

**Energy Model Creation and Calibration Procedures for
a Residential Home using Short Term Monitored Data**

by

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B.S., University of Michigan, 2005

A thesis submitted to the
Faculty of the Graduate School of the
University of Colorado in partial fulfillment
of the requirement for the degree of
Masters of Science
Department Civil, Environmental and Architectural Engineering
2013

This thesis entitled:
Energy Model Creation and Calibration Procedures for a Residential Home using Short Term
Monitored Data
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Find that both the content and the form meet acceptable presentation standards
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Energy Model Creation and Calibration Procedures for a Residential Home using Short Term Monitored Data

Thesis directed by Prof. Michael Brandemuehl, PhD, P.E.

Abstract

Calibrated energy models are used throughout the building science community for many different purposes. There are a number of publications and studies that describe calibration approaches and validation methods. The U.S. Dept of Energy Solar Decathlon program saw the need to develop detailed model creation and calibration procedures using monitored data of energy efficient residential buildings. This document contains detailed procedures and tools that use short term monitored data to create a customized EnergyPlus input file. A multi-step approach is developed that utilizes the data to calibrate the model. Several approaches to calibrating the building envelope are investigated and reveal that each approach produces a calibrated model with different envelope parameters. While these calibrations produce different results, most of them still qualify as adequately calibrated by existing guidelines which calls into questions if the current metrics used to declare an energy model “calibrated” are suitable for residential applications.

ACKNOWLEDGMENTS

I would like to thank the National Renewable Energy Laboratory (NREL) and the U.S. Department of Energy for supporting this project and having the foresight to see its value for the building science community; Michael Wassmer and Blaise Stoltenberg of NREL for their guidance in working through difficulties of this project; Michael Brandemuehl, PhD, P.E. for his support, patience and guidance throughout the changes in directions of this research; Cécile and David Warner for generously allowing their house to be monitored during the course of this project; my parents Jane and Bob for their support; and Jenny Field for her patience, support and love through the many ups and downs of this journey.

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CHAPTER 1 BACKGROUND AND MOTIVATION

This section describes the motivation for this thesis, a general description of the problem, the objectives to be addressed by the work, and an overview of the organization of the document.

1.1 Whole Building Energy Analysis and Model Calibration

For many years a wide variety of tools and methods have been used to calculate building energy consumption. The simplest methods included hand calculations and simple spreadsheet programs which were mostly used to calculate loads in steady state, single zone applications. More specialized programs have also been developed to size HVAC equipment, analyze life cycle cost of proposed building retrofits, optimize energy performance and support various other research related to building energy consumption. The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy website lists a directory of over 400 software tools for evaluating building energy usage in various applications. Two publically available and widely used whole building energy analysis programs developed in the 1970's and early 1980's are BLAST (Building Loads Analysis and Systems Thermodynamics) and DOE-2. Realizing the shortcomings of both tools, the DOE developed and released its next generation building energy simulation program EnergyPlus in April, 2001 which combined the most popular elements of both previous tools. EnergyPlus has the capability of running sub-hourly time step simulations with custom weather files for a user defined building with virtually any HVAC system. The typical audience for EnergyPlus, as described by the DOE includes "Mechanical, energy, and architectural engineers working for architect/engineer firms, consulting firms, utilities, federal agencies, research universities, and research laboratories." This is essentially saying that a wide variety of professionals and scientists in the building energy field rely on the accuracy of EnergyPlus to made decisions on business models, policy, and direction of research. The reality of the situation is that while many tools, including EnergyPlus, are capable of accurately predicting building energy consumption, sizing equipment, etc. there is still a large human element to the equation in that a skilled person has to create the model based on his/her knowledge

and skill. A model built using the most sophisticated tool available can be relatively worthless unless the physical building that it represents is accurately described by the model.

In order for an energy model to accurately represent a physical building, a certain amount of model calibration is required to be performed. Unfortunately this is a difficult task and research has been conducted for many years to try to define the best way to calibrate an energy model. There are documents in existence, such as ASHRAE Guideline 14, that describe various multi-step approaches for model calibration, but they still require a large amount of user knowledge to achieve a “calibrated” model. ASHRAE Guideline 14 also presents metrics that allow the modeler to determine if the energy model is calibrated within an industry adopted “acceptable” range of accuracy. The guideline states that the energy model should be accurate to within 5% for the normalized mean bias error (NMBE) and 15% for the coefficient of variation of the root mean square error (CV(RSME)) relative to monthly energy data. In all cases, in order to calibrate a model, a certain amount of measured data is required. The quantity, quality and type of measured data can vary widely but it can almost always be used to improve a model in some way. In an ideal case the person interested in calibrating an energy model could look at the budget available for measurement and determine what to measure and how to measure it in order to have the most accurately calibrated model possible for each situation. Additionally, it would be ideal to be able to survey the budget available for both measurement as well as energy modeling effort and determine the theoretical level of accuracy that is achievable in every situation. Figure 1 shows a graphical representation of this idea. A study like this has not yet been undertaken but one could imagine as more effort is expended, the graph could get closer to representing a realistic scenario.

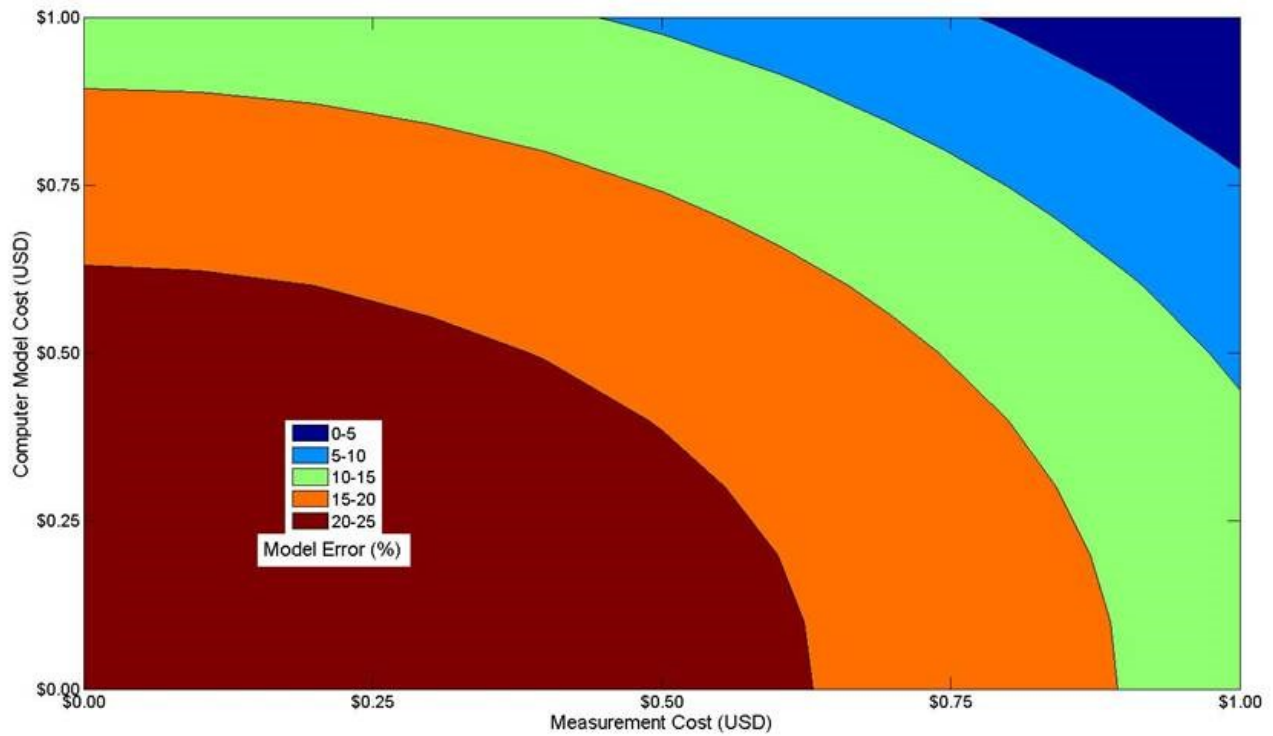


Figure 1: Theoretical model accuracy as a function of modeling and measurement budget

In order to develop the relationship that is displayed in Figure 1, there is a key point in the upper right hand corner of the graph which represents the limiting case when unlimited funding for both measurement and modeling is available. One could imagine that there is a maximum level of accuracy possible, or more realistically a range of accuracy possible when unlimited resources are available. Once this point is established, funding and resources could gradually be scaled back to the point where minimal effort for monitoring and modeling is plausible. This would theoretically correspond to another model accuracy range (likely much lower than the other limiting case). Points in between these two extremes could then be used to populate the graph with more accurate information. By having this relationship better defined; policy makers, researchers, or energy professionals could have a much better idea up front what type of investment is required to reach the level of accuracy desired for their needs. Unfortunately, at this point there has not been a successful effort to figure out what the shape of this graph looks like in a practical sense. Some of this is due to the lack of a clear, uniform procedure for calibrating energy models

to measured data. While this type of procedure would be ideal, it may not be practical or even possible to have a procedure that would be universal enough to become an industry standard that is easy to follow, and the effort required to perform the work necessary to develop this would likely have little to no early returns on investment. Fortunately, circumstances stemming from the U.S. Department of Energy Solar Decathlon program identified the need for such a calibration procedure to be explored and the funding necessary to install a high level of instrumentation in a residential home was made available to perform such a study.

1.2 Solar Decathlon Performance Tracking Project

The Solar Decathlon is a competition between “collegiate teams to design, build, and operate solar-powered homes that are cost-effective, energy-efficient, and attractive. The winner of the competition is the team that best blends affordability, consumer appeal, and design excellence with optimal energy production and maximum efficiency.” Since 2002 there have been four Solar Decathlon competitions with a total of 72 competition homes built. In 2010, the Department of Energy launched the Solar Decathlon Performance Tracking (SDPT) project to study several former competition homes for education, outreach, and research purposes. Before this project began, the homes would leave the competition site and there would be little to no impetus for the participating teams or universities to rebuild the homes at their final destination. The DOE recognized this massive untapped resource of having custom built high performance homes on college campuses with architecture and engineering students available to continue research on the homes and their systems. The intention of the SDPT project was to provide a number of schools with funding and support to outfit the homes with a standard package of instrumentation at the final location of the completed home. The data from this instrumentation could then be used by both the institution and DOE for various purposes including but not limited to outreach, education and research.

In order for the data described above to be of the level of quality desired for use by the intended recipients, certain calibration procedures are required for both the data acquisition system and the energy

models of the homes. For these reasons, the DOE recognized that an additional effort to develop these calibration procedures was required to standardize the instrumentation and modeling to be done on the homes. By having standardized calibration procedures, a significant amount of duplicate work could be avoided by schools attempting to calibrate energy models of their homes from scratch.

Before defining the standard instrumentation package for the homes chosen to be included in the study, NREL outfitted a single family home in Boulder, CO with a large amount of instrumentation to serve as a test bed or pilot house. The data gathered from this pilot house will be used in this thesis, so all of the modeling and calibration procedures contained in the following chapters will be based on one minute interval data collected in the winter and spring of 2011 at 291 Pearl St. in Boulder, CO. The intent of installing such a large amount of instrumentation was multifold. A portion of the project was to be able to have real-time displays of what was going on in the former Solar Decathlon houses to show on site at future Solar Decathlons as well as making the real time displays and data available for educational outreach purposes. Additionally, in order to assess the validity of some of the designs and claims of the Solar Decathlon houses, building highly accurate calibrated energy models of the homes was also desired. In a way, the SDPT program allowed for the opportunity to try to identify the point at the top, right hand corner of Figure 1 by providing a very detailed level of instrumentation. The data could then be used to explore various calibration techniques in order to achieve the highest level of accuracy possible. Before trying to identify the best procedure to use this data to calibrate the energy model, a review of the literature relevant to this topic was conducted.

1.3 Review of Literature Related to Energy Model Calibration Procedures

The challenge of creating a truly calibrated model is formidable (Troncoso, 1997):

Standard building simulation programs typically produce electrical demand and consumption data as a program output. When modeling existing plants, if the results don't match actual monitored data, the programmer will typically "adjust" inputs and operating parameters (almost) on a trial-and-error basis until the program output matches the known data. This "fudging" process often results in the manipulation of a large number of variables which may significantly decrease the credibility of the entire simulation.

While this is specific to the modeling of large central chilling plants, the point being made in this statement is also largely relevant to whole building energy modeling or really any calibration where many parameters are being “tuned” simultaneously. (Reddy et al., 2006) conducted a very detailed literature review in response to ASHRAE Research Project 1051, Procedures for Reconciling Computer-Calculated Results with Measured Energy Data. There were four main areas of interest addressed in the literature review:

- Procedures to Improve Building Design Process
- Procedures to Calibrate Building Simulations to Monitored Data
- Relevant Error and Uncertainty Issues
- Calibration Tools and Capabilities

There is much more breadth to the topics addressed in the literature review so only those which are relevant to the focus of this thesis will be discussed in more detail. The general conclusions resulting from this literature review (Reddy et al., 2006) are as follows. In general, most of the different calibration procedures outlined consist of a combination of various mathematic/analytical procedures, visualization tools, and the acumen of the person calibrating the model which varies from user to user. When implementing spot measurements or short term monitored data are recommended, specific procedures as to how to use this data in a calibration procedure are not addressed. Furthermore, (Reddy et al., 2006) states the following:

No study to date has ever broached the issue of whether an accurate fit to the data would also produce accurate predictions of intended ECM savings. This issue is of great practical importance, and guidelines such as ASHRAE 14 completely ignore this aspect.

ASHRAE-14 (ASHRAE, 2002) goes through general guidelines with eight steps for calibrated simulations. The guideline contains a description of each of these steps as follows (taken from ASHRAE 14, 2002)

- 1) *Produce a calibrated simulation plan.* Before a calibrated simulation analysis may begin, several questions must be answered. Some of these questions include: Which software package will be applied? Will models be calibrated to monthly or hourly measured data, or both? What are to be

the tolerances for the statistical indices? The answers to these questions are to be documented in a simulation plan.

