

Analysis Methods for Post Occupancy Evaluation  
of Energy-Use in High Performance Buildings  
Using Short-Term Monitoring

by  
Vipul Singh

A Thesis Presented in Partial Fulfillment  
of the Requirements for the Degree  
Master of Science

Approved May 2011 by the  
Graduate Supervisory Committee:

T Agami Reddy, Chair  
Harvey Bryan  
Marlin Addison

ARIZONA STATE UNIVERSITY

May 2011

## ABSTRACT

The green building movement has been an effective catalyst in reducing energy demands of buildings and a large number of 'green' certified buildings have been in operation for several years. Whether these buildings are actually performing as intended, and if not, identifying specific causes for this discrepancy falls into the general realm of post-occupancy evaluation (POE). POE involves evaluating building performance in terms of energy-use, indoor environmental quality, acoustics and water-use; the first aspect i.e. energy-use is addressed in this thesis.

Normally, a full year or more of energy-use and weather data is required to determine the actual post-occupancy energy-use of buildings. In many cases, either measured building performance data is not available or the time and cost implications may not make it feasible to invest in monitoring the building for a whole year. Knowledge about the minimum amount of measured data needed to accurately capture the behavior of the building over the entire year can be immensely beneficial.

This research identifies simple modeling techniques to determine best time of the year to begin in-situ monitoring of building energy-use, and the least amount of data required for generating acceptable long-term predictions. Four analysis procedures are studied. The short-term monitoring for long-term prediction (SMLP) approach and dry-bulb temperature analysis (DBTA) approach allow determining the best time and duration of the year for in-situ monitoring to be performed based only on the ambient temperature data of the location. Multivariate change-point (MCP) modeling uses simulated/monitored data to determine best monitoring period of the year. This is also used to validate the

SMLP and DBTA approaches. The hybrid inverse modeling method-1 predicts energy-use by combining a short dataset of monitored internal loads with a year of utility-bills, and hybrid inverse method-2 predicts long term building performance using utility-bills only.

The results obtained show that often less than three to four months of monitored data is adequate for estimating the annual building energy use, provided that the monitoring is initiated at the right time, and the seasonal as well as daily variations are adequately captured by the short dataset. The predictive accuracy of the short data-sets is found to be strongly influenced by the closeness of the dataset's mean temperature to the annual average temperature. The analysis methods studied would be very useful for energy professionals involved in POE.

## DEDICATION

*Thank You, Ma...*

## ACKNOWLEDGMENTS

This thesis concludes extensive work realized through the assistance and encouragement of many individuals. The journey of this research was possible because of a multitude of support systems, some of whom deserve special recognition.

I would like to thank my committee for their guidance throughout my studies at ASU. Particularly, Professor T. Agami Reddy, my thesis Chair, for all his support and encouragement during the course of this research. Having him as my mentor enriched my learning experience. Under his able guidance I was able to complete my thesis and my graduate education with ease and minimal effort. His critiques and inputs played a very important part in the completion of this research. My sincere thanks to Professor Harvey Bryan and Professor Marlin Addison for their encouragement and direction that helped me shape my thesis.

This work has been made possible through the generous funding provided by ASHRAE. The project is a joint venture between Arizona State University (ASU) and Milwaukee School of Engineering (MSoE). I express my sincere gratitude to Dr. Bass Abushakra, the P.I. for this project, and the ASHRAE project monitoring sub-committee for their supervision and direction.

Finally, the unconditional love, support and faith of my family and friends made this journey so much easier for me. I am grateful to them for being there for me always. A special thank you to my uncle, Mr. C.K. Bhagat, without whose support, I would have not been able to achieve this dream.

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## ACRONYMS

ANSI	American National Standard Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CBECS	Commercial Building Energy Consumption Survey
CEC	California Energy Commission
CHW	Cooling Energy Use
CIBSE	Chartered Institute of Building Services Engineers
DBT	Dry Bulb Temperature
DHW	Domestic Hot Water
ECM	Energy Conservation Measure
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EUI	Energy Use Intensity
FEMP	Federal Energy Management Program
GBCI	Green Building Certification Institute
HK-BEAM	Hong Kong Building Environmental Assessment Method
HVAC	Heating Ventilation and Air Conditioning
HW	Heating Energy Use
IEQ	Indoor Environmental Quality



IMT	Inverse Modeling Toolkit
IPMVP	International Performance Measurement & Verification Protocols
LBL	Lawrence Berkeley National Laboratory
LEED	Leadership in Energy and Environmental Design
LTEQ	Light and Equipment
M&V	Measurement and Verification
NEMVP	North American Measurement and Verification Protocol
NREL	National Renewable Energy Laboratory
OA	Outside Air
PMP	Performance Measurement Protocols
POE	Post Occupancy Evaluation
RP	Research Project
TERI GRIHA	The Energy Research Institute-Green Rating for Integrated Habitat Assessment

## INTRODUCTION

### 1.1. Overview

Buildings consume substantial amounts of energy, water and raw materials and have a sizeable environmental footprint. They are big end users of energy and account for 20-40% of the energy demands in developed nations (Birt 2009). Over the past few years, the green building movement has been an effective catalyst in reducing the energy demand of buildings. A large number of early generation 'green' certified commercial buildings have been built and are in operation for several years. Although these buildings seem to consume less energy compared to conventional buildings, there are still areas of improvement. It has become necessary to investigate if these so called 'green' buildings are actually achieving their intended performance targets, and what can be done to improve their performance further.

Energy performance of individual projects is highly variable and it is important that actual building performance data be gathered and analyzed to compare the design-performance with design-intent. Post Occupancy Evaluation (POE) is the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time. It focuses on the requirements of building occupants; and includes issues such as health, safety, security, functionality and efficiency, psychological comfort and aesthetic quality. "It constitutes any activity that originates out of an interest in learning how a building performs once it is built and how satisfied building users are with the environment that has been created." (Preiser et al., 2009).

POE can thus be seen as a practice aimed at understanding design criteria, predicting effectiveness of emerging designs and for linking user response to the performance of the building. It therefore helps determine how well design concepts work once implemented.

An important component of POE relates to energy use. Normally a full year or more of energy use and weather data is needed to determine the actual energy use of the building. However, in many cases, either a full year of measured building performance data is not available or the time and cost implications may not make it feasible for the building owner to invest in monitoring the building for the entire year. Knowledge about what minimum amount of measured data will be sufficient to accurately capture the behavior of the building over the entire year can prove to be immensely beneficial in such cases.

The main focus of this research is to develop and assess methods by which short-term in-situ monitoring of building can be used as a workable alternative to yearlong monitoring and verification (M&V). The intent obviously would be to gather and analyze data for as short a period as possible. Thus the monitored data should not only capture the diurnal variations of the weekdays and weekends but also allow acceptable predictions to be made for seasonal variations over the whole year.

## **1.2. Research outline**

With the aim of promoting sustainable buildings, numerous countries have developed their own green building programs. At the crux of each program is the use of an integrated design approach and a point scheme that allots credits for building design. The energy points allotted are typically based on the size of the predicted reductions versus a locally specified baseline. The first buildings that received accreditation under these green building rating schemes have now been occupied for a reasonable amount of time, and it is germane to ask whether these buildings are living up to expectations?

This research addresses the following three closely related aspects associated with building in-use assessment or post-occupancy evaluation (POE):

### *1. What is the role of POE in the current green building rating systems?*

Most rating systems are quite elaborate and exhaustive in their content with regards to the design of buildings; however, is there enough emphasis being placed on proper operation of the building once it is occupied? These rating systems have been thoroughly explored and compared previously (Cole 1998; Crawley et al., 1999; Todd et al., 2001 Bosch et al., 2003; Fenner et al., 2008; Lee et al., 2008). In this research four green rating systems, namely, Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), Energy Star, and The Energy Research Institute-Green Rating for Integrated Habitat Assessment (TERI-GRIHA) have been reviewed and the categories that relate to post occupancy evaluation have been identified and outlined. The aim is to understand whether these rating systems place adequate emphasis on compliance, i.e., assuring that the buildings are actually

achieving the 'green' goals that were intended during its design and construction.

2. *How is the post-occupancy performance of a building evaluated?*

In order to ascertain whether the design concepts have actually been transformed to reality, it is important that occupied buildings be verified for their actual performance. Over the years, a number of studies have attempted to find the difference between the predicted and the actual energy use in high performance buildings. However, these studies were never based on any consistent set of guidelines and methods for measuring, expressing and comparing energy use making it difficult to compare the results from one study to another (Haberl et al., 2006). Recently, the United States Green Building Council (USGBC) in association with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) & the Chartered Institute of Building Services Engineers (CIBSE) has been instrumental in the development of the "*Performance Measurement Protocols for Commercial Buildings (2010)*" for assessing the performance of commercial buildings. In Chapter 3, the major studies that have been undertaken in the field of post occupancy evaluation of high performance buildings are reviewed and the procedure for measuring energy use in commercial buildings is outlined.

3. *Can the performance of a building be assessed based on short-interval data?*

Almost all POEs adopt the common approach to monitor the actual building performance for the whole year. While sound, this is not only time consuming, but also extremely expensive. The third part of this research, evaluates the effectiveness of using short-term monitoring for predicting energy use in

buildings. The aim is to develop analysis methods by which the time period for field monitoring of energy use in buildings can be reduced to less than a whole year (preferably less than three months) while satisfying preset accuracy levels of annual energy performance verification. Such a method will prove to be a cost effective alternative to year-long monitoring and verification of buildings.

Developing a methodology for determining the best period of the year in which to conduct in-situ monitoring so as to verify long-term building performance is the primary focus of this research.

### **1.3. Potential contribution**

At present there is no systematic guidance available to determine either the best time of the year, or the minimum duration of the year, for in-situ monitoring that can most accurately predict the energy use over the whole year. Many engineering, consulting and services companies would like to see the development of M&V alternatives which provide the sought-after verification with shorter periods of data monitoring. This research aims to develop analysis methods that can be used for making informed decisions in regards to the best short-term M&V period for building performance assessment.

### **1.4. Organization**

This thesis has been structured as follows: Chapter 1 gives an overview of the research topic and outlines different sub-categories within the research undertaken. The scope & limitations of the methods adopted have also been stated. Chapters 2, 3 and 4 are the culmination of the literature review. Chapter 2 reviews issues related to the emphasis placed by the popular energy rating systems on post occupancy evaluation of building energy performance. Four

energy rating systems have been studied, namely, LEED, BREEAM, Energy Star and TERI-GRIHA. Chapter 3 reviews the major studies that have been undertaken in the past for evaluating high performance buildings. The methods that can be adopted for measuring, expressing and comparing energy use in buildings are discussed. Chapter 4 reviews the existing literature on building energy use modeling and the significant work that has already been done in the field of short-term monitoring of building energy use for long term prediction of building performance. The research methods adopted for analysis are discussed in detail in Chapter 5. Chapters 6, 7 and 8 demonstrate how the research methods were applied to data obtained from three buildings. The results of the data analysis have also been presented and analyzed. Chapter 9 concludes this thesis with a summary of findings and it also outlines potential future research.

### **1.5. Scope and limitations**

This report provides a theoretical insight into post occupancy evaluation of buildings in terms of energy use only. A brief description of the other aspects, i.e. Indoor environmental quality (IEQ), acoustics and water use has been included in Appendix B. The analysis methods have been evaluated and refined using year-long data from two synthetic data-sets, a large hotel building of 619,200 ft<sup>2</sup> in Chicago, IL and a 17,430 ft<sup>2</sup> office building in Albuquerque, NM, and one actual measured data-set from a full service hotel building<sup>1</sup> of 212,000ft<sup>2</sup> located in the Washington D.C region. As future scope for the project, the same analysis methodology can be extended to a variety of geographic locations and building types.

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<sup>1</sup> Due to confidentiality agreement, the name, location and description of the hotel has been withheld.

## **ENERGY RATING SYSTEMS IN RELATION TO POE**

### **2.1. Post occupancy evaluation (POE)**

Post Occupancy Evaluation (POE) is the process of evaluating a building's performance once it has been occupied. It focuses on the requirements of building occupants, including health, safety, security, functionality and efficiency, psychological comfort and aesthetic quality. POE can be seen as a practice aimed at:

- i. Understanding design criteria,
- ii. Predicting effectiveness of emerging designs, and
- iii. Linking user response to the performance of the building.

It can be used to measure functionality and appropriateness of design and establish conformance with performance requirements as intended in the functional program. It therefore helps determine how well concepts work once applied.

### **2.2. Energy rating systems & post occupancy evaluation**

With the increasing awareness of sustainable development in the construction industry, implementation of an energy rating procedure to assess actual performance of buildings is becoming extremely important. Some of the most representative building schemes are LEED, BREEAM and Environmental Protection Agency (EPA) Energy Performance Rating System. TERI-GRIHA has been recently developed in India for assessing both non-air-conditioned and partially conditioned buildings. Some other successful international rating programs are: Comprehensive Assessment System for Building Environmental Efficiency (CASBEE- Japan), Hong Kong Building Environmental Assessment



Method (HK-BEAM), Green Globes (Canada) and Green Star (Australia). Roderick et al., (2009) compared the energy performance assessment between LEED, BREEAM and ENERGY STAR.

An extremely important document that can have a considerable impact on the green rating criteria in the future is ASHRAE 189.1: Standard for the design of high-performance green buildings which was approved by American National Standard Institute (ANSI) in January 2010. ASHRAE 189.1 has been designed to provide a “green” foundation for buildings, and is set to complement LEED requirements. Unlike LEED, ASHRAE 189.1 has been created with the eye towards being incorporated into building codes, which would require mandatory compliance. It provides the minimum requirements for the siting, design, construction, and plans for operation of high performance green buildings. Where a requirement is contained in this standard, it supersedes the requirements in all the other standards.

Sections 2.3 to 2.7 that follow are limited to a discussion of the credits/points related to post-occupancy evaluation within the LEED, BREEAM, EPA energy performance (Energy Star) rating and the TERI-GRIHA schemes.

### 2.3. LEED rating system

Leadership in Energy and Environmental Design (LEED) is the most recognized building environment scheme. The current version for new construction is LEED-NC v3, which like the earlier versions, is based on a set of prerequisites and credits. The credits are distributed amongst the following main categories: sustainable sites (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), indoor environmental quality (IEQ) and innovation & design (ID). There are up to 110 points that can be achieved under various categories and based on the awarded points. There are four levels of performance rating that the building can qualify for i.e. Certified (40+ points), Silver (50+ points), Gold (60+ points) and Platinum (80+ points).

LEED-NC specifies two approaches to assess building energy performance. These are included under the *EA Credit 1-Optimize Energy performance*. The first is the *Prescriptive Compliance Path*, which allows projects to achieve certain points when they meet the prescriptive measures of the ASHRAE Advanced Energy Design Guides. The other approach is the *Whole Building Energy Simulation*, which allows up to 19 points when the building demonstrates improvement on energy cost compared to a normalized building. For both approaches, the assessed building needs to meet a minimum performance level, which is 2 points. This is equivalent to 10% improvement in the proposed building performance rating for new buildings, or a 5% improvement in the proposed building performance rating for major renovations to existing buildings (Roderick et al., 2009).

*EA Credit3: Measurement and Verification* allows 3 credit points for new construction. The intent is to provide for the ongoing accountability of building

energy consumption over time. The credit requires development and implementation of a M&V plan consistent with either Option D: Calibrated Simulation (Savings Estimation Method 2) or Option B: Energy Conservation Measure Isolation as specified in the International Performance Measurement & Verification Protocols (IPMVP) Volume III: Concepts and Options for Determining Energy Savings in New Construction, April 2003. The M&V period must cover atleast one year of post construction occupancy.

In addition, the new LEED 2009 rating system requires that all certified projects commit to sharing with USGBC and/or Green Building Certification Institute (GBCI) all available actual whole-project energy and water usage data for a period of at least 5 years. USGBC is convinced that ongoing monitoring and reporting of data is “the single best way to drive higher building performance because it will bring to light external issues such as occupant behavior or unanticipated building usage patterns” (Horst 2009). At present there is no option to revoke an already granted certification based on monitored building performance. USGBC recommends that projects provide performance data and in case a project refuses to comply with this “Minimum Program Requirement” criteria, then it not be certified at the onset. No concrete rules regarding de-certification has yet been framed in case the building is found to under-achieve. Table 2.1 summarizes the points related to building commissioning and post occupancy measurement and verification under the LEED-NC v3.

Table 2.1

*Credits related to POE as allocated by LEED-NC v3 2009.*

<b>LEED V3 2009: Credits Related to POE</b>		<b>Points</b>	<b>Remarks</b>
EA Prereq 1	Fundamental Commissioning of Building Energy Systems		Mandatory
EA Prereq 2	Minimum Energy Performance		Mandatory
EA Credit 1	Optimize Energy Performacne	1 to 19	
EA Credit 2	Enhanced Commissioning	2	
EA Credit 3	Measurement and Verification	3	

#### **2.4. BREEAM-IN-USE rating system**

Building Research Establishment's Environmental Assessment Method (BREEAM) was developed in the United Kingdom in 1990 and is one of the earliest environmental assessment methods. It covers a range of building types including offices, homes, industrial units, retail units and schools. The latest version for BREEAM was released in 2008. Similar to the credit rating system in LEED, BREEAM 2008 defines categories of credits according to the building impact on the environment including management, health and well being, energy, transport, water materials, waste, land use & ecology and pollution. The total score is calculated based on credits available, number of credits achieved for each category and a weighing factor. The overall performance is awarded a 'Pass', 'Good', 'Very Good' or 'Excellent' rating based on the score achieved.

The *BREEAM-in-Use* standard, released in October 2009, has been produced to enable provision of information about the environmental performance of buildings, building operation and how clients are managing their activities within the building. The standard is arranged in three parts and it covers major environmental issues that affect buildings throughout their operational life. The three broad categories of the *BREEAM-in-Use* are:

- i. Asset performance: inherent performance characteristics based on built form, construction and services.
- ii. Building management performance: the management policies, procedures and practices related to the operation of the building, the consumption of key resources such as energy, water and other consumables and environmental impacts such as carbon and waste generation.

iii. Organizational effectiveness: the understanding and implementation of management policies, procedures and practices; staff engagement; and delivery of key outputs.

The BREEAM In-Use certification scheme enables organizations to assess the performance of individual buildings or a portfolio of buildings, and the effectiveness of their designs. The scheme has a simple to use online system and uses licensed BREEAM In-Use auditors to conduct audits, provide an independent perspective and help organizations maximize the benefits of the scheme. The online system enables building managers to conduct a pre-assessment to quantify the impact of their building, existing systems and initiatives, as well as the potential impact of proposed upgrades.

Following a successful audit, licensed Auditors are able to issue reports and certificates on Building Research Establishment (BRE) Global's behalf which highlight how well a building and organization are currently performing and ways for future improvement.

The BREEAM In-Use criteria are currently part of the United Kingdom building regulation codes of practice, climatic conditions and energy methodology. BREEAM has made it mandatory for buildings to obtain a *BREEAM In-Use* certification within the first three years of the buildings operation and use. A building should be occupied for at least a year before getting this certification to ensure that enough data is collected for performance verification.

## **2.5. ENERGY STAR rating system**

The EPA (Environmental Protection Agency) Rating is administered through the *ENERGY STAR program* (EPA 2010b) and the rating is delivered by two online tools:

- *Portfolio Manager* (for existing buildings), and
- *Target Finder* (for design projects)

*Portfolio Manager* is an interactive energy management tool that allows the tracking and assessing of energy and water consumption through a secure online environment. It requires one year of monthly energy consumption data to benchmark existing building energy performance. The rating is done on a scale of 1–100 relative to similar buildings nationwide. Higher the score, better the building performance.

The building being assessed is not compared to other buildings; instead, statistically representative models are used to compare the building against similar buildings from a national survey conducted by the Energy Information Administration (EIA) of the Department of Energy.

This national survey, known as the Commercial Building Energy Consumption Survey (CBECS), is conducted every four years, and gathers data on building characteristics and energy use from thousands of buildings across the United States. The building's peer group of comparison is those buildings in the CBECS survey that have similar building and operating characteristics. A rating of 50 indicates that the building, from an energy consumption standpoint, performs better than 50% of all similar buildings nationwide, while a rating of 75 indicates that the building performs better than 75% of all similar buildings nationwide.

Thus, *Portfolio Manager* provides a platform to track energy and water use trends as compared with the costs of these resources. This is a valuable tool for understanding the relative costs associated with a given level of performance.

The *Target Finder* (EPA 2010c) sets energy performance rating targets and compares the estimated annual energy use of a building design to the measured energy consumption. It is a no-cost online tool that enables architects and building owners to set energy standards and receive an EPA energy performance score for projects during the design process. The projects that earn a score of 75 or higher are eligible for the 'Designed to Earn the Energy Star' certification.

## **2.6. TERI GRIHA rating system**

TERI-Green Rating for Integrated Habitat Assessment (GRIHA) is a five star rating system in India. The rating emphasizes passive solar techniques for optimizing indoor thermal and visual comfort. GRIHA encourages the optimization of building design to reduce conventional energy demand. A building is assessed on its predicted performance over its entire life cycle from inception through operation. GRIHA was developed as an indigenous building rating system, particularly to address and assess non-air conditioned or partially air-conditioned buildings. It integrates all relevant Indian codes and standards for buildings and acts as a tool to facilitate their implementation.

Up to 104 points over 34 different categories can be earned under the GRIHA rating system; there are five levels of star-rating: one star (50-60 points), two stars (61-70 points), three stars (71-80 points), four stars (81-90 points) and five stars (91-100 points). Out of the 34 categories, two are specifically associated with building performance evaluation. These are listed in Table 2.2 below.

Table 2.2

*Credits related to POE as allocated by TERI GRIHA.*

TERI GRIHA: Credits Related to POE		Points	Remarks
Credit 32	Energy Audit and Validation		Mandatory
Credit 33	Operations and Maintenance Protocol for Electrical and Mechanical Equipment	2	Mandatory

- TERI-GRIHA Criterion 32: Energy Audit and Validation

Under this criterion, all buildings certified under the GRIHA rating have to get an audit report prepared by approved auditors of the Bureau of Energy Efficiency (BEE), Government of India. This is done to validate the predicted energy consumption, thermal comfort and visual comfort criteria. In addition to preparation of the audit report, TERI also performs thermal performance monitoring and visual comfort monitoring for typically representative days to verify the data provided in various documents, and for which points have already been awarded. This is a mandatory provision and a building that does not adhere to this category is not awarded the GRIHA Rating.

- TERI-GRIHA Criterion 33: Operation and Maintenance

In order to validate and maintain 'green' performance levels and propagate green practices and concepts, TERI has made it mandatory that all Electrical and mechanical systems be maintained by the owner, supplier or contractor and this have to be ensured by means of an official contract.



## Chapter 3

### **POST OCCUPANCY EVALUATION OF ENERGY USE**

A number of studies and extensive literature is available that describes various procedures relevant to performance measurement of occupied buildings. This database is often used by energy engineers and commissioning agents for the diagnosis of operational problems and commissioning errors in buildings. Knowledge of these techniques can help architects, designers and engineers evaluate how design concepts actually work once applied, and can help them to make informed design decisions.

Building In-Use assessment involves the measurement of its performance under the following sub-categories:

- i. Energy Use
- ii. Indoor environmental quality (IEQ)
  - a. Thermal comfort
  - b. Indoor air quality
  - c. Lighting/daylighting
- iii. Acoustics.
- iv. Water Use

This chapter reviews the published work on post-occupancy performance of green buildings in terms of energy use only. The other aspects, namely, IEQ, Acoustics and Water Use have been briefly outlined in Appendix B.

#### **3.1. Historical overview of POE of building energy use**

The history of M&V of building energy use parallels the development and use of computerized energy calculations in the 1960's, with a much accelerated awareness in 1973, resulting from the Middle East oil crisis. Prior to that energy was cheap and abundant and M&V of energy use in a building was limited to

simple, unadjusted comparisons of monthly utility bills. Some of the earliest efforts to develop standardized methods for the evaluation of building energy use began with efforts to normalize residential heating energy use in single-family and multi-family buildings (Socolow 1978). Procedures and methodologies to baseline energy use in commercial buildings began to appear only in the 1980's and the early 1990's (for example Haberl et al., 1988; Claridge et al., 1991). Modeling toolkits, software, and measurement procedures were developed to aid performance evaluation of buildings and HVAC system components. The prominent ones amongst these include RP-1050 for calculating linear inverse building energy analysis models (Kissock et al., 2001), and RP-1093 for calculating diversity factors for various loads (Abushakra et al., 2001).

Efforts in several states in the United States for measuring the energy and demand savings from retrofits in existing buildings culminated in the development of the U.S. Department of Energy's (USDOE) 1996 North American M&V Protocol (NEMVP), which was accompanied by USDOE's 1996 Federal Energy Management Program (FEMP) Guidelines. In 1997, the NEMVP was updated and republished as the International Performance Measurement and Verification Protocols (IPMVP). The IPMVP was then expanded in 2001 into two volumes: Volume I covering Energy and Water savings, and Volume II covering Indoor Environmental Quality. In 2003 Volume III of the IPMVP was published that covered protocols for New Construction. Finally in 2002, ASHRAE released Guideline 14-2002: Measurement of Energy and Demand Savings intended to serve as the technical document for the IPMVP.

Over the last three decades, significant work has been done with regards to the development of methods for measuring, reporting and validating building energy

use. Much of the foundation for the ASHRAE and IPMVP publications mentioned above was developed through the Texas A&M University's *Loan STAR* (Loan to Save Taxes and Resources) project, which developed energy monitoring guidelines for use in Texas (Haberl et al., 1992, 1996). The Loan STAR program was established in 1988 by the Governor's Energy Office of Texas and aimed at using a revolving loan financing mechanism to fund energy-conserving retrofits in state, public schools and local government buildings. A unique feature of the Loan-STAR was the 'Monitoring and Analysis Program' (MAP) (1992) that was established to measure and report the energy savings from the retrofits. The program resulted in the formulation of a complete workbook that included descriptions and installation instructions for sensors needed for measuring, procedures for retrieving data from remote buildings, and an overview of analysis methods for building energy monitoring.

Torcellini et al., (2004) monitored and evaluated the energy performance of six high-performance buildings around the United States. Evaluations began with extensive one-year minimum building energy use monitoring; the data were then used to calibrate energy simulation models. The energy performance was compared with other buildings and to code-compliant, base case buildings. These case studies proved instrumental in highlighting what could be repeated and/or avoided in future buildings energy-wise. All the buildings were found to perform better than typical buildings; however, none of them performed as well as initially predicted. Torcellini and Deru (2005) also conducted extensive research to identify performance metrics which have the greatest value for determining energy performance. Their research served as a starting point to develop standard definitions and methods for measuring and reporting building

performance. Their findings were published in the National Renewable Energy Laboratory's (NREL) 'Performance Metrics Research Project' (October 2005).

Brook et al., (2005) from California Energy Commission (CEC) and Haves et al., (2005) from the Lawrence Berkeley National Laboratory (LBNL) worked on "Development of a Model Specification for Performance Monitoring Systems for Commercial Buildings" and focused on four key aspects of performance monitoring: (i) performance metrics, (ii) measurement system requirements, (iii) data acquisition and archiving and, (iv) data visualization and reporting. The study reviewed the potential benefits of performance monitoring and briefly discussed the ways in which it could be implemented. It also gave insights into reliable and effective database management and data visualization tools for proper management, archiving and visualization of the data obtained from building monitoring.

Haberl et al., (2006) reviewed significant work that had been done in the field of energy use assessment. The 'Scoping Study: Protocols for Measuring and Reporting the On-site Performance of Buildings except Low-Rise Residential' helped determine shortcomings in existing measurement protocols and make recommendations to ASHRAE on how to proceed. This study formed the basis for the development of the ASHRAE Performance Measurement Protocol for Commercial Buildings (2010).

A large number of ASHRAE research projects have been instrumental in providing the basis for several ASHRAE guidelines and standards related to performance measurement. In ASHRAE RP-1286, "Evaluation of Building Energy Performance Protocols", Glazer (2006), developed guidance regarding baselining of building energy use. The project also provided an evaluation of common

building performance rating tools such as LEED, CAL-ARCH (California building energy reference tool), BREEAM, etc.

More recently, a number of researchers have conducted studies to evaluate the performance of many existing 'green' certified buildings. Turner et.al., (2007), assessed eleven LEED certified buildings in the Cascadia Region, USA, by comparing actual utility usage to three different metrics; namely, design energy use, energy use compared to a code-compliant baseline and average energy use of the commercial building block. Turner and Frankel (2008) undertook the study of 121 North American LEED New Construction (NC) buildings. The study analyzed whole-building energy usage with three different metrics, namely, (i) Energy Use Intensity (EUI) comparison of LEED and national building stock (CBECS national average for commercial building stock), (ii) Energy Star ratings of LEED buildings, and (iii) Measured results compared to initial design and baseline modeling. The authors concluded that on an average, LEED buildings were delivering anticipated results and all the three views of building performance consistently showed that average LEED building energy use was 25-30% better than the national average. They reported that although energy modeling is a good indicator of program wide performance, individual project modeling predictions varies widely from actual project performance outcomes. They suggested improvements in LEED program quality control and follow-ups to help maintain savings. To this end, awarding of LEED credits for advanced commissioning and M&V were recommended.

Fowler and Rauch (2008) reported on a comprehensive study of 12 General Services Administration (GSA) buildings. The buildings chosen were predominantly federal buildings designed with either a green intent or LEED

certified. The study investigated the performance of these buildings by reviewing water and energy use, waste management, occupancy satisfaction, transportation, operation and maintenance, etc. Energy use was determined from at least 12 months of utility bills. The actual building use was compared with the CBECS national and regional averages.

In each of the studies mentioned above there was a noticeable difference between the predicted and the measured energy use of the building. The reason for this variation could be attributed to a number of factors such as occupancy patterns, difference between as-built and the initial design intent, variation in the equipment schedules and improper commissioning of buildings. Most of these factors are unavoidable under practical circumstances and can result in buildings to perform quite differently than designed or predicted. It, therefore, becomes extremely important to verify the performance of the building through actual monitoring once the building is in operation.

A research project called “Probe” (Post-Occupancy Review of Buildings and their Engineering) was carried out by Bordass et al., 1995-2002, under the Partners in Innovation scheme (jointly funded by the UK Government and The Builder Group, publishers of Building Services Journal). The project involved reviewing high performance buildings through site documentation, technical surveys (walk-through and spot checks), energy survey’s (CIBSE TM22 analysis), envelope pressure tests, occupant questionnaire surveys, management interviews and designer’s responses. The project provided tremendous information regarding the actual performance of a number of buildings in the United Kingdom. Bordass proposed that placing a post occupancy or as-built certification label on the

building can drive the need for greater emphasis on build quality/process and commissioning of the building.

USGBC in association with ASHRAE & CIBSE has been instrumental in developing the 'Performance Measurement Protocols for Commercial Buildings' (2010) for assessing the performance of commercial buildings. The document provides a consistent set of guidelines and methods for measuring, expressing and comparing energy use of occupied buildings.

### **3.2. Energy use measurement protocols**

The commonly referenced standards for energy-use measurement in buildings include:

- ASHRAE Guideline 14, Measurement of Energy and Demand Savings (ASHRAE 2002),
- ANSI/ASHRAE Standard 105, Standard Methods for Measuring, Expressing and Comparing Building Energy Performance (ASHRAE 2007a),
- LEED for Existing Buildings Operation and Maintenance, International Performance Measurement and Verification Protocols (IPMVP) DOE (1997), etc.

The ASHRAE Performance Measurement Protocols for Commercial Buildings (2010) identifies the following commonly followed techniques for measuring the energy-use in a building:

- i. Actual physical measurement
- ii. Forward and inverse modeling
- iii. Whole building calibrated simulation

This section limits itself to the measurement protocols for actual physical measurement of building energy use. Forward/Inverse Modeling and Whole Building Calibrated Simulation are briefly discussed in Chapter 4.

Based on the detail, rigor, and accuracy of the measurements required to meet the performance objectives, three levels of performance measurement protocols have been identified, namely; *Basic*, *Intermediate* and *Advanced*.

The *basic performance measurement method* is intended to provide the foundation for characterizing and understanding building energy performance in a way that management can understand and incorporate into planning. The estimated expense for basic level performance verification can range from \$1,000-2,000 per project approximately. The measured/required data are of three types:

- i. Basic building characteristics (project address, location, gross floor area, operation, occupancy patterns, building function etc.).
- ii. Whole-building annual energy use and costs of all Electricity and fuels used, including the highest annual peak demand for each fuel. Actual site energy use and energy cost for all forms of energy over a period of 12 consecutive months (365 days, annual total) must be reported.
- iii. Energy cost indices i.e. energy cost per unit area of the building.

$$\text{Total Energy Use}^2 \text{ Index (EUI)} = \text{Total Annual Energy Use} / \text{Gross Floor Area, kBtu/ ft}^2 \dots\dots\dots (\text{Eq. 3.1})$$

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<sup>2</sup> **Total Energy Use:** The total energy is the sum of all energy used in the building (excluding source energy supplied by heat pumps). It is equal to the energy imported (purchased) to the facility plus on-site generated energy minus energy exported (sold) from the facility.



Net Energy Use Index<sup>3</sup> (Net EUI) = Net Annual Energy Use / Gross Floor Area, \$US/ ft<sup>2</sup> .....(Eq. 3.2)

Energy Cost Index (ECI) = Net Annual Energy Cost<sup>4</sup> / Gross Floor Area, \$US/ ft<sup>2</sup> .....(Eq. 3.3)

The *intermediate performance assessment method* provides measurement and evaluation to support an enhanced level of understanding of buildings and end use performance so as to identify possible areas of performance improvement. This level begins by incorporating the system-level (energy end-use) effects and adds initial systems and end-use assessment to the basic performance determination. The intermediate methods build on the basic annual energy use data and associated EUI's and ECI's by going deeper into monthly and weekly data for the whole building and for major energy end uses. In addition to energy data, the Electrical demand for each of the months in the 12-month period is also reported, and the Electrical Load Factor for each month is calculated as:

$$\text{Electrical Load Factor, ELF}^5 = \frac{\text{Electric Use (kWh) for the month}}{\text{Electric Demand for the month (kW) X No. of days in the month X 24}} \quad \text{..... (Eq. 3.4)}$$

<sup>3</sup> **Net Energy Use:** The net energy is the sum of the imported (purchased) energy minus exported (sold) energy.

<sup>4</sup> **Annual Energy Cost:** The total cost for each energy form used. Monetary compensation for energy exported (sold) from the facility is recorded as a negative number. The cost of stored purchased energy used in the building is determined using the cost of the oldest fuel in storage and not its replacement cost.

<sup>5</sup> **Electric use profiles and ELF** values should be compared against expected patterns. As occupancy factors reduce, ELF values should also go lower. Buildings with efficient energy use often have ELF values of 30% or less. Buildings that have 100% occupancy factors will often have ELF values of 60 % or more.

The Electric load profiles and ELF values are compared against expected patterns. Intermediate instrumentation and analysis to determine this level of performance may cost in the range of \$2,000 to \$10,000 per project approximately.

*Advanced performance assessment method* is used to track daily/hourly whole building energy performance through sub-metered data. This can help identify additional potential improvements to increase building performance and to develop advanced models of building performance.

This level requires that all basic results be updated and reported on a daily basis, i.e., updated every day for the 365-day period. Second, major end uses of energy must be either modeled or measured on an annual basis. Measurement can be by sub- meters installed for HVAC total electric, HVAC fan electric, non-electric heating, indoor lighting, miscellaneous electric etc.

The modeling of major end-uses can be through a combination of analysis and short-term or diagnostic metering. The end uses that should be determined are: heating energy, cooling energy, fan energy for heating/ cooling/ ventilation and/or exhaust, indoor lighting, major equipment centers and all other electric loads.

Due to the extensive instrumentation and sophisticated analytical techniques required, advanced performance evaluation may cost anywhere from \$10,000-100,000 per building. This detailed level of analysis is likely to be justified only for case studies or for buildings that are the subject of a research or detailed case-study or demonstration project.

## **BUILDING ENERGY USE MODELING**

A model is a pattern, plan, representation, or description designed to show the structure or the workings of an object, system or concept. It can also be a simplified representation (usually mathematical) used to explain the workings of a real-world system or event. *(Source: Wikipedia)*

Procedures and methodologies to baseline energy use in commercial buildings began to appear in the 1980's and early 1990's. Since then, a number of modeling toolkits and software have been developed that are useful in developing performance metrics for buildings, as well as HVAC system components. Some of these are: the Princeton Scorekeeping Software (PRISM) (Fels et al., 1995), ASHRAE's HVAC01 software for modeling primary HVAC systems such as boilers and chillers (Lebrun et al., 1999), ASHRAE's HVAC02 software for modeling secondary HVAC systems such as air handlers, blowers, cooling coils and terminal boxes (Brandemuehl et al., 1993). ASHRAE research project 1050-RP (Kissock et al., 2001) dealt with creating toolkits for building energy analysis, e.g., a toolkit for calculating linear, change-point linear and multiple-linear Inverse building energy analysis models. This chapter first outlines some of the commonly used methods for building energy use modeling.

The most common approaches and techniques for modeling building energy use can be classified into:

- (i) Data driven analysis approach
- (ii) Detailed calibrated simulations approach, and
- (iii) Approaches based on artificial intelligence concepts.

These have been discussed in Sections 4.1-4.3. Over the past fifteen years or so, a few researchers have attempted to use short-term monitoring for the purpose of baselining building energy use. An overview of these studies is provided in Section 4.4.

#### **4.1. Data driven analysis: inverse, forward and hybrid modeling**

a. Inverse modeling has been the mainstay of energy analysts and researchers throughout the world for many years. The procedure involves using daily or hourly whole-building energy use to develop a number of feasible regression models for the building, comparing the results, and then selecting the best model using appropriate statistical or model performance factors. The most appropriate statistical indices for model selection factors are usually the model goodness of fit ( $R^2$ ) and co-efficient of variance of the root mean square error (CV -RMSE).

The analysis is conducted on the energy response of the building as it relates to one or more driving forces or parameters. To develop an inverse model, one must assume a physical configuration of the building or system, and then identify the parameter of interest using statistical analysis. Two types of inverse models have been reported in the literature: *steady state* and *dynamic inverse* models.

The simplest steady-state inverse models use linear regression to estimate average behavior, such as average monthly billed utility energy use as a function of average billing period temperatures. More robust methods include multiple linear regression, change point linear regression, and variable-base degree day regressions. Simple steady state inverse models may prove to be insensitive to dynamic effects (i.e., thermal mass) and other variables (i.e., humidity and solar

gain), and are difficult to apply to certain building types; for example, buildings that have strong on/off schedule dependent loads, or buildings that display multiple change-points.

b. In Forward modeling, a thermodynamic model of the building is created using fundamental engineering principles to predict the energy use for 8760 hours of the year, given the location and weather conditions. This requires a complete description of the building, system, or component of interest, as well as the physical description of the building geometry, geographical location, system type, wall insulation, etc.

c. Hybrid modeling combines forward and inverse as used in calibrated simulations. For example, when a traditional fixed-schematic simulation program such as DOE-2 is used to simulate energy use of an existing building then one has a forward analysis method that is being used in an inverse application (Energy Management Handbook, 2009).

#### **4.2. Detailed calibrated simulations**

The process involves using a building simulation program (such as eQuest, EnergyPlus, etc.) to tune or adjust inputs until the predictions match the measured data within criteria deemed acceptable. Calibrated simulations are a powerful tool for savings estimation and for measurement and verification purposes (Reddy et al., 2007). Calibrated simulations are not within the scope of this research project.

#### **4.3. Artificial intelligence**

Artificial intelligence algorithms have the ability to solve complex non-linear problems, the ones that were solved in the past using only human intuition and

experience. For example, neural networks are artificial intelligence based methods that attempt to model the working of the human brain (Kreider et al., 1995). A number of researchers have attempted to use artificial intelligence as a tool for building energy use prediction.

#### **4.4. Short term to annual extrapolation**

There are no absolute rules for determining the minimum acceptable length of monitored data for the regression model to accurately predict long-term performance. A full year of energy consumption data is likely to encompass the entire range of variation of both climate conditions and the different operating modes of the building HVAC systems. However, in many cases a full year of data is not available and one is constrained to develop models using less than a full year of data. The literature shows that only a few studies have attempted to use short-term monitoring for the purpose of base-lining building energy use.

The first attempts in this field started emerging around 15 years ago. Kissock et al., (1993) examined the accuracy with which single-variate standard inverse temperature-dependent regression models, identified from short data sets, could be used to predict annual energy use of buildings. Katipamula et al., (1995) examined the same problem using multi-variate linear regression models. All of these studies concluded that regression modeling could be accurate and reliable only when several months (more than six months) of daily data are used to develop the model. They also noted that excluding the effect of seasonal variation of the outdoor dry-bulb and dew point temperature in the models developed from short data sets can cause significant prediction errors.

In an attempt to find how much data is required for hourly regression models for accurate long term prediction of building energy use, Abushakra (1996) studied

the effect of the length of monitoring periods on long-term prediction of energy consumption of an office building in Montreal., The study used a total of 28 different combinations of regressors to develop 28 different stepwise multiple linear regression models. The data was also divided into two seasons: heating and cooling. For each season, each of these 28 models were developed with one-week, two-week, one-month, two-month, three-month, four-month, five-month and six-month periods of monitoring. He concluded that NMBE did not change substantially as one goes beyond a two-week period of monitored data.

A few more recent studies have suggested analysis methods involving a few weeks of hourly data which provide insight into internal loads and the manner in which the building is operated, in addition to utility bills, which would capture the widest range and the annual average weather variables such as dry-bulb temperature and humidity ratio (Abushakra et al., 2000). Abushakra also developed a procedure for selecting the two week period of the year that has the widest range of dry bulb temperature and humidity ratio while capturing the yearly mean of these two variables.

Tests with synthetic data found that these observations are applicable with 4-P models as well (Reddy et al., 1998). The best predictors of both cooling and heating annual energy use are models from datasets with mean temperatures close to the annual mean temperature and with the range of variation of daily temperature values in the dataset encompassing as much annual variation as possible. Thus, one month dataset in spring and fall would frequently be a better predictor of annual energy than five month data sets from a portion of winter and summer.

#### **4.5. Conclusions from the background literature**

Energy rating systems place a lot of emphasis on assessing the actual performance of buildings. Making building-in-use evaluation mandatory for obtaining green certification is a significant step in the right direction. Ongoing monitoring and reporting of buildings is possibly the best way to ensure higher building performance because it will put to test the strategies and concepts that are being adopted for the design and planning of high performance buildings.

To allow for the comparison of the performance of one building with another, it is important that all the buildings be assessed based on a standard set of guidelines and methods. Comparing the energy use of different high performing buildings can provide the much needed insight into what concepts really work when put to use. Extensive research undertaken over the past three decades has been instrumental in the development of the standardized protocols for the measurement of building performance under various categories (energy, IEQ, acoustics, water use). This can be the starting point for a standardized procedure to be adopted for performance assessment in buildings.

Generally, a full year or more of energy use and weather data is used to construct empirical models for assessing building energy use. However, in many cases, either a full year of measured building performance data is not available or the time & cost implications may not make it viable for the building owner to invest in monitoring the building for the entire year. In such cases, short-term monitoring may be considered an alternative.

For short-term in-situ monitoring, the time-interval over which the measurements are taken is extremely critical., The intent obviously is to gather and analyze data for as short a period as possible. As a minimum, one would monitor all the



necessary variables for atleast one week to capture the diurnal variations of the weekdays and the weekends. However, one week or so of hourly/daily data might not be enough for generating acceptable predictions for the whole season or the whole year.

While many previous studies have attempted to use short-term monitoring for long-term prediction, it was felt that additional research is needed to investigate about factors such as: (i) optimum length of monitoring period, (ii) optimum time or season for monitoring, (iii) necessary variables to monitor, and (iv) effective and simple modeling techniques that can be easily adopted by practitioners. The primary research objective of this thesis is to provide insights and recommendations into some of these factors.

## **RESEARCH METHODS**

This research attempts to develop simple modeling techniques which allow identifying the best periods to start in-situ monitoring of the energy use of a building based on climatic variability, and also to determine the least amount of building energy use data that would be enough to generate acceptable long term predictions. Statistical methods have been adopted for analyzing this issue. As stated earlier, calibrated simulations are not within the scope of this project.

Flowchart in Figure 5.1 summarizes the different sub-categories that have been identified and considered suitable for this research. Three application areas are identified. These include:

- (i) When detailed audit for investment grade energy conservation measures (ECM's) are required,
- (ii) When claims made by the newly constructed green or high performance buildings are to be ascertained, and
- (iii) When savings from already installed ECM's are to be verified against pre-retrofit claims using pre-post monitored data. The type of analysis method to be adopted is governed by the type of building performance data available for analysis.

The analysis procedure that can be adopted for each of these application areas is governed by the type of data that is available for analysis. Four broad categories of analysis procedures are proposed and studied as part of this thesis research: (i) using ambient temperature data only, (ii) using simulated/ monitored data, (iii) using utility bills and a short monitored dataset, and (iv) using utility bills only.

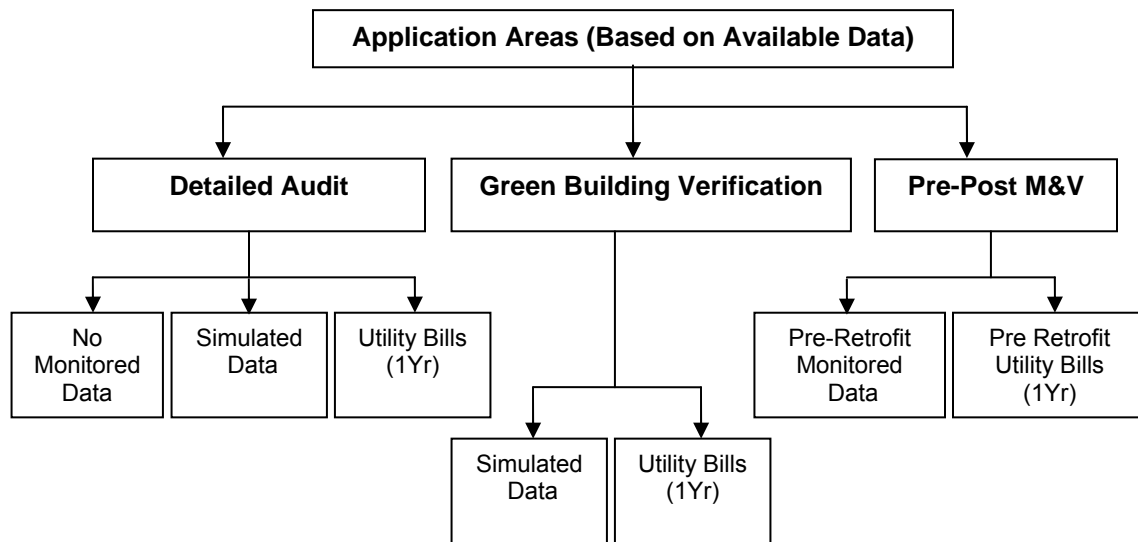


Figure 5.1 Different sub-categories considered suitable for this research.

### 5.1. Climate diversity test/ analysis

Past studies have demonstrated that when a model is identified from short-term data that does not span the entire range of variation of the driving variables (say outdoor dry bulb temperature), erroneous/misleading predictions can result if used outside the range (Reddy et al., 1988). Thus, even before one attempts to develop a meaningful model from the monitored data, the range of associated climatic data should meet certain criteria.

Abushakra (2000) developed an algorithm that checks for the closeness of the outdoor dry-bulb temperature and humidity ratio of any consecutive two-week period of the year to the annual averages, while checking at the same time the amplitude of its dry-bulb temperature and humidity ratio ranges against the annual averages. The algorithm allows the ranking of all possible consecutive two-week periods of the year from best to worst. The method was based on the findings from the past studies (Kissock et al., 1993), in which it was established that building load prediction accuracy will be best when models are identified

from data periods during which outdoor dry bulb temperature (which is usually the single most influential driver of building energy use) is closest to the annual mean and has a large day-to-day variability.

The ‘procedure to select the “best” two-week period’ developed by Abushakra (2000), termed as the *Short Term Monitoring for Long Term Prediction* (SMLP) method forms the starting point for this research. The SMLP method has been explained in detail in Section 5.2.

## 5.2. Short - term Monitoring for Long-term Prediction (SMLP)

Abushakra (1999) developed a procedure for selecting the two week period of the year that has the widest range of dry bulb temperature and humidity ratio while capturing the yearly mean of these two variables. The same algorithm has been applied for monthly time intervals to determine the best month of the year when in-situ monitoring is likely to yield a regression model that is most accurate in its long term predictions. It is based on using the following screening indices:

1. The yearly average (YA) and yearly range (YR) of outdoor dry bulb temperature from hourly/ daily values.
2. Monthly average (MiAi) and monthly range (MiRi) of outdoor dry bulb temperature from hourly/daily values, for all months of the year.
3. For each of the monthly periods obtained above, the outdoor temperature *Average Error* , accounts for how close the two week average is to the yearly average:

$$AE_i = \frac{|MiAi - YA|}{YA} \dots\dots\dots (Eq. 5.1)$$

4. The *Relative Average Error* , accounts for the relative performance of each period in its closeness to the yearly average:

$$RAE_i = \frac{|AE_i - AE_{min}|}{AE_{min}} \dots\dots\dots (Eq. 5.2)$$

5. The *Normalized Error 1* , is meant to avoid differences in the order of magnitude while adding different errors:

$$NE1i = \frac{RAEi}{RAEmax} \dots\dots\dots (Eq. 5.3)$$

6. *Range Error* , accounts for the differences between the two-week outdoor dry bulb temperature range and temperature range:

$$REi = \frac{|MiRi - YR|}{YR} \dots\dots\dots (Eq. 5.4)$$

7. *Relative Range Error* , accounts for the relative performance of each period in its coverage to the yearly range:

$$RREi = \frac{|REi - RE_{min}|}{RE_{min}} \dots\dots\dots (Eq. 5.5)$$

8. *Normalized Error 2* , is meant to avoid differences in the order of magnitude while adding different errors:

$$NE2i = \frac{RREi}{RREmax} \dots\dots\dots (Eq. 5.6)$$

9. *Normalized Average Error*, resulting from averaging NE1 and NE2:

$$NAEi = \frac{NE1i + NE2i}{2} \dots\dots\dots (Eq. 5.7)$$

10. Assign ranks. The “best” one-month period for monitoring is that with the minimum NAE.

The SMLP method has been tested by Abushakra (1999) to show a good consistency on the degradation of the predictions as one uses models from best to worst.

### 5.3. Outdoor Dry-Bulb Temperature Analysis (DBTA)

The SMLP method explained above, although quite accurate, uses a lengthy procedure to reach the desired output. Since the aim of this research is to develop easily usable methods for analysis, a simpler and quicker method called ‘Dry-Bulb Temperature Analysis’ (DBTA) for deriving the best periods for in-situ monitoring has been devised. The analysis is again based on findings by Kissock et al., (1993) proposed and evaluated building load prediction accuracy being

best when models are identified from data periods during which outdoor dry bulb temperature is closest to the annual mean and has a large day-to-day variability. The DBTA method uses a sliding window technique to compare the average outdoor temperatures of the different periods for in-situ monitoring with the annual average. For example, for the month of January, the average temperatures for the periods January, January-February, January-March and so on till January-December are computed and compared to annual average temperature to determine closeness. The analysis is done for each month of the year taken as the starting period for monitoring.

Starting with each month of the year, the results obtained are analyzed to determine how many months of temperature data are needed for the average for the period to reach the annual average. The values obtained are visually translated into a graphical format for easy comprehension. The DBTA method provides a way of ranking the time periods (based on temperature data only) in terms of the expected predictive accuracy of the regression models.

#### **5.4. Multivariate Change Point (MCP) Modeling**

Prior to describing the modeling technique adopted, an insight into regression based modeling and an overview of the software that has been used for analysis is appropriate for better comprehension.

##### **5.4.1. Regression based models**

Regression analysis is a statistical technique used to relate variables. The basic aim is to build a mathematical model to relate dependent variables to independent variables. In general, a regression model will be defined as a single algebraic equation of the form (Draper and Smith, 1981)

$$Z = f(X_1, X_2, \dots, X_k) + u \quad \dots\dots\dots (\text{Eq. 5.8})$$

where, Z is a variable whose movements and values may be described or explained by the variables  $X_1, X_2, \dots, X_k$ . The letters are known as regressors and assumed to have a causal relationship to the dependent variable Z. The additional term u is a random variable, which is included to account for the fact that movements in Z are not completely explained by the variables.

In building energy study, the building energy consumption is considered to be a dependent variable, and the other parameters such as weather and non- weather data are taken as independent variables. Three kinds of regression models have been developed, namely;

- i. Variable-based degree-day model,
- ii. Linear regression model (single-variate and multi-variate), and
- iii. Change-point models. (Kissock et al., 2003)

When only one independent variable (mean temperature) is used in the development of the model, the model is called *single-variate linear regression* model. When there are more than one independent variables is used in the development of the model, the regression model is called a multiple or a *multivariate linear regression model*.

Generally, there exists a non-linear relationship between heating and cooling energy use and the ambient temperature caused by system effects. The Change-point models (Figure 5.2) are able to successfully capture this non-linear relationship. Four basic types of typical change-point models can be identified:

- i. Three-parameter (3P) heating energy use model,
- ii. Three-parameter (3P) cooling energy use model,
- iii. Four-parameter (4P) heating energy use model, and

iv. Four-parameter (4P) cooling energy use model.

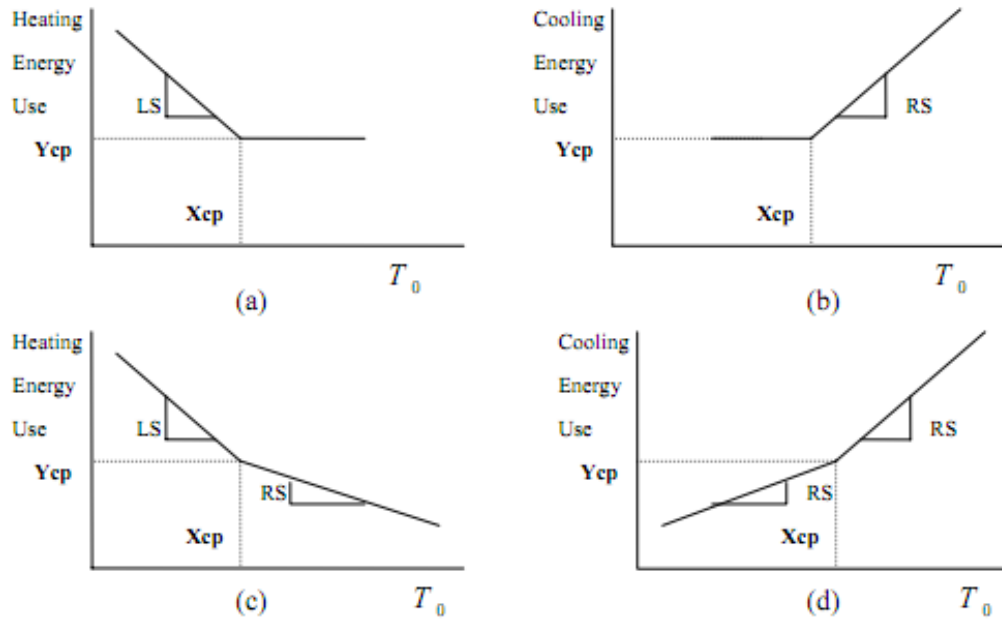


Figure 5.2 Typical Change Point Models (a) three-parameter (3P) heating energy use, (b) three-parameter (3P) cooling energy use, (c) four-parameter (4P) heating energy use model, and (d) four-parameter (4P) cooling energy use model. (Source: Energy Management Handbook, 2009)

a. Three Parameter (3P) Model: When energy use appears to be linearly correlated with an independent variable over part of the range of variation of the independent variable and has another type of variation over the other part, 3P multivariate change point regression models are appropriate. They are of the form:

$$Y = b_1 + b_2 (X_1 - b_3)^+ + b_4 X_2 + b_5 X_3 \quad \dots\dots\dots (\text{Eq. 5.8})$$

where,  $b_1$  is the y-coordinate of the change point,  $b_2$  is the slope term,  $b_3$  is the x-coordinate of the change-point, and  $b_4 - b_5$  are regression coefficients of the optional independent variables  $X_2$  through  $X_4$ . The  $( )^+$  and  $( )^-$  notations indicate



that the values of the parenthetic term shall be set to zero when they are negative and positive respectively.

b. Four Parameter (4P) Model: The 4P model consists of two linear segments joined at a change-point. When energy use appears to be non-linearly correlated with an independent variable, a 4P model may provide a good fit to the data. Typically, 4P Multivariate Regression models can have up to three independent variables, and are of the form:

$$Y = b_1 + b_2 (X_1 - b_4)^- + b_3 (X_1 - b_4)^+ + b_5 X_2 + b_6 X_3 \dots\dots\dots (\text{Eq. 5.9})$$

where,  $b_1$  is the y-coordinate of the change point,  $b_2$  is the left slope,  $b_3$  is the right slope,  $b_4$  is the x-coordinate of the change point, and  $b_5 - b_6$  are regression coefficients of the optional independent variables  $X_2$  and  $X_3$ . The  $( )^+$  and  $( )^-$  notations indicate that the values of the parenthetic term shall be set to zero when they are negative and positive respectively.

