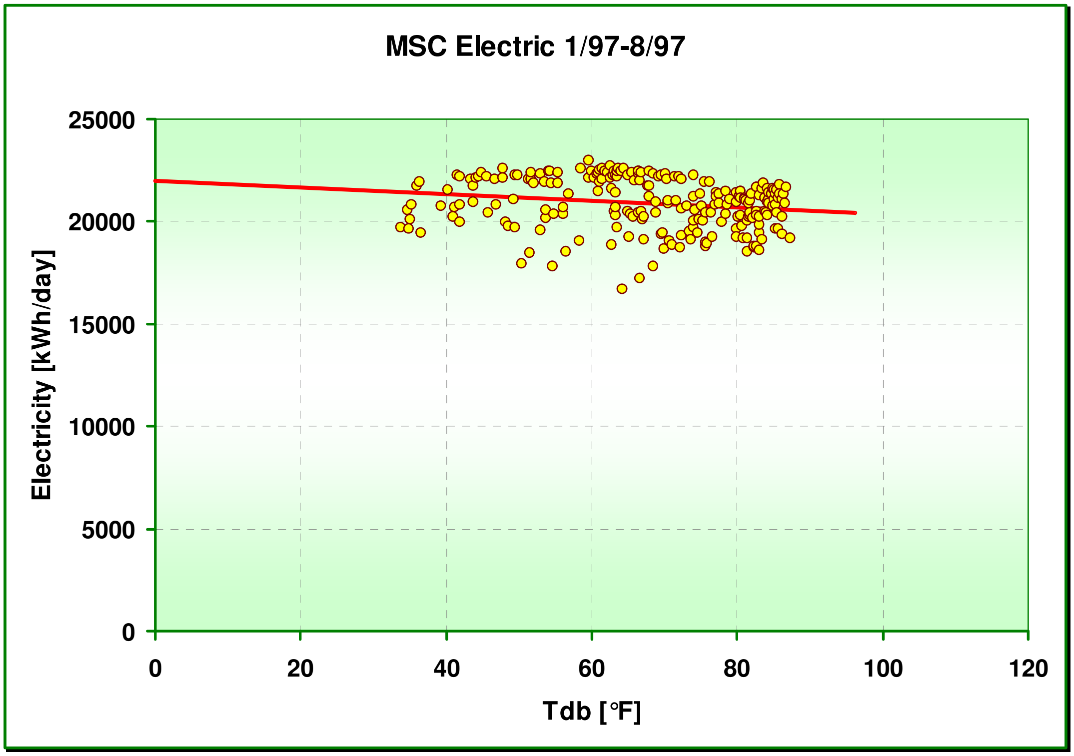

Figure A.58: MSC 1/97-8/97 pre-commissioning period electricity straight line regression model.

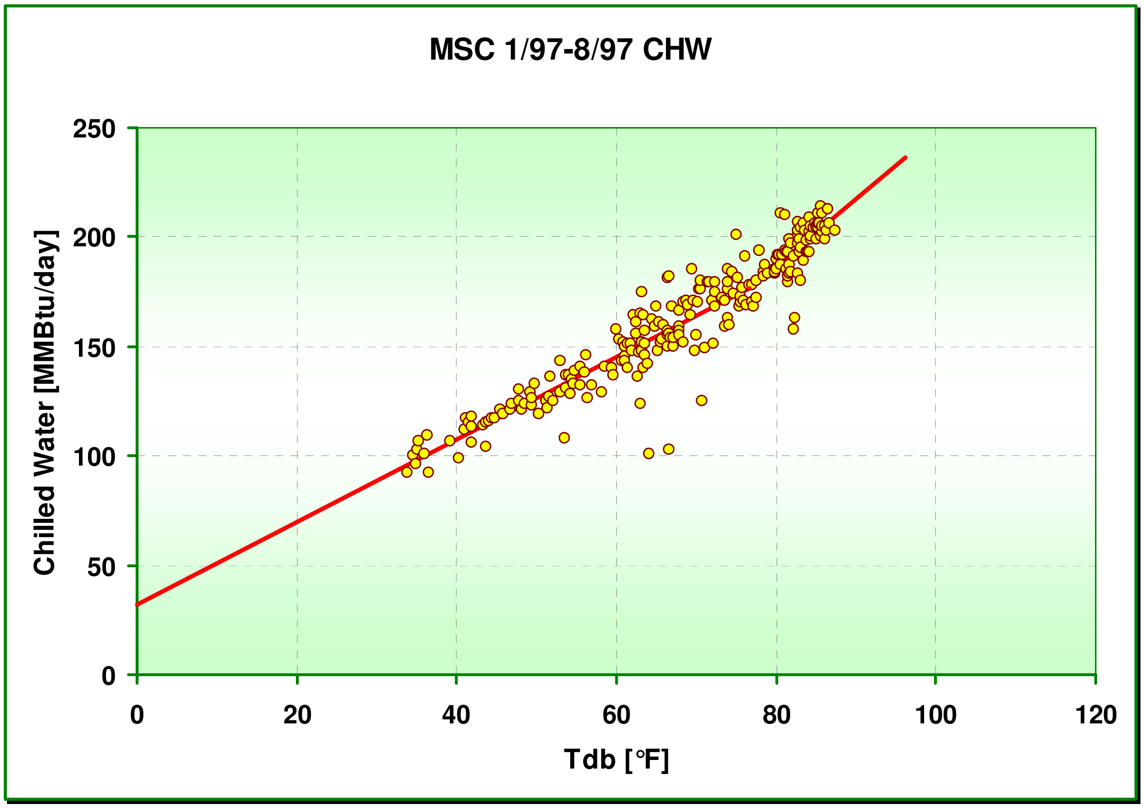

Figure A.59: MSC 1/97-8/97 pre-commissioning period chilled water 4P CP regression model.

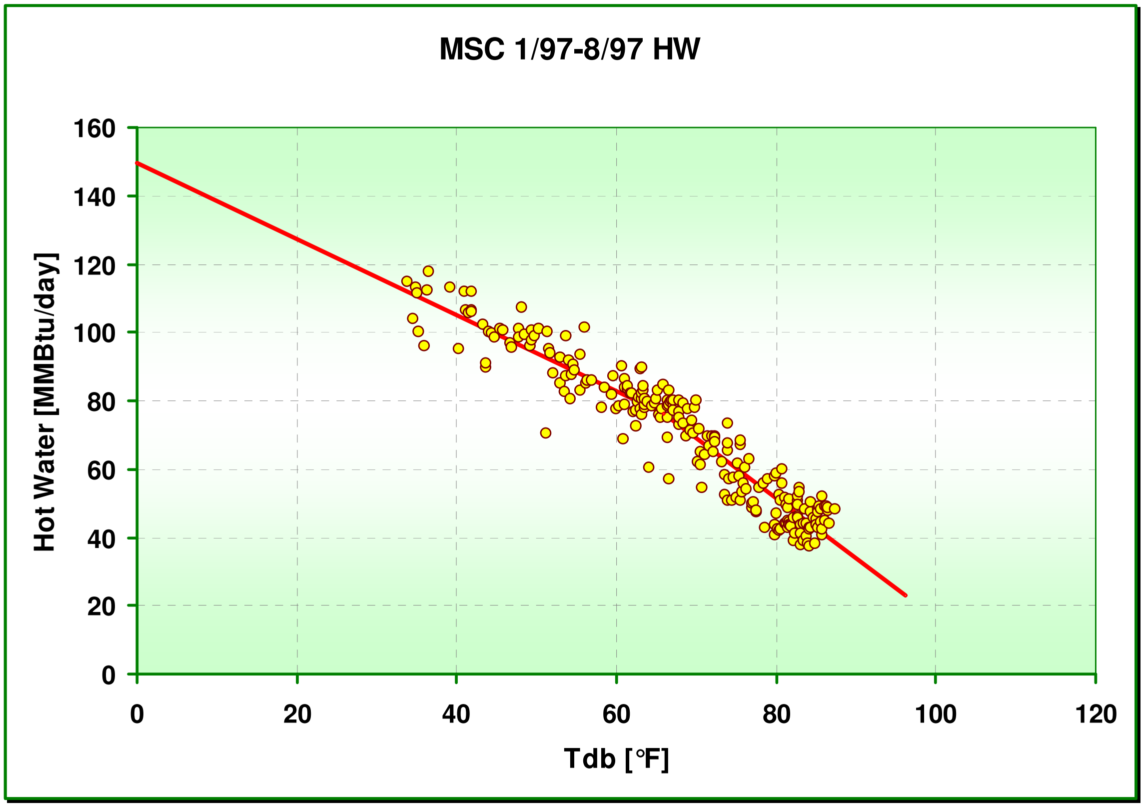

Figure A.60: MSC 1/97-8/97 pre-commissioning period hot water 4P CP regression model.

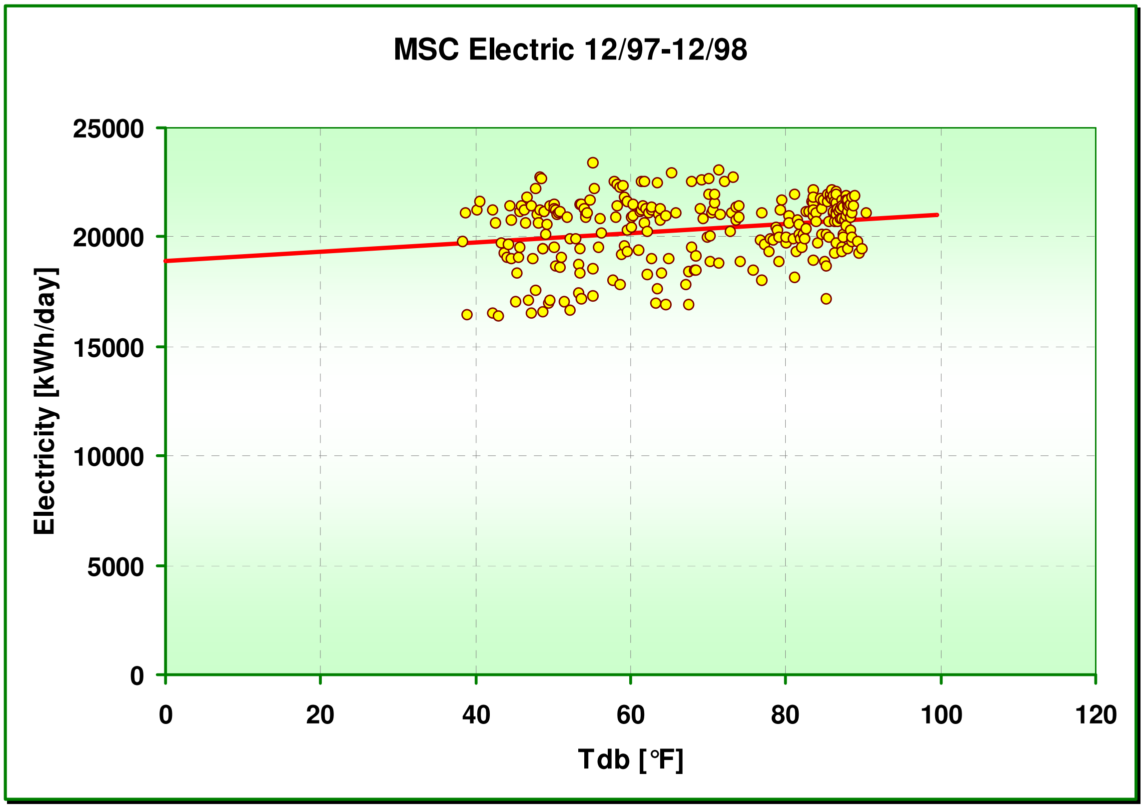

Figure A.61: MSC 12/97-12/98 period electricity straight line regression model.

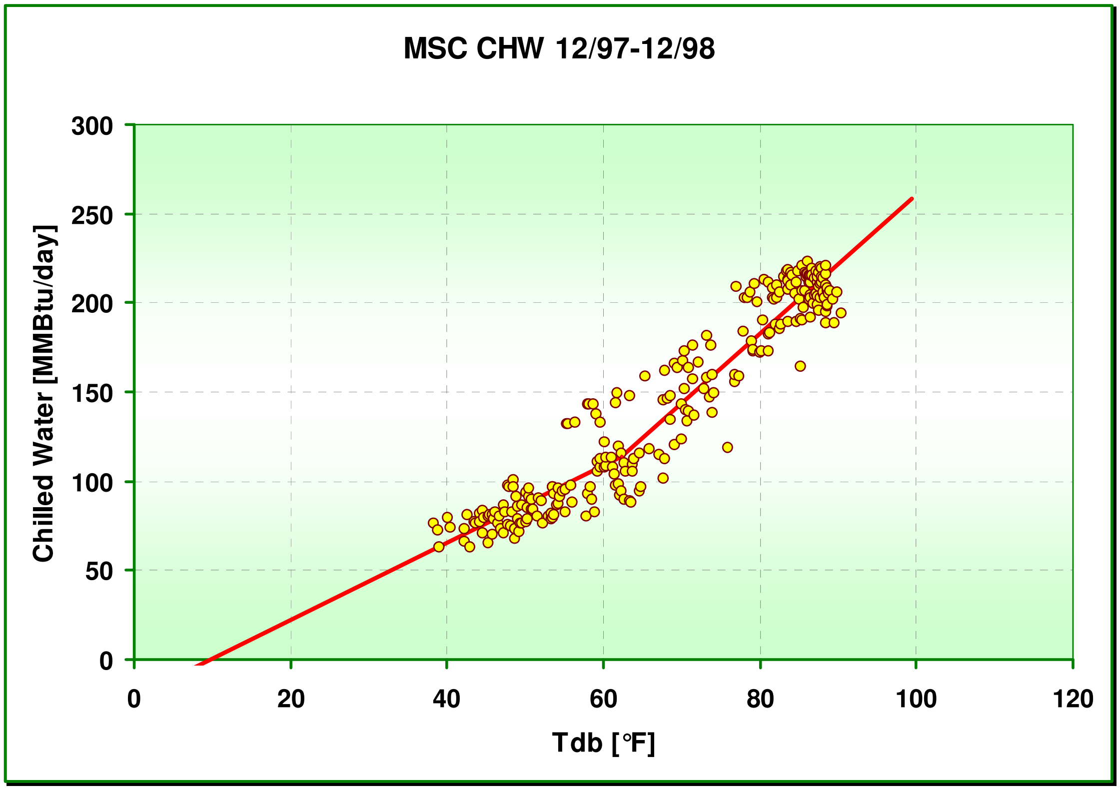

Figure A.62: MSC 12/97-12/98 period chilled water 4P CP regression model.

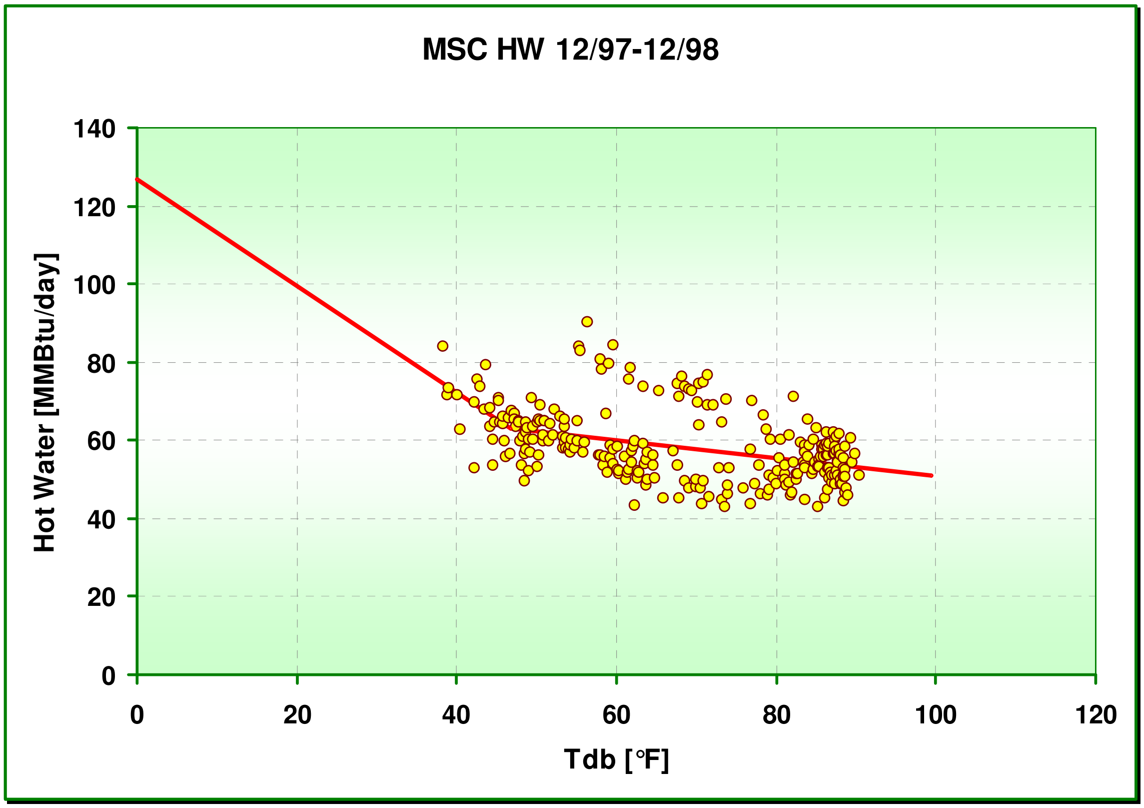

Figure A.63: MSC 12/97-12/98 period hot water 4P CP regression model.

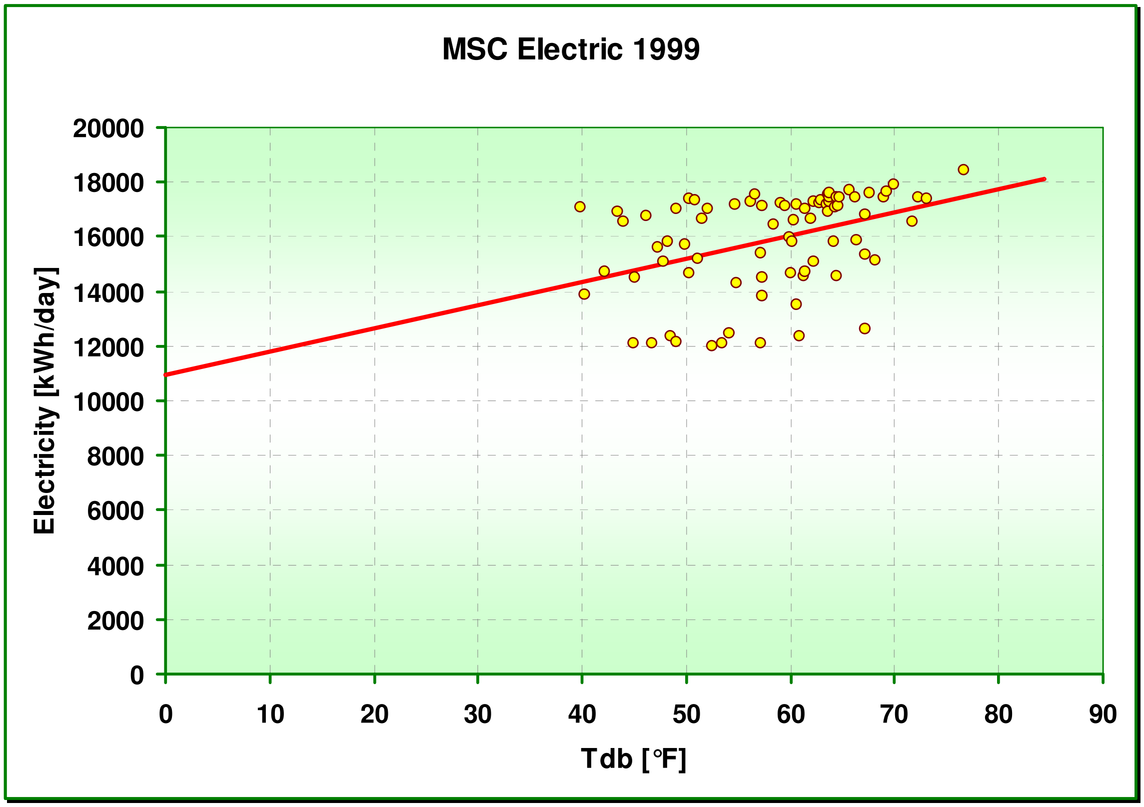

Figure A.64: MSC 1999 period electricity straight line regression model.

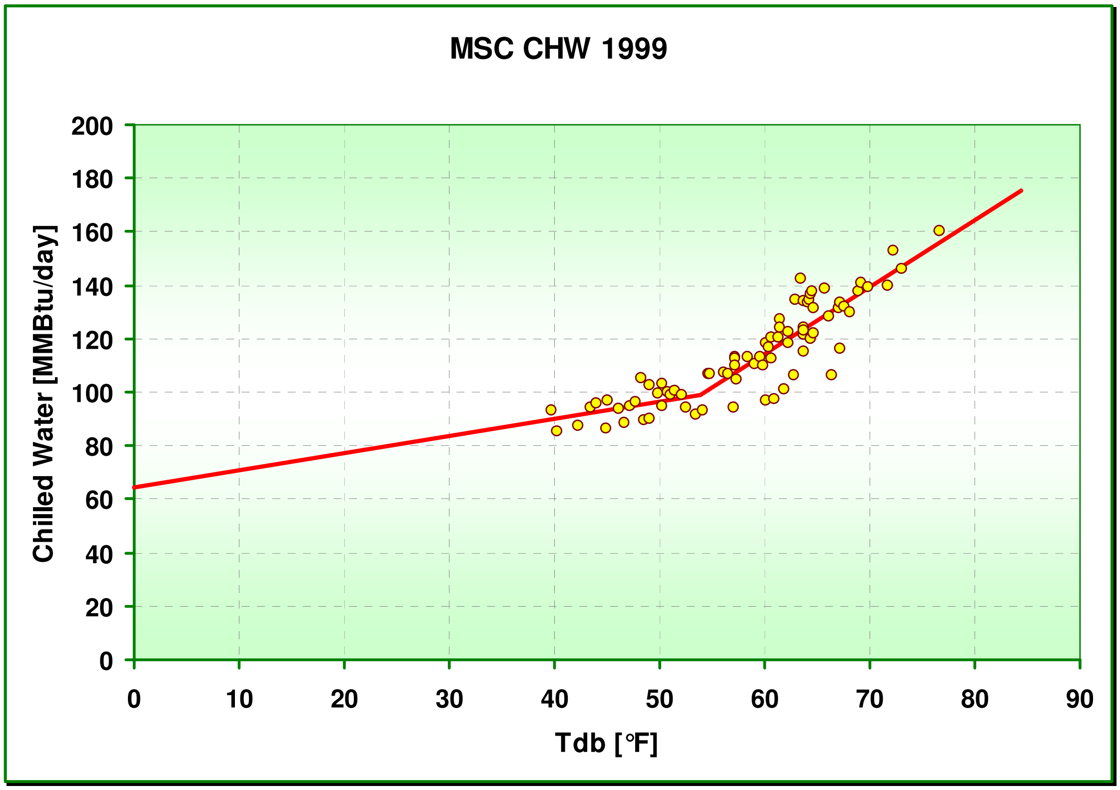

Figure A.65: MSC 1999 period chilled water 4P CP regression model.

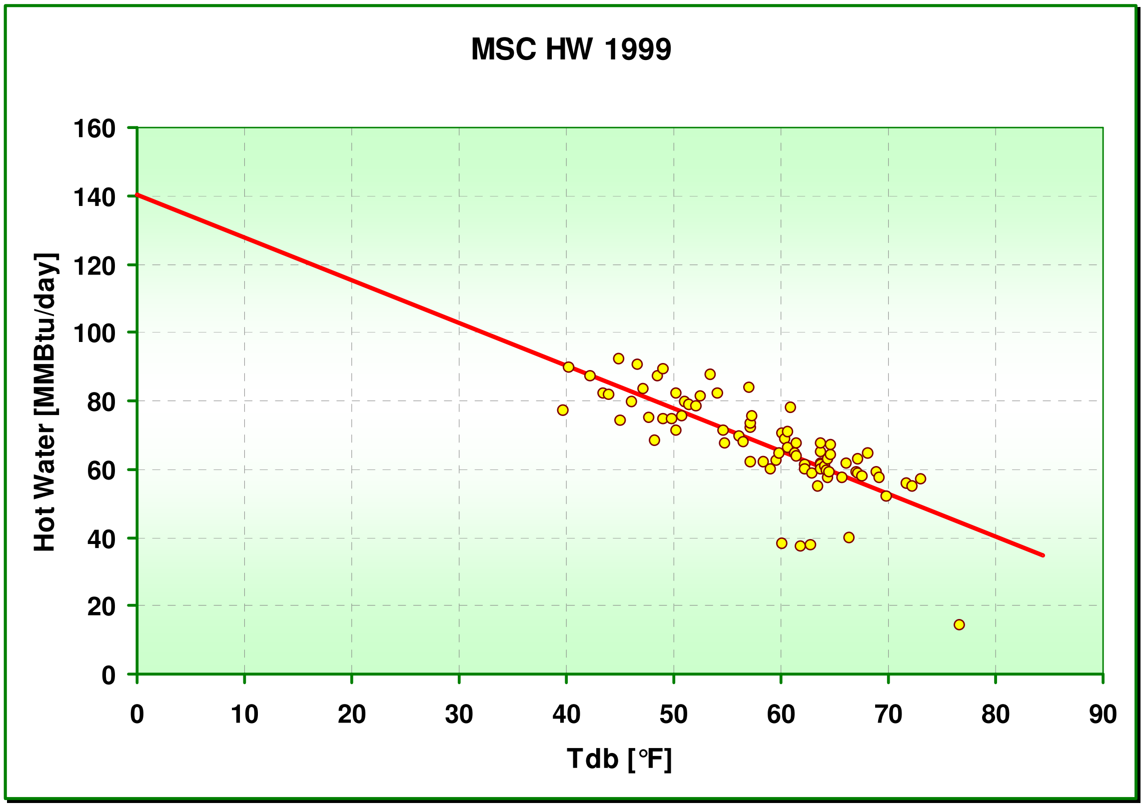

Figure A.66: MSC 1999 period hot water straight line regression model.