- 2) *Collect data.* Data may be collected from the building during the baseline period, the retrofit period, or both. Data collected during this step includes dimensions and properties of building surfaces, monthly and hourly whole-building utility data, nameplate data from HVAC and other building system components, operating schedules, spot-measurements of selected HVAC and other building system components, and weather data.
- 3) *Input data into simulation software and run model.* Over the course of this step the data collected in the previous step is processed to produce a simulation-input file. Modelers are advised to take care when zoning, schedules, HVAC systems, model debugging (searching for and eliminating any malfunctioning or erroneous code), and weather data.
- 4) *Compare simulation model output to measured data.* The approach for this comparison varies depending on the resolution of the measured data. At a minimum, the energy flows projected by the simulation model are compared to monthly utility bills and spot measurements. At best, the two data sets are compared on an hourly basis. Both graphical and statistical means may be used to make this comparison.
- 5) *Refine model until an acceptable calibration is achieved.* Typically, the initial comparison does not yield a match within the desired tolerance. In such a case, the modeler studies the anomalies between the two data sets and makes logical changes to the model to better match the measured data. The user should calibrate to both pre- and post-retrofit data wherever possible and should only calibrate to post-retrofit data alone when both data sets are absolutely unavailable. While the graphical methods are useful to assist in the process, the ultimate determination of acceptable calibration will be the statistical method.
- 6) *Produce baseline and post-retrofit models.* The baseline model represents the building, as it would have existed in the absence of the energy conservation measures. The retrofit model represents the building after the energy conservation measures are installed. How these models are developed from the calibrated model depends on whether a simulation model was calibrated to data collected before the conservation measures were installed, after the conservation measures were installed, or both times. Furthermore, the only differences between the baseline and post-retrofit models must be limited to the measures only. All other factors, including weather and occupancy must uniform between the two models unless a specific differences has been observed that must be accounted for.
- 7) *Estimate savings.* Savings are determined by calculating the difference in energy flows and intensities of the baseline and post-retrofit models using the appropriate weather file.
- 8) *Report on observations and savings.* Savings estimates and observations are documented in a reviewable format. Additionally, sufficient model development and calibration documentation shall be provided to allow for accurate recreation of the baseline and post-retrofit models by informed parties, including: input and weather files.

Variations of this eight-step procedure were the subject of several studies throughout the 1990's and 2000's. (Kaplan et al., 1990) looked at monitored data for several end-uses during a short period for different seasons throughout the year. One month periods were used to tune the DOE-2 model after shorter periods of monitoring produced too much variability. In general, manual tuning was used to produce a model that was within 10% of the annual energy consumption. Another paper (A. Pedrini et al., 2002) uses a three step approach considering the building plans and documentation, walk-thorough

visits, and electric and thermal measurements to calibrate DOE-2 models for a range of commercial buildings. It was determined that the schedule descriptions of energy consumption by end use was the most influential factor to determine model accuracy in all cases. The paper by (Yoon et al., 2003) considers a seven step process for building a calibrated model. The steps are as follows:

- 1) *Base case modeling*: Collect building data, utility data, and weather data and use data to build DOE-2 model
- 2) *Base load consumption analysis*: Analyze the base load electricity and gas consumption using a combination of utility bill analysis and short-term sub-metered data.
- 3) *Swing-season calibration*: Fine tune a number of simulation inputs when heating and cooling loads are minimal and building behavior is dominated by internal loads.
- 4) *Additional site visits and interviews*: Refine schedule values by interviewing building occupants
- 5) *Heating/cooling season calibration*: This is mostly calibrating the HVAC system inputs during the non-swing season times of the year.
- 6) *Validation of calibrated model*: Use numerical and graphical comparisons to determine when a model is adequately calibrated. Generally, mean bias error and root mean square error are considered.
- 7) *Application of calibrated simulation model to investigation of promising ECM's*: Apply the results of the calibration to large commercial buildings in Korea to evaluate the potential savings of a variety of ECM's.

The results of applying this process to several large office building in Korea are presented.

In addition to the multi-step calibration processes described above, there were several other papers that looked into using special tests, short term monitoring, and analytical procedures for calibration. (Soebarto, 1997) presents a calibration methodology to use short term (2-4 weeks) monitored hourly data as well as monthly utility records. The calibration procedure consists of the following steps. First, data is collected via a site visit, interviews, and a review of the architectural drawings. This data is used to create the initial energy model of the building. Next, short term monitoring is used to develop the 24 hour use profiles for the building. Next, the measured energy use is disaggregated into temperature-independent and temperature-dependent components. Finally, the simulation results are analyzed using graphical and statistical methods and certain input parameters are adjusted to match the monitored data and utility information. The paper shows that the energy use in two case study buildings could be predicted as accurately (in terms of CV(RMSE)) as if long term monitored data was used. A paper by (Manke and Hittle, 1996) describes a procedure to use coheating to determine building loss coefficient in addition to a cool-down period to determining the building mass level. After the testing, a set of primary

building parameters are identified and varied individually between 10% and 200% of their nominal values. The RMSE is calculated for each BLAST run and the value of each parameter corresponding to the minimum RSME is chosen until a global minimum is reached. (Carroll and Hitchcock, 1993) describe using analytical methods to minimize the error between simulated and measured energy consumption. For this study, RESEM is used which is a fairly simple whole building energy simulation program as compared to DOE-2 or EnergyPlus. The general approach described in this paper is to formulate an optimization problem varying a set of parameters \mathbf{p} to minimize an objective function which includes one factor that looks at the difference between measured and modeled energy consumption and another term that contains a “penalty” value that adversely weighs guessed values of \mathbf{p} that vary significantly from the initial guess of \mathbf{p} .

ASHRAE-14 addresses the issue of comparing the accuracy of energy simulations. The standard states that for a model to be “calibrated,” it should be accurate to within 5% for the normalized mean bias error (NMBE) and 15% for the coefficient of variation of the root mean square error (CV(RSME)) relative to monthly energy data. In the case when hourly energy data are used for comparison, the NMBE and CV(RSME) are increased to 10% and 30%. In general, these approaches are used fairly widely although as (Reddy et al., 2006) points out, no specific reasons are presented as to why the accuracy tolerances are proposed other than being based on the practical experience of energy modelers who perform calibrated simulations. Reddy points out several issues with using these thresholds to declare a model “calibrated.” To summarize, the following concerns are pointed out:

- 1) Just because the net effect of all the “knobs” yields a simulation output close to the one desired (i.e. measured) is no guarantee that all the individual knobs are tuned correctly.
- 2) There may be statistical measures other than CV and MSE which would be relevant, and these need to be identified.
- 3) How would these statistical indices be affected by time scale (i.e. hourly, daily or monthly data).
- 4) The issue of uncertainty in the building energy use performance data against which calibration is being done.

Two journal articles present the findings of research by (Reddy et al.(1), March, 2007) and (Reddy et al.(2), March, 2007) that intended to cull the best techniques, tools, approaches, and procedures

from the existing body of research to develop a systematic calibration methodology. There are five major steps included in the proposed methodology which include (taken from the paper):

- 1) An important first step is to prepare a preliminary simulation input file of the building that is as realistic and error-free as possible. This would entail making sure that the simulation program has the capability of modeling the type of building and systems present and that the inputs have been entered correctly.
- 2) Next, reduce the dimensionality of the parameter space by resorting to walk-through audits and heuristics. For a given building type, identify/define a set of influential parameters and building operating schedules along with their best-guess estimates (or preferred values) and their range of variation characterized by either the minimum-maximum range or the upper and lower 95th probability threshold values. The set of influential parameters to be selected should be such that they correspond to specific and easy-to-identify inputs to the simulation program.
- 3) Next, perform a “bounded” course grid calibration (or unstructured or blind search) using an MC simulation involving numerous trials or realizations with different combinations of input parameter values. This would result in a preliminary filtering or the identification of a small set of the most promising solutions of input parameter vectors and also provide a means of identifying the more sensitive or strong parameters.
- 4) Subsequently, perform a guided search calibration to further refine or improve on the calibrated solutions identified by the course grid search. In the companion paper, we will evaluate whether the guided search phase is necessary in the first place or whether a blind bounded search is adequate to provide plausible solutions of acceptable accuracy.
- 5) Finally, rather than using only one plausible calibrated solution to make predictions about the effect of intended energy conservation measures (ECMs), use a smaller number of the most plausible solutions. Not only is one likely to obtain a more robust prediction of the energy and demand reductions, but this would allow determining their associated prediction uncertainty as well.

This methodology was deployed on three commercial buildings (two synthetic and one actual) and it was found that the calibrated models were able to predict ECM savings with approximately 50% uncertainty when the effect of the ECM resulted in about 10% savings. The uncertainty of the predicted savings dropped to approximately 20% when the ECM savings reach 30% or more.

1.4 Conclusions of Literature Review

Everything to this point uses various sensitivity analysis, and mathematical/visualization tools to calibrate the energy model to measured whole-building utility data in commercial buildings with complicated HVAC systems, assumed schedules, etc. In general statistical indices such as NMBE and CV(RSME) are used to evaluate the accuracy of the calibrated model, comparing the measured data to the modeled data during the period of time used to calibrate the model. A model is to be considered

“calibrated” when the NMBE is within 5% and CV(RSME) within 15% compared to monthly data and 10% and 30% when compared to hourly data. Generally, the accuracy of the calibrated model’s ability to predict future energy consumption is not considered as a metric to evaluate the accuracy of the calibration, only the errors during the period used for calibration is presented. Various different energy modeling programs were considered but EnergyPlus was not used as the model of choice in any of the procedures described and the shortest simulation time step used in any of the studies is one hour.

There are no specific procedures how to take spot measurement data or data collected during short term monitoring of the building and use them to calibrate the model. In general, no monitored data at less than hour intervals are considered and without having specific calibration procedures, it is not known whether or not collecting data at shorter than one hour intervals has a significant impact on model accuracy. In most of the calibration procedures, when the step involving “tuning” model parameters is described, a specific procedure describing how to tune those parameters is not presented, other than saying they are “adjusted” to satisfy a graphical or statistical threshold.

In nearly all cases, these studies are only concerned with large or medium sized commercial building where whole building energy use is dominated by internal loads and the behavior of the occupants. In many cases, building envelop parameters do not have enough influence on the output of the model to warrant being included in the calibration of the model. For this reason, many of the calibration procedures developed are excellent at determining proper scheduling which is often enough to get the model within the “acceptable” range of a calibrated model as defined in ASHRAE-14, but the envelope parameters are left at their initial guesses and never truly calibrated.

For many reasons, mostly economic, there has been a lack of research related to the calibration of residential building energy models. It is unreasonable to suggest that procedures that have been developed for commercial buildings can simply be transferred to residential buildings and expect results that are meaningful. There is a fairly large discrepancy in that whole building energy consumption of large commercial buildings is largely driven by occupant behavior, internal loads, and schedules; and building energy consumption of residences is largely a function of characteristics of the building envelope and the

HVAC system. Additionally, due to the vast difference in building mass, the response of a commercial building vs. a residential building to changes in environment is much different. For these reasons, calibrating residential building energy models should be considered a separate science that what has been investigated up to this point. More research is required and new approaches should be looked at for calibrating these models.

1.5 Objectives

The objectives of the research are as follows:

1. Provide a procedure and relevant tools for building an EnergyPlus model of a residential home. This includes using building drawings, information gathered on site, and using a certain subset of the measured data from the instrumentation installed at the house to develop the most accurate model of the house as possible. This also includes presenting a procedure or tool to create a customized weather file from the data gathered at the building site.
2. Develop an generic optimization tool to be used to calibrate any set of input parameters by minimizing an objective function to be defined by the energy modeler.
3. Consider how different calibration techniques (i.e. different objective functions, different subsets of data used for calibration) will produce different sets of optimized building envelope parameters.
4. Evaluate how these different calibrated models compare to each other in their ability to predict future energy consumption by looking at a variety of statistics and graphics.

1.6 Organization of the Thesis

The thesis begins with a description of the residence that is being used on the study, including an overview of the building location, its geometry and construction, the building's HVAC system, and a description of the location and type of instrumentation that has been installed in the house for monitoring purposes. Next is a detailed description of how the EnergyPlus model of the house was created. This includes a procedure for converting the measured weather data into a custom weather file to be used in the

simulation. Then a description of how the building location and construction, internal gains, infiltration, and HVAC system and all its components were inputted into the EnergyPlus model. This includes a procedure for converting certain measured data at the house into schedules and inputs to be directly used by the model. The next section discusses the procedures that were used to calibrate the EnergyPlus model. This includes a description of the optimization tool that was developed for calibrating general parameters within EnergyPlus; as well as specific procedures for calibrating the HVAC system, and the building envelope. Finally, several calibration scenarios are presented along with how well the models they produce are able to predict future energy consumption in the home. The different scenarios are compared to each other both graphically and statistically using accepted metrics for determining whether or not an energy model can be considered properly “calibrated.” A discussion of whether or not these accepted metrics are applicable to residential energy models follows to conclude the thesis.

CHAPTER 2 PILOT HOUSE BUILDING DESCRIPTION

This chapter describes the pilot house in terms of its geometry, location, construction and systems. Before an energy model of the building could be created, all of its physical attributes must be defined as much as possible given the available.

2.1 Building Location and Geometry

The pilot house used in this study is located at 291 Pearl St. in Boulder, CO. This is equivalent to 40.016° N latitude and 105.293° W longitude, and the elevation is 1648 meters. Boulder, CO is located in the Mountain Time Zone which is 7 hours west of Greenwich Mean Time. Figure 2 and Figure 3 show the site plan drawing and a satellite image of the pilot house.

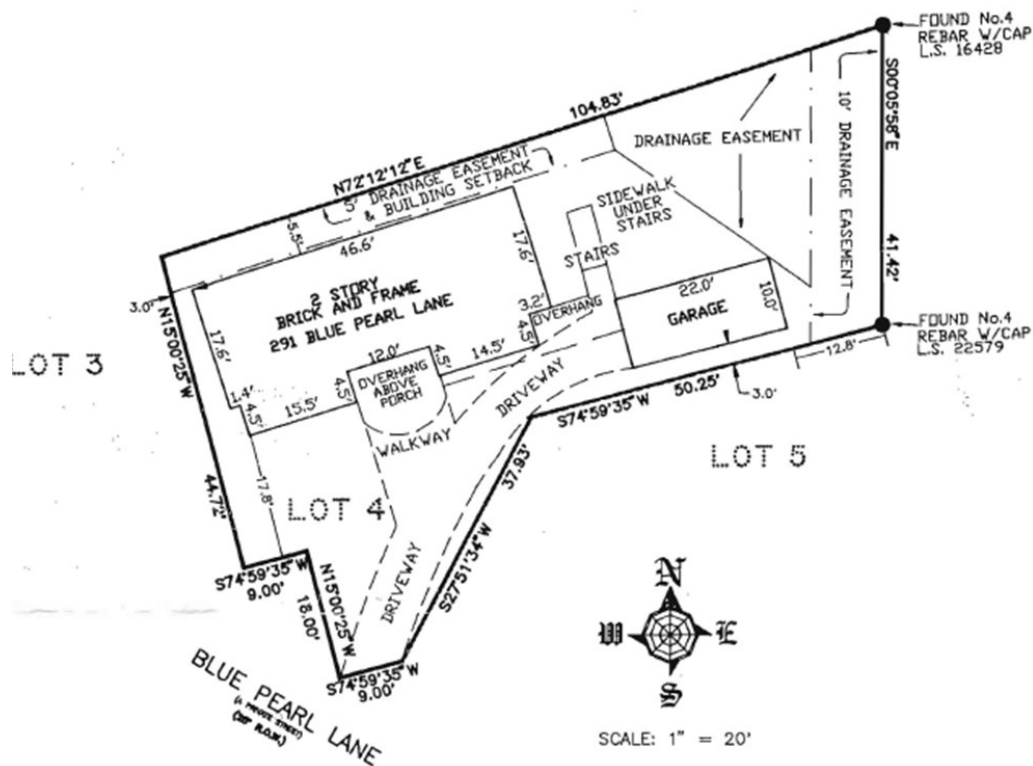


Figure 2: Site plan for pilot house



Figure 3: Satellite picture of pilot house

Google SketchUp 8 was used to create all of the geometry of the house and place it in the correct location and orientation. Fortunately, SketchUp allows the user to take a snapshot within Google Earth of the building site which automatically places it at the correct latitude, longitude, altitude, orientation, and time zone. Figure 4 shows a rendering of the pilot house from Google SketchUp.