#### **5.4.2. Comparison of Energy Explorer software with Inverse Modeling Toolkit**

In 1994, ASHRAE began developing the Guideline GPC-14P, a guideline for measuring retrofit savings. In support of Guideline-14P, ASHRAE initiated RP-1050 (Kissock et al., 2001) to develop a toolkit for calculating linear, change-point linear, and multiple linear inverse energy models. The toolkit was named the 'Inverse Modeling Toolkit' (IMT). The IMT was developed as a FORTRAN90 application for developing regression models of building energy use. The toolkit can be used to identify single and multi-variable least-squares regression models, variable-base degree-day and single and multi-variable change-point models.

Kissock (2008) recently developed the 'Energy Explorer' tool for analyzing building and facility energy-use data. It integrates the laborious tasks of data processing, graphing and statistical modeling through a user-friendly, graphical interface. It allows the user to determine baseline energy use, understand factors that influence energy use, calculate retrofit savings and identify operational and maintenance problems.

Energy Explorer (EE) includes a full package of statistical models specifically designed for analyzing building and facility energy use. Models include mean, median, simple and multiple-linear regression. In addition, specially-developed 2, 3, 4 and 5-parameter change-point models allow the user to precisely and easily quantify relationships between building energy use, weather and other energy drivers. Change-point models accurately model the non-linear energy use patterns characteristic of whole-building Electric, steam, heat-pump, and cooling energy use data. Modeling results are displayed numerically and graphically to facilitate a quick and complete understanding of the model and its fit to the data. In addition, retrofit savings and energy breakdowns can be calculated from the regression models.

Since IMT is the standard software recognized by ASHRAE for modeling change point behavior of energy use in buildings, a partial validation of the results obtained from the Energy Explorer Tool against the output from the IMT was done to provide credibility to the analysis results (Endurthy, 2010). The objective of this exercise was to:

- i. Compare differences in linear & change point model parameters when both IMT and EE programs are applied to the same dataset, and

- ii. Compare prediction accuracies of models identified from IMT and EE programs when applied to the same dataset.

The year-long synthetic dataset of daily energy use values for the large hotel located in Chicago with three available energy use channels; namely, whole building electric (WBE), cooling energy use (CHW) and heating energy use (HW) were used for this analysis. The two regressor variables used are outdoor dry-bulb temperature (DBT) and internal electric loads (LTEQ).

Table 5.1

*Model equations for different base periods identified using EE software and IMT*

Base Period used to identify model	Response	Model	EE Model	IMT Model
			Model Equation	Model Equation
October Only	WBE	3P	$63.35+5.77(\text{DBT}-43.46)^{+}+1.03\text{LTEQ}$	$62.56+5.78(\text{DBT}-43.22)^{+}+1.02\text{LTEQ}$
	CHW	3P	$149.69+108.23(\text{DBT}-50.83)^{+}+0.65\text{LTEQ}$	$141.67+109.98(\text{DBT}-50.98)^{+}+0.67\text{LTEQ}$
	HW	3P	$2825.30+79.69(66.02-\text{DBT})^{+}-2.11\text{LTEQ}$	$2793.85+79.88(66.49-\text{DBT})^{+}-2.12\text{LTEQ}$
Oct- Jan	WBE	4P	$45.35+0.37(40-\text{DBT})^{+}+6.16(\text{DBT}-40)^{+}+1.01\text{LTEQ}$	$44.64+0.38(40.01-\text{DBT})^{+}+6.21(\text{DBT}-40.01)^{+}+1.01\text{LTEQ}$
	CHW	4P	$288.32+1.43(45.04-\text{DBT})^{+}+90.72(\text{DBT}-45.04)^{+}+0.12\text{LTEQ}$	$308.7+0.63(45.79-\text{DBT})^{+}+95.04(\text{DBT}-45.79)^{+}+0.11\text{LTEQ}$
	HW	4P	$3381.85+201.85(56.99-\text{DBT})^{+}-72.69(\text{DBT}-56.99)^{+}-1.88\text{LTEQ}$	$3555.42+202.63(55.89-\text{DBT})^{+}-86.22(\text{DBT}-55.89)^{+}-1.85\text{LTEQ}$
Oct- May	WBE	4P	$54.57-0.12(43.25-\text{DBT})^{+}+7.12(\text{DBT}-43.25)^{+}+1.01\text{LTEQ}$	$56.58-0.22(43.96-\text{DBT})^{+}+7.32(\text{DBT}-43.96)^{+}+1.01\text{LTEQ}$
	CHW	4P	$413.86-3.94(49.59-\text{DBT})^{+}+128.22(\text{DBT}-49.59)^{+}+0.10\text{LTEQ}$	$440.72-4.89(50.06-\text{DBT})^{+}+131.31(\text{DBT}-50.06)^{+}+0.10\text{LTEQ}$
	HW	4P	$2818.98+205.34(59.58-\text{DBT})^{+}-67.66(\text{DBT}-59.58)^{+}-1.60\text{LTEQ}$	$3444.19+207(56.15-\text{DBT})^{+}-107.07(\text{DBT}-56.15)^{+}-1.56\text{LTEQ}$

Table 5.1 assembles the models identified using IMT and EE software for all three energy use channels. Four different base periods have been used to

identify the models. The 'October only' period implies that daily data for the month of October only was used to identify the model, while 'October-January' indicates that data from all four months were used for model identification. There are small differences in model parameters between IMT and EE software, the differences are small. This partially validates the use of EE software. The better test is to gauge differences in CV and NMBE between both models when used for prediction. The linear & change point model outputs from EE and IMT programs are summarized in Table 5.2. Comparison is based on the variation on CV-RMSE (%) and NMBE (%) for predictions for each of the channels of various base periods.

Table 5.2

*Prediction results from EE and IMT software.*

Base Period used for model identification	Response variable	EE Model		IMT Model	
		CV (%)	NMBE (%)	CV (%)	NMBE (%)
October	WBE	6.46	-1.62	6.65	-2.43
	CHW	70.00	-30.32	70.31	-29.67
	HW	68.59	-38.24	68.48	-38.49
Oct- Jan	WBE	6.30	-1.60	6.30	-3.17
	CHW	74.80	-38.70	73.42	-37.26
	HW	24.20	-3.20	24.32	-1.80
Oct - May	WBE	5.50	-2.60	5.41	-2.52
	CHW	61.80	-30.90	61.13	-30.82
	HW	23.30	-2.00	24.05	0.79
Oct- Sep	WBE	3.10	0.00	3.44	0.88
	CHW	24.10	-0.30	24.13	-0.22
	HW	22.80	0.00	22.76	-0.04

Figure 5.3 and Figure 5.4 shows comparison of prediction accuracies of models identified from IMT and EE software when applied to the same dataset. The results for both were found to be consistent and generally very close. The information from Table 5.2 is plotted in these figures for easier comprehension.

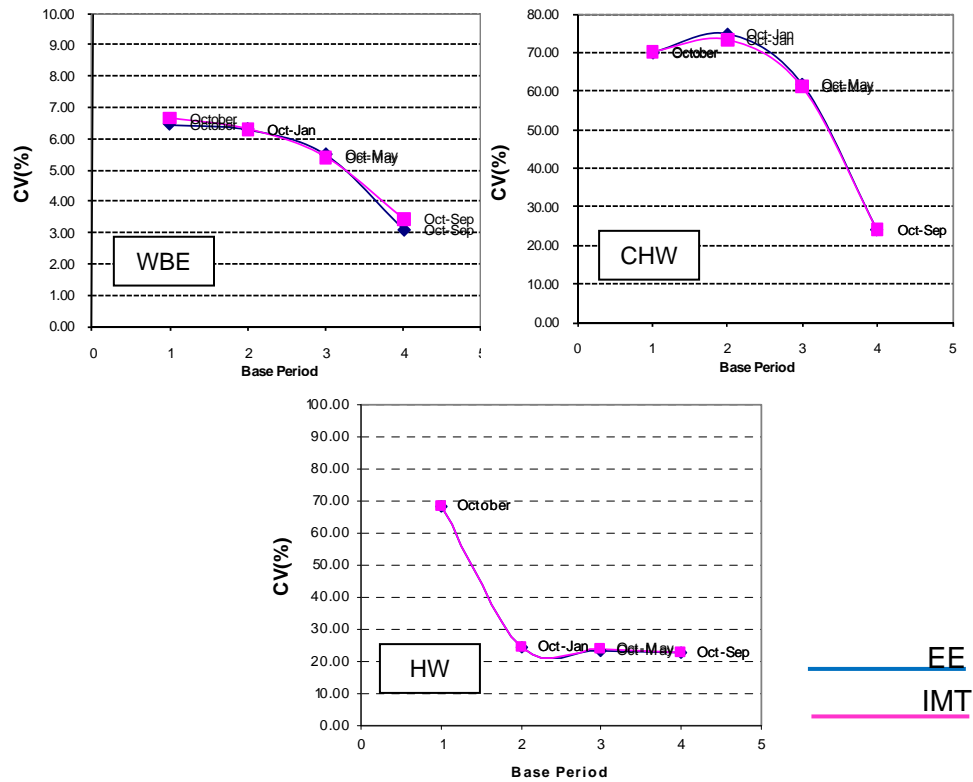


Figure 5.3 Prediction accuracy- CV (%) of models identified from IMT and EE software.

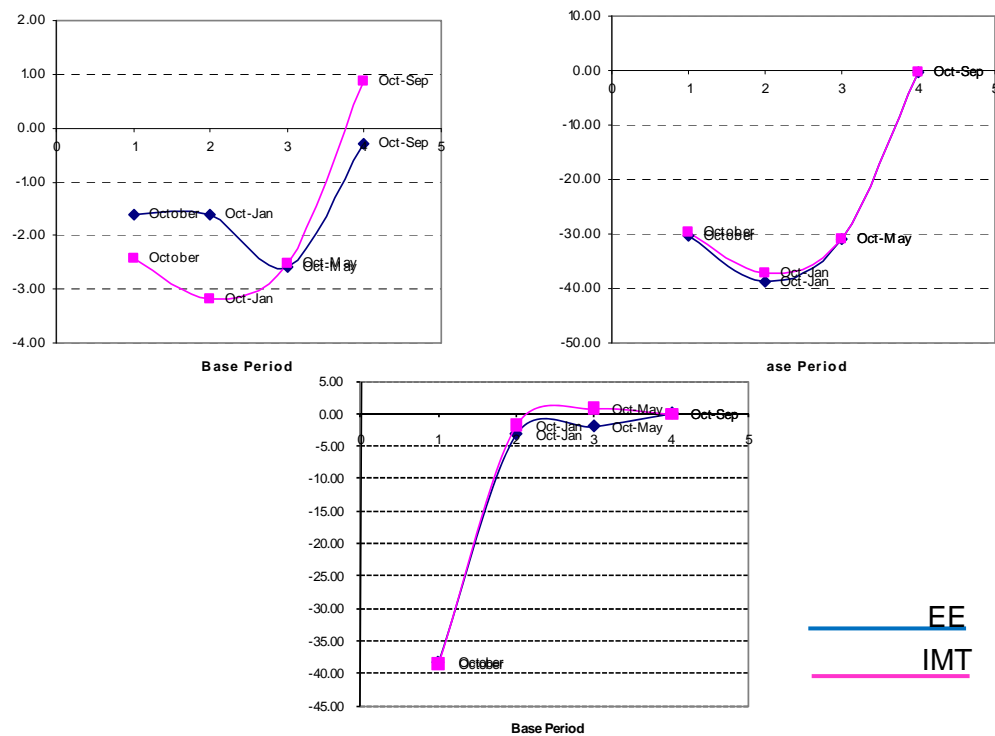


Figure 5.4 Prediction accuracy-NMBE(%) of models identified from IMT and EE software.

#### 5.4.3. MCP modeling technique adopted

The analysis approach is to predict whole building electric (WBE), cooling energy use (CHW), and heating energy use (HW) using a multivariate change point (MCP) model derived from the short data set. The MCP models for the three energy-use channels are generated using daily averages for outdoor dry bulb temperature (DBT) and lighting & equipment load (LTEQ) as the regressors using Energy Explorer software. 2-P, 3-P & 4-P change-point models were evaluated of which 4-P turned out to be the best, and so this was used in all subsequent analysis. The MCP model generated has the form:

$$E_i = A + B (X_1 - \text{DBT})^+ + C(\text{DBT} - X_1)^+ D(\text{LTEQ}) \quad \text{..... (Eq. 5.10)}$$

Where,  $E_i$  is the energy use,  $X_1$  is the x-coordinate of the change point for outdoor dry bulb temperature (DBT) and internal loads (LTEQ). A, B, C & D are regression coefficients.  $( )^+$  notation indicates that the value of the parenthetic term shall be set to zero when it is negative.

The accuracy of the model largely depends on the starting date and the end date of data collection. The start and the end date are influential in that the data within this period should capture the yearly fluctuations in temperature and humidity. In order to determine the best starting month and duration for in-situ monitoring, a systematic approach has been adopted. The models are generated for each starting month of the year (January to December), with each selection subsequently expanded in increments of one month to mimic different durations of monitoring. For example, for the starting month of January, the first model is generated using the data for January only, which is then subsequently increased in increments of one month i.e. January-February, January-March, January-April and so on until the whole year of data is used for generating the model. The

same process is repeated for each month of the year taken as the start period of in-situ measurement.

To determine the accuracy of the models derived from the short data-sets, the values of annual energy use predicted by models obtained from short data-sets are compared to the actual energy use in the original dataset. The predictive accuracy of the models is evaluated based on two statistical indices: Coefficient of Variation of the Root Mean Square Error or  $CV_{RMSE}$  (%) (Written as CV (%) in this report), and the Normalized Mean Bias Error or NMBE (%) defined as:

$$CV_{RMSE} (\%) = \left( \sqrt{\frac{\sum_{i=1}^n (Y_{Predicted,i} - Y_{Actual,i})^2}{(n - p)}} \right) \cdot \left( \frac{100}{\bar{Y}_{Actual}} \right) \quad \dots\dots\dots (\text{Eq. 5.11})$$

$$NMBE (\%) = \left( \frac{\sum_{i=1}^n (Y_{Predicted,i} - Y_{Actual,i})}{n - p} \right) \cdot \left( \frac{100}{\bar{Y}_{Actual}} \right) \quad \dots\dots\dots (\text{Eq. 5.12})$$

where,

- $Y_{Actual,i}$  the actual value of the dependent variable corresponding to a particular set of values of the independent variables
- $Y_{Predicted,i}$  the predicted dependent variable value for the same set of independent variables
- $\bar{Y}_{Actual}$  the mean value of the dependent variable of the actual data set
- $n$  the number of data points in the actual data set
- $p$  the total number of regression parameters in the model.

Since the CV (%) is calculated as the ratio of the root mean squared error (RMSE) to the mean of the dependent variable, it describes the model fit in terms of the relative sizes of the squared residuals and mean outcome values. Lower CV (%) implies smaller residuals relative to the predicted value. NMBE (%), often simply stated as ‘bias error’ refers to how far the average statistic lies from

the parameter it is estimating, i.e., the biased error which arises when estimating a quantity. Thus, low CV (%) and NMBE (%) values are indicative of a good model fit.

When analyzing the results of the regression models for WBE, CHW and HW, it is necessary to understand the difference between the importance of CV (%) and NMBE (%) for the three cases. For WBE, the demand is more important, while for CHW and HW, the consumption is more important. The CV (%) delivers more information about the demand accuracy than does NMBE (%). A model that has high CV (%) value cannot be used to estimate a demand value. Utility companies often charge larger energy consumers by demand use (i.e., the maximum hourly use during the given month) along with the consumption. CHW and HW are usually analyzed by consumption. A model that has a low NMBE (%) can accurately predict the total consumption even if the CV (%) is high. Thus for WBE, a model with lower CV (%) is deemed to be better, and for CHW and HW, a model with lower NMBE (%) is the better choice.

As already mentioned, Energy Explorer software is used to generate the model equations, a MATLAB code (Endurthy, 2011) has been written to calculate external CV & NMBEs for various model equations generated. The Flowchart of the modeling technique adopted is shown in Figure 5.5.



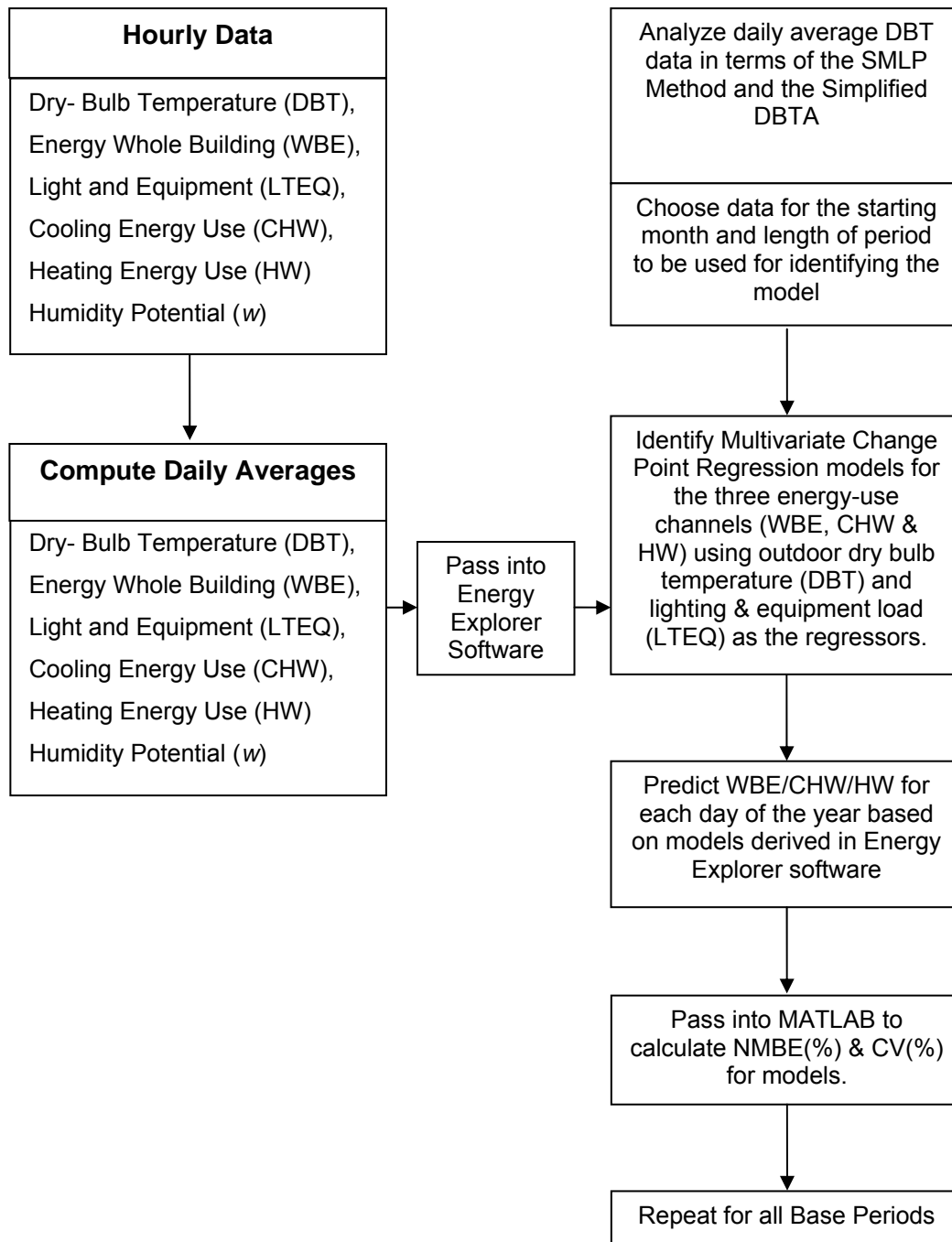


Figure 5.5 Flowchart for Multivariate Change Point (MCP) modeling approach.

## 5.5. Hybrid Inverse Modeling

### 5.5.1. Method1: utility bills + monitored data

This approach for predicting energy use combines the monitored daily energy use and internal loads with atleast one year of recent utility bills (representing the long-term data) to predict the building energy performance for the whole year (Abushakra et al.,1999). Thus, in this modeling technique, information from monthly utility bills is applied to the model. The utility bills are accurate and easily acceptable sources of building energy information. In order to minimize the confounding effects of co-linearity between regression variables, the regression is completed in two stages (Abushakra, 2000).The first stage of the regression model has the form:  $B() + C()$

$$E_k = a + b(X_1 - DBT_k) + c(DBT_k - X_1) + d(w_k - 0.009)^+ \text{ where, } k=1 \text{ to } 12$$

(indicating the 12 months) ..... (Eq. 5.13)

where,  $E$  is the monthly energy use,  $DBT_k$  is average monthly temperature, and  $(w_k - 0.009)^+$  is the average specific humidity potential.,

The second stage uses the daily equipment and lighting loads (LTEQ), which also take into account the occupancy patterns for the building, so as to create a hybrid model. The coefficients  $d$  and  $e$  are found by regressing following:

$$E_k - b(X_1 - DBT_k) - c(DBT_k - X_1) - d(w_k - 0.009)^+ = e + f(LTEQ) \text{ ..... (Eq.5.14)}$$

Finally, the model equations obtained in stage one and two are combined to derive the final model for predicting energy use. This equation has the form:

$$E_i = d + b(X_1 - DBT_k) + c(DBT_k - X_1) + d(w_k - 0.009)^+ + e(LTEQ) \text{ ..... (Eq. 5.15)}$$

Abushakra developed the hybrid models by combining monthly utility bills along with monitored hourly data. He analyzed all consecutive two-week periods of the year and ranked them from “best” to “worst” in terms of their prediction accuracy.

In this research, the analysis has been limited to daily timescales instead of hourly. Since the research aims at finding the shortest period suitable for in-situ energy use monitoring, the length of the period for this analysis is limited to a maximum of three consecutive months. Thus, models are generated for each starting month of the year (January to December), with each selection subsequently expanded in increments of one month to a maximum of three consecutive months to mimic different durations of monitoring. For example, for the starting month of January, the first model is generated using the data for January only and then subsequently increased in increments of one month i.e. January-February and January- February-March. The same is repeated for each starting month of the year.

The NMBE (%) and CV (%) (Section 5.4) indices estimate the predictive accuracy of the results from the regression models generated. The time plots of CV (%) and NMBE (%) for each type of energy use and for different lengths of monitoring periods allow easier understanding of the prediction patterns.

### **5.5.2. Method 2: utility bills only**

Method 2 looks at predicting building performance at daily timescales using utility bills only. The models generated have the form:

$$E_k = a + b(X_1 - DBT_k) + c(DBT_k - X_1) + d(w_k - 0.009)^+ \text{ where, } k=1 \text{ to } 12 \text{ (indicating the 12 months)} \quad \dots\dots\dots (\text{Eq. 5.16})$$

This equation is used for predicting energy use at daily time scales. The NMBE (%) and CV (%) (Refer to Section 5.4) statistical parameters estimate the predictive accuracy of the results from the regression models generated. The results are shown at monthly as well as annual time scales. This helps evaluate

the effectiveness of using utility bills in predicting the energy use for each month of the year as well as annually.

The Flowchart of the hybrid inverse modeling technique (method 1) is shown in Figure 5.6 below:

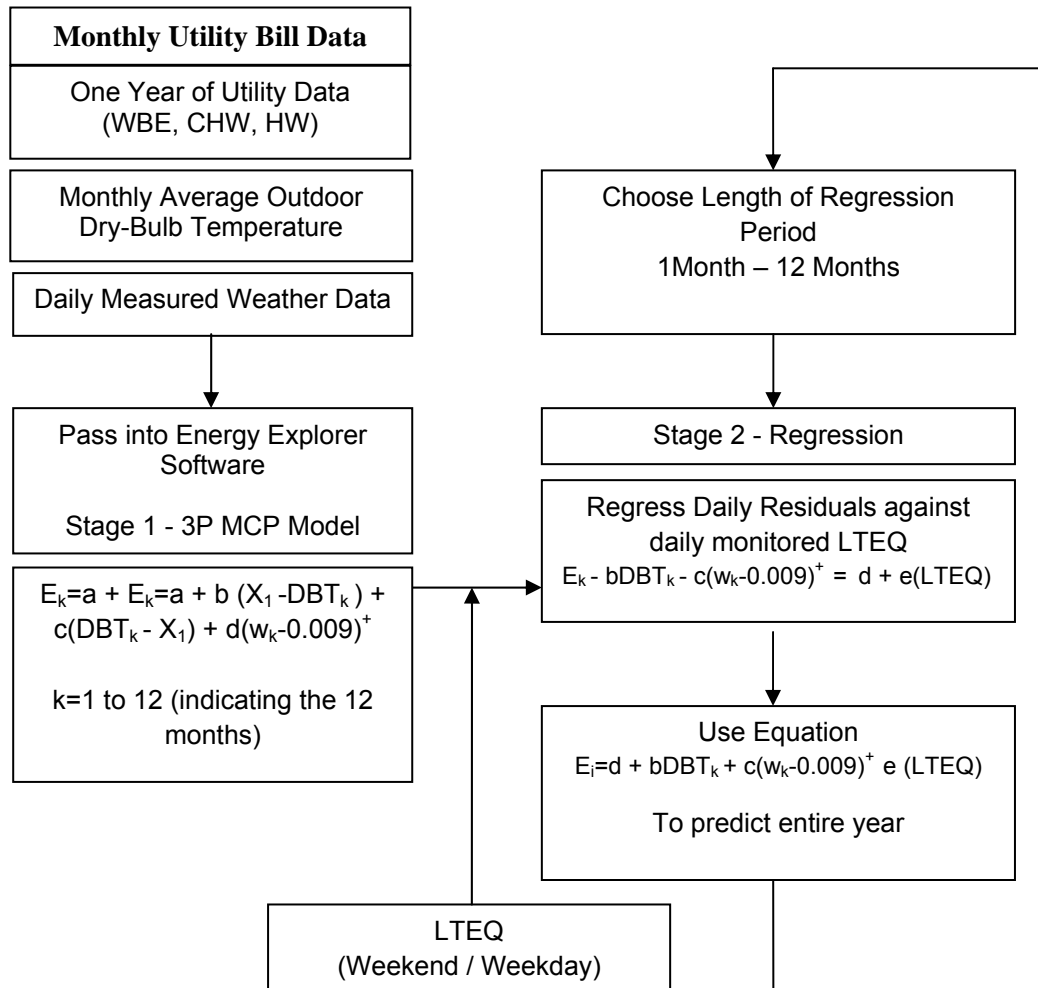


Figure 5.6 Flowchart for Hybrid Inverse Modeling approach (Method 1).

## TEMPERATURE DATA ANALYSIS RESULTS

### 6.1. Datasets

The methodology described in Chapter 5 has been applied to three buildings (two synthetic and one actual) for which a full year of data was available for analysis. Table 6.1 summarizes the key features of buildings chosen for analysis.

Detailed descriptions of these buildings are provided in Appendix A.

Table 6.1

*Summary of buildings chosen for analysis.*

Building Summary					
No	Building Description	Area (Sqft)	Actual(A) / Synthetic(S)	Data Channels	
				Response (Energy)	Regressor
1	Large Hotel, Chicago IL (06/06-05/07 Data)	619,200	S	WBE, CHW, HW	DBT, LTEQ
2	Office Building, Albuquerque, NM (2004 Data)	17,430	S	WBE, HW	DBT, LTEQ
3	Full Service Hotel Washington DC Region (2009 Data)	212,000	A	WBE	DBT

Three energy use channels are considered for analysis, namely, whole building electric (WBE), cooling energy use (CHW), and heating energy use (HW). The analysis has been done at daily timescales. The variation in NMBE (%) & CV (%) for predictive accuracy of these three energy channels when different in-situ monitoring periods are selected for model building forms the basis of evaluation. Following sections summarize the analysis results obtained for each of the three buildings analyzed.

## 6.2. Climate diversity analysis

Outdoor dry-bulb temperature is usually the single most influential driver of building energy use. Figures 6.1 to 6.3 show the variation of the outdoor dry-bulb temperature for the three different locations selected. The dots indicate the monthly mean temperatures and the vertical whiskers represent the monthly temperature range i.e., range of daily temperature values. The annual average temperature and its bands of  $\pm 10\%$  variation (represented by the dashed rectangular area) for each location has also been plotted. The range can be said to represent the swing season for the location. In most cases it is within this temperature range that the “change point” is expected to occur due to a change in the season. This range is therefore also referred to as the ‘change-point’ range.

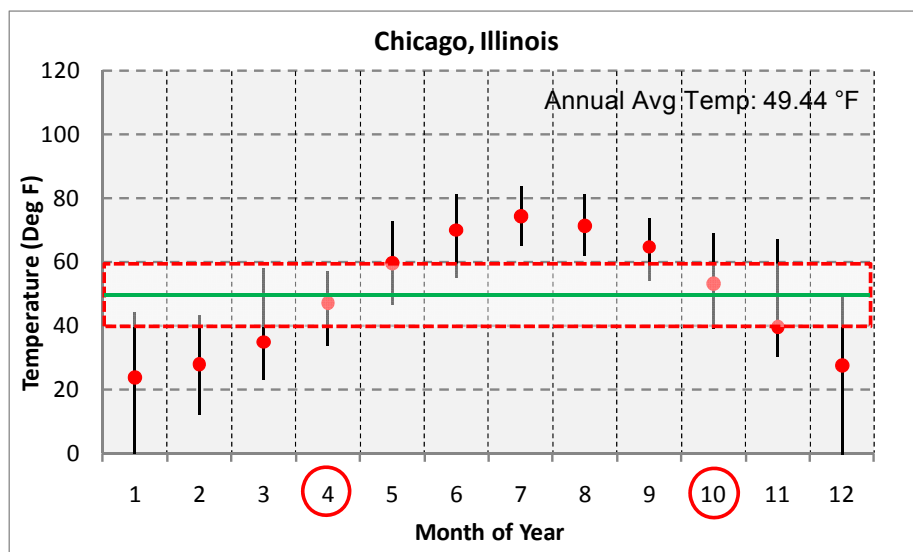


Figure 6.1 Annual variation of outdoor dry bulb temperature for Chicago, IL. Average monthly temperature, monthly temperature range and average annual temperature (49.44°F) with bands of  $\pm 10\%$  variation shown.

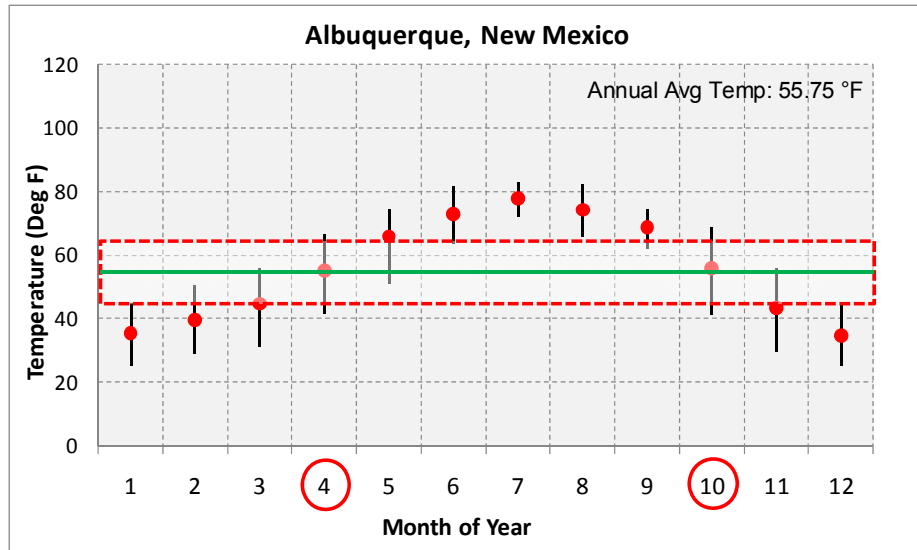


Figure 6.2 Annual variation of outdoor dry-bulb temperature for Albuquerque, IL. Average monthly temperature, monthly temperature range and average annual temperature (55.75°F) with bands of  $\pm 10\%$  variation shown.

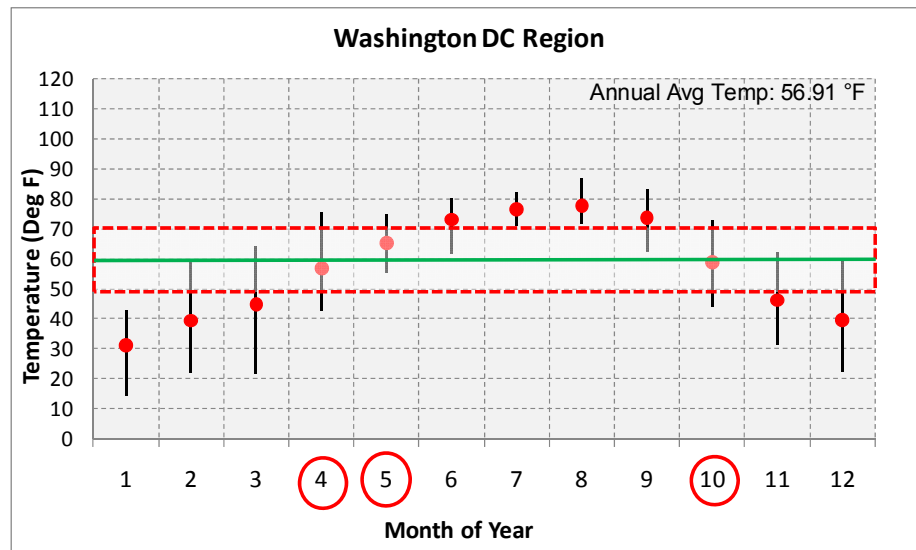


Figure 6.3 Annual variation of outdoor dry-bulb temperature for Washington, D.C. Average monthly temperature, monthly temperature range and average annual temperature (56.91°F) with bands of  $\pm 10\%$  variation shown.

The circles on the x-axis highlight the months that are expected to be the best for in-situ monitoring (due to their monthly mean temperatures being closest to the annual average and large day-to-day variability). This investigation is just a visual assessment of the temperature data and needs to be further verified by analysis.

The results are summarized in Table 6.2.

Table 6.2

*Variation in outdoor dry-bulb temperature for Chicago, Albuquerque & Washington D.C.*

<b>Location</b>	<b>Annual Average Temperature (°F)</b>	<b>Annual Temperature Range Max-Min (°F)</b>	<b>Expected Best Months for In-Situ Monitoring</b>
Chicago, Illinois	49.44	$83.67 - (-3.29) = 86.96$	April, October
Albuquerque, New Mexico	55.75	$83.15 - 25.09 = 58.07$	April, October
Washington DC Region	56.91	$77.75 - 31.19 = 46.56$	March, April, October



### 6.3. Results of the SMLP method

The climate data is analyzed to determine the predicted best month of the year for data monitoring based on the SMLP procedure described in Section 5.2.

#### a. Results for Chicago, Illinois

The criterion for the SMLP method has been discussed earlier in Section 5.2. The method gives an insight into time of the year when in-situ monitoring is likely to yield a regression model that is most accurate in its long term predictions. Figure 6.4 shows the results of the SMLP analysis for Chicago, IL. The ranking obtained for all months of the year is represented graphically. The three best months for in-situ monitoring (ranks 1-3) are indicated in Figure 6.4. The ranking (1 to 12), obtained from the algorithm, for all the months of the year is assembled in Table 6.3.

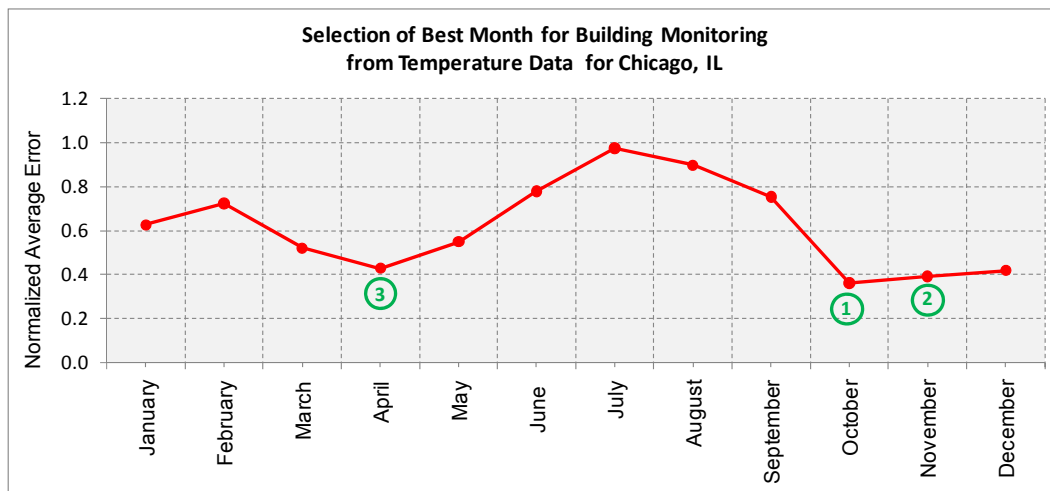


Figure 6.4 SMLP analysis for Chicago, IL

### b. Results for Albuquerque, New Mexico

Figure 6.5 shows the results of the SMLP analysis when applied to Albuquerque, NM. The best months for in-situ monitoring (ranks 1-3) are indicated. The ranking (1 to 12) obtained from the algorithm, for all the months of the year, is provided in Table 6.3.

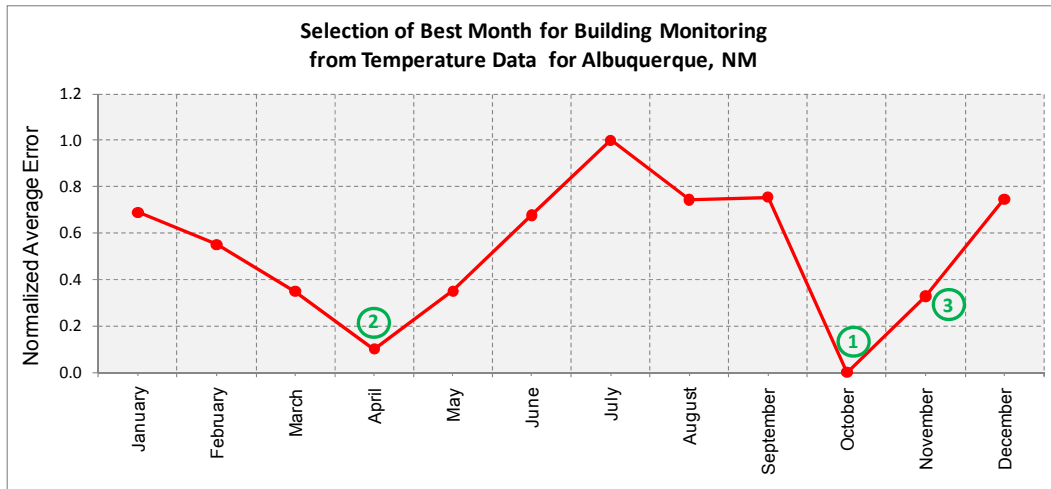


Figure 6.5 SMLP Analysis for Albuquerque, NM

### c. Results for Washington DC Area

Figure 6.6 shows the results of the SMLP analysis when applied to the Washington DC Region. The best months for in-situ monitoring (ranks 1-3) are indicated. The ranking (1 to 12) obtained from the algorithm, for all the months of the year, is provided in Table 6.3.

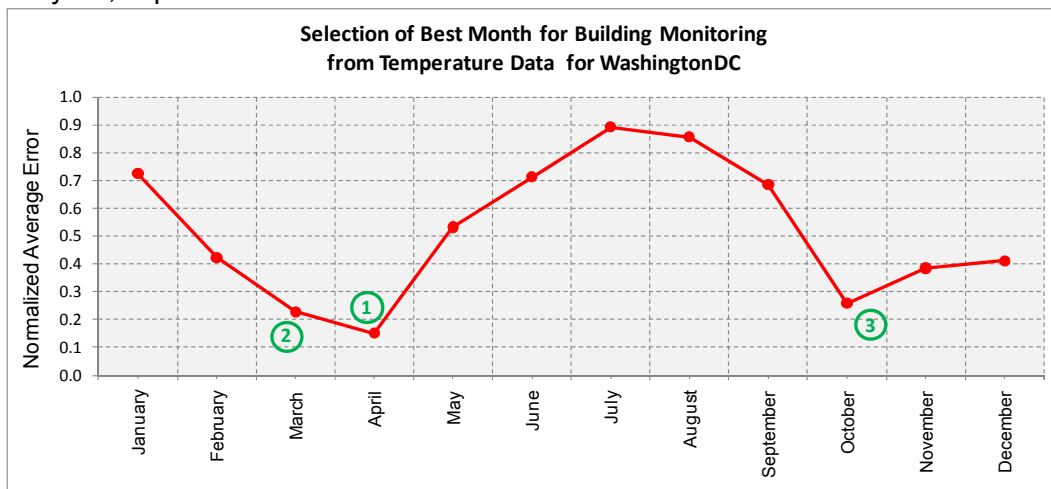


Figure 6.6 SMLP Analysis for Washington DC Region.

Table 6.3

*Ranking obtained from the SMLP Algorithm for each month of the year for Chicago, Albuquerque and Washington D.C.*

Ranking Based on SMLP Analysis			
Rank	Chicago , IL	Albuquerque, NM	Washington D.C. Area
1	October	October	April
2	November	April	March
3	April	November	October
4	December	March	November
5	March	May	December
6	May	February	February
7	January	June	May
8	February	January	September
9	September	August	June
10	June	December	January
11	August	September	August
12	July	July	July

#### 6.4. Results of the DBTA method

The temperature data has been analyzed to determine time periods expected to be the best for in-situ monitoring based on the procedure described in Section 5.3,.

The numbers 1-12 on the x-axis represent increase in the monitoring periods in successive increments of a month, i.e., sliding window lengths for each month of the year taken as the starting period for monitoring. Each month is ranked based on the length of period required to reach the yearly average temperature value. The results for all the three locations are shown graphically in Figure 6.7 to Figure 6.9 and in a tabular format in Table 6.4.

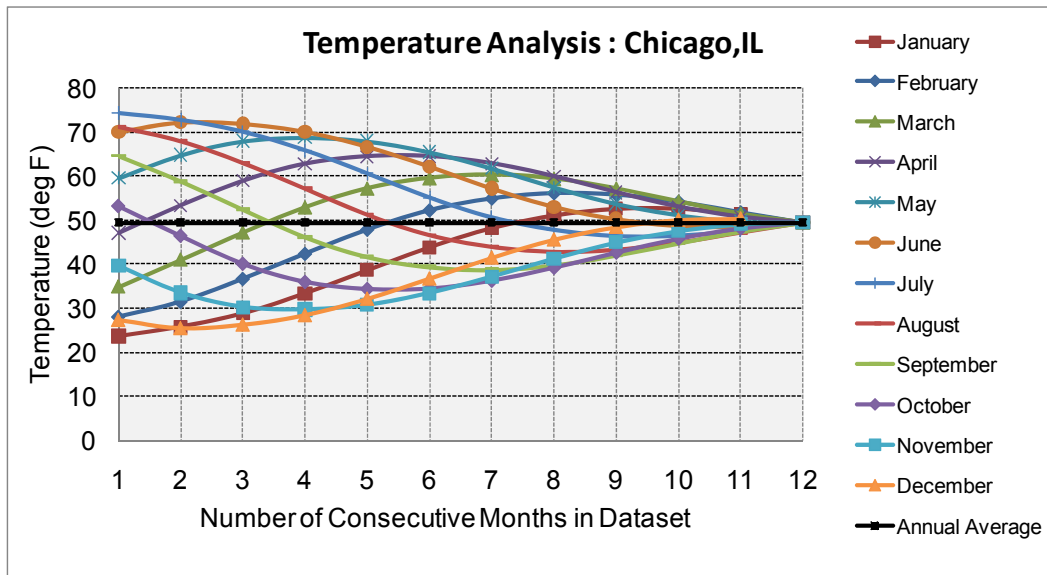


Figure 6.7 Outdoor Dry-Bulb Temperature Analysis: Chicago, IL. Annual average temperature: 49.44 °F

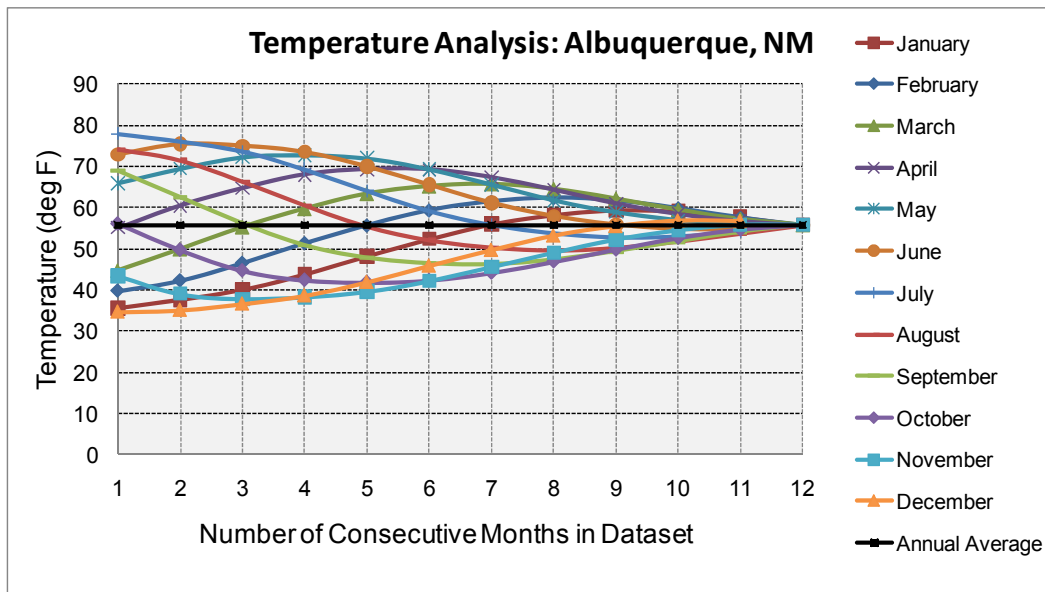


Figure 6.8 Outdoor Dry-Bulb Temperature Analysis: Albuquerque, NM. Annual average temperature: 55.75 °F

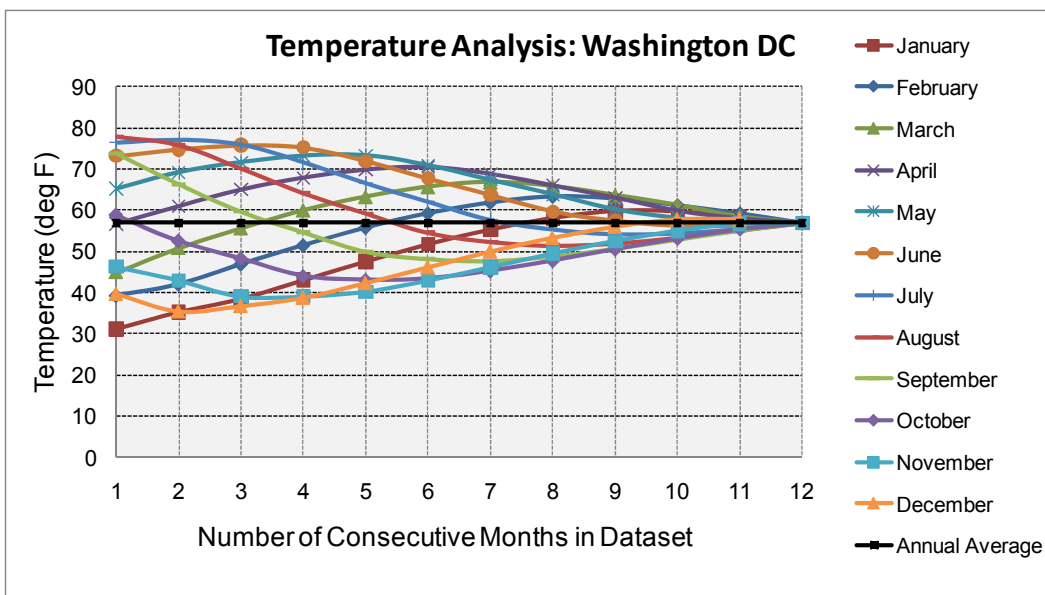


Figure 6.9 Outdoor Dry-Bulb Temperature Analysis: Washington DC. Annual average temperature: 56.91 °F

Table 6.4

*Summary of ranking based on DBTA method for each month of the Year for Chicago, Albuquerque and Washington D.C.*

Ranking is based on the number of months required to come close to yearly average temperature									
Start Month	Chicago, Illinois			Albuquerque, New Mexico			Washington DC Region		
	End Month	No. Of Months of Data Required	Ranking	End Month	No. Of Months of Data Required	Ranking	End Month	No. Of Months of Data Required	Ranking
January	July	7	7	July	7	7	July-August	7.5	7
February	June-July	6	6	June	5	5	June	5	5
March	May-June	3	3	May	3	3	May-June	3.5	3
April	April-May	2	1	April	1	1	April	1	1
May	March	11	11	February	10	11	Feb-March	10.5	11
June	February	9	9	Jan-Feb	8.5	9	Jan-Feb	8.5	9
July	January	7	7	January	7	7	Jan-Feb	7.5	7
August	December	5	5	December	5	5	Dec-Jan	5.5	5
September	Nov-Dec	3	3	November	3	3	Nov-Dec	3.5	3
October	November	2	1	October	1	1	Oct-Nov	1.5	1
November	September	11	11	September	11	12	September	11	12
December	Aug-Sept	9	10	August	9	10	August	9	10

## 6.5. Comparison of results of SMLP and DBTA methods

This section investigates into the consistency between the rankings obtained from the SMLP Algorithm and the DBTA methods. The SMLP rankings are based on the algorithm developed by Abushakra (1999) which requires several indices to rank the different months of year based on the closeness of the monthly mean temperatures to the annual average. The DBTA, on the other hand, ranks the months based on the length of data required to reach the annual average temperatures for each starting month. While the rankings obtained are not exactly the same, they are somewhat related, and consistency between them is clearly evident from the Figure 6.10 to Figure 6.12. The analysis methods clearly indicate March, April and October to be the best periods with the other months with extremes in weather conditions ranked poorly in both analysis methods. In Chapter 7 the rankings obtained from the DBTA are analyzed further against actual modeling of energy-use data using the MCP modeling explained in Chapter 5.

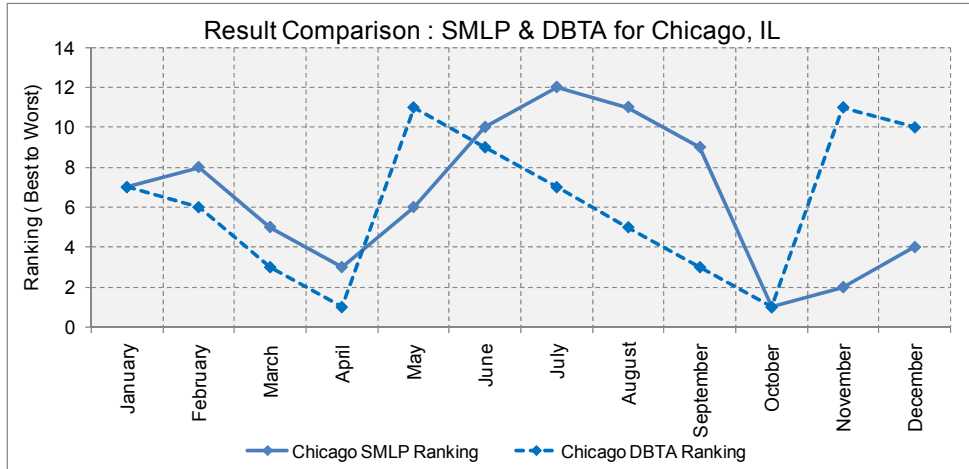


Figure 6.10 Result comparison for SMLP and DBTA for Chicago, IL.

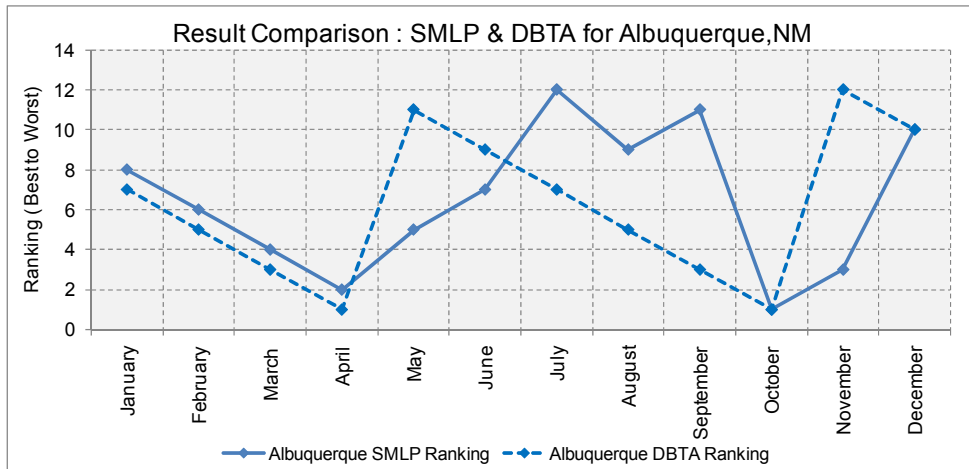


Figure 6.11 Result comparison of SMLP and DBTA for Albuquerque, NM.

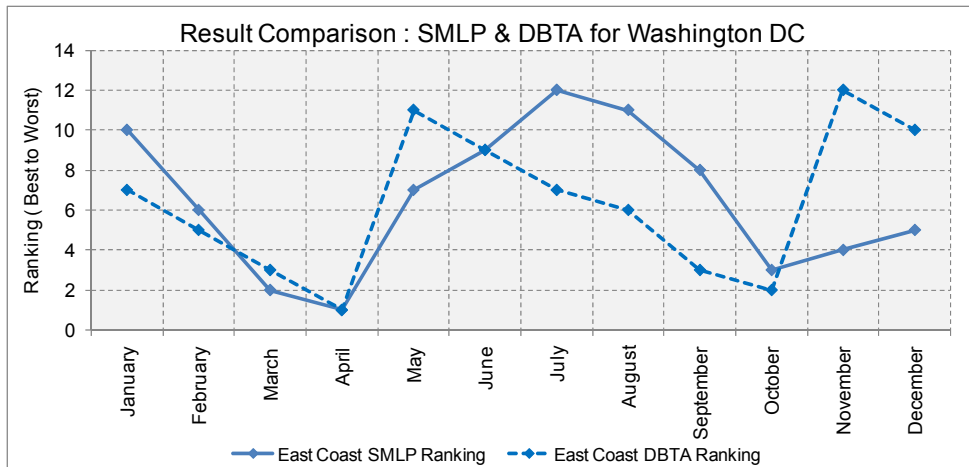


Figure 6.12 Result comparison of SMLP and DBTA for Washington DC.