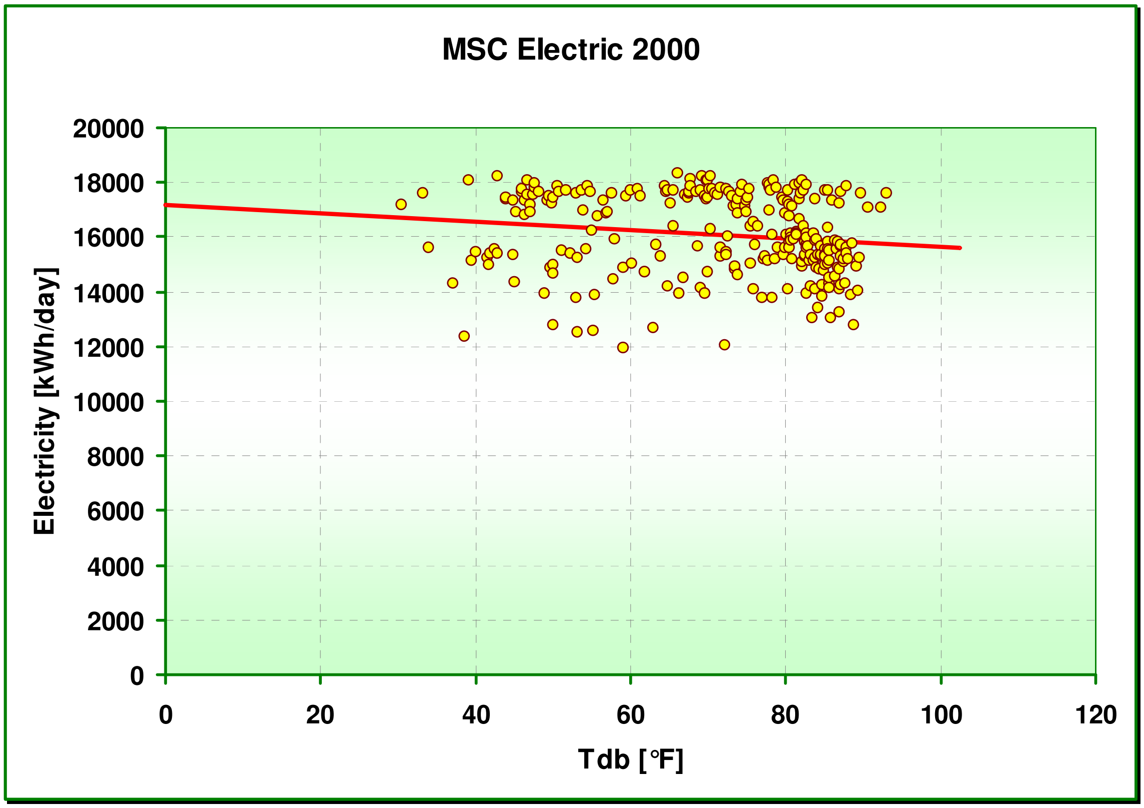

Figure A.67: MSC 2000 period electricity straight line regression model.

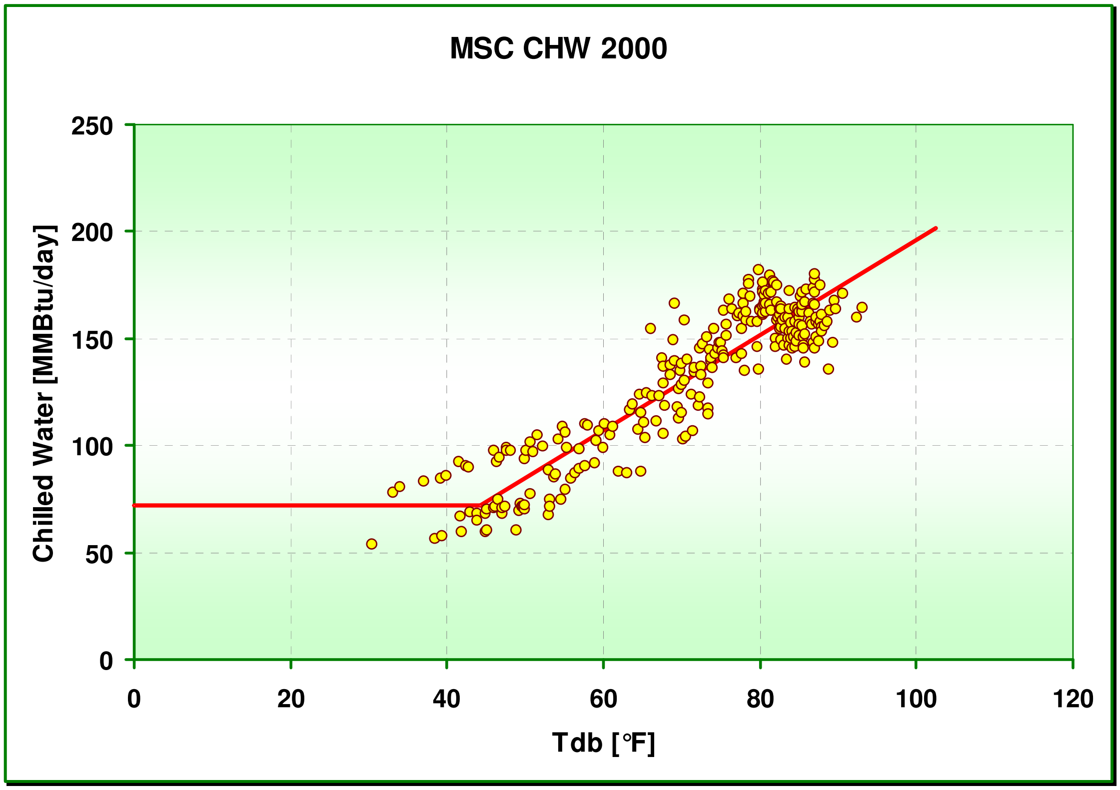

Figure A.68: MSC 2000 period chilled water 3P-cooling regression model.

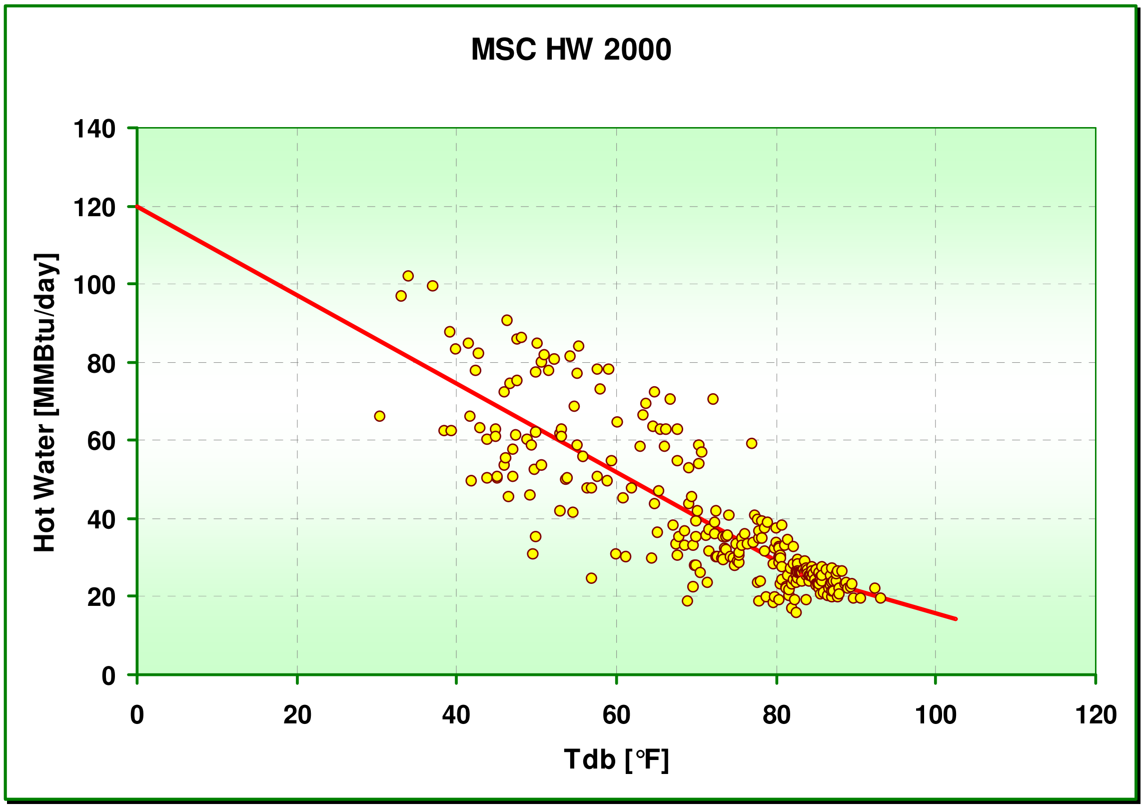

Figure A.69: MSC 2000 period hot water 4P CP regression model.

APPENDIX B
DATA QUALITY ASSURANCE PLOTS

CE/TTI

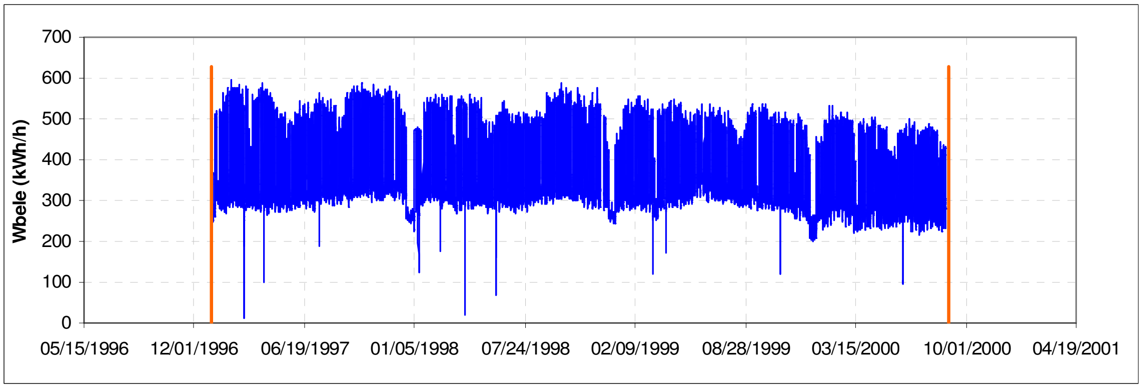

Figure B.1: CE/TTI electricity hourly time series data 1/1/1997-8/31/2000.

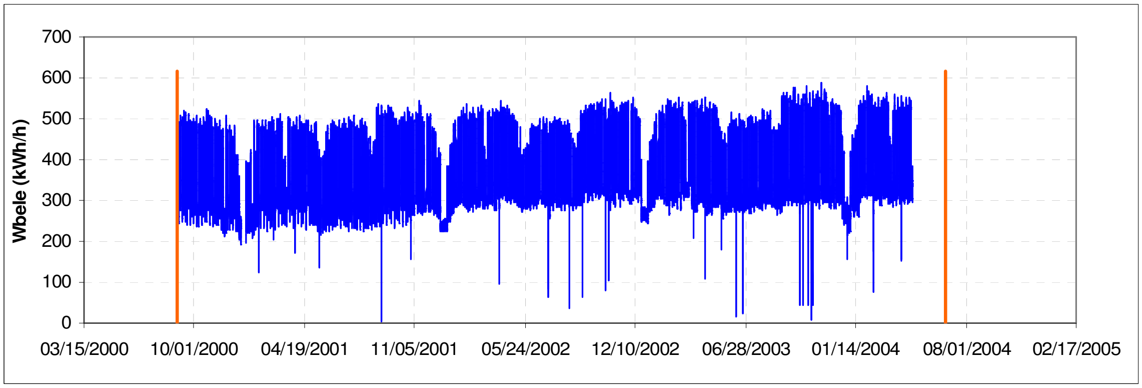

Figure B.2: CE/TTI electricity hourly time series data 9/1/2000-6/22/2004.

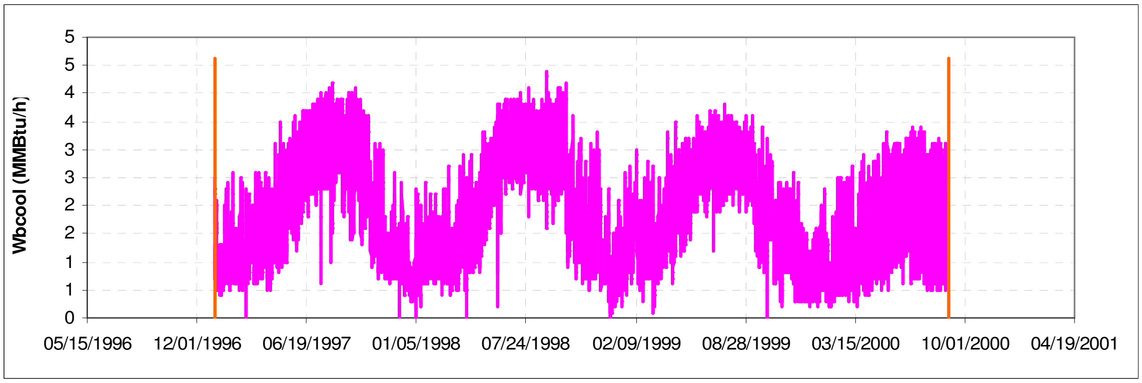

Figure B.3: CE/TTI chilled water hourly time series data 1/1/1997-8/31/2000.

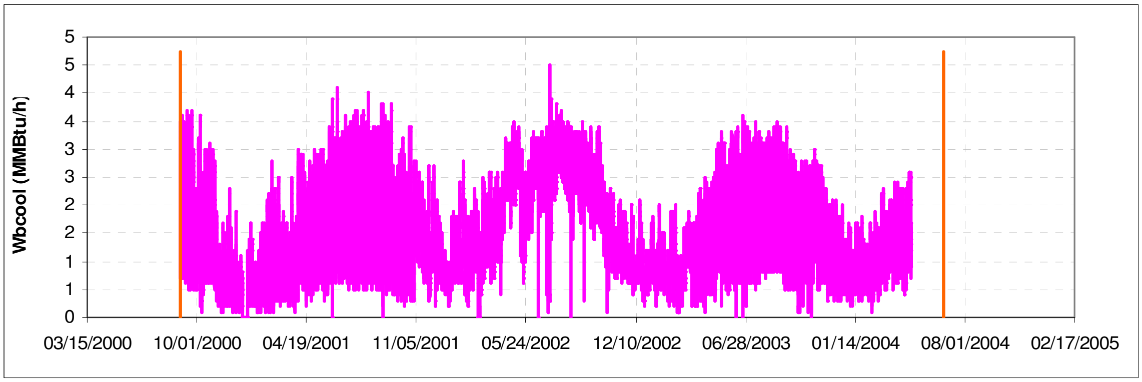

Figure B.4: CE/TTI chilled water hourly time series data 9/1/2000-6/22/2004.

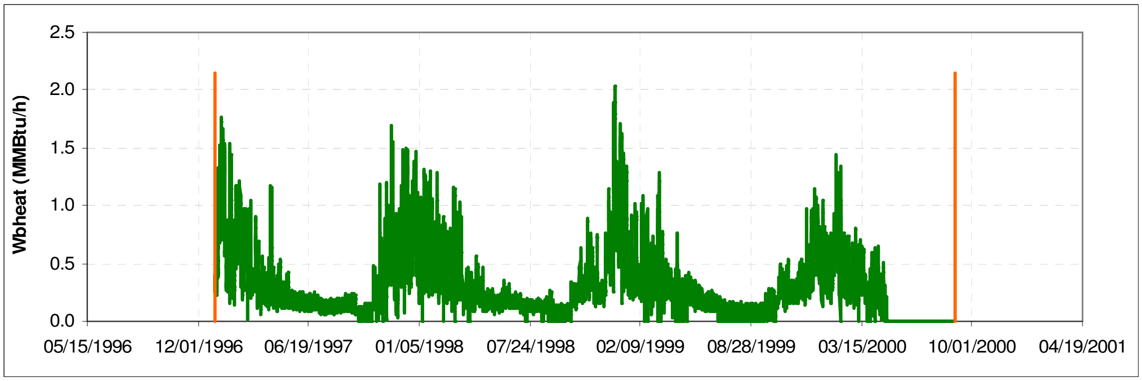

Figure B.5: CE/TTI hot water hourly time series data 1/1/1997-8/31/2000.

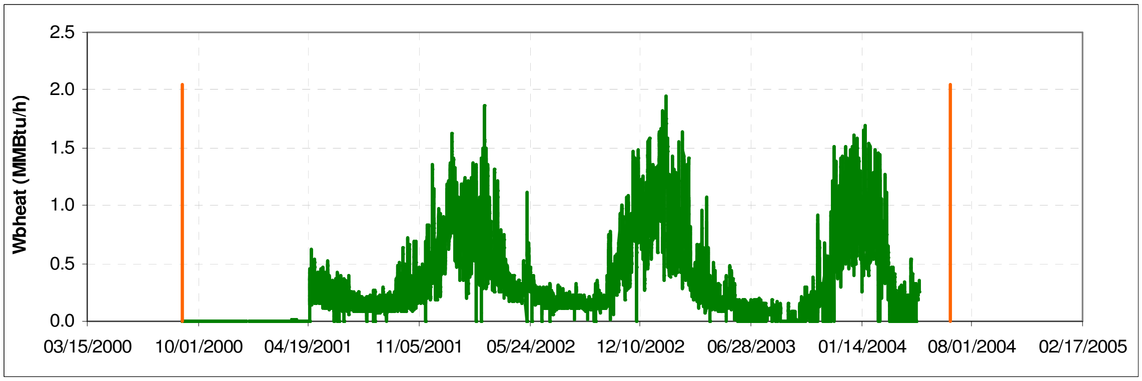

Figure B.6: CE/TTI hot water hourly time series data 9/1/2000-6/22/2004.

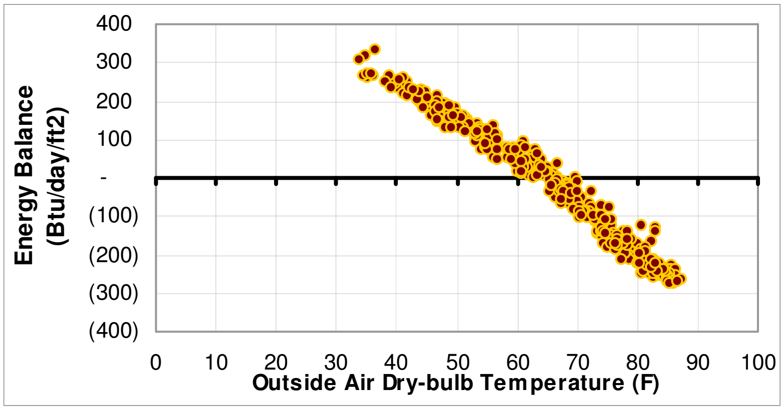

Figure B.7: CE/TTI 1997 energy balance plot.

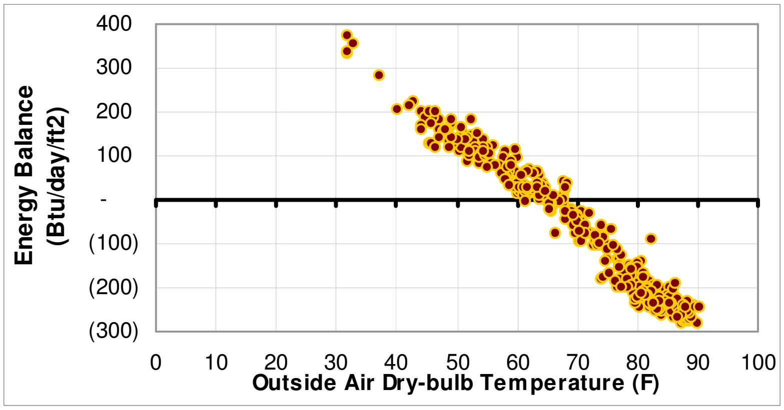

Figure B.8: CE/TTI 1998 energy balance plot.

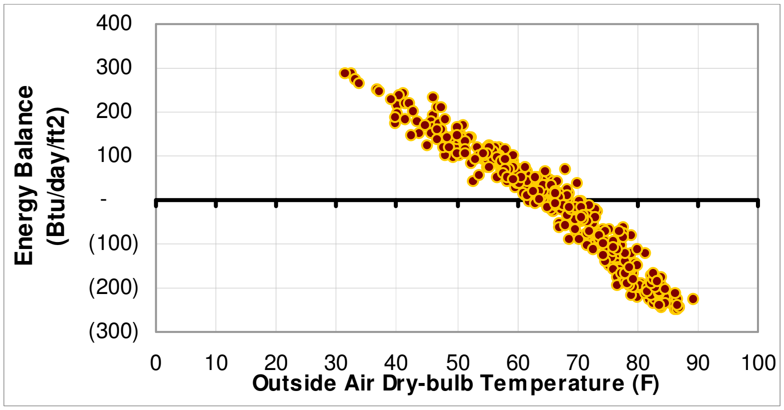

Figure B.9: CE/TTI 1/1/99-4/24/00 energy balance plot.

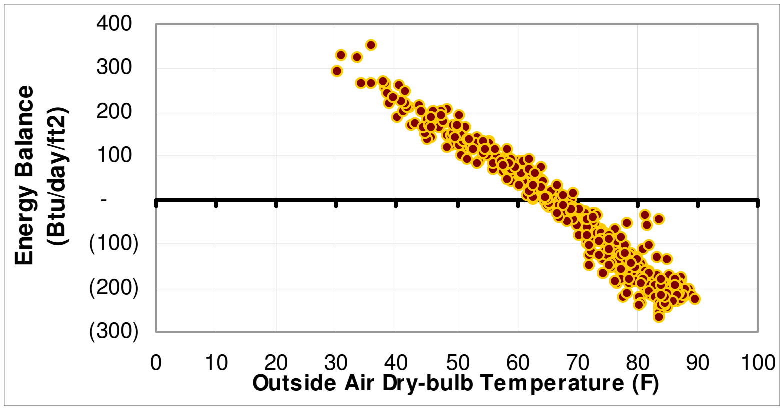

Figure B.10: CE/TTI 4/24/01-7/31/02 energy balance plot.

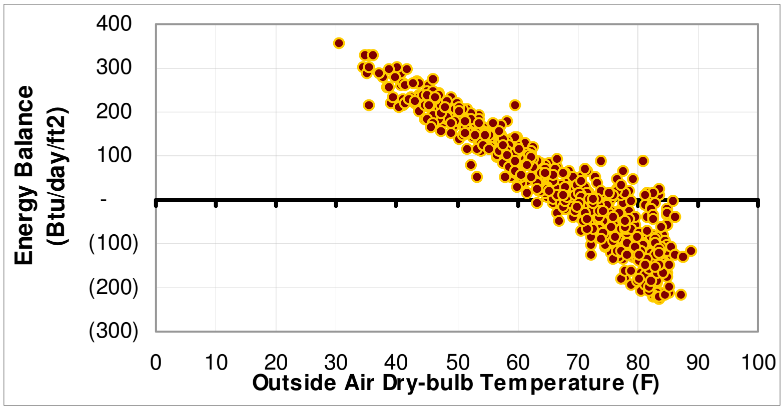

Figure B.11: CE/TTI 8/1/02-6/22/04 energy balance plot.

Heep Center

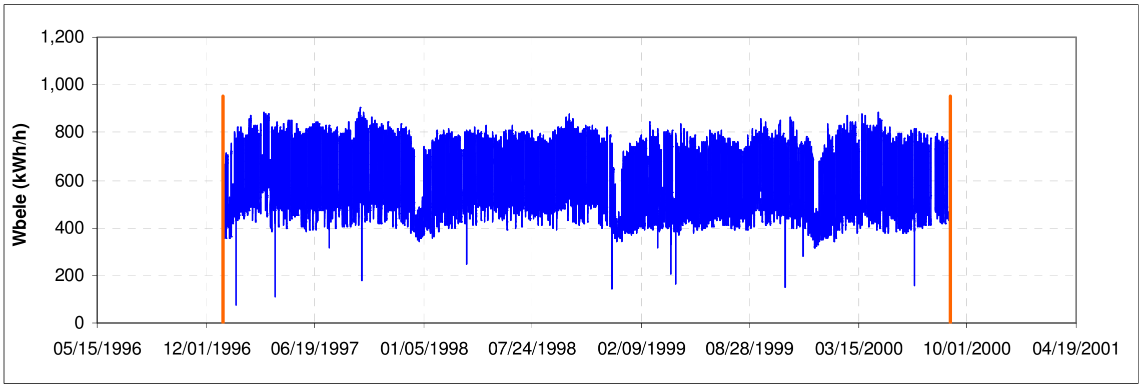

Figure B.12: Heep Center electricity hourly time series data 1/1/1997-8/31/2000.

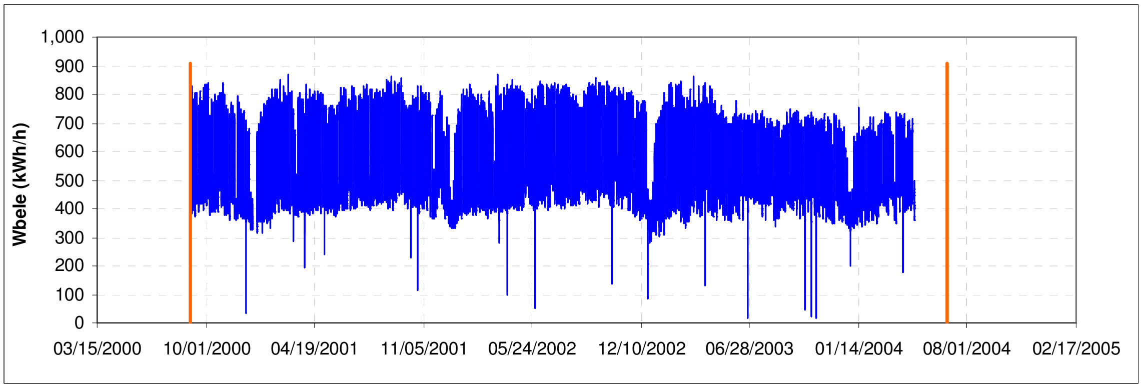

Figure B.13: Heep Center electricity hourly time series data 9/1/2000-6/22/2004.

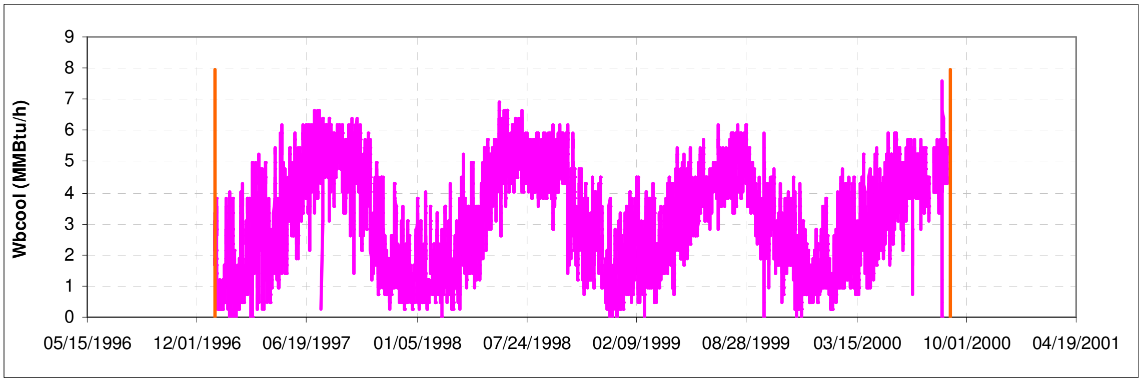

Figure B.14: Heep Center chilled water hourly time series data 1/1/1997-8/31/2000.

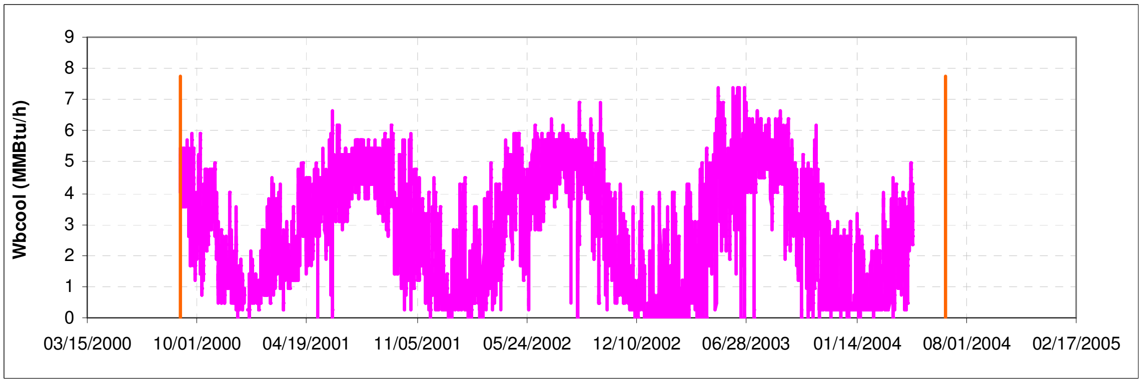

Figure B.15: Heep Center chilled water hourly time series data 9/1/2000-6/22/2004.