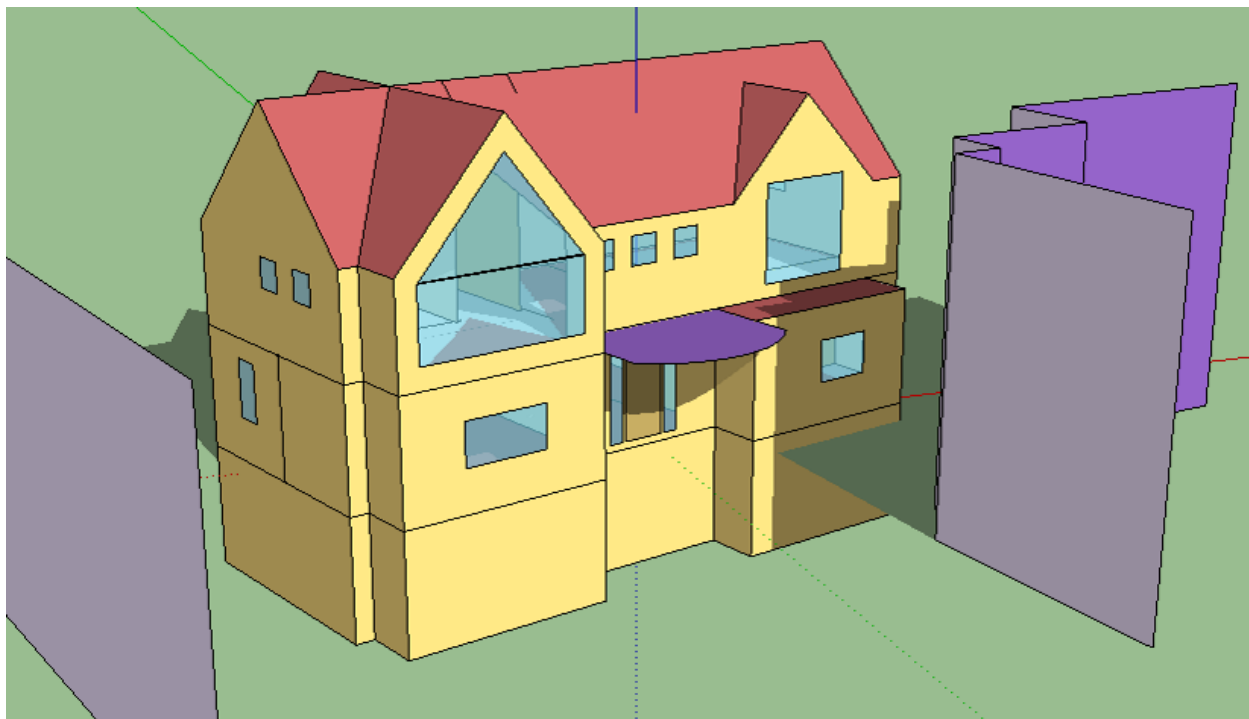
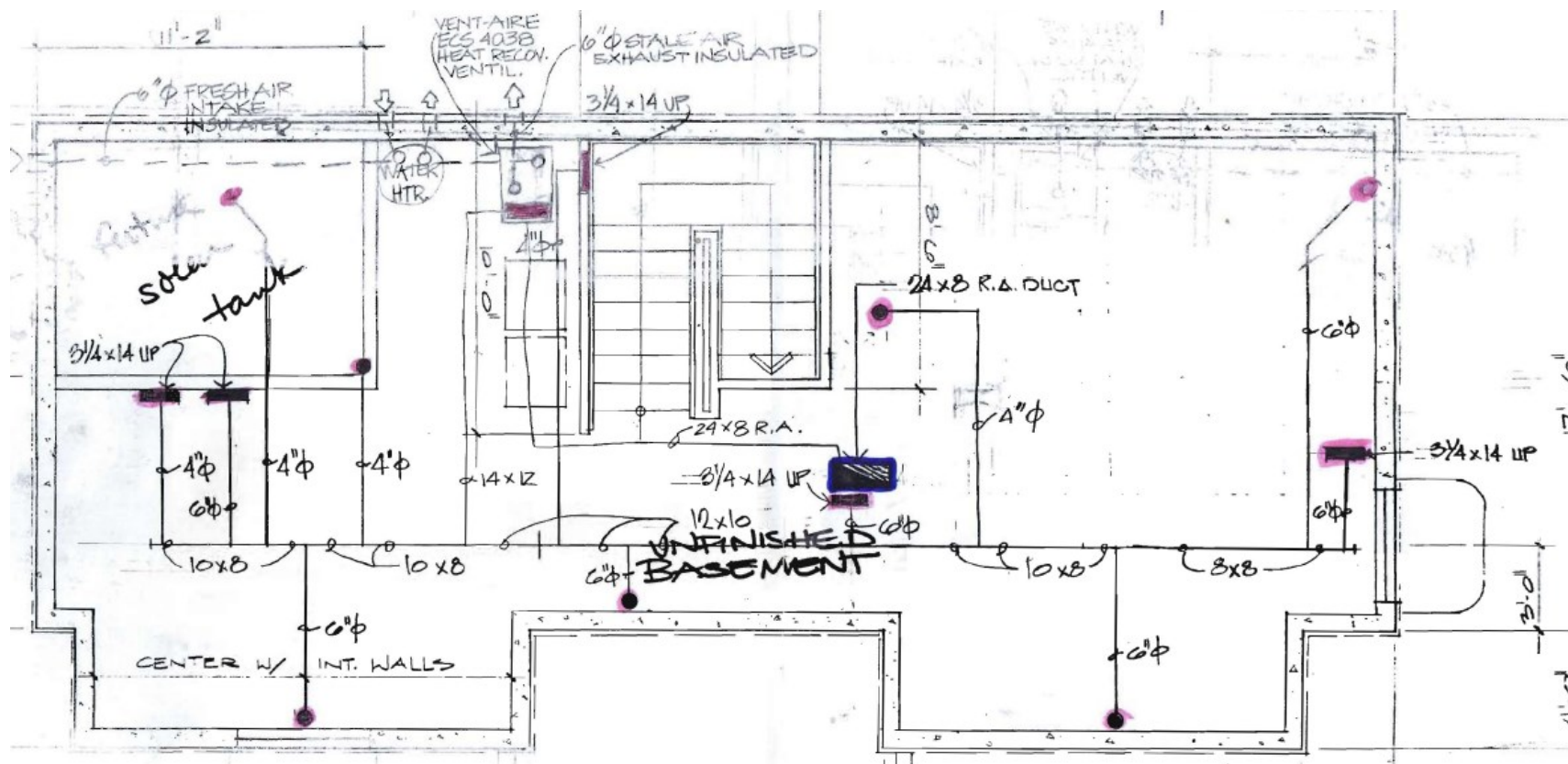


Figure 4: Google SketchUp rendering of pilot house

The purple surfaces in the rendering represent exterior shading devices. The shade above the front door is part of a second floor porch. The two purpose surfaces external to the house represent the neighboring houses and structures. There are three levels to the house with the bottom being a full under-grade basement with no exterior windows. The first level has three bedrooms, two full bathrooms, and an entryway with a stairwell up to the top level. The top level has a living room, dining room, kitchen, and half bath all with vaulted ceilings and no full interior walls separating the spaces. The pilot house only has a single HVAC zone controlled by one thermostat on the first floor in the entryway of the house. All of the dimensions in the model as well as fenestration placement, roof geometry, etc. were based on several architectural drawings provided by the home owner. Figure 5 - Figure 7 contain floor plans for the three levels of the house; these drawings were used to create the SketchUp model shown in Figure 4. Figure 8 also contains a cross section of the house showing the floor-ceiling dimensions as well as top level ceiling dimensions.



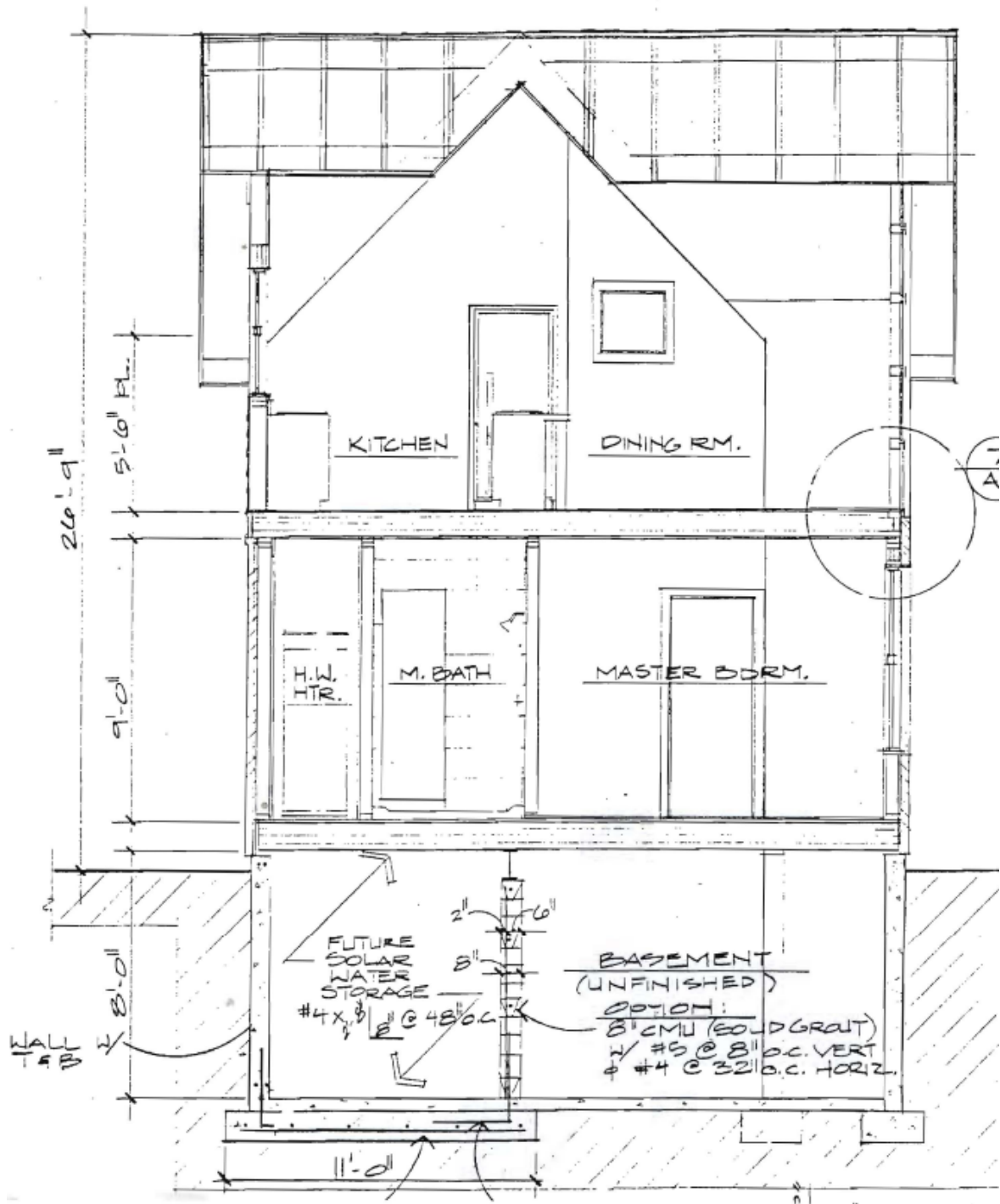


Figure 8: Cross section of pilot house

2.2 Building Construction

In addition to the architectural drawings, the owner also provided a fact sheet for the house with some construction information as well as approximate insulation levels, glazing types, etc. Table 1 shows some of the key information from this fact sheet.

Table 1: Fact sheet for pilot house

<u>Floor area:</u>	2650 ft ²
<u>Wall construction:</u>	2 x 6s on 24" centers
<u>Wall insulation types:</u>	1" non-CFC extruded polystyrene exterior, 5 1/2" high density blown-in-blanket fiberglass
<u>Wall insulation value:</u>	R-23 (fiberglass) plus R-5 (foam) = R-28 (approx.)
<u>Ceiling insulation value:</u>	R-47 (fiberglass, approximate)
<u>Glazing, South:</u>	200 ft ² heat mirror 88 (fixed glass, casements, patio door)
<u>Glazing, North:</u>	45 ft ² In-Sol-8 casement and low-E skylight
<u>Glazing, East/West:</u>	35 ft ² heat mirror 88 casements
<u>Air Tightness:</u>	Equivalent infiltration area = 25 in ² based on blower door test

Since one of the primary goals of this project is to produce a calibration procedure identifying a set of parameter values for various aspects of the building envelope which cannot be directly measured, some of the values in Table 1 were used as educated first guesses on values for insulation, and infiltration. Additionally, while the manufacturer and model for the glazing is listed (Heat Mirror 88), there were no associated values for solar heat gain coefficient (SHGC) or overall U-Value of the windows. The estimated range of values for SHGC and U-Value provided by the manufacturer of these windows was chosen based on the different glass configurations, thickness, outside dimensions, and gas fill available for this glazing type. The SHGC varies from 0.3 – 0.8 for the different available configurations of the Heat Mirror 88 glazing, and the overall U-factor for the window installation ranges from 0.65 - 1.53 W/m²-K.

2.3 HVAC System

The HVAC system in the pilot house consists of a central air handling unit (AHU) with one supply blower and one exhaust blower. There is a hot water coil in the AHU which is supplied by a 50 gallon domestic hot water heater and a small Taco circulation pump. When the system is in heating mode,

the supply fan and circulation pump run at single constant speeds to deliver hot air to the house. There are no re-heat coils in any of the ducts so the distribution of heating to each floor of the house is manually controlled at the diffusers in each room. There is only one thermostat and it is located near the front door on the first level. The signal from the thermostat is used by a two-position controller to turn the AHU either on or off for heating. There is no active cooling in the pilot house but there is a heat recovery ventilator (HRV) which is integrated into the AHU. When the HRV is operating, only the exhaust fan is running inside the AHU to circulate outside air through the house after it passes through the HRV transfer element. During the period of time of testing for this study, the HRV was never turned on. Control of the HRV is entirely up to the house occupants and conversations with the house occupants revealed that the HRV is rarely used. Figure 9 shows a physical diagram of the AHU and hot water heater with all of the components, hot water path, and air paths labeled.