## **MCP MODELING RESULTS**

### **7.1. Multivariate change point modeling approach**

The results obtained from the methods in Chapter 6 are based only on the temperature data. It is important to verify these rankings with actual modeling of the energy use data.

This section assembles the results of the MCP modeling approach explained in Section 5.4. The MCP models for the three energy-use channels, namely, whole building electric (WBE), cooling energy use (CHW), and heating energy use (HW) are generated using daily averages for outdoor dry bulb temperature (DBT) and lighting & equipment load (LTEQ) as the regressors.

The models are generated for each starting month of the year (January to December), with each selection subsequently expanded in increments of one month to mimic different durations of monitoring.

To determine the accuracy of the models derived from the short data-sets, the values of annual energy use predicted by models from short data-sets are compared to the actual energy use. The predictive accuracy of the models is evaluated based on two statistical indices: Coefficient of Variation of the Root Mean Square Error or CV (%), and the Normalized Mean Bias Error or NMBE (%). The results are presented graphically below.

(Refer to Appendix C for all regression model equations and corresponding CV (%) and NMBE (%) results for the three buildings).



## 7.2. Results for the large hotel - Chicago, Illinois

The time series plots of CV (%) and NMBE (%) of each type of energy use channels (WBE, CHW & HW) and for different lengths of monitoring are displayed in Figure 7.1 and Figure 7.2 respectively. For the sake of clarity, the graphs for each energy channel have been split into two. The graphs on the left assemble results when starting periods for monitoring are from January to June. The ones on the right have monitoring periods starting from July to December. Numbers 1-12 on the x-axis denote the length in months as the monitoring period is increased in successive increments of a month.

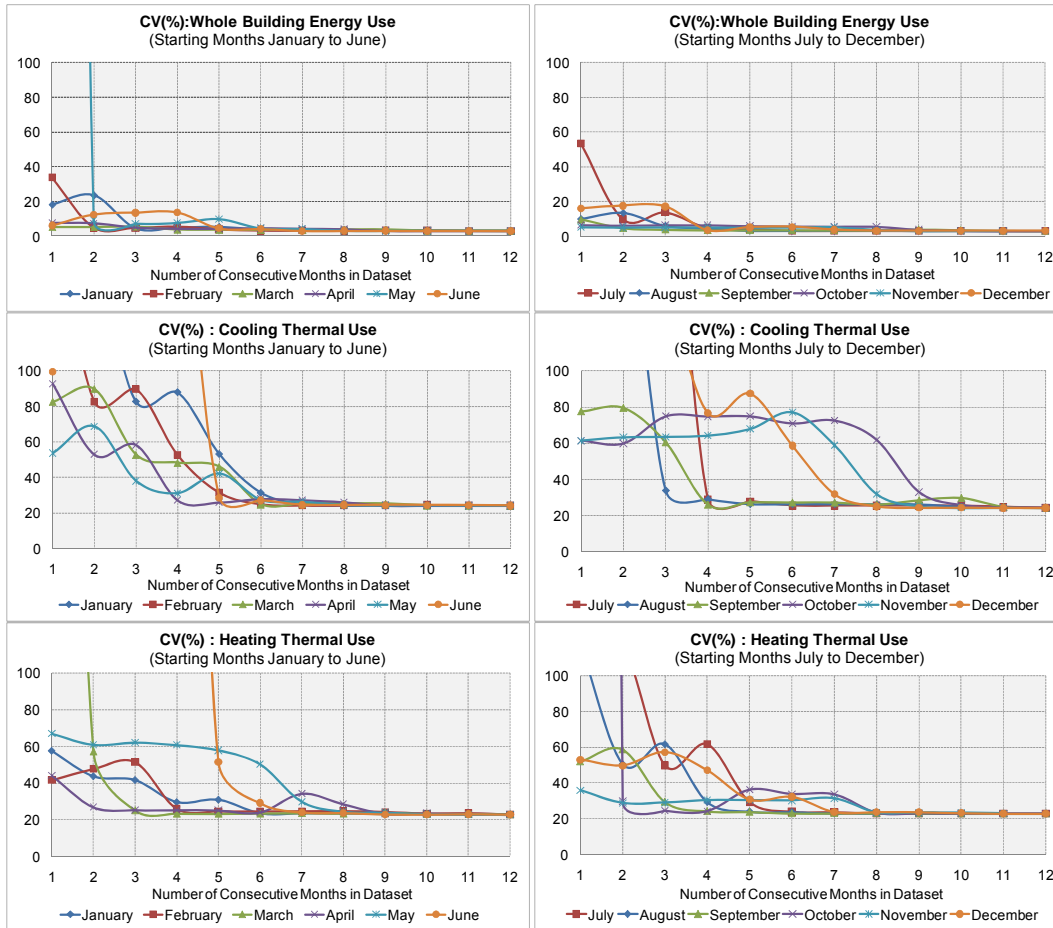


Figure 7.1 CV (%) for energy channels WBE, CHW & HW when different lengths of monitoring are used for predicting annual energy-use for the Large Hotel at Chicago, IL.

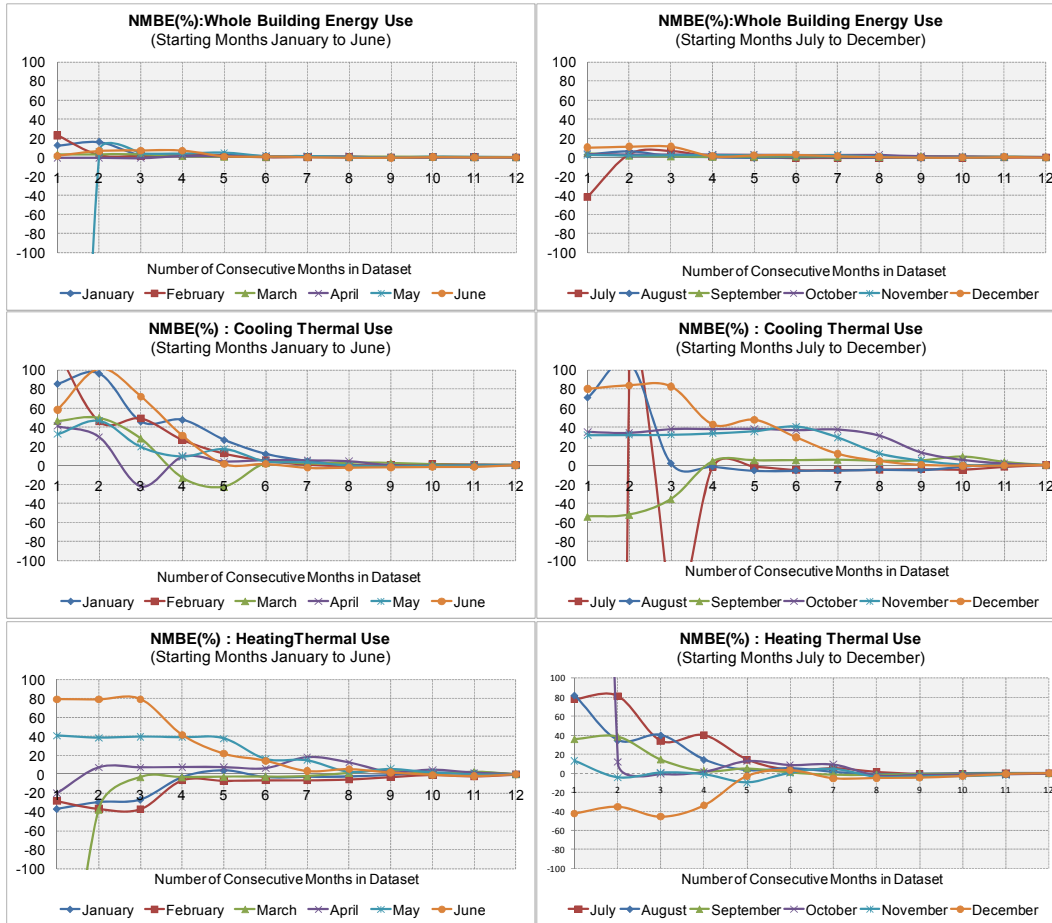


Figure 7.2 NMBE (%) for energy channels WBE, CHW & HW when different lengths of monitoring are used for predicting annual energy-use for the Large Hotel at Chicago, IL

### 7.2.1. Results for Whole Building Electric for Large Hotel, Chicago, IL

Figure 7.3 below shows results for WBE from Figures 7.1-7.2 in more detail. All the twelve starting months have been combined into one figure. The graph for CV(%) shows all the monitoring periods that predicted WBE within 10% of the actual energy use while the graph for NMBE (%) shows monitoring periods within a bias of  $\pm 20\%$ . Clearly, November, March and October are the best months to start in-situ monitoring with energy use prediction varying from annual energy use by only 5.2%, 5.3% and 6.4% respectively. The average interval prediction

errors of models identified from one month of data only are 2.65%, 3.01% and 3.72%, respectively, for these three months.

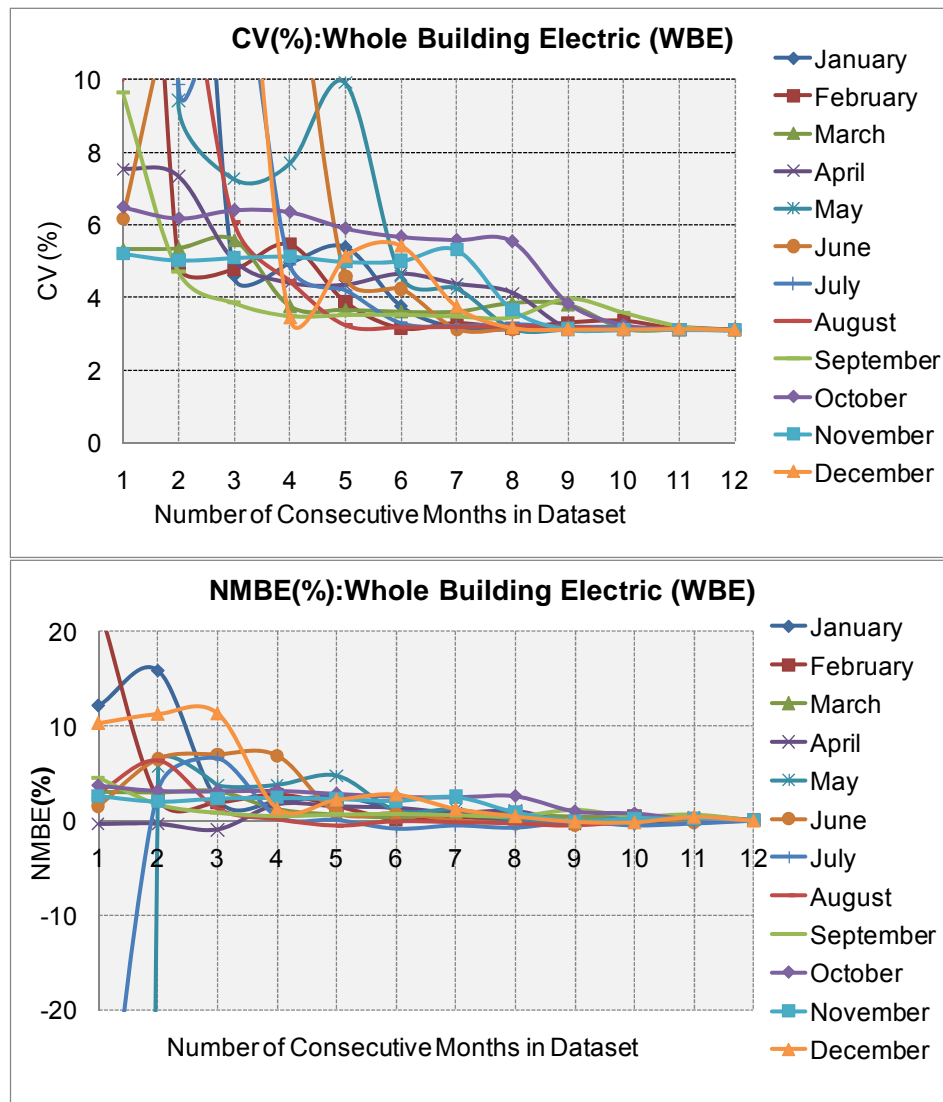


Figure 7.3 Variation in CV (%) and NMBE (%) for WBE. Graphs show monitoring periods for which predicted CV (%) is within 10% and predicted NMBE (%) within  $\pm 20\%$  of actual energy-use. Building: Large Hotel at Chicago, IL.

Intuitively, one would expect prediction accuracy of the models to improve with the length of the data-set. This improvement is not that significant in the case of WBE. For example, for the starting month of November, the prediction improves

only by a small margin of 0.2% when the monitoring period is increased from one month to six-months. The difference in the predictive accuracy of short data set of the month of November compared to the prediction using the model obtained from whole year of data is merely 2.11%. Thus, in this case, for WBE only one month of data is adequate for predicting the building performance for the whole year within acceptable limits.

The worst monitoring periods for monitoring WBE are July, February and January with CV(%) of 53.58%, 33.88% and 18.14% respectively and NMBE(%) of -41.5%, 22.91% and 12.16% respectively.

The ranking for all the one-month periods for in-situ monitoring of WBE, as predicted by the MCP modeling approach, are given in Table 7.1.

Table 7.1

*Ranking (based on the MCP Approach) of best to worst months of the year for in-situ monitoring of WBE energy use for Large Hotel in Chicago, IL.*

Ranking: WBE Prediction			
Rank	Month	Rank	Month
1	November	7	September
2	March	8	August
3	October	9	December
4	June	10	January
5	April	11	February
6	May	12	July

### 7.2.2. Results for Cooling Energy Use (CHW) for Large Hotel, Chicago, IL

Figure 7.4 shows results for CHW from Figures 7.1-7.2 in more detail. All the twelve starting months have been combined into one figure. The graph for CV (%) shows all the monitoring periods that predicted CHW within 50% of the actual energy use while the graph for NMBE (%) shows monitoring periods with bias of  $\pm 20\%$ .

On an average, the CV (%) for cooling energy use models never really decreases below 24%, irrespective of the length of the dataset used for modeling. The average errors range from -22.57% to 118.88% for different base periods (outliers such as predictions using July data are ignored due to marked inconsistency with other results). Since for cooling energy use (CHW) no single month data is enough for extrapolating the performance of the building over the whole year, longer periods of monitoring are therefore required.

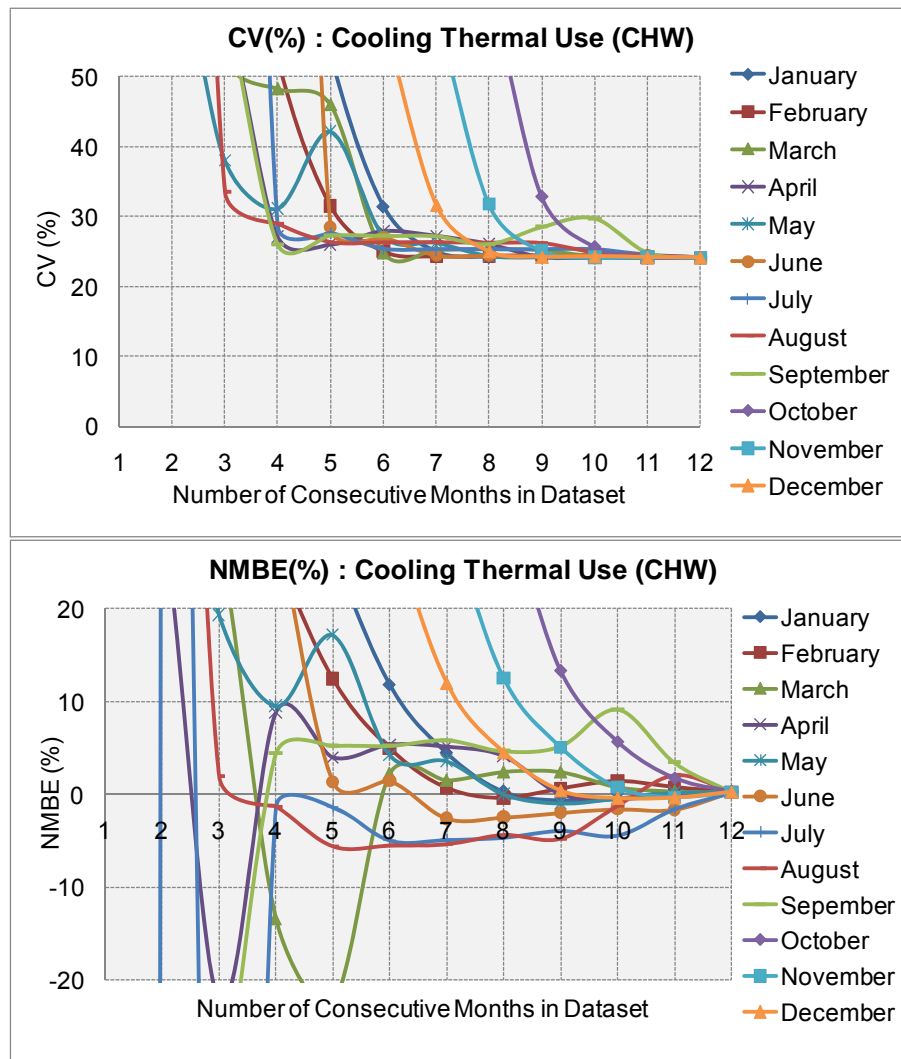


Figure 7.4 Variation in CV(%) and NMBE(%) for CHW Channel. Graphs show monitoring periods with predicted CV (%) within 50% and predicted NMBE (%) within  $\pm$  20% of actual energy use. Building: Large Hotel at Chicago, IL

The general trend observed is that models identified from low or high temperature regions tend to seriously err in the prediction of annual energy use. For example, when in-situ monitoring is started from the month of January or June (Table 7.2) at least seven months of data is required for the prediction of energy use to reach acceptable levels of accuracy. On the other hand, if monitoring is started in the months from the swing season, say April or August, then only four months of data is enough to achieve similar results. In all the cases, irrespective of the start time for monitoring, as we include data from the months during which the outdoor dry bulb temperature is close to the annual mean (March-April and October-November in this case), the prediction results of the identified model gradually becomes more accurate.

Table 7.2

*Cooling energy-use prediction results of models derived using data from the months of January-July, April-July, June-December and August-December for the Large Hotel, Chicago, IL.*

	Monitoring Period		Duration of Monitoring (Months)	Prediction Accuracy -	
	Start Month	End Month		CV (%)	NMBE (%)
1	January	July	7	25	5
	April	July	4	27	8
2	June	December	7	25	2.57
	August	December	5	26	5.6

Conversely, models become poorer in the annual predictive ability as more monitored data is added which include months during which the outdoor dry bulb temperature is not close to the annual mean. Thus, considering the case of October as the starting month for monitoring, predictions worsen as data for almost 6 additional months is added for identifying the energy use model. It

starts stabilizing again when more data from months of March-April is used. Table 7.3 gives five options of short term monitoring periods for CHW energy channel which give prediction results similar to the results obtained when the model is generated using whole year data.

Table 7.3

*Monitoring periods with prediction results closest to the results obtained when monitoring is done for the whole year. Energy Channel: CHW; Building: Large Hotel, Chicago, IL.*

S.No.	Monitoring Period		Duration of Monitoring (Months)	Prediction Accuracy (CHW)	
	Start Month	End Month		CV (%)	NMBE (%)
	January	December	12	24.15	0.28
1	February	July	6	25.02	4.96
2	July	December	6	25.38	-4.87
3	April	August	5	26.03	3.99
4	September	December	4	26.06	4.45
5	August	December	5	26.33	-5.6

### 7.2.3. Results for Heating Energy Use (HW) for Large Hotel, Chicago, IL

Figure 7.5 shows results for HW from Figures 7.1-7.2 in more detail. All the twelve starting months have been combined into one figure. The graph for CV (%) shows all the monitoring periods that predicted HW within 50% of the actual energy use while the graph for NMBE (%) shows monitoring periods with bias of  $\pm 20\%$ .

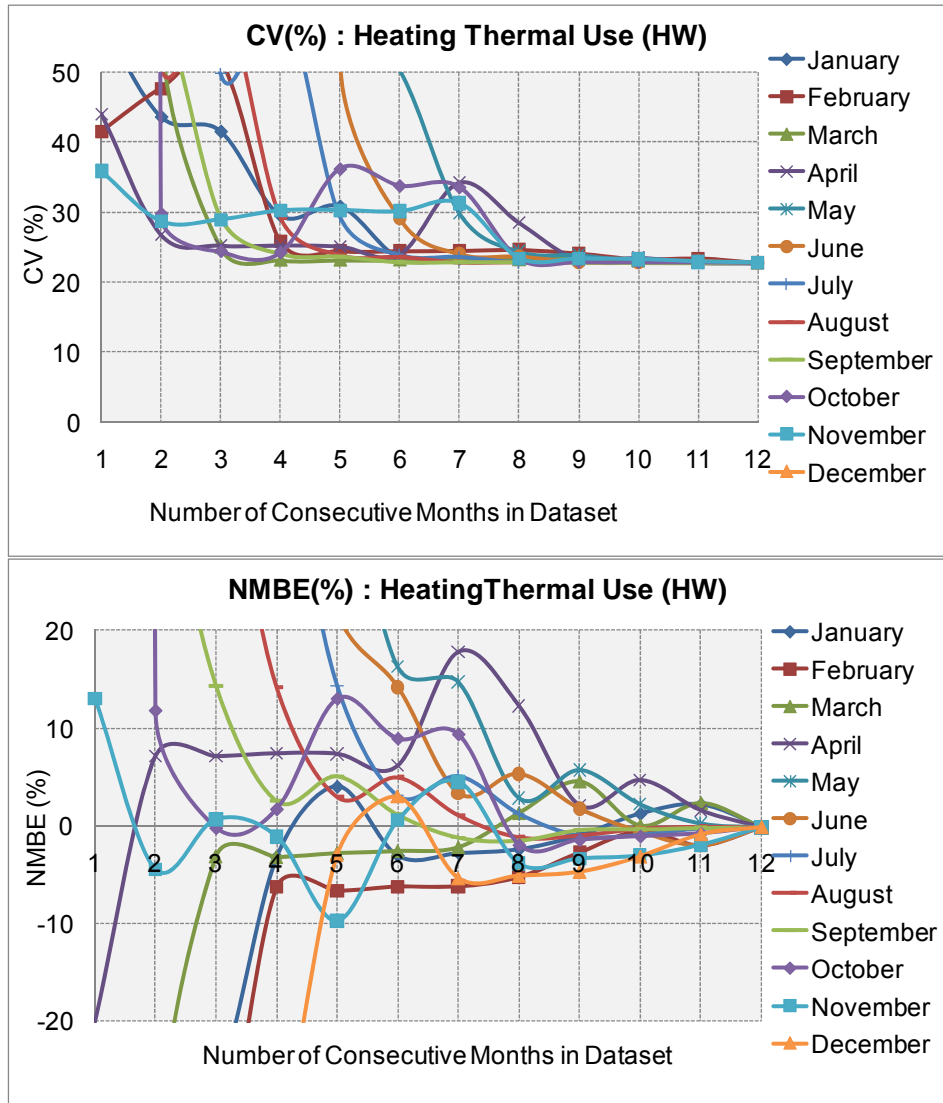


Figure 7.5 Variation in CV(%) and NMBE (%) for HW Channel. Graphs show monitoring periods with predicted CV (%) within 50% and predicted NMBE (%) within  $\pm 20\%$  of actual energy use. Building: Large Hotel at Chicago, IL



Similar to CHW, the CV (%) for heating thermal use energy models never really decrease below 23%, irrespective of the length of the dataset used for modeling. The average errors range from -45.68% to 81.74% for different base periods (outliers such as predictions using October data are ignored due to marked inconsistency with other results). Since for heating energy use prediction no single month data is enough for accurately extrapolating the performance of the building over the whole year, longer periods of monitoring are therefore required. Similar to the predictions of cooling thermal use, for heating also the general trend observed is that models constructed in low or high temperature regions tend to seriously err in the prediction of annual energy use. For example, when in-situ monitoring is started from the month of June (Table 7.4) at least seven months of data are required to identify a model whose prediction of energy use is within acceptable accuracy levels. On the other hand, if monitoring is started in the months of the swing season, say October, then only three months of data is enough to achieve the same results. In all the cases, irrespective of the start time for monitoring, as we add data from the months during which the outdoor dry bulb temperature is close to the annual mean (October-November in this case), the prediction results start becoming more accurate.

Table 7.4

*Heating energy-use prediction results for June-December and October-December for Large Hotel, Chicago, IL.*

S.No.	Monitoring Period		Duration of Monitoring (Months)	Prediction Accuracy - HW	
	Start Month	End Month		CV (%)	NMBE (%)
Case 1	June	December	7	24.1	3.3
	October	December	3	24.38	-0.28

Table 7.5

*Monitoring periods for which identified models predict energy use closest to those for which model is identified using whole year data. Energy Channel: HW; Building: Large Hotel, Chicago, IL.*

S.No.	Monitoring Period		Duration of Monitoring (Months)	Prediction Accuracy (HW)	
	Start Month	End Month		CV (%)	NMBE (%)
	January	December	12	22.76	-0.16
1	March	June	4	23.14	-3.21
2	September	January	5	23.70	5.08
3	April	September	6	24.04	6.16
4	October	December	3	24.38	-0.28
5	February	June	5	24.45	-6.66

Table 7.5 gives five options of short-term monitoring periods for heating energy use that give prediction results very close to the ones derived from models generated using whole year data.

### 7.3. Results for Office Building - Albuquerque, New Mexico

The time series plots of CV (%) and NMBE (%) for each type of energy use are displayed in Figure 7.6 and Figure 7.7 respectively.

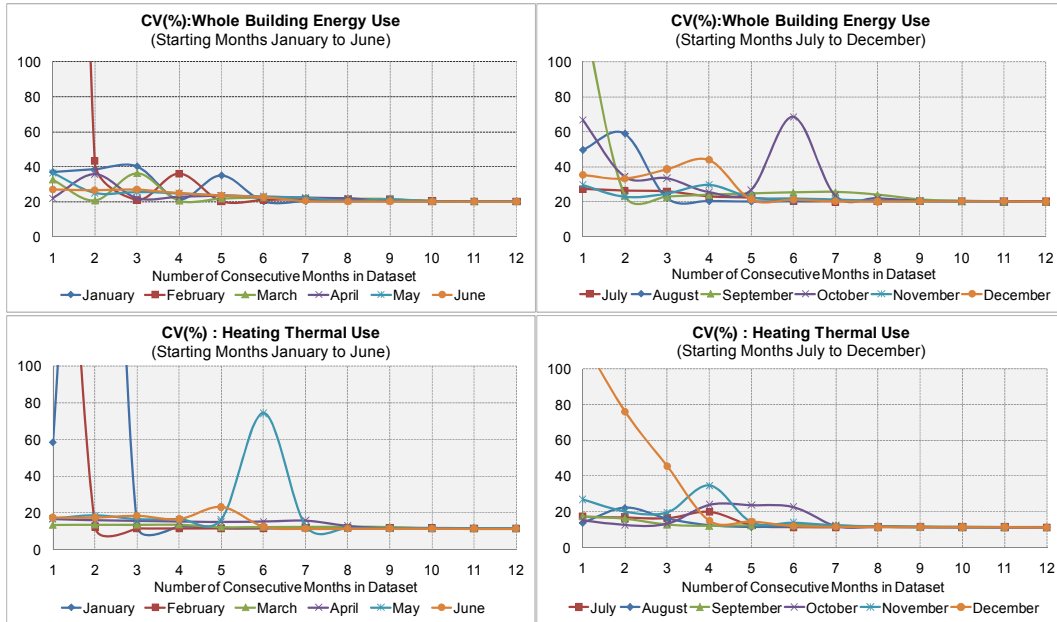


Figure 7.6 CV (%) for energy channels WBE & HW when different lengths of monitoring are used for predicting annual energy use. Building: Office at Albuquerque, NM.

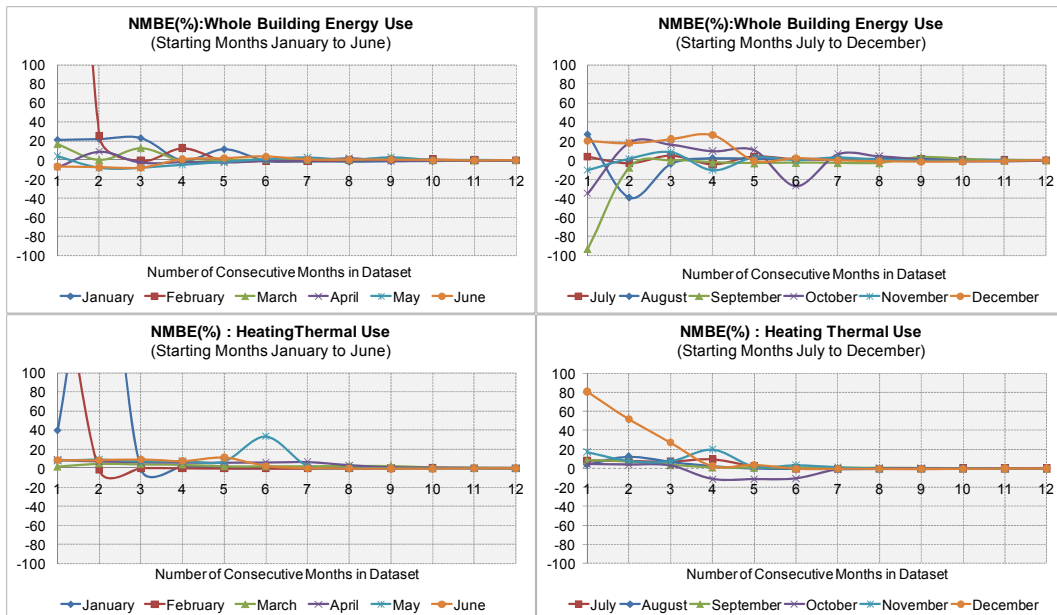


Figure 7.7 NMBE (%) for energy channels WBE & HW when different lengths of monitoring are used for predicting annual energy use for office at Albuquerque, NM.

Albuquerque does not have a predominant cooling season; thus only two channels, WBE and HW have been analyzed for this case.

### 7.3.1. Results for WBE energy use for office at Albuquerque, NM

Figure 7.8 shows results for whole building Electric from Figures 7.6 - 7.7 in more detail. All the twelve starting months have been combined into one figure. The graph for CV(%) shows all monitoring periods that predicted WBE within 50% of the actual energy use while the graph for NMBE(%) shows monitoring periods which resulted in predictions with bias of  $\pm 20\%$

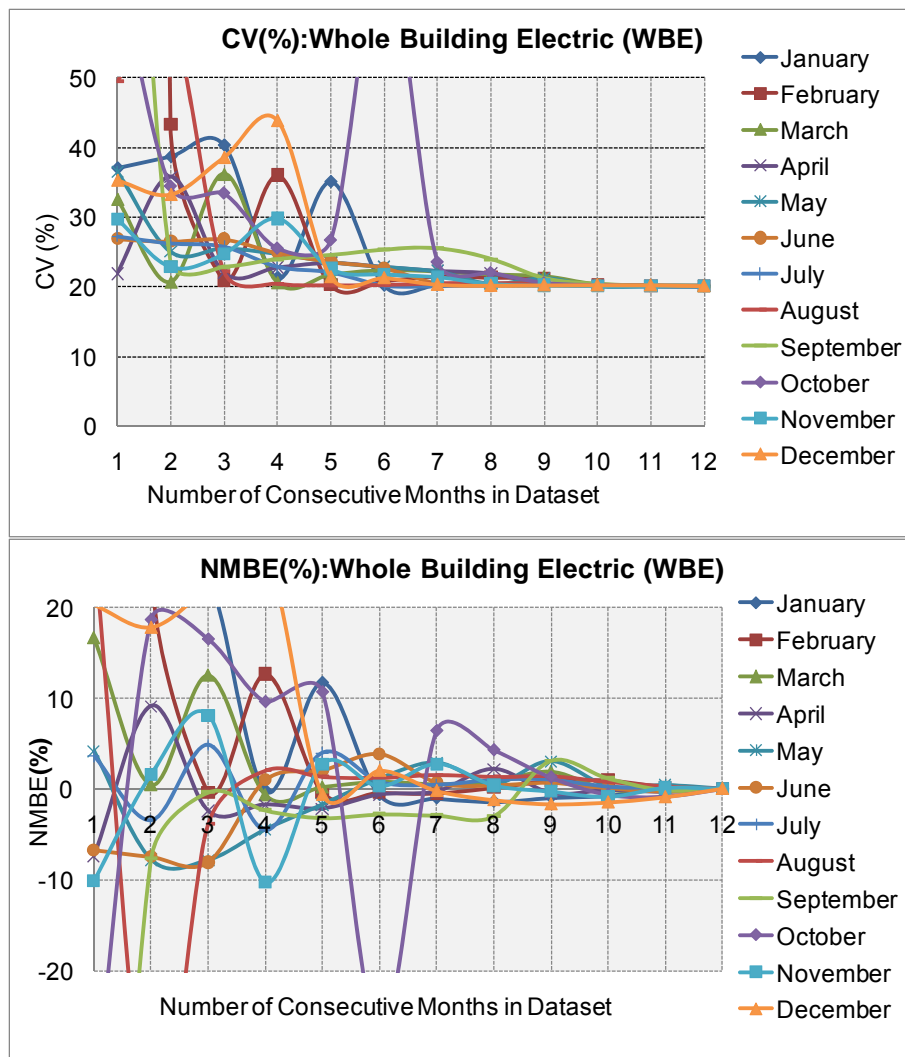


Figure 7.8 Variation in CV (%) and NMBE (%) for Whole Building Electric.

Building: Office at Albuquerque, NM

On an average, the predicted CV (%) for whole building electric never decrease below 20%, irrespective of the length of the dataset used for modeling. Clearly, for Albuquerque, no single month data is adequate for extrapolating the performance of the building over the whole year; longer periods of monitoring therefore are required. Minimum of four months of in-situ monitoring is required to yield predictions within acceptable accuracy.

Table 7.6 summarizes the five best options of short-term monitoring periods for the WBE channel. The prediction results of the models obtained from the data from these periods is very close to the results derived from models generated using whole year data.

Table 7.6

*Monitoring periods for which identified models predict energy use closest to those for which model is identified using whole year data. Energy Channel: WBE; Building: Large Office, Albuquerque, NM.*

S.No.	Monitoring Period		Duration of Monitoring (Months)	Prediction Accuracy <b>Whole Building Electric</b>	
	Start Month	End Month		CV (%)	NMBE (%)
	January	December	12	20.13	0.04
1	February	June	5	20.29	-0.34
2	March	June	4	20.57	-0.68
3	August	November	4	20.48	2.06
4	November	April	6	21.83	0.32
5	December	April	5	21.42	-0.62

Note that, each of the above cases includes periods with outdoor dry bulb temperatures close to the annual mean.

### 7.3.2. Results for Heating Energy Use for Office at Albuquerque, NM

Figure 7.9 shows results for HW from Figures 7.6 – 7.7 in more detail. All the twelve starting months have been combined into one figure. The graph for CV (%) shows all the monitoring periods that predicted HW within 50% of the actual energy use while the graph for NMBE (%) shows monitoring periods with bias of  $\pm 20\%$ .

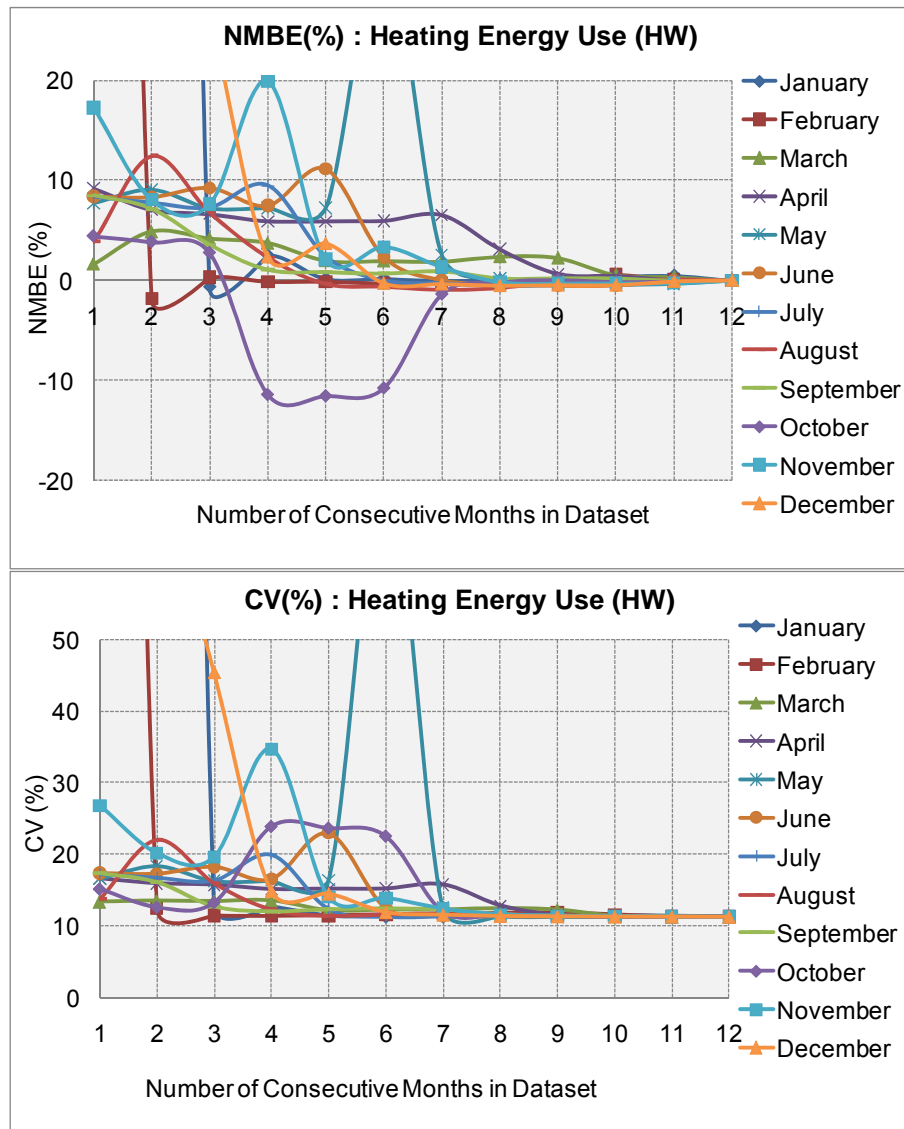


Figure 7.9 Variation in CV (%) and NMBE (%) for HW for office at Albuquerque, NM.

The predicted CV (%) for heating energy use in this case never decreases below 11%, irrespective of the length of the dataset used for modeling. Table 7.7 summarizes the five best options of short-term monitoring periods for the HW channel. The prediction results of the models obtained from the data from these periods is very close to the results derived from models generated using whole year data.

Table 7.7

*Monitoring periods for which identified models predict energy use closest to those for which model is identified using whole year data. Energy Channel: HW; Building: Large Office, Albuquerque, NM.*

S.No.	Monitoring Period		Duration of Monitoring (Months)	Prediction Accuracy <b>Heating Energy-Use</b>	
	Start Month	End Month		CV (%)	NMBE (%)
	January	December	12	11.26	-0.02
1	January	May	5	11.38	0.17
2	February	May	4	11.33	-0.11
3	August	December	5	11.36	-0.39
4	September	January	5	12.3	0.81
5	December	May	6	11.9	-0.31

#### 7.4. Results for Full Service Hotel – Washington DC Region

This section presents analysis results of the actual measured data for whole building electric energy-use channel. The time series plots of CV (%) and NMBE (%) are displayed in Figure 7.10 and Figure 7.11.

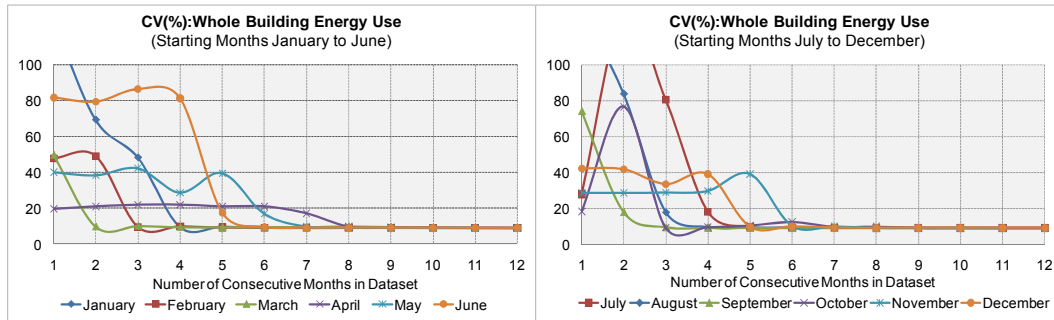


Figure 7.10 CV (%) for WBE energy-use channel when different lengths of monitoring are used for predicting annual energy for hotel in Washington D.C. area.

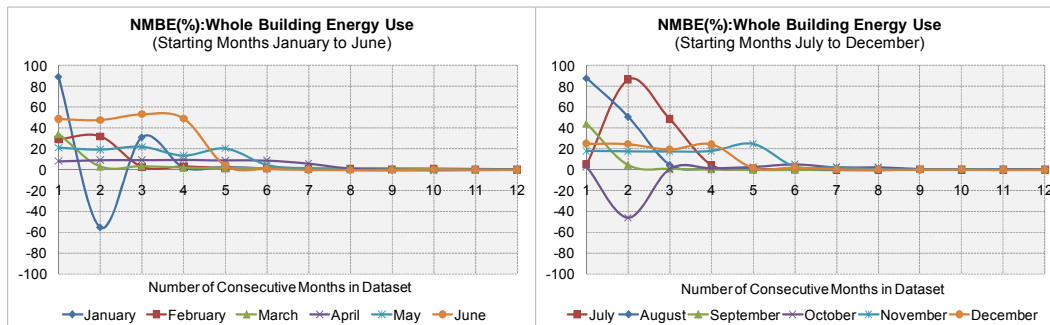


Figure 7.11 NMBE (%) for WBE energy-use channel when different lengths of monitoring are used for predicting annual energy use for hotel in Washington D.C area.

Figure 7.12 below shows results for WBE from Figures 7.10 – 7.11 in more detail. All the twelve starting months have been combined into one figure. The graph for CV(%) shows all monitoring periods that predicted WBE value within 50% of the actual energy use while the graph for NMBE(%) shows monitoring periods with bias of  $\pm 20\%$ .



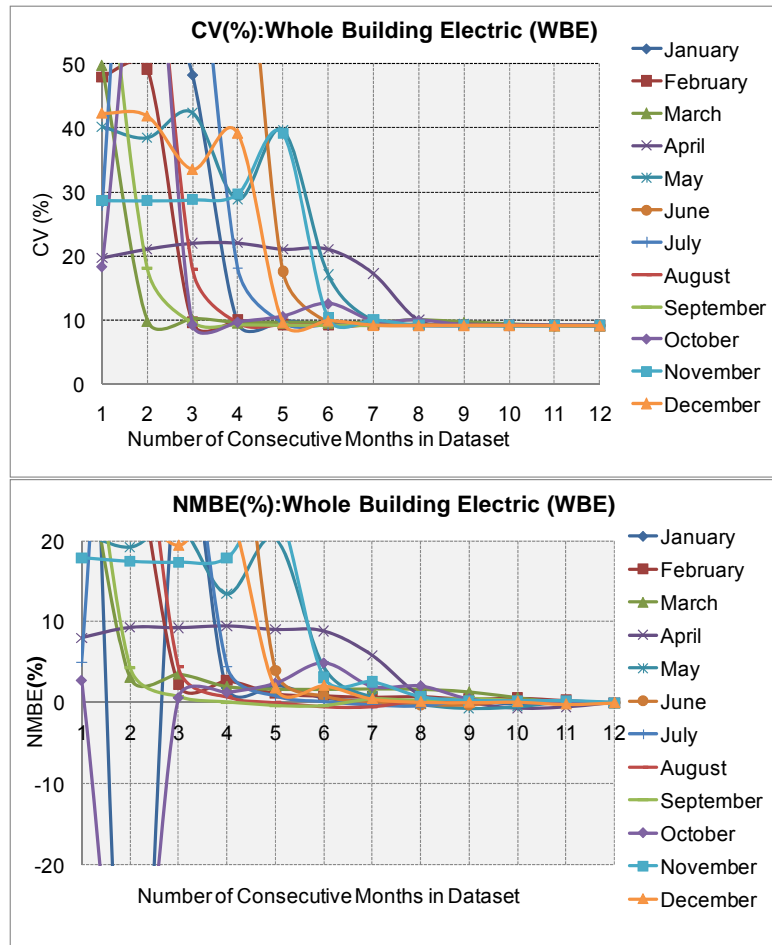


Figure 7.12 Variation in CV (%) and NMBE (%) for WBE. Graphs show periods with predicted CV (%) within 50% and predicted NMBE (%) within  $\pm 20\%$  of actual energy use for full service hotel located in Washington D.C area.

Table 7.8

Monitoring periods for which identified models predict energy use closest to those for which model is identified using whole year data. Energy Channel: WBE; Building: Full service hotel, Washington DC.

S.No.	Monitoring Period		Duration of Monitoring (Months)	Prediction Accuracy (WBE)	
	Start Month	End Month		CV (%)	NMBE (%)
	January	December	12	9.13	0.00
1	March	May	3	10.2	3.5
2	August	November	4	9.59	0.79
3	September	November	3	9.62	0.76
4	October	December	3	9.31	0.59
5	February	June	5	9.28	1.16

## 7.5. Validation of DBTA approach

In this section, the rankings obtained from the DBTA and MCP Modeling Approach have been compared. The results for the Large Hotel, Chicago, IL are shown in Table 7.9 and Figure 7.13 below.

Table 7.9

*Comparison of results for DBTA and MCP Modeling approaches for the large hotel building in Chicago, IL.*

Monitoring Period for Best Building Performance Prediction					Ranking			
Start Month	End Month							
	Temperature Analysis	MCP Method			Temperature Analysis	MCP Method		
		WBE	CHW	HW		WBE	CHW	HW
January	July	July	Aug-Sept	June	7	7	8	7
February	June-July	July	Aug-Sept	June	6	5	7	5
March	May-June	June	August	June	3	3	3	3
April	April-May	May	May	May-June	1	1	1	1
May	March	Nov-Dec	Dec-Jan	December	11	9	8	10
June	February	January	Nov-Dec	December	9	10	6	8
July	January	January	Oct-Nov	January	7	7	5	8
August	December	January	Oct-Nov	December	5	5	3	5
September	Nov-Dec	December	Nov-Dec	December	3	3	2	3
October	November	November	August	Nov-Dec	2	1	12	1
November	September	July	August	July	11	11	11	12
December	Aug-Sept	August	Aug-Sept	July	10	11	10	10

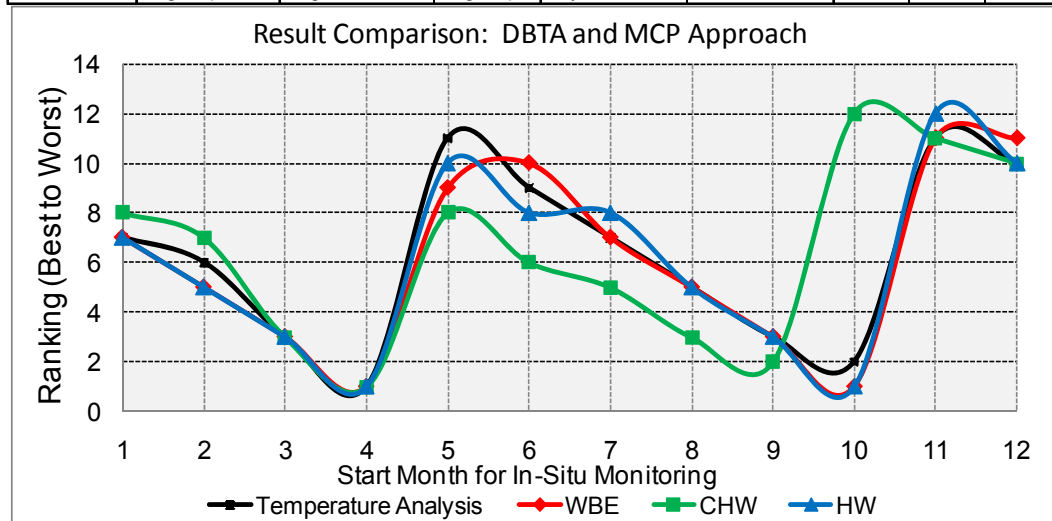


Figure 7.13 Comparison of results for Simplified DBTA and MCP modeling approaches for the large hotel building in Chicago, IL.

The results for the Office Building, Albuquerque, NM are shown in Table 7.10 and Figure 7.14.

Table 7.10

*Comparison of results for simplified DBTA and MCP Modeling approaches for the office building in Albuquerque, NM.*

Monitoring Period for Best Building Performance Prediction				Ranking for Each Starting Month		
Start Month	End Month					
	Temperature Analysis	MCP Method		Temperature Analysis	MCPMethod	
		WBE	HW		WBE	HW
January	July	June	July-Aug	7	7	8
February	June	June	June	5	6	5
March	May	April	June-July	3	3	4
April	April	June	May	1	4	1
May	February	January	January	11	11	11
June	Jan-Feb	December	Dec-Jan	9	9	10
July	January	Dec-Jan	December	7	8	7
August	December	November	December	5	5	5
September	November	Oct-Nov	December	3	2	3
October	October	October	Nov-Dec	1	1	2
November	September	July	June-July	12	11	12
December	August	June	June	10	9	9

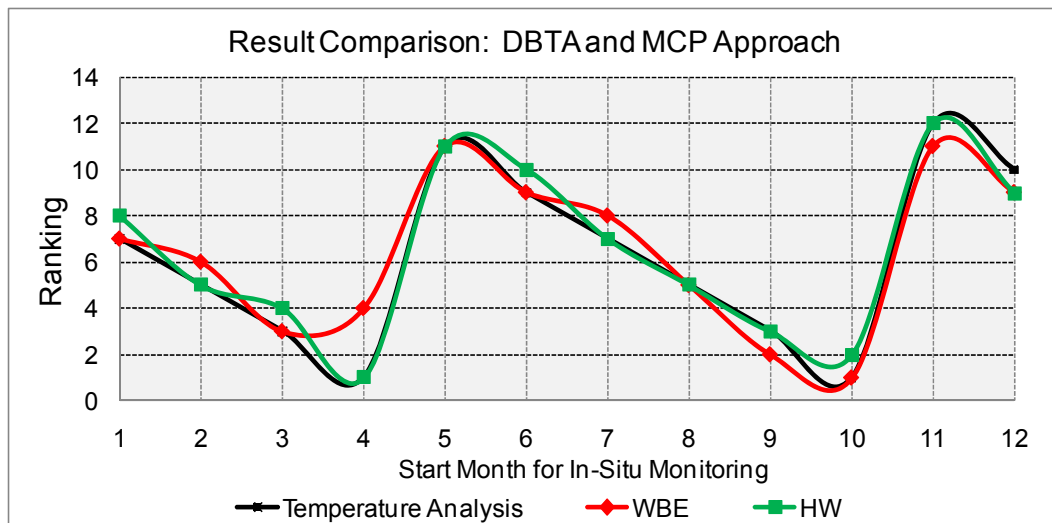


Figure 7.14 Comparison of results for Simplified DBTA and MCP modeling approaches for the large hotel building in Albuquerque, NM.

The results for the full service hotel, Washington DC Region are shown in Table 7.11 and Figure 7.15 below.

Table 7.11

*Comparison of results for simplified DBTA and MCP Modeling approaches for the hotel, Washington DC area.*

Monitoring Period for Best Building Performance Prediction			Ranking for Each Starting Month	
Start Month	End Month		Temperature Analysis	MCP Method
	Temperature Analysis	MCP Method WBE		
January	July-August	June	7	7
February	June	June	5	5
March	May-June	June	3	4
April	April	April	1	1
May	Feb-March	December	11	10
June	Jan-Feb	Dec-Jan	9	9
July	Jan-Feb	Dec-Jan	7	8
August	Dec-Jan	December	6	5
September	Nov-Dec	Nov-Dec	3	3
October	Oct-Nov	October	2	1
November	September	July	12	11
December	August	August	10	11

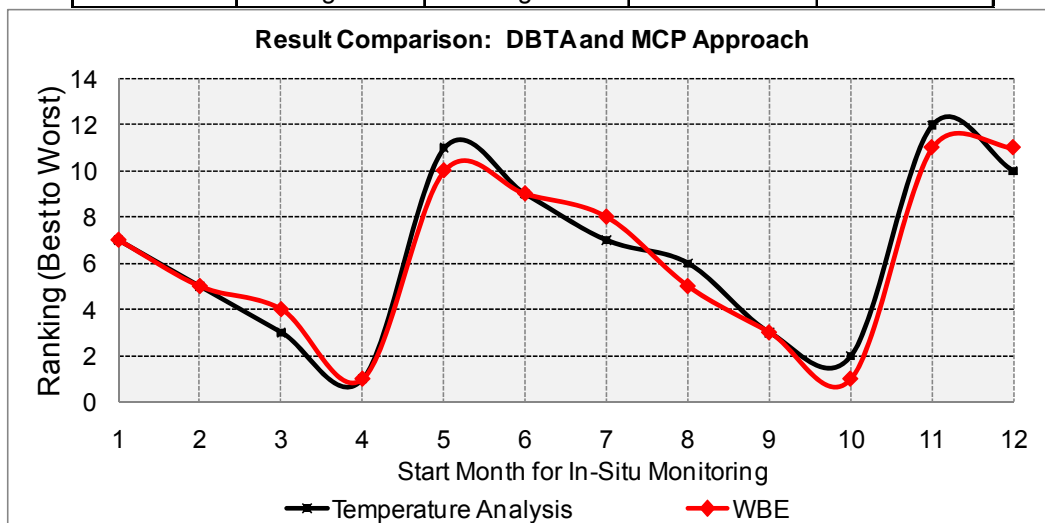


Figure 7.15 Comparison of results for DBTA and MCP modeling approaches for the hotel, Washington DC area.

## **7.6. Conclusion**

The above ranking is based on the duration of building monitoring needed such that models identified from the data provide predictions which are closest to those when a whole year worth of data is used. The objective is to identify the most suitable month to install data acquisition equipment to in the building and the length of monitoring needed to make accurate annual predictions.

Outdoor temperature is the most important factor influencing the energy use in a building. In the above analysis, a distinct pattern linking the outdoor dry-bulb temperatures to actual building energy use emerged.

Clearly, from Figures 7.13, 7.14 & 7.15 it is evident that the results obtained from the simplified DBTA and the MCP approach are fairly consistent for all the three buildings analyzed. As seen here, the months of April and October prove to be the best to begin in-situ monitoring of the building energy performance. Beginning in these months, only two to three months of data is enough to allow models to be identified which would predict the long-term energy performance of the buildings within acceptable accuracy levels.

Considering a scenario where neither any simulated data nor any utility history regarding the building performance is available, and, if the building operator has the option of choosing when to install the data acquisition equipment, the simplified DBTA can be used as a tool to make recommendations for the best time of the year to start energy-use measurement and the minimum duration of monitoring required for predicting building energy use.

## **HYBRID INVERSE MODELING RESULTS**

This chapter assembles the results of the two hybrid inverse modeling approaches explained in Sections 5.5.1 and 5.5.2. The hybrid inverse modeling (method 1) predicts energy use by combining a short data-set of monitored daily energy use and internal loads with at least one year of recent utility bills (representative of the long-term building energy use behavior data). The hybrid inverse modeling (method 2), on the other hand, uses information from only the utility bills for estimating building energy-use.

### **8.1. Hybrid Inverse Modeling-Method 1**

In this method, the model identification is done in two stages explained in Section 5.5. First stage involves regressing the monthly energy use with outdoor dry bulb temperature and average specific humidity potential as the regressors. The second stage then uses the model residuals of the first stage and finds another regression model using the daily equipment and lighting loads as the regressor. Finally, the model equations obtained from stages 1 and 2 are combined to derive the final model for predicting energy use.