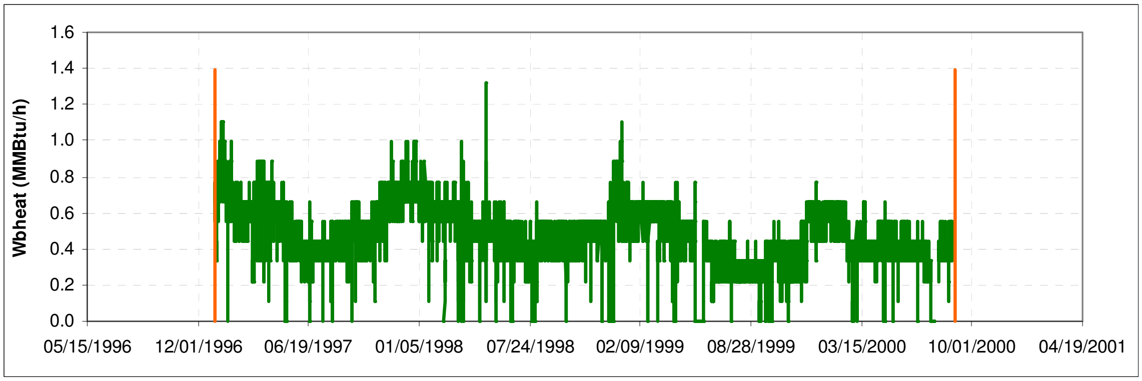

Figure B.16: Heep Center hot water hourly time series data 1/1/1997-8/31/2000.

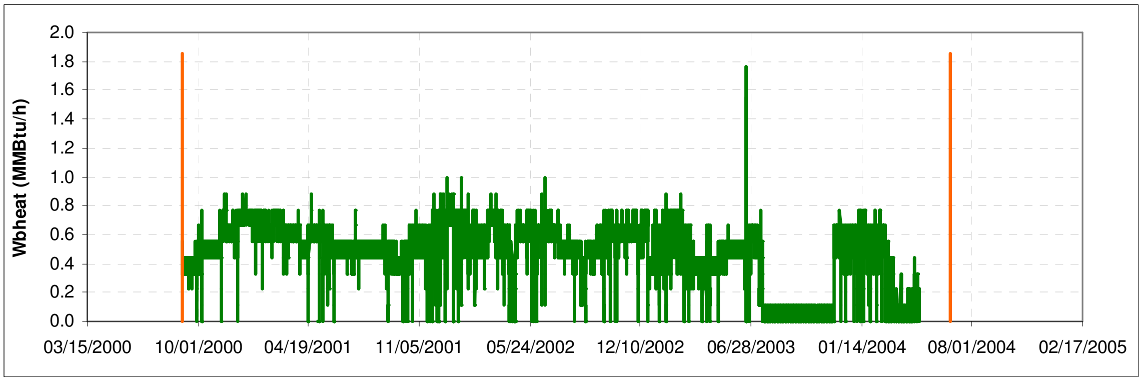

Figure B.17: Heep Center hot water hourly time series data 9/1/2000-6/22/2004.

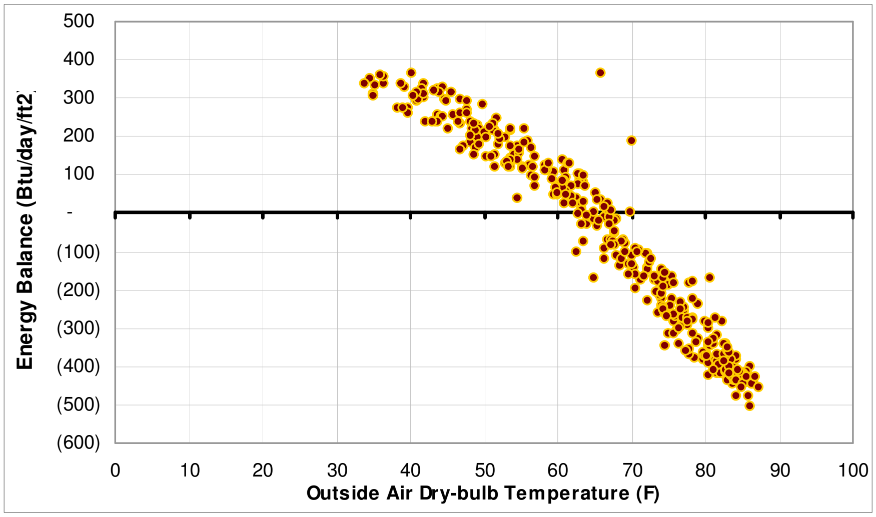

Figure B.18: Heep Center 1997 energy balance plot.

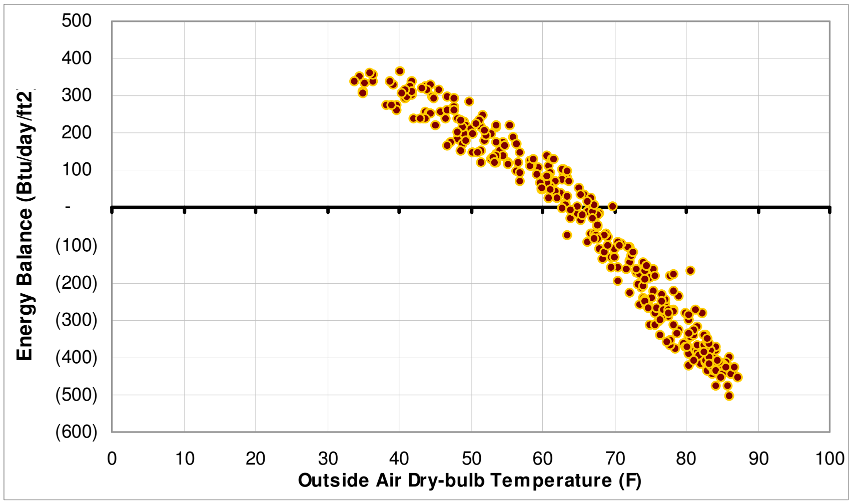

Figure B.19: Heep Center 1997 energy balance plot after removing poor data.

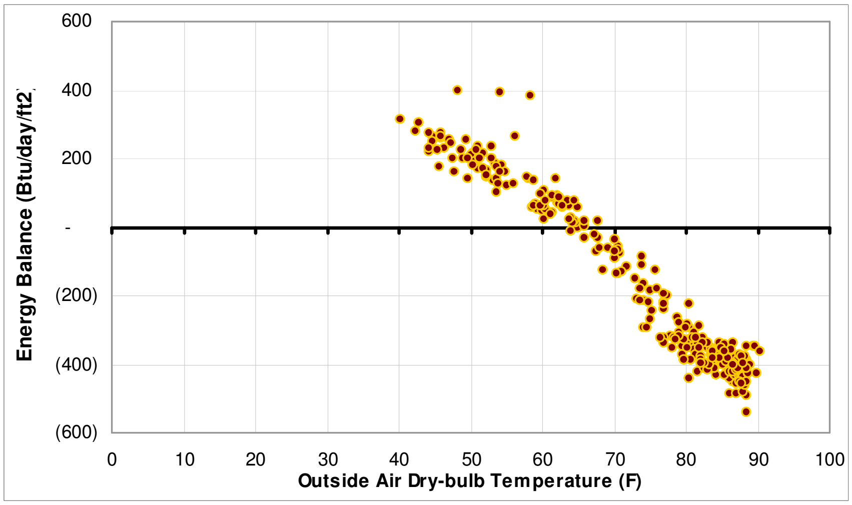

Figure B.20: Heep Center 1/98-9/98 energy balance plot.

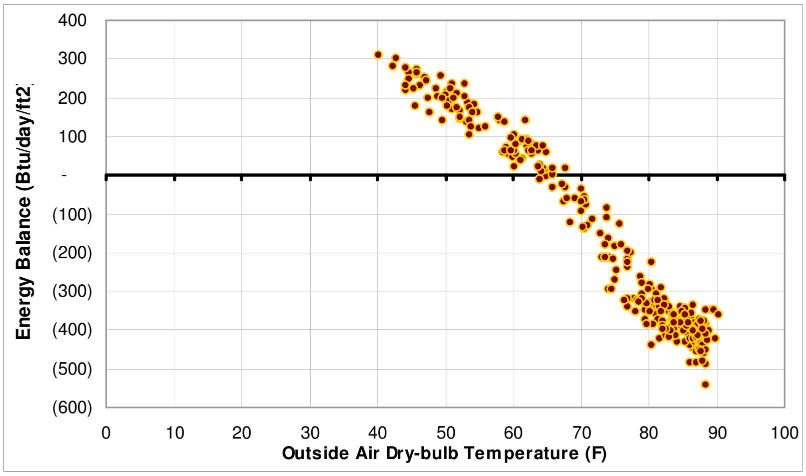

Figure B.21: Heep Center 1/98-9/98 energy balance plot after removing poor data.

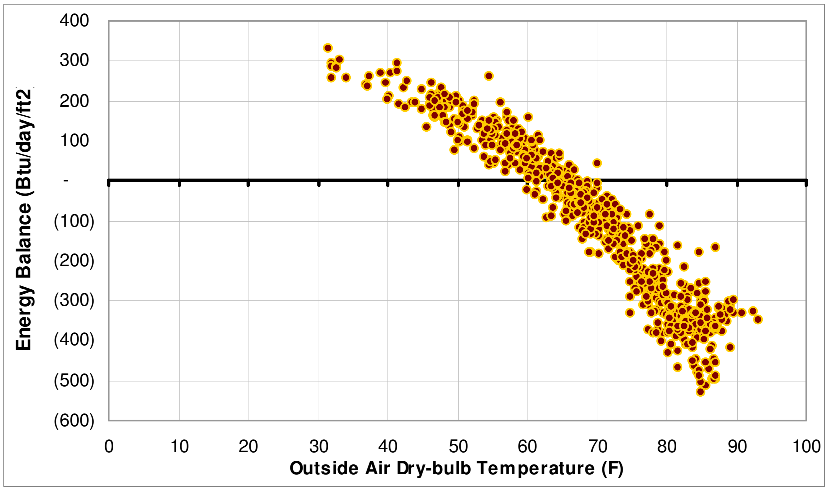

Figure B.22: Heep Center 10/98-10/00 energy balance plot.

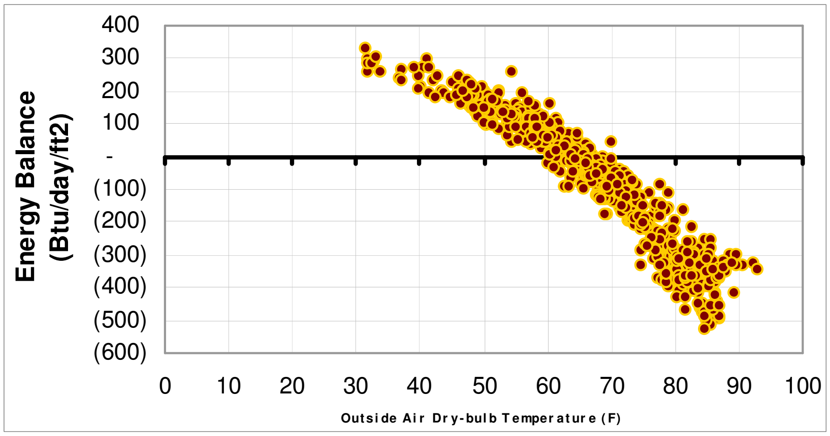

Figure B.23: Heep Center 10/98-10/00 energy balance plot after removing poor data.

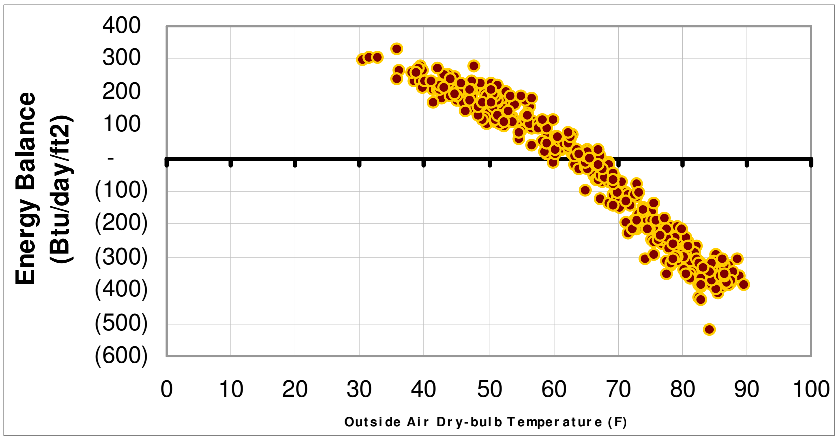

Figure B.24: Heep Center 11/00-12/01 energy balance plot.

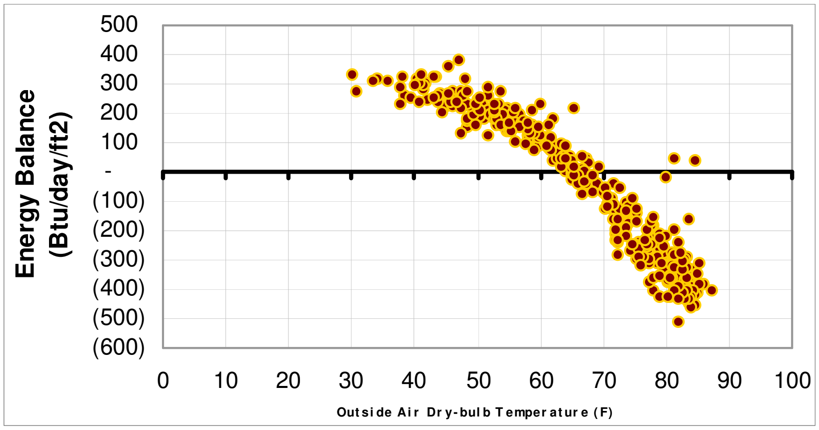

Figure B.25: Heep Center 2002 energy balance plot.

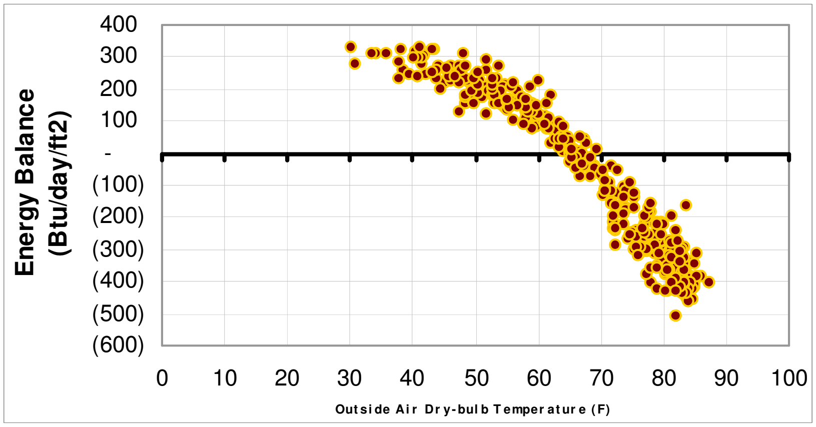

Figure B.26: Heep Center 2002 energy balance plot after removing poor data.

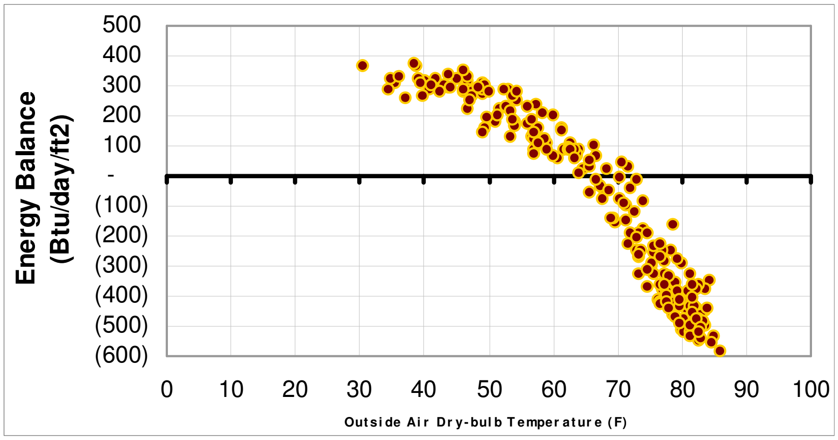

Figure B.27: Heep Center 1/1/03-7/19/03 energy balance plot.

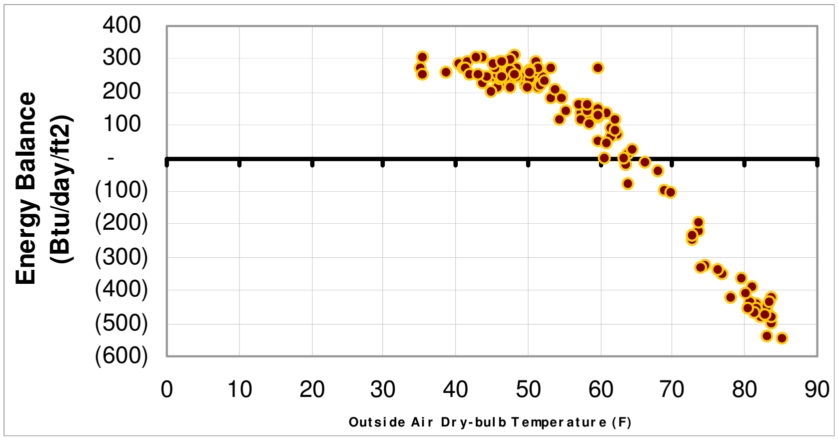

Figure B.28: Heep Center 11/25/03-6/24/04 energy balance plot.

MSC

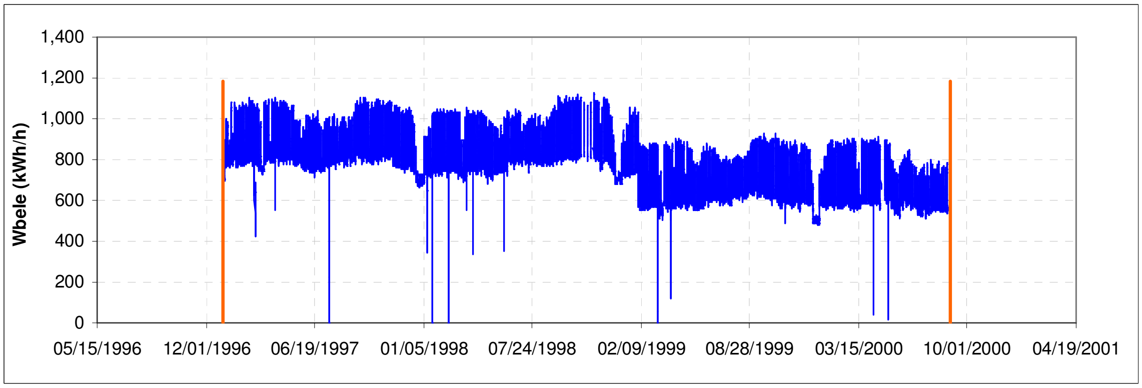

Figure B.29: MSC electricity hourly time series data 1/1/1997-8/31/2000.

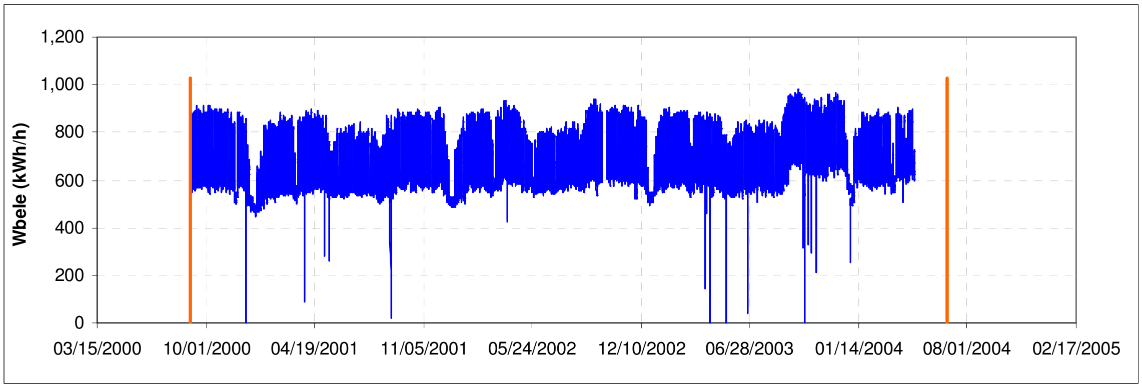

Figure B.30: MSC electricity hourly time series data 9/1/2000-6/22/2004.

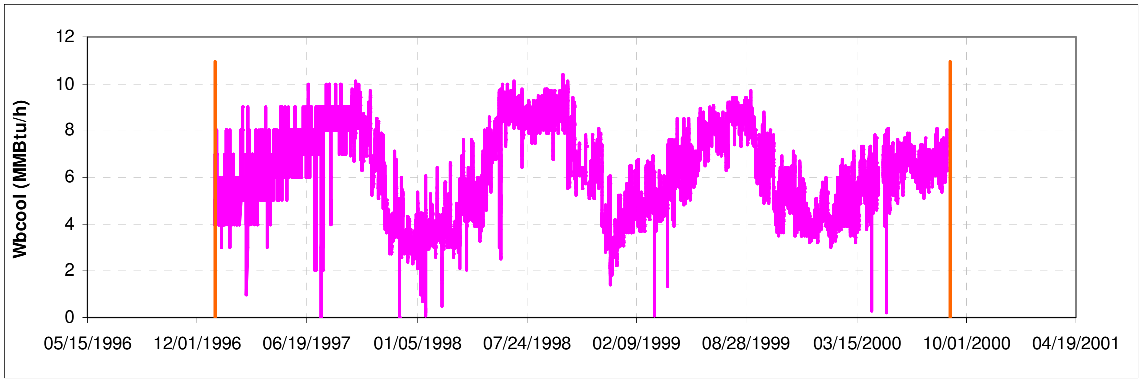

Figure B.31: MSC chilled water hourly time series data 1/1/1997-8/31/2000.

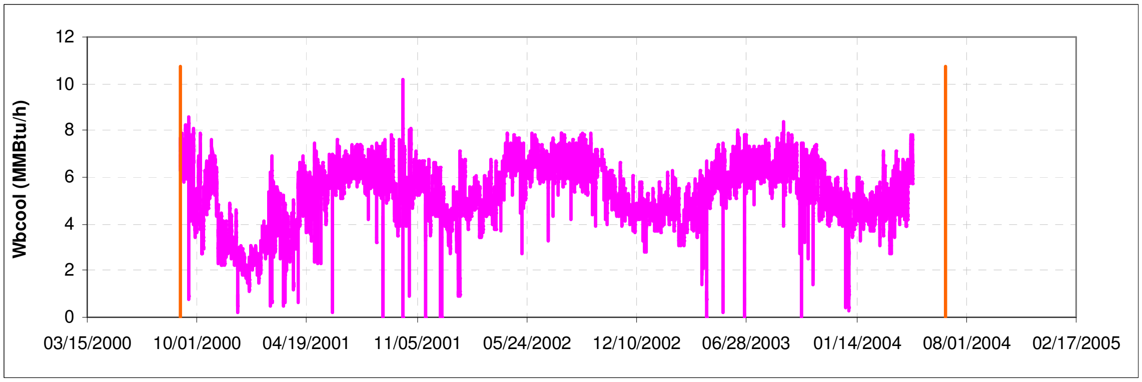

Figure B.32: MSC chilled water hourly time series data 9/1/2000-6/22/2004.

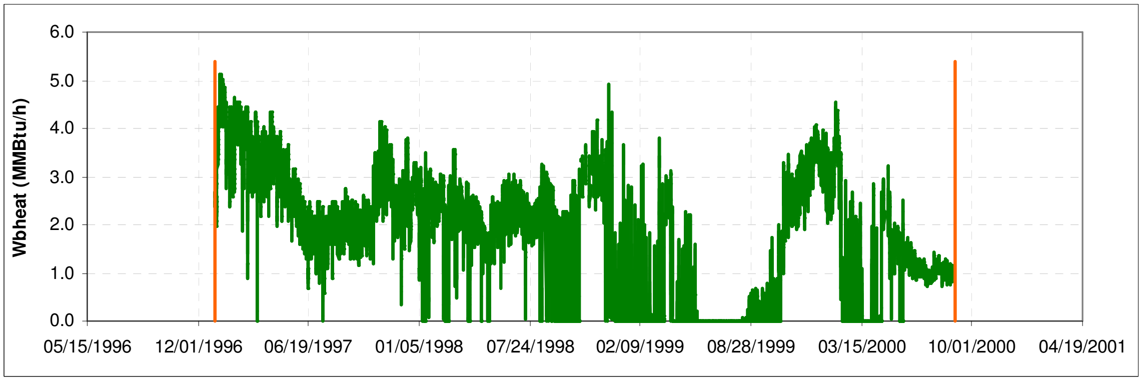

Figure B.33: MSC hot water hourly time series data 1/1/1997-8/31/2000.

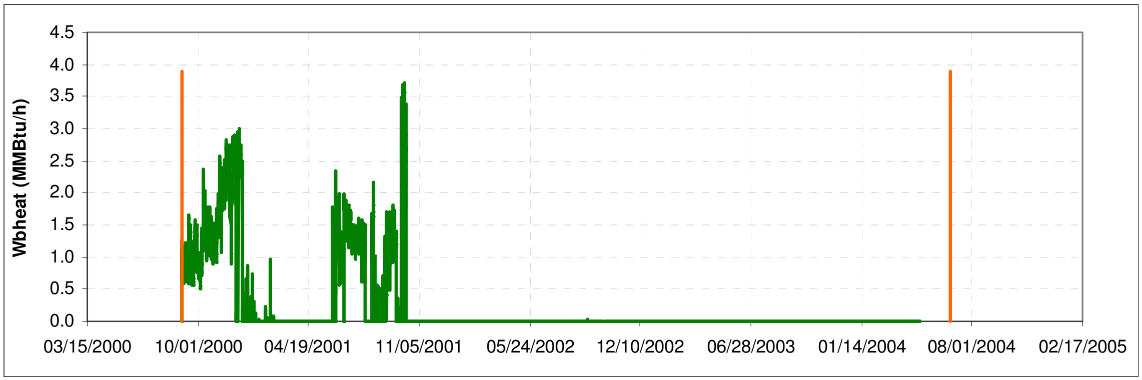

Figure B.34: MSC hot water hourly time series data 9/1/2000-6/22/2004.