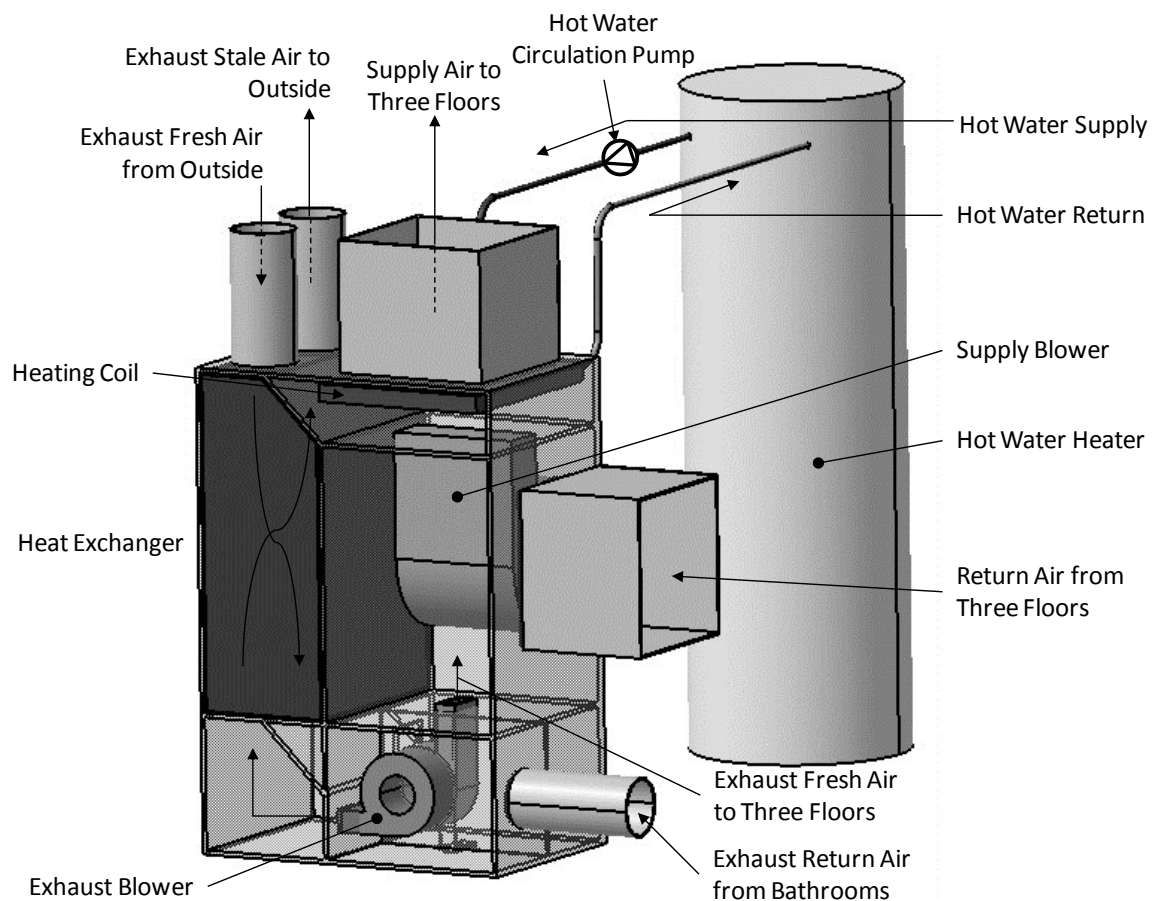


Figure 9: Annotated diagram of HVAC

2.4 Instrumentation Location Description

A data acquisition system (DAQ) and large suite of sensors was installed in the pilot house for monitoring during the period of this study. The objective of the DAQ system is to capture outdoor weather conditions, interior zone air conditions, various HVAC system temperatures and flows, and energy consumption of each electrical circuit of the home at one minute intervals. Table 2 contains a full list of the variables being measured in the pilot house along with the type of measurement, units and the category that the measurement falls into. It should be noted that not all of these measurements will be used in the creation or calibration of the energy model for the pilot house but they are included in the table anyway as they were sensors that were installed and available to the modeler.

Table 2: List of variables being measured in the pilot house

Variable	Type	Unit	Category
Timestamp	Time	mm/dd/yyyy	1
Global Horizontal Solar Radiation	Irradiance	W/m ²	1
Wind Speed	Velocity	mph	1
Outside Air Temperature	Temperature	°F	1
Outside Air Relative Humidity	Humidity	%	1
Main Floor Temperature	Temperature	°F	3
Main Floor Relative Humidity	Humidity	%	3
ERV Return Air Main Bathroom Temperature	Temperature	°F	3
ERV Return Air Master Bathroom Temperature	Temperature	°F	3
Water Heater Top Temperature	Temperature	°F	3
Water Heater Middle Temperature	Temperature	°F	3
Water Heater Bottom Temperature	Temperature	°F	3
ERV Exhaust Air Temperature	Temperature	°F	3
ERV Outside Air Temperature	Temperature	°F	3
Air Handler Return Air Temperature	Temperature	°F	3
Air Handler Supply Air Temperature	Temperature	°F	3
Heating Coil Return Water Temperature	Temperature	°F	3
Heating Coil Supply Water Temperature	Temperature	°F	3
Domestic Hot Water Supply Temperature (East)	Temperature	°F	2
Domestic Hot Water Supply Temperature (West)	Temperature	°F	2
Domestic Cold Water Supply Temperature	Temperature	°F	2
Top Floor Temperature	Temperature	°F	3
Refrigerator Temperature	Temperature	°F	2
Freezer Temperature	Temperature	°F	2
Dishwasher Water Temperature	Temperature	°F	2
Domestic Cold Water Supply Flow	Flow	gallon	2
Domestic Hot Water Supply Flow (East)	Flow	gallon	2
Domestic Hot Water Supply Flow (West)	Flow	gallon	2
Heating Coil Flow	Flow	gallon	2,3
Natural Gas Flow	Flow	ft ³	2,3
Basement Energy	Energy	Wh	2
Oven Energy	Energy	Wh	2
Garage Energy	Energy	Wh	2
Living Room Energy	Energy	Wh	2
Master Bedroom Energy	Energy	Wh	2
Inverter Energy	Energy	Wh	2
Master Bathroom Energy	Energy	Wh	2
Kitchen/Dining Room Lighting Energy	Energy	Wh	2
Dishwasher Energy	Energy	Wh	2
Clothes Dryer Energy	Energy	Wh	2
Kitchen/Dining Room Receptacle Energy	Energy	Wh	2
Total Grid Energy	Energy	kWh	3
Main Floor Energy	Energy	kWh	2
Clothes Washer Energy	Energy	kWh	2
Mechanical Room Energy	Energy	kWh	2,3
Basement Temp	Temperature	°F	3

Category 1: EPW File Input

Category 2: IDF File Input

Category 3: Calibration Tool Input

The hardware that was used to measure the variables listed in Table 2 are shown in Table 3.

Table 3: Sensors used for measurements in the pilot house

Variable	Sensor Type	Make	Model
Global Horizontal Solar Radiation	Pyranometer	Licor	LI-200
Wind Speed	3-Cup Anemometer	RM Young	03002
Outside Air Temperature/Relative Humidity	Platinum Resistance Thermometer / Capacitive Chip	Viasala	HMP50
Main Floor Temperature/Relative Humidity	Platinum Resistance Thermometer / Capacitive Chip	Viasala	HMP50
Water Heater Temperatures	Type T Thermocouple	Various	Various
HVAC System Air Temps	Type T Thermocouple	Various	Various
Energy Measurements	Split Core / Solid Core Current Transformers	Continental Control Systems	Various
Energy Measurements	WattNode	Continental Control Systems	Various
Heating Coil Flow	High Frequency Pulse Output (75.7 pulsus/gallon)	Omega	FTB-4607
Datalogger	N/A	Campbell Scientific	CR1000
Relay multiplexer	Voltage Output Multiplexer	Campbell Scientific	AM16/32
Solid-state multiplexer	Thermocouple Multiplexer	Campbell Scientific	AM25T
Switch-closure multiplexer	Pulse Counter Multiplexer	Campbell Scientific	SDM-SW8A

The temperature/RH probes used to measure ambient air conditions (both outside and inside) are housed in a radiation shield to prevent the sun and other sources of radiation and reflected heat from sullyng the temperature measurements. The remaining temperature sensors are type T thermocouples. The thermocouples used to measure fluid temperature are housed in stainless steel sheathes and have a covered, ungrounded tips. The thermocouples used to measure air temperatures within the HVAC system are similar to the fluid probes, but the thermocouple tips are exposed and grounded (exposed tip thermocouple have a faster response that those housed in a sheath). The flow meter used to measure the water flow rate in the heating coil loop is capable of reading between 0.15 and 20 gallons per minute. For each gallon of flow, the meter outputs 75.7 pulses to be read by the datalogger. The pyranometer is capable of reading global solar radiation and translating the level of radiation into a current proportional to the intensity of the radiation. By measuring the voltage drop across a precision resistor in the circuit, the datalogger can translate voltage into solar radiation. It should be noted that the pyranometer is

mounted horizontally, so the radiation being measured by the DAQ is global horizontal solar radiation. There are two components used to measure the energy consumed in each circuit, a current transformer and a WattNode. The current transformers (CT) are mounted around the “hot” wire on each separate circuit (or group of circuits) to be measured. The signal from the CTs is then fed into a WattNode which is also connected to the neutral line and ground and the instantaneous power is calculated by the WattNode. The signals from the WattNodes are then fed into a voltage multiplexer and all of the power signals are sent to the datalogger in a single wire where they can be translated into energy consumed during each one minute time interval. The Datalogger is capable of taking all of these individual or multiplexed signals and recording them to a comma separated value (CSV) file for all of the channels measured. The information contained in this file can then be used or manipulated by any program capable of reading a CSV file.

Figure 10 shows where all of the sensors within the HVAC system are physically located. While the figure is not a photograph, its scale is relatively accurate and the location of each sensor is close to the actual location of the sensor within the system.

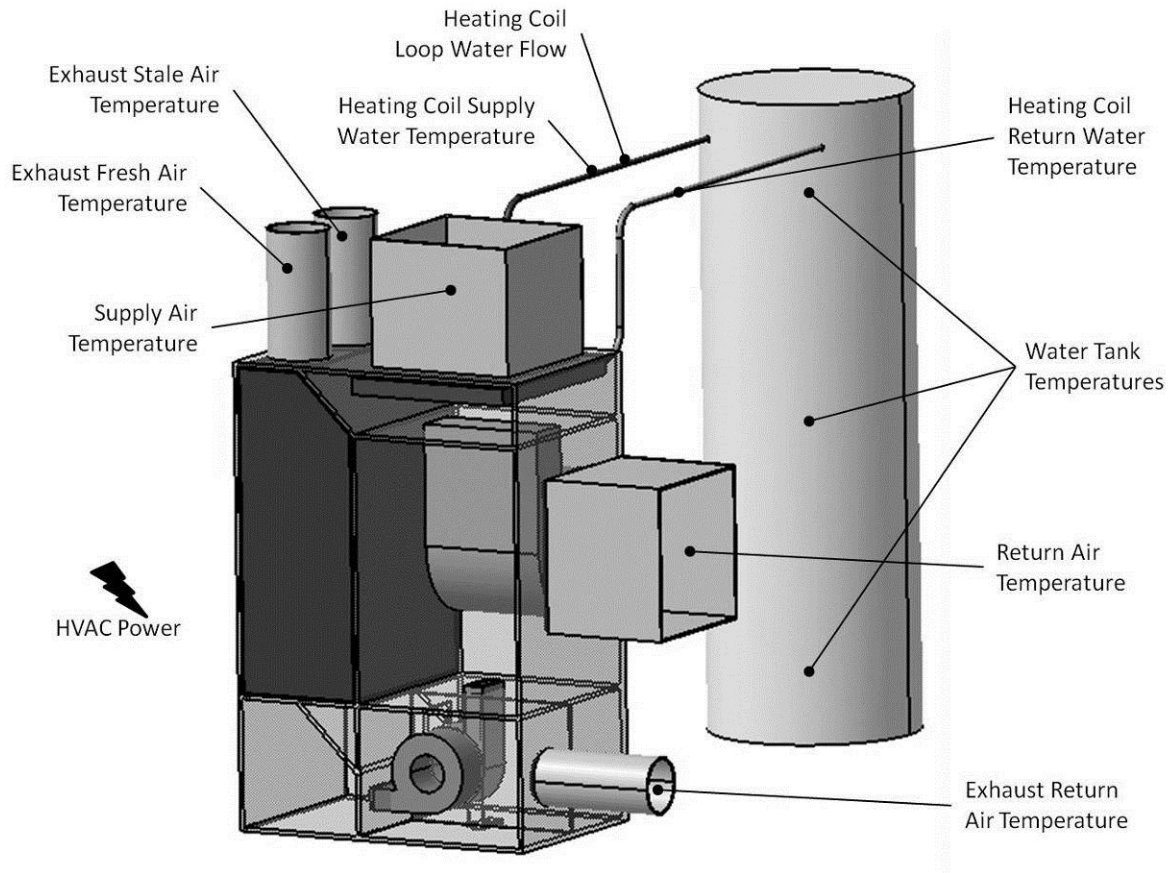
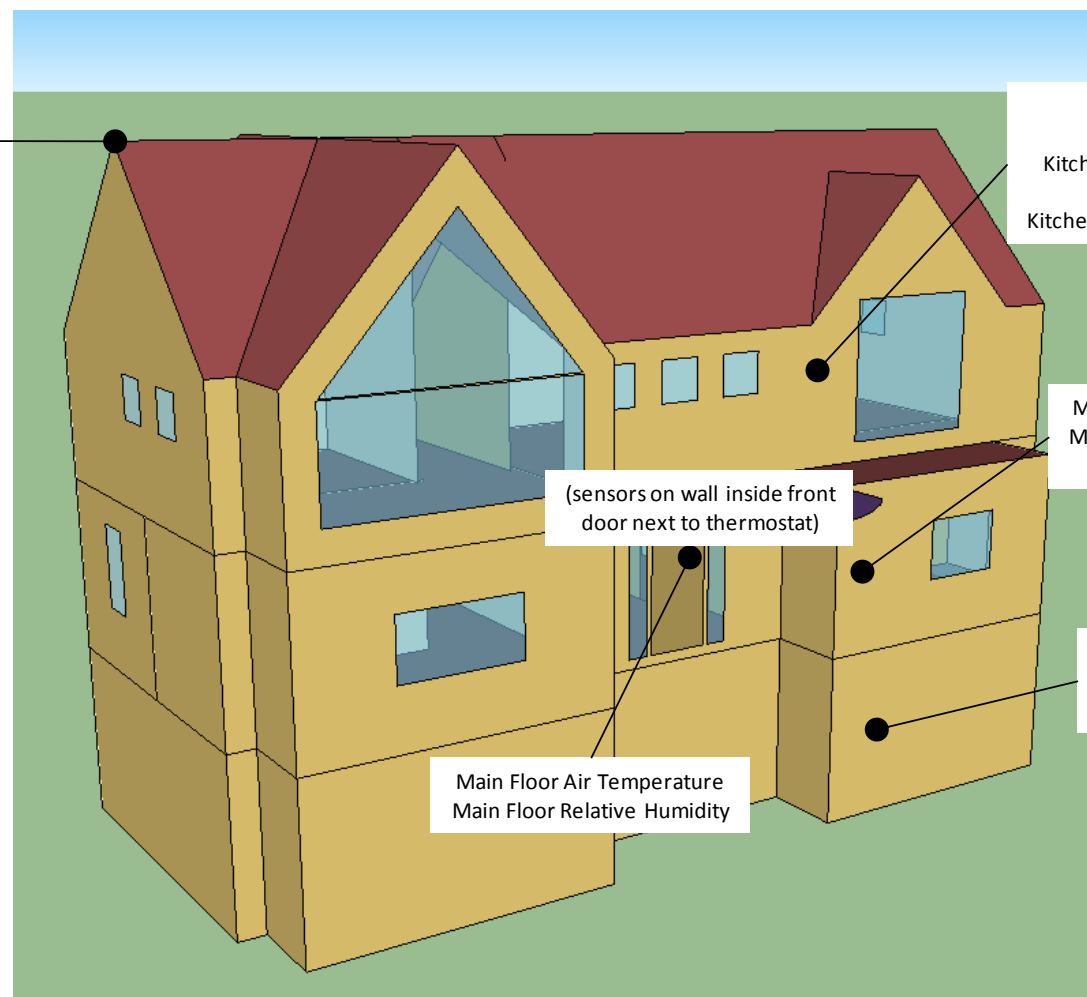