Since the research aims at finding the shortest period suitable for in-situ energy use monitoring, the length of the period for this analysis is limited to a maximum of three consecutive months. Thus, models are generated for each starting month of the year (January to December), with each selection subsequently expanded in increments of one month to a maximum of three consecutive months to mimic different durations of monitoring.

### 8.1.1. Results for large hotel - Chicago, Illinois

The time series plots of CV (%) and NMBE (%) and for the three energy use channels namely, whole building Electric, cooling energy use and heating energy use (WBE, CHW & HW) are displayed in Figures 8.1 to 8.3, respectively, for different lengths of monitoring. The results for the MCP approach adopted previously have also been shown on the graphs to allow for a comparison. There is a clear advantage of using hybrid inverse modeling approach compared to the MCP approach since the CV(%) and NMBE(%) values are lower.

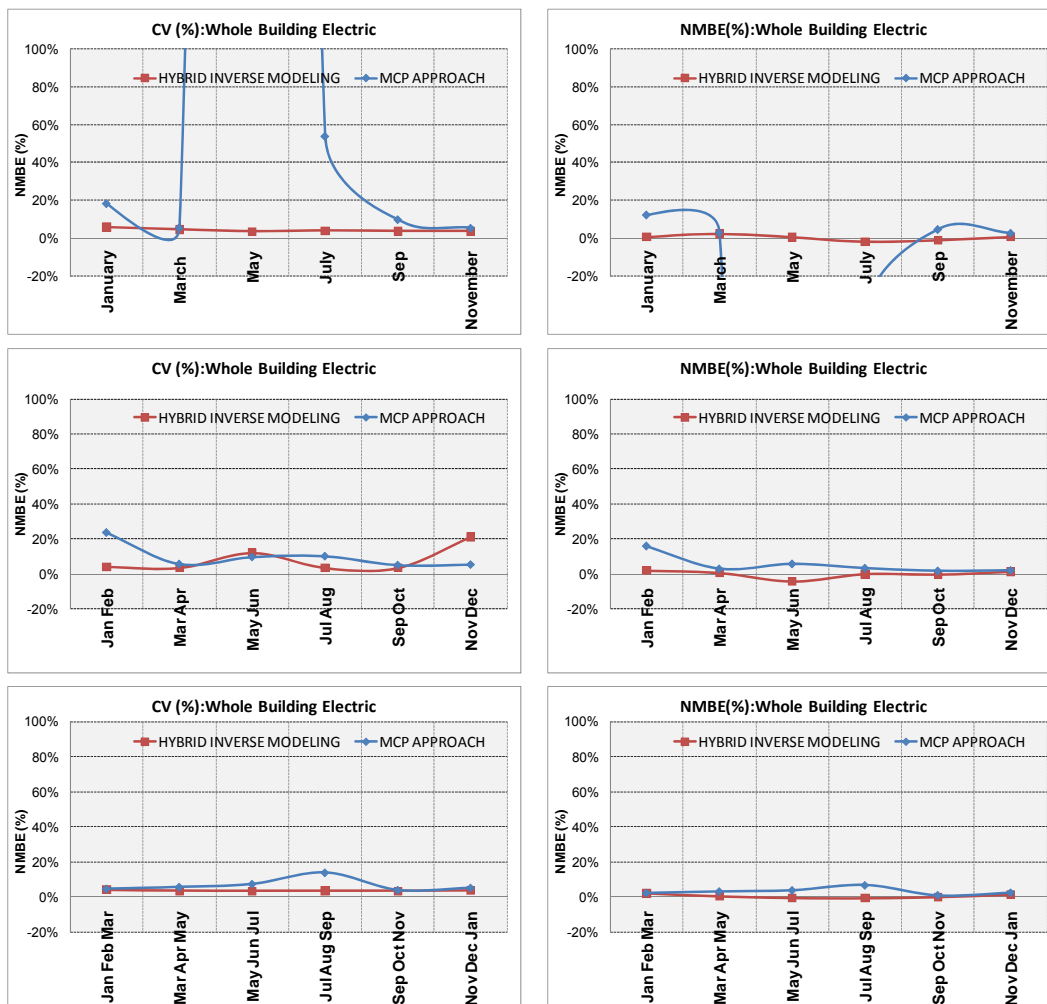


Figure 8.1 Variation in CV (%) and NMBE (%) for different monitoring periods for the large hotel at Chicago, IL. Analysis procedure: Hybrid Inverse Modeling (Method 1).

Energy Channel: WBE.

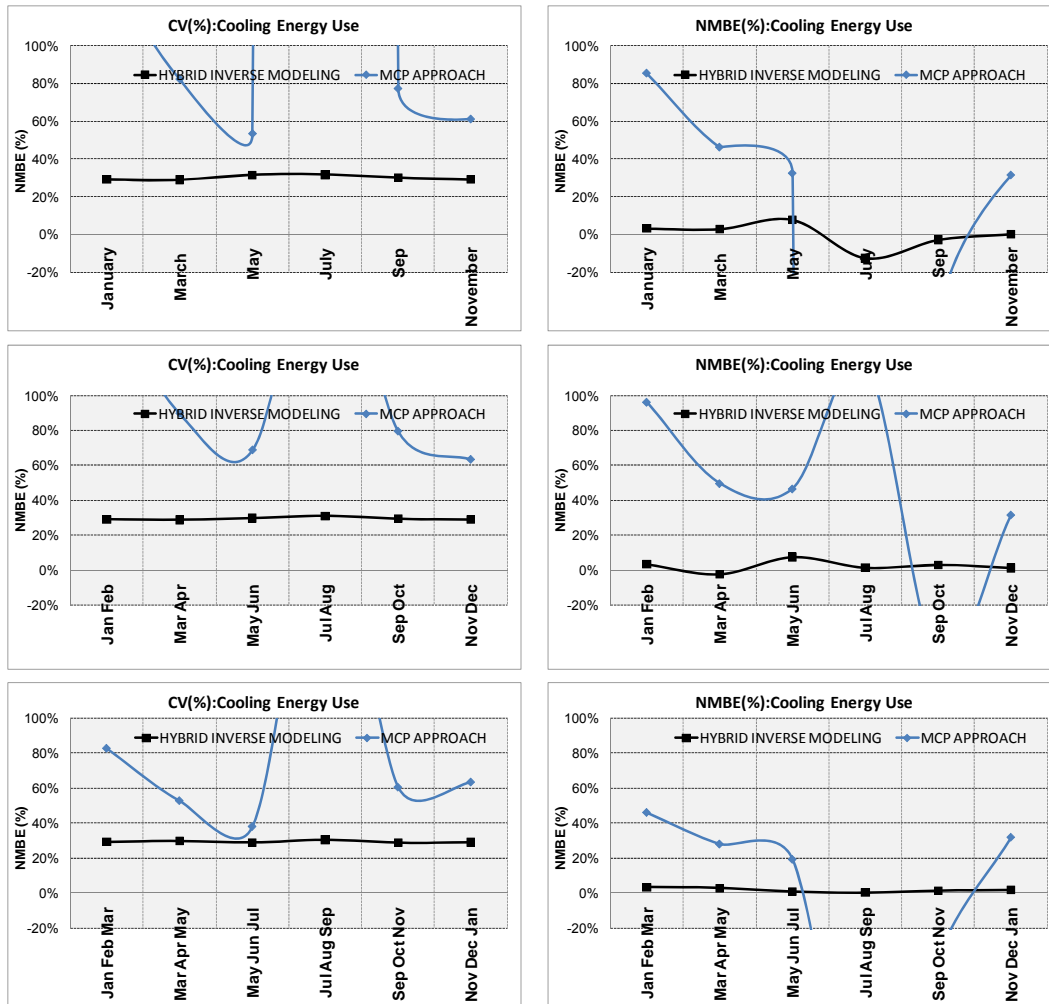


Figure 8.2 Variation in CV (%) and NMBE (%) for different monitoring periods for the large hotel at Chicago, IL. Analysis procedure: Hybrid Inverse Modeling (Method 1). Energy channel: CHW.



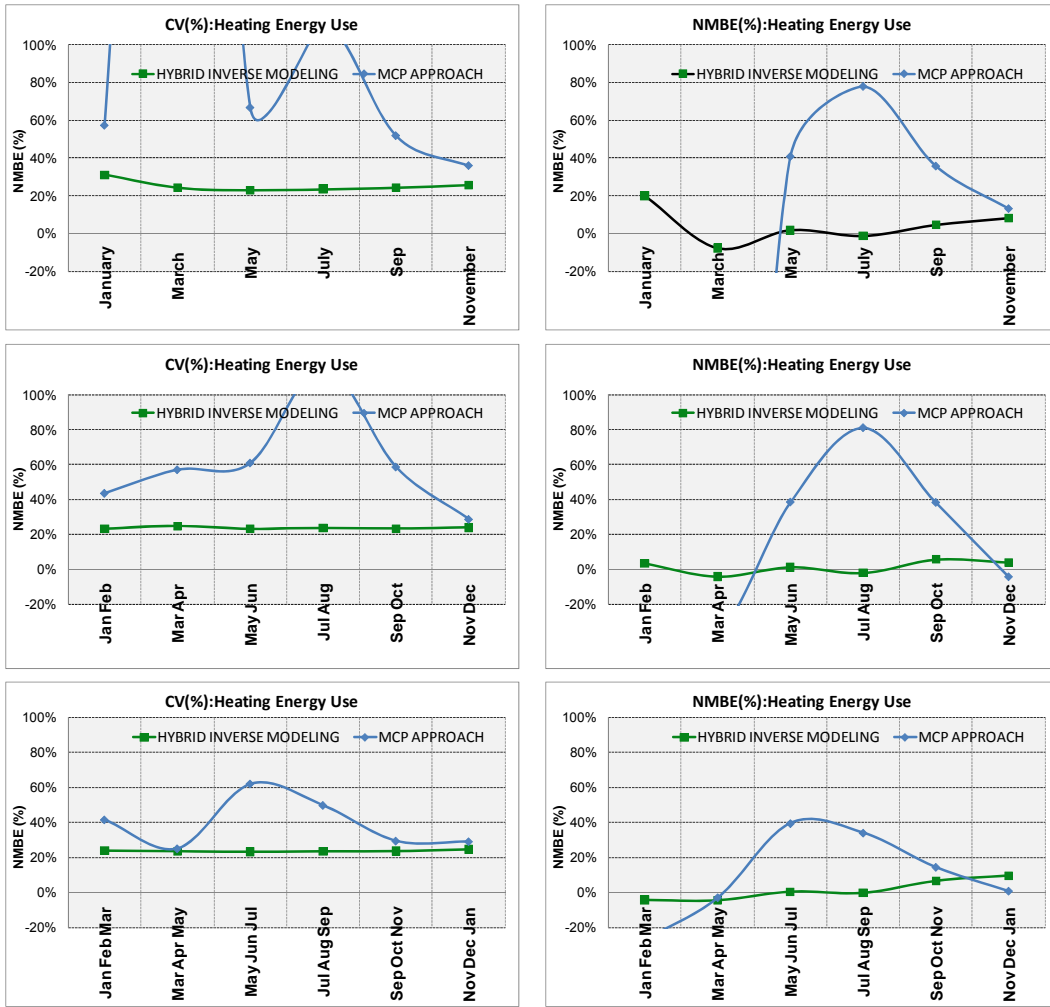


Figure 8.3 Variation in CV (%) and NMBE (%) for different monitoring periods for the large hotel at Chicago, IL. Analysis procedure: Hybrid Inverse Modeling (Method 1). Energy channel: HW.

### 8.1.2. Results for office building - Albuquerque, New Mexico

The time series plots of CV (%) and NMBE (%) for both energy use channels, namely, whole building electric and heating energy use (WBE & HW) are displayed in Figure 8.4 and Figure 8.5, respectively, for different lengths of monitoring. The results for the MCP approach adopted previously have also been shown on the graphs to allow for a comparison. Note that the CV (%) and NMBE (%) values for the hybrid model vary little with the monitoring length chosen or the month in which monitoring is initiated.

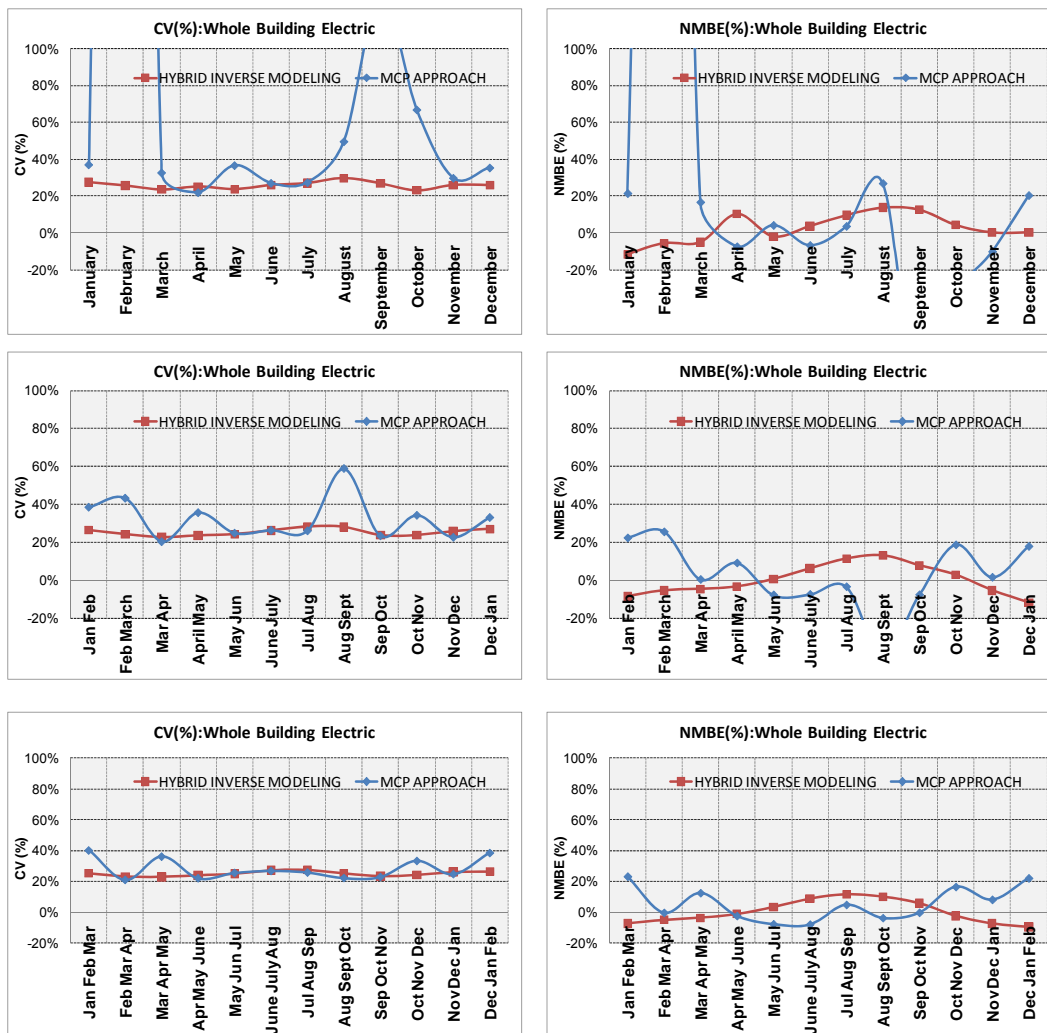


Figure 8.4 Variation in CV (%) and NMBE (%) for different monitoring periods for office building at Albuquerque, NM. Analysis Procedure: Hybrid Inverse Modeling (Method 1).

Energy channel: WBE.

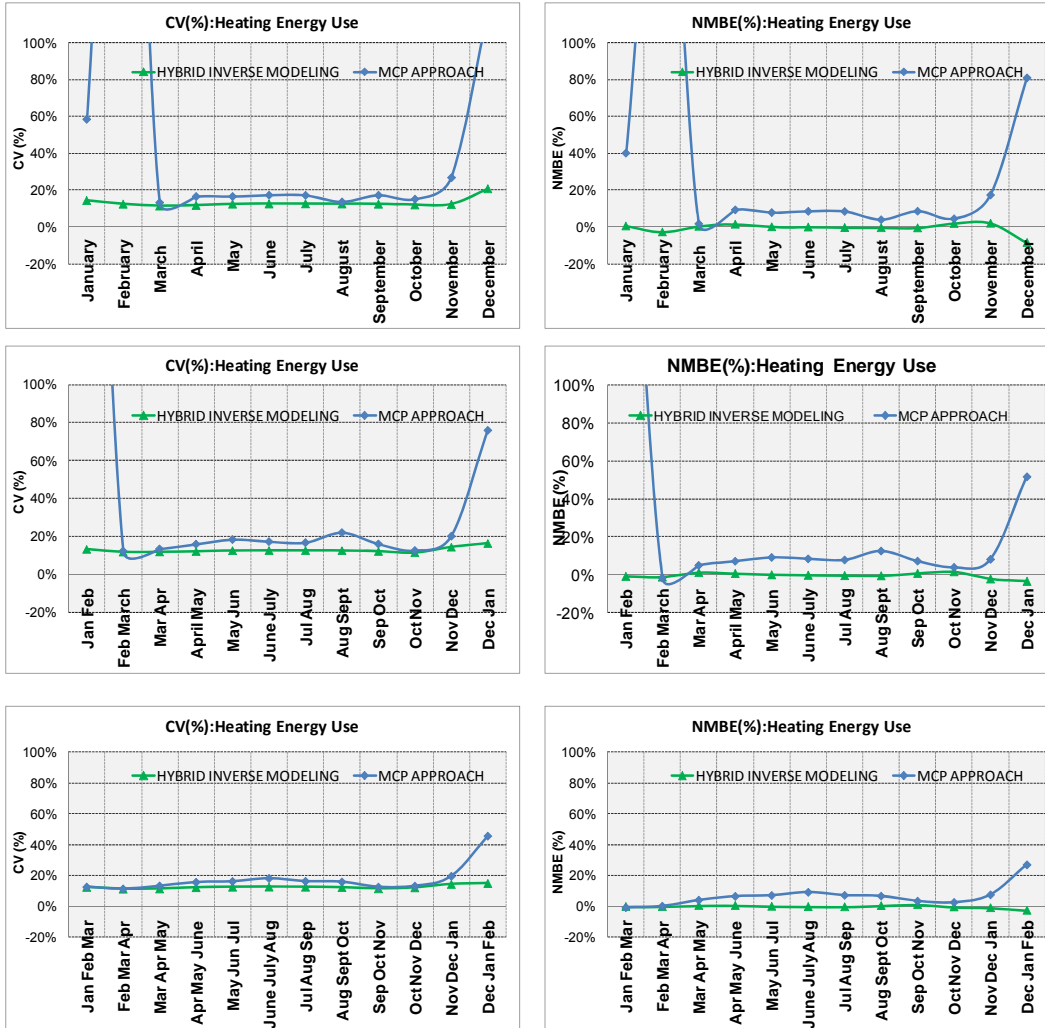


Figure 8.5 Variation in CV (%) and NMBE (%) for different monitoring periods for office building at Albuquerque, NM. Analysis Procedure: Hybrid Inverse Modeling (Method 1). Energy channel: HW.

### 8.1.3. Conclusions

The results in Sections 8.1.1 and 8.1.2 show a clear advantage of using the hybrid inverse modeling approach in predicting energy use in a building compared with the MCP modeling approach. Since the method uses utility history to represent the long-term data, a much shorter period of in-situ monitoring can be used for estimating energy use. The long-term predictions for the energy

channels are found to be almost the same irrespective of the time of the year chosen for monitoring. Not much improvement in the long term predictions is observed when the period from which the regression models are generated is increased from one to three months.

Looking closely at the results, one finds that the models regressed with data from the swing seasons tend to have marginally better predictions compared to the data obtained from the peak summer or winter periods. In the case of the building in Chicago, if the data acquisition system could be applied for only a period of one month, April or October would be the best choices. In the case of Albuquerque, March and October are found to be the best for measuring the whole building Electric and any month from April to September is good for predicting heating energy use of the building.

If the building owner has the option to keep the data acquisition equipment for a longer period, it would be better not just to obtain data from the swing season (spring or fall) but also capture a little more variability by extending the measurement into the cooling or heating season depending upon which energy channel is being modeled.

Combination of information from the utility bills with a short period of monitored daily energy use data is therefore a good source of information for predicting long term building performance. In most cases, only one month of monitored data is sufficient in predicting long term energy use of the building.

## **8.2. Hybrid Inverse Modeling-Method 2**

The hybrid inverse modeling (method 2) aims at predicting long-term building performance at daily timescales using utility bills only with no monitoring at all. The analysis method has been tested only for the WBE energy channel for the three datasets. The intent is to determine if utility bills alone can be used to predict the performance of buildings and by how much does the predictive accuracy decrease when no information about daily energy use and internal loads is added to the regression model.

In this case, the statistical parameters, NMBE(%) and CV(%), are analyzed at monthly as well as annual time scales. This would help provide an insight into how well the model generated from utility history alone is able to predict the energy use for each month of the year as well as for the whole year.

### **8.2.1 Results for the large hotel – Chicago, IL**

In Figure 8.6, the whole building electricity consumption for the entire year obtained from the simulated data and the prediction results from the hybrid inverse modeling (method 1) and hybrid inverse modeling (method 2) are shown. Monitored data for the two months (March-April) is used for identifying the regression model for hybrid inverse modeling (method 1). The inaccuracy in prediction of energy-use for the entire year using the model equation obtained from utility data only is clearly evident. Since the utility data does not capture the daily trends of internal loads in the building, the model over-predicts the energy use over the weekends for a major portion of the year and under-predicts for some portions. On the other hand, the energy use prediction profile obtained from the regression model of the hybrid inverse modeling (method 2) is very close to the profile derived from the simulated data.

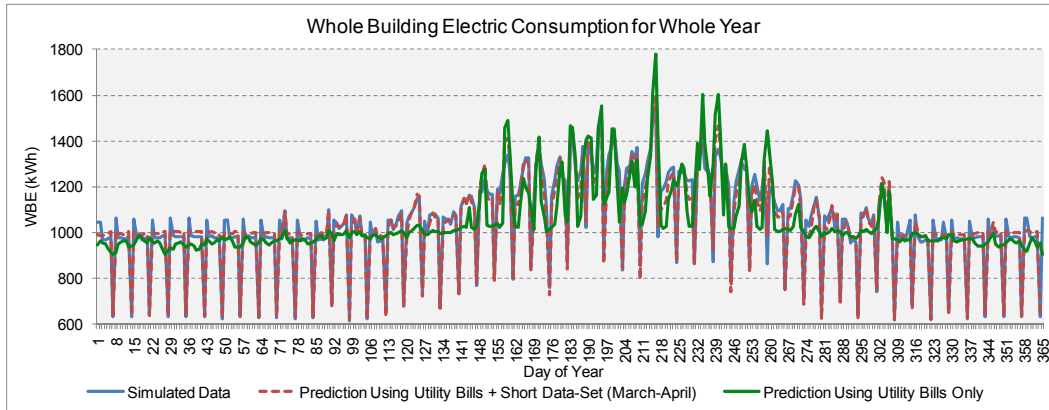


Figure 8.6 WBE use profiles for the entire year obtained from the simulated data & the prediction results of the hybrid inverse modeling methods 1 &2 for the large hotel, Chicago, IL.

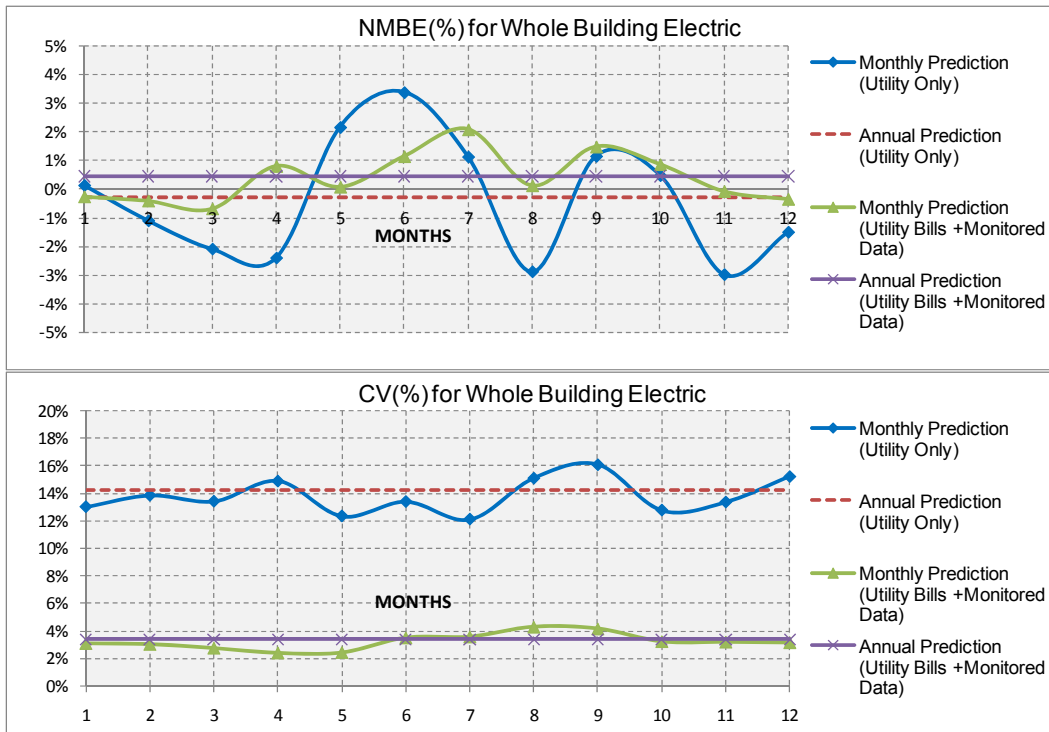


Figure 8.7 Comparison of NMBE(%) and CV(%) for WBE for the Large Hotel, Chicago, IL at monthly and annual timescales for Hybrid Inverse Modeling analysis methods 1 & 2.

The time series plots of CV (%) and NMBE (%) in Figure 8.7 compare the predictive accuracy of the models obtained using utility bills and a short dataset

and utility bills alone, i.e. hybrid inverse modeling methods 1 and 2 respectively. The average errors do not vary more than  $\pm 5\%$  for either case. The errors from method 1, however, are slightly lower compared to the results from method 2. Since the CV (%) is a better indicator of the predictive accuracy when analysis is done at monthly timescales, clearly, the hybrid inverse analysis (method 1) yields more accurate predictions on both monthly as well as annual timescales. The monthly CV(%), when only utility data (hybrid inverse modeling method 2) is used, varies from 12% to 16%. It is further reduced by approximately 10% when information from monitored data from just two months (March-April in this case) is used in addition to utility history for generating the regression model. The CV(%) values of monthly predictions for hybrid inverse modeling (method 1) ranges from 4.3%-2.4%. The annual CV (%) for hybrid inverse method 1 and method 2 is 3.38% and 14.26%, respectively.

### **8.2.2. Results for office building – Albuquerque, NM**

Figure 8.8 shows the whole building Electricity consumption for the entire year obtained from the simulated data and the prediction results from the hybrid inverse modeling (method 1) and hybrid inverse modeling (method 2). Monitored data for the two months (March-April) is used for obtaining the regression model for hybrid inverse approach (method 1).

Analysis of the office building at Albuquerque also reveals (as was the case for the large hotel in Chicago) that the utility data fails to capture the daily trends of internal loads in the building. Not surprisingly, the model generated using utility data only over-predicts the energy use for the weekends when internal loads are lower. The energy use prediction profile obtained from the regression model of

the hybrid inverse modeling (method 2) is very close to the profile derived from the simulated or as-designed dataset.

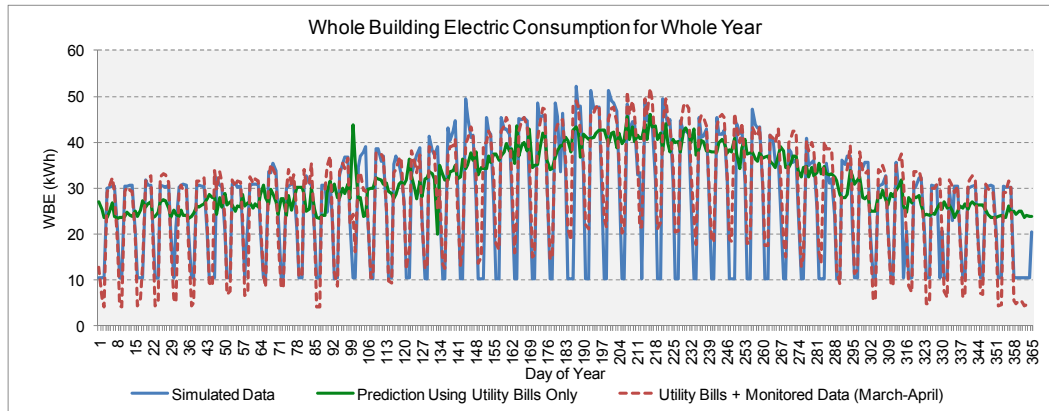


Figure 8.8 WBE profiles for the entire year obtained using the simulated data & the prediction results of the Hybrid Inverse Modeling Methods 1 & 2 for the office building at Albuquerque, NM.

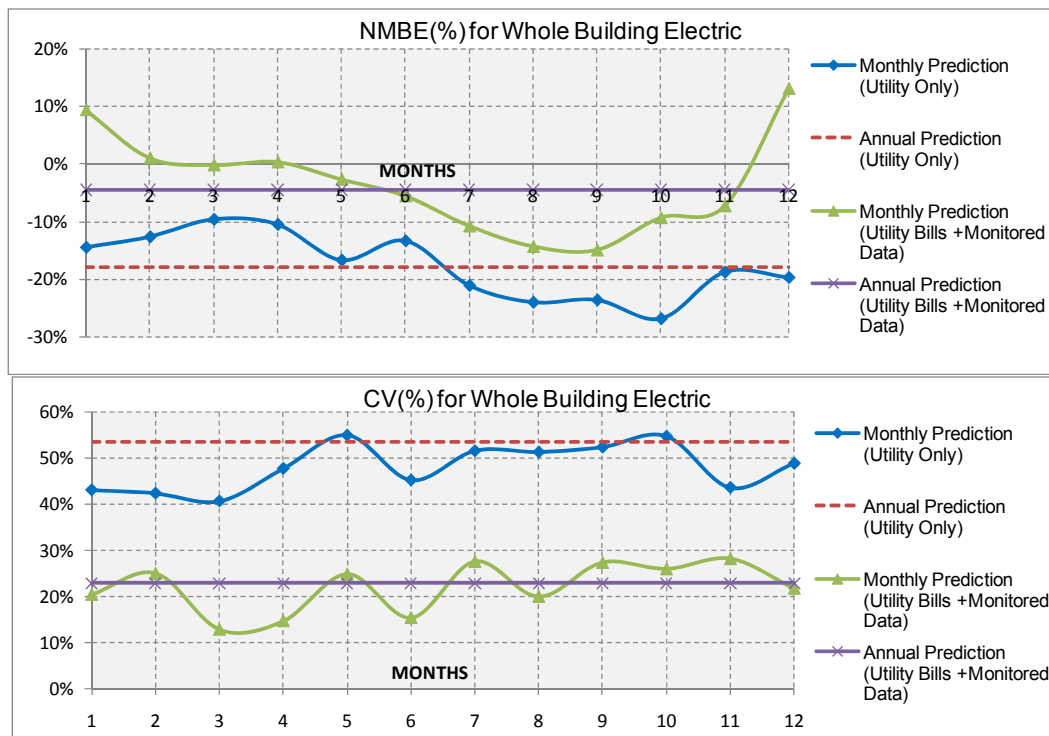


Figure 8.9 Comparison of NMBE(%) and CV(%) for Whole Building electric for the Office at Albuquerque, NM at Monthly and Annual Timescales for Hybrid Inverse Modeling Analysis Methods 1 & 2.



The time plots of CV (%) and NMBE (%) in Figure 8.9 allow comparison of the predictive accuracy of the models obtained using utility bills and a short dataset (two months) and utility bills alone, i.e. hybrid inverse modeling methods 1 and 2 respectively. The average errors for method 1 range from -15% to 13%, and for method 2 they vary from -9% to -26.8%. Since the CV (%) is a better indicator of the predictive accuracy when analysis is done at monthly timescales, clearly, the hybrid inverse analysis (method 1) yields more accurate predictions monthly as well as annually. The monthly CV(%) value, when only utility data (hybrid inverse modeling method 2) is used, varies from 40% to 55%. Further, it reduces to approximately half when information from monitored data from two months (March-April in this case) is used in addition to utility history for generating the regression model. The CV(%) values of monthly predictions for hybrid inverse modeling (method 1) ranges from 12%-28%. The annual CV (%) for hybrid inverse method 1 and method 2 is 22.9% and 53.5% respectively.

### **8.2.3. Results for hotel – Washington DC area**

The data available for the full service hotel located in the Washington DC region includes only monitored data for WBE and DBT for one complete year. Since there is no information available regarding the LTEQ loads of the building, only utility bills have been used for predicting the performance of the building. The humidity potential (w) was also not measured, therefore, only DBT is used as the regressor. The analysis procedure adopted is explained in Section 5.5.2. The energy use profiles for actual monitored data and the energy-use predicted using the model obtained from utility data only are shown in Figure 8.10.

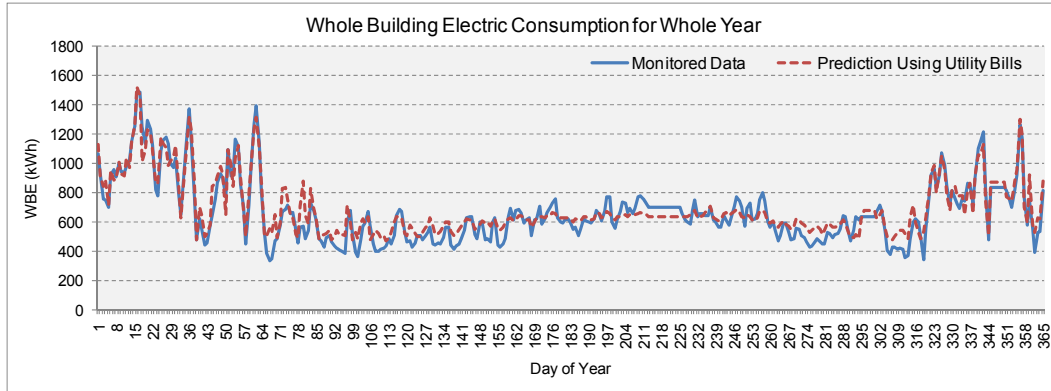


Figure 8.10 WBE Consumption for full service hotel, Washington DC Region. Actual monitored data and predicted energy use based on utility bills are shown.

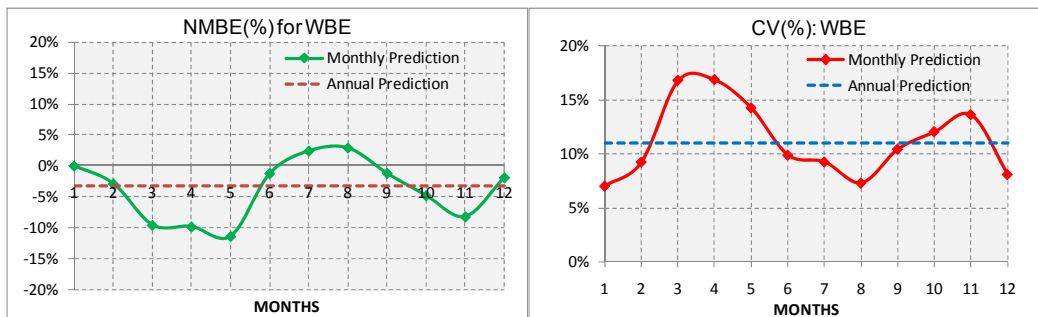


Figure 8.11 NMBE (%) and CV (%) for WBE Predictions using utility history only. The variations in prediction and average errors at monthly as well as annual timescales have been indicated for hotel, Washington D.C. Region. Analysis procedure: Hybrid Inverse Modeling (Method 2).

The time series plots of NMBE (%) and CV (%) in Figure 8.11 show the predictive accuracy of the model obtained using utility bills only. The average errors for predictions for different months of the year vary from -11.3% to 2.9%. The CV(%) also shows large variations over the year and ranges between 7% to 16.9%. The annual CV (%) for this case is 11%. In this case, the utility bills prove to be a good source for accurately predicting the building energy use. However, additional knowledge regarding internal loads would have probably made the prediction results even more accurate.

#### **8.2.4. Conclusions**

Clearly, there is an advantage in using some amount of monitored data for predicting building performance. As seen above, adding only two-months of monitored data to the utility information greatly improves the prediction results. However, in case no monitored data is available, utility bills can be used to provide a fairly accurate estimate of the long term energy use patterns of the building energy use at both monthly as well as annual timescales.

## **SUMMARY, CONCLUSIONS & FUTURE WORK**

### **9.1. Summary**

The main focus throughout this research was to investigate if short-term in-situ monitoring of energy use in buildings can be adopted as a workable alternative to year-long monitoring and verification. Simple modeling techniques to determine best time of the year to begin in-situ monitoring of building energy-use, and the least amount of data required for generating acceptable long-term predictions were identified. To determine the amount of short-term building energy-use data that would be enough to generate acceptable annual predictions, four different analysis methods were tested on year-long datasets from three buildings (two synthetic and one actual) from diverse geographical locations within the United States.

Three application areas for a research of this nature were identified; namely, detailed audits, green building performance verification and verification of post-retrofit claims using pre-post monitored data. The analysis methods proposed and studied were categorized based on the type of data that could be available for analysis. These categories include use of: (i) ambient temperature data only, (ii) simulated/ monitored year-long data, (iii) year-long utility bills and a short monitored dataset, and (iv) year-long utility bills only.

The short-term monitoring for long-term prediction (SMLP) and dry-bulb temperature analysis (DBTA) approaches used only temperature data to determine the best time and duration of the year for in-situ monitoring. Multivariate change-point (MCP) modeling technique was used to determine best monitoring period of the year based on simulated/monitored data. The method

was also used to verify the findings of the temperature analysis using DBTA method. The hybrid inverse modeling method-1 predicted energy-use by combining a short dataset of monitored internal loads with a year of utility-bills, and hybrid inverse method-2 predicted long term building performance using utility-bills only. The results of each of these analysis methods are summarized in Section 9.2.

## **9.2. Conclusions**

### **a. DBTA and SMLP Approaches**

The DBTA method, devised as a simple and easy-to-use alternative to the SMLP method (Abushakra, 2000), was used for analyzing the temperature data for the three different locations. The rankings obtained from the SMLP method and the DBTA showed similar patterns with months from the swing seasons ranked best in both analysis procedures. March, April and October were found to be the best periods for starting in-situ monitoring, while, the other months with extremes in weather conditions ranked poorly in both analysis methods. If monitoring was to be initiated from these months, only two to three months of data was found to be adequate to identify models which would predict the long-term energy performance of the buildings within acceptable accuracy levels. The DBTA method was also found to be quite accurate in capturing the information regarding the duration of monitoring required for making acceptable energy-use predictions.

The rankings obtained from the DBTA were further verified by means of actual modeling of energy-use data using the MCP modeling method. The results obtained from the DBTA and the MCP approaches were found to be fairly consistent for all the three buildings analyzed. A distinct pattern linking the

outdoor dry-bulb temperatures to actual building energy-use emerged. It was established that the annual predictive ability of short data-sets is strongly influenced by the closeness of the dataset's mean temperature to the annual mean temperature.

Considering a scenario where neither any simulated data nor any utility history regarding the building performance is available, and, if the building operator has the option of choosing the time of the year when to install the data acquisition equipment, the simplified DBTA can be used as a tool to make recommendations for best time of the year to start energy-use measurement and the minimum duration of monitoring required for predicting building energy use.

#### **b. MCP Modeling**

This analysis approach was used to predict whole building electric (WBE), cooling energy use (CHW), and heating energy use (HW) using a multivariate change point (MCP) models derived from short datasets. The outdoor dry bulb temperature (DBT) and lighting and equipment loads (LTEQ) were used as regressors. To determine the accuracy of the models derived from the short data-sets, the values of annual energy use predicted by models obtained from short data-sets were compared to the actual energy use in the original dataset. The predictive accuracy of the models was evaluated based on two statistical indices;  $CV_{RMSE}$  (%) and the NMBE (%).

The accuracy of the models was found to largely depend on the starting date and the end date of data collection. The months from the swing season, namely, March, April, October and November were found to be the best months to begin in-situ monitoring of building energy use. The general trend observed was that

models identified from low or high temperature regions tend to seriously err in the prediction of annual energy use.

The results from the MCP modeling method gave insight into the importance of the length of duration of monitoring the energy-use for predicting performance. Intuitively, one would expect the prediction accuracy of the annual energy to improve as the length of the data-set increases. In many cases, the average annual prediction was seen to decline as the length of the data-set was increased. Thus, one may infer that for accurate prediction results, not only is it important to know the best starting period to begin in-situ measurements, but correctly determining the length of data-set is of equal significance. For the three buildings analyzed, three to four months of monitored data was found to be adequate for making long term predictions of building performance within acceptable accuracy levels.

### **c. Hybrid Inverse Modeling**

The Hybrid Inverse Modeling (method 1) aimed at predicting building energy-use by combining a short data-set of monitored daily energy-use and internal loads with at least one year of recent utility bills (representing the long-term data). The results showed a clear advantage of using hybrid inverse modeling approach in predicting energy use in a building when compared with the MCP approach. Since the method uses utility history to represent the long-term data, a much shorter period was found to be sufficient for estimating long-term energy-use. The long-term predictions for the energy channels were found to be almost the same irrespective of the time of the year chosen for monitoring. Not much improvement in the long term predictions was observed when the period from which the regression models were generated was increased from one to three

months. In almost all cases, only one month of monitored data was sufficient in predicting long term energy use of the building within acceptable accuracy levels. Models regressed with data from the swing seasons were found to have marginally better predictions compared to the data obtained from the peak summer or winter periods. In the case of the building in Chicago, if the data acquisition system could be applied for only a period of one month, April or October would be the best choices. In the case of Albuquerque, March and October were found to be the best for measuring the whole building electric and any month from April to September were good for predicting heating energy use of the building. Combination of information from the utility bills with a short period of monitored daily energy use data is therefore a good way of acquiring data from which models can be identified which would predict long term building performance.

In the hybrid inverse modeling (method 2) the information from only the utility bills was used to identify models for estimating building energy-use. The advantage of using some amount of monitored data, as in the case of method 1, for predicting building performance was clearly demonstrated. Adding only two-months of monitored data to the utility information was able to improve the prediction results by almost 10-15%. However, in case no monitored data is available, utility bills were found to provide a fairly accurate estimate of the long term energy use patterns of the building energy use, at both monthly as well as annual timescales, provided there are no marked differences in the internal lights and equipment loads between weekdays and weekends.



To conclude, these findings and proposed strategies might be unacceptable in cases when one does not have the luxury of waiting until the climatic conditions are favorable to perform the in-situ tests. In case such an option is available, the analysis procedures can be used for finding the optimum start time and optimum length to monitor the energy-use in the building for predicting annual performance within acceptable accuracy levels. This can result in both time and cost benefits for the building owner.

In Chapter 5, three application areas for a research of this nature were identified. Table 9.1 summarizes the different application areas identified and the proposed research method that can be adopted to determine the best period for carrying out building energy-use monitoring. In cases where neither simulated nor any monitored data is available for analysis, the SMLP and DBTA approaches can be used to estimate the best time of the year and minimum duration for carrying out in-situ monitoring of building energy use. These methods utilize information from the weather variables for predicting best time of monitoring. In cases where simulated building performance data is available, the MCP modeling technique can be adopted. This method can be used for performance verification of the newly constructed green buildings for which simulated data is usually available. In cases where a building has been in operation for some time, and, there is atleast a year worth of utility data available for analysis, the hybrid inverse modeling methods can provide information regarding best periods of the year to begin in-situ monitoring of the building energy-use.

Table 9.1

*Application Areas Identified and the Proposed Research Methods.*

Summary of Cases and Analysis Methods		
Application Areas	Type of Baseline Energy Use Data Available for Analysis	Recommended Analysis Strategy
Detailed Audit	Weather Variables Only	Climate Diversity Test + DBTA / SMLP Approach
	Weather Variables + Simulated Data	Climate Diversity Test + DBTA / SMLP Approach MCP Modeling
	Weather Variables + Short Term Monitored Data	Climate Diversity Test + DBTA / SMLP Approach MCP Modeling
Green Building Performance Verification	Weather Variables + Utility Bills (One Year)+ Short Monitored Dataset	Climate Diversity Test + DBTA / SMLP Approach Hybrid Inverse Modeling – Method 1
Pre-Post M&V	Weather Variables + Utility Bills (One Year)+ Short Monitored Dataset	Climate Diversity Test + DBTA / SMLP Analysis Hybrid Inverse Modeling – Method 2
	Weather Variables+ Pre-Retrofit Monthly Data (1 year)+ Post-Retrofit Monitored Data	Climate Diversity Test + DBTA / SMLP Approach Hybrid Inverse Modeling – Method 1/ MCP Modeling (depending on availability of Utility Bills)

### **9.3. Future Work**

Broader sample of buildings from diverse geographical locations should be used to generalize the results obtained. The research methods discussed in this report can be further refined by analyzing more datasets from actual buildings and of different building types. The actual building energy-use data analyzed in this research consisted of the whole building electric use data only. The pre-post retrofit cases were not investigated at in this research and could form a potential study for the future. In this study, a MATLAB code was written to obtain the CV (%) and NMBE (%) indices for the predictions made by the regression models generated in the Energy Explorer software. The procedure adopted is a bit more time consuming since the data has to be manually extracted from one software and fed into another. Automating the entire process would result energy engineers as well as designers and building operators adopt these approaches in order to determine best periods of the year to begin in-situ monitoring of their buildings and the associated lengths of monitoring.

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APPENDIX A  
DESCRIPTION OF BUILDINGS ANALYZED

**A1. Large Hotel Chicago, Illinois**

*Description extracted from final report of ASHRAE RP 1340 (Maor, Reddy et al. 2009).*

**Type of Building:** Synthetic

**Energy Use Channels Analyzed:** Whole building Electric, cooling energy use, heating energy use.

A synthetic DOE 2.1 E building energy simulation model is developed for the large, 650-guest room hotel. The location selected for the hotel is Chicago, IL, which corresponds to area 5A in the geographical locations established for this research project. The building is a forty three story 619,200 ft<sup>2</sup>, rectangular shaped building with 8 thermal zones. Floor 1 is lobby, shops and restaurants. Floors 2, 3, and 4 accommodate conference rooms, banquet and offices. Floors 5 thru 42 are guest rooms in a perimeter – core layout where the core includes corridors, shafts and service rooms. Floor 43 accommodates mechanical rooms and service areas. Building envelope properties, systems efficiencies, etc. are based on typical design practices for the late 1980. Sections of ASHRAE 90.1-2004 minimum requirements used as well.

Operating schedules (lighting, occupancy, etc.) are based mainly on data from ASHRAE 90.1-1989. Although a variety of secondary air systems (such as VAV, Fan Coils etc.) can be found in large hotels, for simplicity, Variable Air Volume (VAV) with Hot Water (HW) reheat is used in the lobby, conference rooms, and other administrative areas. Four Pipe Fan Coils (FPFC) units (chilled water and hot water) used for the guest rooms. The guest rooms floors (5-42) core areas

served by a 100% OA, Dedicated Outdoor Air System (DOAS) which comprises a Reheat Fan System (RHFS). The intent of this approach is to allow introduction of pretreated OA to each guest room directly, provisions in the model applied to decouple the core cooling and heating load and the need of constant supply of OA to the guest rooms. The chiller plant has a cooling capacity of 1,400 Ton, which comprise of two (2) 700 Ton, Water Cooled, Electric, Centrifugal Chillers). The Hot Water heating plant is 20,086 MBtu /h, which comprises two (2) 300 BHP or 10,043 MBtu/h, gas fired boilers.

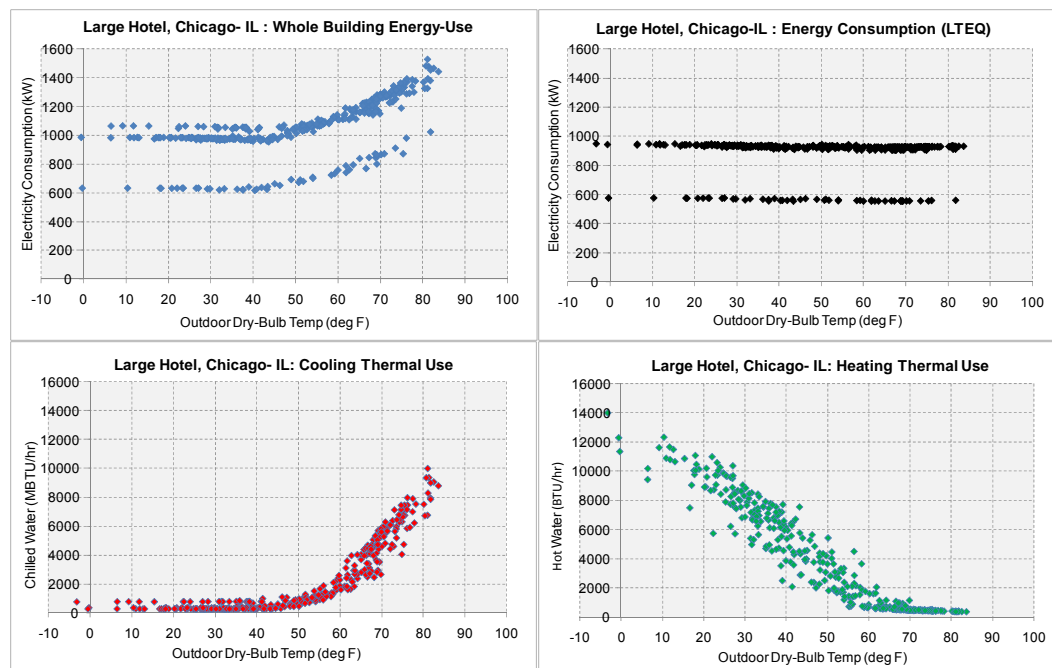
Table A1.1

*Building Description: Large Hotel, Chicago, Illinois*

General	Description
Location	Chicago, IL
Floor Area (Sqft)	619,200
Above Grade Floors	43
Below Grade Floors	0
% Conditioned and Lit	100
Geometry	
Footprint Shape	Square (120' x 120')
Zoning (1 <sup>st</sup> thru 4 <sup>th</sup> floor)	Each floor is single zone
Zoning (5 <sup>th</sup> thru 42 <sup>nd</sup> floor)	4 Perimeter /1 Interior
Zoning (43 <sup>rd</sup> floor)	Single zone
Perimeter Depth (Feet)	20
Floor to Floor Height (Feet)	13
Floor to Ceiling Height (Feet)	9
Envelope	
Roof	Massive, R-27
Walls	Glass Curtain Wall, U=0.11(Btu/h-Ft <sup>2</sup> -Deg F)
Foundation	Slab, U=0.025 (Btu/h-Ft <sup>2</sup> -Deg F)
Windows	Double Glazing Reflective=0.55 (Btu/h-Ft <sup>2</sup> -DegF), SC=0.41
Windows to Wall Ratio (%)	36.0
Exterior and Interior Shades	None
Schedules	
Operation schedule	24/7
Secondary Systems	
Lobby, Conf. Rooms, offices	VAV with HW reheats.
Guest Rooms.	Four Pipe Fans Coils
Guest Rooms – DOAS/ Vent.	Reheat Fan System
Mechanical Room 43 <sup>rd</sup> floor	SZ

The building loads of interest are the whole-building energy, thermal cooling loads, the thermal heating loads and lights & equipment load (non-cooling electrical loads). The hourly values of these four loads in conjunction with the climatic data (such as ambient air dry-bulb temperature) are available from the building energy simulation program results. The electric loads vary from about 550 – 1,400 kW from daytime to nighttime and from weekday to weekend with no seasonal trend. On the other hand the thermal loads vary widely from season to season.

The graphs in Figure A1 are scatter plots of the daily energy-use over a year for the four energy channels mentioned above.



*Figure A1.1* Scatter plots of the daily energy-use over a year for the energy use channels for Hotel at Chicago, IL.

## A2. Office Building, Albuquerque, NM

**Type of Building:** Synthetic

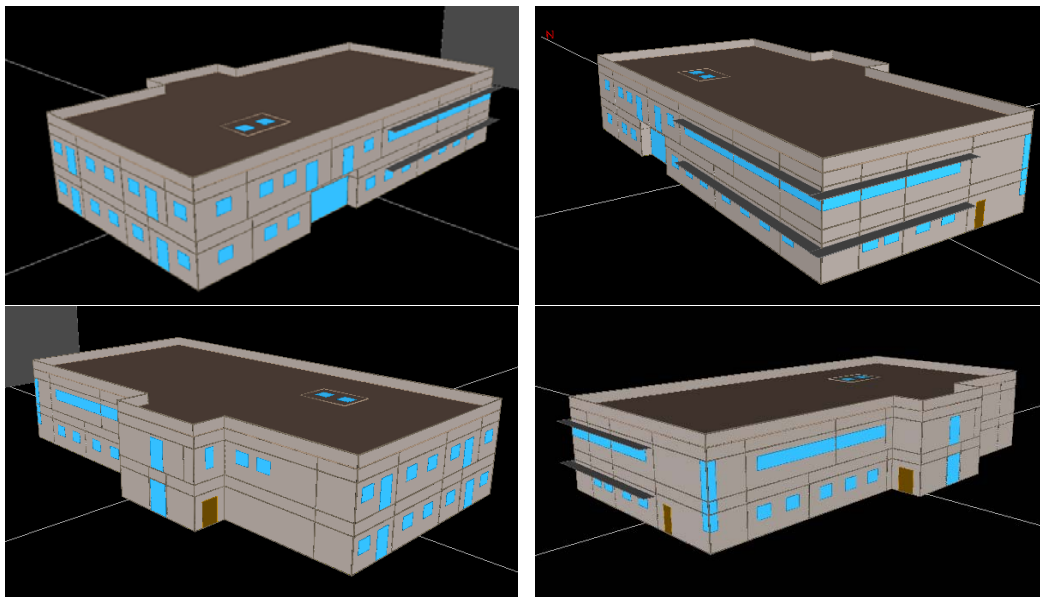
**Energy Use Channels Analyzed:** Whole building electric, heating energy use.

The Office Building, located in Albuquerque, New Mexico is a two storied building with a net conditioned area amounting to approximately 17,430 sqft. Full year simulated data for whole building electric and heating energy use channels are available for analysis. The basic details of the size and orientation are summarized in Table A2.1 and the images of the simulation model are provided in Figure A2.1.

Table A2.1

*Building Description for Office at Albuquerque, NM.*

Building Description	
<i>Location</i>	<i>Albuquerque, NM</i>
<i>Total Conditioned Area</i>	<i>17,430 sqft</i>
<i>Aspect Ratio</i>	<i>2.1 to 1</i>
<i>Orientation</i>	<i>Long axis faces east/west</i>
<i>Floor to Floor Height/ Floor to Ceiling Height.</i>	<i>12ft</i>
<i>Window Area</i>	<i>1497 sqft</i>



FigureA2.1: Simulation Model Images for the Office at Albuquerque.