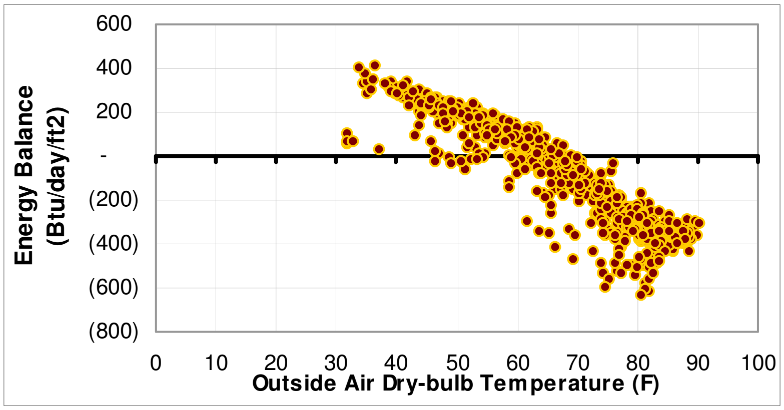

Figure B.35: MSC 1/97-12/98 energy balance plot.

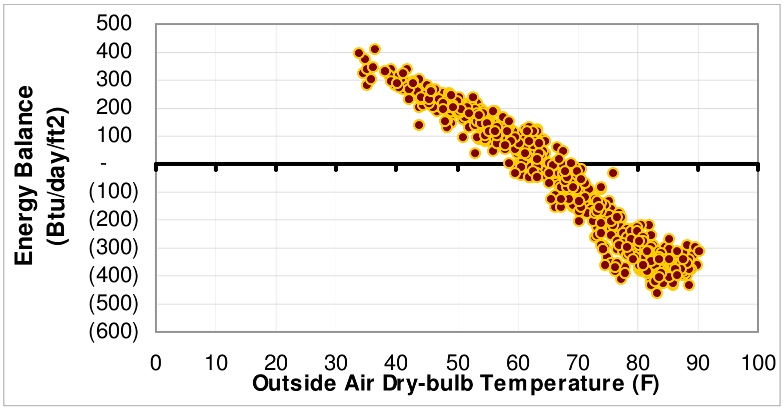

Figure B.36: MSC 1/97-12/98 energy balance plot after removing poor data.

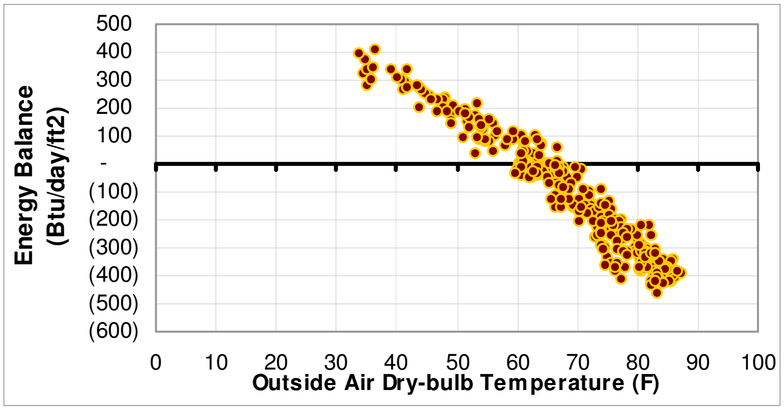

Figure B.37: MSC 1/97-10/97 energy balance plot after removing poor data.

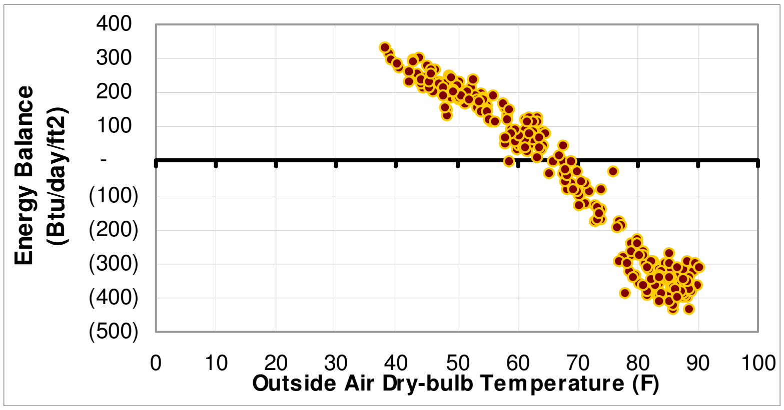

Figure B.38: MSC 12/97-12/98 energy balance plot after removing poor data.

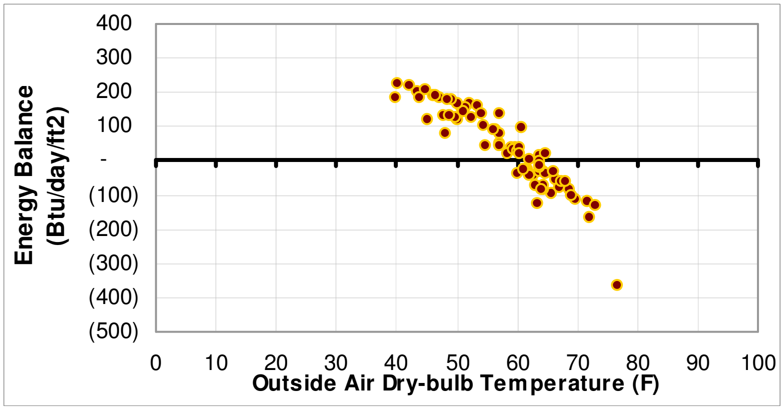

Figure B.39: MSC 1999 energy balance plot after removing poor data.

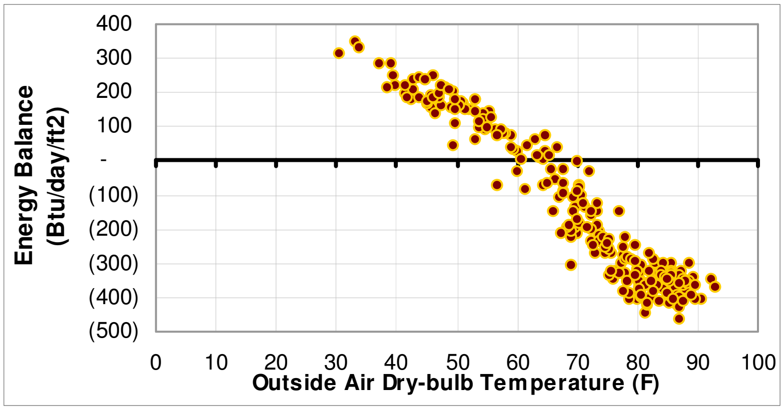

Figure B.40: MSC 2000 energy balance plot after removing poor data.

APPENDIX C

CALIBRATED SIMULATION INPUT PARAMETERS

Appendix C contains input files used in the simulations for the six CE/TTI post-commissioning periods the data was broken down into, as well as the 1996 baseline period adjusted from the 1997 calibrated simulation according to the commissioning report. Additionally, the 1997 Heep Center data was used to calibrate a simulation, whose inputs were subsequently changed according to the commissioning report to simulate the 1996 baseline period. To understand the meanings of the input numbers arranged, please refer to the user's manual for Air Side Simulation (AirModel) programs (Liu 1995) available.

CE/TTI

C.1: Input Parameters Used in the CE/TTI 1996 Baseline 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)
10 120
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
5 15 5 16
1.7 The second vacation period:month, day to month day
8 15 8 16
1.8 The third vacation period:month, day to month day
12 23 12 30
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.08 7.00 11.00
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
133251.4 0.6
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
7 19 10 14 11 15 10 15
4. Room temperature for occupied and unoccupied (heating and cooling)

```
   72  72  72  72
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.2  0.2
6.  Minimum air flow for occupied and unoccupied
   0.37   .37
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
    45      60
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.37    2.37
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
      0.78        0.40000        0.400000        0.400000
      0.4        0.40000        0.400000        0.400000
      0.4        0.650000       0.8500000        0.8500000
      0.860000   0.820000        0.8500000        0.850000
      0.820000   0.700000        0.550000        0.40000
      0.4        0.40000        0.400000        0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
      0.65        0.33        0.33  0.33
      0.33        0.33        0.33  0.33
      0.33        0.54        0.71  0.71
      0.72        0.68        0.71  0.71
      0.68        0.58        0.46  0.33
      0.33        0.33        0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
      0.65        0.33        0.33  0.33
      0.33        0.33        0.33  0.33
      0.33        0.54        0.71  0.71
      0.72        0.68        0.71  0.71
      0.68        0.58        0.46  0.33
```

```
        0.33        0.33        0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
        0.65        0.28        0.28  0.28
        0.28        0.28        0.28  0.28
        0.28        0.46        0.60  0.60
        0.61        0.57        0.60  0.60
        0.57        0.49        0.39  0.28
        0.28        0.28        0.28  0.28
21. Nighttime Base Electrical Gain Ratio
    0.3
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
    76976.88  0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
    26278.91   0.95
24. Air infiltration for interior and exterior zones (ACH)
    0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
    0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
    64.5 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
    0  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
   53  25   53  45   50  70   50  100   50  110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
   90  20   90  40   90  60  90  70   80  110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
   40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
   95  160  95  260  95  360  95  460  97  560
Section 3: Inputs for sub-system 2
1.  System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6
SDHCH)
   6
2.  Conditioned floor area (sq-ft) and fraction of interior area
   24592.7   0.15
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
   72  72  72  72
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.4  0.4
6.  Minimum air flow for occupied and unoccupied
   0.85   0.85
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;
    3
13.  Economizer Range Tmin, Tmax
    10       70
14.  Minimum and maximum outside air intake fraction
```

```
   0.05   0.9
15. Internal Heat Gain W/sq-ft
   2.37     2.37
16. Average Floor Area For Each Person sq-ft/person
    250
17. Clock Internal Electrical gain Ratio for Weekdays
      0.78        0.40000        0.400000        0.400000
      0.4        0.40000        0.400000        0.400000
      0.4        0.650000       0.8500000        0.8500000
      0.860000   0.820000        0.8500000        0.850000
      0.820000   0.700000        0.550000        0.40000
      0.4        0.40000        0.400000        0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
      0.65        0.33        0.33  0.33
      0.33        0.33        0.33  0.33
      0.33        0.54        0.71  0.71
      0.72        0.68        0.71  0.71
      0.68        0.58        0.46  0.33
      0.33        0.33        0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
      0.65        0.33        0.33  0.33
      0.33        0.33        0.33  0.33
      0.33        0.54        0.71  0.71
      0.72        0.68        0.71  0.71
      0.68        0.58        0.46  0.33
      0.33        0.33        0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
      0.65        0.28        0.28  0.28
      0.28        0.28        0.28  0.28
      0.28        0.46        0.60  0.60
      0.61        0.57        0.60  0.60
      0.57        0.49        0.39  0.28
      0.28        0.28        0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.25
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   14206.72   0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
   4849.99  0.95
24. Air infiltration for interior and exterior zones (ACH)
   0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
   0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   21  2
```

```
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   1  2
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
   2  30  2  50   2  60   2  70   2  100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
   90  120   90  140   90  160  90  170   80  210
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
   40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
   95  160  95  260  95  360  95  460  97  560
```

C.2: Input Parameters Used in the CE/TTI 1997 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)
   10  120
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
   5   15   5   16
1.7 The second vacation period:month, day to month day
   8   15    8    16
1.8 The third vacation period:month, day to month day
   12   23    12    30
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
   0.08       7.00      11.00
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
   133251.4  0.6
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
   72  72  72  72
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.2  0.2
6.  Minimum air flow for occupied and unoccupied
   0.37   .37
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
    45       60
```

```
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.37     2.37
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
       0.78        0.40000        0.400000        0.400000
       0.4        0.40000        0.400000        0.400000
       0.4        0.650000       0.8500000        0.8500000
       0.860000   0.820000        0.8500000        0.850000
       0.820000   0.700000        0.550000        0.40000
       0.4        0.40000        0.400000        0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
       0.65        0.33        0.33  0.33
       0.33        0.33        0.33  0.33
       0.33        0.54        0.71  0.71
       0.72        0.68        0.71  0.71
       0.68        0.58        0.46  0.33
       0.33        0.33        0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
       0.65        0.33        0.33  0.33
       0.33        0.33        0.33  0.33
       0.33        0.54        0.71  0.71
       0.72        0.68        0.71  0.71
       0.68        0.58        0.46  0.33
       0.33        0.33        0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
       0.65        0.28        0.28  0.28
       0.28        0.28        0.28  0.28
       0.28        0.46        0.60  0.60
       0.61        0.57        0.60  0.60
       0.57        0.49        0.39  0.28
       0.28        0.28        0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.3
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   76976.88  0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
   26278.91   0.95
24. Air infiltration for interior and exterior zones (ACH)
   0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
   0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
```

```
   64.5 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   0  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  25   55  45   52  70   52  100   52  110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
   90  20   90  40   90  60  90  70   80  110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
   40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
   95  160  95  260  95  360  95  460  97  560
Section 3: Inputs for sub-system 2
1.  System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6
SDHCH)
   6
```

```
2.  Conditioned floor area (sq-ft) and fraction of interior area
   24592.7   0.15
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
   72  72  72  72
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.4  0.4
6.  Minimum air flow for occupied and unoccupied
   0.85   0.85
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;
    3
13.  Economizer Range Tmin, Tmax
    10       70
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.37     2.37
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
      0.78        0.40000       0.400000       0.400000
      0.4        0.40000       0.400000       0.400000
      0.4        0.650000      0.8500000       0.8500000
      0.860000   0.820000       0.8500000       0.850000
      0.820000   0.700000       0.550000       0.40000
      0.4        0.40000       0.400000       0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
      0.65        0.33        0.33  0.33
      0.33        0.33        0.33  0.33
      0.33        0.54        0.71  0.71
      0.72        0.68        0.71  0.71
      0.68        0.58        0.46  0.33
      0.33        0.33        0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
```

```
      0.65      0.33      0.33  0.33
      0.33      0.33      0.33  0.33
      0.33      0.54      0.71  0.71
      0.72      0.68      0.71  0.71
      0.68      0.58      0.46  0.33
      0.33      0.33      0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
      0.65      0.28      0.28  0.28
      0.28      0.28      0.28  0.28
      0.28      0.46      0.60  0.60
      0.61      0.57      0.60  0.60
      0.57      0.49      0.39  0.28
      0.28      0.28      0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.25
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   14206.72   0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
   4849.99  0.95
24. Air infiltration for interior and exterior zones (ACH)
   0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
   0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
   21  2
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
   1  2
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
   2  30  2  50   2  60   2  70   2  100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
   90  120   90  140   90  160  90  170   80  210
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
   40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
   95  160  95  260  95  360  95  460  97  560
```

C.3: Input Parameters Used in the CE/TTI 1998 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)
   10  120
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
   5   15   5   16
1.7 The second vacation period:month, day to month day
   8   15    8    16
1.8 The third vacation period:month, day to month day
   12   23    12    30
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
   0.08       7.00       11.00
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
   133251.4  0.6
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
   71  72  71  72
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.17  0.17
6.  Minimum air flow for occupied and unoccupied
   0.36   .36
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
    45      60
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.31     2.31
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
       0.78        0.40000       0.400000       0.400000
       0.4       0.40000       0.400000       0.400000
       0.4       0.650000      0.8500000       0.8500000
       0.860000   0.820000       0.8500000       0.850000
       0.820000   0.700000       0.550000       0.40000
       0.4       0.40000       0.400000       0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
       0.65        0.33        0.33  0.33
       0.33        0.33        0.33  0.33
       0.33        0.54        0.71  0.71
       0.72        0.68        0.71  0.71
       0.68        0.58        0.46  0.33
       0.33        0.33        0.33  0.33
```

```
19. Clock Internal Electrical Gain Ratio for Sunday
      0.65      0.33      0.33  0.33
      0.33      0.33      0.33  0.33
      0.33      0.54      0.71  0.71
      0.72      0.68      0.71  0.71
      0.68      0.58      0.46  0.33
      0.33      0.33      0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
      0.65      0.28      0.28  0.28
      0.28      0.28      0.28  0.28
      0.28      0.46      0.60  0.60
      0.61      0.57      0.60  0.60
      0.57      0.49      0.39  0.28
      0.28      0.28      0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.3
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   76976.88  0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
   26278.91   0.95
24. Air infiltration for interior and exterior zones (ACH)
   0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
   0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   64.5 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   0  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
   56  25   56  45   52  70   52  100   52  110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
   90  20   90  40   90  60  90  70   80  110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
   40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
   95  160  95  260  95  360  95  460  97  560
Section 3: Inputs for sub-system 2
1.  System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6
SDHCH)
   6
2.  Conditioned floor area (sq-ft) and fraction of interior area
   24592.7   0.15
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
   71  72  71  72
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.4  0.4
6.  Minimum air flow for occupied and unoccupied
   0.85   0.85
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;
    3
13.  Economizer Range Tmin, Tmax
    10      70
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.31     2.31
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
       0.78        0.40000        0.400000        0.400000
       0.4        0.40000        0.400000        0.400000
       0.4        0.650000       0.8500000        0.8500000
       0.860000   0.820000        0.8500000        0.850000
       0.820000   0.700000        0.550000        0.40000
       0.4        0.40000        0.400000        0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
       0.65        0.33        0.33  0.33
       0.33        0.33        0.33  0.33
       0.33        0.54        0.71  0.71
       0.72        0.68        0.71  0.71
       0.68        0.58        0.46  0.33
       0.33        0.33        0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
       0.65        0.33        0.33  0.33
       0.33        0.33        0.33  0.33
       0.33        0.54        0.71  0.71
       0.72        0.68        0.71  0.71
       0.68        0.58        0.46  0.33
       0.33        0.33        0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
       0.65        0.28        0.28  0.28
       0.28        0.28        0.28  0.28
       0.28        0.46        0.60  0.60
       0.61        0.57        0.60  0.60
       0.57        0.49        0.39  0.28
       0.28        0.28        0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.25
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   14206.72   0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
   4849.99  0.95
24. Air infiltration for interior and exterior zones (ACH)
```

```
  0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
  0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
  21  2
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
  1  2
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
  2  30  2  50   2  60   2  70   2  100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
  90  120   90  140   90  160  90  170   80  210
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
  40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
```

95 160 95 260 95 360 95 460 97 560

C.4: Input Parameters Used in the CE/TTI January 1, 1999-April 24, 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)
10 120
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
5 15 5 16
1.7 The second vacation period:month, day to month day
8 15 8 16
1.8 The third vacation period:month, day to month day
12 23 12 30
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.08 7.00 11.00
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
133251.4 0.6
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
7 19 10 14 11 15 10 15
4. Room temperature for occupied and unoccupied (heating and cooling)
70 72 70 72
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
0.97 0.97 0.17 0.17
6. Minimum air flow for occupied and unoccupied
0.35 .35
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
    45      60
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.17     2.17
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
       0.78        0.40000        0.400000        0.400000
       0.4        0.40000        0.400000        0.400000
       0.4        0.650000       0.8500000        0.8500000
       0.860000   0.820000        0.8500000        0.850000
       0.820000   0.700000        0.550000        0.40000
       0.4        0.40000        0.400000        0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
       0.65        0.33        0.33  0.33
       0.33        0.33        0.33  0.33
       0.33        0.54        0.71  0.71
       0.72        0.68        0.71  0.71
       0.68        0.58        0.46  0.33
       0.33        0.33        0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
       0.65        0.33        0.33  0.33
       0.33        0.33        0.33  0.33
       0.33        0.54        0.71  0.71
       0.72        0.68        0.71  0.71
       0.68        0.58        0.46  0.33
       0.33        0.33        0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
       0.65        0.28        0.28  0.28
       0.28        0.28        0.28  0.28
       0.28        0.46        0.60  0.60
       0.61        0.57        0.60  0.60
       0.57        0.49        0.39  0.28
       0.28        0.28        0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.3
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   76976.88  0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
```

```
   26278.91   0.95
24. Air infiltration for interior and exterior zones (ACH)
   0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
   0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   64.5 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   0  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
   58  25   58  45   51  70   51  100   51  110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
   90  20   90  40   90  60  90  70   80  110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
```

```
   40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
   95  160  95  260  95  360  95  460  97  560
Section 3: Inputs for sub-system 2
1.  System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6
SDHCH)
   6
2.  Conditioned floor area (sq-ft) and fraction of interior area
   24592.7   0.15
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
   70  72  70  72
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.4  0.4
6.  Minimum air flow for occupied and unoccupied
   0.85   0.85
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;
    3
13.  Economizer Range Tmin, Tmax
    10       70
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.17     2.17
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
       0.78        0.40000        0.400000        0.400000
       0.4        0.40000        0.400000        0.400000
       0.4        0.650000       0.8500000        0.8500000
       0.860000   0.820000        0.8500000        0.850000
       0.820000   0.700000        0.550000        0.40000
       0.4        0.40000        0.400000        0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
```

```
        0.65       0.33       0.33  0.33
        0.33       0.33       0.33  0.33
        0.33       0.54       0.71  0.71
        0.72       0.68       0.71  0.71
        0.68       0.58       0.46  0.33
        0.33       0.33       0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
        0.65       0.33       0.33  0.33
        0.33       0.33       0.33  0.33
        0.33       0.54       0.71  0.71
        0.72       0.68       0.71  0.71
        0.68       0.58       0.46  0.33
        0.33       0.33       0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
        0.65       0.28       0.28  0.28
        0.28       0.28       0.28  0.28
        0.28       0.46       0.60  0.60
        0.61       0.57       0.60  0.60
        0.57       0.49       0.39  0.28
        0.28       0.28       0.28  0.28
21. Nighttime Base Electrical Gain Ratio
    0.25
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
    14206.72   0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
    4849.99  0.95
24. Air infiltration for interior and exterior zones (ACH)
    0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
    0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
    21  2
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
    1  2
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
2 30 2 50 2 60 2 70 2 100

34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
90 120 90 140 90 160 90 170 80 210

35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
40 -120 40 -100 40 -80 40 -44 40 -30

36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
95 160 95 260 95 360 95 460 97 560

C.5: Input Parameters Used in the CE/TTI April 24, 2001-December 31, 2001 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)
10 120

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
5 15 5 16

1.7 The second vacation period:month, day to month day

```
   8   15    8    16
1.8 The third vacation period:month, day to month day
   12   23    12    30
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
   0.08       7.00      11.00
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
   133251.4  0.6
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
   71  73  71  73
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.15  0.15
6.  Minimum air flow for occupied and unoccupied
   0.33   .33
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
    45       60
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.07     2.07
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
       0.78        0.40000        0.400000       0.400000
       0.4        0.40000        0.400000       0.400000
       0.4        0.650000       0.8500000       0.8500000
       0.860000   0.820000        0.8500000       0.850000
       0.820000   0.700000        0.550000        0.40000
```

```
    0.4        0.40000       0.400000       0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
    0.65       0.33       0.33  0.33
    0.33       0.33       0.33  0.33
    0.33       0.54       0.71  0.71
    0.72       0.68       0.71  0.71
    0.68       0.58       0.46  0.33
    0.33       0.33       0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
    0.65       0.33       0.33  0.33
    0.33       0.33       0.33  0.33
    0.33       0.54       0.71  0.71
    0.72       0.68       0.71  0.71
    0.68       0.58       0.46  0.33
    0.33       0.33       0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
    0.65       0.28       0.28  0.28
    0.28       0.28       0.28  0.28
    0.28       0.46       0.60  0.60
    0.61       0.57       0.60  0.60
    0.57       0.49       0.39  0.28
    0.28       0.28       0.28  0.28
21. Nighttime Base Electrical Gain Ratio
  0.3
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
  76976.88  0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
  26278.91   0.95
24. Air infiltration for interior and exterior zones (ACH)
  0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
  0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
  64.5 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
  0  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  25   57  45   50  70   50  100   50  110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
   90  20   90  40   90  60  90  70   80  110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
   40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
   95  160  95  260  95  360  95  460  97  560
Section 3: Inputs for sub-system 2
1.  System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6
SDHCH)
   6
2.  Conditioned floor area (sq-ft) and fraction of interior area
   24592.7   0.15
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
   71  73  71  73
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.4  0.4
6.  Minimum air flow for occupied and unoccupied
   0.85   0.85
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;
    3
13.  Economizer Range Tmin, Tmax
    10      70
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.07     2.07
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
        0.78        0.40000        0.400000        0.400000
        0.4         0.40000        0.400000        0.400000
        0.4         0.650000       0.8500000       0.8500000
        0.860000   0.820000        0.8500000       0.850000
        0.820000   0.700000        0.550000        0.40000
        0.4         0.40000        0.400000        0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
        0.65        0.33        0.33  0.33
        0.33        0.33        0.33  0.33
        0.33        0.54        0.71  0.71
        0.72        0.68        0.71  0.71
        0.68        0.58        0.46  0.33
        0.33        0.33        0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
        0.65        0.33        0.33  0.33
        0.33        0.33        0.33  0.33
        0.33        0.54        0.71  0.71
        0.72        0.68        0.71  0.71
        0.68        0.58        0.46  0.33
        0.33        0.33        0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
        0.65        0.28        0.28  0.28
        0.28        0.28        0.28  0.28
        0.28        0.46        0.60  0.60
        0.61        0.57        0.60  0.60
        0.57        0.49        0.39  0.28
```

```
     0.28       0.28       0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.25
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   14206.72   0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
   4849.99  0.95
24. Air infiltration for interior and exterior zones (ACH)
   0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
   0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   21  2
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   1  2
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
2 30 2 50 2 60 2 70 2 100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
90 120 90 140 90 160 90 170 80 210
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
40 -120 40 -100 40 -80 40 -44 40 -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
95 160 95 260 95 360 95 460 97 560

C.6: Input Parameters Used in the CE/TTI January 1, 2002-November 30, 2002 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)
10 120
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
5 15 5 16
1.7 The second vacation period:month, day to month day
8 15 8 16
1.8 The third vacation period:month, day to month day
12 23 12 30
1.9 Energy price \$/kWh, \$/MMBtu-CHW \$/MMBtu-HW
0.08 7.00 11.00
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
133251.4 0.6
3. Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
7 19 10 14 11 15 10 15
4. Room temperature for occupied and unoccupied (heating and cooling)
73 73 73 73
5. Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
0.97 0.97 0.15 0.15
6. Minimum air flow for occupied and unoccupied
0.36 .36

```
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
    45      60
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.19     2.19
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
       0.78       0.40000       0.400000       0.400000
       0.4       0.40000       0.400000       0.400000
       0.4       0.650000      0.8500000       0.8500000
       0.860000   0.820000       0.8500000       0.850000
       0.820000   0.700000       0.550000       0.40000
       0.4       0.40000       0.400000       0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
       0.65       0.33       0.33  0.33
       0.33       0.33       0.33  0.33
       0.33       0.54       0.71  0.71
       0.72       0.68       0.71  0.71
       0.68       0.58       0.46  0.33
       0.33       0.33       0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
       0.65       0.33       0.33  0.33
       0.33       0.33       0.33  0.33
       0.33       0.54       0.71  0.71
       0.72       0.68       0.71  0.71
       0.68       0.58       0.46  0.33
       0.33       0.33       0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
       0.65       0.28       0.28  0.28
       0.28       0.28       0.28  0.28
       0.28       0.46       0.60  0.60
```

```
     0.61       0.57       0.60  0.60
     0.57       0.49       0.39  0.28
     0.28       0.28       0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.3
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   76976.88  0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
   26278.91   0.95
24. Air infiltration for interior and exterior zones (ACH)
   0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
   0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   64.5 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   0  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  25   57  45   50  70   50  100   50  110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
   90  20   90  40   90  60  90  70   80  110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
   40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
   95  160  95  260  95  360  95  460  97  560
Section 3: Inputs for sub-system 2
1.  System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6
SDHCH)
   6
2.  Conditioned floor area (sq-ft) and fraction of interior area
   24592.7   0.15
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
   73  73  73  73
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.4  0.4
6.  Minimum air flow for occupied and unoccupied
   0.85   0.85
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;
    3
13.  Economizer Range Tmin, Tmax
    10       70
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.19     2.19
16. Average Floor Area For Each Person sq-ft/person
     250
```