Figure 10: Sensor locations in the HVAC system

Figure 11 shows the physical location of more of the sensors installed in the pilot house. The weather station is located at the top ridge of the house near the west facing exterior wall. The main floor zone air temperature and relative humidity sensors are located on the wall inside the front door, very close to the thermostat that controls the HVAC system. Each of the three floors of the home had several electric circuits that are measured separately and listed in Table 2. Figure 11 indicates which of the three floors each of these electric circuits is located in.

Outdoor Air Temperature
Outdoor Relative Humidity
Solar Radiation
Wind Speed
Wind Direction



Over Energy
Living Room Total Energy
Kitchen/Dining Room Lighting Energy
Dishwasher Energy
Kitchen/Dining Room Receptacle Energy

Master Bedroom Total Energy
Master Bathroom Total Energy
Main Floor Total Energy

(sensors on wall inside front
door next to thermostat)

Main Floor Air Temperature
Main Floor Relative Humidity

Basement Total Energy
Clothes Dryer Energy
Clothes Washer Energy

Figure 11: Sensor locations in pilot house

CHAPTER 3 ENERGYPLUS MODEL DESCRIPTION OF PILOT HOUSE

This section provides a general description of how the EnergyPlus model was created for the pilot house, including the creation of a custom weather file generated from the conditions measured on site. This is not intended to be a tutorial on how to build an EnergyPlus model, but rather a high level description of the model including some of the settings, how the building was defined and how the HVAC system in the building was defined. In general, if a field is not mentioned in reference to the EnergyPlus model, the reader can assume that default values were used in those fields. Throughout this section, several values are called out as parameters to be entered into the calibration tool. In the next chapter, a tool will be described which was developed for this thesis to optimize a user defined set of parameters within the EnergyPlus model by minimizing a user defined objective function. The parameters to be entered into the tool are indicated within this chapter so they can be presented in the context of how they relate to the different physical parts of the building or HVAC system. More details can be found in A.1.1.1.1 Appendix A related to creating various EnergyPlus schedules from the measured data for things such as domestic water use, internal gains, and any other item that can be scheduled into the model.

3.1 Building Geometry and Construction

In general, whenever the EnergyPlus library contains a material that was used in the construction of the building, its default values for material properties was used in the model. When a material was encountered in the construction that was not available in the EnergyPlus library; the ASHRAE Handbook of Fundamentals (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2009) list of material properties was used to create these materials in the EnergyPlus model.

The model uses seven different constructions to make up the surfaces of the building. These include a foundation wall and floor, exterior walls and roof, interior walls and ceiling and interior floors. Table 4 shows a list of the different constructions used in the building with each layer of the construction identified.

Table 4: Layers and material properties of each building construction

<u>Construction/Layers</u>	<u>Thickness (m)</u>	<u>Conductivity (W/m-K)</u>	<u>Density (kg/m³)</u>	<u>Specific Heat (J/kg-K)</u>	<u>Thermal Resistance (m²-K/W)</u>
Foundation Floor					
Poured Concrete	0.1524	1.874	2242	879	
Foundation Walls					
Concrete Block	0.2032	1.95	2240	900	
Interior Ceiling					
Wood	0.0254	0.15	608	1630	
Gypsum	0.019	0.16	800	1090	
Interior Floor					
Gypsum	0.019	0.16	800	1090	
Wood	0.0254	0.15	608	1630	
Interior Wall					
Gypsum	0.019	0.16	800	1090	
Gypsum	0.019	0.16	800	1090	
Exterior Wall					
Siding	0.016	0.216	1000	837	
1" Extruded Polystyrene	0.0254	2.306	32	1465	
5.5" Blown-in Insulation	0.1397	0.0928	64	1465	
Wall Air Space					0.15
Gypsum	0.019	0.16	800	1090	
Exterior Roof					
Shingles	0.00635	0.035	1922	1256	
Wood	0.0254	0.15	608	1630	
Blown-in Insulation	0.3048	0.0337	13	837	
Gypsum	0.019	0.16	800	1090	

Each of the layers in Table 4 has a thickness, conductivity, density, specific heat, and (when applicable) thermal resistance called out with the values for each listed. Where the exact construction was not known, a best guess was used for materials. The thickness of each layer was based on the building drawings shown in Figure 5 - Figure 8. Naturally, all of these values are not exactly correct for the materials used in the actual building. Additionally, there are many other assumptions that the energy model makes when calculating the overall resistance and mass of the constructions. For purposes of calibration, there are two parameters that are boxed out in Table 4 which can be entered into the calibration tool as parameters to be “tuned” by the optimizer. These two parameters are the conductivity of the wall and roof insulation and can be used to represent the overall R-value of the building envelope.

Therefore, by calibrating the values of these two parameters, the optimizer is determining the best value for overall thermal resistance of the house.

EnergyPlus has an option to add internal mass to each zone as a “lump” mass to represent all of the furniture/appliances, etc. within the house. The physical properties of the thermal mass are described the same way as the building materials in Table 4 and then assigned a surface area for each zone. Thermal mass is another important variable which affects how the building responds to changes in outside conditions as well as how it responds when the HVAC system is on and other internal gains are present. In order to calibrate the thermal mass of the building, the surface area of the internal mass is entered into the calibration tool as another parameter to be optimized.

3.2 Internal Gains

Internal heat gains from electric equipment, lighting, appliances, etc. is also defined in the EnergyPlus model. For the pilot house, all of the internal gains were grouped together by thermal zone based on the measured data. In order to keep the model run-time reasonable and for reasons listed below, the internal gains were scheduled hourly for the year. In general, the magnitude of internal gains was very low compared to the HVAC system capacity and there was very little variation in the internal gains throughout the period of monitoring, so reducing the granularity of the internal gain schedule was not a concern. Theoretically, the radiant fraction of power used by electric equipment contributing to internal heat gains could be a parameter to be calibrated by the optimizer, but the contribution is so small in this case that it would likely not produce a result with any confidence. Table 5 lists all of the measured internal gains grouped together by the thermal zone that they are located in.

Table 5: Internal gains by thermal zone

Zone	Component
Basement	Basement Energy Clothes Dryer Energy Clothes Washer Energy
First Level	Master Bedroom Energy Master Bathroom Energy Main Floor Energy
Top Level	Oven Energy Living Room Energy Kitchen/Dining Room Lighting Energy Dishwasher Energy Kitchen/Dining Room Receptacle Energy

A much more detailed procedure for importing the measured energy consumption at the pilot home and converting the one minute time step data file into an hourly schedule of internal gains is detailed in Appendix A.2. In the case of internal gains for the pilot house, the values for each of the circuits shown in Table 5 are combined together by the zone then made into three hourly schedules for the three zones in the house. Additionally, electric equipment objects are created for the three zones based on the values in the schedules. An example of the electric equipment object to be used for internal gains is shown in Figure 101 in the appendix.

3.3 Infiltration

EnergyPlus has several different ways to define the tightness of the building envelope. For this project, the ZoneInfiltration:EffectiveLeakageArea object is used to define tightness since blower door test results were available. The heat loss or gain in each zone due to infiltration is a function of this tightness, the outdoor weather conditions, a stack coefficient, and wind coefficient. EnergyPlus uses Equation 1 to calculate the infiltration loads on the house.

Equation 1: Infiltration load equation

$$Infiltration = (F_{Schedule}) \frac{A_L}{1000} \sqrt{C_s \Delta T + C_w (WindSpeed)^2}$$

In this equation, F_{Schedule} is used to modify the flow rate calculated by the model, its value is between 0 and 1 and it always set to 1 for this project. A_L is the effective leakage area which is a function of the construction of the house. This is another parameter that will be entered into the optimizer and allowed to vary around the estimated value of 25 in^2 , which was determined in an earlier blower door as shown in Table 1. ΔT in the question represents the difference in temperature between the zone and the outdoor air, this is automatically calculated by EnergyPlus at each time step. The value for C_s or stack coefficient is obtained from the EnergyPlus documentation and shown in Table 6. The value for a two story house was the one used.

Table 6: Stack coefficient values

<u>One Story House</u>	<u>Two Story House</u>	<u>Three Story House</u>
0.000145	0.00029	0.000435

The value for C_w or wind coefficient is also obtained from the EnergyPlus documentation for a two story house in shelter class 4. Table 7 contains the values for the wind coefficient used in the EnergyPlus model.

Table 7: Wind coefficient values

<u>Shelter Class</u>	<u>One Story House</u>	<u>Two Story House</u>	<u>Three Story House</u>
1	0.000319	0.000420	0.000494
2	0.000246	0.000325	0.000382
3	0.000174	0.000231	0.000271
4	0.000104	0.000137	0.000161
5	0.000032	0.000042	0.000049

<u>Shelter Class</u>	<u>Description</u>
1	No obstructions or local shielding
2	Typical shelter for an isolated rural house
3	Typical shelter caused by other buildings across the street
4	Typical shelter for urban buildings across the street
5	Typical shelter produced by buildings that are immediately adjacent

The last term used in the equation is *WindSpeed* which is simply the wind speed from the weather file defined in the simulation. Since the basement is not exposed to the outside conditions, infiltration objects are only defined for the first floor zone and top level zone.

3.4 HVAC System

Perhaps the most complicated and non-intuitive portion of the EnergyPlus model is the definition of the HVAC system. In many cases, especially as it pertains to the innovative homes designed for the Solar Decathlon, the definition of the HVAC system will be unique to each home modeled. For some older, more standard residential homes, EnergyPlus has a series of HVAC templates that may be able to be used to simplify the process but this is not the case for the pilot house. Therefore, the HVAC system had to be created from scratch using an air loop, a hot water loop, node-branch management, and a customized control system.

In order to accurately model the HVAC system in EnergyPlus, each of the components in Figure 9 had to be defined and then connected together to mimic the system in the actual house. Due to the fact that the HRV was not used during the monitoring period, it was not included in the model as its existence would have no impact on the outcome of this study. The following sections will go through each of the components within the HVAC system and how they were defined in EnergyPlus.

3.4.1 Supply Blower

The supply blower was defined using the Fan:ConstantVolume object in EnergyPlus. There are three main variables used to characterize the fan in the model. The three variables are fan efficiency, pressure rise, and flow rate. None of these three variables were directly measured with the installed instrumentation but good estimations they can be backed out of other measured data. By invoking the law of conservation of energy it can be said that all of the energy extracted from the hot water in the heating coil as well as all of the energy consumed by the supply fan (since it is located entirely within the air

stream) are added to the air traveling through the AHU and into the house. Equation 2 through Equation 5 governs the heat transfer between the different components in the heating system.

Equation 2: Energy balance for air loop

$$TotalHeatingEnergy = HeatingCoilEnergy + SupplyFanEnergy$$

Equation 3: Heating coil energy delivered

$$HeatingCoilEnergy = \dot{m}_{Water} c_{p,Water,Coil} \Delta T_{Water,Coil}$$

Equation 4: Fan energy equation for supply fan

$$SupplyFanEnergy = \frac{\Delta p \dot{V}_{Air}}{\eta_{Fan,Motor}} t$$

Equation 5: Total air loop heating energy

$$TotalHeatingEnergy = \dot{m}_{Air} c_{p,Air} \Delta T_{Air}$$

The four equations above contain 14 variables. Using the sensors shown in Figure 10 and published material properties, 9 of the 14 variables are known which leaves 4 equations and 5 unknown variables. Knowing the exact value for the ratio of Δp to $\eta_{Fan,Motor}$ is really not important to the other variables so an assumed value for 0.3 was used for the combined fan and motor efficiency. With this assumption, the system of equations has 4 equations and 4 unknown variables and is solvable. With an assumed value of combined fan and motor efficiency given, the four remaining unknown variables that are not directly measured are fan pressure rise, air flow rate, total heating energy, and heating coil energy. In order to solve the system of equations, certain values for the measured variables had to be chosen from the data. In order to minimize transient effects, an average value for the measured temperatures, power, and water flow rate were pulled from a period when the HVAC system was on for a long period of time and temperatures had stabilized. Once the system of equations was solved, two of the variables (fan pressure rise, and air flow rate) were used in the remaining required fields to define the supply fan. The values for pressure rise were 370.5 Pa and the volumetric flow rate was 0.234 m³.

3.4.2 Heating Coil

The heating coil was defined using the Coil:Heating:Water object in EnergyPlus. There are two different ways that this type of coil can be characterized in EnergyPlus depending on what is known about the coil. The first option is *NominalCapacity* which is used when the rated capacity of the coil is known, in this case the “Maximum Water Flow Rate” and “U Factor Times Area” fields are ignored. The other option, which is the one used in this study is *UFactorTimesAreaAndDesignWaterFlowRate*. In this case, the “Rated Capacity” field is ignored and the “Maximum Water Flow Rate” and “U Factor Times Area” fields are filled with values. Since the water flow rate is one of the measured variables, it was entered directly from the measured data. The “U Factor Times Area” field is the variable entered into the HVAC system calibration tool which will be described in succeeding sections.