Table A2.2

*Detailed Description of the Office Building at Albuquerque, NM.*

S.No	Description	As Designed
<b>1</b>	<b>Building Description</b>	
	Location	Albuquerque, New Mexico
	Total conditioned area	17,430 sqsft
	Aspect ratio	2.1 to 1 (~132ft x 64ft)
	Orientation	long axis faces east/west
	Floor-to-floor / Flr to Ceiling Ht.	12 ft/9ft
	Window Area	1497 sqft
<b>2</b>	<b>Exterior Wall Description</b>	
	opaque wall U-value	U=0.061
	wall finish color	0.5 (medium light)
<b>3</b>	<b>Roof Construction</b>	
	roof U-value (R-value)	0.031 (32.3)
	roof exterior finish color	0.5 (medium light)
<b>4</b>	<b>Window- Door Type</b>	
	Glass Type	Dbl Pilkington CTG 6851
	U-value (incl. frame effects)	0.34, ctr glass (0.55 w bad frm)
	solar heat gain coefficient	0.38 (SC=0.44)
	window wall ratio	15%
<b>5</b>	<b>Window Shading</b>	
	exterior shading	3 ft overhang at south & SW
	interior shading	None
<b>6</b>	<b>Interior Wall Type</b>	
	2x4in Metal Stud, 24in o.c	
	cavity fill batt	nominal 4 in fiberglass batt (R-
<b>7</b>	<b>Floor Construction</b>	
	First floor	6 inch slab on grade with carpet
	Second floor	4 in concrete with carpet
	Perimeter insulation	2 ft vertical ext. R-5 EPS
<b>8</b>	<b>Cooling System Type</b>	
	Package Rooftop VAV, HW	
	area served	all but electrical rooms
	capacity	67 tons total, 62 tons sensible
	supply CFM	24000 CFM
	VAV terminal minimum flow	0.4
	fan Control	VSD
	cooling / heating setpoint	74F / 70F
	Unoccupied Set Point	82F / 64F
	outside air (OA) supply	15 cfm/person (~7.5% of design
	supply air temperature	55 F minimum
	SAT reset	reset by zone demand to 68F
	fan static, supply/return	3.75/1.5 in WG
	economizer high limit	65F
	cooling EER	11.2

		Simulation 1
<b>S.No</b>	<b>Description</b>	<b>As Designed</b>
<b>9</b>	<b>Heating System Type</b>	
	boiler efficiency	0.85
	HW loop design operation	40F DT, 180F setpt, reset to 140F
	HW pipe UA	153 Btu/hr-F
	HW preheat coil	45F mixed air T
	terminal reheat delta T	35F
<b>10</b>	<b>DHW System Type</b>	
	Electric Tank (50 gal)elec	2 - 6 kW elements
	DHW setpoint	126F
	DHW peak demand	6.5 gal/hr (measured)
	DHW recirculation	2 gpm recirc loop pump
<b>11</b>	<b>Schedules</b>	
	Occupancy Schedule	7am - 5pm M-Th, 1/2 on Fri
	Lighting & Equipment Schedule	7am - 5pm M-Th, 1/2 on Fri
	Fan Schedule	6am - 6pm WD
	Seasonal Occupancy	Closed: Dec 24- Dec 31
	Lighting Power Density (W/sf)	ATE598 Example Bldg Ltg Loads
	Receptacle Load	ATE598 Example Bldg Plug Loads
	Number of Occupants	actual: 90 (~200); design: 122
	Occupant Sens/Lat (Btu/per)	250/200

The building loads of interest are the whole-building energy, thermal heating loads and lights & equipment load (non-cooling Electrical loads). The hourly values of these four loads in conjunction with the climatic data (such as ambient air dry-bulb temperature) are available from the building energy simulation program results. The graphs below show the annual energy-use profiles for the three energy channels mentioned above. The data shown is at daily timescale.

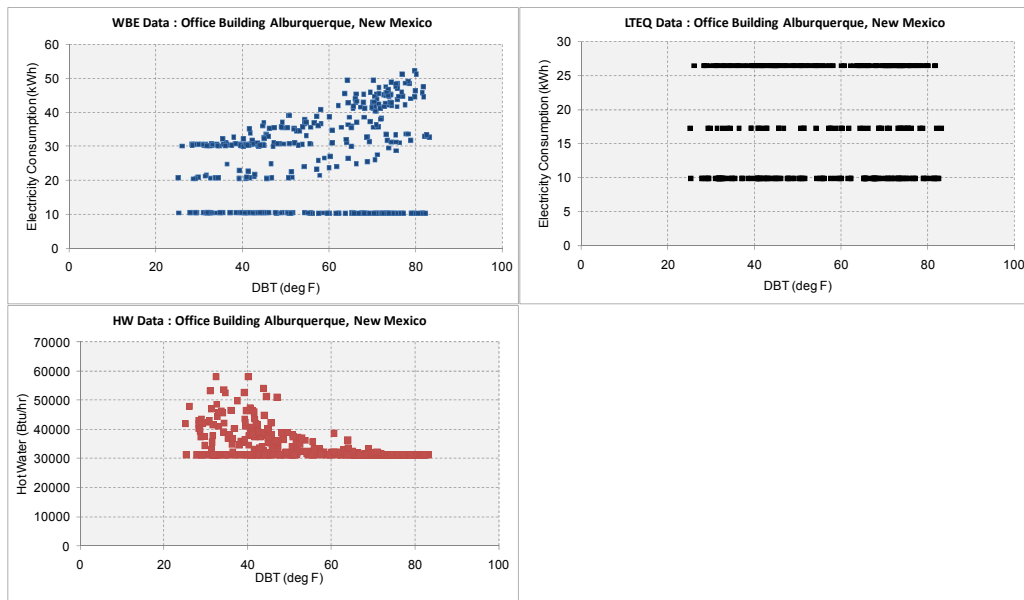


Figure A2.2 Scatter plots of the daily energy-use over a year for the energy use channels for Office at Albuquerque, NM.

### **A3. Full Service Hotel, Washington DC Region**

**Type of Building:** Actual (Whole Building Electric Utility Data for 2009 available)

**Energy Use Channels Analyzed:** Whole building Electric.

The data used for analysis is of a full-service, large hotel. Intensive metering and monitoring effort aimed at understanding energy end use patterns in the hotel was undertaken in order to come up with retrofit strategies to reduce its energy consumption by at least 30%. About 10% of the guest rooms (32), as well as circuits for most of the end uses in public spaces (lighting, LTQvators, air handlers and other HVAC system components, and various equipment), were equipped with meters.

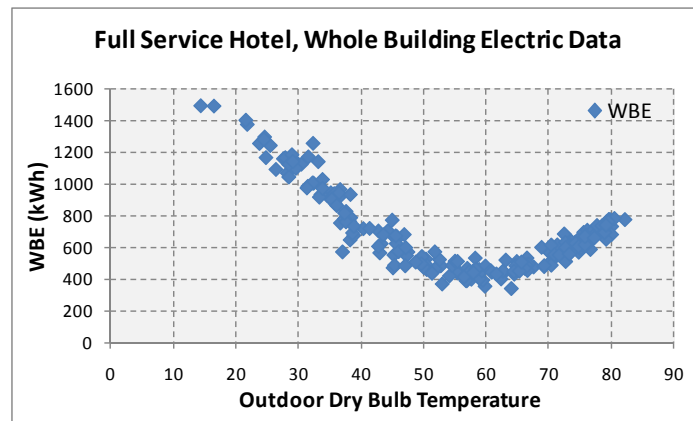
Located at the Washington DC Region, USA, the building is a twelve-story, full-service hotel with over 300 guest rooms and gross floor area of 212,000 ft<sup>2</sup>. The building energy systems are somewhat outdated. The hotel has an energy management system (EMS) that is not connected to all building energy systems (e.g., the newly-installed chiller, exhaust fans) and is not being used in a fully-functional way. Also, single-pane windows and un-insulated exterior masonry walls result in a thermally-inefficient building envelope. Most of the packaged terminal heat pumps (PTHP) serving the guest rooms are 7-years old or more.

The baseline energy use of the project was measured and a detailed study of the end-use energy consumption patterns was conducted. The metering provided a detailed and accurate picture of energy consumption at this particular property. The end use consumption data from this hotel can be considered typical of the large hotel sector in general since the guest room equipment and various other features of the hotel are typical of large hotels in the United States.



The analysis of the 2009 Electricity interval data from the utility shows a relatively flat daily load curve in all the seasons across all days of the week. The lack of variation between weekdays and weekends is not surprising, given the hotel has a very high occupancy rate and serves both tourists (including weekend stays) and business guests (typically during the week).

The graphs in Figure A3.1 below is a scatter plot of daily whole building electric use versus outdoor DBT for the whole year of 2009. One notes that the data is well behaved with a clear 4P change point behavior.



*Figure A3.1* Scatter plot of the daily energy-use over a year for the WBE energy channel for a Hotel at the Washington DC area, USA.

## APPENDIX B

### POST OCCUPANCY EVALUATION: IEQ, ACOUSTICS, WATER

Post Occupancy Evaluation involves the measurement of the performance of a building in actual use in terms of the following aspects:

- i. Energy Use,
- ii. Indoor environmental quality (IEQ): Thermal comfort, Indoor air quality, Lighting/daylighting,
- iii. Acoustics, and
- iv. Water Use

Published work on post-occupancy performance of green buildings in terms of energy use has been reviewed in Chapter 4. The other aspects, namely, IEQ, acoustics and water are briefly discussed below.

#### **B1. Indoor Environmental Quality (IEQ) Measurement**

##### **B1.1. Thermal Comfort**

###### **a. Background**

Comfort conditioning is the largest component of energy consumed in buildings and it accounts for nearly 15-20% of the total national energy use in the United States. Thermal discomfort can be a major source of dissatisfaction for the users of a building (Huizenga et al., 2006a). The physiological and psychological bases of thermal comfort have been studied for many years now; however, few benchmarks or standard procedures for evaluating a building's thermal performance can be found.

Thermal comfort has largely been studied in controlled laboratory experiments which often do not represent realistic building environments. Due to this reason,

over the past couple of decades, many research projects involved taking measurements of physical environment in occupied buildings and analyzing such data.

Most high performance buildings aim to improve occupant comfort while reducing the energy use associated with indoor environmental conditioning.

*ASHRAE Standard 55: Thermal Environmental conditions for Human Occupancy* (ASHRAE 2004), relates to thermal comfort. The standard specifies the warm and cool temperature limits for the thermal comfort as affected by four environmental parameters, namely, air temperature, radiant temperature, humidity and air movement and two personal variables, namely; clothing insulation and metabolic activity level (Figure B1.1).

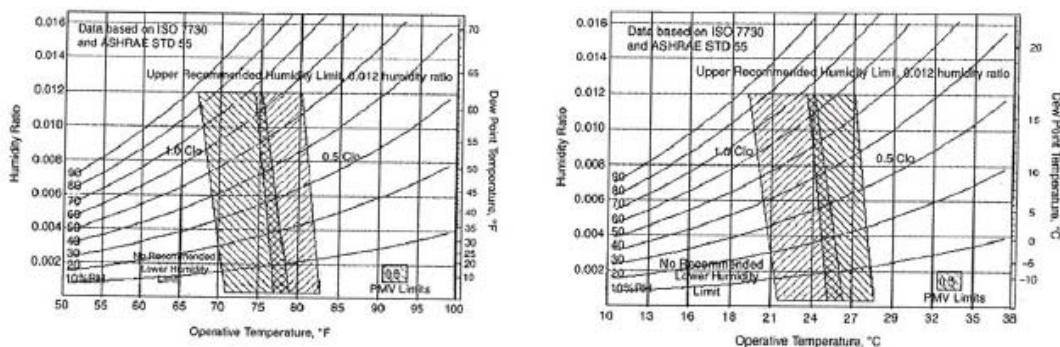


Figure B1.1 ASHRAE Standard 55 Comfort Zone (Source: ASHRAE 2004)

Recently, there have been a number of field studies in office buildings and schools in which the occupants' surveyed comfort responses were matched with simultaneous laboratory-grade measurements of their nearby thermal environment (Leaman and Bordass, 2006). Other occupant surveys use questionnaires alone to directly measure occupant satisfaction with the quality of the indoor environment, and to address the specific causes of discomfort in real building environments.

**b. Thermal Comfort Measurement Protocols: Basic, Intermediate & Advanced**

The measurement protocol adopted for evaluating the performance of any indoor environment is based on the complexity of the environment. Conventional and uniform environments and occupancies can be adequately evaluated by basic level techniques, while non-uniform environments and unusual occupancies may need evaluation at the advanced level.

In the basic level, physical measurements of thermal conditions are optional and are often employed only to discover the causes of problems that may have been identified by occupant surveys. Under this level, the instruments used are generally hand-held readout instruments, e.g., portable thermometer (temperature), Electric or sling psychrometer (humidity), globe thermometer (MRT), IR gun (surface temperature), shortwave-spectrum pyranometer (solar gain), handheld anemometer (air speed), smoke tube/ chalk dust puffer (airflow), etc.

The intermediate level protocol involves monitoring the physical environment and concurrent 'right-now' occupant perceptions of the thermal environment. This type of monitoring is used for comfort prediction, commissioning and controlling environmental control systems and for identifying and correcting faults more precisely than the basic level. The methods and tools adopted under this category are: background data, 'right-now' subjective surveys and actual physical data collection ranging from something as simple as reading the thermostat to detailed workstation sensing.

The advanced level covers detailed quantification of complex comfort environments and environmental control systems affecting the occupants. Numerous measurement and analysis approaches can be adopted under this

performance measurement category. Such detailed measurements may impose upon the occupants or disrupt normal work. The method can be used for the analysis of asymmetrical environments (temperature stratification, radiant heating and cooling systems, solar radiation impacts on occupants through fenestration etc.) and transient environments (occupant experience in a series of different environments when moving, as in transit stations, etc.).

Usually an indoor climate monitoring station is installed on the occupant desk. It measures temperature, mean radiant temperature, relative humidity, nearly omnidirectional air speed, plane radiant temperature, etc. Solar pathfinder, fish eye camera are used for predicting annual sunpaths at a given point indoors. Heated object sensor can emulate the human body's heat transfer via radiation and convection. Vertical temperature profiles are measured using sensor string and moving sensor arm and surface temperatures can be measured with an IR spot meter and imaging. Air speed (omni-directional, directional, turbulence, wave form fluctuating flow) can be measured using various types of anemometers.

*Source: Performance Measurement Protocols for Commercial Buildings  
(ASHRAE 2010)*

## **B1.2. Indoor Air Quality (IAQ)**

### **a. Background**

Good Indoor Air Quality (IAQ) requires the control of contaminants in the air supply. These contaminants may come from outside or from sources within the building, e.g. equipment, activities, people and materials. The commonly followed strategies to control the contamination of inside air include: general ventilation, local exhaust ventilation, filtration, isolation or capture. In the context of measurement of IAQ performance, two aspects need to be considered: health

impacts of IAQ and the comfort or perceived IAQ (*Indoor Air Quality Guide: Best Practices for Design, Construction, Commissioning* (ASHRAE 2009b)). The basic and intermediate levels of performance measurement of IAQ focus on “perceived” IAQ. Three fundamental characteristics are assessed while measuring the IAQ performance. These are: building system characteristics (HVAC characteristics), environmental factors (thermal conditions, presence of contaminants, acoustics and illumination) and occupant perception (ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*).

**b. IAQ Measurement Protocols: Basic, Intermediate & Advanced**

Basic measurements of IAQ are used to obtain information about the building, its environment, and the occupant responses to the environment. The measurements determine the quality of air at the project site methods such as testing the quality of air on site, conducting facility pre-evaluations and surveys-review of complaint logs and similar unstructured reports. Previous occupant surveys can be used as the starting point for IAQ performance evaluation, reviewing operational documentation of the facility and site assessment to evaluate the condition of the building systems (HVAC, mechanical equipment, OA damper operation, HVAC distribution system, coil cleanliness, filter specifications etc.). Occupant surveys are often used to determine occupant satisfaction with IAQ. Surveys include questions regarding the perceptions of fresh air, stuffiness, presence of odors, temperature/humidity adequacy etc. In order to ensure compliance with ASHRAE Standard 62.1, ventilation rates should be measured at the OA intake to each HVAC fan system.

If combustion sources are present in or near the building, Carbon dioxide concentrations should be measured in occupied spaces and compared with the EPA ambient air levels (EPA, 2008b).

Intermediate measurements are conducted to present a level of IAQ evaluations that give a higher level of confidence regarding the quality of indoor air. In addition to the tools specified for the basic level, the intermediate level uses additional analysis to obtain information about the building, its indoor environment and the occupant responses to that environment. The building site and the immediate surroundings are surveyed for local contaminants that may be of concern if allowed to enter the building. Smoke tests and differential pressure measurements are carried out to evaluate airflow patterns and duct leakages that might have occurred. Potential contaminant sources are analyzed and evaluated. This level also aims at measuring the OA flow rates and building pressure differential to confirm that the exhaust ducts are at negative pressure to avoid cross contamination.

The advanced measurements are for the purpose of pollutant identification and source control. This is helpful in establishing the baseline and long-term measurements for pollutants and also helps identify the events that might need investigation and/or corrective action. In addition to the intermediate level measurements, the advanced measurements report baseline and continuously measured carbon dioxide concentrations, fine particulates, and TVOC's as well as look at any corrective action that may be required to be taken.

*Source: Performance Measurement Protocols for Commercial Buildings  
(ASHRAE 2010)*

### **B1.3. Lighting/ Daylighting**

#### **a. Background**

Lighting/ Daylighting has a very crucial role to play in the quality of the built environment. The right amount of lighting can improve worker productivity, enhance aesthetic appeal of the space, improve tenant retention, increase retail sales, facilitate education and create the desired mood for visitors. Lighting quality is defined as the degree to which luminous environment supports the visual performance, social interaction & communication, health & safety and aesthetic judgment of the occupants of a space (*IESNA Lighting Handbook*).

#### **b. Lighting/ Daylighting Measurement Protocols: Basic, Intermediate & Advanced**

Basic measurements of the Lighting/Daylighting in the building are used to determine the building occupant satisfaction with the lighting, comparing it against benchmarks and identifying problems. Spot measurements of the important photometric parameters are taken to assess the light quality in space. The methods adopted generally include: occupant surveys (Center for the Built Environment, CBE, has developed the Occupant Surveys that cover various issues related to the Indoor Environmental Quality). At this level one often takes spot measurements of the illuminance levels in the space and compares them with recommended levels for the particular space. Spot measurements can help the building owner discover areas within the building where the light levels are not appropriate for the tasks being performed.

The goal of the intermediate methods is quite similar to the basic measurements but a greater resolution is sought. The problems identified at the basic level are diagnosed and solutions are developed. The parameters measured and



calculated include: Illuminance, luminance and luminance ratios and discomfort glare. Unlike the spot measurements taken at the basic level, the intermediate level requires the use of a regular grid of measurement points is used to completely cover the surface under consideration. Typically, the spacing between measurement points is set to one-fourth the spacing between luminaires. The height of the points depends on where the primary task is performed. In addition to actual measurements, occupant surveys can be used to evaluate the day-to-day satisfaction of the building's regular users with the lighting systems. The survey generally deals with both lighting as well as daylighting.

The advanced level protocol is intended to provide high-resolution data gathering for lighting-critical situations. The metrics mentioned in the intermediate level are dealt with in far more detail. The conventional methods, if used, are generally extremely time consuming and laborious. A relatively new technique, HDR photography is now being used as a quick, high-resolution approach to evaluate this issue.

*Source: Performance Measurement Protocols for Commercial Buildings  
(ASHRAE 2010)*

## **B2. Acoustics**

### **a. Background**

Of all the factors studied for performance evaluation of a built environment, acoustic performance can be the cause of greatest dissatisfaction for the space users. Acoustic performance requirements are embodied in the types of activities that the occupants engage in during their time spent in these spaces. The building's acoustical environment is made up of internal sound contributions from

occupant conversations, HVAC equipment, electrical equipment and plumbing systems as well as from external sound penetrating the building envelope.

Numerous acoustic standards are available for the measurement of building elements and mechanical systems. However, there are few standards being mandated for the actual performance of architectural spaces as it relates to human perception and performance. A majority of buildings built in the past few decades have been shown to be acoustically challenged, and often green decisions can lead to bad acoustic results (Jensen and Arens, 2005; Salter and Waldeck, 2006; Abbaszadeh et al., 2006). Many green design guidelines and rating systems have now begun address acoustic design needs for high performance buildings.

**b. Acoustics Measurement Protocols: Basic, Intermediate & Advanced**

Basic measurements help assess the acoustic annoyance that may affect the study and work performance in an environment. The basic methods of evaluating the acoustic performance of commercial buildings include occupant surveys, survey of the A-weighted sound pressure level that can help determine the background noise in the room.

The acoustic measurements should be conducted with the room vacated by its normal occupants. All the non-HVAC related equipment (computers/radios etc.) should be turned off for the duration of the measurements. If possible the measurement should be conducted with the system operating at full capacity, i.e. maximum cooling for VAV system. In cases when there is intruding noise from outside sources, testing should be scheduled during time periods when these sounds are at maximum. If windows are designed to be opened for ventilation, measurements are to be taken with and without windows open.

The intermediate level looks at accurate assessment of the background noise and reverberation time in a room. The objective is to assess acoustic annoyance that would affect study and work performance as well as speech and telephone communication, listening conditions and privacy. These measurements should be conducted by an acoustical consultant or personnel with training in acoustic testing. The procedure requires measurement of background noise in octave bands. Acoustic performance criteria vary from room to room and are based on the type of activities that occupants engage in during their time spent in these spaces. The overall result is that any commercial building will typically have some spaces that are acceptable and others that are not acceptable. If more than 90% of the room background noise measurements are found to be acceptable, then the building may be considered acceptable.

The buildings that claim to meet high levels of acoustic performance require a much higher level of proof of achieving those goals. This level of evaluating acoustic performance has to be performed by experienced acoustical consultants. Advanced measurements provide accurate assessment of speech privacy, speech communication and isolation from intruding noise. The instrumentation of the Intermediate level fulfill most of the requirements of the advanced level.

Sound isolation or acoustic privacy can be differentiated into two categories: freedom from intrusive noise, such as outside traffic, telephones ringing, footsteps on the floor above, and speech privacy, or freedom from being overheard and from over hearing others. The acoustical performance of many building elements such as walls, windows, and doors are initially evaluated by manufacturers in acoustical laboratories.

### **B3. Water Use**

#### **a. Background**

The rising shortage of quality potable water supplies all over the globe has resulted in an increased interest in water conservation strategies. Building owners and operators are beginning to actively monitor and control the water use in their buildings to conserve water reserves in their regions. Potable water requires a great deal of energy use for its treatment, pumping and transport. Similarly, waste water also requires energy for transport and treatment. Conserving water can thus benefit in two ways, save water as well as save energy.

#### **Water-Use Measurement Protocols: Basic, Intermediate & Advanced**

The objective of 'Basic' measurements is to determine the periodic and annual total water use and cost delivered from the utility and used on the building site. The lowest cost and easiest method of measuring total water usage is to use utility water meter data shown on the building's water utility bill. The basic level simply measures the volume of water metered at the site and its cost on monthly and annual basis.

In addition to tracking monthly and annual site water use, the intermediate measurement level segregates the use and cost into the portion that enters the wastewater system and that which does not. In addition to all measurements in the basic level, the intermediate measurement provides improved feedback since water usage from each flow stream is determined. This level uses the utility water meter and a separate landscape water meter.

Based in the utility bills and landscape meter readings, water saving strategies for each flow can be determined and then evaluated in the next billing cycle.

The objective of advanced level measurements is to measure as many separate water-using components as possible to better determine usage patterns of the total site water use. The following water meters can be used: Main utility water meter, landscape water use, HVAC equipment water use (cooling tower, boilers), water use for swimming pools & water features, kitchen water use, hot water use, water use for process investment, recycled gray water use, etc. The measured values are compared and evaluated over time to determine if the water saving strategies adopted are effective or not.

*Source: Performance Measurement Protocols for Commercial Buildings*

*(ASHRAE 2010)*

APPENDIX C  
ANALYSIS DATA

**C1. Regression Models for the MCP Approach**

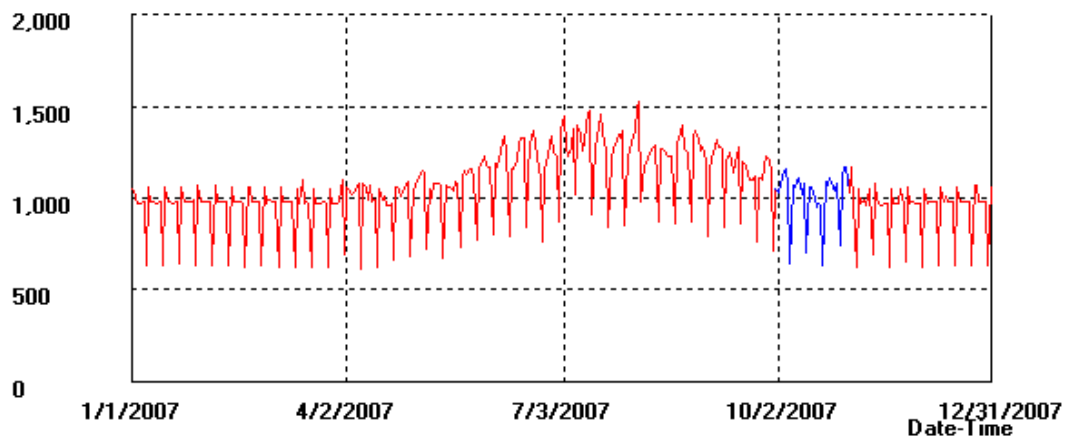
(Refer to Section 6.3 and Sections 7.6.1, 7.6.2 and 7.6.3)

The analysis technique employed in the MCP Approach is to predict whole building Electric (WBE), cooling energy use (CHW), and heating energy use (HW) using multiple linear regression (MCP) models derived from the short data sets. The MCP models for the three energy-use channels are generated using daily averages for outdoor dry bulb temperature (DBT) and lighting & equipment load (LTEQ) as the regressors using Energy Explorer software. The models and plots obtained for the three buildings used for analysis are given in the following sections.

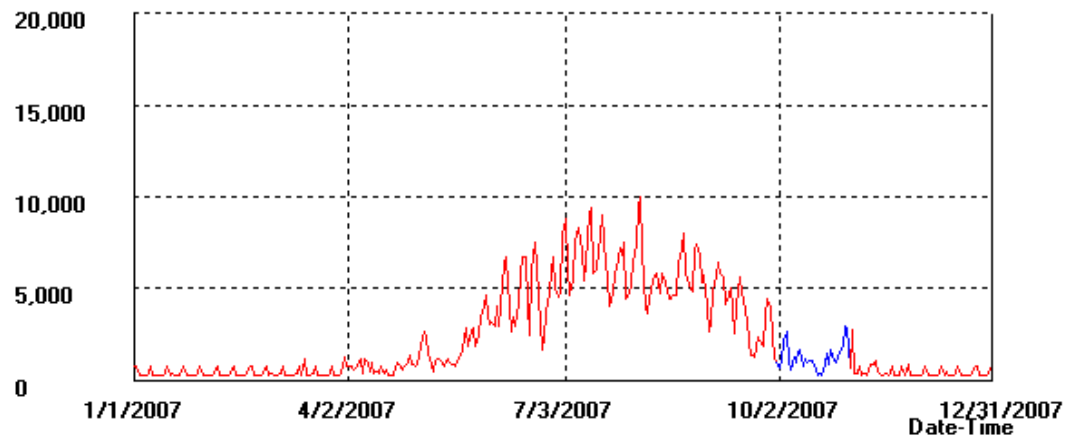
**C1.1. Large Hotel at Chicago, Illinois**

**a. Time Series and Scatter Plots**

Figures C1.1.1 to C1.1.6 are examples of the time series plots for the three energy channels. The blue portion on the graphs represents the short data-set used to estimate the energy use over the whole year represented by the red portion on the graphs. The time-series graphs were plotted for each of all the base periods shown in Table C1.1.1 Typical examples for the three energy channels; WBE, HW and CHW are shown below.



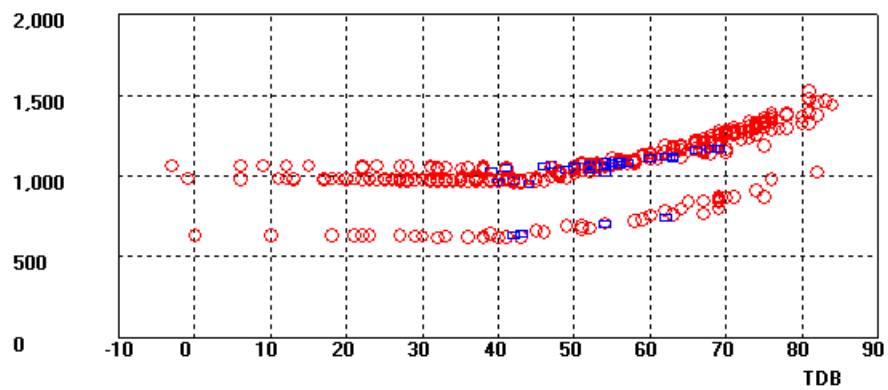
Set for the Large Hotel, Chicago, IL





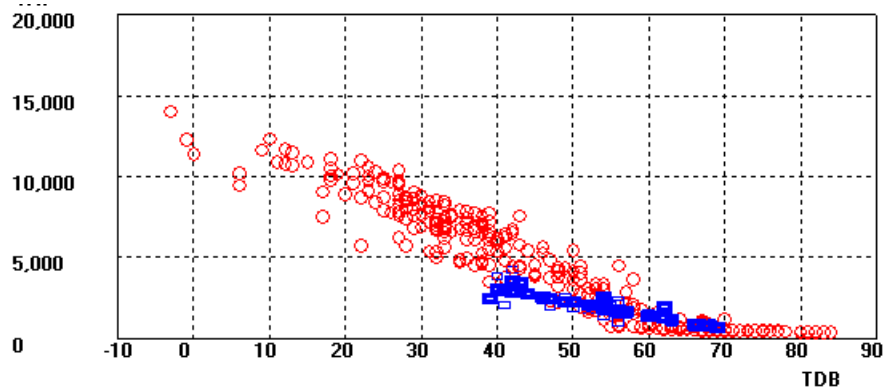
*FigureC1.1.3* Time Series Plots for HW from Month of October Used as the Short Data-Set for the Large Hotel, Chicago, IL

Examples of the scatter plots of the MCP models for the three energy channels for Large Hotel, Chicago, IL are shown in Figure C1.1.4 to C1.1.6.



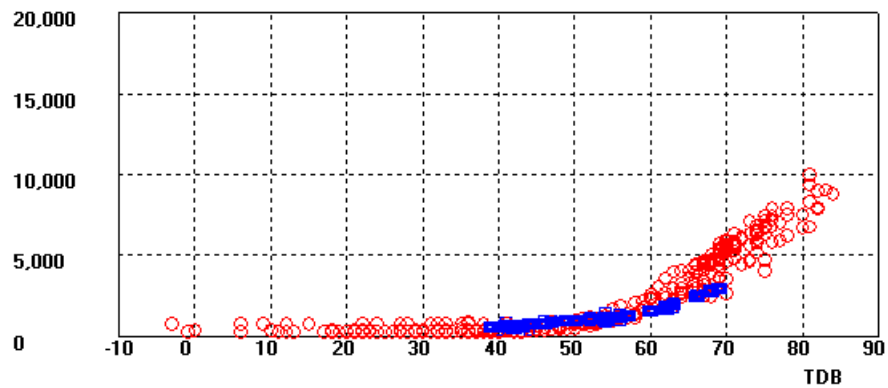
*FigureC1.1.4* MCP Scatter Plot for WBE versus DBT & LTEQ from Month of October Used as the Short Data-Set. Building: Large Hotel, Chicago, IL





FigureC1.1.5 MCP Scatter Plot for CHW versus DBT & LTEQ from Month of October

Used as the Short Data-Set. Building: Large Hotel, Chicago, IL



FigureC1.1.6 MCP Scatter Plot for HW versus DBT & LTEQ from Month of October Used

as the Short Data-Set. Building: Large Hotel, Chicago, IL

The blue points on the graphs represent the baseline data used to identify the model and the red points indicate the whole year data. The scatter graphs shown above were plotted for each of all the base periods shown in Table C1.1.

## b. Multivariate Change Point Models

Table C1.1.1

*MCP Models for all Base Periods and Energy Channels for Large Hotel at Chicago, IL.*

S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R <sup>2</sup>	RMSE	CV-RMSE
1	January	WBE	$WBE = 62.32 - 16.64(0.88 - DBT) + + -0.49 (DBT - 0.88) + + 1.01LTEQ$	0.95	30.46	3.21%
		CHW	$CHW = 405.01 - 113.21(0.83 - DBT) + + -3.27(DBT - 0.83) + + 0.09LTEQ$	0.04	200.89	50.06%
		HW	$HW = 9737.36 - 159.06(28 - DBT) + + -97.76(DBT - 28) + + -2.65LTEQ$	0.73	1147.36	13.94%
2	Jan-Feb	WBE	$WBE = 63.67 - 0.40 (38.01 - DBT) + + -3.56 (DBT - 38.01) + + 1.00 LTEQ$	0.95	29.28	3.10%
		CHW	$CHW = 416.93 - 2.60(38.01 - DBT) + + -23.15(DBT - 38.01) + + 0.03LTEQ$	0.03	193.17	48.69%
		HW	$HW = 13295.80 - 36.12(12 - DBT) + + -148.66(DBT - 12.00) + + -2.96 LTEQ$	0.68	1076.05	12.57%
3	Jan-March	WBE	$WBE = 53.83 - 0.18(46.01 - DBT) + + 8.74(DBT - 46.01) + + 1.01LTEQ$	0.95	27.92	2.95%
		CHW	$CHW = 358.29 - 1.18(48.02 - DBT) + + 87.61(DBT - 48.02) + + 0.06LTEQ$	0.31	184.43	45.33%
		HW	$HW = 13055.24 - 42.07(11.99 - DBT) + + -150.09(DBT - 11.99) + + -2.74LTEQ$	0.76	900.78	11.18%
4	Jan-April	WBE	$WBE = 60.98 - 0.31(44.68 - DBT) + + 7.73(DBT - 44.68) + + 1.01 LTEQ$	0.96	26.8	2.83%
		CHW	$CHW = 408.18 - 2.29(45.88 - DBT) + + 71.21(DBT - 45.88) + + 0.04 LTEQ$	0.55	178.41	37.27%
		HW	$HW = 12600.07 - 17.61(13.01 - DBT) + + -186.53(DBT - 13.01) + + -1.92LTEQ$	0.85	945.46	13.44%
5	Jan-May	WBE	$WBE = 55.69 - 0.31(44.07 - DBT) + + 7.40(DBT - 44.07) + + 1.01LTEQ$	0.97	25.46	2.62%
		CHW	$CHW = 606.37 - 9.73(53.40 - DBT) + + 164.63(DBT - 53.40) + + 0.07LTEQ$	0.91	233.52	30.82%
		HW	$HW = 12423.68 - 16.97(13.55 - DBT) + + -197.34(DBT - 13.55) + + -1.71 LTEQ$	0.91	975.86	16.60%
6	Jan-June	WBE	$WBE = 48.04 - 0.32 (46 - DBT) + + 9.50(DBT - 46) + + 1.02 LTEQ$	0.97	28.05	2.78%
		CHW	$CHW = 512.93 - 11.79(55.53 - DBT) + + 243.90(DBT - 55.53) + + 0.27LTEQ$	0.95	402.62	28.91%
		HW	$HW = 1733.56 - 197.87(64.65 - DBT) + + -15.03(DBT - 64.65) + + -1.21 LTEQ$	0.93	941.6	18.87%
7	Jan-July	WBE	$WBE = 43.26 - 0.50(48.37 - DBT) + + 11.47(DBT - 48.37) + + 1.03LTEQ$	0.97	32.2	3.08%
		CHW	$CHW = 372.60 - 12.74(56.41 - DBT) + + 289.69(DBT - 56.41) + + 0.47LTEQ$	0.96	529.03	24.66%
		HW	$HW = 1497.93 - 197.81(64.99 - DBT) + + -13.50(DBT - 64.99) + + -1.01 LTEQ$	0.94	870.73	20.13%
8	Jan-August	WBE	$WBE = 36.17 - 0.49(48.67 - DBT) + + 12.07(DBT - 48.67) + + 1.04LTEQ$	0.97	33.32	3.12%
		CHW	$CHW = 131.31 - 11.62(55.70 - DBT) + + 294.97(DBT - 55.70) + + 0.70LTEQ$	0.95	575.32	21.88%
		HW	$HW = 1390.06 - 198.54(64.98 - DBT) + + -12.53(DBT - 64.98) + + -0.92LTEQ$	0.95	814.58	21.24%
9	Jan-Sept	WBE	$WBE = 37.25 - 0.50(48.50 - DBT) + + 11.97(DBT - 48.50) + + 1.04LTEQ$	0.97	31.94	2.97%
		CHW	$CHW = 151.97 - 12.34(55.24 - DBT) + + 287.17(DBT - 55.24) + + 0.69LTEQ$	0.95	565.96	20.67%
		HW	$HW = 1293.82 - 205.25(63.57 - DBT) + + -14.24(DBT - 63.57) + + -0.77LTEQ$	0.95	801.18	23.01%
10	Jan-October	WBE	$WBE = 47.04 - 0.75(49.17 - DBT) + + 11.91(DBT - 49.17) + + 1.04LTEQ$	0.97	32.96	3.08%
		CHW	$CHW = 378.42 - 17.12(56.55 - DBT) + + 298.21(DBT - 56.55) + + 0.62 LTEQ$	0.95	576.21	22.29%
		HW	$HW = 1422.18 - 209.42(61.80 - DBT) + + -21.34(DBT - 61.80) + + -0.78 LTEQ$	0.94	860.6	25.83%
11	Jan-Nov	WBE	$WBE = 52.38 - 0.81(49.20 - DBT) + + 11.89(DBT - 49.20) + + 1.03LTEQ$	0.97	32.86	3.10%
		CHW	$CHW = 415.18 - 17.08(56.53 - DBT) + + 298.84 (DBT - 56.53) + + 0.55LTEQ$	0.95	559.22	23.28%
		HW	$HW = 1455.89 - 205.88(62.22 - DBT) + + -17.57(DBT - 62.22) + + -0.88LTEQ$	0.93	868.49	24.90%
12	Jan-Dec	WBE	$WBE = 45.68 - 0.45(48.49 - DBT) + + 11.82(DBT - 48.49) + + 1.03LTEQ$	0.97	32.73	3.12%

S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R^2	RMSE	CV-RMSE
		CHW	CHW = 398.55 - 14.96(56.39 - DBT)+ +298.98(DBT-56.39)+ + 0.52LTEQ	0.95	541.41	24.25%
		HW	HW = 1580.05 - 209.93(62.39 - DBT)+ + -17.34(DBT - 62.39)++1.02 LTEQ	0.94	899.5	22.81%
13	February	WBE	WBE= 112.52 - 2.10(38 - DBT)+ + -9.52(DBT - 38)+ + 0.97LTEQ	0.97	26.47	280.00%
		CHW	CHW = 741.62 - 13.91(38 - DBT)+ + -62.32(DBT - 38)+ + -0.19LTEQ	0.25	174.37	44.51%
		HW	HW = 12109.92 - 65.36(24 - DBT)+ + -186.31(DBT - 24)+ + -2.51LTEQ	0.94	375.19	4.21%
14	Feb-March	WBE	WBE= 64.09 - 0.78(46 - DBT)+ + 8.04(DBT - 46)+ + 1.01LTEQ	0.96	26.59	2.81%
		CHW	CHW= 441.43 - 5.24(48.74 - DBT)+ + 87.56(DBT - 48.74)+ + 0.04LTEQ	0.45	175.68	42.86%
		HW	HW= 9017.01 - -177.59(35.99 - DBT)+ + -137.62(DBT - 35.99)+ + -2.16LTEQ	0.88	580.99	7.30%
15	Feb-April	WBE	WBE= 69.12 - 0.93(45.99-DBT)+ + 7.99(DBT - 45.99)+ + 1.01LTEQ	0.97	25.43	2.67%
		CHW	CHW= 448.88 - 5.72(46.04 - DBT)+ + 67.49(DBT-46.04)+ + 0.03 LTEQ	0.65	169.39	33.49%
		HW	HW= 4579.66 - -213(52.17 - DBT)+ + 5.08(DBT - 52.17)+ + -1.47LTEQ	0.9	764.17	11.55%
16	Feb-May	WBE	WBE= 62.68 - 0.94(45.10 -DBT)+ + 7.39(DBT - 45.10)+ + 1.01LTEQ	0.97	23.93	2.44%
		CHW	CHW= 682.40 - 15.57 (54.32 - DBT)+ + 168.45(DBT-54.32)+ +0.11LTEQ	0.93	228.6	26.90%
		HW	HW= 3373.74 - -228(54.99 - DBT)+ + - 115.04(DBT - 54.99)++ -1.23LTEQ	0.93	814.97	15.46%
17	Feb-June	WBE	WBE= 56.08 - 1.02(47.31 - DBT)+ + 9.59(DBT - 47.31)+ + 1.02LTEQ	0.97	27.51	2.70%
		CHW	CHW= 611.06 - 18.53(56.33 - DBT)+ + 247.93(DBT - 56.33)+ + 0.31LTEQ	0.95	424.8	26.60%
		HW	HW= 1605.63 - -225.96(62.12 - DBT)+ + -16.78(DBT - 62.12)+ + -1LTEQ	0.95	749.72	17.35%
18	Feb-July	WBE	WBE= 48.44 - 1.07(49.09 - DBT)+ + 11.46(DBT - 49.09)+ + 1.04LTEQ	0.97	32.34	3.05%
		CHW	CHW= 403.33 - 18.41(56.74 - DBT)+ + 289.48(DBT - 56.74)+ + 0.55LTEQ	0.95	560.77	22.95%
		HW	HW= 1393.27 - -225.90(62.36 - DBT)++16.12(DBT-62.36)++0.82LTEQ	0.96	683.31	18.68%
19	Feb-August	WBE	WBE= 72.79 - 2.10(53.47 - DBT)+ + 13.12(DBT - 53.47)+ + 1.04LTEQ	0.97	33.52	3.08%
		CHW	CHW= 186.73 - 18.34(56.28)+ +297.42(DBT - 56.28)+ + 0.79LTEQ	0.95	606.49	20.53%
		HW	HW= 1282.39 - -226.05(62.47-DBT)+ + -14.99(DBT-62.47)++-0.72LTEQ	-0.96	631.55	19.79%
20	Feb-Sept	WBE	WBE= 42.58 - 1.06(49.20 - DBT)+ + 11.96(DBT-49.20)+ + 1.04LTEQ	0.97	32	2.93%
		CHW	CHW= 170.21 - 18.20(55.57)+ + 287.03(DBT -55.57)+ + 0.79LTEQ	0.95	592.37	19.51%
		HW	HW= 1186.79 - -232.54(61.61-DBT)+ + -13.93(DBT-61.61)+ + -0.62LTEQ	0.96	619.55	21.57%
21	Feb-October	WBE	WBE= 81.70 - 2.31(53.41-DBT)+ + 12.73(DBT-53.41)+ +1.04LTEQ	0.97	32.68	3.02%
		CHW	CHW= 408.48 - 23.23(56.86 -DBT)++298.13(DBT-56.86)+ +0.69LTEQ	0.95	597.76	21.10%
		HW	HW= 1360.62--236.48(59.68 - DBT)+ + -24.49(DBT-59.68)+ + -0.61LTEQ	0.94	730.75	26.33%
22	Feb-October	WBE	WBE= 83.86 - 2.35(53.33-DBT)+ +12.74(DBT-53.33)++1.03LTEQ	0.97	32.68	3.05%
		CHW	CHW= 455.19 - 23.28(56.84-DBT)++298.74(DBT-56.84)++0.61LTEQ	0.95	577.21	22.14%
		HW	HW= 1473.95- -228.33(59.92 - DBT)+ + -24.36(DBT - 59.92)+ + -0.75LTEQ	0.93	775.21	25.82%
23	Feb-Nov	WBE	WBE= 47.21 - 0.67(48.78 - DBT)+ + 11.81(DBT - 48.78)+ + 1.03LTEQ	0.97	32.94	3.11%
		CHW	CHW= 408.99 - 18.31(56.58 - DBT)+ + 298.87(DBT-56.58)++0.57LTEQ	0.95	558.88	23.26%
		HW	HW= 1604.22 - -228.35(60.44 - DBT)+ + -23.21(DBT-60.44)+ + -0.93LTEQ	0.94	807.68	22.78%
24	Feb-Dec	WBE	WBE = 45.68 - 0.45(48.49 - DBT)+ +11.82(DBT - 48.49)+ +1.03LTEQ	0.97	32.73	3.12%
		CHW	CHW = 398.55 - 14.96(56.39 - DBT)+ +298.98(DBT-56.39)+ + 0.52LTEQ	0.95	541.41	24.25%
		HW	HW = 1580.05 - -209.93(62.39 - DBT)+ + -17.34(DBT - 62.39)++1.02 LTEQ	0.94	899.5	22.81%
25	March	WBE	WBE=69.92 - 1.22(46-DBT)+ + 7.88(DBT-46)++1.0LTEQ	0.97	25.29	2.67%

S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R^2	RMSE	CV-RMSE
		CHW	CHW=490.52-8(48.96-DBT)+87.52(DBT-48.96)+0.01LTEQ	0.64	167.95	39.41%
		HW	HW=10934.76 - 6718.97(23.08-DBT)+137.54(DBT-23.08)+2.53LTEQ	0.9	429.12	6.05%
26	March-April	WBE	WBE=72.27-1.28(46-DBT)+7.76(DBT-46)+1LTEQ	0.97	24.3317	2.54%
		CHW	CHW=470.59-7.81(46.23-DBT)+67.51(DBT-46.23)+0.02LTEQ	0.72	163.47	29.29%
		HW	HW=4509.16 - 207.23(52-DBT)+ 37.46(DBT-52)+1.55LTEQ	0.89	674.01	12.12%
27	March-May	WBE	WBE=64.92-1.40(45.59-DBT)+7.39(DBT-45.59)+1.01LTEQ	0.98	22.65	2.29%
		CHW	CHW=731.44-21.46(54.77-DBT)+168.42(DBT-54.77)+0.14LTEQ	0.93	231.93	23.45%
		HW	HW=3641.24--226.55(52.96-DBT)+117.69(DBT-52.96)+1.23LTEQ	0.92	751.91	18.06%
28	March-June	WBE	WBE=57.76-1.52(47.84-DBT)+9.59(DBT-47.84)+1.03LTEQ	0.98	27.45	2.65%
		CHW	CHW=642.24-25.05(56.66-DBT)+247.71(DBT-56.66)+0.37LTEQ	0.94	457.64	24.42%
		HW	HW=1552.50--218.32(61.96-DBT)+17.07(DBT-61.96)+0.93LTEQ	0.94	684.35	20.95%
29	March-July	WBE	WBE=104.98-3.36(56.38-DBT)+13.14(DBT-56.38)+1.04LTEQ	0.97	32.49	3.00%
		CHW	CHW=447.03-25.79(57.22-DBT)+291.11(DBT-57.22)+0.63LTEQ	0.95	601.44	21.33%
		HW	HW=1324.07--218.23(62.21-DBT)+16.35(DBT-62.21)+0.73LTEQ	0.95	611.81	22.71%
30	March-Aug	WBE	WBE=88.80-3.2(55.49-DBT)+13.46(DBT-55.49)+1.05LTEQ	0.97	33.71	3.04%
		CHW	CHW=168.17-24.66(56.54-DBT)+297.07(DBT-56.54)+0.90LTEQ	0.95	643.89	19.25%
		HW	HW=1212.95--218.48(62.32-DBT)+15.30(DBT-62.32)+0.64LTEQ	0.95	557.95	24.04%
31	March-Sept	WBE	WBE=79.70-2.92(53.56-DBT)+12.71(DBT-53.56)+1.04LTEQ	0.97	32.24	2.90%
		CHW	CHW=266.77-28.34(56.40-DBT)+291.16(DBT-56.40)+0.87LTEQ	0.94	623.01	18.42%
		HW	HW=1124.96--226.68(61.36-DBT)+14.30(DBT-61.36)+0.54LTEQ	0.95	548.81	26.36%
32	March-Oct	WBE	WBE=110.51-3.75(56.76-DBT)+13.48(DBT-56.76)+1.04LTEQ	0.97	32.48	2.95%
		CHW	CHW=438.45-30.56(57.18-DBT)+298.60(DBT-57.18)+0.76LTEQ	0.94	623.74	20.05%
		HW	HW=1320.76--224.48(59.72-DBT)+24.65(DBT-59.72)+0.56LTEQ	0.92	669.44	32.29%
33	March-Nov	WBE	WBE=111.43-3.71(56.64-DBT)+13.51(DBT-56.64)+1.04LTEQ	0.97	32.49	3.00%
		CHW	CHW=498.22-30.23(57.20-DBT)+299.54(DBT-57.20)+0.67LTEQ	0.94	598.88	21.14%
		HW	HW=1427.75--211.81(60.44-DBT)+23.87(DBT-60.44)+0.71LTEQ	0.92	706.97	29.45%
34	March-Dec	WBE	WBE=44.90-0.59(48.75-DBT)+11.82(DBT-48.75)+1.03LTEQ	0.97	33.4	3.13%
		CHW	CHW=383.92-19.73(56.65-DBT)+298.62(DBT-56.65)+0.63LTEQ	0.95	580.04	22.43%
		HW	HW=1587.84--223.65(60.30-DBT)+23.19(DBT-60.30)+0.90LTEQ	0.94	770.87	25.25%
35	March-Jan	WBE	WBE=43.64-0.37(48.43-DBT)+11.82(DBT-48.43)+1.03LTEQ	0.97	33.11	3.13%
		CHW	CHW=741.62-13.91(38-DBT)+62.32(DBT-38)+0.19LTEQ	0.25	174.37	44.51%
		HW	HW=1587.84--223.65(60.30-DBT)+23.19(DBT-60.30)+0.90LTEQ	0.94	770.87	25.25%
36	March-Feb	WBE	WBE = 45.68 - 0.45(48.49 - DBT)+ 11.82(DBT - 48.49)+ 1.03LTEQ	0.97	32.73	3.12%
		CHW	CHW = 398.55 - 14.96(56.39 - DBT)+ +298.98(DBT-56.39)+ 0.52LTEQ	0.95	541.41	24.25%
		HW	HW = 1580.05 - 209.93(62.39 - DBT)+ +17.34(DBT - 62.39)+1.02 LTEQ	0.94	899.5	22.81%
37	April	WBE	WBE=57.26- 5.62(43-DBT)+ 7.52(DBT-43)+1.0LTEQ	0.98	21.68	2.24%
		CHW	CHW=356.48 - 38.40(43.48-DBT)+64.20(DBT-43.48)+0.02LTEQ	0.73	149.62	21.55%
		HW	HW=6270.93- 393.77(38.74-DBT)+108.13(DBT-38.74)+1.68LTEQ	0.82	442.62	11.14%
38	April-May	WBE	WBE=44.98- 5.07(43-DBT)+7.33(DBT-43)+1.02LTEQ	0.98	20.29	2.00%

S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R^2	RMSE	CV-RMSE
		CHW	CHW=761.70-28.29(55.42-DBT)++170.75(DBT-55.42)+0.20LTEQ	0.93	254.68	19.97%
		HW	HW=2112.62-179.15(62.08-DBT)++-28.39(DBT-62.08)++1.32LTEQ	0.84	625.72	23.42%
39	April-June	WBE	WBE=32.40--2.72(45.67-DBT)++9.46(DBT-45.67)++1.04LTEQ	0.98	27.92	2.61%
		CHW	CHW=686.79-35.23(57.20-DBT)++249.04(DBT-57.20)++0.45LTEQ	0.93	519.15	21.93%
		HW	HW=1480.64-189.46(62.36-DBT)+ +17.44(DBT-62.36)+ + -0.86LTEQ	0.89	550.03	28.04%
40	April-July	WBE	WBE=113.24-4.29(57.45-DBT)+ +13.20(DBT-57.45)++1.04LTEQ	0.97	33.6	3.01%
		CHW	CHW=418.95-34.08(57-DBT)++290.65(DBT-57.48)++0.76LTEQ	0.94	666.82	19.46%
		HW	HW=1230.75--189.33(62.65-DBT)++-16.64(DBT-62.64)++-0.63LTEQ	0.91	476.15	30.21%
41	April-August	WBE	WBE=98.27-4.18(56.81-DBT)++13.61(DBT-56.81)++1.05LTEQ	0.97	34.8	3.05%
		CHW	CHW=92.80-31.39(56.72-DBT)++296.11(DBT-56.72)++1.07LTEQ	0.93	700.04	17.79%
		HW	HW=1123.26-190.41(62.72-DBT)++-15.51(DBT-62.72)++0.54LTEQ	0.91	425.63	31.46%
42	April-Sept	WBE	WBE=108.82-4.73(56.84-DBT)++13.22(DBT-56.84)++1.05LTEQ	0.97	33.01	2.90%
		CHW	CHW=251.37-39.76(56.69)++290.23(DBT-56.69)++1LTEQ	0.93	667.01	17.17%
		HW	HW=1058.19--205.06(61.32-DBT)++-14.54(DBT-61.32)++-0.46LTEQ	0.9	428.05	34.74%
43	April-Oct	WBE	WBE=116.11-4.57(57.47-DBT)++13.48(DBT-57.47)++1.05LTEQ	0.97	32.64	2.91%
		CHW	CHW=406.29-38.93(57.35-DBT)++297.77(DBT-57.35)++0.88LTEQ	0.93	650.88	18.58%
		HW	HW=1215.12-164.79(62.48-DBT)++-17.64(DBT-62.48)++-0.61LTEQ	0.84	530.89	39.37%
44	April-Nov	WBE	WBE=114.60-4.13(57.16-DBT)++13.53(DBT-57.16)++1.04LTEQ	0.97	32.97	3.00%
		CHW	CHW=475.51-34.34(57.33-DBT)++299.13(DBT-57.33)++0.75LTEQ	0.94	631.08	20.11%
		HW	HW=1362.88--183.42(61.37-DBT)++-22.06(DBT-61.37)++-0.69LTEQ	0.89	590.78	32.75%
45	April-Dec	WBE	WBE=45.83-0.58(49.23-DBT)++11.88(DBT-49.23)++1.04LTEQ	0.97	34.06	3.15%
		CHW	CHW=332.89-18.86(56.66-DBT)++298.30(DBT-56.66)++0.70LTEQ	0.94	607.66	21.47%
		HW	HW=1593.14--224.41(59.50-DBT)++-24.04(DBT-59.50)++-0.87LTEQ	0.94	734.76	28.29%
46	April-Jan	WBE	WBE=42.82-0.34(48.56-DBT)++11.80(DBT-48.56)++1.03LTEQ	0.97	33.7	3.15%
		CHW	CHW=441.43-5.24(48.74-DBT)++87.56(DBT-48.74)++0.04LTEQ	0.45	175.68	42.68%
		HW	HW=9017.01--177.59(35.99-DBT)++-137.62(DBT-35.99)++-2.16LTEQ	0.88	580.99	7.30%
47	April-Feb	WBE	WBE=69.92-1.22(46-DBT)+ +7.88(DBT-46)++1.0LTEQ	0.97	25.29	2.67%
		CHW	CHW=490.52-8(48.96-DBT)++87.52(DBT-48.96)++0.01LTEQ	0.64	167.95	39.41%
		HW	HW=10934.76-6718.97(23-DBT)++-137.54(DBT-23.08)++-2.53LTEQ	0.9	429.12	6.05%
48	April-March	WBE	WBE=45.68-0.45(48.49-DBT)+ +11.82(DBT-48.49)+ +1.03LTEQ	0.97	32.73	3.12%
		CHW	CHW=398.55-14.96(56.39-DBT)+ +298.98(DBT-56.39)+ +0.52LTEQ	0.95	541.41	24.25%
		HW	HW=1580.05-209.93(62.39-DBT)+ + -17.34(DBT-62.39)++-1.02LTEQ	0.94	899.5	22.81%
49	May	WBE	WBE=60.70--1522.37(47.03-DBT)++7.35(DBT-47.03)++1.03LTEQ	0.99	17.76	1.68%
		CHW	CHW=897.25-39.79(56.69)++175.83(DBT-56.69)++0.23LTEQ	0.92	306.18	16.67%
		HW	HW=2039.29--87.13(65-DBT)++-27.55(DBT-65)++-1.34LTEQ	0.8	297.91	12.12%
50	May-June	WBE	WBE=246.89-8.40(70-DBT)++13.15(DBT-70)++1.04LTEQ	0.97	29.01	2.60%
		CHW	CHW=1415.01-108.14(61.51-DBT)++264.79(DBT-61.51)++0.64LTEQ	0.9	621.06	19.47%
		HW	HW=1253.88--105.70(63.65-DBT)++-19.28(DBT-63.65)++-0.61LTEQ	0.8	297.05	30.59%
51	May-July	WBE	WBE=159.46-7.01(62.10-DBT)++13.70(DBT-62.10)++1.05LTEQ	0.96	34.87	2.99%