```
17. Clock Internal Electrical gain Ratio for Weekdays
      0.78       0.40000       0.400000       0.400000
      0.4      0.40000       0.400000       0.400000
      0.4      0.650000      0.8500000       0.8500000
      0.860000   0.820000       0.8500000       0.850000
      0.820000   0.700000       0.550000       0.40000
      0.4      0.40000       0.400000       0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
      0.65       0.33       0.33  0.33
      0.33       0.33       0.33  0.33
      0.33       0.54       0.71  0.71
      0.72       0.68       0.71  0.71
      0.68       0.58       0.46  0.33
      0.33       0.33       0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
      0.65       0.33       0.33  0.33
      0.33       0.33       0.33  0.33
      0.33       0.54       0.71  0.71
      0.72       0.68       0.71  0.71
      0.68       0.58       0.46  0.33
      0.33       0.33       0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
      0.65       0.28       0.28  0.28
      0.28       0.28       0.28  0.28
      0.28       0.46       0.60  0.60
      0.61       0.57       0.60  0.60
      0.57       0.49       0.39  0.28
      0.28       0.28       0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.25
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   14206.72   0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
   4849.99  0.95
24. Air infiltration for interior and exterior zones (ACH)
   0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
   0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
   21  2
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
   1  2
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
2 30 2 50 2 60 2 70 2 100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
90 120 90 140 90 160 90 170 80 210
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
40 -120 40 -100 40 -80 40 -44 40 -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
95 160 95 260 95 360 95 460 97 560

C.7: Input Parameters Used in the CE/TTI September 1, 2003-June 22, 2004 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)
10 120
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
   5   15   5   16
1.7 The second vacation period:month, day to month day
   8   15    8    16
1.8 The third vacation period:month, day to month day
   12   23    12    30
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
   0.08       7.00      11.00
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
   133251.4  0.6
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
   74  74  74  74
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.15  0.15
6.  Minimum air flow for occupied and unoccupied
   0.37   .37
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
    45       60
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.3     2.3
16. Average Floor Area For Each Person sq-ft/person
```

```
    250
17. Clock Internal Electrical gain Ratio for Weekdays
      0.78       0.40000      0.400000      0.400000
      0.4       0.40000      0.400000      0.400000
      0.4       0.650000     0.8500000      0.8500000
      0.860000  0.820000      0.8500000      0.850000
      0.820000  0.700000      0.550000      0.40000
      0.4       0.40000      0.400000      0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
      0.65       0.33       0.33  0.33
      0.33       0.33       0.33  0.33
      0.33       0.54       0.71  0.71
      0.72       0.68       0.71  0.71
      0.68       0.58       0.46  0.33
      0.33       0.33       0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
      0.65       0.33       0.33  0.33
      0.33       0.33       0.33  0.33
      0.33       0.54       0.71  0.71
      0.72       0.68       0.71  0.71
      0.68       0.58       0.46  0.33
      0.33       0.33       0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
      0.65       0.28       0.28  0.28
      0.28       0.28       0.28  0.28
      0.28       0.46       0.60  0.60
      0.61       0.57       0.60  0.60
      0.57       0.49       0.39  0.28
      0.28       0.28       0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.3
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   76976.88  0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
   26278.91   0.95
24. Air infiltration for interior and exterior zones (ACH)
   0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
   0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   64.5 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   0  1
28. Temp. Diff. Between Return and Room Air Temp F
```

```
     2.000000
29. Clock HVAC Operation Model for Weekdays
     0.860000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     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
     0.860000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     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
     0.860000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     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
     0.860000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     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  45   52  70   52  100   52  110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
   90  20   90  40   90  60  90  70   80  110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
   40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
   95  160  95  260  95  360  95  460  97  560
Section 3: Inputs for sub-system 2
1.  System type (1-DDPOA, 2 DDPMA, 3 SDRHOA,4 SDRHMA, 5 SDHC, and 6
SDHCH)
   6
2.  Conditioned floor area (sq-ft) and fraction of interior area
   24592.7   0.15
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
```

```
   74  74  74  74
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   0.97   0.97   0.4  0.4
6.  Minimum air flow for occupied and unoccupied
   0.85   0.85
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;
    3
13.  Economizer Range Tmin, Tmax
    10      70
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    2.3    2.3
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
      0.78       0.40000       0.400000       0.400000
      0.4       0.40000       0.400000       0.400000
      0.4       0.650000      0.8500000       0.8500000
      0.860000   0.820000       0.8500000       0.850000
      0.820000   0.700000       0.550000       0.40000
      0.4       0.40000       0.400000       0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
      0.65       0.33       0.33  0.33
      0.33       0.33       0.33  0.33
      0.33       0.54       0.71  0.71
      0.72       0.68       0.71  0.71
      0.68       0.58       0.46  0.33
      0.33       0.33       0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
      0.65       0.33       0.33  0.33
      0.33       0.33       0.33  0.33
      0.33       0.54       0.71  0.71
      0.72       0.68       0.71  0.71
      0.68       0.58       0.46  0.33
```

```
     0.33       0.33       0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
     0.65       0.28       0.28  0.28
     0.28       0.28       0.28  0.28
     0.28       0.46       0.60  0.60
     0.61       0.57       0.60  0.60
     0.57       0.49       0.39  0.28
     0.28       0.28       0.28  0.28
21. Nighttime Base Electrical Gain Ratio
  0.25
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
  14206.72   0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
  4849.99  0.95
24. Air infiltration for interior and exterior zones (ACH)
  0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
  0.03    30   0.16   100
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
  21  2
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
  1  2
28. Temp. Diff. Between Return and Room Air Temp F
     2.000000
29. Clock HVAC Operation Model for Weekdays
     0.750000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     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
     0.750000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     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
     0.750000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     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
     0.750000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     1.000000     1.000000     1.000000     1.000000
     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
   2  30  2  50   2  60   2  70   2  100
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
   90  120   90  140   90  160  90  170   80  210
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
   40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
   95  160  95  260  95  360  95  460  97  560
```

Heep Center

C.8: Input Parameters Used in the Heep Center 1996 Baseline 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)
   10  120
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)
   2
1.6 The first Vacation period:month, day to month day
   5   15   5   22
1.7 The second vacation period:month, day to month day
   8   15    8    22
1.8 The third vacation period:month, day to month day
   12   23    12    30
1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
   0.08       7.00       11.00
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
```

```
   158979  0.328
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
   7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
   72  74  72  74
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
   1.03   1.03   0.44  0.44
6.  Minimum air flow for occupied and unoccupied
   0.78   0.78
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
    30       60
14.  Minimum and maximum outside air intake fraction
    0.05   0.9
15. Internal Heat Gain W/sq-ft
    4.0     3.45
16. Average Floor Area For Each Person sq-ft/person
     250
17. Clock Internal Electrical gain Ratio for Weekdays
       0.86        0.40000        0.400000        0.400000
       0.4        0.40000        0.400000        0.400000
       0.4        0.650000       0.8500000       0.8500000
       0.860000   0.820000        0.8500000        0.850000
       0.820000   0.700000        0.550000        0.40000
       0.4        0.40000        0.400000        0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
       0.80        0.33        0.33  0.33
       0.33        0.33        0.33  0.33
       0.33        0.54        0.71  0.71
       0.72        0.68        0.71  0.71
       0.68        0.58        0.46  0.33
       0.33        0.33        0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
       0.80        0.33        0.33  0.33
```

```
      0.33      0.33      0.33  0.33
      0.33      0.54      0.71  0.71
      0.72      0.68      0.71  0.71
      0.68      0.58      0.46  0.33
      0.33      0.33      0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
      0.80      0.28      0.28  0.28
      0.28      0.28      0.28  0.28
      0.28      0.46      0.60  0.60
      0.61      0.57      0.60  0.60
      0.57      0.49      0.39  0.28
      0.28      0.28      0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.3
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   74810.35  0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
   18339.65   1.0
24. Air infiltration for interior and exterior zones (ACH)
   0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
   0.02    30   0.36   110
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
   64.5 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-BFDAD
   1  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 45 55 55 55 85 55 100 55 110

34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
90 20 90 40 90 60 90 70 80 110

35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
40 -120 40 -100 40 -80 40 -44 40 -30

36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
95 160 95 260 95 360 95 460 97 560

C.9: Input Parameters Used in the Heep Center 1997 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)
10 120

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)
2

1.6 The first Vacation period:month, day to month day
5 15 5 22

1.7 The second vacation period:month, day to month day
8 15 8 22

1.8 The third vacation period:month, day to month day
12 23 12 30

1.9 Energy price $/kWh, $/MMBtu-CHW $/MMBtu-HW
0.08 7.00 11.00

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
    158979  0.328
3.  Occupied period: Start and end for Weekday, Saturday, Sunday, Vacation
    7  19  10  14  11  15  10  15
4.  Room temperature for occupied and unoccupied (heating and cooling)
    72  74  72  74
5.  Total flow rate and outside air flow rate (cfm/sq-ft)to interior and exterior zones
    0.89   0.89   0.27  0.27
6.  Minimum air flow for occupied and unoccupied
    0.78   0.78
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
     30       60
14.  Minimum and maximum outside air intake fraction
     0.05   0.9
15. Internal Heat Gain W/sq-ft
     4.0     3.45
16. Average Floor Area For Each Person sq-ft/person
      250
17. Clock Internal Electrical gain Ratio for Weekdays
        0.86        0.40000        0.400000        0.400000
        0.4        0.40000        0.400000        0.400000
        0.4        0.650000       0.8500000        0.8500000
        0.860000   0.820000        0.8500000        0.850000
        0.820000   0.700000        0.550000        0.40000
        0.4        0.40000        0.400000        0.400000
18. Clock Internal Electrical Gain Ratio for Saturday
        0.80        0.33        0.33  0.33
        0.33        0.33        0.33  0.33
        0.33        0.54        0.71  0.71
        0.72        0.68        0.71  0.71
        0.68        0.58        0.46  0.33
        0.33        0.33        0.33  0.33
19. Clock Internal Electrical Gain Ratio for Sunday
```

```
      0.80        0.33        0.33  0.33
      0.33        0.33        0.33  0.33
      0.33        0.54        0.71  0.71
      0.72        0.68        0.71  0.71
      0.68        0.58        0.46  0.33
      0.33        0.33        0.33  0.33
20. Clock Internal Electrical Gain Ratio for Vacation
      0.80        0.28        0.28  0.28
      0.28        0.28        0.28  0.28
      0.28        0.46        0.60  0.60
      0.61        0.57        0.60  0.60
      0.57        0.49        0.39  0.28
      0.28        0.28        0.28  0.28
21. Nighttime Base Electrical Gain Ratio
   0.3
22. Exterior Wall Area (sq-ft) and U value (Btu/sq-ft hr F)
   74810.35  0.074
23. Exterior Window Area (sq-ft) and U value (Btu/sq-ft hr F)
   18339.65   1.0
24. Air infiltration for interior and exterior zones (ACH)
   0   0
25. Solar Gains (Solarmin, Toa; Solarmax, Toa)
   0.02    30   0.36   110
26. Supply air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   64.5 1
27 Return air fan HP and control model(1-VFD, 2-IGV, 3-VSD, 4-DAD, 5-BFIGV, 6-
BFDAD
   1  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
   61  45   58  55   53  85   53  100   53  110
34. Hot Deck Schedule: Th1, Ta1;..... Th5, Ta5
   90  20   90  40   90  60  90  70   80  110
35. Pre-heat deck schedule: Tph1, Ta1;..... Tph5, Ta5
   40  -120   40  -100   40   -80   40  -44   40  -30
36. Pre-cooling Deck Schedule Tpc1, Ta1,..... Tpc5, Ta5
   95  160  95  260  95  360  95  460  97  560
```

APPENDIX D

QUASI-CALIBRATION SIGNATURE PLOTS FOR HEEP CENTER AND MSC

Heep Center

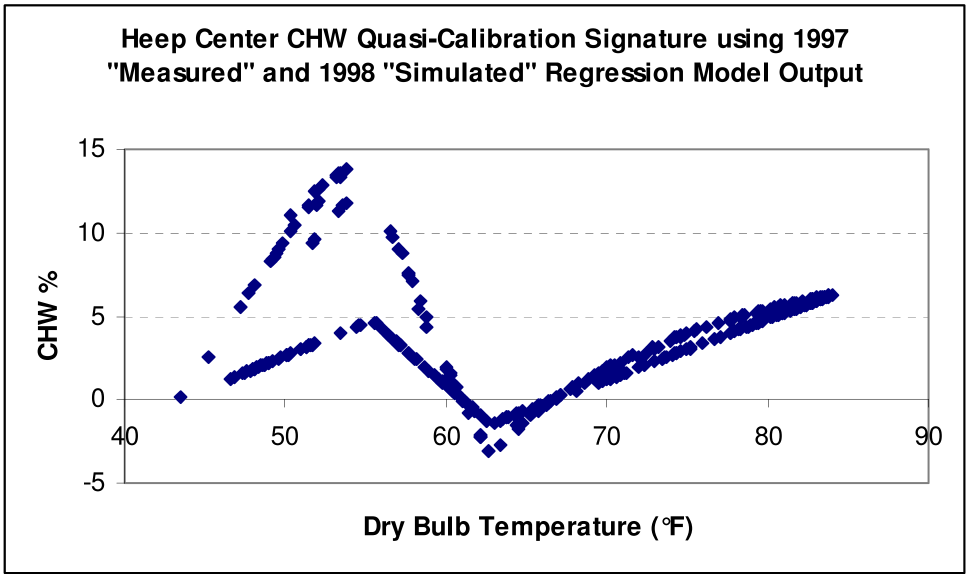

Figure D.1: Heep Center CHW calibration signature 1997→1998.

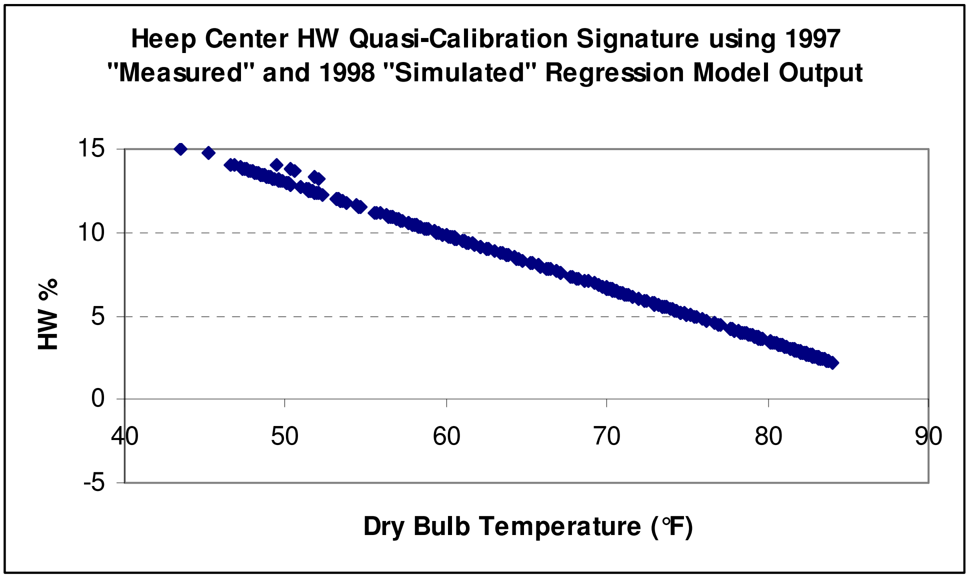

Figure D.2: Heep Center HW calibration signature 1997→1998.

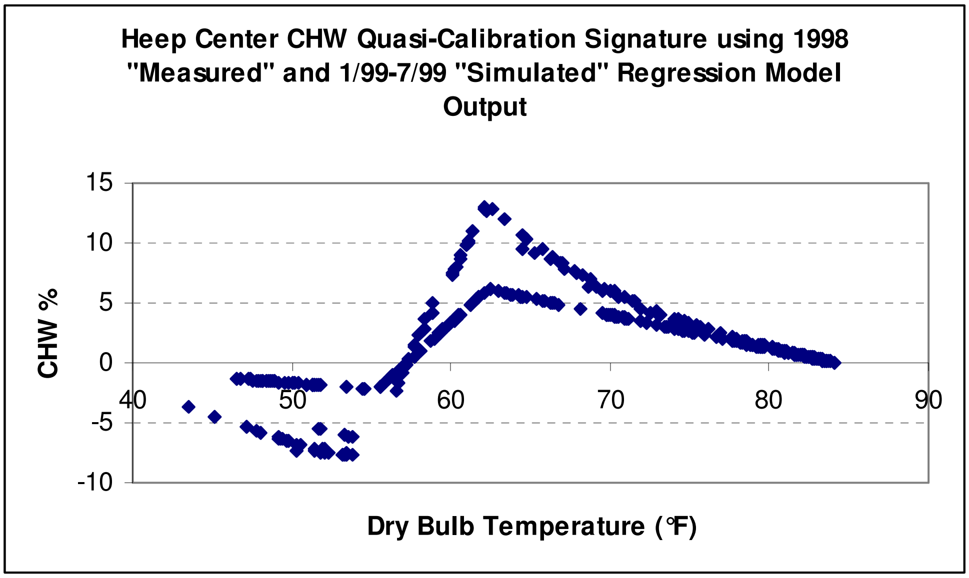

Figure D.3: Heep Center CHW calibration signature 1998→1/99-7/99.

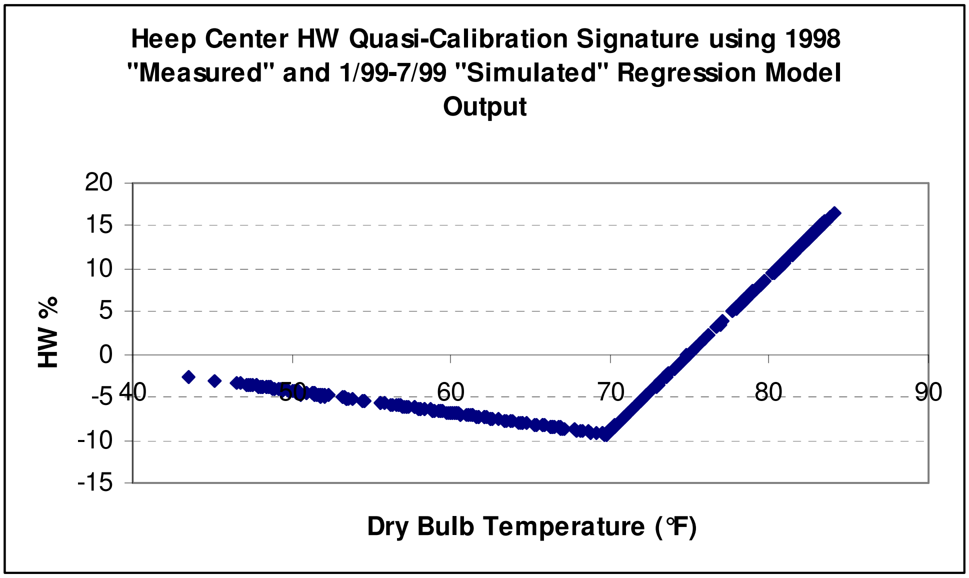

Figure D.4: Heep Center HW calibration signature 1998→1/99-7/99.

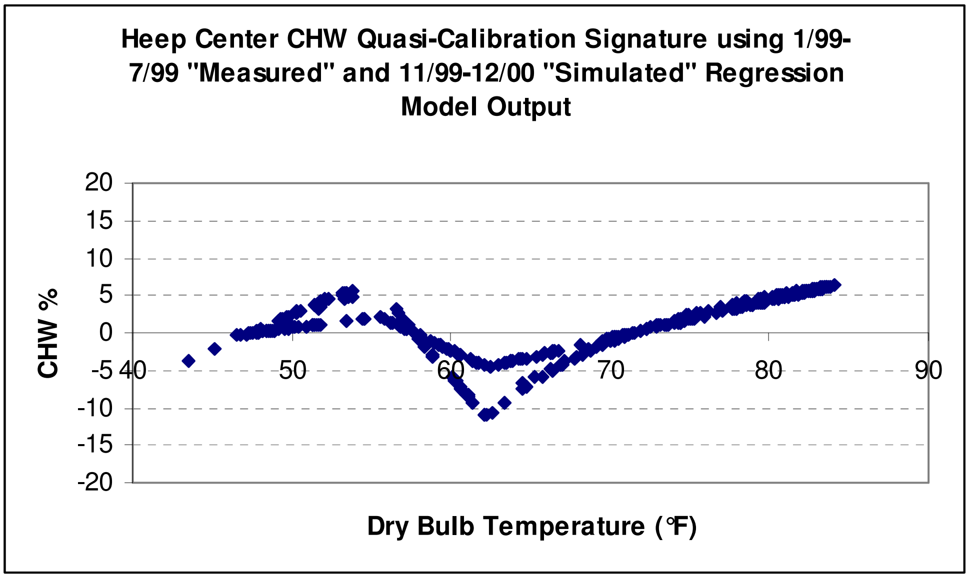

Figure D.5: Heep Center CHW calibration signature 1/99-7/99→11/99-12/00.

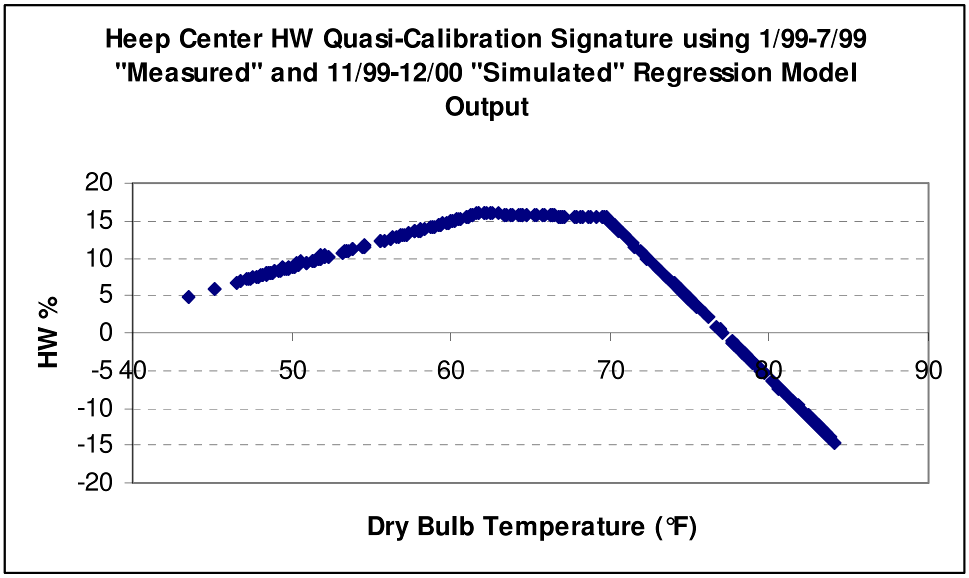

Figure D.6: Heep Center HW calibration signature 1/99-7/99→11/99-12/00.

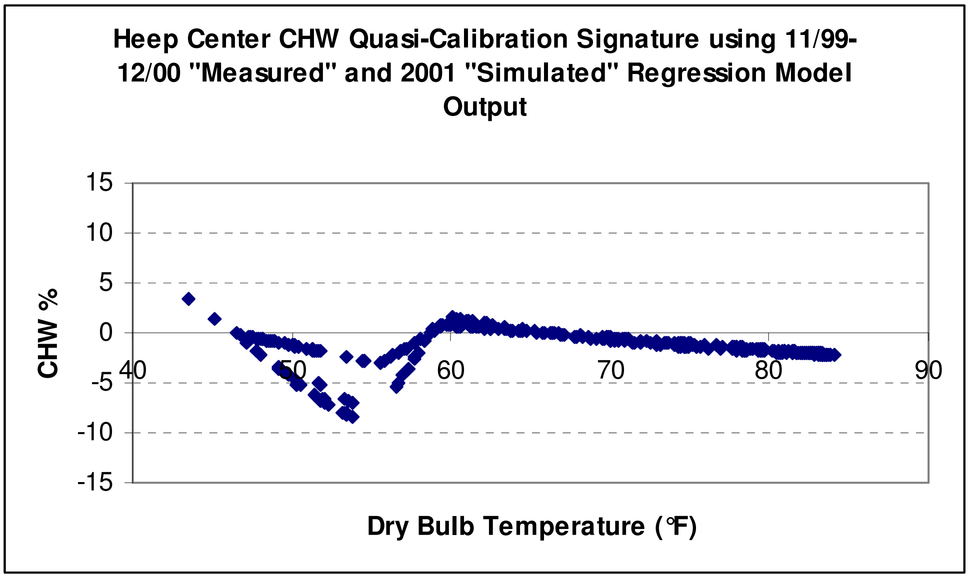

Figure D.7: Heep Center CHW calibration signature 11/99-12/00→2001.

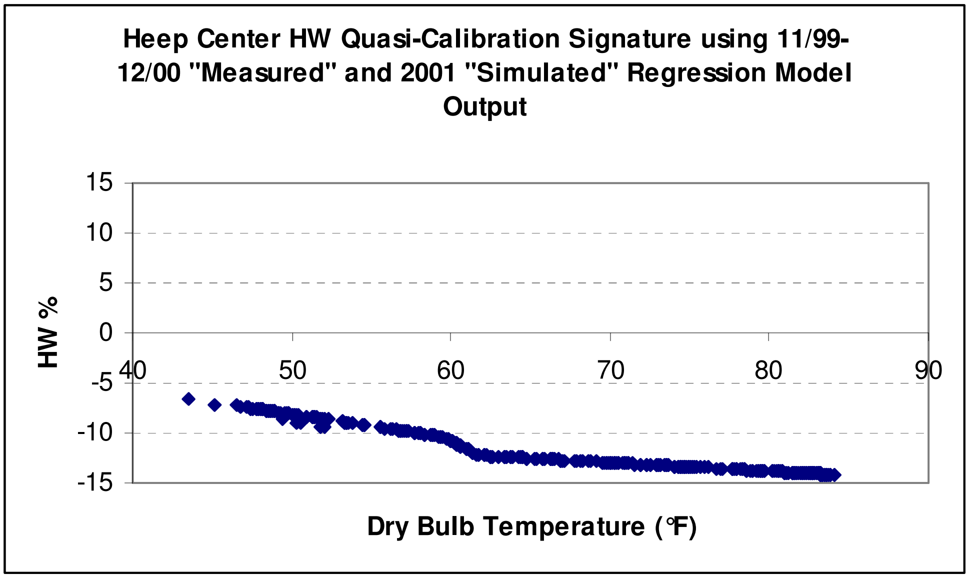

Figure D.8: Heep Center HW calibration signature 11/99→2001.