3.4.3 Hot Water Circulating Pump

The pump used to supply hot water to the heating coil is a Taco Model 006 Cartridge Circulator. This is a constant speed pump so it is defined in EnergyPlus as a Pump:ConstantSpeed object. The main concern related to the pump for this project was that it delivered the correct flow rate to the heating coil. Since this was a measured variable, this value was directly inputted into the rated flow rate field. The value for flow rate is $0.000219 \text{ m}^3/\text{s}$.

3.4.4 Water Heater

For the water heater, there are also several objects available in energy plus to define the component. For the purposes of this project, it was mostly important that the water heater model delivered hot water at the correct temperatures to the heating coil so the simple WaterHeater:Mixed object was used. For this object, several fields are required to define the water heater including: tank volume, set point temperature, temperature dead band, and heater capacity. Water heater temperature was one of the measured variables and a calibration procedure to be described in the succeeding sections used it to determine the values needed for the three fields described above.

3.4.5 Miscellaneous HVAC Equipment

In order to connect the previously described components to each other and actually deliver hot air to the three floors of the home, a series of pipes and ducts are required to tie the system together. Additionally, a controller is required to tell the system when to turn on and off depending on the thermostat reading. All of the details regarding how the node-branch system is set up in EnergyPlus can be found in the EnergyPlus documentation and is really not necessary to describe in this section. It is important to note that within the hot water loop, the path consists of: water heater outlet – pump inlet – pump outlet – coil inlet – coil outlet – water heater inlet. All of these connections were made via Pipe:Adiabatic objects. On the air side, the air loop path consists of: return air zone mixer – coil inlet – coil outlet – fan inlet – fan outlet – supply air zone splitter – uncontrolled single ducts air terminal. Due to type of HVAC system in the house, it was not possible to set up a set point manager with a simple thermostat build in to EnergyPlus. Instead, the Energy Management System was used with the first floor zone mean air temperature used as the thermostat measured temperature. The controller was set up to turn the heat on when the measured temperature drops below the set point and turn off when the measured temperature reaches 2°F above the set point. This 2°F dead band was chosen after observing the first floor temperature monitored data when the heating system is on and looking at the fluctuations in temperature during this period.

3.4.6 HVAC System Diagram from EnergyPlus

One of the EnergyPlus output files generated after each run is a diagram of the HVAC system so that the user can be confident that the HVAC system has been modeled correctly. Figure 12 contains this diagram for the EnergyPlus model created for the pilot house. There are two separate loops, one on the air side and one on the water side. Note that the loops are diagrammed separately with the exception of a line connecting the “AHU Heating Coil” in each loop. This is means to indicate the point at which the air side and water side interact.

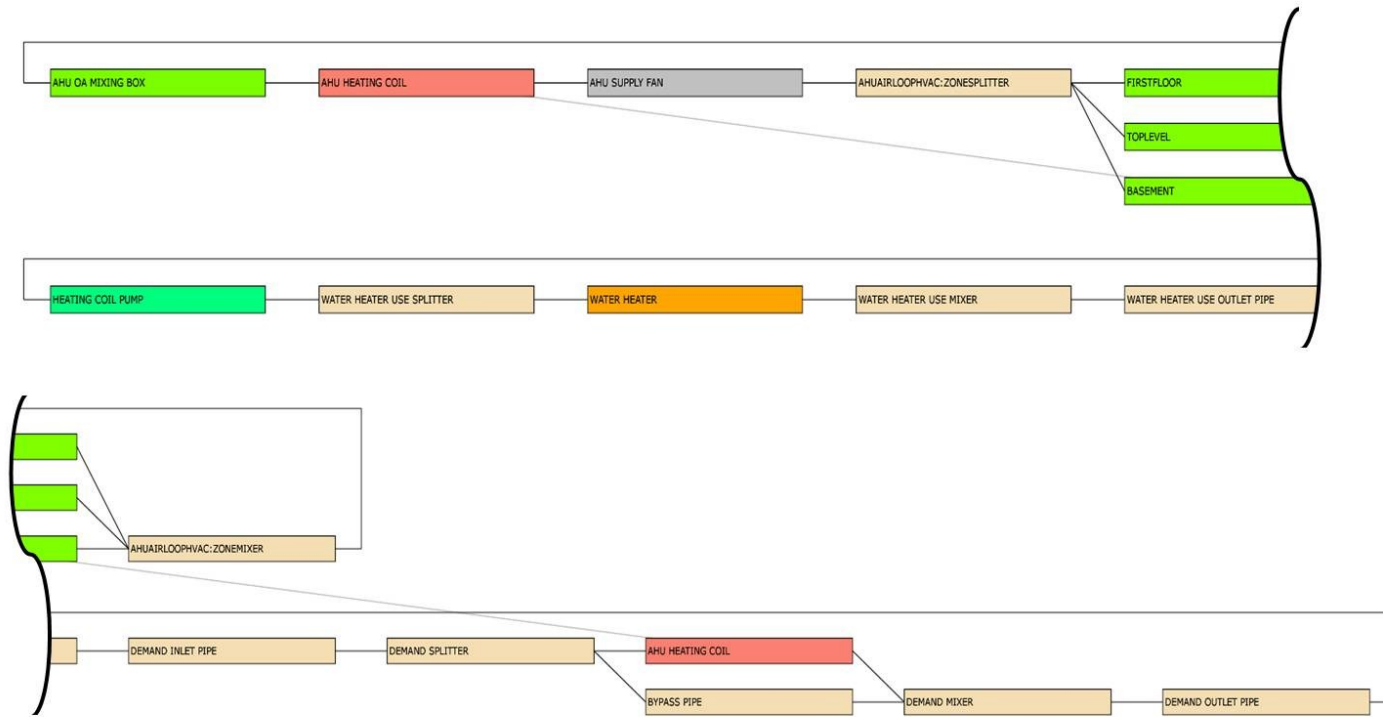


Figure 12: HVAC system diagram from EnergyPlus output

3.5 Custom Weather File Creation

In order for the model to be calibrated to the measured data, a customized weather file is required using the conditions measured on site during the period of the study. Two different files are required to run the weather converter program included in the EnergyPlus download. Input to the weather converter program consists of a file with weather data in a different format than the EPW format and a definitions file describing how the data in that file is arranged. With these two files the user or a script can run the EnergyPlus weather conversion program to create an EPW file which can be used to run the EnergyPlus simulation. Both of the input files described above must be located in the same folder and have the same name (before the file extension) as each other.

3.5.1 Definitions (.def) File

The .def file is the first of two files that the weather converter program requires to create an EPW file. Figure 13 shows the format of this file for use with the measured data. Boilerplate text is written in “normal” font, this text shall always be included in the .def file regardless of the test site or weather measurements taken at that site. “**Bold**” font represents text where the user (or script) inputs specific information based on the test site or weather measurements available at that site. “*Italicized*” font is used for comments and clarifications that are not to be included in the text of the .def file.

```

&location
City='National Mall'
StateProv='Washington D.C.'
Country=' USA '
InWMO=""
InLat=38.87
InLong=-77.03
InElev=3
InTime=-5      Hours behind GMT
/
&miscdata
Comments1='Test Weather File'
/
&wthdata
NumInHour= 60      Number of records per hour
InputFileType='CUSTOM'
InFormat='DELIMITED'
DataElements=Month,Day,Hour,Minute,DryBulb,Relative_Humidity,glohorrad,WindDir,Wind_Speed
This list can be modified for whatever weather data have been gathered on site, if more
measurements have been made that are available inputs listed in the EnergyPlus reference documentation
under “Weather Converter Program,” the can be added to this list.
DataUnits=x,x,x,x,'C','%', 'wh/m2','deg','m/s'
DataConversionFactors=1,1,1,1,1,1,1,1,1
DelimiterChar=', '
/
&datacontrol
NumRecordsToSkip=0
/

```

Figure 13: Sample .def file for use in the weather converter program

3.5.2 Data File (.txt)

The second file required by the weather converter program contains the raw weather data from the data logger. This is simply a text file with each record on a separate line and each data point separated by a comma. The location of each field within each record must match the list of “Data Elements” in the definitions exactly of the weather converter will not produce an accurate EPW file. Figure 14 shows a small sample of what the .txt file looks like for a weather file starting on Jan 1 at 12:00 AM and ending on Jan 1 at 12:18 AM. Again, as in Figure 13, “normal” font indicates text that shall always be included in the .txt file and “*Italicized*” font is used for comments and clarifications that are not to be included in the text of the .txt file. Note that the interval between records in the .txt file (which is one minute in the example) must match the number of records per hour defined in the .def file next to “NumInHour.”

```

1,1,0,0,15,77,0,219,1
1,1,0,1,19,57,0,98,6
1,1,0,2,12,60,0,255,9
1,1,0,3,15,78,0,9,6
1,1,0,4,15,82,0,218,8
1,1,0,5,11,61,0,314,2
1,1,0,6,16,65,0,5,0
1,1,0,7,14,52,0,23,0
1,1,0,8,17,71,0,149,6
1,1,0,9,20,85,0,259,6
1,1,0,10,17,76,0,122,8
1,1,0,11,20,65,0,158,7
1,1,0,12,18,81,0,135,1
1,1,0,13,16,86,0,156,1
1,1,0,14,13,59,0,347,2
1,1,0,15,18,64,0,347,3
1,1,0,16,18,60,0,153,6
1,1,0,17,13,75,0,102,4
1,1,0,18,17,63,0,254,2

```

This continues with a record for each minute or whatever interval is desired for the period of data gathered. The weather file does not need to start on Jan 1st or end on Dec 31st as long as the simulation run period is not outside the bounds of the data in the weather file.

Figure 14: Sample .txt file for use with the weather converter program

3.5.3 Lapses in measured data

As with all data acquisition systems, there will always be times when there are lapses in the measured data being recorded. If the lapse occurs during the time period when the user would like to create the weather file, it has to be dealt with in order for the weather converter program to successfully create an EPW file. There are three options for dealing with lapses in the measured data with respect to the weather file.

The first option would be to simply output an error informing the user that the weather file cannot contain certain time periods where data is missing. Since there cannot be breaks in the EPW file for EnergyPlus to run successfully, the user would have to create multiple EPW files surrounding the lapse in data, run multiple simulations and look at the results separately. This would likely be the easiest solution for the developer of the weather files but would add extra complexity and time for the modeler.

The second option would be to fill in the missing records with either the same information as the last record before the lapse occurs or the first records after the data resumes. Another option would be to

take the average of the values for each of the fields of the last record before the lapse and the next record after the lapse and fill in the missing records with that data. If this option is chosen, it would be advantageous for the developer of the software creating the EPW file to give the user the ability to choose the maximum size of data lapse which should be populated in this manner. Allowing the user a choice between methods of filling in the data (as described above) would also help their ability to understand anomalies in the output from the EnergyPlus model.

The third option for dealing with lapses in monitored data would be most useful when the lapse is for a long period of time. In situations when weather data is missing for extended periods of time (hours, days, etc.), the conditions inside the modeled building need to be “reset” to match the conditions inside the actual building. In order to do this, the missing records in the weather file shall be populated with the same conditions that exist inside the house once the data resumes. For example, if the datalogger stops recording on Jan 1st at 12:00 PM and resumes on Jan 3rd at 2:53AM, the outside temperature and relative humidity used to fill in the missing data in the weather file should be the same as the measured zone air temperature and relative humidity on Jan 3rd at 2:53 AM. After the lapse is filled in, the weather file shall continue on with the actual measured weather data. By doing this, the user will have to “throw out” the simulation results for the period when the lapse occurred, but can continue with analysis shortly after the data resumes since the conditions inside the modeled house will be very close to the actual house; and the weather file will once again match the conditions during the measured period. The other fields in the weather file such as solar radiation, wind speed and wind direction should all be set to zero while filling in the missing records to be sure that excess solar heat gains do not increase the zone air temperature in the model.

CHAPTER 4 ENERGYPLUS MODEL CALIBRATION

The purpose of this project is to study different calibration methodologies using measured data and see how well the calibrated models they produce are able to predict future energy usage. With each individual case, there is always a varying amount of information available to the energy modeler for building the energy model. Ideally, the energy modeler would be able to survey the information available and the funding available for performing an energy audit on the building, enter this information into a tool which will output to the user the optimal package of instrumentation and auditing techniques to build the most accurate model possible. Having a calibrated model is necessary to properly assess the buildings current level of efficiency and the potential for energy savings by making certain improvements to the building. Unfortunately, there is not enough data available in this study to fully produce the tool described above. The following chapter will describe a calibration technique that was developed for the model of the pilot house using the data that was collected at the pilot house.

4.1 Calibration Tool Description

In order to be able to calibrate the EnergyPlus model as desired, a tool was required which could find the optimum values for a set of bounded model variables at the global minimum value of a given objective function. Ideally, this tool would allow the user to choose any EnergyPlus parameters, define their initial conditions and bounds; and be returned their calibrated values based on the objective function to be minimized. The calibration tool developed by the author of this report was created using MATLAB which is described by its developer (MathWorks) as “a high-level language and interactive environment that enables you to perform computationally intensive tasks faster than with traditional programming languages such as C, C++, and Fortran.” The general methodology behind the MATLAB calibration tool is to take a series of inputs from the user, call EnergyPlus to run the simulation, read the EnergyPlus output file, compute the objective function and then iterate as many times as needed to minimize the objective function by changing the EnergyPlus inputs. There are a number of MATLAB functions and scripts required to perform this series of tasks; they are all available in Appendix B. Figure 15 contains a

graphical representation of how the calibration tool reads data, files, and user inputs to produce a calibrated result.