S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R^2	RMSE	CV-RMSE
		CHW	CHW=492.33-61.26(58.42-DBT)+291.65(DBT-58.42)+0.96LTEQ	0.9	759.8	17.59%
		HW	HW=971.37--102.39(64.89-DBT)+15.56(DBT-64.89)+0.39LTEQ	0.83	244.99	30.86%
52	May-Aug	WBE	WBE=142.57-7.26(61-DBT)+13.90(DBT-61)+1.06LTEQ	0.96	36.1	3.05%
		CHW	CHW=17.11-47.40(57.19-DBT)+295.60(DBT-57.19)+1.32LTEQ	0.89	773.03	16.36%
		HW	HW=908.61--106.26(64.66-DBT)+14.15(DBT-64.66)+0.35LTEQ	0.83	215.58	30.22%
53	May-Sept	WBE	WBE=198.43-9.09(64.66-DBT)+14.03(DBT-64.66)+1.06LTEQ	0.96	33.28	2.84%
		CHW	CHW=325.61-71.10(57.49-DBT)+289.34(DBT-57.49)+1.20LTEQ	0.9	720.9	15.99%
		HW	HW=938--119.29(62-DBT)+15.14(DBT-62)+0.33LTEQ	0.77	229.07	32.98%
54	May-Oct	WBE	WBE=125.79-4.89(58.55-DBT)+13.55(DBT-58.55)+1.05LTEQ	0.97	33.05	2.88%
		CHW	CHW=360.41-40.55(57.59-DBT)+297.36(DBT-57.59)+1.02LTEQ	0.92	695.23	17.54%
		HW	HW=1070.44--104.50(64.52-DBT)+14.28(DBT-64.52)+0.53LTEQ	0.83	310.34	33.81%
55	May-Nov	WBE	WBE=119.86-4.33(57.76-DBT)+13.52(DBT-57.76)+1.04LTEQ	0.97	33.46	2.99%
		CHW	CHW=452.32-36.17(57.53-DBT)+298.80(DBT-57.53)+0.85LTEQ	0.93	668.27	19.20%
		HW	HW=1386.51--191.54(59.10-DBT)+24.76(DBT-59.10)+0.62LTEQ	0.9	530.11	35.36%
56	May-Dec	WBE	WBE=52.62-1.17(50.52-DBT)+12.19(DBT-50.52)+1.04LTEQ	0.97	34.6	3.15%
		CHW	CHW=375.42-22.68(56.99-DBT)+298.97(DBT-56.99)+0.75LTEQ	0.94	637.31	20.55%
		HW	HW=1704.25--240.55(57.09-DBT)+30.59(DBT-57.09)+0.82LTEQ	0.94	714.86	30.02%
57	May-Jan	WBE	WBE=37.87-0.26(48.68-DBT)+11.99(DBT-48.68)+1.04LTEQ	0.97	33.7	3.15%
		CHW	CHW=322.01-15.28(56.58-DBT)+299.12(DBT-56.58)+0.67LTEQ	0.94	610.33	21.88%
		HW	HW=1662.25-211.03(59.92-DBT)+23.69(DBT-59.92)+0.97LTEQ	0.94	837.68	27.19%
58	May-Feb	WBE	WBE=40.64-0.36(48.73-DBT)+11.99(DBT-48.73)+1.03LTEQ	0.97	33.88	3.17%
		CHW	CHW=360.79-15.07(56.53-DBT)+299.39(DBT-56.53)+0.6LTEQ	0.95	585.3	22.79%
		HW	HW=1657.26--216.47(60.48-DBT)+23.04(DBT-60.48)+0.99LTEQ	0.94	908.04	25.10%
59	May-March	WBE	WBE=41.46-0.36(48.63-DBT)+12.01(DBT-48.63)+1.03LTEQ	0.97	33.22	3.14%
		CHW	CHW=381.86-15.15(56.46-DBT)+299.59(DBT-56.46)+0.55LTEQ	0.95	561.82	23.70%
		HW	HW=1642.54--213.22(61.64-DBT)+20.94(DBT-61.64)+1.03LTEQ	0.94	917.9	23.30%
60	May-April	WBE	WBE = 45.68 - 0.45(48.49 - DBT) + 11.82(DBT - 48.49) + 1.03LTEQ	0.97	32.73	3.12%
		CHW	CHW = 398.55 - 14.96(56.39 - DBT) + 298.98(DBT-56.39) + 0.52LTEQ	0.95	541.41	24.25%
		HW	HW = 1580.05 - 209.93(62.39 - DBT) + -17.34(DBT - 62.39) + 1.02 LTEQ	0.94	899.5	22.81%
61	June	WBE	WBE=187.42-6.84(65-DBT)+9.89(DBT-65)+1.08LTEQ	0.97	28.1	2.38%
		CHW	CHW=1558.08-164.85(64-DBT)+228.11(DBT-64)+1.83LTEQ	0.87	629.97	13.73%
		HW	HW=625.57-15.43(68.70-DBT)+9.21(DBT-68.70)+0.12LTEQ	0.88	32.28	6.25%
62	June-July	WBE	WBE=350.31-10.68(79.84-DBT)+25.55(DBT-79.84)+1.09LTEQ	0.97	32.89	2.70%
		CHW	CHW=5678.70-245.93(80-DBT)+424.17(DBT-80)+2.03LTEQ	0.85	720.52	12.91%
		HW	HW=582.51--16.88(69.72)+8.53(DBT-69.72)+0.11LTEQ	0.9	27.34	5.69%
63	June-Aug	WBE	WBE=343.19-11.30(78-DBT)+19.11(DBT-78)+1.09LTEQ	0.96	33.28	2.71%
		CHW	CHW=1781.17-211.98(64-DBT)+272.04(DBT-64)+2.01LTEQ	0.84	698.01	12.25%
		HW	HW=590.85--16.16(69.59-DBT)+8.70(DBT-69.59)+0.12LTEQ	0.9	24.05	5.03%
64	June-Sept	WBE	WBE=354.35-11.42(77.80-DBT)+19.01(DBT-77.80)+1.08LTEQ	0.97	30.23	2.51%

S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R^2	RMSE	CV-RMSE
		CHW	CHW=-151.67--196.69(56.17-DBT)++273.72(DBT-56.17)++1.74LTEQ	0.89	642.36	12.38%
		HW	HW=821.97--1291.25(54.32-DBT)++-13.96(DBT-54.32)++-0.11LTEQ	0.87	43.09	8.41%
65	June-Oct	WBE	WBE=112.24-4.87(57.49-DBT)++13.10(DBT-57.49)++1.06LTEQ	0.97	31.41	2.70%
		CHW	CHW=152.84-44.41(57-DBT)++288.39(DBT-57)++1.34LTEQ	0.93	646.56	14.70%
		HW	HW=936--108.70(63.86-DBT)++-11.34(DBT-63.86)++0.41LTEQ	0.84	297.15	36.35%
66	June-Nov	WBE	WBE=110.02-4.37(56.86-DBT)++13.20(DBT-56.86)++1.05LTEQ	0.97	32.39	2.87%
		CHW	CHW=287.44-39.04(56.92-DBT)++291.06(DBT-56.92)++1.08LTEQ	0.94	627.85	16.70%
		HW	HW=1204.15--196.67(59.02-DBT)++-21.47(DBT-59.02)++-0.47LTEQ	0.91	543.04	35.86%
67	June-Dec	WBE	WBE=38.89-0.52(49.39-DBT)++12.30(DBT-49.39)++1.04LTEQ	0.97	33.26	3.02%
		CHW	CHW=55.50-16.17(55.43-DBT)++286.98(DBT-55.43)++0.93LTEQ	0.95	598.58	18.29%
		HW	HW=1464.45--234.75(58.47-DBT)++-20.15(DBT-58.47)++-0.78LTEQ	0.94	745.27	28.93%
68	June-Jan	WBE	WBE=33.92-0.16(48.31-DBT)++12.12(DBT-48.31)++1.04LTEQ	0.97	32.85	3.03%
		CHW	CHW=21.90-9.83(54.72-DBT)++283.45(DBT-54.72)++0.80LTEQ	0.96	567.58	19.51%
		HW	HW=1516.14--209.07(60.77-DBT)++-18.62(DBT-60.77)++-0.91LTEQ	0.94	870.92	26.45%
69	June-Feb	WBE	WBE=37.36-0.28(48.40-DBT)++12.13(DBT-48.40)++1.04LTEQ	0.97	32.4	3.03%
		CHW	CHW=74.78-9.60(54.65-DBT)++284.01(DBT-54.65)++0.71LTEQ	0.96	541.68	20.43%
		HW	HW=1530.93--213.41(61.45-DBT)++-18.63(DBT-61.45)++-0.95LTEQ	0.94	939.3	24.28%
70	June-March	WBE	WBE=38.87-0.28(48.35-DBT)++12.16(DBT-48.35)++1.03LTEQ	0.97	31.79	3.01%
		CHW	CHW=110.88-9.27(54.59-DBT)++284.80(DBT-54.59)++0.64LTEQ	0.93	254.68	19.97%
		HW	HW=1457.87--207.92(63.35-DBT)++-10.79(DBT-63.35)++-1.00LTEQ	0.94	940.77	22.41%
71	June-April	WBE	WBE=43.76-0.39(48.19-DBT)++11.95(DBT-48.19)++1.03LTEQ	0.97	31.36	2.99%
		CHW	CHW=198.42-10.55(54.77-DBT)++285.43(DBT-54.77)++0.58LTEQ	0.92	306.18	16.67%
		HW	HW=1446.29--206.18(63.57-DBT)++-10.98(DBT-63.57)++-0.99LTEQ	0.94	917.39	21.96%
72	June-May	WBE	WBE = 45.68 - 0.45(48.49 - DBT)+ +11.82(DBT - 48.49)+ +1.03LTEQ	0.97	32.73	3.12%
		CHW	CHW = 398.55 - 14.96(56.39 - DBT)+ +298.98(DBT-56.39)+ + 0.52LTEQ	0.95	541.41	24.25%
		HW	HW = 1580.05 - 209.93(62.39 - DBT)+ + -17.34(DBT - 62.39)++1.02 LTEQ	0.94	899.5	22.81%
73	July	WBE	WBE = 163.78 - 15.03(67.12 - DBT)+ +13.30(DBT - 67.12)+ +1.16LTEQ	0.99	20.44	1.62%
		CHW	CHW = 1290.92 -- 9144.49(65.10 - DBT)+ +260.56(DBT-65.10)+ + 3.26LTEQ	0.93	417.14	6.38%
		HW	HW = 564.92 - 19.10(69.69 - DBT)+ + -7.80(DBT - 69.69)++0.10 LTEQ	0.91	17.63	3.96%
74	July-August	WBE	WBE = 249.07 - 9.73(71.03 - DBT)+ +15.11(DBT - 71.03)+ +1.11LTEQ	0.98	22.67	1.81%
		CHW	CHW = 6493.50 - 288.34(81.00 - DBT)+ + -4.71(DBT-81.00)+ + 2.47LTEQ	0.93	420.88	6.75%
		HW	HW = 579.34 - -12.90(70.30 - DBT)+ + -8.79(DBT - 70.30)++-0.12 LTEQ	0.93	15.48	3.37%
75	July-Sept	WBE	WBE = 283.92 - 11.59(72 - DBT)+ +15.81(DBT - 72)+ +1.09LTEQ	0.98	22.52	1.86%
		CHW	CHW = -401.06 -- 243.04(56.20 - DBT)+ +290.23(DBT-56.20)+ + 1.99LTEQ	0.94	469.08	8.71%
		HW	HW = 789.02 - -161.75(56.87 - DBT)+ + -13.08(DBT - 56.87)++-0.13 LTEQ	0.9	39.79	7.78%
76	July-October	WBE	WBE = 122.62 - 5.29(59.37 - DBT)+ +14.58(DBT - 59.37)+ +1.07LTEQ	0.98	27.59	2.38%
		CHW	CHW = 70.50 - 41.39(57.36 - DBT)+ +309.79(DBT-57.36)+ + 1.40LTEQ	0.95	568.59	13.10%
		HW	HW = 1004.10 - -106.03(64.47 - DBT)+ + -12.26(DBT - 64.47)++-0.49 LTEQ	0.84	317.96	35.71%
77	July-Nov	WBE	WBE = 105.96 - 4.26(57.46 - DBT)+ +14.45(DBT - 57.46)+ +1.06LTEQ	0.98	29.13	2.60%

S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R^2	RMSE	CV-RMSE
		CHW	CHW = 218.92 - 37.37(57.23 - DBT)+ +311.74(DBT-57.23)+ + 1.14LTEQ	0.96	539.83	15.01%
		HW	HW = 1317.93 - -194.44(59 - DBT)+ + -25.21(DBT - 59)++-0.55 LTEQ	0.91	589.04	34.45%
78	July-Dec	WBE	WBE = 40.42 - 0.65(50.38 - DBT)+ +13.13(DBT - 50.38)+ +1.05LTEQ	0.98	31.26	2.87%
		CHW	CHW = 111.77 - 18.48(56.39 - DBT)+ +312.07(DBT-56.39)+ + 0.95LTEQ	0.96	517.2	16.91%
		HW	HW = 1611.61 - -233.70(58.35 - DBT)+ + -24.21(DBT - 58.35)++-0.88 LTEQ	0.94	800.62	27.49%
79	July-Jan	WBE	WBE = 38.01 - 0.32(49.53 - DBT)+ +12.99(DBT - 49.53)+ +1.04LTEQ	0.98	31.14	2.91%
		CHW	CHW = 47.94 - 10.39(55.31 - DBT)+ +304.40(DBT-55.31)+ + 0.79LTEQ	0.97	489.09	18.28%
		HW	HW = 1649.29 - -207.48(60.88 - DBT)+ + -21.89(DBT - 60.88)++-1.03 LTEQ	0.94	925.24	25.15%
80	July-Feb	WBE	WBE = 41.35 - 0.41(49.57 - DBT)+ +13.00(DBT - 49.57)+ +1.04LTEQ	0.98	30.82	2.92%
		CHW	CHW = 108.75 - 10.15(55.24 - DBT)+ +304.39(DBT-55.24)+ + 0.70LTEQ	0.97	465.44	19.29%
		HW	HW = 1662.82 - -211.59(61.61 - DBT)+ + -22.03(DBT - 61.61)++-1.06 LTEQ	0.93	990.5	23.13%
81	July-March	WBE	WBE = 42.62 - 0.41(49.46 - DBT)+ +13.02(DBT - 49.46)+ +1.03LTEQ	0.98	30.3	2.91%
		CHW	CHW = 146.65 - 9.84(55.17 - DBT)+ +304.84(DBT-55.17)+ + 0.62LTEQ	0.97	444.07	20.30%
		HW	HW = 1570.58 - -206.18(63.59 - DBT)+ + -13.09(DBT - 63.59)++-1.11 LTEQ	0.93	983.88	21.38%
82	July-April	WBE	WBE = 44.74 - 0.39(48.56 - DBT)+ +12.51(DBT - 48.56)+ +1.03LTEQ	0.97	30.06	2.90%
		CHW	CHW = 229.29 - 10.94(55.29 - DBT)+ +305.08(DBT-55.29)+ + 0.57LTEQ	0.97	426.78	20.92%
		HW	HW = 1544.47 - -204.60(63.80 - DBT)+ + -12.97(DBT - 63.80)++-1.09 LTEQ	0.93	954.61	21.03%
83	July-May	WBE	WBE = 46.81 - 0.44(48.80 - DBT)+ +12.26(DBT - 48.80)+ +1.03LTEQ	0.97	32.18	3.10%
		CHW	CHW = 407.88 - 14.53(56.79 - DBT)+ +317.75(DBT-56.79)+ + 0.50LTEQ	0.96	495.81	24.53%
		HW	HW = 1698.79 - -208.76(62.41 - DBT)+ + -20.93(DBT - 62.41)++-1.12 LTEQ	0.93	933.41	21.96%
84	July-June	WBE	WBE = 45.68 - 0.45(48.49 - DBT)+ +11.82(DBT - 48.49)+ +1.03LTEQ	0.97	32.73	3.12%
		CHW	CHW = 398.55 - 14.96(56.39 - DBT)+ +298.98(DBT-56.39)+ + 0.52LTEQ	0.95	541.41	24.25%
		HW	HW = 1580.05 - -209.93(62.39 - DBT)+ + -17.34(DBT - 62.39)++-1.02 LTEQ	0.94	899.5	22.81%
85	August	WBE	WBE =293.83 - 9.76(72.82 - DBT)+ +24.50(DBT - 72.82)+ +1.08LTEQ	0.99	11.91	0.96%
		CHW	CHW = 4300.48 - 237.40(72.28 - DBT)+ +421.14(DBT-72.28)+ + 1.87LTEQ	0.97	259.1	4.36%
		HW	HW = 587.85 - -11.55(70 - DBT)+ + -10.30(DBT - 70)++-0.12 LTEQ	0.95	11.98	2.53%
86	Aug-Sept	WBE	WBE =315.15 - 11.34(73 - DBT)+ +25.41(DBT - 73)+ +1.06LTEQ	0.99	16.51	1.39%
		CHW	CHW = 4857.63 - 268.89(72.62 - DBT)+ +449.19(DBT-72.62)+ + 1.23LTEQ	0.95	411.42	8.58%
		HW	HW = 829.53 - -159.53(56.71 - DBT)+ + -15.11(DBT - 56.71)++-0.14 LTEQ	0.9	43.33	7.98%
87	Aug-October	WBE	WBE =186.60 - 6.43(63.33 - DBT)+ +17.42(DBT - 63.33)+ +1.04LTEQ	0.98	27.66	2.45%
		CHW	CHW = 794.22 - 55.59(59.44 - DBT)+ +348.91(DBT-59.44)+ + 0.88LTEQ	0.94	560.82	15.59%
		HW	HW = 1169.69 - -105.96(64.12 - DBT)+ + -15.59(DBT - 64.12)++-0.64 LTEQ	0.82	367.38	35.31%
88	Aug-Nov	WBE	WBE =139.99 - 4.60(59.66 - DBT)+ +15.95(DBT - 59.6)+ +1.04LTEQ	0.97	29.9	2.76%
		CHW	CHW = 698.31 - 39.88(58.63 - DBT)+ +344.59(DBT-58.63)+ + 0.70LTEQ	0.95	522.82	18.35%
		HW	HW = 1519.58 - -194.07(68.62 - DBT)+ + -31.90(DBT - 58.62)++-0.68 LTEQ	0.9	658.7	32.43%
89	Aug-Dec	WBE	WBE =55.21 - 0.63(50.34 - DBT)+ +13.09(DBT - 50.34)+ +1.03LTEQ	0.97	32.53	3.08%
		CHW	CHW = 452.76 - 18.52(57.40 - DBT)+ +338.79(DBT-57.40)+ + 0.59LTEQ	0.96	497.82	21.15%
		HW	HW = 1855.27 - -233.67(58.00 - DBT)+ + -30.63(DBT - 58.00)++-1.06 LTEQ	0.93	876.99	25.70%
90	Aug-Jan	WBE	WBE =51.87 - 0.32(49.45 - DBT)+ +12.90(DBT - 49.45)+ +1.02LTEQ	0.97	32.13	3.10%



S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R^2	RMSE	CV-RMSE
		CHW	CHW = 464.88 - 13.85(57.13 - DBT)+ +339.19(DBT-57.13)+ + 0.46LTEQ	0.96	468.25	23.13%
		HW	HW = 1880.76 - 207.46(60.50- DBT)+ + -28.92(DBT - 60.50)++-1.20 LTEQ	0.93	999.35	23.66%
91	Aug-Feb	WBE	WBE =53.86 - 0.41(49.48 - DBT)+ +12.90(DBT -49.48)+ +1.02LTEQ	0.97	31.61	3.08%
		CHW	CHW = 500.01 - 13.54(57.06 - DBT)+ +339.25(DBT-57.06)+ + 0.40LTEQ	0.96	442.52	24.46%
		HW	HW = 1879.74 - 211.58(61.23- DBT)+ + -29.84(DBT - 61.23)++-1.21 LTEQ	0.92	1059.69	21.88%
92	Aug-March	WBE	WBE =54.23 - 0.41(49.40 - DBT)+ +12.93(DBT -49.40)+ +1.02LTEQ	0.97	30.92	3.05%
		CHW	CHW = 501.01 - 13.23(56.86 - DBT)+ +336.88(DBT-56.86)+ + 0.35LTEQ	0.96	420.38	25.75%
		HW	HW = 1749.48 - 206.20(63.36- DBT)+ + -17.28(DBT - 63.36)++-1.26 LTEQ	0.92	1044.29	20.35%
93	Aug-April	WBE	WBE =55.21 - 0.39(48.39 - DBT)+ +12.29(DBT -48.39)+ +1.02LTEQ	0.97	30.52	3.02%
		CHW	CHW = 517.52 - 13.40(56.72 - DBT)+ +333.58(DBT-56.72)+ + 0.34LTEQ	0.96	402.82	26.34%
		HW	HW = 1704.24 - 204.63(63.56- DBT)+ + -17.28(DBT - 63.56)++-1.22 LTEQ	0.92	1006.85	20.12%
94	Aug-May	WBE	WBE =55.57 - 0.44(48.39 - DBT)+ +11.72(DBT -48.39)+ +1.02LTEQ	0.96	32.43	3.20%
		CHW	CHW = 641.10 - 15.31(57.48 - DBT)+ +331.38(DBT-57.48)+ + 0.27LTEQ	0.94	479.18	30.70%
		HW	HW = 1928.34 - 209.26(61.93- DBT)+ + -31.89(DBT - 61.73)++-1.24 LTEQ	0.92	978.79	21.10%
95	Aug-June	WBE	WBE =51.16 - 0.39(47.72 - DBT)+ +11.14(DBT -47.72)+ +1.02LTEQ	0.97	32.49	3.16%
		CHW	CHW = 555.70 - 14.98(56.40 - DBT)+ +291.66(DBT-56.40)+ + 0.34LTEQ	0.94	526.79	28.75%
		HW	HW = 1697.66 - 209.94(62.25- DBT)+ + -18.87(DBT - 62.25)++-1.13 LTEQ	0.93	939.66	22.02%
96	Aug-July	WBE	WBE = 45.68 - 0.45(48.49 - DBT)+ +11.82(DBT - 48.49)+ +1.03LTEQ	0.97	32.73	3.12%
		CHW	CHW = 398.55 - 14.96(56.39 - DBT)+ +298.98(DBT-56.39)+ + 0.52LTEQ	0.95	541.41	24.25%
		HW	HW = 1580.05 - 209.93(62.39 - DBT)+ + -17.34(DBT - 62.39)++-1.02 LTEQ	0.94	899.5	22.81%
97	September	WBE	WBE =212.89 - 9.03(63.00 - DBT)+ +12.24(DBT - 63.00)+ +1.03LTEQ	0.99	16.72	1.49%
		CHW	CHW = 579.60 - 53.04(56.52 - DBT)+ +268.25(DBT-56.52)+ + 0.95LTEQ	0.92	435.51	12.04%
		HW	HW = 880.35 - 156.04(56.51 - DBT)+ + -17.38(DBT - 56.51)++-0.16 LTEQ	0.89	56.9	9.22%
98	Sept-Oct	WBE	WBE =141.19 - 4.83(57.15 - DBT)+ +11.82(DBT - 57.15)+ +1.02LTEQ	0.97	27.34	2.56%
		CHW	CHW = 1122.45 - 50.84(58.50 - DBT)+ +291.99(DBT-58.50)+ + 0.36LTEQ	0.89	556.34	23.10%
		HW	HW = 1704.63 - 116.49(59.00 - DBT)+ + -45.13(DBT - 59.00)++-0.76 LTEQ	0.78	444.76	33.49%
99	Sept-Nov	WBE	WBE =107.73 - 3.41(52.57 - DBT)+ +10.77(DBT - 52.57)+ +1.02LTEQ	0.97	29.26	2.84%
		CHW	CHW = 959.88 - 37.00(57.40 - DBT)+ +279.53(DBT-57.40)+ + 0.29LTEQ	0.91	490.97	27.33%
		HW	HW = 1782.90 - 193.99(58.00 - DBT)+ + -40.20(DBT - 58.00)++-0.85LTEQ	0.87	762.52	29.77%
100	Sept-Dec	WBE	WBE =55.54 - 0.01(44.70 - DBT)+ +9.50(DBT - 44.70)+ +1.01LTEQ	0.97	29.81	2.96%
		CHW	CHW = 689.27 - 17.41(55.27 - DBT)+ +258.89(DBT-55.27)+ + 0.20LTEQ	0.92	454.87	31.41%
		HW	HW = 2109.59 - 237.68(57.31 - DBT)+ + -35.94(DBT - 57.31)++-1.24LTEQ	0.91	979.94	24.03%
101	Sept-Jan	WBE	WBE =50.59 - 0.21(44.32 - DBT)+ +9.50(DBT - 44.32)+ +1.01LTEQ	0.96	29.84	3.00%
		CHW	CHW = 498.27 - 6.47(53.38 - DBT)+ +241.19(DBT-53.38)+ + 0.13LTEQ	0.92	422.31	34.29%
		HW	HW = 2239.96 - 207.98(59.42 - DBT)+ + -46.11(DBT - 59.42)++-1.37LTEQ	0.91	1095.17	21.97%
102	Sept-Feb	WBE	WBE =52.17 - 0.02(44.56 - DBT)+ +9.50(DBT - 44.56)+ +1.01LTEQ	0.96	29.64	3.00%
		CHW	CHW = 504.33 - 6.65(53.35 - DBT)+ +241.28(DBT-53.35)+ + 0.12LTEQ	0.92	394.53	35.81%
		HW	HW = 2127.21 - 211.37(60.74 - DBT)+ + -39.76(DBT - 60.74)++-1.37LTEQ	0.9	1146.23	20.50%
103	Sept-March	WBE	WBE =53.76 - 0.04(44.83 - DBT)+ +9.61(DBT - 44.83)+ +1.01LTEQ	0.96	29.11	2.97%

S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R^2	RMSE	CV-RMSE
		CHW	CHW = 505.21 - 6.41(53.36 - DBT)+ +242.92(DBT-53.36)+ + 0.09LTEQ	0.92	371.82	37.07%
		HW	HW = 2027.90 - 206.32(62.65 - DBT)+ + -30.14(DBT - 62.65)++1.42LTEQ	0.9	1117.42	19.22%
104	Sept-April	WBE	WBE =57.55 - 0.11(45.20 - DBT)+ +9.65(DBT - 45.20)+ +1.01LTEQ	0.96	28.54	2.91%
		CHW	CHW = 624.92 - 10.33(54.58 - DBT)+ +257.58(DBT-54.58)+ + 0.09LTEQ	0.91	356.42	36.95%
		HW	HW = 1876.60 - 204.38(63.31 - DBT)+ + -19.66(DBT - 63.31)++1.34LTEQ	0.9	1068.71	19.14%
105	Sept-May	WBE	WBE =54.59 - 0.10(44.65 - DBT)+ +8.88(DBT - 44.65)+ +1.01LTEQ	0.96	28.67	2.90%
		CHW	CHW = 637.15 - 11.38(54.55 - DBT)+ +230.08(DBT-53.36)+ + 0.11LTEQ	0.89	398.89	37.50%
		HW	HW = 2133.29 - 209.26(61.20 - DBT)+ + -39.44(DBT - 61.20)++1.35LTEQ	0.91	1031.53	20.18%
106	Sept-June	WBE	WBE =49.63 - 0.11(45.23 - DBT)+ +9.45(DBT - 45.23)+ +1.02LTEQ	0.97	28.94	2.87%
		CHW	CHW = 518.36 - 11.42(54.57 - DBT)+ +238.40(DBT-54.57)+ + 0.24LTEQ	0.93	432.88	30.64%
		HW	HW = 1873.25 - 210.56(61.70 - DBT)+ + -24.02(DBT - 61.70)++1.22LTEQ	0.92	985.77	21.17%
107	Sept-July	WBE	WBE = 49.21 - 0.39(47.86 - DBT)+ +11.17(DBT - 47.86)+ +1.02LTEQ	0.97	31.66	3.07%
		CHW	CHW = 521.70 - 14.96(56.47 - DBT)+ +287.10(DBT-56.47)+ + 0.38LTEQ	0.95	504.55	26.72%
		HW	HW = 1671.19 - 209.86(62.28 - DBT)+ + -17.98(DBT - 62.28)++1.10 LTEQ	0.93	939.86	22.04%
108	Sept-Aug	WBE	WBE = 45.68 - 0.45(48.49 - DBT)+ +11.82(DBT - 48.49)+ +1.03LTEQ	0.97	32.73	3.12%
		CHW	CHW = 398.55 - 14.96(56.39 - DBT)+ +298.98(DBT-56.39)+ + 0.52LTEQ	0.95	541.41	24.25%
		HW	HW = 1580.05 - 209.93(62.39 - DBT)+ + -17.34(DBT - 62.39)++1.02 LTEQ	0.94	899.5	22.81%
109	October	WBE	WBE = 128.02 - 4.31(57.38 - DBT)+ +7.43(DBT - 57.38)+ +1.03LTEQ	0.97	25.18	2.48%
		CHW	CHW = 843.46 - 38.02(58.61 - DBT)+ +159.93(DBT-58.61)+ + 0.49LTEQ	0.9	231.46	18.71%
		HW	HW = 4917.98 - 19566.40(39.03 - DBT)+ + -81.06(DBT - 39.03)++1.99 LTEQ	0.76	437.89	21.72%
110	Oct-Nov	WBE	WBE = 67.89 - 1.60(43.65 - DBT)+ +6.34(DBT - 43.65)+ +1.01LTEQ	0.96	27.78	2.82%
		CHW	CHW = 879.46 - 32.86(57.99 - DBT)+ +165.11(DBT-57.99)+ + 0.31LTEQ	0.89	233.21	25.89%
		HW	HW = 3573.14 --194.52(52 - DBT)+ + -80.85(DBT - 52)++1.58 LTEQ	0.8	882.84	25.10%
111	Oct-Dec	WBE	WBE = 43.88 - 0.70(39.48 - DBT)+ +6.08(DBT - 39.48)+ +1.01LTEQ	0.96	28.57	2.95%
		CHW	CHW = 280.81 -- 2.45(45.01 - DBT)+ +90.72(DBT-45.01)+ + 0.12LTEQ	0.85	243.36	33.19%
		HW	HW = 3595.40 --232.82(53.81 - DBT)+ + -68.36(DBT - 53.81)++1.91 LTEQ	0.88	1101.91	20.74%
112	Oct-Jan	WBE	WBE = 45.35 - 0.37(40.00 - DBT)+ +6.16(DBT - 40.00)+ +1.01LTEQ	0.96	28.89	3.00%
		CHW	CHW = 288.32 -- 1.43(45.04 - DBT)+ +90.72(DBT-45.04)+ + 0.12LTEQ	0.83	231.26	35.60%
		HW	HW = 3381.42 --201.85(56.99 - DBT)+ + -72.69(DBT - 56.99)++1.88 LTEQ	0.86	1191.79	19.70%
113	Oct-Feb	WBE	WBE = 52.13 - 0.00(42.14 - DBT)+ +6.68(DBT - 42.14)+ +1.01LTEQ	0.96	28.88	3.01%
		CHW	CHW = 307.18 -- 0.18(45.21 - DBT)+ +90.80(DBT-45.21)+ + 0.11LTEQ	0.82	223.76	37.18%
		HW	HW = 10722.87 --133.53(23.11 - DBT)+ + -214.35(DBT - 23.11)++1.79 LTEQ	0.86	1204.27	18.30%
114	Oct-March	WBE	WBE = 54.53 - 0.08(42.79 - DBT)+ +6.92(DBT - 42.79)+ +1.01LTEQ	0.96	28.39	2.96%
		CHW	CHW = 382.54 - 2.24(47.89 - DBT)+ +105.30(DBT-47.89)+ + 0.08LTEQ	0.8	216.62	37.88%
		HW	HW = 10699.01 --133.45(23.28 - DBT)+ + -209.12(DBT - 23.28)++1.78 LTEQ	0.85	1146.47	17.19%
115	Oct-April	WBE	WBE = 57.35 - 0.12(43.27 - DBT)+ +7.00(DBT - 43.27)+ +1.01LTEQ	0.96	27.72	2.89%
		CHW	CHW = 394.41 - 2.46(47.56 - DBT)+ +100.71(DBT-47.89)+ + 0.08LTEQ	0.8	210.87	35.79%
		HW	HW = 10554.93 --135.87(23.01 - DBT)+ + -207.66(DBT - 23.01)++1.62 LTEQ	0.86	1091.16	17.35%
116	Oct-May	WBE	WBE = 54.57 - 0.12(43.25 - DBT)+ +7.12(DBT - 43.25)+ +1.01LTEQ	0.96	26.74	2.75%

S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R^2	RMSE	CV-RMSE
		CHW	CHW = 413.86 - 3.94(49.59 - DBT)+ +128.22(DBT-49.59)+ + 0.10LTEQ	0.88	241.35	32.25%
		HW	HW = 2818.98 --205.34(59.58 - DBT)+ + -67.66(DBT - 59.58)++-1.60 LTEQ	0.89	1069.26	18.87%
117	Oct-June	WBE	WBE = 49.88 - 0.11(45.10 - DBT)+ +9.05(DBT - 45.10)+ +1.02LTEQ	0.97	29.06	2.92%
		CHW	CHW = 634.47 - 13.60(56.64 - DBT)+ +251.89(DBT-56.64)+ + 0.21LTEQ	0.93	382.96	32.72%
		HW	HW = 2028.05 --205.81(62.49 - DBT)+ + -21.62(DBT - 62.49)++-1.40 LTEQ	0.91	1019.85	20.00%
118	Oct-July	WBE	WBE = 51.02 - 0.45(48.28 - DBT)+ +11.25(DBT - 48.28)+ +1.02LTEQ	0.97	32.71	3.20%
		CHW	CHW = 560.42 - 14.21(57.43 - DBT)+ +300.72(DBT-57.43)+ + 0.33LTEQ	0.95	490.93	28.58%
		HW	HW = 1814.85 --205.77(62.82 - DBT)+ + -20.28(DBT - 62.82)++-1.23 LTEQ	0.92	967.92	20.93%
119	Oct-Aug	WBE	WBE = 45.58 - 0.45(48.61 - DBT)+ +11.88(DBT - 48.61)+ +1.03LTEQ	0.97	33.79	3.24%
		CHW	CHW = 377.03 - 13.57(56.77 - DBT)+ +306.66(DBT-56.77)+ + 0.50LTEQ	0.95	541.1072	25.67%
		HW	HW = 1654.01 --205.48(63.26 - DBT)+ + -15.83(DBT - 63.26)++-1.14 LTEQ	0.93	922.78	21.76%
120	Oct-Sept	WBE	WBE = 45.68 - 0.45(48.49 - DBT)+ +11.82(DBT - 48.49)+ +1.03LTEQ	0.97	32.73	3.12%
		CHW	CHW = 398.55 - 14.96(56.39 - DBT)+ +298.98(DBT-56.39)+ + 0.52LTEQ	0.95	541.41	24.25%
		HW	HW = 1580.05 - -209.93(62.39 - DBT)+ + -17.34(DBT - 62.39)++-1.02 LTEQ	0.94	899.5	22.81%
121	November	WBE	WBE = 73.11 - 0.60(44.39 - DBT)+ +7.66(DBT - 44.39)+ +0.99LTEQ	0.95	30.23	3.17%
		CHW	CHW = 722.60 - 12.00(50.36 - DBT)+ +129.27(DBT-50.36)+ + -0.14LTEQ	0.83	204.4	36.96%
		HW	HW = 5447.28 --122.44(46.01 - DBT)+ + -171.85(DBT - 46.01)++-1.23 LTEQ	0.71	802.63	15.83%
122	Nov-Dec	WBE	WBE = 47.75 -- 0.71(43.00 - DBT)+ +7.70(DBT - 43.00)+ +1.01LTEQ	0.96	29.31	3.10%
		CHW	CHW = 416.60 -- 2.44(47.85 - DBT)+ +121.80(DBT-47.85)+ + -0.05LTEQ	0.71	201.78	42.27%
		HW	HW = 8169.40 --218.73(35.99 - DBT)+ + -171.19(DBT - 35.99)++-2.14 LTEQ	0.83	1051.18	15.04%
123	Nov-Jan	WBE	WBE = 47.15 -- 0.40(43.41 - DBT)+ +7.76(DBT - 43.41)+ +1.01LTEQ	0.95	29.34	3.10%
		CHW	CHW = 383.14 -- 1.44(47.89 - DBT)+ +121.49(DBT-47.89)+ + -0.00LTEQ	0.62	198.63	43.97%
		HW	HW = 12777.64 --107.14(12.01 - DBT)+ + -182.33(DBT - 12.01)++-2.29 LTEQ	0.79	1129.88	15.25%
124	Nov-Feb	WBE	WBE = 49.66 -- 0.15(43.83 - DBT)+ +7.75(DBT - 43.83)+ +1.01LTEQ	0.95	29.23	3.09%
		CHW	CHW = 384.47 -- 0.15(48.04 - DBT)+ +121.32(DBT-48.04)+ + -0.02LTEQ	0.57	196.24	44.83%
		HW	HW = 10953.60 --134.61(23.84 - DBT)+ + -194.96(DBT - 23.84)++-2.18 LTEQ	0.77	1114.89	14.37%
125	Nov-March	WBE	WBE = 51.58 -- 0.07(44.36 - DBT)+ +7.95(DBT - 44.36)+ +1.01LTEQ	0.95	28.45	3.01%
		CHW	CHW = 389.28 -0.16(48.32 - DBT)+ +115.01(DBT-48.32)+ + 0.01LTEQ	0.56	192.24	44.16%
		HW	HW = 12698.06 --95.35(12.99 - DBT)+ + -176.84(DBT - 12.99)++-2.16 LTEQ	0.78	1023.9	13.43%
126	Nov-April	WBE	WBE = 55.62 -0.01(44.08 - DBT)+ +7.71(DBT - 44.08)+ +1.01LTEQ	0.96	27.7	2.92%
		CHW	CHW = 387.62 -0.27(46.52 - DBT)+ +91.80(DBT-46.52)+ + 0.02LTEQ	0.61	190.07	39.74%
		HW	HW = 10742.14 --135.49(23.00 - DBT)+ + -195.34(DBT - 23.00)++-1.82 LTEQ	0.83	997.03	14.20%
127	Nov-May	WBE	WBE = 52.10 -0.01(43.68 - DBT)+ +7.48(DBT - 43.68)+ +1.01LTEQ	0.96	26.61	2.76%
		CHW	CHW = 415.50 -2.32(49.52 - DBT)+ +135.42(DBT-49.52)+ + 0.05LTEQ	0.89	225.34	33.29%
		HW	HW = 10634.89 --135.61(23.01 - DBT)+ + -201.04(DBT - 23.01)++-1.70 LTEQ	0.89	1006.09	16.23%
128	Nov-June	WBE	WBE = 47.47 -0.03(45.38 - DBT)+ +9.42(DBT - 45.38)+ +1.02LTEQ	0.97	28.47	2.87%
		CHW	CHW = 506.37 -9.74(55.36 - DBT)+ +244.13(DBT-55.36)+ + 0.21LTEQ	0.94	370.58	31.90%
		HW	HW = 1969.50 --199.53(64.49 - DBT)+ + -15.96(DBT - 64.49)++-1.45 LTEQ	0.92	967.35	17.61%
129	Nov-July	WBE	WBE = 43.32 -0.19(47.56 - DBT)+ +11.31(DBT - 47.56)+ +1.03LTEQ	0.97	31.89	3.12%

S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R^2	RMSE	CV-RMSE
		CHW	CHW = 402.64 -10.69(56.32 - DBT)+ +291.04(DBT-56.32)+ + 0.37LTEQ	0.96	484.11	27.31%
		HW	HW = 1733.41 --199.46(64.88 - DBT)+ + -14.14(DBT - 64.88)++1.27LTEQ	0.94	912.25	18.54%
130	Nov-Aug	WBE	WBE = 39.37 -0.27(48.24 - DBT)+ +11.99(DBT - 48.24)+ +1.03LTEQ	0.97	32.92	3.15%
		CHW	CHW = 202.33 -9.70(55.60 - DBT)+ +296.05(DBT-55.60)+ + 0.56LTEQ	0.96	530.96	24.17%
		HW	HW = 1616.86 --200.05(64.91 - DBT)+ + -12.90(DBT - 64.91)++1.17LTEQ	0.94	865.98	19.38%
131	Nov-Sept	WBE	WBE = 37.37 -0.20(47.77 - DBT)+ +11.82(DBT - 47.77)+ +1.03LTEQ	0.97	31.81	3.02%
		CHW	CHW = 164.54 -9.00(54.77 - DBT)+ +284.61(DBT-54.77)+ + 0.57LTEQ	0.96	527.52	22.69%
		HW	HW = 1518.12 --206.05(63.69 - DBT)+ + -14.08(DBT - 63.69)++1.02LTEQ	0.95	852.58	20.68%
132	Nov-Oct	WBE	WBE = 45.68 - 0.45(48.49 - DBT)+ +11.82(DBT - 48.49)+ +1.03LTEQ	0.97	32.73	3.12%
		CHW	CHW = 398.55 - 14.96(56.39 - DBT)+ +298.98(DBT-56.39)+ + 0.52LTEQ	0.95	541.41	24.25%
		HW	HW = 1580.05 - -209.93(62.39 - DBT)+ + -17.34(DBT - 62.39)++1.02 LTEQ	0.94	899.5	22.81%
133	December	WBE	WBE = 50.44 - -3.81(20.00 - DBT)+ +0.46(DBT - 20.00)+ +1.00LTEQ	0.97	25.3	2.69%
		CHW	CHW = 332.77 -- 25.21(20.00 - DBT)+ +3.01(DBT-20.00)+ + 0.01LTEQ	0.33	166.41	41.18%
		HW	HW = 12140.93 - -193.36(20.00 - DBT)+ + -143.90(DBT - 20.00)++2.63 LTEQ	0.91	573.23	6.48%
134	Dec-Jan	WBE	WBE = 55.01 - -1446.23(-2.97 - DBT)+ +0.34(DBT -- 2.97)+ +1.02LTEQ	0.96	28.72	3.04%
		CHW	CHW = 361.43 -- 28589.32(-2.99 - DBT)+ +2.24(DBT--2.99)+ + 0.11LTEQ	0.08	189.26	47.00%
		HW	HW = 14588.56 - -859.93(-0.37 - DBT)+ + -132.82(DBT -- 0.37)++3.01 LTEQ	0.72	1047.1	12.26%
135	Dec-Feb	WBE	WBE = 48.46 - -734.62(-2.93 - DBT)+ +0.05(DBT -- 2.93)+ +1.01LTEQ	0.95	28.69	3.04%
		CHW	CHW = 317.83 -- 654.12(-2.45 - DBT)+ +0.34(DBT--2.45)+ + 0.10LTEQ	0.05	189.1	47.36%
		HW	HW = 14699.95 - -857.97(-0.81 - DBT)+ + -135.02(DBT -- 0.81)++2.73 LTEQ	0.72	968.65	11.19%
136	Dec-March	WBE	WBE = 43.12 - -0.16(48.68 - DBT)+ +12.13(DBT - 48.68)+ +1.01LTEQ	0.96	28.15	2.98%
		CHW	CHW = 284.51 -- 1.04(49.06 - DBT)+ +103.83(DBT-49.06)+ + 0.10LTEQ	0.25	185.73	45.73%
		HW	HW = 14741.77 - -860.60(-0.97 - DBT)+ + -142.06(DBT -- 0.97)++2.62 LTEQ	0.78	871.24	10.55%
137	Dec-April	WBE	WBE = 52.39 - -0.33(44.20 - DBT)+ +7.76(DBT - 44.20)+ +1.01LTEQ	0.96	27.55	2.90%
		CHW	CHW = 353.54 - 0.17(45.69 - DBT)+ +72.69(DBT-45.69)+ + 0.06LTEQ	0.48	183	39.49%
		HW	HW = 10676.91 - -128.63(25.00 - DBT)+ + -197.84(DBT -25.00)++1.94LTEQ	0.85	936.06	12.64%
138	Dec-May	WBE	WBE = 49.16 - -0.02(43.68 - DBT)+ +7.50(DBT - 43.68)+ +1.01LTEQ	0.97	26.3	2.72%
		CHW	CHW = 351.78 - 1.49(49.38 - DBT)+ +135.79(DBT-49.38)+ + 0.10LTEQ	0.9	228.89	32.82%
		HW	HW = 10524.84 - -128.96(25.00 - DBT)+ + -206.96(DBT -25.00)++1.77LTEQ	0.91	970.14	15.91%
139	Dec-June	WBE	WBE = 43.39 -0.03(45.69 - DBT)+ +9.58(DBT - 45.69)+ +1.02LTEQ	0.97	28.33	2.84%
		CHW	CHW = 400.75 - 8.10(54.64 - DBT)+ +236.94(DBT-54.64)+ + 0.28LTEQ	0.95	383.41	30.72%
		HW	HW = 1888.42 - 200.14(65.16 - DBT)+ + -12.19(DBT -65.16)++1.42LTEQ	0.93	950.5	17.11%
140	Dec-July	WBE	WBE = 36.01 -0.11(47.51 - DBT)+ +11.38(DBT - 47.51)+ +1.03LTEQ	0.97	31.93	3.10%
		CHW	CHW = 348.49 - 10.59(56.23 - DBT)+ +289.79(DBT-56.23)+ + 0.44LTEQ	0.96	502.15	26.11%
		HW	HW = 1675.49 - 200.46(65.28 - DBT)+ + -13.84(DBT -65.28)++1.21LTEQ	0.94	889.25	18.14%
141	Dec-Aug	WBE	WBE = 32.43 -0.21(48.30 - DBT)+ +12.10(DBT - 48.30)+ +1.04LTEQ	0.97	32.98	3.13%
		CHW	CHW = 133.61 - 9.52(55.53 - DBT)+ +295.17(DBT-55.53)+ + 0.64LTEQ	0.96	548.14	23.06%
		HW	HW = 1553.09 - -201.10(65.31 - DBT)+ + -12.19(DBT -65.31)++1.11LTEQ	0.95	839.27	19.07%
142	Dec-Sept	WBE	WBE = 30.35 -0.10(47.69 - DBT)+ +11.88(DBT - 47.69)+ +1.04LTEQ	0.97	31.76	2.99%

S.No.	Base Period	Channel	Large Hotel, Chicago, IL: Model Equations (4P)	R^2	RMSE	CV-RMSE
		CHW	$CHW = 99.60 - 8.75(54.72 - DBT) + +284.18(DBT - 54.72) + +0.64LTEQ$	0.96	542.09	21.69%
		HW	$HW = 1427.84 - 207.17(64.11 - DBT) + + -11.94(DBT - 64.11) + + -0.96LTEQ$	0.95	829.91	20.60%
143	Dec-Oct	WBE	$WBE = 41.07 - 0.41(48.56 - DBT) + +11.88(DBT - 48.56) + +1.03LTEQ$	0.97	32.81	3.10%
		CHW	$CHW = 364.75 - 15.05(56.39 - DBT) + +298.27(DBT - 56.39) + +0.58LTEQ$	0.95	555.88	23.33%
		HW	$HW = 1512.00 - 211.79(62.49 - DBT) + + -16.97(DBT - 62.49) + + -0.96LTEQ$	0.94	889.58	23.15%

### **c. Monthly Prediction Results:**

Figures C1.1.7 to C1.1.10 are typical examples of plots for monthly prediction results obtained from the MCP models for the three energy channels. The plots show how well the models generated from the short dataset are able to predict the energy use for each month of the year. Examples for datasets derived from one month data from the months of January, April, July and October have been included in this appendix. The graphs summarize the NMBE (%) and CV (%) values obtained for the three channels under analysis, namely, Whole building Electric (WBE), cooling energy use (CHW), and heating energy use (HW) for each month of the year.

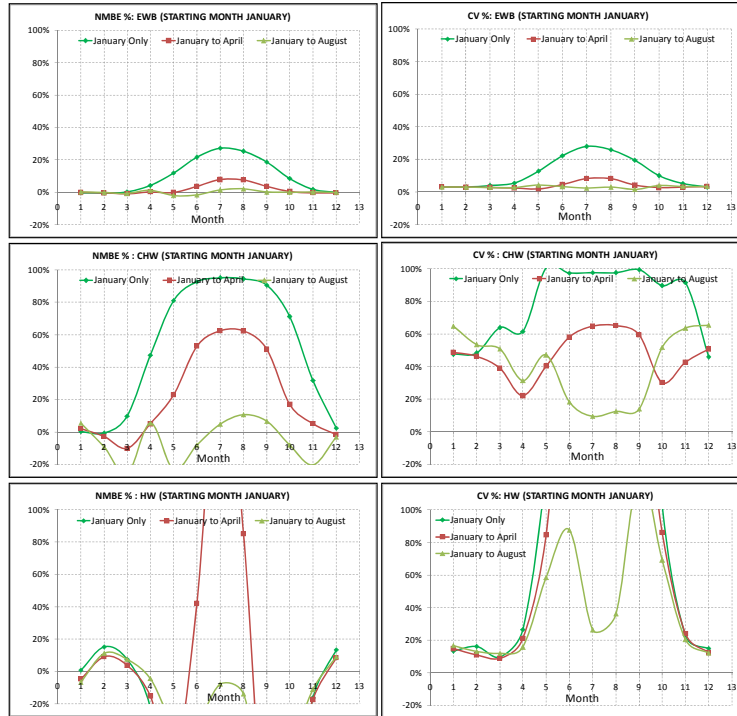


Figure C1.1.7 Monthly Prediction Results obtained from the MCP models.  
Dataset: January. Building: Large Hotel, Chicago, IL.

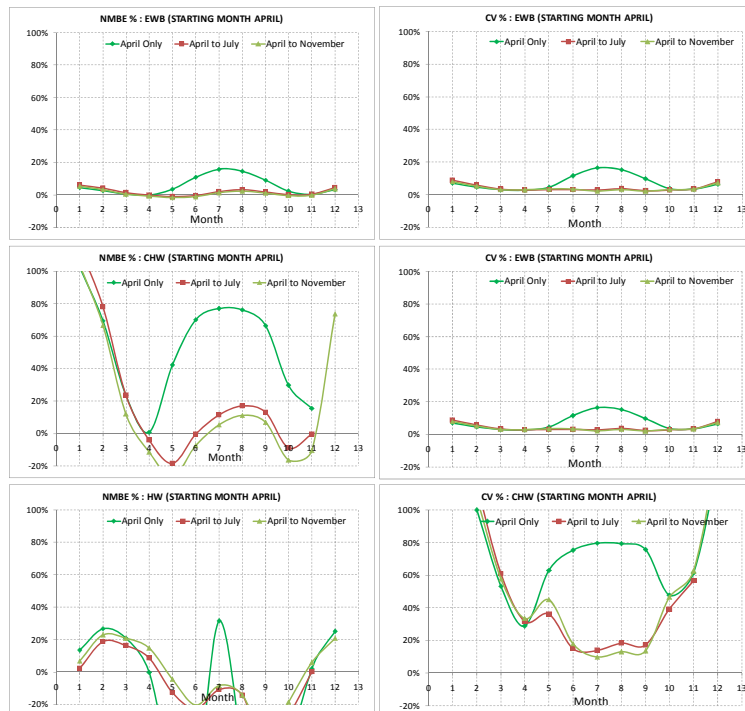


Figure C1.1.8 Monthly Prediction Results obtained from the MCP models.  
Dataset: April. Building: Large Hotel, Chicago, IL.

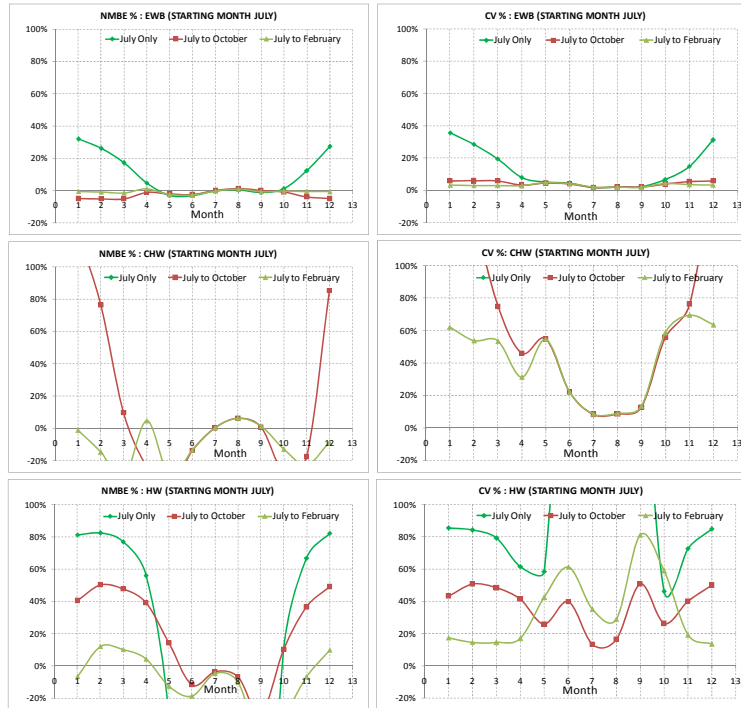


Figure C1.1.9 Monthly Prediction Results obtained from the MCP models.  
Dataset: July. Building: Large Hotel, Chicago, IL.



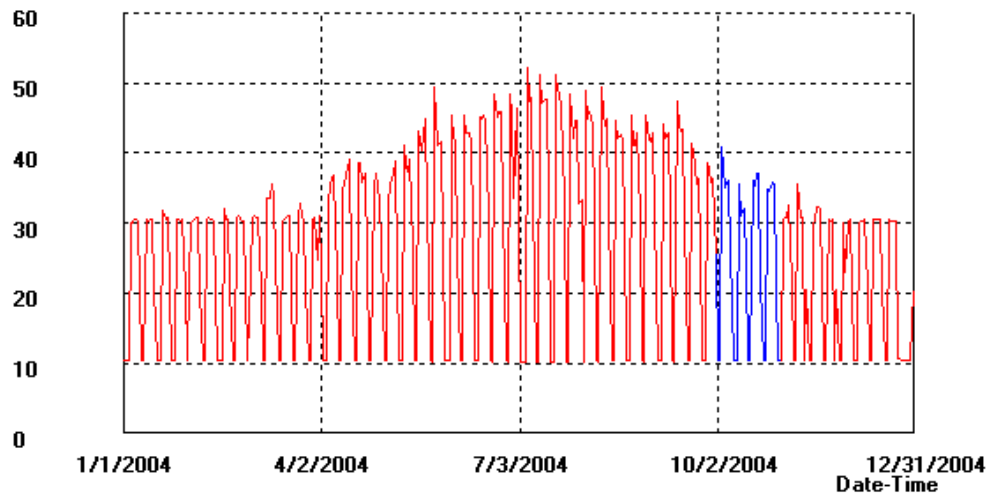
Figure C1.1.10 Monthly Prediction Results obtained from the MCP models.  
Dataset: July. Building: Large Hotel, Chicago, IL



## C1.2. Office Building at Albuquerque, New Mexico

### a. Time Series and Scatter Plots

Typical examples of the time series plots for the two energy channels; namely, WBE and HW, are shown in Fig C1.2.1 to Fig. C1.2.2. The blue portion on the graphs represents the short data-set used to estimate the energy use over the whole year represented by the red portion on the graphs. The time-series graphs are plotted for each of all the base periods shown in Table C2.1.