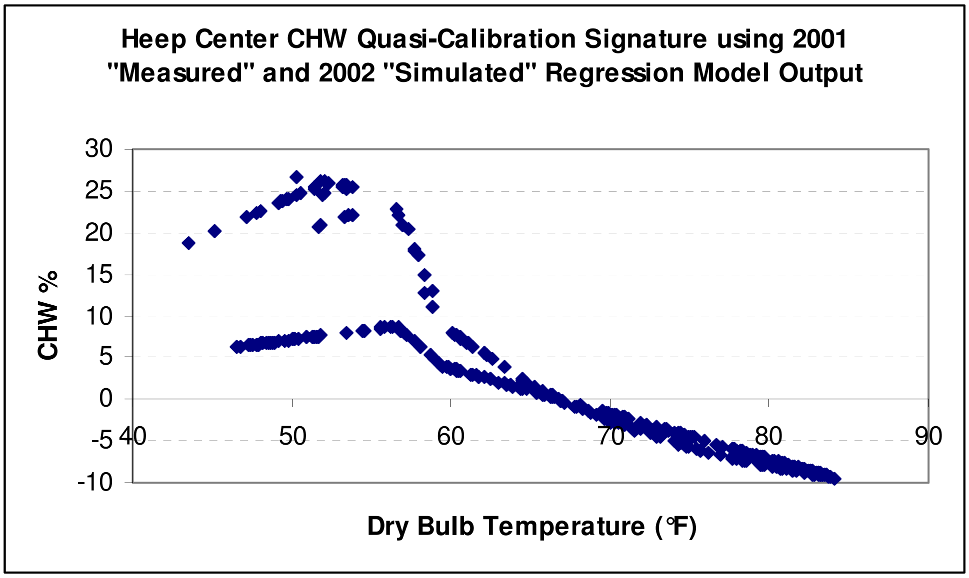

Figure D.9: Heep Center CHW calibration signature 2001→2002.

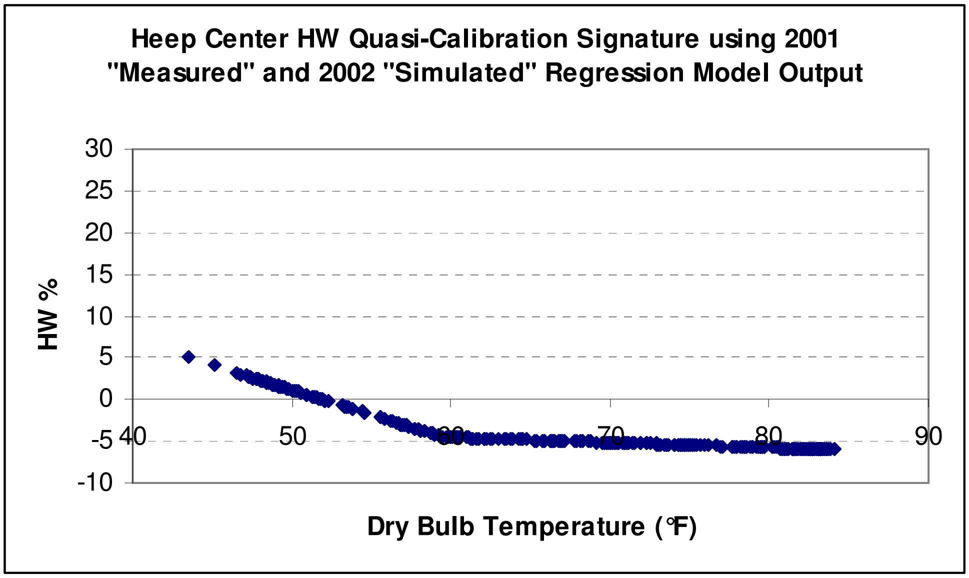

Figure D.10: Heep Center HW calibration signature 2001→2002.

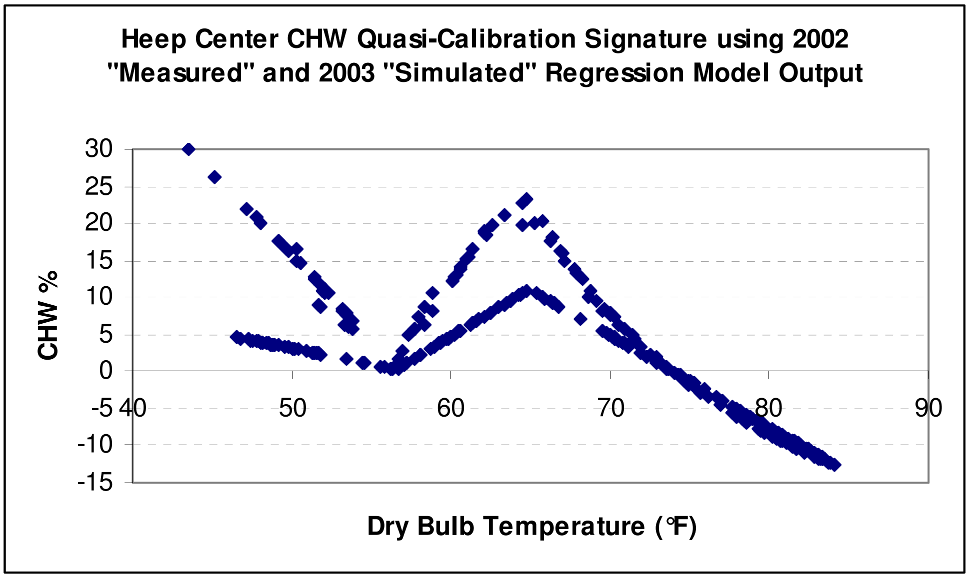

Figure D.11: Heep Center CHW calibration signature 2002→2003.

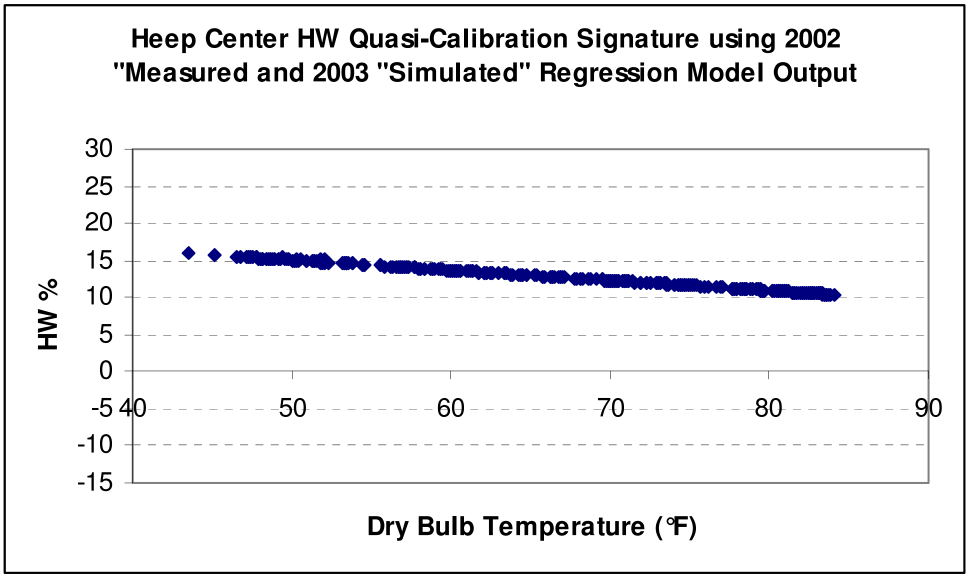

Figure D.12: Heep Center HW calibration signature 2002→2003.

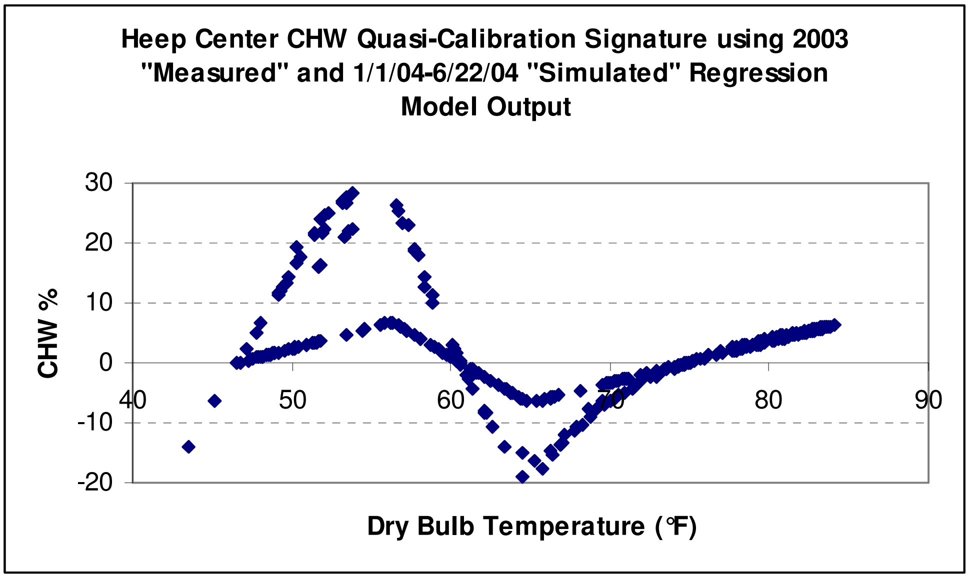

Figure D.13: Heep Center CHW calibration signature 2003→1/1/04-6/22/04.

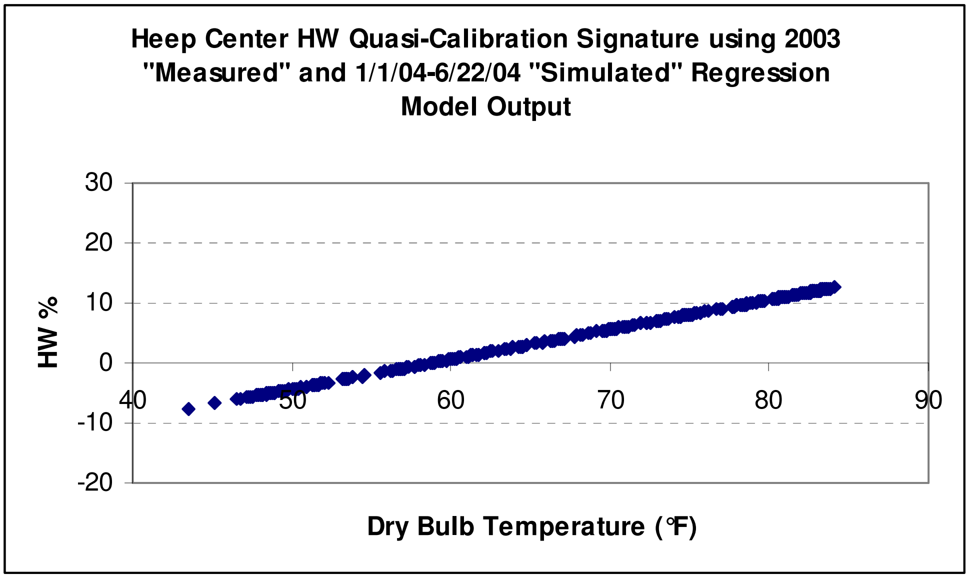

Figure D.14: Heep Center HW calibration signature 2003→1/1/04-6/22/04.

MSC

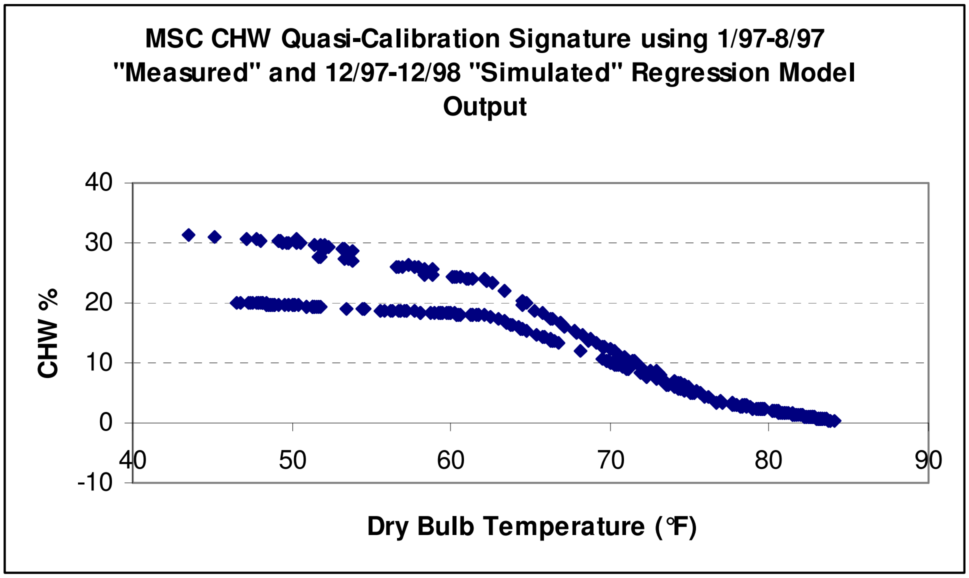

Figure D.15: MSC CHW calibration signature 1/97-8/97→12/97-12/98.

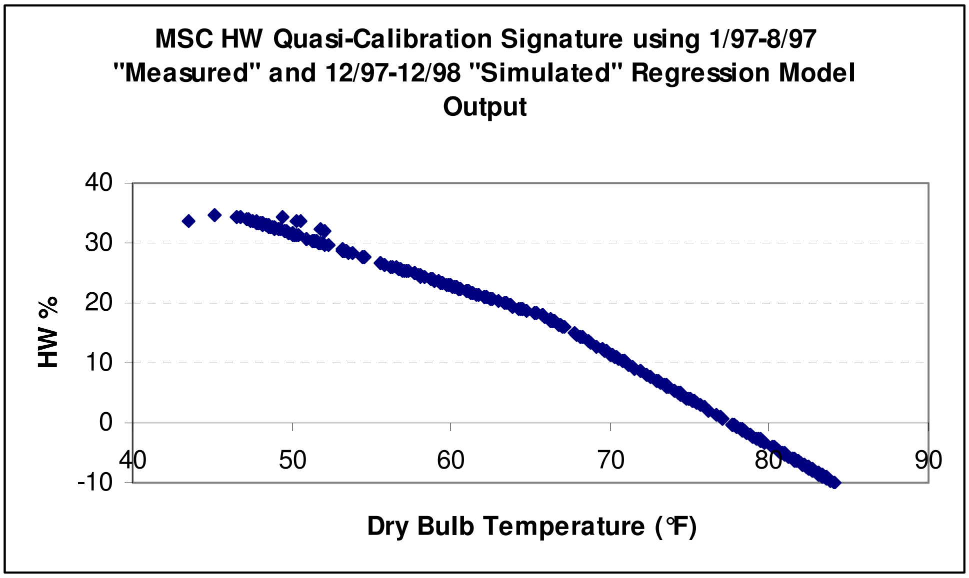

Figure D.16: MSC HW calibration signature 1/97-8/97→12/97-12/98.

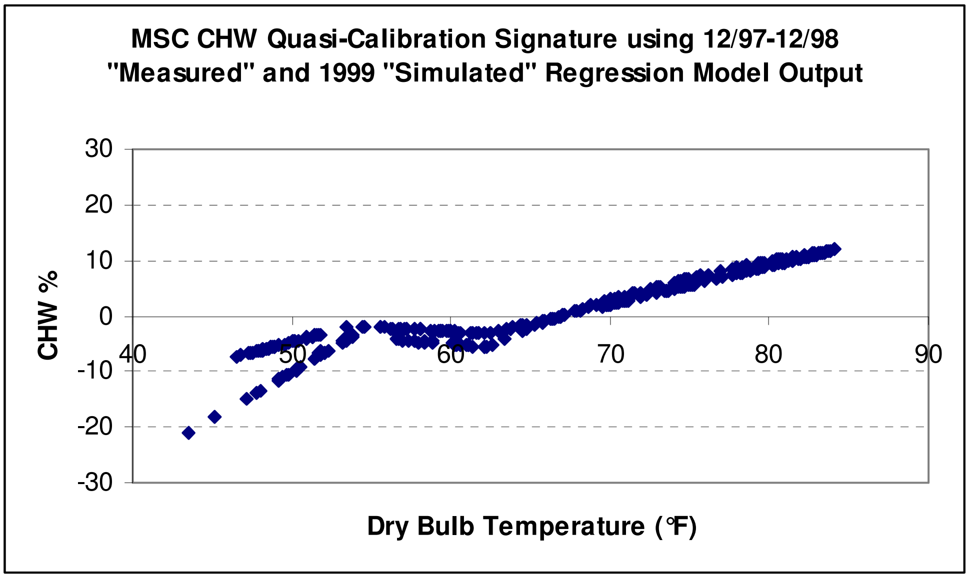

Figure D.17: MSC CHW calibration signature 12/97-12/98→1999.

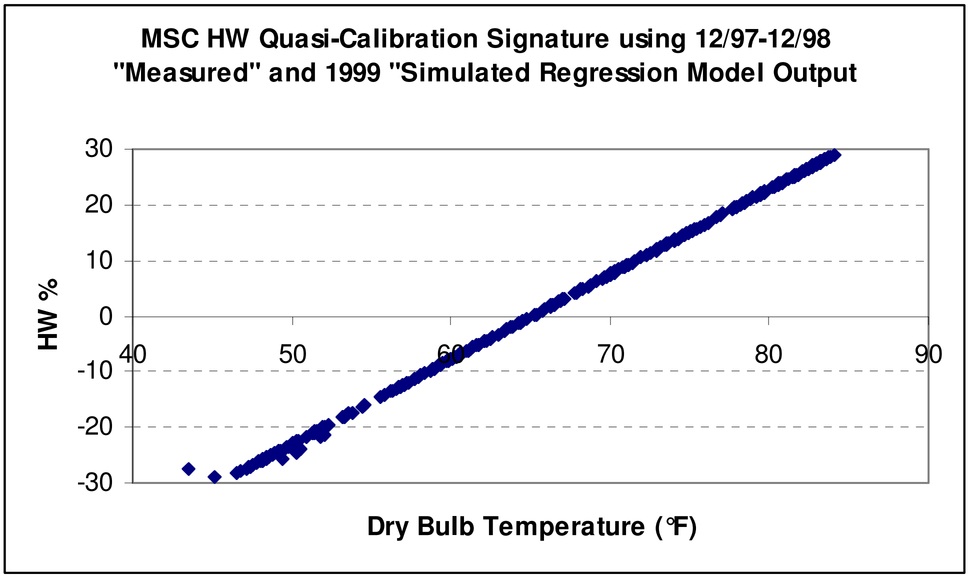

Figure D.18: MSC HW calibration signature 12/97-12/98→1999.

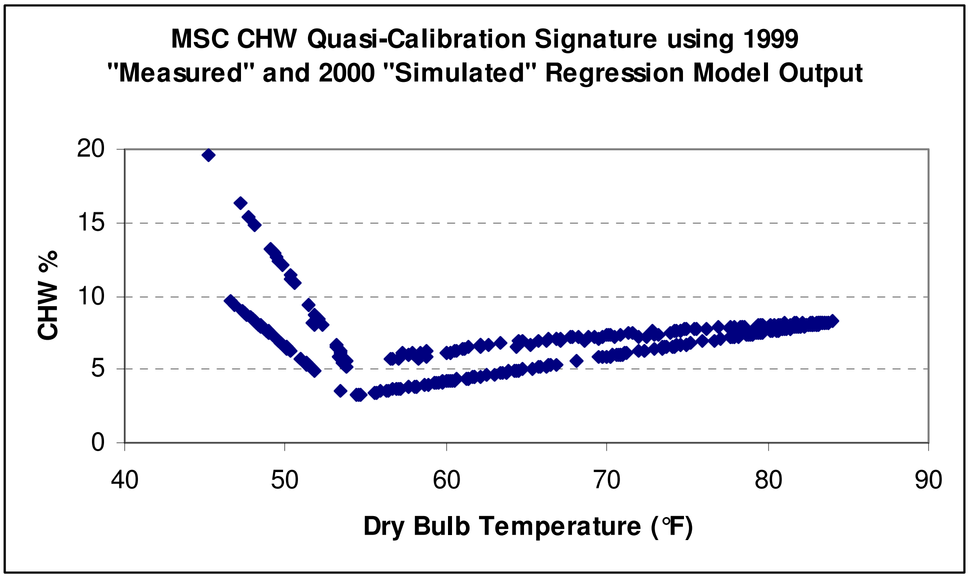

Figure D.19: MSC CHW calibration signature 1999→2000.

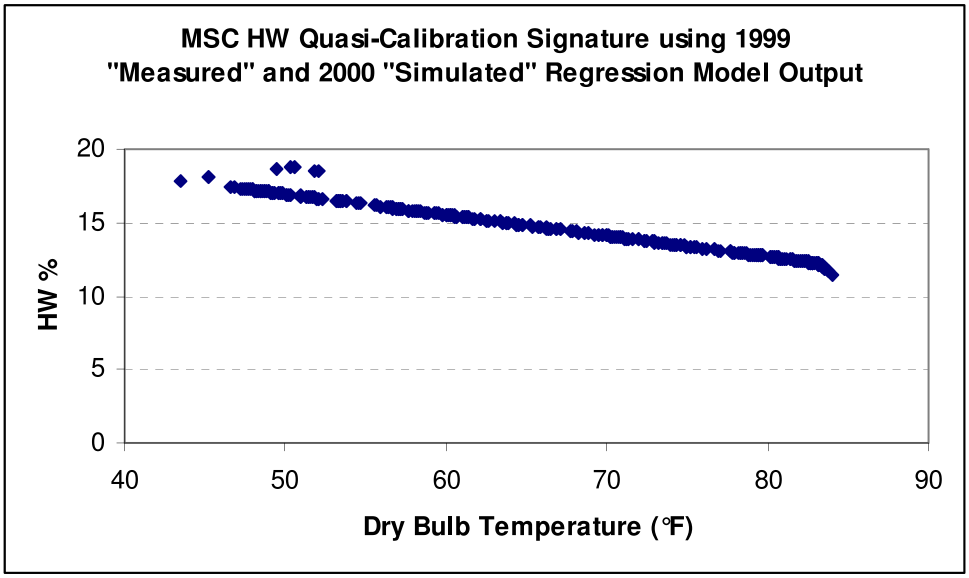

Figure D.20: MSC HW calibration signature 1999→2000.

APPENDIX E

MSC COMMISSIONING MEASURES

The following is a list of commissioning measures that were recommended but not implemented during the commissioning that took place between September and November of 1997. This list was given to the Energy Office of Texas A&M University to complete when feasible.

1. Replace/repair the control valves on the return HW line and the pump discharge line and the pump discharge line for Main MSC HW loop.
2. Repair/replace the manual valve before the check valve in the blending station for board of Regent HW loop.
3. Replace/repair the OA fan (SF 1) for AHUs 1, 3, MB5, 12, 13, 17, and 18. All these AHUs are served by one OA fan. The CC team will revisit to balance the OA intakes for each AHU after the OA fan is replaced/repaired.
4. Clean the reheat coils for AHU 9 and 10 in the kitchen area.
5. Replace the incandescent light bulbs in the dining area near the Halla Balloo area served by AHU 4 with energy efficient fluorescent bulbs. Currently, approximately 100 kBtu/h of heat is being generated by these incandescent bulbs.
6. Clean the reheat coils for AHU 31.
7. Since the building is suffering from negative pressurization, excessive outside air is drawn through the doors, windows, and other openings. At the same time, conditioned air is being exhausted through the kitchen hoods, resulting in excessive energy waste. It is suspected that the makeup air fans have been turned off because the makeup air is not conditioned and this creates a large cooling load in the summer resulting in the kitchen being too hot. However, since the kitchen is only operated certain time of the days, we recommend that the makeup fans be interlocked with the kitchen exhaust fans and run both exhaust and makeup fans only during cooking and service hours. This can be achieved by either installing weekly timers or installing ON/OFF points in the

Landis & Staefa control system. In addition to turning the makeup air fans on based on kitchen schedule, please refer to recommendations # 3 and 4. SF 1 supplies OA to AHU MB5 which served Halla Balloo and AHUs 9 and 10 supplies OA to the first floor kitchen.

APPENDIX F

CONSUMPTION AND SAVINGS RESULTS USING DIFFERENT WEATHER NORMALIZATION APPROACHES AND IPMVP SAVINGS OPTIONS

Results from MBE Adjusted Option D (Calibrated Simulations) with College Station Weather

NAC Weather Normalization Approach

Table F.1: CE/TTI chilled water annual consumption (MMBtu/yr) using different College Station weather years with AirModel calibrated simulations (MBE adjusted). Ranges are shown in bold.

Weather Data Year	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Range**
1973	16751	15981	15339	14666	14386	15572	13031	**3720**
1974	16705	15921	15300	14652	14389	15579	13009	**3696**
1975	16646	15874	15231	14565	14294	15481	12950	**3695**
1976	16065	15267	14676	13991	13797	14972	12574	**3491**
1977	17175	16421	15784	15122	14826	15994	13364	**3811**
1978	17306	16583	15928	15221	14927	16096	13502	**3804**
1979	16022	15238	14654	13962	13795	14976	12593	**3429**
1980	17322	16575	15908	15210	14911	16089	13495	**3827**
1981	17737	17009	16266	15568	15152	16348	13675	**4063**
1983	16326	15558	14942	14226	14002	15177	12773	**3553**
1984	17250	16505	15877	15239	14914	16088	13399	**3850**
1985	17342	16607	15944	15251	14929	16114	13486	**3856**
1989	17130	16387	15734	15049	14748	15932	13330	**3800**
1990	17998	17248	16539	15885	15493	16687	13905	**4093**
1991	17317	16581	15893	15209	14849	16037	13405	**3912**
1992	16978	16208	15577	14933	14642	15821	13198	**3781**
1993	16962	16202	15557	14855	14571	15749	13210	**3752**
1994	17606	16866	16167	15504	15125	16309	13599	**4007**
1996	18874	18182	17368	16686	16172	17372	14486	**4388**
1997	17017	16253	15579	14878	14586	15765	13232	**3784**
1998	18564	17840	17066	16376	15910	17103	14285	**4279**
1999	17763	17004	16311	15685	15300	16492	13706	**4057**
2000	17972	17247	16540	15866	15468	16654	13894	**4078**
2001	17850	17123	16397	15715	15305	16489	13781	**4069**
2002	17477	16748	16056	15355	14980	16164	13524	**3954**
2003	17460	16731	16039	15360	14981	16161	13492	**3968**
2004	17938	17200	16481	15835	15416	16606	13819	**4118**
2005	17801	17071	16407	15768	15390	16562	13785	**4016**
Avg Yr	16800	16024	15409	14745	14469	15639	13069	**3732**
Range	**2852**	**2943**	**2714**	**2724**	**2377**	**2400**	**1912**	959

Table F.2: CE/TTI chilled water annual savings (MMBtu/yr) using different College Station weather years with AirModel calibrated simulations (MBE adjusted). Ranges are shown in bold.