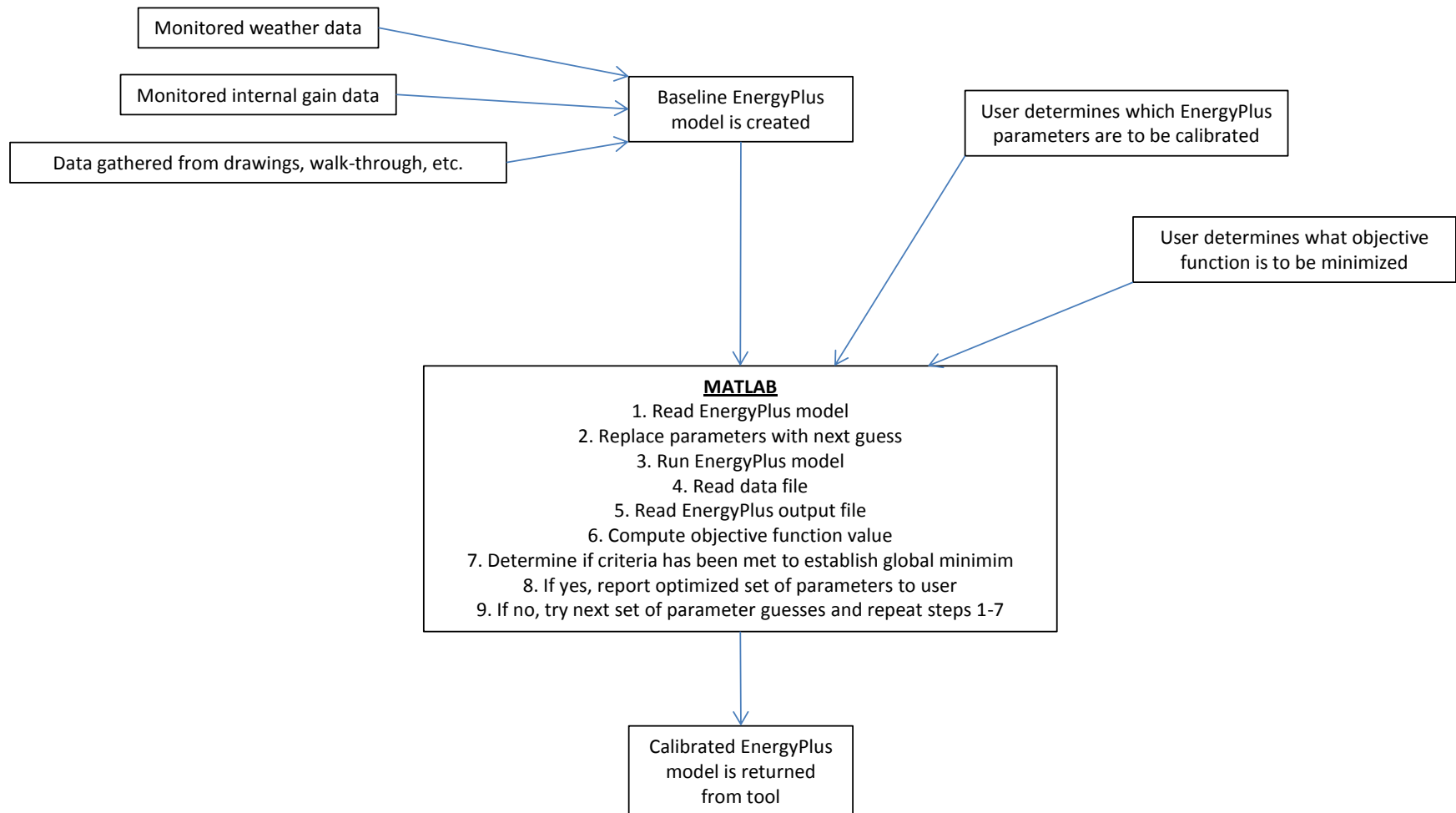


Figure 15: Basic flowchart showing how the calibration tool works

4.2 Measured Data to be used in Calibration Tool

Once the EnergyPlus model is created using the physical characteristics of the home to be studied, the modeler can use the procedures outlined in Chapter 3 and A.1.1.1 Appendix A to take a portion of the measured data and directly input it into the EnergyPlus model. In order to calibrate the unknown or “guessed” parameters that define certain aspects of the building envelope, it helps to know as much as possible about things that can be directly measured and imported into EnergyPlus (a few examples are described in section A.2). For variables that have to be calibrated using the optimization procedure to be defined, the measured data has to be imported in a certain format. Table 8 lists the measured data that is not used directly in the EnergyPlus IDF, but can be compared to output from the EnergyPlus simulation in order to calibrate the model.

Table 8: Variables to be used for calibrating energy model

Variable	Type	Unit
Main Floor Temperature	Temperature	°F
Water Heater Middle Temperature	Temperature	°F
Air Handler Return Air Temperature	Temperature	°F
Air Handler Supply Air Temperature	Temperature	°F
Heating Coil Return Water Temperature	Temperature	°F
Heating Coil Supply Water Temperature	Temperature	°F
Heating Coil Flow	Flow	gallon
Mechanical Room Energy	Energy	kWh

There are a number of software packages that have the ability to compare arrays of data and perform calculations. This type of analysis is required in order to determine how close the EnergyPlus model output is to the measured data and has to be pre-processed before the calculations can be performed. Later in this report, the actual procedures for calibrating the EnergyPlus model will be discussed in detail but in order to talk about those procedures, the measured data has to be processed in a certain way.

Main floor temperature is a fairly straightforward measurement to process. The only thing that the user must be sure of is that the units are consistent between the measured data and the EnergyPlus output.

In most cases, EnergyPlus deals in the International System of Units (SI) so the temperature is in units of degrees Celsius. The only other processing that may necessary with temperature is to make sure that the time intervals between the measured data matches the EnergyPlus output. EnergyPlus has the ability to output zone temperature at the time step that the simulation is being run at or at larger increments. Since the measured data is taken in one minute intervals, it can either be left as is or reduced to 15 minute averages, one hour averages or however the user desires.

In addition to temperature, building or HVAC energy consumption is a very common metric that is used to compare an energy model to the actual building that it is supposed to represent. In the case of the pilot house that is the subject of this report, the internal gains are known and scheduled into the EnergyPlus model so it is not necessary to compute whole building energy consumption from the measured data. Instead, HVAC system energy consumption is used to compare how accurately the calibrated energy model predicts how the home performs during the monitored period. EnergyPlus has the ability to output air loop total heating energy (in Joules), so in order to compare the measured data to this, total heating energy must be computed from the available data. Table 8 lists the available measurements related to the HVAC system. From these measurements, the heat delivered to the air from the hot water coil can be calculated using water flow, coil supply water temperature, and coil return water temperature. Additionally, the HVAC supply fan power is also being measured and with the fan located entirely in the airflow, all of its power consumed gets added to the air as heat. These two things make up the entirety of the heat being added to the air within the HVAC system. Equation 6 shows the HVAC system total heating energy calculation. Equation 7 shows the calculation for the hot water heating energy. Equation 8 shows the calculation for fan heating energy.

Equation 6: HVAC system total heating energy

$$Energy_{HVAC} = Energy_{coil} + Energy_{fan}$$

Equation 7: Hot water coil energy

$$Energy_{coil} = (t)(\dot{m})(c_p)(T_{water_{supply}} - T_{water_{return}})$$

Equation 8: Fan heating energy

$$Energy_{fan} = Power_{fan}(t)$$

The EnergyPlus output for energy is reported in Joules for each time step. Table 8 shows the units for each of the measured variables (which in this case are °F, kWh, and gallons). In order have energy in Joules in the equations above, the units must be converted to what is shown in Table 9.

Table 9: Units for HVAC system energy calculations

Variable	Unit
\dot{m}	$\frac{kg}{s}$
c_p	$\frac{J}{kgK}$
T	K
$Power_{fan}$	W
t	sec

Once the data is converted, it can be used to calculate the heating energy which can then be compared to the EnergyPlus output for calibration purposes.

4.3 Calibration Tool Validation

Two tests were performed in order to increase confidence that the calibration tool does indeed output parameter values that satisfy the objective function criteria (global minimum). The whole point of using an optimization algorithm is to find a set of multiple inter-related input variables that satisfy an objective function criterion since it is not possible (or very difficult) to calculate these variables manually. It is simple to manually determine a minimum objective function value when just one or two input parameters are allowed to vary. The first of the two tests that was performed to validate that the optimizer was finding a global minimum involved holding all model parameters constant except for infiltration, which was allowed to vary between the upper and lower bounds of 50 and 500 cm² of equivalent leakage area. The model was allowed to run for 10 days in late January and the objective function was the RMS error between the daily energy consumption of the model vs. the measured energy consumption of the

house for the ten day period. Table 10 shows the optimized value outputted by the calibration tool as well as the objective function value at that point.

Table 10: Calibration tool output for single variable optimization

Parameter	Optimized Value	Lower Bound	Upper Bound	Error (J)
Inf (cm ²)	173.48	50	500	2.39E+07

To validate this calibration, the model was run at a variety of infiltration values and the objective function was calculated and manually plotted to visually observe where the optimized infiltration value occurs. Table 11 below shows the error values associated with each infiltration input value.

Table 11: Single variable manual optimization

Infiltration (cm²)	Error (J)
50	4.7008E+07
72.5	4.2517E+07
83.75	4.0844E+07
95	3.8534E+07
117.5	3.4833E+07
140	2.6422E+07
170	2.4081E+07
175	2.3935E+07
180	2.4867E+07
185	2.4361E+07
190	2.4345E+07
200	2.4188E+07
210	2.4628E+07
230	2.6773E+07
275	3.7912E+07

Figure 16 shows the values in Table 11 plotted to visually demonstrate where the minimum error value occurs.

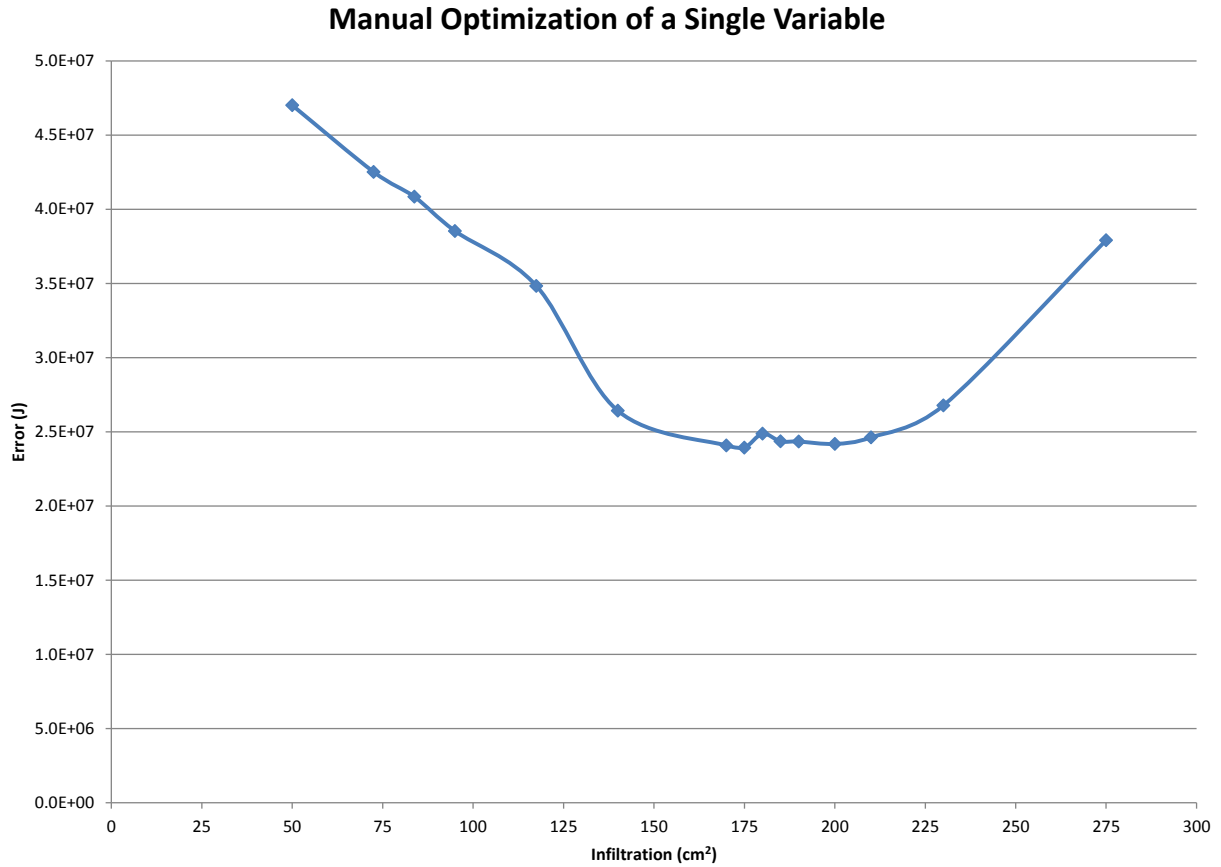


Figure 16: Graph of error as a function of infiltration input value

According to the calibration tool, the minimum error occurs at an infiltration value of approximately 173 cm². The manual calibration confirms that the optimized infiltration value is approximately 175 cm².

Once it was confirmed that the calibration tool could locate the correct value when only a single input parameter was varied, the same process was deployed for two variables, infiltration and mass. Infiltration was given lower and upper bounds of 50 & 500 cm² and mass was given lower and upper bounds of 10 & 1000 m². Table 12 shows the optimized value outputted by the calibration tool as well as the objective function value at that point.

Table 12: Calibration tool output for a tow-variable optimization

Parameter	Optimized Value	Lower Bound	Upper Bound	Error (J)
Inf (cm ²)	168.035	50	500	2.35E+07
Mass (m ²)	133.156	10	1000	

In this case, in order to avoid running too many simulations, the model for the manual optimization was run at infiltration values between 50 & 275 cm² at nine equal intervals and mass values between 10 & 505 m² at six equal intervals. Table 13 shows a matrix of the error values for the varying inputs of both mass and infiltration.

Table 13: Two-variable manual optimization

		Error (J)					
		Mass (m² Surface Area)					
		10	109	208	307	406	505
Infiltration (cm²)	50	4.97E+07	4.70E+07	4.32E+07	4.55E+07	5.41E+07	6.24E+07
	72.5	4.60E+07	4.25E+07	3.94E+07	4.36E+07	5.26E+07	6.14E+07
	83.75	4.33E+07	4.08E+07	3.77E+07	4.31E+07	5.27E+07	6.11E+07
	95	4.16E+07	3.85E+07	3.64E+07	4.38E+07	5.35E+07	6.13E+07
	117.5	3.91E+07	3.48E+07	3.06E+07	3.98E+07	5.13E+07	6.85E+07
	140	3.60E+07	2.64E+07	2.83E+07	3.91E+07	5.21E+07	7.26E+07
	185	2.94E+07	2.44E+07	2.93E+07	4.33E+07	5.68E+07	7.58E+07
	230	3.01E+07	2.68E+07	3.62E+07	5.10E+07	7.23E+07	9.11E+07
	275	3.71E+07	3.79E+07	4.74E+07	6.05E+07	7.93E+07	9.70E+07

Figure 17 shows the values in Table 12 plotted to visually demonstrate where the minimum error value occurs.