FigureC1.2.1 Time Series Plots for WBE for October used as the Short Data-Set for the Office, Albuquerque, NM.

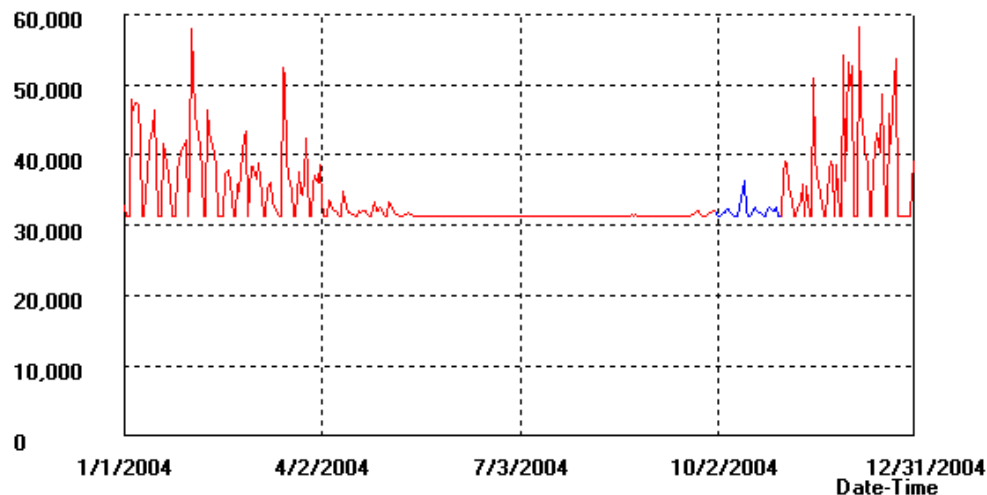


Figure C1.2.2 Time Series Plots for HW for October used as the Short Data-Set for the Office, Albuquerque, NM

Figures C1.2.3 to C1.2.4 are examples of the scatter plots of the MCP models for the two energy channels, WBE and HW.

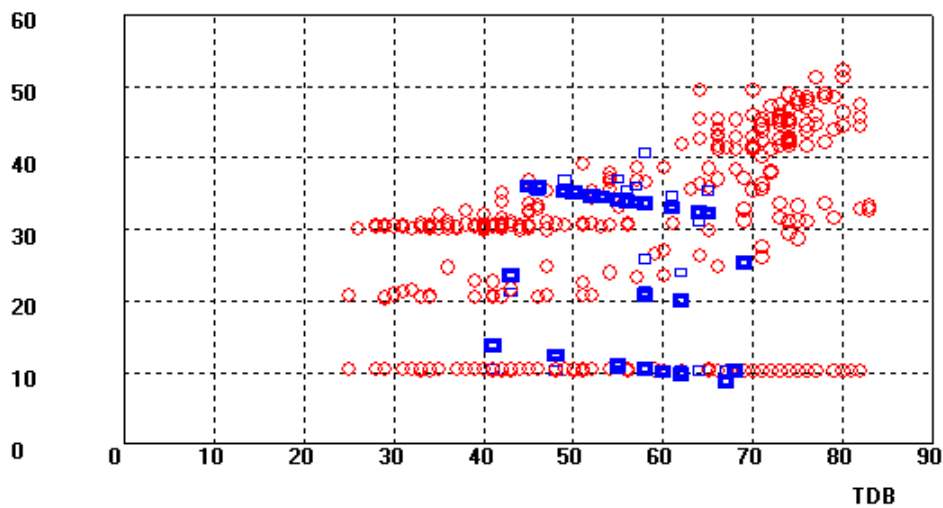


Figure C1.2.3 MCP Scatter Plot for WBE versus DBT & LTEQ for October Used as the Short Data-Set for the Office, Albuquerque, NM

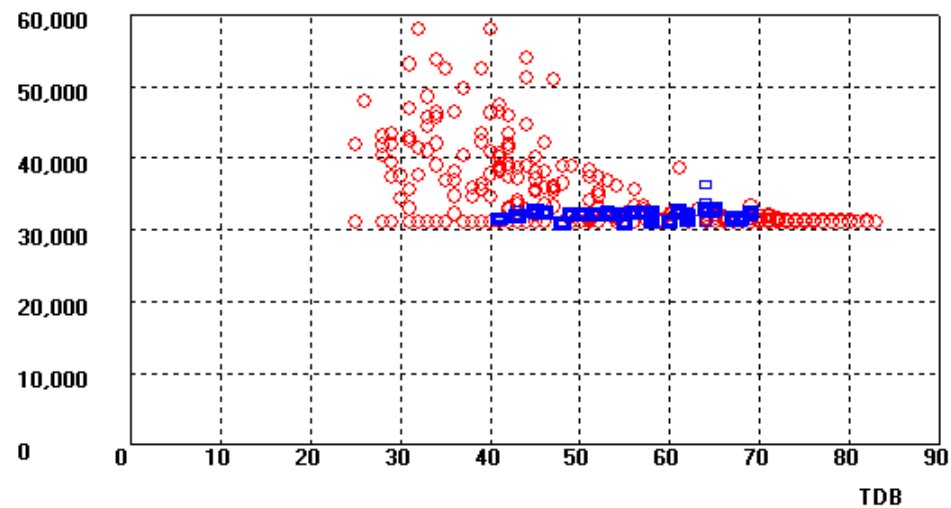


Figure C1.2.4 MCP Scatter Plot for HW versus DBT & LTEQ for October Used as the Short Data-Set for the Office, Albuquerque, NM

## b. Multivariate Change Point Models

Table C1.2.1

*MCP Models for all Base Periods and Energy Channels for Office Building at Albuquerque, NM.*

S.No	Base Period	Channel	Equation	R <sup>2</sup>	RMSE	CV-RMSE
1	January	WBE	$WBE = 0.37 - 0.20(32.00 - DBT) + + 0.12 (DBT - 32.00) + + 1.18LTEQ$	0.96	2	9.24%
		HW	$HW = 26308.16 - 49.02(41 - DBT) + + -1152.86(DBT - 41) + + 645.92LTEQ$	0.7	3415	8.99%
2	Jan-Feb	WBE	$WBE = 0.42 - 0.01 (49.93 - DBT) + + -18.81 (DBT - 49.93) + + 1.14 LTEQ$	0.95	2	9.49%
		HW	$HW = 24859.23 - 179.25(50.03 - DBT) + + -9055.33(DBT - 50.03) + + 575.35LTEQ$	0.58	4035	10.56%
3	Jan-March	WBE	$WBE = 1.12 - 0.06(41.00 - DBT) + + 0.20(DBT - 41.00) + + 1.14LTEQ$	0.9	3	12.67%
		HW	$HW = 29948.87 - 1626.60(28.00 - DBT) + + -196.33(DBT - 28.00) + + 485.72LTEQ$	0.47	4333	11.58%
4	Jan-April	WBE	$WBE = -1.29 - 0.00(51.00 - DBT) + + 0.34(DBT - 51.00) + + 1.24LTEQ$	0.9	3	13.10%
		HW	$HW = 31918.15 - 1601.50(28.00 - DBT) + + -240.38(DBT - 28.00) + + 394.49LTEQ$	0.46	4130	11.43%
5	Jan-May	WBE	$WBE = 1.87 - 0.15(71.00 - DBT) + + -2.00(DBT - 71.00) + + 1.33LTEQ$	0.85	4	17.37%
		HW	$HW = 26532.67 - 289.07(54.00 - DBT) + + -95.50(DBT - 54.00) + + 317.88 LTEQ$	0.48	3872	11.01%
6	Jan-June	WBE	$WBE = -5.65 - -0.02(47.01 - DBT) + + 0.29(DBT - 47.01) + + 1.45 LTEQ$	0.86	5	17.59%
		HW	$HW = 27468.93 - 290.19(54.16 - DBT) + + -90.90(DBT - 54.16) + + 267.60 LTEQ$	0.49	3636	10.53%
7	Jan-July	WBE	$WBE = -7.23 - -0.03(47.99 - DBT) + + 0.33(DBT - 47.99) + + 1.52LTEQ$	0.83	5	19.75%
		HW	$HW = 27582.76 - 283.66(57.00 - DBT) + + -49.02(DBT - 57.00) + + 227.02LTEQ$	0.5	3431	10.08%
8	Jan-August	WBE	$WBE = -8.70 - -0.04(47.01 - DBT) + + 0.32(DBT - 47.01) + + 1.59LTEQ$	0.85	5	18.92%
		HW	$HW = 27905.95 - 283.02(57.98 - DBT) + + -35.01(DBT - 57.98) + + 197.72LTEQ$	0.5	3251	9.65%
9	Jan-Sept	WBE	$WBE = -8.90 - -0.04(47.01 - DBT) + + 0.31(DBT - 47.01) + + 1.60LTEQ$	0.84	5	19.30%
		HW	$HW = 28232.01 - 283.68(58.14 - DBT) + + -33.32(DBT - 58.14) + + 178.48LTEQ$	0.51	3093	9.25%
10	Jan-October	WBE	$WBE = -7.83 - 0.01(51 - DBT) + + 0.33(DBT - 51) + + 1.58LTEQ$	0.83	6	19.64%
		HW	$HW = 28782.84 - 305.99(55.00 - DBT) + + -43.93(DBT - 55.00) + + 167.82 LTEQ$	0.49	3006	9.03%
11	Jan-Nov	WBE	$WBE = -8.57 - -0.11(44 - DBT) + + 0.30(DBT - 44.00) + + 1.54LTEQ$	0.82	6	20.43
		HW	$HW = 28259.91 - 259.77(57.47 - DBT) + + -45.22(DBT - 57.47) + + 189.33LTEQ$	0.45	3271	9.76%
12	Jan-Dec	WBE	$WBE = -7.77 - 0.12(44.00 - DBT) + + 0.30(DBT - 44.00) + + 1.50LTEQ$	0.82	5	20.28%
		HW	$HW = 27047.32 - 269.50(58.00 - DBT) + + -49.03(DBT - 58.00) + + 251.04 LTEQ$	0.44	3855	11.32%
13	February	WBE	$WBE = 1.26 - 0.00(49.90 - DBT) + + -18.35(DBT - 49.90) + + 1.11LTEQ$	0.94	2	10.09%
		HW	$HW = 26205.60 - 230.18(50 - DBT) + + -8123.05(DBT - 50) + + 498.13LTEQ$	0.51	4730	12.30%
14	Feb-March	WBE	$WBE = 2.04 - 0.15(41 - DBT) + + -0.26(DBT - 41) + + 1.12LTEQ$	0.87	3	13.99%
		HW	$HW = 29058.09 - 577.55(36.00 - DBT) + + -161.23(DBT - 36.00) + + 424.1716LTEQ$	0.38	4726	12.74%
15	Feb-April	WBE	$WBE = -1.79 - 0.01(51.00 - DBT) + + 0.32(DBT - 51.00) + + 1.28LTEQ$	0.88	3	13.91%
		HW	$HW = 27419.61 - 321.80(51.00 - DBT) + + -122.81(DBT - 51.00) + + 304.24LTEQ$	0.4	4197	11.83%
16	Feb-May	WBE	$WBE = 1.14 - 0.18(70.99 - DBT) + + -2.20(DBT - 70.99) + + 1.39LTEQ$	0.83	5	18.00%
		HW	$HW = 28055.60 - 327.81(53.84 - DBT) + + -71.32(DBT - 53.84) + + 226.29LTEQ$	0.44	3731	10.83%

S.No	Base Period	Channel	Equation	R <sup>2</sup>	RMSE	CV-RMSE
17	Feb-June	WBE	$WBE = -5.97 - 0.08(51.00 - DBT) + 0.29(DBT - 51.00) + 1.52LTEQ$	0.85	5	17.91%
		HW	$HW = 28869.48 - 333.06(53.99 - DBT) + -68.83(DBT - 53.99) + 181.67LTEQ$	0.46	3393	10.04%
18	Feb-July	WBE	$WBE = 0.97 - 0.24(82.01 - DBT) + 10.35(DBT - 82.01) + 1.61LTEQ$	0.82	6	19.89%
		HW	$HW = 29294.79 - 339.15(54.51 - DBT) + -49.33(DBT - 54.51) + 149.01LTEQ$	0.47	3126	9.37%
19	Feb-August	WBE	$WBE = -0.21 - 0.25(82.01 - DBT) + 10.62(DBT - 82.01) + 1.68LTEQ$	0.85	5	18.73%
		HW	$HW = 29588.25 - 340.79(55.00 - DBT) + -41.68(DBT - 55.00) + 126.10LTEQ$	0.48	2912	8.81%
20	Feb-Sept	WBE	$WBE = -0.44 - 0.24(82.01 - DBT) + 10.87(DBT - 82.01) + 1.67LTEQ$	0.84	6	19.14%
		HW	$HW = 29755.87 - 341.49(55.31 - DBT) + -38.25(DBT - 55.31) + 112.59LTEQ$	0.49	2737	8.33%
21	Feb-October	WBE	$WBE = -0.24 - 0.24(82.01 - DBT) + 11.00(DBT - 82.01) + 1.65LTEQ$	0.83	6	19.58%
		HW	$HW = 30001.95 - 361.43(53.25 - DBT) + -41.71(DBT - 53.25) + 109.13LTEQ$	0.47	2654	8.10%
22	Feb-Nov	WBE	$WBE = -10.68 - 0.33(39.00 - DBT) + 0.29(DBT - 39.00) + 1.58LTEQ$	0.81	6	20.58%
		HW	$HW = 29224.84 - 263.27(57.03 - DBT) + -43.23(DBT - 57.03) + 140.99LTEQ$	0.4	3051	9.23%
23	Feb-Dec	WBE	$WBE = -8.56 - 0.09(44.00 - DBT) + 0.30(DBT - 44.00) + 1.54LTEQ$	0.82	6	20.37%
		HW	$HW = 27758.72 - 274.60(57.68 - DBT) + -46.36(DBT - 57.68) + 214.55LTEQ$	0.41	3789	11.26%
24	Feb-Jan	WBE	$WBE = -7.77 - 0.12(44.00 - DBT) + 0.30(DBT - 44.00) + 1.50LTEQ$	0.82	5	20.28%
		HW	$HW = 27047.32 - 269.50(58.00 - DBT) + -49.03(DBT - 58.00) + 251.04LTEQ$	0.44	3855	11.32%
25	March	WBE	$WBE = 0.08 - 0.45(36 - DBT) + -0.09(DBT - 36) + 1.22LTEQ$	0.96	2	7.88%
		HW	$HW = 30616.69 - 1038.56(35 - DBT) + 162.56(DBT - 35) + 343.15LTEQ$	0.9	429	6.05%
26	March-April	WBE	$WBE = -3.93 - 0.00(47 - DBT) + 0.23(DBT - 47) + 1.39LTEQ$	0.97	24	2.54%
		HW	$HW = 32364.08 - 972.62(35 - DBT) + 190.30(DBT - 35) + 229.28LTEQ$	0.89	674	12.12%
27	March-May	WBE	$WBE = -0.39 - 0.20(70.93 - DBT) + -2.27(DBT - 70.93) + 1.49LTEQ$	0.87	4	16.31%
		HW	$HW = 33316.84 - 884.73(35 - DBT) + -158.59(DBT - 35.00) + 157.67LTEQ$	0.32	3045	9.16%
28	March-June	WBE	$WBE = -8.71 - 0.01(46.99 - DBT) + 0.27(DBT - 46.99) + 1.62LTEQ$	0.88	5	16.28%
		HW	$HW = 33728.23 - 823.15(35.00 - DBT) + 139.15(DBT - 35.00) + 122.26LTEQ$	0.33	2701	8.25%
29	March-July	WBE	$WBE = -0.79 - 0.25(82.00 - DBT) + 10.78(DBT - 82.00) + 1.70LTEQ$	0.85	6	18.69%
		HW	$HW = 29329.03 - 160.44(66.01 - DBT) + 5.47(DBT - 66.01) + 98.62LTEQ$	0.34	2445	7.54%
30	March-Aug	WBE	$WBE = -1.89 - 0.26(82.00 - DBT) + 11.05(DBT - 82.00) + 1.76LTEQ$	0.87	5	17.40%
		HW	$HW = 29585.87 - 162.42(66.25 - DBT) + 3.06(DBT - 66.25) + 82.53LTEQ$	0.35	2240	6.95%
31	March-Sept	WBE	$WBE = -1.88 - 0.25(82.00 - DBT) + 11.23(DBT - 82.00) + 1.75LTEQ$	0.85	5	18.08%
		HW	$HW = 29940.44 - 170.41(64.40 - DBT) + 10.44(DBT - 64.40) + 72.54LTEQ$	0.35	2084	6.49%
32	March-Oct	WBE	$WBE = -1.41 - 0.24(82.02 - DBT) + 11.50(DBT - 82.02) + 1.71LTEQ$	0.84	6	18.76%
		HW	$HW = 30571.00 - 184.34(57.48 - DBT) + 40.23(DBT - 57.23) + 71.08LTEQ$	0.31	2030	6.32%
33	March-Nov	WBE	$WBE = 0.22 - 0.26(82.00 - DBT) + 10.67(DBT - 82.00) + 1.64LTEQ$	0.82	6	20.05%
		HW	$HW = 28849.23 - 138.33(70.00 - DBT) + 28.60(DBT - 70.00) + 110.95LTEQ$	0.31	2610	8.03%
34	March-Dec	WBE	$WBE = -10.21 - 0.32(40.00 - DBT) + 0.29(DBT - 40.00) + 1.58LTEQ$	0.83	6	20.10%
		HW	$HW = 28266.14 - 241.55(58.42 - DBT) + 47.60(DBT - 58.42) + 188.72LTEQ$	0.37	3625	10.91%
35	March-Jan	WBE	$WBE = -8.58 - 0.15(44.00 - DBT) + 0.30(DBT - 44.00) + 1.54LTEQ$	0.83	5	19.94%
		HW	$HW = 26731.70 - 227.55(63.37 - DBT) + 7.18(DBT - 63.37) + 230.58LTEQ$	0.41	3732	11.08%

S.No.	Base Period	Channel	Equation	R <sup>2</sup>	RMSE	CV-RMSE
36	March-Feb	WBE	$WBE = -7.77 - 0.12(44.00 - DBT) + 0.30(DBT - 44.00) + 1.50LTEQ$	0.82	5	20.28%
		HW	$HW = 27047.32 - 269.50(58.00 - DBT) + -49.03(DBT - 58.00) + 251.04 LTEQ$	0.44	3855	11.32%
37	April	WBE	$WBE = -3.40 - 0.06(64.21 - DBT) + 0.72(DBT - 64.21) + 1.52LTEQ$	0.97	2	7.41%
		HW	$HW = 30667.31 - 47.01(61.00 - DBT) + 285.03(DBT - 61.00) + 104.12LTEQ$	0.3	1302	4.03%
38	April-May	WBE	$WBE = -2.80 - 0.15(70.77 - DBT) + 2.13(DBT - 70.77) + 1.61LTEQ$	0.87	5	17.18%
		HW	$HW = 31025.24 - 14.93(61.00 - DBT) + 98.00(DBT - 61.00) + 61.66LTEQ$	0.25	1032	3.24%
39	April-June	WBE	$WBE = -3.72 - 0.17(78.00 - DBT) + 0.92(DBT - 78.00) + 1.74LTEQ$	0.88	5	16.23%
		HW	$HW = 31225.89 - 4.16(61.00 - DBT) + 65.41(DBT - 61.00) + 41.50LTEQ$	0.24	879	2.78%
40	April-July	WBE	$WBE = -3.21 - 0.23(82.01 - DBT) + 11.74(DBT - 82.01) + 1.82LTEQ$	0.85	6	18.65%
		HW	$HW = 30495.77 - 40.39(77.87 - DBT) + 52.56(DBT - 77.87) + 31.14LTEQ$	0.24	775	2.45%
41	April-August	WBE	$WBE = -4.10 - 0.23(82.01 - DBT) + 11.96(DBT - 82.01) + 1.87LTEQ$	0.87	5	16.97%
		HW	$HW = 30693.91 - 40.85(75.68 - DBT) + 20.33(DBT - 75.68) + 24.74LTEQ$	0.24	697	2.21%
42	April-Sept	WBE	$WBE = -3.71 - 0.23(82.01 - DBT) + 12.02(DBT - 82.01) + 1.83LTEQ$	0.86	6	17.89%
		HW	$HW = 30757.74 - 40.96(74.19 - DBT) + 8.57(DBT - 74.19) + 23.52LTEQ$	0.23	646	2.05%
43	April-Oct	WBE	$WBE = -2.80 - 0.23(82.00 - DBT) + 11.74(DBT - 82.00) + 1.78LTEQ$	0.85	6	18.78%
		HW	$HW = 31320.72 - 12.86(61.00 - DBT) + 42.29(DBT - 61.00) + 28.30LTEQ$	0.23	702	2.22%
44	April-Nov	WBE	$WBE = -0.60 - 0.27(82.02 - DBT) + 11.08(DBT - 82.02) + 1.69LTEQ$	0.82	6	20.35%
		HW	$HW = 29853.16 - 123.38(66.43 - DBT) + 10.07(DBT - 66.43) + 75.94LTEQ$	0.26	2131	6.64%
45	April-Dec	WBE	$WBE = -10.90 - 0.37(39.24 - DBT) + 0.29(DBT - 39.24) + 1.61LTEQ$	0.83	6	20.58%
		HW	$HW = 28599.82 - 267.27(56.64 - DBT) + 42.63(DBT - 56.64) + 172.20LTEQ$	0.37	3489	10.59%
46	April-Jan	WBE	$WBE = -8.97 - 0.14(44.00 - DBT) + 0.30(DBT - 44.00) + 1.56LTEQ$	0.83	6	20.45%
		HW	$HW = 27643.76 - 268.58(57.00 - DBT) + 45.42(DBT - 57.00) + 221.00LTEQ$	0.43	3637	10.87%
47	April-Feb	WBE	$WBE = -8.07 - 0.12(44 - DBT) + 0.30(DBT - 44) + 1.52LTEQ$	0.82	6	20.81%
		HW	$HW = 27161.45 - 290.23(56.99 - DBT) + 43.65(DBT - 56.99) + 243.41LTEQ$	0.46	3781	11.16%
48	April-March	WBE	$WBE = -7.77 - 0.12(44.00 - DBT) + 0.30(DBT - 44.00) + 1.50LTEQ$	0.82	5	20.28%
		HW	$HW = 27047.32 - 269.50(58.00 - DBT) + -49.03(DBT - 58.00) + 251.04 LTEQ$	0.44	3855	11.32%
49	May	WBE	$WBE = -4.24 - 0.09(70.49 - DBT) + 2.03(DBT - 70.49) + 1.70LTEQ$	0.82	6	22.93%
		HW	$HW = 31043.28 - 0.04(69 - DBT) + 69.11(DBT - 69) + 24.38LTEQ$	0.19	458	1.45%
50	May-June	WBE	$WBE = -6.28 - 0.09(78 - DBT) + 0.92(DBT - 78) + 1.85LTEQ$	0.87	5	17.93%
		HW	$HW = 31377.87 - 86.62(53.68 - DBT) + 17.47(DBT - 53.68) + 13.06LTEQ$	0.14	339	1.08%
51	May-July	WBE	$WBE = -8.08 - 0.10(73.00 - DBT) + 0.45(DBT - 73.00) + 1.92LTEQ$	0.84	6	19.66%
		HW	$HW = 31032.68 - 16.84(77.69 - DBT) + 12.24(DBT - 77.69) + 8.97LTEQ$	0.15	279	0.89%
52	May-Aug	WBE	$WBE = -5.88 - 0.20(82.01 - DBT) + 12.72(DBT - 82.01) + 1.95LTEQ$	0.87	6	17.65%
		HW	$HW = 31091.05 - 16.25(76.31 - DBT) + 5.19(DBT - 76.31) + 7.30LTEQ$	0.14	243	0.78%
53	May-Sept	WBE	$WBE = -4.89 - 0.22(82.00 - DBT) + 12.30(DBT - 82.00) + 1.89LTEQ$	0.85	6	18.57%
		HW	$HW = 31044.12 - 15.25(78 - DBT) + 12.17(DBT - 78) + 9.24LTEQ$	0.16	244	0.78%
54	May-Oct	WBE	$WBE = -3.46 - 0.25(82.01 - DBT) + 11.94(DBT - 82.01) + 1.82LTEQ$	0.84	6	19.58%
		HW	$HW = 31841.67 - 5685.75(41.13 - DBT) + 25.75(DBT - 41.13) + 16.72LTEQ$	0.22	473	1.50%

S.No	Base Period	Channel	Equation	R <sup>2</sup>	RMSE	CV-RMSE
55	May-Nov	WBE	WBE=-0.94-0.28(82.00-DBT)++10.86(DBT-82.00)++1.71LTEQ	0.81	6	21.28%
		HW	HW=29928.19-140.57(66.08-DBT)++10.30(DBT-66.08)++72.50LTEQ	0.29	2190	6.83%
56	May-Dec	WBE	WBE=-11.42-0.37(40.00-DBT)+0.30(DBT-40.00)++1.62LTEQ	0.82	6	21.49%
		HW	HW=28002.99-246.74(61.02-DBT)++23.58(DBT-61.02)++179.85LTEQ	0.39	3620	20.97%
57	May-Jan	WBE	WBE=-9.56-0.18(44.00-DBT)++0.32(DBT-44.00)++1.57LTEQ	0.82	6	21.29%
		HW	HW=26733.69-237.92(63.26-DBT)++10.45(DBT-63.26)++232.55LTEQ	0.44	3751	11.17%
58	May-Feb	WBE	WBE=-8.47-0.15(44.00-DBT)++0.31(DBT-44.00)++1.52LTEQ	0.81	6	21.62%
		HW	HW=26242.15-257.98(62.68-DBT)++8.63(DBT-62.68)++256.09LTEQ	0.47	3886	11.42%
59	May-March	WBE	WBE=-8.06-0.15(44.17-DBT)++0.31(DBT-44.17)++1.50LTEQ	0.82	6	21.00%
		HW	HW=26068.89-242.80(63.79-DBT)++7.92(DBT-63.79)++263.81LTEQ	0.45	3948	11.55%
60	May-April	WBE	WBE =-7.77 - 0.12(44.00 - DBT)+ 0.30(DBT - 44.00)+ 1.50LTEQ	0.82	5	20.28%
		HW	HW = 27047.32 - 269.50(58.00 - DBT)+ + -49.03(DBT - 58.00)++251.04 LTEQ	0.44	3855	11.32%
61	June	WBE	WBE=-8.14-0.20(73.05-DBT)++0.16(DBT-73.05)++2.02LTEQ	0.96	3	9.45%
		HW	HW=31249.24 -5.28(71.00-DBT)++3.58(DBT-71.00)++1.08LTEQ	0.19	30	0.09%
62	June-July	WBE	WBE=-6.96-0.18(82.18-DBT)++15.39(DBT-82.18)++2.02LTEQ	0.87	6	17.54%
		HW	HW=31248.25-3.47(71-DBT)++1.77(DBT-71.00)++0.68LTEQ	0.13	23	0.07%
63	June-Aug	WBE	WBE=-7.31-0.17(82.00-DBT)++12.83(DBT-82.00)++2.03LTEQ	0.9	5	14.94%
		HW	HW=31257.76-30.20(66.00-DBT)++3.09(DBT-66.00)++1.70LTEQ	0.15	46	0.15%
64	June-Sept	WBE	WBE=-5.26-0.28(82.00-DBT)++11.93(DBT-82.00)++1.95LTEQ	0.87	6	17.14%
		HW	HW=31127.07-11.48(78.00-DBT)++6.65(DBT-78.00)++5.55LTEQ	0.16	142	0.45%
65	June-Oct	WBE	WBE=-3.54-0.28(82.01-DBT)++11.64(DBT-82.01)++1.85LTEQ	0.85	6	18.71%
		HW	HW=31946.88-858.76(41.99-DBT)++28.42(DBT-41.99)++14.88LTEQ	0.25	476	1.52%
66	June-Nov	WBE	WBE=-0.69-0.30(82.00-DBT)++10.57(DBT-82.00)++1.71LTEQ	0.82	6	20.84%
		HW	HW=29478.98-131.94(69.99-DBT)++18.26(DBT-69.99)++82.96LTEQ	0.3	2342	7.28%
67	June-Dec	WBE	WBE=-11.09-0.18(44.00-DBT)++0.34(DBT-44.00)++1.62LTEQ	0.83	6	20.86%
		HW	HW=27194.20-228.18(64.34-DBT)++4.17(DBT-64.34)++205.49LTEQ	0.39	3836	11.55%
68	June-Jan	WBE	WBE=-9.50-0.20(44.00-DBT)++0.33(DBT-44.00)++1.55LTEQ	0.83	6	20.84%
		HW	HW=25471.65-212.08(70.00-DBT)++81.79(DBT-70.00)++260.80LTEQ	0.45	3921	11.59%
69	June-Feb	WBE	WBE=-7.65-0.06(51.00-DBT)++0.40(DBT-51.00)++1.50LTEQ	0.82	6	21.18%
		HW	HW=25537.78-252.57(64.00-DBT)++1.96(DBT-64.00)++284.26LTEQ	0.47	4039	11.77%
70	June-March	WBE	WBE=-7.08-0.06(51.00-DBT)++0.40(DBT-51.00)++1.48LTEQ	0.82	5	20.47%
		HW	HW=24816.17-219.09(70.00-DBT)++90.91(DBT-70.00)++290.39LTEQ	0.45	4086	11.85%
71	June-April	WBE	WBE=-6.49-0.02(51.00-DBT)++0.37(DBT-51.00)++1.48LTEQ	0.83	5	19.76%
		HW	HW=25705.85-244.69(63.80-DBT)++6.31(DBT-63.80)++273.22LTEQ	0.44	3983	11.62%
72	June-May	WBE	WBE =-7.77 - 0.12(44.00 - DBT)+ 0.30(DBT - 44.00)+ 1.50LTEQ	0.82	5	20.28%
		HW	HW = 27047.32 - 269.50(58.00 - DBT)+ + -49.03(DBT - 58.00)++251.04 LTEQ	0.44	3855	11.32%
73	July	WBE	WBE = -6.37 - 0.33(82.25 - DBT)+ 15.69(DBT - 82.25)+ 2.04LTEQ	0.79	8	23.31%
		HW	HW = 31242.52 - 2.38(75.00 - DBT)+ + -0.36(DBT - 75.00)++0.32 LTEQ	0.1	11	0.03%

S.No	Base Period	Channel	Equation	R <sup>2</sup>	RMSE	CV-RMSE
74	July-August	WBE	$WBE = -7.12 - 0.24(82.01 - DBT) + 12.56(DBT - 82.01) + 2.05LTEQ$	0.88	6	17.17%
		HW	$HW = 31199.45 - 7.33(77.98 - DBT) + 3.19(DBT - 77.98) + 2.16LTEQ$	0.23	50	0.16%
75	July-Sept	WBE	$WBE = -4.58 - 0.33(82.00 - DBT) + 11.51(DBT - 82.00) + 1.93LTEQ$	0.84	6	19.09%
		HW	$HW = 31093.00 - 14.62(78.00 - DBT) + 10.14(DBT - 78.00) + 7.11LTEQ$	0.21	156	0.50%
76	July-October	WBE	$WBE = -9.90 - 0.00(64.00 - DBT) + 0.53(DBT - 64.00) + 1.80LTEQ$	0.82	6	20.49%
		HW	$HW = 31884.44 - 507.83(42.62 - DBT) + -28.32(DBT - 42.62) + 18.37LTEQ$	0.25	523	1.66%
77	July-Nov	WBE	$WBE = 0.24 - 0.29(82.00 - DBT) + 10.46(DBT - 82.00) + 1.65LTEQ$	0.79	7	22.53%
		HW	$HW = 29050.41 - 128.62(71.30 - DBT) + 39.14(DBT - 71.30) + 99.81LTEQ$	0.29	2550	7.88%
78	July-Dec	WBE	$WBE = -9.89 - 0.18(44.00 - DBT) + 0.34(DBT - 44.00) + 1.56LTEQ$	0.81	6	22.21%
		HW	$HW = 26506.02 - 229.75(64.46 - DBT) + 4.22(DBT - 64.46) + 237.81LTEQ$	0.39	4092	12.20%
79	July-Jan	WBE	$WBE = -8.28 - 0.19(44.00 - DBT) + 0.33(DBT - 44.00) + 1.49LTEQ$	0.81	6	21.89%
		HW	$HW = 24584.78 - 213.87(70.75 - DBT) + 124.15(DBT - 70.75) + 296.23LTEQ$	0.45	4119	12.04%
80	July-Feb	WBE	$WBE = -6.56 - 0.07(51.01 - DBT) + 0.40(DBT - 51.01) + 1.44LTEQ$	0.8	6	22.03%
		HW	$HW = 24840.67 - 254.69(64.00 - DBT) + 10.47(DBT - 64.00) + 317.56LTEQ$	0.47	4215	12.15%
81	July-March	WBE	$WBE = -6.02 - 0.06(51.01 - DBT) + 0.39(DBT - 51.01) + 1.42LTEQ$	0.81	6	21.09%
		HW	$HW = 24015.63 - 219.61(70.81 - DBT) + 136.04(DBT - 70.81) + 321.39LTEQ$	0.45	4242	12.81%
82	July-April	WBE	$WBE = -5.51 - 0.02(51.00 - DBT) + 0.36(DBT - 51.00) + 1.43LTEQ$	0.82	5	20.25%
		HW	$HW = 25153.19 - 245.98(63.86 - DBT) + 14.65(DBT - 63.86) + 299.09LTEQ$	0.44	4126	11.93%
83	July-May	WBE	$WBE = -6.85 - 0.12(44.00 - DBT) + 0.29(DBT - 44.00) + 1.46LTEQ$	0.97	32	3.10%
		HW	$HW = 26671.58 - 271.63(57.68 - DBT) + -48.08(DBT - 57.68) + 272.62LTEQ$	0.44	3984	11.62%
84	July-June	WBE	$WBE = -7.77 - 0.12(44.00 - DBT) + 0.30(DBT - 44.00) + 1.50LTEQ$	0.82	5	20.28%
		HW	$HW = 27047.32 - 269.50(58.00 - DBT) + -49.03(DBT - 58.00) + 251.04LTEQ$	0.44	3855	11.32%
85	August	WBE	$WBE = -8.01 - 0.82(70.00 - DBT) + 0.05(DBT - 70.00) + 2.02LTEQ$	0.97	3	8.00%
		HW	$HW = 31240.88 - 108.35(66.40 - DBT) + -3.67(DBT - 66.40) + 3.53LTEQ$	0.24	67	0.21%
86	Aug-Sept	WBE	$WBE = -9.32 - 0.58(68.00 - DBT) + 0.46(DBT - 68.00) + 1.87LTEQ$	0.88	5	16.57%
		HW	$HW = 31240.05 - 140.87(63.30 - DBT) + -11.34(DBT - 63.30) + 10.04LTEQ$	0.2	187	0.60%
87	Aug-October	WBE	$WBE = -8.44 - 0.02(64.00 - DBT) + 0.47(DBT - 64.00) + 1.74LTEQ$	0.85	6	18.77%
		HW	$HW = 31243.48 - 9.80(64.00 - DBT) + -45.35(DBT - 64.00) + 26.49LTEQ$	0.24	597	1.89%
88	Aug-Nov	WBE	$WBE = -11.34 - 0.51(39.00 - DBT) + 0.31(DBT - 39.00) + 1.57LTEQ$	0.8	6	21.46%
		HW	$HW = 28349.02 - 128.37(72.44 - DBT) + 133.44(DBT - 72.44) + 127.17LTEQ$	0.29	2835	8.69%
89	Aug-Dec	WBE	$WBE = -8.21 - 0.31(39.99 - DBT) + 0.28(DBT - 39.99) + 1.47LTEQ$	0.82	6	21.03%
		HW	$HW = 24576.67 - 210.04(71.80 - DBT) + 287.59(DBT - 71.80) + 286.00LTEQ$	0.39	4404	12.94%
90	Aug-Jan	WBE	$WBE = -6.40 - 0.14(43.99 - DBT) + 0.29(DBT - 43.99) + 1.42LTEQ$	0.83	5	20.27%
		HW	$HW = 23213.66 - 216.27(72.30 - DBT) + 373.88(DBT - 72.30) + 346.78LTEQ$	0.45	4350	12.54%
91	Aug-Feb	WBE	$WBE = -4.77 - 0.04(51.00 - DBT) + 0.36(DBT - 51.00) + 1.37LTEQ$	0.82	5	20.55%
		HW	$HW = 22723.38 - 228.18(72.18 - DBT) + 394.33(DBT - 72.18) + 366.02LTEQ$	0.47	4411	12.53%
92	Aug-March	WBE	$WBE = -4.41 - 0.04(51.00 - DBT) + 0.35(DBT - 51.00) + 1.36LTEQ$	0.83	5	19.46%
		HW	$HW = 22845.89 - 220.42(72.31 - DBT) + 390.91(DBT - 72.31) + 362.88LTEQ$	0.44	4415	12.51%

S.No.	Base Period	Channel	Equation	R <sup>2</sup>	RMSE	CV-RMSE
93	Aug-April	WBE	WBE = -5.04 - 0.09(44.00 - DBT) + 0.27(DBT - 44.00) + 1.37LTEQ	0.84	5	18.58%
		HW	HW = 25721.64 - 271.09(57.00 - DBT) + -66.36(DBT - 57.00) + 332.16 LTEQ	0.43	4285	12.26%
94	Aug-May	WBE	WBE = -5.51 - 0.08(43.99 - DBT) + 0.26(DBT - 43.99) + 1.41LTEQ	0.83	5	19.50%
		HW	HW = 26298.62 - 272.94(57.00 - DBT) + -63.18(DBT - 57.00) + 299.94 LTEQ	0.13	23	0.07%
95	Aug-June	WBE	WBE = -6.72 - 0.10(44.00 - DBT) + 0.28(DBT - 44.00) + 1.46LTEQ	0.84	5	19.18%
		HW	HW = 26820.77 - 271.68(57.00 - DBT) + -67.17(DBT - 57.00) + 274.36 LTEQ	0.44	3986	11.62%
96	Aug-July	WBE	WBE = -7.77 - 0.12(44.00 - DBT) + 0.30(DBT - 44.00) + 1.50LTEQ	0.82	5	20.28%
		HW	HW = 27047.32 - 269.50(58.00 - DBT) + -49.03(DBT - 58.00) + 251.04 LTEQ	0.44	3855	11.32%
97	September	WBE	WBE = -6.70 - 1.69(68.00 - DBT) + 1.60(DBT - 68.00) + 1.56LTEQ	0.82	6	20.69%
		HW	HW = 31117.79 - 12.96(71.00 - DBT) + -81.73(DBT - 71.00) + 17.44 LTEQ	0.27	241	0.77%
98	Sept-Oct	WBE	WBE = -4.50 - 0.03(68.00 - DBT) + 1.32(DBT - 68.00) + 1.51LTEQ	0.8	6	21.43%
		HW	HW = 31076.09 - 2.18(64.00 - DBT) + -81.24(DBT - 64.00) + 42.66 LTEQ	0.25	700	2.21%
99	Sept-Nov	WBE	WBE = -0.96 - 0.14(68.00 - DBT) + 1.28(DBT - 68.00) + 1.36LTEQ	0.76	6	23.47%
		HW	HW = 31843.98 - 32.33(44.00 - DBT) + -154.32(DBT - 44.00) + 162.31LTEQ	0.28	3223	9.74%
100	Sept-Dec	WBE	WBE = -0.10 - 0.09(68.00 - DBT) + 1.46(DBT - 68.00) + 1.29LTEQ	0.79	5	21.87%
		HW	HW = 32565.49 - 435.01(33.40 - DBT) + -241.08(DBT - 33.40) + 336.03LTEQ	0.4	4758	13.70%
101	Sept-Jan	WBE	WBE = 0.30 - 0.07(68.00 - DBT) + 1.53(DBT - 68.00) + 1.26LTEQ	0.82	5	20.38%
		HW	HW = 31058.79 - 102.46(34.00 - DBT) + -241.06(DBT - 34.00) + 403.40LTEQ	0.45	4604	13.01%
102	Sept-Feb	WBE	WBE = 0.61 - 0.07(68.00 - DBT) + 1.62(DBT - 68.00) + 1.23LTEQ	0.8	5	20.38%
		HW	HW = 31160.25 - 120.38(33.01 - DBT) + -245.32(DBT - 33.01) + 415.87LTEQ	0.46	4625	12.90%
103	Sept-March	WBE	WBE = 0.42 - 0.06(68.00 - DBT) + 1.66(DBT - 68.00) + 1.23LTEQ	0.82	5	18.98%
		HW	HW = 30900.49 - 40.70(34.00 - DBT) + -236.68(DBT - 34.00) + 403.90LTEQ	0.44	4605	12.84%
104	Sept-April	WBE	WBE = 0.54 - 0.09(68.00 - DBT) + 1.43(DBT - 68.00) + 1.27LTEQ	0.83	4	18.15%
		HW	HW = 25395.65 - 272.76(55.00 - DBT) + -108.73(DBT - 55.00) + 375.41LTEQ	0.43	4452	12.57%
105	Sept-May	WBE	WBE = -4.26 - 0.13(39.99 - DBT) + 0.20(DBT - 39.99) + 1.33LTEQ	0.82	5	19.56%
		HW	HW = 26117.07 - 275.81(55.00 - DBT) + -99.23(DBT - 55.00) + 334.79LTEQ	0.43	4283	12.25%
106	Sept-June	WBE	WBE = -5.42 - 0.08(44.00 - DBT) + 0.26(DBT - 44.00) + 1.40LTEQ	0.83	5	19.50%
		HW	HW = 26701.12 - 274.82(55.14 - DBT) + -95.52(DBT - 55.14) + 303.53LTEQ	0.44	4128	11.93%
107	Sept-July	WBE	WBE = -6.74 - 0.12(44.00 - DBT) + 0.30(DBT - 44.00) + 1.45LTEQ	0.81	5	20.81%
		HW	HW = 26802.67 - 271.88(57.02 - DBT) + -61.78(DBT - 57.02) + 274.85 LTEQ	0.44	3986	11.62%
108	Sept-Aug	WBE	WBE = -7.77 - 0.12(44.00 - DBT) + 0.30(DBT - 44.00) + 1.50LTEQ	0.82	5	20.28%
		HW	HW = 27047.32 - 269.50(58.00 - DBT) + -49.03(DBT - 58.00) + 251.04 LTEQ	0.44	3855	11.32%
109	October	WBE	WBE = -5.11 - 0.19(67.68 - DBT) + 4.88(DBT - 67.68) + 1.40LTEQ	0.83	5	19.85%
		HW	HW = 29851.91 - 88.32(50.77 - DBT) + 58.14(DBT - 50.77) + 83.48 LTEQ	0.35	856	2.67%
110	Oct-Nov	WBE	WBE = 1.79 - 0.22(57.00 - DBT) + 0.34(DBT - 57.00) + 1.20LTEQ	0.74	6	23.09%
		HW	HW = 30508.49 - 30.00(44.00 - DBT) + -163.26(DBT - 44.00) + 230.43 LTEQ	0.25	3870	11.41%
111	Oct-Dec	WBE	WBE = 1.23 - 0.12(58.00 - DBT) + 0.30(DBT - 58.00) + 1.20LTEQ	0.82	4	19.75%
		HW	HW = 30966.62 - 536.73(33.58 - DBT) + -285.12(DBT - 33.58) + 437.12 LTEQ	0.4	5249	14.67%



S.No.	Base Period	Channel	Equation	R <sup>2</sup>	RMSE	CV-RMSE
112	Oct-Jan	WBE	$WBE = -1.52 - 0.12(39.00 - DBT) + 0.10(DBT - 39.00) + 1.19LTEQ$	0.84	4	18.20%
		HW	$HW = 20666.50 - 257.91(64.80 - DBT) + 1208.83(DBT - 64.80) + 508.53LTEQ$	0.44	4892	13.45%
113	Oct-Feb	WBE	$WBE = -0.83 - 0.09(39.00 - DBT) + 0.07(DBT - 39.00) + 1.17LTEQ$	0.82	4	18.51%
		HW	$HW = 20776.65 - 265.21(64.79 - DBT) + 1193.18(DBT - 64.79) + 503.41LTEQ$	0.45	4852	13.20%
114	Oct-March	WBE	$WBE = 0.04 - 0.01(68.01 - DBT) + 5.13(DBT - 68.01) + 1.18LTEQ$	0.84	4	16.97%
		HW	$HW = 21562.18 - 246.86(64.95 - DBT) + 1119.75(DBT - 64.95) + 476.30LTEQ$	0.42	4808	13.14%
115	Oct-April	WBE	$WBE = -1.88 - 0.08(39.80 - DBT) + 0.13(DBT - 39.80) + 1.23LTEQ$	0.85	4	16.50%
		HW	$HW = 24253.58 - 282.94(55.00 - DBT) + 27.26(DBT - 55.00) + 424.77LTEQ$	0.42	4640	12.89%
116	Oct-May	WBE	$WBE = -3.21 - 0.10(39.99 - DBT) + 0.17(DBT - 39.99) + 1.29LTEQ$	0.83	5	18.65%
		HW	$HW = 25351.52 - 280.23(54.86 - DBT) + 79.67(DBT - 54.86) + 372.13LTEQ$	0.42	4459	12.59%
117	Oct-June	WBE	$WBE = -4.84 - 0.08(44.00 - DBT) + 0.26(DBT - 44.00) + 1.37LTEQ$	0.83	5	18.95%
		HW	$HW = 26137.67 - 276.36(54.99 - DBT) + 90.85(DBT - 54.99) + 333.27LTEQ$	0.43	4289	12.27%
118	Oct-July	WBE	$WBE = -5.89 - 0.06(47.01 - DBT) + 0.33(DBT - 47.01) + 1.43LTEQ$	0.82	5	20.59%
		HW	$HW = 26357.60 - 270.92(56.99 - DBT) + 59.49(DBT - 56.99) + 299.04LTEQ$	0.44	4132	11.95%
119	Oct-Aug	WBE	$WBE = -7.49 - 0.12(44.00 - DBT) + 0.31(DBT - 44.00) + 1.49LTEQ$	0.83	5	20.06%
		HW	$HW = 26786.16 - 271.48(57.36 - DBT) + 52.75(DBT - 57.36) + 271.33LTEQ$	0.44	3988	11.64%
120	Oct-Sept	WBE	$WBE = -7.77 - 0.12(44.00 - DBT) + 0.30(DBT - 44.00) + 1.50LTEQ$	0.82	5	20.28%
		HW	$HW = 27047.32 - 269.50(58.00 - DBT) + 49.03(DBT - 58.00) + 251.04LTEQ$	0.44	3855	11.32%
121	November	WBE	$WBE = -2.06 - 0.51(40.00 - DBT) + 0.66(DBT - 44.00) + 1.05LTEQ$	0.72	5	23.55%
		HW	$HW = 28562.32 - 200.17(47.00 - DBT) + 695.37(DBT - 47.00) + 439.01LTEQ$	0.38	4587	12.82%
122	Nov-Dec	WBE	$WBE = -1.14 - 0.15(44.00 - DBT) + 0.35(DBT - 44.00) + 1.11LTEQ$	0.83	4	18.43%
		HW	$HW = 28373.28 - 272.49(37.00 - DBT) + 472.42(DBT - 37.00) + 619.44LTEQ$	0.45	5588	14.84%
123	Nov-Jan	WBE	$WBE = -0.92 - 0.17(40.00 - DBT) + 0.17(DBT - 40.00) + 1.12LTEQ$	0.87	3	15.92%
		HW	$HW = 27533.81 - 128.73(37.00 - DBT) + 445.74(DBT - 37.00) + 636.49LTEQ$	0.5	4931	13.06%
124	Nov-Feb	WBE	$WBE = -0.80 - 0.10(51.00 - DBT) + 0.80(DBT - 51.00) + 1.10LTEQ$	0.85	4	16.66%
		HW	$HW = 25471.23 - 123.96(47.00 - DBT) + 874.44(DBT - 47.00) + 601.90LTEQ$	0.49	4881	12.87%
125	Nov-March	WBE	$WBE = -0.67 - 0.06(51.00 - DBT) + 0.37(DBT - 51.00) + 1.14LTEQ$	0.86	3	15.31%
		HW	$HW = 28817.65 - 119.40(34.00 - DBT) + 284.10(DBT - 34.00) + 541.48LTEQ$	0.44	4907	13.09%
126	Nov-April	WBE	$WBE = -1.01 - 0.02(50.01 - DBT) + 0.37(DBT - 50.01) + 1.19LTEQ$	0.87	4	15.19%
		HW	$HW = 29969.61 - 109.47(34.00 - DBT) + 294.93(DBT - 34.00) + 474.58LTEQ$	0.43	4758	12.98%
127	Nov-May	WBE	$WBE = -2.75 - 0.06(44.00 - DBT) + 0.23(DBT - 44.00) + 1.27LTEQ$	0.84	4	18.13%
		HW	$HW = 30861.10 - 40.54(34.00 - DBT) + 243.43(DBT - 34.00) + 406.05LTEQ$	0.43	4603	12.82%
128	Nov-June	WBE	$WBE = -4.87 - 0.10(44.00 - DBT) + 0.29(DBT - 44.00) + 1.36LTEQ$	0.84	5	18.42%
		HW	$HW = 25484.16 - 256.10(57.02 - DBT) + 110.14(DBT - 57.02) + 365.07LTEQ$	0.44	4423	12.52%
129	Nov-July	WBE	$WBE = -6.39 - 0.13(44.00 - DBT) + 0.32(DBT - 44.00) + 1.42LTEQ$	0.82	5	20.31%
		HW	$HW = 24557.45 - 235.82(66.01 - DBT) + 14.07(DBT - 66.01) + 323.69LTEQ$	0.45	4248	12.19%
130	Nov-Aug	WBE	$WBE = -7.64 - 0.13(44.00 - DBT) + 0.32(DBT - 44.00) + 1.49LTEQ$	0.84	5	19.76%
		HW	$HW = 24995.00 - 236.02(66.70 - DBT) + 42.23(DBT - 66.70) + 292.65LTEQ$	0.45	4086	11.84%

S.No.	Base Period	Channel	Equation	R <sup>2</sup>	RMSE	CV-RMSE
131	Nov-Sept	WBE	$WBE = -7.96 - 0.13(44.00 - DBT) + 0.31(DBT - 44.00) + 1.50LTEQ$	0.83	5	20.04%
		HW	$HW = 25888.32 - 243.90(64.07 - DBT) + -2.12(DBT - 64.07) + 268.37LTEQ$	0.46	3941	11.52%
132	Nov-Oct	WBE	$WBE = -7.77 - 0.12(44.00 - DBT) + 0.30(DBT - 44.00) + 1.50LTEQ$	0.82	5	20.28%
		HW	$HW = 27047.32 - 269.50(58.00 - DBT) + -49.03(DBT - 58.00) + 251.04LTEQ$	0.44	3855	11.32%
133	December	WBE	$WBE = 0.31 - 0.43(29.00 - DBT) + 0.08(DBT - 29.00) + 1.16LTEQ$	0.97	2	8.86%
		HW	$HW = 28405.82 - 542.42(39.00 - DBT) + -2129.50(DBT - 39.00) + 852.15LTEQ$	0.69	4971	12.54%
134	Dec-Jan	WBE	$WBE = 0.23 - 0.24(29.00 - DBT) + 0.06(DBT - 29.00) + 1.17LTEQ$	0.96	2	8.88%
		HW	$HW = 27417.06 - 302.07(39.00 - DBT) + -1457.69(DBT - 39.00) + 777.08LTEQ$	0.66	4330	11.19%
135	Dec-Feb	WBE	$WBE = -0.03 - 0.01(49.95 - DBT) + 19.06(DBT - 49.95) + 1.15LTEQ$	0.95	2	9.23%
		HW	$HW = 24278.60 - 127.97(50.07 - DBT) + -11659.86(DBT - 50.07) + 672.60LTEQ$	0.57	4679	12.11%
136	Dec-March	WBE	$WBE = 0.31 - 0.00(45.90 - DBT) + 0.28(DBT - 45.90) + 1.15LTEQ$	0.92	3	11.94%
		HW	$HW = 28767.00 - 163.01(34.00 - DBT) + -314.25(DBT - 34.00) + 574.06LTEQ$	0.48	4844	12.77%
137	Dec-April	WBE	$WBE = -1.06 - 0.00(50.99 - DBT) + 0.35(DBT - 50.99) + 1.23LTEQ$	0.91	3	12.55%
		HW	$HW = 30189.38 - 139.64(34.00 - DBT) + -321.55(DBT - 34.00) + 487.98LTEQ$	0.47	4709	12.79%
138	Dec-May	WBE	$WBE = -2.83 - 0.02(43.99 - DBT) + 0.20(DBT - 43.99) + 1.31LTEQ$	0.86	4	16.78%
		HW	$HW = 24994.33 - 288.23(54.01 - DBT) + -126.75(DBT - 54.01) + 415.49LTEQ$	0.47	4550	12.67%
139	Dec-June	WBE	$WBE = -4.80 - 0.03(47.00 - DBT) + 0.29(DBT - 47.00) + 1.40LTEQ$	0.87	4	17.24%
		HW	$HW = 25390.71 - 279.08(57.00 - DBT) + -96.21(DBT - 57.00) + 359.84LTEQ$	0.47	4344	12.32%
140	Dec-July	WBE	$WBE = -6.31 - 0.04(47.77 - DBT) + 0.33(DBT - 47.77) + 1.47LTEQ$	0.84	5	19.49%
		HW	$HW = 24877.54 - 257.82(64.00 - DBT) + 1.45(DBT - 64.00) + 314.46LTEQ$	0.48	4153	11.95%
141	Dec-Aug	WBE	$WBE = -7.65 - 0.05(47.01 - DBT) + 0.32(DBT - 47.01) + 1.54LTEQ$	0.85	5	18.89%
		HW	$HW = 25195.29 - 250.90(66.01 - DBT) + 42.05(DBT - 66.01) + 281.27LTEQ$	0.48	3975	11.57%
142	Dec-Sept	WBE	$WBE = -7.94 - 0.06(47.01 - DBT) + 0.32(DBT - 47.01) + 1.55LTEQ$	0.84	5	19.27%
		HW	$HW = 26022.29 - 257.48(64.00 - DBT) + 8.47(DBT - 64.00) + 255.77LTEQ$	0.25	3870	11.41%
143	Dec-Oct	WBE	$WBE = -7.02 - 0.00(51.00 - DBT) + 0.33(DBT - 51.00) + 1.54LTEQ$	0.84	5	19.59%
		HW	$HW = 27265.25 - 295.64(56.99 - DBT) + -43.32(DBT - 56.99) + 238.00LTEQ$	0.47	3722	10.99%
144	Dec-Nov	WBE	$WBE = -7.77 - 0.12(44.00 - DBT) + 0.30(DBT - 44.00) + 1.50LTEQ$	0.82	5	20.28%
		HW	$HW = 27047.32 - 269.50(58.00 - DBT) + -49.03(DBT - 58.00) + 251.04LTEQ$	0.44	3855	11.32%

### C1.3. Hotel, Washington D.C Region

#### a. Time Series and Scatter Plots

Typical examples of the time series and scatter plots for the WBE energy channel for the hotel in Washington D.C. are shown in Fig C1.3.1 and Fig. C1.3.2, respectively. The blue portion on the graphs represents the short data-set used to estimate the energy use over the whole year represented by the red portion on the graphs. The graphs were plotted for each of all the base periods shown in Table C1.3.