Weather Data Year	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Range**
1973	Baseline	770	1413	2086	2365	1180	3720	**2950**
1974	Baseline	784	1405	2052	2316	1126	3696	**2912**
1975	Baseline	772	1414	2081	2352	1165	3695	**2924**
1976	Baseline	798	1389	2074	2268	1093	3491	**2693**
1977	Baseline	755	1391	2054	2349	1181	3811	**3056**
1978	Baseline	723	1378	2085	2379	1210	3804	**3082**
1979	Baseline	784	1368	2060	2227	1047	3429	**2645**
1980	Baseline	747	1414	2112	2411	1234	3827	**3080**
1981	Baseline	728	1472	2169	2586	1390	4063	**3334**
1983	Baseline	768	1384	2101	2324	1149	3553	**2785**
1984	Baseline	744	1372	2011	2335	1161	3850	**3106**
1985	Baseline	735	1399	2091	2413	1229	3856	**3122**
1989	Baseline	743	1397	2081	2382	1198	3800	**3057**
1990	Baseline	750	1459	2113	2504	1311	4093	**3343**
1991	Baseline	737	1425	2108	2468	1280	3912	**3176**
1992	Baseline	771	1401	2046	2336	1157	3781	**3010**
1993	Baseline	760	1405	2107	2391	1213	3752	**2992**
1994	Baseline	741	1439	2102	2482	1297	4007	**3266**
1996	Baseline	692	1506	2189	2702	1502	4388	**3696**
1997	Baseline	764	1438	2139	2431	1252	3784	**3020**
1998	Baseline	724	1498	2188	2654	1461	4279	**3555**
1999	Baseline	758	1452	2077	2462	1271	4057	**3299**
2000	Baseline	726	1432	2107	2505	1318	4078	**3353**
2001	Baseline	727	1453	2135	2545	1361	4069	**3342**
2002	Baseline	729	1422	2122	2497	1314	3954	**3224**
2003	Baseline	729	1420	2100	2479	1299	3968	**3239**
2004	Baseline	737	1457	2103	2522	1331	4118	**3381**
2005	Baseline	730	1394	2033	2411	1239	4016	**3286**
Norm Yr	Baseline	777	1392	2056	2331	1161	3732	**2955**
	Range	**105**	**138**	**178**	**475**	**455**	**959**	**1050**

Table F.3: CE/TTI chilled water annual percent savings (MMBtu/yr) using different College Station weather years with AirModel calibrated simulations (MBE adjusted). Range and range/average values are shown in bold.

Weather Data Year	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Range**
1973	Baseline	4.60%	8.43%	12.45%	14.12%	7.04%	22.21%	**17.61%**
1974	Baseline	4.69%	8.41%	12.29%	13.86%	6.74%	22.12%	**17.43%**
1975	Baseline	4.64%	8.50%	12.50%	14.13%	7.00%	22.20%	**17.56%**
1976	Baseline	4.97%	8.64%	12.91%	14.12%	6.80%	21.73%	**16.76%**
1977	Baseline	4.39%	8.10%	11.96%	13.68%	6.88%	22.19%	**17.79%**
1978	Baseline	4.18%	7.96%	12.05%	13.75%	6.99%	21.98%	**17.81%**
1979	Baseline	4.89%	8.54%	12.86%	13.90%	6.53%	21.40%	**16.51%**
1980	Baseline	4.31%	8.17%	12.19%	13.92%	7.12%	22.09%	**17.78%**
1981	Baseline	4.11%	8.30%	12.23%	14.58%	7.83%	22.90%	**18.80%**
1983	Baseline	4.71%	8.48%	12.87%	14.24%	7.04%	21.76%	**17.06%**
1984	Baseline	4.31%	7.96%	11.66%	13.54%	6.73%	22.32%	**18.01%**
1985	Baseline	4.24%	8.06%	12.06%	13.91%	7.08%	22.24%	**18.00%**
1989	Baseline	4.34%	8.15%	12.15%	13.91%	6.99%	22.18%	**17.84%**
1990	Baseline	4.17%	8.10%	11.74%	13.92%	7.28%	22.74%	**18.58%**
1991	Baseline	4.25%	8.23%	12.18%	14.25%	7.39%	22.59%	**18.34%**
1992	Baseline	4.54%	8.25%	12.05%	13.76%	6.82%	22.27%	**17.73%**
1993	Baseline	4.48%	8.28%	12.42%	14.10%	7.15%	22.12%	**17.64%**
1994	Baseline	4.21%	8.18%	11.94%	14.10%	7.37%	22.76%	**18.55%**
1996	Baseline	3.67%	7.98%	11.60%	14.32%	7.96%	23.25%	**19.58%**
1997	Baseline	4.49%	8.45%	12.57%	14.28%	7.36%	22.24%	**17.75%**
1998	Baseline	3.90%	8.07%	11.79%	14.30%	7.87%	23.05%	**19.15%**
1999	Baseline	4.27%	8.17%	11.70%	13.86%	7.15%	22.84%	**18.57%**
2000	Baseline	4.04%	7.97%	11.72%	13.94%	7.33%	22.69%	**18.66%**
2001	Baseline	4.07%	8.14%	11.96%	14.26%	7.62%	22.79%	**18.72%**
2002	Baseline	4.17%	8.13%	12.14%	14.29%	7.52%	22.62%	**18.45%**
2003	Baseline	4.18%	8.14%	12.03%	14.20%	7.44%	22.73%	**18.55%**
2004	Baseline	4.11%	8.12%	11.72%	14.06%	7.42%	22.96%	**18.85%**
2005	Baseline	4.10%	7.83%	11.42%	13.54%	6.96%	22.56%	**18.46%**
Norm Yr	Baseline	4.62%	8.28%	12.24%	13.87%	6.91%	22.21%	**17.59%**
	Range	**1.30%**	**0.81%**	**1.49%**	**1.04%**	**1.42%**	**1.84%**	**3.07%**
	Range/Avg	**29.94%**	**9.90%**	**12.27%**	**7.40%**	**19.81%**	**8.23%**	**16.98%**

Table F.4: CE/TTI hot water annual consumption (MMBtu/yr) using different College Station weather years with AirModel calibrated simulations (MBE adjusted). Ranges are shown in bold.

Weather Data Year	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Range**
1973	3893	3184	2999	2924	3285	4015	3309	**1091**
1974	3751	3039	2863	2809	3169	3904	3192	**1095**
1975	3797	3086	2905	2840	3209	3933	3232	**1093**
1976	4043	3317	3110	3002	3376	4139	3458	**1137**
1977	3818	3112	2930	2861	3228	3941	3230	**1080**
1978	4165	3474	3263	3155	3526	4278	3562	**1122**
1979	4275	3558	3334	3212	3615	4397	3696	**1185**
1980	3979	3264	3065	2968	3340	4088	3392	**1119**
1981	3718	3012	2832	2758	3101	3818	3124	**1061**
1983	4271	3551	3320	3179	3565	4341	3656	**1162**
1984	3586	2889	2735	2693	3020	3734	3012	**1040**
1985	3954	3260	3064	2965	3328	4074	3360	**1109**
1989	4035	3335	3133	3044	3415	4158	3430	**1114**
1990	3572	2856	2698	2658	3003	3713	2991	**1055**
1991	3713	3014	2836	2757	3103	3825	3127	**1068**
1992	3603	2890	2719	2670	3028	3741	3037	**1071**
1993	3883	3168	2967	2844	3204	3967	3294	**1123**
1994	3579	2877	2714	2662	3010	3709	2999	**1047**
1996	3643	2954	2793	2761	3105	3792	3054	**1031**
1997	3961	3249	3043	2944	3322	4053	3373	**1110**
1998	3604	2902	2733	2678	3000	3712	3011	**1035**
1999	3375	2666	2525	2523	2853	3542	2814	**1019**
2000	3630	2942	2770	2711	3046	3758	3047	**1047**
2001	3705	3007	2829	2767	3100	3813	3113	**1047**
2002	3789	3093	2906	2812	3133	3874	3181	**1062**
2003	3664	2977	2800	2731	3059	3774	3071	**1043**
2004	3474	2779	2635	2619	2945	3628	2901	**1008**
2005	3516	2817	2666	2638	2957	3655	2931	**1017**
Avg Yr	3642	2921	2739	2659	3007	3737	3058	**1078**
Range	**900**	**892**	**809**	**689**	**761**	**855**	**882**	**176**

Table F.5: CE/TTI hot water annual savings (MMBtu/yr) using different College Station weather years with AirModel calibrated simulations (MBE adjusted). Ranges are shown in bold.

Weather Data Year	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Range**
1973	Baseline	709	894	969	607	-122	584	**1091**
1974	Baseline	712	888	943	582	-153	560	**1095**
1975	Baseline	710	892	956	587	-136	564	**1093**
1976	Baseline	726	933	1041	667	-96	585	**1137**
1977	Baseline	706	888	957	589	-123	588	**1080**
1978	Baseline	691	902	1010	639	-113	603	**1122**
1979	Baseline	717	942	1063	661	-121	580	**1185**
1980	Baseline	715	914	1011	639	-109	587	**1119**
1981	Baseline	706	886	960	617	-101	593	**1061**
1983	Baseline	720	950	1091	705	-70	614	**1162**
1984	Baseline	697	851	893	566	-148	573	**1040**
1985	Baseline	694	890	988	625	-120	593	**1109**
1989	Baseline	700	902	991	620	-123	604	**1114**
1990	Baseline	716	874	914	569	-141	581	**1055**
1991	Baseline	699	877	956	610	-111	586	**1068**
1992	Baseline	712	883	933	574	-139	566	**1071**
1993	Baseline	716	917	1039	679	-84	589	**1123**
1994	Baseline	703	866	917	569	-130	581	**1047**
1996	Baseline	690	850	883	539	-148	589	**1031**
1997	Baseline	713	918	1018	639	-92	588	**1110**
1998	Baseline	702	871	927	604	-108	593	**1035**
1999	Baseline	710	850	853	522	-167	561	**1019**
2000	Baseline	687	859	918	583	-129	582	**1047**
2001	Baseline	698	876	938	604	-109	592	**1047**
2002	Baseline	696	883	977	656	-85	608	**1062**
2003	Baseline	687	864	933	605	-110	593	**1043**
2004	Baseline	695	839	854	528	-154	572	**1008**
2005	Baseline	699	850	879	560	-139	586	**1017**
Norm Yr	Baseline	720	903	983	635	-95	584	**1078**
	Range	**39**	**111**	**239**	**184**	**96**	**54**	**176**

Table F.6: CE/TTI hot water annual percent savings (MMBtu/yr) using different College Station weather years with AirModel calibrated simulations (MBE adjusted). Range and range/average values are shown in bold.

Weather Data Year	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Range**
1973	Baseline	18.21%	22.97%	24.90%	15.61%	-3.14%	15.00%	**28.04%**
1974	Baseline	18.98%	23.68%	25.13%	15.51%	-4.07%	14.92%	**29.20%**
1975	Baseline	18.71%	23.49%	25.19%	15.47%	-3.59%	14.86%	**28.78%**
1976	Baseline	17.95%	23.08%	25.75%	16.49%	-2.38%	14.46%	**28.13%**
1977	Baseline	18.49%	23.26%	25.06%	15.44%	-3.23%	15.40%	**28.29%**
1978	Baseline	16.59%	21.66%	24.24%	15.34%	-2.70%	14.47%	**26.95%**
1979	Baseline	16.78%	22.03%	24.87%	15.45%	-2.83%	13.56%	**27.71%**
1980	Baseline	17.96%	22.97%	25.40%	16.05%	-2.73%	14.74%	**28.13%**
1981	Baseline	18.98%	23.82%	25.82%	16.59%	-2.71%	15.96%	**28.53%**
1983	Baseline	16.86%	22.25%	25.55%	16.52%	-1.65%	14.38%	**27.20%**
1984	Baseline	19.44%	23.72%	24.89%	15.78%	-4.12%	15.99%	**29.01%**
1985	Baseline	17.55%	22.51%	24.99%	15.81%	-3.05%	15.01%	**28.04%**
1989	Baseline	17.35%	22.35%	24.56%	15.36%	-3.06%	14.98%	**27.62%**
1990	Baseline	20.05%	24.46%	25.59%	15.94%	-3.95%	16.27%	**29.53%**
1991	Baseline	18.83%	23.62%	25.76%	16.43%	-3.00%	15.78%	**28.76%**
1992	Baseline	19.77%	24.52%	25.89%	15.94%	-3.85%	15.71%	**29.74%**
1993	Baseline	18.43%	23.61%	26.77%	17.49%	-2.15%	15.17%	**28.92%**
1994	Baseline	19.64%	24.18%	25.62%	15.90%	-3.63%	16.22%	**29.25%**
1996	Baseline	18.93%	23.33%	24.23%	14.79%	-4.07%	16.17%	**28.30%**
1997	Baseline	18.00%	23.18%	25.69%	16.14%	-2.32%	14.85%	**28.01%**
1998	Baseline	19.48%	24.17%	25.71%	16.76%	-2.99%	16.47%	**28.71%**
1999	Baseline	21.02%	25.19%	25.26%	15.46%	-4.94%	16.63%	**30.20%**
2000	Baseline	18.94%	23.68%	25.30%	16.08%	-3.55%	16.04%	**28.85%**
2001	Baseline	18.84%	23.64%	25.32%	16.31%	-2.94%	15.98%	**28.26%**
2002	Baseline	18.36%	23.31%	25.78%	17.31%	-2.25%	16.04%	**28.03%**
2003	Baseline	18.74%	23.57%	25.46%	16.51%	-3.01%	16.19%	**28.47%**
2004	Baseline	20.01%	24.15%	24.59%	15.21%	-4.44%	16.47%	**29.03%**
2005	Baseline	19.88%	24.18%	24.99%	15.92%	-3.95%	16.65%	**28.93%**
Norm Yr	Baseline	19.78%	24.79%	26.98%	17.43%	-2.61%	16.02%	**29.60%**
	Range	**4.43%**	**3.53%**	**2.76%**	**2.70%**	**3.29%**	**3.09%**	**3.25%**
	Range/Avg	**23.69%**	**15.03%**	**10.87%**	**16.82%**	**-102.69%**	**19.90%**	**11.39%**

Standard IPMVP Weather Normalization Approach

Table F.7: Sequence of College Station weather years for 29 different random runs used for both AirModel and regression models with the standard IPMVP weather normalization approach.

Run	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04
1	1984	1993	1993	1980	1985	1984	2001
2	1991	1984	1976	1999	1998	1993	1974
3	1978	1977	1998	2001	1984	1991	1999
4	2001	1979	2005	1978	2005	1978	1991
5	1998	1992	1981	2003	2005	1998	1998
6	2004	1980	1996	1975	1979	1985	2004
7	1990	1976	2000	1992	1981	1990	2000
8	1996	1990	1973	1999	2004	2002	Avg Yr
9	1992	Avg Yr	Avg Yr	1996	2002	1985	Avg Yr r
10	1980	1990	1983	1997	1999	1978	1990
11	2002	2000	1997	1994	1977	1983	1999
12	1977	2004	1993	1996	1973	1984	2001
13	1996	1991	1985	1990	2005	1994	2003
14	1977	1991	2000	2000	1984	1985	2001
15	1996	1973	1998	1990	1999	1997	1997
16	1981	1993	1975	2003	2002	1975	2004
17	1985	1974	1978	2001	2000	1985	Avg Yr
18	1977	1975	1981	1973	1997	2004	1984
19	1976	1999	Avg Yr	1996	1999	2002	2000
20	1978	2004	1973	2004	1998	2002	1990
21	1998	Avg Yr	1985	1979	1985	1996	1984
22	1990	1992	1985	2002	2001	1989	1992
23	1992	1994	1989	1989	1976	1991	1981
24	1984	1981	Avg Yr	1999	2001	1978	2001
25	1976	2004	1990	1977	1999	2000	1979
26	1974	1979	1996	1980	1998	1977	1978
27	1983	2004	1993	1979	2003	1978	2000
28	1998	1994	2000	1997	1981	1999	2003
29	2003	1999	1983	1973	1996	1975	1996

Table F.8: CE/TTI chilled water savings (MMBtu/yr) using random runs with different College Station weather years with standard IPMVP weather normalization approach and AirModel calibrated simulations (MBE adjusted). Ranges are shown in bold.

Rand Run	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Range
1	Baseline	760	1405	2112	2413	1161	4069	**3308**
2	Baseline	744	1389	2077	2654	1213	3696	**2952**
3	Baseline	755	1498	2135	2335	1280	4057	**3303**
4	Baseline	784	1394	2085	2411	1210	3912	**3128**
5	Baseline	771	1472	2100	2411	1461	4279	**3509**
6	Baseline	747	1506	2081	2227	1229	4118	**3371**
7	Baseline	798	1432	2046	2586	1311	4078	**3281**
8	Baseline	750	1413	2077	2522	1314	3732	**2982**
9	Baseline	777	1392	2189	2497	1229	3732	**2955**
10	Baseline	750	1384	2139	2462	1210	4093	**3343**
11	Baseline	726	1438	2102	2349	1149	4057	**3332**
12	Baseline	737	1405	2189	2365	1161	4069	**3331**
13	Baseline	737	1399	2113	2411	1297	3968	**3231**
14	Baseline	737	1432	2107	2335	1229	4069	**3332**
15	Baseline	770	1498	2113	2462	1252	3784	**3014**
16	Baseline	760	1414	2100	2497	1165	4118	**3358**
17	Baseline	784	1378	2135	2505	1229	3732	**2948**
18	Baseline	772	1472	2086	2431	1331	3850	**3078**
19	Baseline	758	1392	2189	2462	1314	4078	**3320**
20	Baseline	737	1413	2103	2654	1314	4093	**3356**
21	Baseline	777	1399	2060	2413	1502	3850	**3074**
22	Baseline	771	1399	2122	2545	1198	3781	**3010**
23	Baseline	741	1397	2081	2268	1280	4063	**3322**
24	Baseline	728	1392	2077	2545	1210	4069	**3340**
25	Baseline	737	1459	2054	2462	1318	3429	**2692**
26	Baseline	784	1506	2112	2654	1181	3804	**3020**
27	Baseline	737	1405	2060	2479	1210	4078	**3341**
28	Baseline	741	1432	2139	2586	1271	3968	**3227**
29	Baseline	758	1384	2086	2702	1165	4388	**3630**
	Range	**72**	**128**	**143**	**475**	**353**	**959**	**938**

Table F.9: CE/TTI chilled water percent savings using random runs with different College Station weather years with standard IPMVP weather normalization approach and AirModel calibrated simulations (MBE adjusted). Range and range/average values are shown in bold.

Rand Run	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Range**
1	Baseline	4.41%	8.14%	12.24%	13.99%	6.73%	23.59%	**19.18%**
2	Baseline	4.30%	8.02%	12.00%	15.32%	7.00%	21.34%	**17.04%**
3	Baseline	4.36%	8.66%	12.33%	13.49%	7.40%	23.44%	**19.08%**
4	Baseline	4.39%	7.81%	11.68%	13.51%	6.78%	21.92%	**17.53%**
5	Baseline	4.15%	7.93%	11.31%	12.99%	7.87%	23.05%	**18.90%**
6	Baseline	4.16%	8.40%	11.60%	12.42%	6.85%	22.96%	**18.79%**
7	Baseline	4.43%	7.96%	11.37%	14.37%	7.28%	22.66%	**18.23%**
8	Baseline	3.97%	7.48%	11.01%	13.36%	6.96%	19.77%	**15.80%**
9	Baseline	4.57%	8.20%	12.89%	14.71%	7.24%	21.98%	**17.40%**
10	Baseline	4.33%	7.99%	12.35%	14.22%	6.99%	23.63%	**19.30%**
11	Baseline	4.15%	8.23%	12.03%	13.44%	6.57%	23.21%	**19.06%**
12	Baseline	4.29%	8.18%	12.74%	13.77%	6.76%	23.69%	**19.39%**
13	Baseline	3.90%	7.41%	11.19%	12.77%	6.87%	21.02%	**17.12%**
14	Baseline	4.29%	8.34%	12.27%	13.60%	7.15%	23.69%	**19.40%**
15	Baseline	4.08%	7.94%	11.19%	13.05%	6.63%	20.05%	**15.97%**
16	Baseline	4.29%	7.97%	11.84%	14.08%	6.57%	23.22%	**18.93%**
17	Baseline	4.52%	7.94%	12.31%	14.44%	7.08%	21.52%	**17.00%**
18	Baseline	4.49%	8.57%	12.14%	14.15%	7.75%	22.42%	**17.92%**
19	Baseline	4.72%	8.66%	13.62%	15.33%	8.18%	25.39%	**20.67%**
20	Baseline	4.26%	8.16%	12.15%	15.33%	7.59%	23.65%	**19.39%**
21	Baseline	4.18%	7.53%	11.10%	13.00%	8.09%	20.74%	**16.56%**
22	Baseline	4.28%	7.77%	11.79%	14.14%	6.66%	21.01%	**16.72%**
23	Baseline	4.36%	8.23%	12.26%	13.36%	7.54%	23.93%	**19.57%**
24	Baseline	4.22%	8.07%	12.04%	14.75%	7.02%	23.59%	**19.37%**
25	Baseline	4.59%	9.08%	12.78%	15.33%	8.21%	21.35%	**16.76%**
26	Baseline	4.69%	9.02%	12.64%	15.89%	7.07%	22.77%	**18.08%**
27	Baseline	4.52%	8.60%	12.62%	15.19%	7.41%	24.98%	**20.46%**
28	Baseline	3.99%	7.71%	11.52%	13.93%	6.84%	21.37%	**17.38%**
29	Baseline	4.34%	7.93%	11.95%	15.48%	6.67%	25.13%	**20.79%**
	Range	**0.82%**	**1.67%**	**2.62%**	**3.47%**	**1.64%**	**5.62%**	**4.99%**
	Range/Avg	**18.93%**	**20.53%**	**21.74%**	**24.59%**	**22.88%**	**24.78%**	**27.20%**

Table F.10: CE/TTI hot water savings (MMBtu/yr) using random runs with different College Station weather years with standard IPMVP weather normalization approach and AirModel calibrated simulations (MBE adjusted). Ranges are shown in bold.

Rand Run	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Range
1	Baseline	716	917	1011	625	-148	592	**1158**
2	Baseline	697	933	853	604	-84	560	**1017**
3	Baseline	706	871	938	566	-111	561	**1050**
4	Baseline	717	850	1010	560	-113	586	**1122**
5	Baseline	712	886	933	560	-108	593	**1041**
6	Baseline	715	850	956	661	-120	572	**1077**
7	Baseline	726	859	933	617	-141	582	**1074**
8	Baseline	716	894	853	528	-85	584	**979**
9	Baseline	720	903	883	656	-120	584	**1023**
10	Baseline	716	950	1018	522	-113	581	**1130**
11	Baseline	687	918	917	589	-70	561	**989**
12	Baseline	695	917	883	607	-148	592	**1064**
13	Baseline	699	890	914	560	-130	593	**1044**
14	Baseline	699	859	918	566	-120	592	**1039**
15	Baseline	709	871	914	522	-92	588	**1006**
16	Baseline	716	892	933	656	-136	572	**1069**
17	Baseline	712	902	938	583	-120	584	**1059**
18	Baseline	710	886	969	639	-154	573	**1123**
19	Baseline	710	903	883	522	-85	582	**988**
20	Baseline	695	894	854	604	-85	581	**979**
21	Baseline	720	890	1063	625	-148	573	**1212**
22	Baseline	712	890	977	604	-123	566	**1100**
23	Baseline	703	902	991	667	-111	593	**1102**
24	Baseline	706	903	853	604	-113	592	**1015**
25	Baseline	695	874	957	522	-129	580	**1086**
26	Baseline	717	850	1011	604	-123	603	**1134**
27	Baseline	695	917	1063	605	-113	582	**1176**
28	Baseline	703	859	1018	617	-167	593	**1184**
29	Baseline	710	950	969	539	-136	589	**1105**
	Range	**38**	**100**	**211**	**145**	**96**	**43**	**232**

Table F.11: CE/TTI hot water percent savings using random runs with different College Station weather years with standard IPMVP weather normalization approach and AirModel calibrated simulations (MBE adjusted). Range and range/average values are shown in bold.

Rand Run	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Range
1	Baseline	19.96%	25.56%	28.19%	17.43%	-4.12%	16.51%	**32.31%**
2	Baseline	18.77%	25.12%	22.96%	16.27%	-2.25%	15.07%	**27.38%**
3	Baseline	16.95%	20.91%	22.52%	13.59%	-2.68%	13.48%	**25.20%**
4	Baseline	19.37%	22.95%	27.26%	15.11%	-3.04%	15.82%	**30.29%**
5	Baseline	19.76%	24.57%	25.88%	15.53%	-2.99%	16.47%	**28.88%**
6	Baseline	20.58%	24.47%	27.53%	19.02%	-3.47%	16.47%	**31.00%**
7	Baseline	20.31%	24.06%	26.11%	17.26%	-3.95%	16.30%	**30.06%**
8	Baseline	19.66%	24.54%	23.40%	14.50%	-2.34%	16.02%	**26.88%**
9	Baseline	19.99%	25.05%	24.50%	18.21%	-3.34%	16.20%	**28.40%**
10	Baseline	18.00%	23.88%	25.58%	13.11%	-2.83%	14.60%	**28.41%**
11	Baseline	18.14%	24.24%	24.20%	15.56%	-1.86%	14.82%	**26.10%**
12	Baseline	18.20%	24.01%	23.12%	15.91%	-3.87%	15.51%	**27.88%**
13	Baseline	19.19%	24.42%	25.09%	15.36%	-3.57%	16.27%	**28.65%**
14	Baseline	18.31%	22.51%	24.05%	14.82%	-3.16%	15.51%	**27.21%**
15	Baseline	19.46%	23.91%	25.09%	14.32%	-2.52%	16.15%	**27.61%**
16	Baseline	19.25%	23.99%	25.09%	17.64%	-3.66%	15.39%	**28.76%**
17	Baseline	18.00%	22.82%	23.73%	14.76%	-3.05%	14.76%	**26.78%**
18	Baseline	18.61%	23.19%	25.38%	16.75%	-4.04%	15.02%	**29.42%**
19	Baseline	17.55%	22.33%	21.83%	12.91%	-2.11%	14.40%	**24.43%**
20	Baseline	16.69%	21.47%	20.51%	14.50%	-2.05%	13.95%	**23.51%**
21	Baseline	19.98%	24.69%	29.51%	17.34%	-4.11%	15.91%	**33.62%**
22	Baseline	19.94%	24.91%	27.35%	16.92%	-3.45%	15.84%	**30.80%**
23	Baseline	19.51%	25.03%	27.51%	18.51%	-3.09%	16.47%	**30.60%**
24	Baseline	19.68%	25.17%	23.78%	16.85%	-3.14%	16.51%	**28.31%**
25	Baseline	17.19%	21.61%	23.67%	12.91%	-3.18%	14.34%	**26.85%**
26	Baseline	19.13%	22.66%	26.94%	16.10%	-3.29%	16.07%	**30.23%**
27	Baseline	16.27%	21.47%	24.90%	14.16%	-2.64%	13.63%	**27.54%**
28	Baseline	19.50%	23.84%	28.24%	17.11%	-4.62%	16.45%	**32.86%**
29	Baseline	19.37%	25.94%	26.45%	14.71%	-3.72%	16.08%	**30.17%**
	Range	**4.31%**	**5.02%**	**9.00%**	**6.11%**	**2.77%**	**3.03%**	**10.11%**
	Range/Avg	**22.81%**	**21.12%**	**35.74%**	**38.77%**	**-87.07%**	**19.54%**	**35.30%**

Results from Option C with Regression Models with College Station Weather

NAC Weather Normalization Approach

Table F.12: CE/TTI chilled water annual consumption (MMBtu/yr) using different College Station weather years with regression models. Ranges are shown in bold.

Weather Data Year	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Range
1973	16770	15993	15353	14505	14422	15412	12880	**3113**
1974	16873	16171	15536	14685	14583	15586	12989	**3183**
1975	16631	15904	15279	14414	14357	15342	12828	**3075**
1976	16165	15396	14779	13907	13892	14873	12495	**2901**
1977	17770	16913	16194	15334	15110	16148	13447	**3466**
1978	17959	17013	16210	15376	15082	16123	13441	**3572**
1979	16151	15409	14746	13923	13866	14837	12437	**2972**
1980	17771	16795	16059	15165	14942	15993	13377	**3418**
1981	17614	16736	16052	15136	14964	16007	13379	**3356**
1983	16420	15576	14905	14058	13987	14969	12576	**3001**
1984	17980	17167	16463	15568	15332	16395	13634	**3533**
1985	17793	16937	16180	15315	15064	16109	13426	**3511**
1989	17430	16637	15904	15080	14868	15883	13225	**3413**
1990	18352	17454	16742	15816	15560	16638	13846	**3608**
1991	17489	16678	15987	15108	14922	15965	13313	**3365**
1992	17423	16656	15999	15110	14951	15991	13325	**3330**
1993	17459	16517	15816	14877	14706	15764	13224	**3293**
1994	17807	16995	16311	15415	15211	16264	13540	**3456**
1996	18860	17944	17158	16275	15924	17002	14103	**3841**
1997	17142	16253	15564	14684	14547	15564	13038	**3215**
1998	18840	17825	17059	16122	15794	16897	14074	**3751**
1999	18034	17254	16592	15685	15481	16537	13737	**3516**
2000	18547	17653	16886	15982	15659	16749	13920	**3734**
2001	18058	17170	16440	15549	15298	16359	13625	**3545**
2002	17841	16923	16199	15288	15056	16125	13471	**3453**
2003	17757	16937	16229	15344	15123	16178	13476	**3461**
2004	18094	17302	16606	15715	15485	16535	13734	**3568**
2005	18638	17729	16991	16080	15778	16864	14007	**3722**
Norm Yr	17356	16491	15849	14890	14767	15822	13256	**3235**
Range	**2709**	**2548**	**2412**	**2368**	**2059**	**2165**	**1666**	940

Table F.13: CE/TTI chilled water annual savings (MMBtu/yr) using different College Station weather years with regression models. Ranges are shown in bold.

Weather Data Year	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Range**
1973	Baseline	777	1417	2265	2348	1357	3890	**3113**
1974	Baseline	702	1336	2188	2290	1287	3884	**3183**
1975	Baseline	727	1351	2217	2274	1288	3802	**3075**
1976	Baseline	769	1386	2257	2273	1292	3669	**2901**
1977	Baseline	857	1576	2436	2660	1622	4323	**3466**
1978	Baseline	946	1749	2583	2877	1836	4518	**3572**
1979	Baseline	742	1405	2228	2286	1314	3714	**2972**
1980	Baseline	975	1711	2605	2829	1777	4394	**3418**
1981	Baseline	879	1562	2478	2651	1607	4235	**3356**
1983	Baseline	844	1516	2362	2434	1451	3845	**3001**
1984	Baseline	813	1517	2412	2648	1585	4346	**3533**
1985	Baseline	857	1613	2478	2730	1685	4368	**3511**
1989	Baseline	793	1526	2350	2562	1547	4205	**3413**
1990	Baseline	898	1611	2537	2792	1714	4506	**3608**
1991	Baseline	811	1501	2380	2567	1524	4176	**3365**
1992	Baseline	767	1423	2313	2472	1432	4097	**3330**
1993	Baseline	941	1643	2582	2753	1695	4234	**3293**
1994	Baseline	811	1496	2392	2595	1543	4267	**3456**
1996	Baseline	916	1702	2585	2936	1858	4757	**3841**
1997	Baseline	889	1578	2458	2595	1578	4104	**3215**
1998	Baseline	1015	1780	2718	3046	1942	4766	**3751**
1999	Baseline	781	1442	2349	2553	1497	4297	**3516**
2000	Baseline	893	1661	2565	2888	1797	4627	**3734**
2001	Baseline	888	1618	2509	2760	1699	4433	**3545**
2002	Baseline	918	1642	2554	2785	1716	4371	**3453**
2003	Baseline	820	1528	2413	2634	1579	4281	**3461**
2004	Baseline	792	1488	2380	2609	1559	4360	**3568**
2005	Baseline	909	1647	2558	2860	1774	4630	**3722**
Norm Yr	Baseline	864	1507	2466	2589	1534	4100	**3235**
	Range	**313**	**444**	**530**	**773**	**656**	**1096**	**940**

Table F.14: CE/TTI chilled water annual percent savings (MMBtu/yr) using different College Station weather years with regression models. Range and range/average values are shown in bold.

Weather Data Year	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Range**
1973	Baseline	4.63%	8.45%	13.51%	14.00%	8.09%	23.19%	**18.56%**
1974	Baseline	4.16%	7.92%	12.97%	13.57%	7.62%	23.02%	**18.86%**
1975	Baseline	4.37%	8.13%	13.33%	13.67%	7.75%	22.86%	**18.49%**
1976	Baseline	4.75%	8.57%	13.96%	14.06%	7.99%	22.70%	**17.94%**
1977	Baseline	4.82%	8.87%	13.71%	14.97%	9.13%	24.33%	**19.50%**
1978	Baseline	5.27%	9.74%	14.38%	16.02%	10.22%	25.16%	**19.89%**
1979	Baseline	4.59%	8.70%	13.79%	14.15%	8.13%	23.00%	**18.40%**
1980	Baseline	5.49%	9.63%	14.66%	15.92%	10.00%	24.72%	**19.24%**
1981	Baseline	4.99%	8.87%	14.07%	15.05%	9.12%	24.04%	**19.05%**
1983	Baseline	5.14%	9.23%	14.39%	14.82%	8.84%	23.41%	**18.27%**
1984	Baseline	4.52%	8.44%	13.42%	14.73%	8.82%	24.17%	**19.65%**
1985	Baseline	4.81%	9.07%	13.93%	15.34%	9.47%	24.55%	**19.73%**
1989	Baseline	4.55%	8.76%	13.48%	14.70%	8.87%	24.13%	**19.58%**
1990	Baseline	4.90%	8.78%	13.82%	15.22%	9.34%	24.55%	**19.66%**
1991	Baseline	4.64%	8.58%	13.61%	14.68%	8.71%	23.88%	**19.24%**
1992	Baseline	4.40%	8.17%	13.27%	14.19%	8.22%	23.52%	**19.12%**
1993	Baseline	5.39%	9.41%	14.79%	15.77%	9.71%	24.25%	**18.86%**
1994	Baseline	4.56%	8.40%	13.43%	14.57%	8.66%	23.96%	**19.41%**
1996	Baseline	4.86%	9.02%	13.71%	15.57%	9.85%	25.22%	**20.37%**
1997	Baseline	5.19%	9.20%	14.34%	15.14%	9.20%	23.94%	**18.76%**
1998	Baseline	5.39%	9.45%	14.42%	16.17%	10.31%	25.30%	**19.91%**
1999	Baseline	4.33%	8.00%	13.02%	14.15%	8.30%	23.83%	**19.50%**
2000	Baseline	4.82%	8.96%	13.83%	15.57%	9.69%	24.95%	**20.13%**
2001	Baseline	4.92%	8.96%	13.90%	15.29%	9.41%	24.55%	**19.63%**
2002	Baseline	5.15%	9.20%	14.31%	15.61%	9.62%	24.50%	**19.35%**
2003	Baseline	4.62%	8.60%	13.59%	14.83%	8.89%	24.11%	**19.49%**
2004	Baseline	4.38%	8.22%	13.15%	14.42%	8.62%	24.10%	**19.72%**
2005	Baseline	4.88%	8.84%	13.72%	15.35%	9.52%	24.84%	**19.97%**
Norm Yr	Baseline	4.98%	8.68%	14.21%	14.92%	8.84%	23.62%	**18.64%**
	Range	**1.33%**	**1.82%**	**1.82%**	**2.59%**	**2.69%**	**2.60%**	**2.42%**
	Range/Avg	**27.64%**	**20.70%**	**13.17%**	**17.40%**	**29.84%**	**10.78%**	**12.56%**

Table F.15: CE/TTI hot water annual consumption (MMBtu/yr) using different College Station weather years with regression models. Ranges are shown in bold.

Weather Data Year	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Range**
1973	3837	3225	3108	2915	3395	4056	3172	**1142**
1974	3699	3105	3010	2823	3312	3951	3039	**1129**
1975	3784	3175	3058	2876	3364	4038	3133	**1162**
1976	4019	3358	3239	3024	3532	4249	3373	**1225**
1977	3754	3116	3036	2754	3290	3888	3045	**1134**
1978	4079	3495	3383	3014	3544	4112	3368	**1098**
1979	4199	3653	3500	3249	3723	4394	3566	**1145**
1980	3929	3183	3112	2799	3359	3996	3193	**1197**
1981	3688	2948	2889	2662	3196	3850	2980	**1188**
1983	4187	3554	3419	3141	3654	4344	3527	**1203**
1984	3545	2878	2822	2602	3120	3717	2834	**1115**
1985	3878	3274	3183	2885	3401	3990	3186	**1105**
1989	3904	3377	3262	2971	3471	4055	3237	**1084**
1990	3473	2722	2687	2489	3006	3612	2732	**1123**
1991	3716	3052	2987	2715	3270	3896	3028	**1181**
1992	3570	2887	2835	2616	3158	3793	2882	**1177**
1993	3885	3090	3033	2764	3323	4007	3177	**1242**
1994	3537	2853	2803	2571	3115	3731	2836	**1160**
1996	3547	2898	2845	2565	3089	3624	2798	**1059**
1997	3948	3249	3154	2872	3420	4086	3251	**1214**
1998	3559	2759	2741	2435	3027	3619	2791	**1184**
1999	3318	2625	2586	2447	2937	3543	2603	**1096**
2000	3597	2911	2873	2555	3132	3697	2865	**1142**
2001	3678	2986	2930	2625	3200	3800	2955	**1174**
2002	3778	3038	2988	2698	3263	3895	3063	**1197**
2003	3661	3005	2945	2675	3225	3834	2970	**1158**
2004	3434	2790	2731	2527	3041	3628	2726	**1101**
2005	3454	2722	2696	2436	2994	3568	2702	**1132**
Norm Yr	3625	2804	2770	2553	3127	3828	2923	**1275**
Range	**881**	**1029**	**914**	**815**	**786**	**852**	**963**	**216**

Table F.16: CE/TTI hot water annual savings (MMBtu/yr) using different College Station weather years with regression models. Ranges are shown in bold.

Weather Data Year	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Range
1973	Baseline	612	730	922	442	-219	665	**1142**
1974	Baseline	594	690	876	388	-252	660	**1129**
1975	Baseline	609	725	907	419	-255	650	**1162**
1976	Baseline	661	781	995	488	-230	647	**1225**
1977	Baseline	638	718	1000	464	-134	709	**1134**
1978	Baseline	584	695	1065	535	-33	710	**1098**
1979	Baseline	546	700	950	477	-195	633	**1145**
1980	Baseline	746	817	1130	569	-67	735	**1197**
1981	Baseline	740	799	1026	491	-162	708	**1188**
1983	Baseline	633	768	1046	533	-157	659	**1203**
1984	Baseline	667	723	943	425	-172	711	**1115**
1985	Baseline	604	695	993	477	-112	693	**1105**
1989	Baseline	527	643	933	434	-151	667	**1084**
1990	Baseline	751	785	984	467	-139	741	**1123**
1991	Baseline	664	730	1002	446	-180	689	**1181**
1992	Baseline	683	735	954	412	-223	688	**1177**
1993	Baseline	795	852	1121	562	-121	709	**1242**
1994	Baseline	685	734	967	422	-194	701	**1160**
1996	Baseline	649	702	983	458	-76	749	**1059**
1997	Baseline	700	794	1076	529	-138	697	**1214**
1998	Baseline	801	819	1125	533	-60	768	**1184**
1999	Baseline	694	732	872	382	-224	715	**1096**
2000	Baseline	686	724	1042	465	-100	732	**1142**
2001	Baseline	692	748	1053	478	-122	723	**1174**
2002	Baseline	740	790	1081	516	-117	715	**1197**
2003	Baseline	656	716	986	436	-173	691	**1158**
2004	Baseline	643	703	907	393	-194	708	**1101**
2005	Baseline	731	757	1017	460	-115	752	**1132**
Norm Yr	Baseline	821	856	1072	498	-203	702	**1275**
	Range	**295**	**213**	**258**	**188**	**222**	**135**	**216**

Table F.17: CE/TTI hot water annual percent savings (MMBtu/yr) using different College Station weather years with regression models. Range and range/average values are shown in bold.

Weather Data Year	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Range
1973	Baseline	15.94%	19.01%	24.04%	11.52%	-5.71%	17.33%	**29.75%**
1974	Baseline	16.07%	18.64%	23.69%	10.48%	-6.82%	17.83%	**30.51%**
1975	Baseline	16.10%	19.17%	23.98%	11.08%	-6.73%	17.19%	**30.72%**
1976	Baseline	16.46%	19.42%	24.76%	12.14%	-5.72%	16.09%	**30.48%**
1977	Baseline	17.00%	19.13%	26.64%	12.36%	-3.56%	18.88%	**30.20%**
1978	Baseline	14.31%	17.05%	26.11%	13.12%	-0.81%	17.42%	**26.91%**
1979	Baseline	13.00%	16.66%	22.63%	11.36%	-4.64%	15.08%	**27.27%**
1980	Baseline	18.98%	20.80%	28.76%	14.49%	-1.70%	18.72%	**30.46%**
1981	Baseline	20.06%	21.66%	27.82%	13.33%	-4.40%	19.20%	**32.22%**
1983	Baseline	15.11%	18.35%	24.97%	12.73%	-3.76%	15.75%	**28.74%**
1984	Baseline	18.80%	20.39%	26.61%	11.99%	-4.84%	20.04%	**31.45%**
1985	Baseline	15.57%	17.93%	25.61%	12.31%	-2.89%	17.86%	**28.50%**
1989	Baseline	13.49%	16.46%	23.90%	11.11%	-3.87%	17.10%	**27.76%**
1990	Baseline	21.63%	22.62%	28.33%	13.45%	-4.00%	21.34%	**32.33%**
1991	Baseline	17.87%	19.63%	26.95%	12.00%	-4.84%	18.53%	**31.79%**
1992	Baseline	19.13%	20.58%	26.71%	11.53%	-6.25%	19.28%	**32.97%**
1993	Baseline	20.47%	21.94%	28.86%	14.47%	-3.12%	18.24%	**31.98%**
1994	Baseline	19.35%	20.75%	27.33%	11.93%	-5.47%	19.81%	**32.80%**
1996	Baseline	18.30%	19.79%	27.70%	12.92%	-2.15%	21.12%	**29.85%**
1997	Baseline	17.72%	20.12%	27.26%	13.39%	-3.49%	17.65%	**30.75%**
1998	Baseline	22.50%	23.00%	31.60%	14.97%	-1.67%	21.58%	**33.27%**
1999	Baseline	20.91%	22.07%	26.27%	11.50%	-6.76%	21.54%	**33.03%**
2000	Baseline	19.08%	20.12%	28.96%	12.92%	-2.78%	20.34%	**31.74%**
2001	Baseline	18.83%	20.34%	28.62%	13.00%	-3.30%	19.65%	**31.92%**
2002	Baseline	19.59%	20.91%	28.60%	13.65%	-3.09%	18.92%	**31.69%**
2003	Baseline	17.92%	19.56%	26.92%	11.91%	-4.72%	18.86%	**31.64%**
2004	Baseline	18.74%	20.48%	26.41%	11.45%	-5.66%	20.62%	**32.07%**
2005	Baseline	21.18%	21.93%	29.46%	13.31%	-3.32%	21.78%	**32.78%**
Norm Yr	Baseline	22.66%	23.60%	29.58%	13.72%	-5.59%	19.36%	**35.16%**
	Range	**9.65%**	**7.14%**	**8.97%**	**4.49%**	**6.01%**	**6.70%**	**8.25%**
	Range/Avg	**53.14%**	**35.57%**	**33.39%**	**35.77%**	**-143.28%**	**35.51%**	**26.57%**

Standard IPMVP Weather Normalization Approach

Table F.18: CE/TTI chilled water savings (MMBtu/yr) using random runs with different College Station weather years with standard IPMVP weather normalization approach and regression models. Ranges are shown in bold.

Rand Run	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Range
1	Baseline	941	1643	2605	2730	1585	4433	**3492**
2	Baseline	813	1386	2349	3046	1695	3884	**3071**
3	Baseline	857	1780	2509	2648	1524	4297	**3440**
4	Baseline	742	1647	2583	2860	1836	4176	**3434**
5	Baseline	767	1562	2413	2860	1942	4766	**3999**
6	Baseline	975	1702	2217	2286	1685	4360	**3385**
7	Baseline	769	1661	2313	2651	1714	4627	**3859**
8	Baseline	898	1417	2349	2609	1716	4100	**3201**
9	Baseline	864	1507	2585	2785	1685	4100	**3235**
10	Baseline	898	1516	2458	2553	1836	4506	**3608**
11	Baseline	893	1578	2392	2660	1451	4297	**3403**
12	Baseline	792	1643	2585	2348	1585	4433	**3641**
13	Baseline	811	1613	2537	2860	1543	4281	**3471**
14	Baseline	811	1661	2565	2648	1685	4433	**3622**
15	Baseline	777	1780	2537	2553	1578	4104	**3327**
16	Baseline	941	1351	2413	2785	1288	4360	**3419**
17	Baseline	702	1749	2509	2888	1685	4100	**3398**
18	Baseline	727	1562	2265	2595	1559	4346	**3619**
19	Baseline	781	1507	2585	2553	1716	4627	**3847**
20	Baseline	792	1417	2380	3046	1716	4506	**3714**
21	Baseline	864	1613	2228	2730	1858	4346	**3481**
22	Baseline	767	1613	2554	2760	1547	4097	**3330**
23	Baseline	811	1526	2350	2273	1524	4235	**3424**
24	Baseline	879	1507	2349	2760	1836	4433	**3554**
25	Baseline	792	1611	2436	2553	1797	3714	**2922**
26	Baseline	742	1702	2605	3046	1622	4518	**3777**
27	Baseline	792	1643	2228	2634	1836	4627	**3835**
28	Baseline	811	1661	2458	2651	1497	4281	**3470**
29	Baseline	781	1516	2265	2936	1288	4757	**3976**
	Range	**274**	**429**	**389**	**773**	**654**	**1052**	**1077**

Table F.19: CE/TTI chilled water percent savings using random runs with different College Station weather years with standard IPMVP weather normalization approach and regression models. Range and range/average values are shown in bold.

Rand Run	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Range
1	Baseline	5.24%	9.14%	14.49%	15.18%	8.82%	24.66%	**19.42%**
2	Baseline	4.65%	7.92%	13.43%	17.42%	9.69%	22.21%	**17.56%**
3	Baseline	4.77%	9.91%	13.97%	14.74%	8.49%	23.92%	**19.15%**
4	Baseline	4.11%	9.12%	14.30%	15.84%	10.17%	23.12%	**19.02%**
5	Baseline	4.07%	8.29%	12.81%	15.18%	10.31%	25.30%	**21.22%**
6	Baseline	5.39%	9.41%	12.25%	12.63%	9.31%	24.10%	**18.71%**
7	Baseline	4.19%	9.05%	12.60%	14.44%	9.34%	25.21%	**21.02%**
8	Baseline	4.76%	7.51%	12.45%	13.83%	9.10%	21.74%	**16.97%**
9	Baseline	4.96%	8.65%	14.84%	15.99%	9.67%	23.53%	**18.57%**
10	Baseline	5.06%	8.53%	13.83%	14.36%	10.33%	25.36%	**20.30%**
11	Baseline	5.01%	8.84%	13.41%	14.91%	8.13%	24.08%	**19.08%**
12	Baseline	4.46%	9.25%	14.55%	13.21%	8.92%	24.95%	**20.49%**
13	Baseline	4.30%	8.55%	13.45%	15.17%	8.18%	22.70%	**18.40%**
14	Baseline	4.56%	9.35%	14.43%	14.90%	9.48%	24.95%	**20.39%**
15	Baseline	4.12%	9.44%	13.45%	13.53%	8.37%	21.76%	**17.64%**
16	Baseline	5.34%	7.67%	13.70%	15.81%	7.31%	24.75%	**19.41%**
17	Baseline	3.94%	9.83%	14.10%	16.23%	9.47%	23.04%	**19.10%**
18	Baseline	4.09%	8.79%	12.75%	14.60%	8.78%	24.46%	**20.36%**
19	Baseline	4.83%	9.32%	15.99%	15.79%	10.61%	28.62%	**23.80%**
20	Baseline	4.41%	7.89%	13.25%	16.96%	9.55%	25.09%	**20.68%**
21	Baseline	4.59%	8.56%	11.83%	14.49%	9.86%	23.07%	**18.48%**
22	Baseline	4.18%	8.79%	13.92%	15.04%	8.43%	22.33%	**18.15%**
23	Baseline	4.66%	8.76%	13.49%	13.04%	8.75%	24.31%	**19.65%**
24	Baseline	4.89%	8.38%	13.06%	15.35%	10.21%	24.66%	**19.77%**
25	Baseline	4.90%	9.96%	15.07%	15.79%	11.12%	22.98%	**18.08%**
26	Baseline	4.40%	10.09%	15.44%	18.05%	9.61%	26.78%	**22.38%**
27	Baseline	4.82%	10.01%	13.57%	16.04%	11.18%	28.18%	**23.36%**
28	Baseline	4.31%	8.82%	13.05%	14.07%	7.95%	22.73%	**18.42%**
29	Baseline	4.40%	8.54%	12.76%	16.53%	7.26%	26.79%	**22.39%**
	Range	**1.45%**	**2.58%**	**4.16%**	**5.42%**	**3.92%**	**6.89%**	**6.82%**
	Range/Avg	**31.44%**	**28.91%**	**30.48%**	**35.80%**	**42.40%**	**28.32%**	**34.59%**

Table F.20: CE/TTI hot water savings (MMBtu/yr) using random runs with different College Station weather years with standard IPMVP weather normalization approach and regression models. Ranges are shown in bold.

Rand Run	**1996 Pre-CC**	**1997**	**1998**	**1/99-4/24/00**	**2001**	**1/02-11/02**	**9/03-6/04**	**Range**
1	Baseline	795	852	1130	477	-172	723	**1302**
2	Baseline	667	781	872	533	-121	660	**993**
3	Baseline	638	819	1053	425	-180	715	**1232**
4	Baseline	546	757	1065	460	-33	689	**1098**
5	Baseline	683	799	986	460	-60	768	**1045**
6	Baseline	746	702	907	477	-112	708	**1019**
7	Baseline	661	724	954	491	-139	732	**1093**
8	Baseline	751	730	872	393	-117	702	**988**
9	Baseline	821	856	983	516	-112	702	**1095**
10	Baseline	751	768	1076	382	-33	741	**1109**
11	Baseline	686	794	967	464	-157	715	**1124**
12	Baseline	643	852	983	442	-172	723	**1154**
13	Baseline	664	695	984	460	-194	691	**1177**
14	Baseline	664	724	1042	425	-112	723	**1154**
15	Baseline	612	819	984	382	-138	697	**1122**
16	Baseline	795	725	986	516	-255	708	**1241**
17	Baseline	594	695	1053	465	-112	702	**1165**
18	Baseline	609	799	922	529	-194	711	**1117**
19	Baseline	694	856	983	382	-117	732	**1099**
20	Baseline	643	730	907	533	-117	741	**1024**
21	Baseline	821	695	950	477	-76	711	**1027**
22	Baseline	683	695	1081	478	-151	688	**1232**
23	Baseline	685	643	933	488	-180	708	**1113**
24	Baseline	740	856	872	478	-33	723	**905**
25	Baseline	643	785	1000	382	-100	633	**1100**
26	Baseline	546	702	1130	533	-134	710	**1264**
27	Baseline	643	852	950	436	-33	732	**983**
28	Baseline	685	724	1076	491	-224	691	**1301**
29	Baseline	694	768	922	458	-255	749	**1177**
	Range	**275**	**213**	**258**	**151**	**222**	**135**	**397**

Table F.21: CE/TTI hot water percent savings using random runs with different College Station weather years with standard IPMVP weather normalization approach and regression models. Range and range/average values are shown in bold.

Rand Run	1996 Pre-CC	1997	1998	1/99-4/24/00	2001	1/02-11/02	9/03-6/04	Range
1	Baseline	22.43%	24.04%	31.88%	13.47%	-4.84%	20.39%	**36.72%**
2	Baseline	17.94%	21.00%	23.46%	14.34%	-3.26%	17.75%	**26.71%**
3	Baseline	15.65%	20.07%	25.81%	10.42%	-4.41%	17.53%	**30.21%**
4	Baseline	14.85%	20.59%	28.95%	12.50%	-0.89%	18.73%	**29.84%**
5	Baseline	19.18%	22.44%	27.69%	12.92%	-1.67%	21.58%	**29.37%**
6	Baseline	21.72%	20.44%	26.42%	13.89%	-3.26%	20.62%	**29.68%**
7	Baseline	19.05%	20.84%	27.46%	14.15%	-4.00%	21.07%	**31.47%**
8	Baseline	21.17%	20.57%	24.57%	11.08%	-3.29%	19.78%	**27.86%**
9	Baseline	23.00%	23.96%	27.52%	14.44%	-3.14%	19.65%	**30.66%**
10	Baseline	19.12%	19.55%	27.40%	9.71%	-0.84%	18.86%	**28.24%**
11	Baseline	18.16%	21.02%	25.59%	12.28%	-4.17%	18.92%	**29.75%**
12	Baseline	17.14%	22.70%	26.17%	11.78%	-4.57%	19.25%	**30.75%**
13	Baseline	18.72%	19.60%	27.73%	12.96%	-5.46%	19.47%	**33.19%**
14	Baseline	17.69%	19.28%	27.75%	11.32%	-2.98%	19.25%	**30.73%**
15	Baseline	17.24%	23.08%	27.73%	10.76%	-3.88%	19.65%	**31.62%**
16	Baseline	21.56%	19.67%	26.73%	13.98%	-6.91%	19.20%	**33.64%**
17	Baseline	15.33%	17.93%	27.14%	11.98%	-2.89%	18.09%	**30.03%**
18	Baseline	16.22%	21.27%	24.57%	14.08%	-5.18%	18.93%	**29.75%**
19	Baseline	17.26%	21.28%	24.45%	9.49%	-2.90%	18.20%	**27.35%**
20	Baseline	15.78%	17.89%	22.24%	13.06%	-2.86%	18.17%	**25.09%**
21	Baseline	23.07%	19.53%	26.70%	13.41%	-2.14%	19.96%	**28.84%**
22	Baseline	19.66%	20.02%	31.12%	13.77%	-4.35%	19.82%	**35.46%**
23	Baseline	19.18%	18.00%	26.13%	13.67%	-5.04%	19.84%	**31.17%**
24	Baseline	20.87%	24.13%	24.59%	13.49%	-0.93%	20.39%	**25.52%**
25	Baseline	16.01%	19.54%	24.88%	9.49%	-2.49%	15.75%	**27.37%**
26	Baseline	14.76%	18.98%	30.55%	14.40%	-3.61%	19.20%	**34.16%**
27	Baseline	15.37%	20.36%	22.70%	10.41%	-0.79%	17.47%	**23.48%**
28	Baseline	19.23%	20.33%	30.24%	13.81%	-6.30%	19.40%	**36.54%**
29	Baseline	18.95%	20.98%	25.20%	12.52%	-6.96%	20.47%	**32.16%**
	Range	**8.31%**	**6.25%**	**9.64%**	**4.95%**	**6.17%**	**5.82%**	**13.24%**
	Range/Avg	**44.94%**	**30.23%**	**36.15%**	**39.45%**	**-172.17%**	**30.29%**	**43.75%**

VITA

Name: Kenneth Paul Engan

Address: Louisiana Energy Services, P.O. Box 1789, Eunice, NM 88231

Email Address: kenengan@gmail.com

Education: B.S., Mechanical Engineering, 2005, Brigham Young University
M.S., Mechanical Engineering, 2007, Texas A&M University