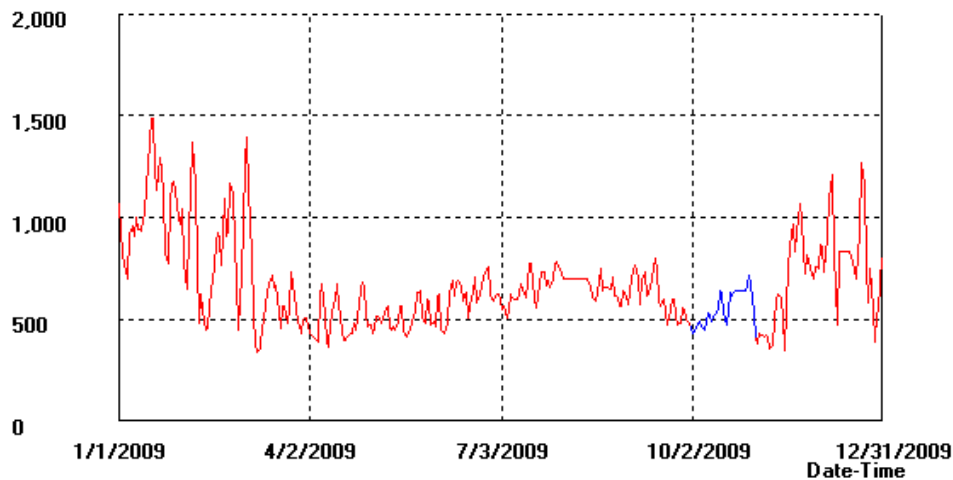


Figure C1.3.1 Time Series Plots for WBE for October used as the Short Data-Set for Service Hotel, Washington D.C.

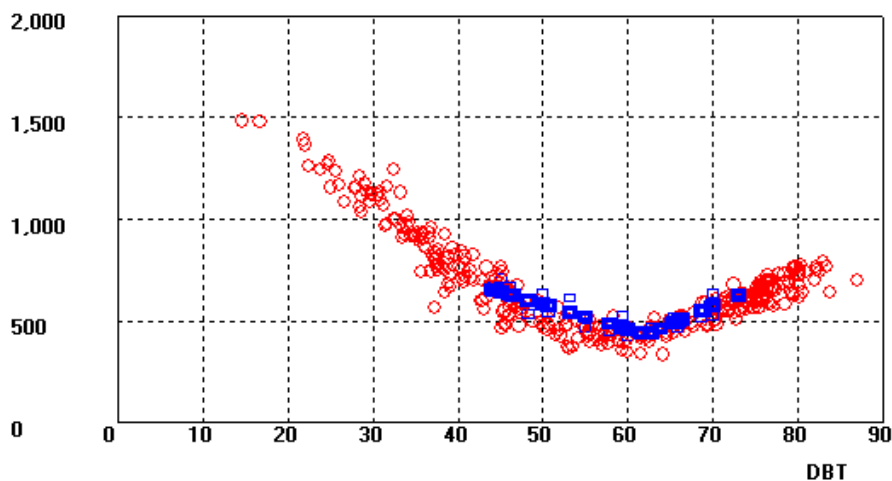


Figure C1.3.2 Scatter Plot for WBE for October used as the Short Data-Set for the Hotel, Washington D.C.

## b. Multivariate Change Point Models

Table C1.3.1

*MCP Models for all Base Periods and Energy Channels for Full Service Hotel, Washington D.C.*

S.No.	Base Period	Channel	Equation	R <sup>2</sup>	RMSE	CV-RMSE
1	January	WBE	WBE=1014.60 - -25.57 (33.20-DBT) + + -39.67 (DBT-33.20)+ + 0.0 LTEQ	0.87	73.75	7.05%
2	Jan-Feb	WBE	WBE = 690.42 -- 31.22 (42.36-DBT)+ + -17.18 (DBT - 42.36)+ + 0.00 LTEQ	0.92	73.73	7.88%
3	Jan-March	WBE	WBE = 636.47 - -33.52(43.02 - DBT)+ + -15.69(DBT - 43.02)+ + 0.00LTEQ	0.93	75.01	9.02%
4	Jan-April	WBE	WBE = 382.32 - -29.39(53.36 - DBT)+ + 10.19(DBT -53.36)+ + 0.00LTEQ	0.93	76.35	10.21%
5	Jan-May	WBE	WBE = 390.62 - -29.39(53.08 - DBT)+ + 9.26(DBT-53.08)+ + 0.00LTEQ	0.94	70.88	10.15%
6	Jan-June	WBE	WBE = 377.35 - -29.39(53.53 - DBT)+ + 11.46(DBT-53.53)+ + 0.00 LTEQ	0.93	67.73	9.91%
7	Jan-July	WBE	WBE = 370.80 - -29.38(53.76 - DBT)+ + 12.29(DBT - 53.76)+ + 0.00LTEQ	0.93	65.04	9.58%
8	Jan-August	WBE	WBE = -373.02 --29.41(53.68 - DBT)+ + 12.31(DBT - 53.68)+ + 0.00LTEQ	0.92	63.2	9.34%
9	Jan-Sept	WBE	WBE = 369.52 - -29.41(53.80 - DBT)+ + 12.38(DBT-53.80)+ + 0.00LTEQ	0.92	61.35	9.16%
10	Jan-October	WBE	WBE = 375.37 - -28.54(54.24 - DBT)+ + 12.35(DBT - 54.24)+ + 0.00LTEQ	0.91	61.45	9.34%
11	Jan-Nov	WBE	WBE =372.04 - -28.53(54.33- DBT)+ + 12.54(DBT - 54.33)+ + 0.00LTEQ	0.92	61.35	9.35
12	Jan-Dec	WBE	WBE =372.74 - -28.56(54.32 - DBT)+ + 12.49(DBT - 54.32)+ + 0.00LTEQ	0.92	61.39	9.17%
13	February	WBE	WBE= 718.80 - -34.51(40.40 - DBT)+ + -16.76(DBT - 40.40)+ + 0.00LTEQ	0.92	70.35	8.67%
14	Feb-March	WBE	WBE= 685.87 - -38.29(40.16 - DBT)+ + 16.07(DBT - 40.16)+ + 0.00LTEQ	0.93	70.27	9.78%
15	Feb-April	WBE	WBE= 383.48 - -28.46(53.50-DBT)+ + 10.22(DBT - 53.50)+ + 0.00LTEQ	0.9	76.49	11.88%
16	Feb-May	WBE	WBE= 391.76 - -28.46(53.20 - DBT)+ + 9.26(DBT - 53.20)+ + 0.00LTEQ	0.9	69.49	11.42%
17	Feb-June	WBE	WBE= 378.76 - -28.46(53.66 - DBT)+ + 11.46(DBT - 53.66)+ + 0.00LTEQ	0.89	65.87	10.83%
18	Feb-July	WBE	WBE= 372.34 - -28.45(53.89 - DBT)+ + 12.29(DBT - 53.89)+ + 0.00LTEQ	0.89	62.96	10.22%
19	Feb-August	WBE	WBE= 374.68 - -28.46(53.80 - DBT)+ + 12.13(DBT - 53.80)+ + 0.00LTEQ	0.88	61.1	9.81%
20	Feb-Sept	WBE	WBE= 371.17 - -28.45(53.93 - DBT)+ + 12.39(DBT-53.93)+ + 0.00LTEQ	0.87	59.2	9.53%
21	Feb-October	WBE	WBE= 378.16 - -27.33(54.45-DBT)+ + 12.34(DBT-54.45)+ + 0.00LTEQ	0.86	59.43	9.68%
22	Feb-Nov	WBE	WBE= 373.89 - -27.23(54.70 - DBT)+ + 12.68(DBT - 54.70)+ + 0.00LTEQ	0.87	59.51	9.66%
23	Feb-Dec	WBE	WBE = 374.56 --27.81(54.48 - DBT)+ + 12.51(DBT - 54.48)+ + 0.00LTEQ	0.89	59.84	9.43%
24	Feb-Jan	WBE	WBE =372.74 - -28.56(54.32 - DBT)+ + 12.49(DBT - 54.32)+ + 0.00LTEQ	0.92	61.39	9.17%
25	March	WBE	WBE=700.79 - -44.01(38.02-DBT)+ + -15.62(DBT-38.02)++0.00LTEQ	0.94	62.97	9.92%
26	March-April	WBE	WBE=377.98--27.32(53.83-DBT)++10.78(DBT-53.83)++0.00LTEQ	0.86	77.59	13.68%
27	March-May	WBE	WBE=389.21--27.32(53.42-DBT)++9.55(DBT-53.42)++0.00LTEQ	0.85	68.14	12.47%
28	March-June	WBE	WBE=376.30 --27.32(53.89-DBT)++11.75(DBT-53.89)++0.00LTEQ	0.84	63.74	11.35%
29	March-July	WBE	WBE=369.51--27.12(54.26-DBT)++12.66(DBT-54.26)++0.00LTEQ	0.84	60.49	10.43%
30	March-Aug	WBE	WBE=372.58--27.33(54.02-DBT)++12.35(DBT-54.02)++0.00LTEQ	0.83	58.75	9.89%
31	March-Sept	WBE	WBE=368.95--27.13(54.27-DBT)++12.69(DBT-54.27)++0.00LTEQ	0.82	56.79	9.52%
32	March-Oct	WBE	WBE=377.01--24.06(55.96-DBT)++13.40(DBT-55.96)++0.00LTEQ	0.81	56.79	9.60%
33	March-Nov	WBE	WBE=370.71--24.99(55.89-DBT)++13.67(DBT-55.89)++0.00LTEQ	0.84	57.29	9.61%

34	March-Dec	WBE	WBE=368.93--26.17(55.63-DBT)++13.57(DBT-55.63)++0.00LTEQ	0.87	58.31	9.43%
35	March-Jan	WBE	WBE=370.48--28.54(54.43-DBT)++12.68(DBT-54.43)++0.00LTEQ	0.92	60.27	9.16%
36	March-Feb	WBE	WBE =372.74 - -28.56(54.32 - DBT)+ +12.49(DBT - 54.32)+ +0.00LTEQ	0.92	61.39	9.17%
37	April	WBE	WBE=377.12- -13.53(61.11-DBT)+ +19.33(DBT-61.11)++0.00LTEQ	0.72	55.31	11.13%
38	April-May	WBE	WBE=405.95--12.12(60.26-DBT)++14.99(DBT-60.26)++0.00LTEQ	0.67	48.5	9.67%
39	April-June	WBE	WBE=403.55--11.39(61.07-DBT)++16.83(DBT-61.07)++0.00LTEQ	0.79	45.04	8.39%
40	April-July	WBE	WBE=400.54--11.38(61.33-DBT)+ +17.21(DBT-61.33)++0.00LTEQ	0.83	43.25	7.64%
41	April-August	WBE	WBE=406.01--12.12(60.25-DBT)++15.28(DBT-60.25)++0.00LTEQ	0.81	46.1	7.87%
42	April-Sept	WBE	WBE=406.37-12.12(60.22-DBT)++15.24(DBT-60.22)++0.00LTEQ	0.81	45.21	7.66%
43	April-Oct	WBE	WBE= 409.02--14.22(60.19-DBT)++15.07(DBT-60.19)++0.00LTEQ	0.8	45.37	7.75%
44	April-Nov	WBE	WBE=383.23--23.28(56.66-DBT)++13.58(DBT-56.66)++0.00LTEQ	0.83	50.07	8.47%
45	April-Dec	WBE	WBE=378.06--25.39(56.09-DBT)++13.44(DBT-56.09)++0.09LTEQ	0.88	52.35	8.49%
46	April-Jan	WBE	WBE=373.01--26.99(55.69-DBT)++13.43(DBT-55.69)++0.00LTEQ	0.91	63.19	7.77%
47	April-Feb	WBE	WBE=378.48 - -27.95(54.71-DBT)+ +12.48(DBT-54.71)++0.00LTEQ	0.93	57.55	8.55%
48	April-March	WBE	WBE =372.74 - -28.56(54.32 - DBT)+ +12.49(DBT - 54.32)+ +0.00LTEQ	0.92	61.39	9.17%
49	May	WBE	WBE=460.48--0.55(64.50-DBT)++15.50(DBT-64.50)++0.00LTEQ	0.67	37.82	7.47%
50	May-June	WBE	WBE=453.10--1.50(64.35-DBT)++17.35(DBT-64.35)++0.00LTEQ	0.83	37.68	6.77%
51	May-July	WBE	WBE=466.18-0.51(65.95-DBT)++18.54(DBT-65.95)++0.00LTEQ	0.85	37.46	6.38%
52	May-Aug	WBE	WBE=432.67--6.74(62.00-DBT)++15.26(DBT-62.00)++0.00LTEQ	0.79	43.18	7.11%
53	May-Sept	WBE	WBE=-458.12--0.84(63.93-DBT)++15.61(DBT-63.93)++0.00LTEQ	0.79	42.64	7.01%
54	May-Oct	WBE	WBE=425.80--13.42(61.25-DBT)++15.00(DBT-61.25)++0.00LTEQ	0.8	41.96	7.00%
55	May-Nov	WBE	WBE=-380.49-23.28(57.02-DBT)++14.00(DBT-57.02)++0.00LTEQ	0.84	48.66	8.05%
56	May-Dec	WBE	WBE=374.32--25.54(56.27-DBT)++13.77(DBT-56.27)++0.00LTEQ	0.88	51.42	8.16%
57	May-Jan	WBE	WBE=368.26--27.11(55.83-DBT)++13.76(DBT-55.83)++0.00LTEQ	0.93	55.07	8.12%
58	May-Feb	WBE	WBE=375.29--28.30(54.59-DBT)++12.57(DBT-54.59)++0.00LTEQ	0.93	57.32	8.31%
59	May-March	WBE	WBE=367.32--28.82(54.33-DBT)++12.77(DBT-54.33)++0.00LTEQ	0.92	61.41	8.96%
60	May-April	WBE	WBE =372.74 - -28.56(54.32 - DBT)+ +12.49(DBT - 54.32)+ +0.00LTEQ	0.92	61.39	9.17%
61	June	WBE	WBE=662.09-16.18(76.60-DBT)++26.38(DBT-76.60)++0.00LTEQ	0.82	38.08	6.26%
62	June-July	WBE	WBE=624.13-15.17(75.10-DBT)++23.94(DBT-75.10)++0.00LTEQ	0.82	36.33	5.76%
63	June-Aug	WBE	WBE=716.00-17.50(79.60-DBT)++2.77(DBT-79.60)++0.00LTEQ	0.69	41.8	6.52%
64	June-Sept	WBE	WBE=753.89-16.02(82.48-DBT)++14.45(DBT-82.48)++0.00LTEQ	0.73	42.21	6.66%
65	June-Oct	WBE	WBE=436.86--12.66(61.84-DBT)++14.91(DBT-61.84)++0.00LTEQ	0.77	42.36	6.84%
66	June-Nov	WBE	WBE=366.44--24.54(56.76-DBT)++14.62(DBT-56.76)++0.00LTEQ	0.83	48.62	7.82%
67	June-Dec	WBE	WBE=362.80--26.38(56.13-DBT)++14.33(DBT-56.13)++0.00LTEQ	0.89	51.45	7.93%
68	June-Jan	WBE	WBE=356.67--27.71(55.78-DBT)++14.37(DBT-55.71)++0.00LTEQ	0.93	55.41	7.93%
69	June-Feb	WBE	WBE=-359.80--27.51(55.74-DBT)++14.21(DBT-55.74)++0.00LTEQ	0.93	57.83	8.13%
70	June-March	WBE	WBE=359.29--28.83(54.61-DBT)++13.43(DBT-54.61)++0.00LTEQ	0.92	62.21	8.85%
71	June-April	WBE	WBE=368.01--28.55(54.49-DBT)++12.93(DBT-54.49)++0.00LTEQ	0.92	62.22	9.09%
72	June-May	WBE	WBE =372.74 - -28.56(54.32 - DBT)+ +12.49(DBT - 54.32)+ +0.00LTEQ	0.92	61.39	9.17%
73	July	WBE	WBE = 546.94 - -3.42(72.18 - DBT)+ +24.69(DBT - 72.18)+ +0.00LTEQ	0.83	32.72	5.01%

74	July-August	WBE	WBE = 683.81 - 29.44(76.67 - DBT)+ +3.88(DBT - 76.67)+ +0.00LTEQ	0.58	41.55	6.32%
75	July-Sept	WBE	WBE = 753.57 - 15.78(82.67 - DBT)+ +15.25(DBT - 82.67)+ +0.00LTEQ	0.69	43.7	6.80%
76	July-October	WBE	WBE = 439.07 --12.30(61.72 - DBT)+ +14.53(DBT - 61.72)+ +0.00LTEQ	0.76	43.62	7.03%
77	July-Nov	WBE	WBE = 369.28 - -24.55(56.64 - DBT)+ +14.31(DBT - 56.64)+ +0.00LTEQ	0.84	50.38	8.07%
78	July-Dec	WBE	WBE = 366.14 -- 26.31(56.01 - DBT)+ +14.01(DBT - 56.01)+ +0.00LTEQ	0.89	53.25	8.12%
79	July-Jan	WBE	WBE = 360.82 - -27.70(55.64 - DBT)+ +14.01(DBT - 55.64)+ +0.00LTEQ	0.93	57.2	8.03%
80	July-Feb	WBE	WBE = 372.18 - -28.29(54.71 - DBT)+ +12.85(DBT - 54.71)+ +0.00LTEQ	0.93	59.66	8.24%
81	July-March	WBE	WBE = 362.68 -- 28.83(54.49 - DBT)+ +13.13(DBT - 54.49)+ +0.00LTEQ	0.92	64.17	8.99%
82	July-April	WBE	WBE = 370.85 -- 28.55(54.39 - DBT)+ +12.68(DBT - 54.39)+ +0.00LTEQ	0.92	63.92	9.23%
83	July-May	WBE	WBE = 375.10 - -28.54(54.24 - DBT)+ +12.27(DBT - 54.24)+ +0.00LTEQ	0.92	62.84	9.31%
84	July-June	WBE	WBE =372.74 - -28.56(54.32 - DBT)+ +12.49(DBT - 54.32)+ +0.00LTEQ	0.92	61.39	9.17%
85	August	WBE	WBE =676.49 - 29.89(76.30 - DBT)+ +0.61(DBT - 76.30)+ +0.00LTEQ	0.46	36.31	5.49%
7	Aug-Sept	WBE	WBE =665.70 -16.98(76.30 - DBT)+ +6.54(DBT - 76.30)+ +0.00LTEQ	0.7	44.28	6.95%
87	Aug-October	WBE	WBE =443.53 - -12.46(61.17 - DBT)+ +13.53(DBT -61.17)+ +0.00LTEQ	0.76	44.18	7.24%
88	Aug-Nov	WBE	WBE =375.51 - -24.54(56.39 - DBT)+ +13.67(DBT -56.39)+ +0.00LTEQ	0.85	52.34	8.49%
89	Aug-Dec	WBE	WBE =372.30 --26.30(55.78 - DBT)+ +13.41(DBT -55.78)+ +0.00LTEQ	0.9	55.2	8.41%
90	Aug-Jan	WBE	WBE =369.44 - -27.94(55.14 - DBT)+ +13.17(DBT -55.14)+ +0.00LTEQ	0.93	59.28	8.21%
91	Aug-Feb	WBE	WBE =377.81 -- 28.30(54.51 - DBT)+ +12.32(DBT -54.51)+ +0.00LTEQ	0.93	61.55	8.38%
92	Aug-March	WBE	WBE =367.65 - -28.83(54.32 - DBT)+ +12.64(DBT -54.32)+ +0.00LTEQ	0.83	43.25	7.64%
93	Aug-April	WBE	WBE =374.17 - -28.55(54.27 - DBT)+ +12.34(DBT -54.27)+ +0.00LTEQ	0.92	65.7	9.43%
94	Aug-May	WBE	WBE= 379.06 - -28.60(54.07 - DBT)+ +11.77(DBT -54.07)+ +0.00LTEQ	0.92	64.28	9.49%
95	Aug-June	WBE	WBE =375.74 - -28.55(54.22 - DBT)+ +12.16(DBT -54.22)+ +0.00LTEQ	0.92	62.67	9.34%
96	Aug-July	WBE	WBE =372.74 - -28.56(54.32 - DBT)+ +12.49(DBT - 54.32)+ +0.00LTEQ	0.82	5.46	20.28%
97	September	WBE	WBE =687.84 - 13.80(79.50 - DBT)+ +23.76(DBT - 79.50)+ +0.00LTEQ	0.83	41.8	6.83%
98	Sept-Oct	WBE	WBE =437.63 - -12.30(61.84 - DBT)+ +14.96(DBT - 61.84)+ +0.00LTEQ	0.83	39.47	6.76%
99	Sept-Nov	WBE	WBE =368.00 - -24.54(56.70 - DBT)+ +14.51(DBT - 56.70)+ +0.00LTEQ	0.88	52.57	8.74%
100	Sept-Dec	WBE	WBE =365.66 - -26.30(56.03 - DBT)+ +14.07(DBT - 56.03)+ +0.00LTEQ	0.91	56.2	8.58%
101	Sept-Jan	WBE	WBE =360.24 -- 27.70(55.66 - DBT)+ +14.09(DBT - 55.66)+ +0.00LTEQ	0.94	60.91	8.29%
102	Sept-Feb	WBE	WBE =374.16 - -28.29(54.64 - DBT)+ +12.54(DBT - 54.64)+ +0.00LTEQ	0.94	63.42	8.49%
103	Sept-March	WBE	WBE =364.60 - -28.83(54.42 - DBT)+ +12.80(DBT - 54.42)+ +0.00LTEQ	0.93	68.39	9.37%
104	Sept-April	WBE	WBE =372.96 - -28.56(54.31 - DBT)+ +12.28(DBT - 54.31)+ +0.00LTEQ	0.93	67.55	9.63%
105	Sept-May	WBE	WBE = -379.45 - -28.61(54.05 - DBT)+ +11.48(DBT - 54.05)+ +0.00LTEQ	0.93	65.72	9.68%
106	Sept-June	WBE	WBE =374.69 - -28.55(54.26 - DBT)+ +12.16(DBT - 54.26)+ +0.00LTEQ	0.93	63.88	9.50%
107	Sept-July	WBE	WBE = 371.05 - -28.55(54.38 - DBT)+ +12.63(DBT - 54.38)+ +0.00LTEQ	0.92	62.39	9.31%
108	Sept-Aug	WBE	WBE =372.74 - -28.56(54.32 - DBT)+ +12.49(DBT - 54.32)+ +0.00LTEQ	0.82	5.46	20.28%
109	October	WBE	WBE = 434.11 - -12.30(62.13 - DBT)+ +17.80(DBT - 62.13)+ +0.00LTEQ	0.82	37.7	6.77%
110	Oct-Nov	WBE	WBE = 370.22 - -24.54(56.60 - DBT)+ +14.39(DBT - 56.60)+ +0.00LTEQ	0.89	57.76	9.69%
111	Oct-Dec	WBE	WBE = 372.96 - -26.30(55.75 - DBT)+ +12.92(DBT - 55.75)+ +0.00LTEQ	0.92	60.43	9.03%
112	Oct-Jan	WBE	WBE = 383.53 - -28.20(54.46 - DBT)+ +10.49(DBT - 54.46)+ +0.00LTEQ	0.94	64.71	8.64%
113	Oct-Feb	WBE	WBE = 400.93 - -28.53(53.53 - DBT)+ +8.24(DBT - 53.53)+ +0.00LTEQ	0.94	66.4	8.59%

114	Oct-March	WBE	WBE = 412.62 - -29.59(52.28 - DBT)+ +5.72(DBT - 52.28)+ +0.00LTEQ	0.93	71.21	9.50%
115	Oct-April	WBE	WBE = 387.75 - -28.76(53.66 - DBT)+ +9.67(DBT - 53.66)+ +0.00LTEQ	0.93	70.09	9.82%
116	Oct-May	WBE	WBE = 392.63 - -28.75(53.50 - DBT)+ +9.24(DBT - 53.50)+ +0.00LTEQ	0.93	67.34	9.80%
117	Oct-June	WBE	WBE = 379.53 - -28.60(54.05 - DBT)+ +11.53(DBT - 54.05)+ +0.00LTEQ	0.93	65.67	9.68%
118	Oct-July	WBE	WBE = 373.59 - -28.56(54.29 - DBT)+ +12.39(DBT - 54.29)+ +0.00LTEQ	0.92	63.99	9.46%
119	Oct-Aug	WBE	WBE = 375.07 - -28.55(54.24 - DBT)+ +12.31(DBT - 54.24)+ +0.00LTEQ	0.92	55.2	8.41%
120	Oct-Sept	WBE	WBE = 372.74 - -28.56(54.32 - DBT)+ +12.49(DBT - 54.32)+ +0.00LTEQ	0.82	5.46	20.28%
121	November	WBE	WBE = 422.38 - -29.81(51.77 - DBT)+ +3.26(DBT - 51.77)+ +0.00LTEQ	0.94	54.96	8.63%
122	Nov-Dec	WBE	WBE = 426.93 - -29.07(52.13 - DBT)+ +3.50(DBT - 52.13)+ +0.00LTEQ	0.94	58.51	8.05%
123	Nov-Jan	WBE	WBE = 428.34 - -29.59(51.95 - DBT)+ +3.60(DBT - 51.95)+ +0.00LTEQ	0.94	64.24	7.70%
124	Nov-Feb	WBE	WBE = 447.66 - -29.69(51.16 - DBT)+ +4.72(DBT - 51.16)+ +0.00LTEQ	0.94	66.08	7.97%
125	Nov-March	WBE	WBE = 513.61 - -30.84(48.21 - DBT)+ +10.47(DBT - 48.21)+ +0.00LTEQ	0.93	69.52	7.75%
126	Nov-April	WBE	WBE = 383.62 - -29.38(53.37 - DBT)+ +9.14(DBT - 53.37)+ +0.00LTEQ	0.93	71.34	9.63%
127	Nov-May	WBE	WBE = 388.76 - -29.37(53.20 - DBT)+ +9.13(DBT - 53.20)+ +0.00LTEQ	0.94	67.93	9.63%
128	Nov-June	WBE	WBE = 376.62 - -29.37(53.62 - DBT)+ +11.43(DBT - 53.62)+ +0.00LTEQ	0.93	66.17	9.53%
129	Nov-July	WBE	WBE = 368.97 - -29.18(54.01 - DBT)+ +12.47(DBT - 54.01)+ +0.00LTEQ	0.93	64.25	9.32%
130	Nov-Aug	WBE	WBE = 370.89 - -29.18(53.94 - DBT)+ +12.35(DBT - 53.94)+ +0.00LTEQ	0.92	62.88	9.16%
131	Nov-Sept	WBE	WBE = 368.22 - -29.19(54.03 - DBT)+ +12.55(DBT - 54.03)+ +0.00LTEQ	0.92	61.27	9.01%
132	Nov-Oct	WBE	WBE = 372.74 - -28.56(54.32 - DBT)+ +12.49(DBT - 54.32)+ +0.00LTEQ	0.82	5.46	20.28%
133	December	WBE	WBE = 576.86 - -28.52(47.30 - DBT)+ +13.63(DBT - 47.30)+ +0.00LTEQ	0.91	63.19	7.77%
134	Dec-Jan	WBE	WBE = 573.70 - -29.21(47.30 - DBT)+ +13.34(DBT - 47.30)+ +0.00LTEQ	0.91	68.9	7.41%
135	Dec-Feb	WBE	WBE = 511.30 - -29.54(49.13 - DBT)+ +8.41(DBT - 49.13)+ +0.00LTEQ	0.92	69.55	7.79%
136	Dec-March	WBE	WBE = 521.85 - -30.72(47.99 - DBT)+ +10.72(DBT - 47.99)+ +0.00LTEQ	0.93	72.86	8.81%
137	Dec-April	WBE	WBE = 383.90 - -29.31(53.42 - DBT)+ +10.06(DBT - 53.42)+ +0.00LTEQ	0.93	73.55	9.66%
138	Dec-May	WBE	WBE = 391.51 - -29.31(53.17 - DBT)+ +9.22(DBT - 53.17)+ +0.00LTEQ	0.77	42.36	6.84%
139	Dec-June	WBE	WBE = 378.62 - -29.31(53.60 - DBT)+ +11.43(DBT - 53.60)+ +0.00LTEQ	0.93	66.92	9.53%
140	Dec-July	WBE	WBE = 372.35 - -29.31(53.82 - DBT)+ +12.24(DBT - 53.82)+ +0.00LTEQ	0.93	64.68	9.29%
141	Dec-Aug	WBE	WBE = 374.56 - -29.32(53.74 - DBT)+ +12.09(DBT - 53.74)+ +0.00LTEQ	0.92	63.09	9.11%
142	Dec-Sept	WBE	WBE = 371.15 - -29.32(53.85 - DBT)+ +12.34(DBT - 53.85)+ +0.00LTEQ	0.92	61.44	8.98%
143	Dec-Oct	WBE	WBE = 376.02 - -28.56(54.23 - DBT)+ +12.31(DBT - 54.23)+ +0.00LTEQ	0.92	61.48	9.14%
144	Dec-Nov	WBE	WBE = 372.74 - -28.56(54.32 - DBT)+ +12.49(DBT - 54.32)+ +0.00LTEQ	0.82	5.46	20.28%

## C2. Hybrid Inverse Modeling Approach-Method 1

(Refer Section 6.5 and Sections 9.1.1 and 9.1.2)

This approach for predicting energy use combines the monitored daily energy use and internal loads with atleast one year of recent utility bills (representing the long-term data) to provide a prediction of the building energy performance for the whole year (Abushakra, Reddy, Claridge 1999). Thus, in this modeling technique, information from monthly utility bills is applied to the model. The utility bills are accurate and easily acceptable sources of building energy information. In order to minimize the confounding effects of co-linearity between regression variables, the regression is completed in two stages (Abushakra 2000).

### C2.1. Large Hotel at Chicago, Illinois

Table C2.1.1

*One Year of Monthly Utility History (Daily Average Values) for Large Hotel at Chicago, IL.*

Monthly Utility History							
S.No.	Year	Month	DBT <sub>k</sub>	$(w_k - 0.009)^+$	WBE <sub>k</sub> k Wh	HW <sub>k</sub> MBTU/hr	CHW <sub>k</sub> MBTU/hr
1	2007	1	23.6	0.00000	948	8232	401
2	2007	2	28.0	0.00000	944	8918	392
3	2007	3	34.9	0.00000	947	7096	426
4	2007	4	47.1	0.00000	967	3975	694
5	2007	5	59.5	0.00027	1057	1411	1837
6	2006	6	70.0	0.00141	1181	517	4588
7	2006	7	74.3	0.00263	1259	445	6540
8	2006	8	71.2	0.00315	1243	474	5937
9	2006	9	64.6	0.00113	1123	617	3618
10	2006	10	53.1	0.00015	1018	2016	1237
11	2006	11	39.6	0.00007	953	5070	553
12	2006	12	27.4	0.00000	939	8847	404



**a. Regression Equations Obtained from Utility Bills (Stage 1):**

Table C2.1.2

*Regression Equations for Stage-1 of Hybrid Inverse Modeling (Method 1) for Large Hotel at Chicago, IL*

Model	Model Equation	R <sup>2</sup>	RMSE	CV-RMSE
4P Model	WBEk = 945.70 - 0.00 (44.32 - DBTk) + + 7.07(DBTk - 44.32) + + 35757.29 (wk-0.009) +	1	5.49	0.50%
	HW <sub>k</sub> = 664.71 --226.29 (61.40 - DBTk) + + 0.00(DBTk - 61.40) + + 72833.71 (wk-0.009) +	0.98	532.01	13.40%
	CHW <sub>k</sub> = 469.37 - 0.00 (50.33 - DBTk) + + 156.92(DBTk - 50.33) + + 767034.10 (wk-0.009) +	0.99	192.24	8.70%

**b. Regression Equations Obtained from Utility Bills and Monitored Data (Stage 2):**

Table C2.1.3

*Regression Equations for Stage-2 of Hybrid Inverse Modeling (Method 1) for Large Hotel at Chicago, IL*

Base Period	Model	Model Equation
January	2P Linear	2E* = -954.52 - 0.00 (44.32 - DBTk) + + 7.07(DBTk - 44.32) + + 35757.29 (wk-0.009) + + 2.09LTEQ(WD) + 2.76LTEQ(WE)
		2C* = -6314.82 --226.29 (61.40 - DBTk) + + 0.00(DBTk - 61.40) + + 72833.71 (wk-0.009) + + 7.20LTEQ(WD) + 11.64 LTEQ(WE)
		2H* = 9478.60 - 0.00 (50.33 - DBTk) + + 156.92(DBTk - 50.33) + + 767034.10 (wk-0.009) + + -10.57 LTEQ(WD) + -16.18LTEQ(WE)
Jan-Feb	2P Linear	2E* = -866.30 - 0.00 (44.32 - DBTk) + + 7.07(DBTk - 44.32) + + 35757.29 (wk-0.009) + + 1.99LTEQ(WD) + 2.61LTEQ(WE)
		2C* = -5646.07 --226.29 (61.40 - DBTk) + + 0.00(DBTk - 61.40) + + 72833.71 (wk-0.009) + + 6.47LTEQ(WD) + 10.48 LTEQ(WE)
		2H* = -4498.33 - 0.00 (50.33 - DBTk) + + 156.92(DBTk - 50.33) + + 767034.10 (wk-0.009) + + 5.24 LTEQ(WD) + 9.59LTEQ(WE)
Jan-March	2P Linear	2E* = -997.35 - 0.00 (44.32 - DBTk) + + 7.07(DBTk - 44.32) + + 35757.29 (wk-0.009) + + 2.13LTEQ(WD) + 2.84LTEQ(WE)
		2C* = -5109.42 --226.29 (61.40 - DBTk) + + 0.00(DBTk - 61.40) + + 72833.71 (wk-0.009) + + 5.89LTEQ(WD) + 9.56 LTEQ(WE)
		2H* = 5779.94 - 0.00 (50.33 - DBTk) + + 156.92(DBTk - 50.33) + + 767034.10 (wk-0.009) + + -5.54 LTEQ(WD) + -7.95LTEQ(WE)
March	2P Linear	2E* = -1574.13 - 0.00 (44.32 - DBTk) + + 7.07(DBTk - 44.32) + + 35757.29 (wk-0.009) + + 2.75LTEQ(WD) + 3.85LTEQ(WE)
		2C* = -1867.58 --226.29 (61.40 - DBTk) + + 0.00(DBTk - 61.40) + + 72833.71 (wk-0.009) + + 7.20LTEQ(WD) + 11.64 LTEQ(WE)
		2H* = -36271.21 - 0.00 (50.33 - DBTk) + + 156.92(DBTk - 50.33) + + 767034.10 (wk-0.009) + + 40.05 LTEQ(WD) + 66.42LTEQ(WE)
March-April	2P Linear	2E* = 73.10 - 0.00 (44.32 - DBTk) + + 7.07(DBTk - 44.32) + + 35757.29 (wk-0.009) + + 0.99LTEQ(WD) + 0.98LTEQ(WE)
		2C* = 4578.98 --226.29 (61.40 - DBTk) + + 0.00(DBTk - 61.40) + + 72833.71 (wk-0.009) + - 4.45LTEQ(WD) + - 7.25 LTEQ(WE)
		2H* = -52457.90 - 0.00 (50.33 - DBTk) + + 156.92(DBTk - 50.33) + + 767034.10 (wk-0.009) + + 57.38 LTEQ(WD) + 94.84LTEQ(WE)
March-May	2P Linear	2E* = -35.91 - 0.00 (44.32 - DBTk) + + 7.07(DBTk - 44.32) + + 35757.29 (wk-0.009) + + 1.11LTEQ(WD) + 1.17LTEQ(WE)
		2C* = -11579.46 --226.29 (61.40 - DBTk) + + 0.00(DBTk - 61.40) + + 72833.71 (wk-0.009) + + 12.87LTEQ(WD) + 21.21 LTEQ(WE)
		2H* = -35635.27 - 0.00 (50.33 - DBTk) + + 156.92(DBTk - 50.33) + + 767034.10 (wk-0.009) + + 39.21 LTEQ(WD) + 65.24LTEQ(WE)
May	2P	2E* = -296.81 - 0.00 (44.32 - DBTk) + + 7.07(DBTk - 44.32) + + 35757.29 (wk-0.009) + + 1.39LTEQ(WD) + 1.64LTEQ(WE)
		2C* = -17348.51 --226.29 (61.40 - DBTk) + + 0.00(DBTk - 61.40) + + 72833.71 (wk-0.009) + + 18.96LTEQ(WD) + 31.43

Base Period	Model	Model Equation
	Linear	LTEQ(WE)
		$2H^* = -2826.49 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 3.50 LTEQ(WD) + 6.82LTEQ(WE)$
May-June	2P Linear	$2E^* = 784.88 - 0.00 (44.32 - DBTk) + 7.07(DBTk - 44.32) + 35757.29 (wk-0.009)^* + 0.23LTEQ(WD) + 0.28LTEQ(WE)$
		$2C^* = 7784.02 - 226.29 (61.40 - DBTk) + 0.00(DBTk - 61.40) + 72833.71 (wk-0.009)^* + 8.13LTEQ(WD) + 13.49 LTEQ(WE)$
		$2H^* = -582.94 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 1.14 LTEQ(WD) + 2.49LTEQ(WE)$
May-July	2P Linear	$2E^* = 630.86 - 0.00 (44.32 - DBTk) + 7.07(DBTk - 44.32) + 35757.29 (wk-0.009)^* + 0.40LTEQ(WD) + 0.00LTEQ(WE)$
		$2C^* = 10073.86 - 226.29 (61.40 - DBTk) + 0.00(DBTk - 61.40) + 72833.71 (wk-0.009)^* + 10.44LTEQ(WD) + 17.34LTEQ(WE)$
		$2H^* = 1013.30 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 0.53 LTEQ(WD) + 0.45LTEQ(WE)$
July	2P Linear	$2E^* = 358.69 - 0.00 (44.32 - DBTk) + 7.07(DBTk - 44.32) + 35757.29 (wk-0.009)^* + 0.71LTEQ(WD) + 0.51LTEQ(WE)$
		$2C^* = 13256.23 - 226.29 (61.40 - DBTk) + 0.00(DBTk - 61.40) + 72833.71 (wk-0.009)^* + 13.53LTEQ(WD) + 22.66 LTEQ(WE)$
		$2H^* = 3728.96 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 3.36 LTEQ(WD) + 5.46LTEQ(WE)$
July-August	2P Linear	$2E^* = 814.15 - 0.00 (44.32 - DBTk) + 7.07(DBTk - 44.32) + 35757.29 (wk-0.009)^* + 0.20LTEQ(WD) + 0.35LTEQ(WE)$
		$2C^* = 23941.41 - 226.29 (61.40 - DBTk) + 0.00(DBTk - 61.40) + 72833.71 (wk-0.009)^* + 25.36LTEQ(WD) + 42.57 LTEQ(WE)$
		$2H^* = 3577.26 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 3.16 LTEQ(WD) + 5.15LTEQ(WE)$
July-September	2P Linear	$2E^* = 671.64 - 0.00 (44.32 - DBTk) + 7.07(DBTk - 44.32) + 35757.29 (wk-0.009)^* + 0.36LTEQ(WD) + 0.10LTEQ(WE)$
		$2C^* = 18192.01 - 226.29 (61.40 - DBTk) + 0.00(DBTk - 61.40) + 72833.71 (wk-0.009)^* + 19.12LTEQ(WD) + 32.41LTEQ(WE)$
		$2H^* = 2820.77 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 2.42 LTEQ(WD) + 3.93LTEQ(WE)$
September	2P Linear	$2E^* = 297.48 - 0.00 (44.32 - DBTk) + 7.07(DBTk - 44.32) + 35757.29 (wk-0.009)^* + 0.77LTEQ(WD) + 0.57LTEQ(WE)$
		$2C^* = 6037.19 - 226.29 (61.40 - DBTk) + 0.00(DBTk - 61.40) + 72833.71 (wk-0.009)^* + 5.91LTEQ(WD) + 10.84 LTEQ(WE)$
		$2H^* = 7363.87 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 7.53 LTEQ(WD) + 12.34LTEQ(WE)$
Sept-Oct	2P Linear	$2E^* = 696.41 - 0.00 (44.32 - DBTk) + 7.07(DBTk - 44.32) + 35757.29 (wk-0.009)^* + 0.33LTEQ(WD) + 0.13LTEQ(WE)$
		$2C^* = 11434.23 - 226.29 (61.40 - DBTk) + 0.00(DBTk - 61.40) + 72833.71 (wk-0.009)^* + 11.92LTEQ(WD) + 20.23LTEQ(WE)$
		$2H^* = 18452.46 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 20.25 LTEQ(WD) + 33.82LTEQ(WE)$
Sept-November	2P Linear	$2E^* = 496.82 - 0.00 (44.32 - DBTk) + 7.07(DBTk - 44.32) + 35757.29 (wk-0.009)^* + 0.54LTEQ(WD) + 0.23LTEQ(WE)$
		$2C^* = 5589.33 - 226.29 (61.40 - DBTk) + 0.00(DBTk - 61.40) + 72833.71 (wk-0.009)^* + 5.60LTEQ(WD) + 9.50LTEQ(WE)$
		$2H^* = 23430.92 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 25.57 LTEQ(WD) + 42.76LTEQ(WE)$
November	2P Linear	$2E^* = 660.90 - 0.00 (44.32 - DBTk) + 7.07(DBTk - 44.32) + 35757.29 (wk-0.009)^* + 1.78LTEQ(WD) + 2.29LTEQ(WE)$
		$2C^* = 3357.27 - 226.29 (61.40 - DBTk) + 0.00(DBTk - 61.40) + 72833.71 (wk-0.009)^* + 4.04LTEQ(WD) + 6.89 LTEQ(WE)$
		$2H^* = 52807.28 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 57.22 LTEQ(WD) + 94.74LTEQ(WE)$
Nov-Dec	2P Linear	$2E^* = 396.78 - 0.00 (44.32 - DBTk) + 7.07(DBTk - 44.32) + 35757.29 (wk-0.009)^* + 1.49LTEQ(WD) + 1.80LTEQ(WE)$
		$2C^* = 3789.35 - 226.29 (61.40 - DBTk) + 0.00(DBTk - 61.40) + 72833.71 (wk-0.009)^* + 4.50LTEQ(WD) + 7.42LTEQ(WE)$
		$2H^* = 43343.35 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 47.16 LTEQ(WD) + 78.43LTEQ(WE)$
Nov-Jan	2P Linear	$2E^* = 462.60 - 0.00 (44.32 - DBTk) + 7.07(DBTk - 44.32) + 35757.29 (wk-0.009)^* + 1.56LTEQ(WD) + 1.91LTEQ(WE)$
		$2C^* = 3924.56 - 226.29 (61.40 - DBTk) + 0.00(DBTk - 61.40) + 72833.71 (wk-0.009)^* + 4.64LTEQ(WD) + 7.60LTEQ(WE)$
		$2H^* = 19761.35 - 0.00 (50.33 - DBTk) + 156.92(DBTk - 50.33) + 767034.10 (wk-0.009)^* + 21.45 LTEQ(WD) + 36.33LTEQ(WE)$

## C2.2 Office Building at Albuquerque, New Mexico

Table C2.2.1

*One Year of Monthly Utility History (Daily Average Values) for Office Building at Albuquerque, NM.*

Monthly Utility History						
S.No.	Year	Month	DBT <sub>k</sub>	(w <sub>k</sub> -0.009) <sup>+</sup>	EWB <sub>k</sub> kWh	HW <sub>k</sub> Mbtu/hr
1	2004	1	35.6	0.00000	22	37984
2	2004	2	39.7	0.00000	23	38448
3	2004	3	44.7	0.00000	25	35875
4	2004	4	55.1	0.00079	27	32309
5	2004	5	65.9	0.00026	28	31468
6	2004	6	72.9	0.00184	33	31258
7	2004	7	77.9	0.00405	34	31247
8	2004	8	74.2	0.00416	33	31286
9	2004	9	68.9	0.00190	30	31417
10	2004	10	56.0	0.00019	25	31998
11	2004	11	43.4	0.00000	23	35781
12	2004	12	34.7	0.00000	21	39657

### a. Regression Equations Obtained from Utility Bills (Stage 1):

Table C2.2.2

*Regression Equations for Stage-1 of Hybrid Inverse Modeling (Method-1) for Office at Albuquerque, NM.*

Model Type	Model Equation	R <sup>2</sup>	RMSE	CV-RMSE
4P Model	$WBE_k = 21.57 - 0.00 (34.71 - DBT_k)^+ + 0.22(DBT_k - 34.71)^+ + 777.72 (wk-0.009)^+$	0.97	0.93	3.5
	$HW_k = 31447.21 - 337.56 (57.70 - DBT_k)^+ + 0.00(DBT_k - 57.70)^+ + -45822.31(wk-0.009)^+$	0.98	490.83	1.40%

Table C2.2.3

*Regression Equations for Stage-2 of Hybrid Inverse Modeling (Method-1) for Office at Albuquerque, NM.*

Base Period	Model	Model Equation
January	2P Linear	WBE*=-4 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.17LTEQ(WD)+1.29LTEQ(WE)
		HW* =23926.30 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 424.80 LTEQ(WD)+ -19.40LTEQ(WE)
Jan-Feb	2P Linear	WBE*=-3.71 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.12LTEQ(WD)+1.19LTEQ(WE)
		HW* =26527.53 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 319.89 LTEQ(WD)+ -141.97LTEQ(WE)
Jan-March	2P Linear	WBE*=-3.45 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.11LTEQ(WD)+1.05LTEQ(WE)
		HW* =27469.35 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 260.26 LTEQ(WD)+ -180.65LTEQ(WE)
February	2P Linear	WBE*=-3.93 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.10LTEQ(WD)+1.13LTEQ(WE)
		HW* =33454.84 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 45.90 LTEQ(WD)+ -667.97LTEQ(WE)
Feb-March	2P Linear	WBE*=-3.25 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.09LTEQ(WD)+0.92LTEQ(WE)
		HW* =31781.28 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 80.80 LTEQ(WD)+ -494.16LTEQ(WE)
Feb-April	2P Linear	WBE*=-4.24 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.16LTEQ(WD)+0.82LTEQ(WE)
		HW* =31760.39 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 49.72 LTEQ(WD)+ -406.83LTEQ(WE)
March	2P Linear	WBE*=-2.43 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.08LTEQ(WD)+0.69LTEQ(WE)
		HW* =29885.95 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 128.57 LTEQ(WD)+ -297.85LTEQ(WE)
March-April	2P Linear	WBE*=-4.38 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.19LTEQ(WD)+0.66LTEQ(WE)
		HW* =31007.31 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 51.42 LTEQ(WD)+ -285.80LTEQ(WE)
March-May	2P Linear	WBE*=-4.91 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.22LTEQ(WD)+0.58LTEQ(WE)
		HW* =30858.94 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 45.56 LTEQ(WD)+ -153.91LTEQ(WE)
April	2P Linear	WBE*=-6.57 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.32LTEQ(WD)+0.66LTEQ(WE)
		HW* =32450.94 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 42.00 LTEQ(WD)+ -306.44LTEQ(WE)
April-May	2P Linear	WBE*=-6.29 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.30LTEQ(WD)+0.55LTEQ(WE)
		HW* =31553.16--337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ +6.52 LTEQ(WD)+ -116.49LTEQ(WE)
April-June	2P Linear	WBE*=-9.33 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk- 0.009)+1.41LTEQ(WD)+0.75LTEQ(WE)
		HW* =31495.92 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + - 4.81 LTEQ(WD)+ -81.89LTEQ(WE)
May	2P Linear	WBE*=-6.04- 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.28LTEQ(WD)+0.47LTEQ(WE)
		HW* =30449.91 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 36.72 LTEQ(WD)+ 74.52LTEQ(WE)
		WBE*=-11.14 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.47LTEQ(WD)+0.85LTEQ(WE)

Base Period	Model	Model Equation
May-June	2P Linear	$HW^* = 30906.52 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 18.01$ $LTEQ(WD) + 34.63LTEQ(WE)$
May-July	2P Linear	$WBE^* = -11.19 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.45LTEQ(WD) + 0.74LTEQ(WE)$ $HW^* = 31108.20 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 11.03$ $LTEQ(WD) + 20.29LTEQ(WE)$
June	2P Linear	$WBE^* = -16.24 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.66$ $LTEQ(WD) + 1.20LTEQ(WE)$ $HW^* = 31359.12 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + -0.48$ $LTEQ(WD) + -3.25LTEQ(WE)$
June0July	2P Linear	$WBE^* = -13.41 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.52$ $LTEQ(WD) + 0.82LTEQ(WE)$ $HW^* = 31402.42 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 0.49$ $LTEQ(WD) + -2.17LTEQ(WE)$
June-August	2P Linear	$WBE^* = -13.23 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.49$ $LTEQ(WD) + 0.70LTEQ(WE)$ $HW^* = 31383.94 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 1.66$ $LTEQ(WD) + 1.54LTEQ(WE)$
July	2P Linear	$WBE^* = -10.67 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.37$ $LTEQ(WD) + 0.46LTEQ(WE)$ $HW^* = 31416.16 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 0.72$ $LTEQ(WD) + 1.30LTEQ(WE)$
July-August	2P Linear	$WBE^* = -11.69 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.40$ $LTEQ(WD) + 0.46LTEQ(WE)$ $HW^* = 31384.34 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 3.23$ $LTEQ(WD) + 4.75LTEQ(WE)$
July-September	2P Linear	$WBE^* = -10.29 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.33$ $LTEQ(WD) + 0.38LTEQ(WE)$ $HW^* = 31276.09 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 9.01$ $LTEQ(WD) + 12.58LTEQ(WE)$
August	2P Linear	$WBE^* = -13.13 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.44$ $LTEQ(WD) + 0.51LTEQ(WE)$ $HW^* = 31364.25 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 5.21$ $LTEQ(WD) + 7.01LTEQ(WE)$
August-Sept	2P Linear	$WBE^* = -10.31 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.31$ $LTEQ(WD) + 0.36LTEQ(WE)$ $HW^* = 31211.22 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 12.88$ $LTEQ(WD) + 17.61LTEQ(WE)$
August-October	2P Linear	$WBE^* = -8.64 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.24$ $LTEQ(WD) + 0.48LTEQ(WE)$ $HW^* = 31055.20 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 13.44$ $LTEQ(WD) + -27.85LTEQ(WE)$
September	2P Linear	$WBE^* = -7.483 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.18$ $LTEQ(WD) + 0.21LTEQ(WE)$ $HW^* = 31058.20 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 20.55$ $LTEQ(WD) + 27.59LTEQ(WE)$
Sept-Oct	2P Linear	$WBE^* = -6.52 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.15$ $LTEQ(WD) + 0.48LTEQ(WE)$ $HW^* = 30932.41 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 16.25$ $LTEQ(WD) + -48.50LTEQ(WE)$
Sept-November	2P Linear	$WBE^* = -2.02 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 0.96$ $LTEQ(WD) + 0.25LTEQ(WE)$ $HW^* = 27327.78 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 180.83$ $LTEQ(WD) + 186.73LTEQ(WE)$
October	2P Linear	$WBE^* = -5.86 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 1.13$ $LTEQ(WD) + 0.71LTEQ(WE)$ $HW^* = 30977.53 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) + 4.35$ $LTEQ(WD) + -124.16LTEQ(WE)$
October-	2P	$WBE^* = 0.45 - 0.00 (34.71 - DBTk) + 0.22(DBTk - 34.71) + 777.72 (wk-0.009) + 0.86$ $LTEQ(WD) + 0.26LTEQ(WE)$ $HW^* = 25588.87 - 337.56 (57.70 - DBTk) + 0.00(DBTk - 57.70) + -45822.31(wk-0.009) +$

Base Period	Model	Model Equation
November	Linear	+256.76 LTEQ(WD)+ 265.67LTEQ(WE)
October- December	2P Linear	WBE*=-0.43 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +0.94LTEQ(WD)+0.57LTEQ(WE)
		HW* =29331.22 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 183.13 LTEQ(WD)+ -320.97LTEQ(WE)
November	2P Linear	WBE*= 7.82- 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +0.56LTEQ(WD)+-0.24LTEQ(WE)
		HW* =19723.37 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 521.79 LTEQ(WD)+ 664.70LTEQ(WE)
Nov-Dec	2P Linear	WBE*=3.58 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +0.79LTEQ(WD)+0.35LTEQ(WE)
		HW* =29391.72--337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ +239.11 LTEQ(WD)+ -492.47LTEQ(WE)
Nov-Jan	2P Linear	WBE*=-0.56 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +0.98LTEQ(WD)+0.83LTEQ(WE)
		HW* =25934.02 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 364.98 LTEQ(WD)+ -167.17LTEQ(WE)
December	2P Linear	WBE*= -1.90- 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.09LTEQ(WD)+1.00LTEQ(WE)
		HW* =42478.22 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + -149.12 LTEQ(WD)+ -1920.61LTEQ(WE)
December - Jan	2P Linear	WBE*=-3.58 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.16LTEQ(WD)+1.21LTEQ(WE)
		HW* =27219.71--337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ +367.53 LTEQ(WD)+ -364.90LTEQ(WE)
December- Feb	2P Linear	WBE*= -3.53 - 0.00 (34.71 - DBTk)+ + 0.22(DBTk - 34.71)+ + 777.72 (wk-0.009)+ +1.13LTEQ(WD)+1.17LTEQ(WE)
		HW* =28768.46 --337.56 (57.70 - DBTk)+ + 0.00(DBTk - 57.70)+ + -45822.31(wk-0.009)+ + 279.35 LTEQ(WD)+ -439.65LTEQ(WE)

### C3. Hybrid Inverse Modeling Approach-Method 2

Method 2 looks at predicting building performance at daily timescales using utility bills only.

#### C3.1. Large Hotel at Chicago, Illinois

Table C3.1.1

*Regression Equations derived from Utility Bills Only for Large Hotel at Chicago, IL*

Model	Model Equation	R <sup>2</sup>	RMSE	CV-RMSE
4P Model	WBE <sub>k</sub> = 945.70 - 0.00 (44.32 - DBTk)+ + 7.07(DBTk - 44.32)+ + 35757.29 (wk-0.009)+	1	5.49	0.50%
	HW <sub>k</sub> = 664.71 --226.29 (61.40 - DBTk) <sup>+</sup> + 0.00(DBTk - 61.40) <sup>+</sup> + 72833.71 (wk-0.009) <sup>+</sup>	0.98	532.01	13.40%
	CHW <sub>k</sub> = 469.37 - 0.00 (50.33 - DBTk) <sup>+</sup> + 156.92(DBTk - 50.33) <sup>+</sup> + 767034.10 (wk-0.009) <sup>+</sup>	0.99	192.24	8.70%

### C3.2. Office Building at Albuquerque, New Mexico

Table C3.2.1

*Regression Equations derived from Utility Bills Only for Office, Albuquerque, NM.*

Model Type	Model Equation	R <sup>2</sup>	RMSE	CV-RMSE
4P Model	$WBE_k = 21.57 - 0.00(34.71 - DBT_k)^+ + 0.22(DBT_k - 34.71)^+ + 777.72(wk-0.009)^+$	0.97	0.93	3.5
	$HW_k = 31447.21 - 337.56(57.70 - DBT_k)^+ + 0.00(DBT_k - 57.70)^+ - 45822.31(wk-0.009)^+$	0.98	490.83	1.40%

### C3.3 Full Service Hotel, Washington D.C. Area

Table C3.3.1

*One Year of Monthly Utility History (Daily Average Values) for Full Service Hotel, Washington D.C. Area.*

Monthly Utility History					
S.No.	Year	Month	Days	DBT <sub>k</sub>	EWB (kWh)
1	2009	1	31	31.3	1046.85
2	2009	2	28	39.3	811.77
3	2009	3	31	44.8	634.78
4	2009	4	30	56.7	497.06
5	2009	5	31	65.2	506.37
6	2009	6	30	73.1	608.27
7	2009	7	31	76.4	653.07
8	2009	8	31	77.2	661.67
9	2009	9	30	73.6	612.08
10	2009	10	31	56.9	556.62
11	2009	11	30	46.3	637.00
12	2009	12	31	39.3	813.78

Table C3.3.2

*Regression Equation derived from Utility Bills Only for Full Service Hotel, Washington D.C. Area.*

Model Type	Model Equation Derived from Utility Bills	R <sup>2</sup>	RMSE	CV-RMSE
4P	$WBE_k = 472.63 - 28.55(51.28 - TDB)^+ + 6.55(TDB - 51.28)^+$	0.91	1029.2	8.79%