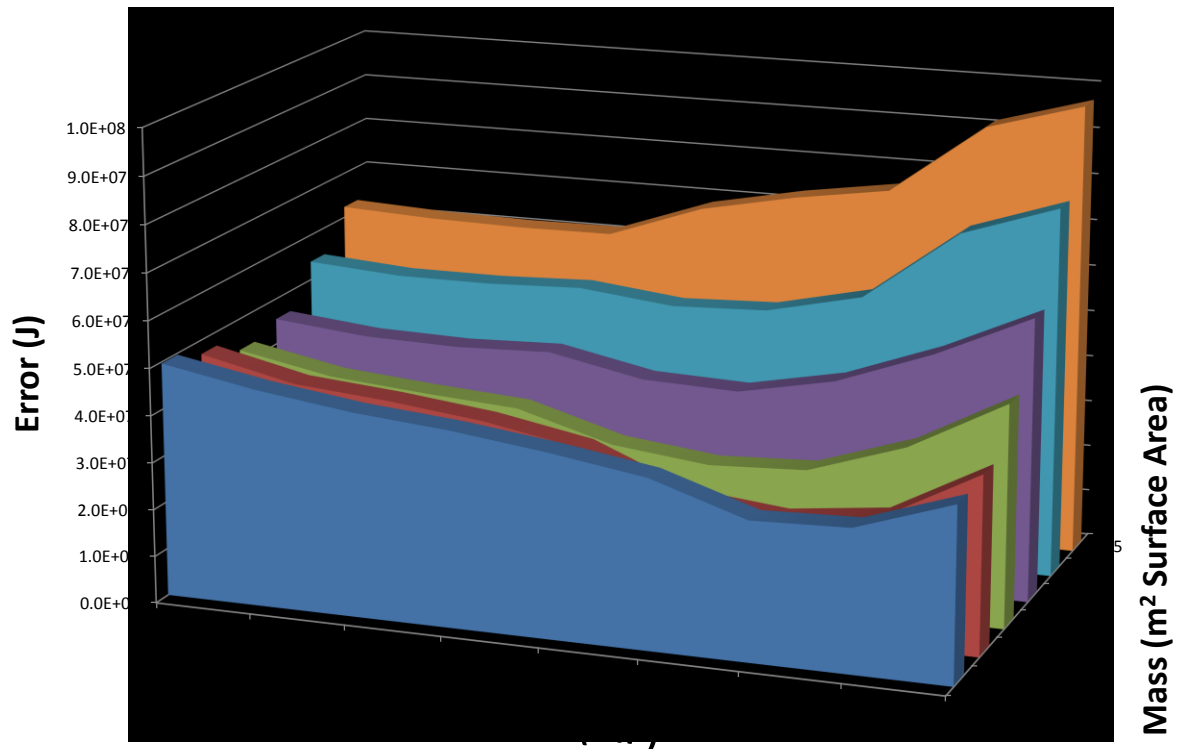


Figure 17: Three-dimensional plot of error as a function of both mass and infiltration

According to the calibration tool, the minimum error occurs at an infiltration value of approximately 168 cm^2 and a mass value of approximately 133 m^2 surface area. The manual calibration confirms that the optimized infiltration value is approximately 185 cm^2 and the optimized mass value is approximately 109 m^2 . While these numbers are not exactly the same, they are the closest values within the matrix to the calibration tool values; there is no reason to believe that if more manual runs were performed, the values would not have converged.

These two tests confirm that the calibration tool is indeed outputting a set of model parameters at the global minimum of the objective function.

4.4 Water Heater Calibration Procedure

As noted in section 3.4.4, the water heater model requires four parameters to be defined: tank volume, set point temperature, temperature dead band, and heating capacity. Before the HVAC system could be calibrated, it was imperative that the water delivered to the heating coil in the model accurately

represented what was taking place in the pilot house. This required that the water heater model was calibrated before anything else could be done with the building model. Figure 18 contains sample text from the EnergyPlus IDF defining the WaterHeater:Mixed object. The highlighted fields show the four unknown parameter values that must be determined in order to have a calibrated model.

```

WaterHeater:Mixed,
  Water Heater,          !- Name
  0.1893,                !- Tank Volume {m3}
  Hot Water Setpoint Temp Schedule, !- Setpoint Temperature Schedule Name
  5.2,                   !- Deadband Temperature Difference {deltaC}
  82,                    !- Maximum Temperature Limit {C}
  Cycle,                 !- Heater Control Type
  6650,                  !- Heater Maximum Capacity {W}
  ,                      !- Heater Minimum Capacity {W}
  ,                      !- Heater Ignition Minimum Flow Rate {m3/s}
  ,                      !- Heater Ignition Delay {s}
  NaturalGas,            !- Heater Fuel Type
  0.9,                   !- Heater Thermal Efficiency
  ,                      !- Part Load Factor Curve Name
  ,                      !- Off Cycle Parasitic Fuel Consumption Rate {W}
  ,                      !- Off Cycle Parasitic Fuel Type
  ,                      !- Off Cycle Parasitic Heat Fraction to Tank
  ,                      !- On Cycle Parasitic Fuel Consumption Rate {W}
  ,                      !- On Cycle Parasitic Fuel Type
  ,                      !- On Cycle Parasitic Heat Fraction to Tank
  Zone,                  !- Ambient Temperature Indicator
  ,                      !- Ambient Temperature Schedule Name
  Basement,              !- Ambient Temperature Zone Name
  ,                      !- Ambient Temperature Outdoor Air Node Name
  1,                     !- Off Cycle Loss Coefficient to Ambient Temperature {W/K}
  1,                     !- Off Cycle Loss Fraction to Zone
  1,                     !- On Cycle Loss Coefficient to Ambient Temperature {W/K}
  1,                     !- On Cycle Loss Fraction to Zone
  ,                      !- Peak Use Flow Rate {m3/s}
  ,                      !- Use Flow Rate Fraction Schedule Name
  ,                      !- Cold Water Supply Temperature Schedule Name
  Water Heater Use Inlet Node, !- Use Side Inlet Node Name
  Water Heater Use Outlet Node, !- Use Side Outlet Node Name
  1,                     !- Use Side Effectiveness
  ,                      !- Source Side Inlet Node Name
  ,                      !- Source Side Outlet Node Name
  ,                      !- Source Side Effectiveness
  autosize,              !- Use Side Design Flow Rate {m3/s}
  ,                      !- Source Side Design Flow Rate {m3/s}
  1.5;                   !- Indirect Water Heating Recovery Time {hr}

```

Figure 18: Example text from EnergyPlus IDF for WaterHeater:Mixed object

Figure 19 shows the label from the water heater which indicates that the volume of the tank is 50 gallons (0.1893 m3).

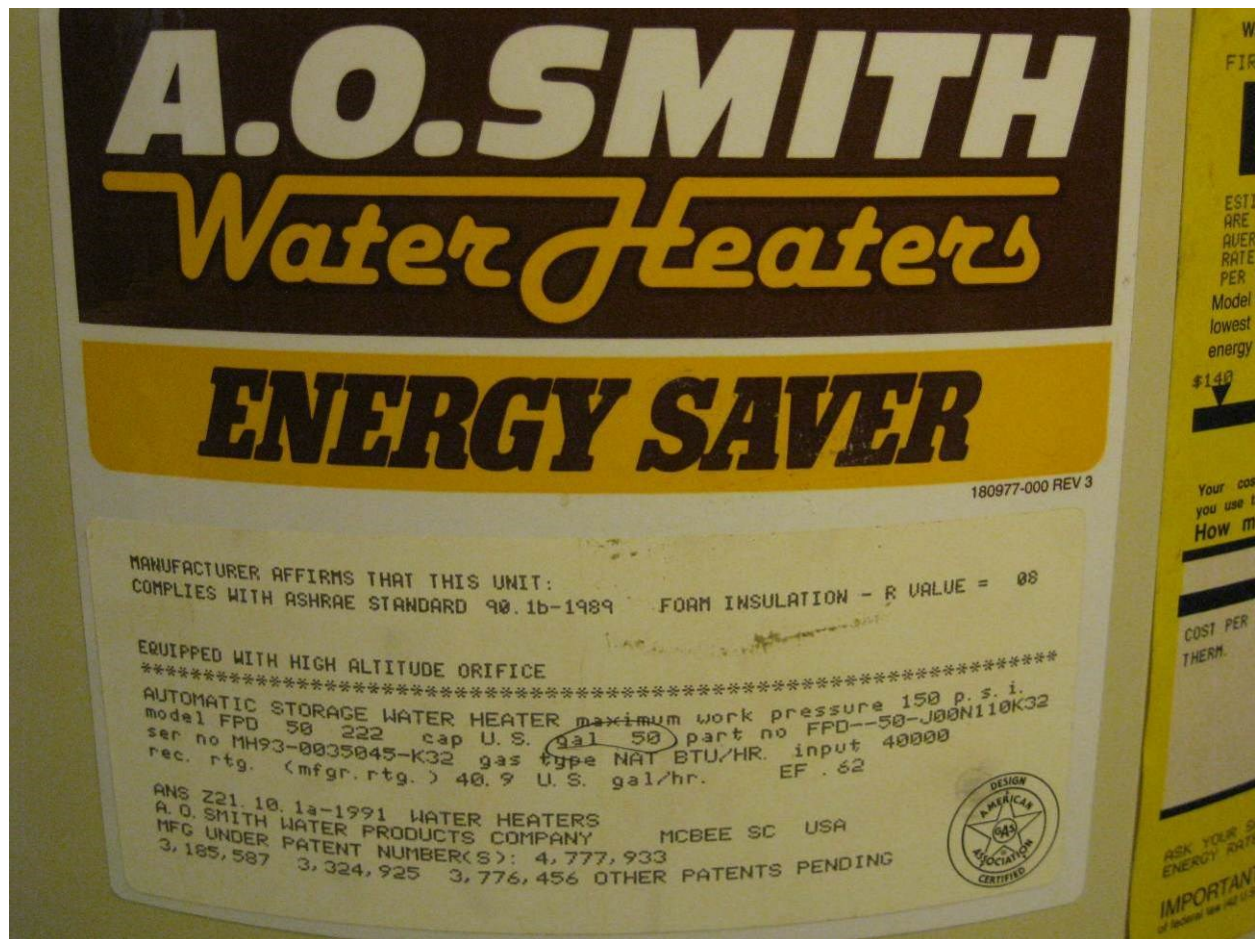


Figure 19: Label from the hot water heater in the pilot house

With the volume of the water heater being a known value, it was simply entered directly into the EnergyPlus IDF. Two of the other three parameters to be inputted into the water heater model, water heater set point and dead band, were both determined by looking at the measured water heater temperature data during a period when the HVAC system was on for a long period of time (long enough so that the heater cycles on and off several times). Figure 20 shows the temperature of the hot water being delivered to the heating coil during an approximately 12 hour period when the HVAC system was operating.

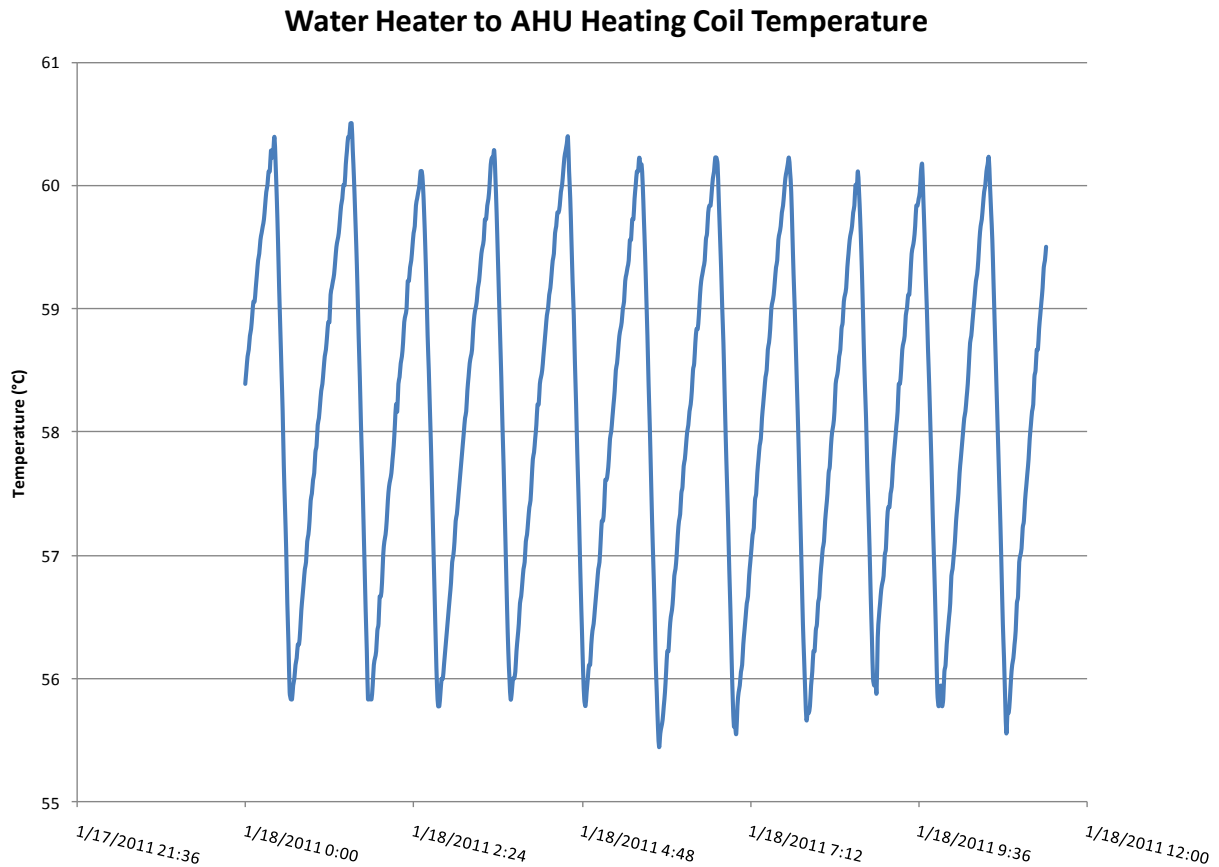


Figure 20: Measured hot water temperature entering the heating coil during a period when the HVAC system was operating

EnergyPlus allows the user to enter a water heater set point schedule. For the pilot house, there is only one set point which does not change throughout the year so a schedule with one value was all that was required. The water heater set point is the temperature at which the heating element turns off (i.e. the temperature shouldn't go above the set point, only reach it). There are a number of reasons why the shut off temperature observed in the cycling of the water heater in the measured data isn't always exactly the same, but as seen in Figure 20, it does not vary by more than one or two tenths of a degree Celsius. To determine a value to be used in the model, an average value of these shut off temperatures was used as the constant set point. This turned out to be 60.5°C.

Another of the required variables to be entered into the EnergyPlus model is the dead band temperature difference. The value of this parameter is equal to the number of degrees Celsius that the

temperature of the hot water is allowed to drift below the set point before the heating element comes back on. Again, this is not something that was observed to be exactly consistent each time the water heater cycled, but it was very close to the same number. Therefore, the average value for dead band over the 10 full cycles observed in the measured data was used for the model. This value was 5.4°C.

With three of the four required parameters now known from either published manufacturer data or observed measured data, the only remaining parameter needed to have a calibrated water heater model is the heating capacity (in Watts). In order to determine the heating capacity of the water heater, the EnergyPlus-MATLAB calibration tool was used. In all cases, the calibration tool requires an objective function to be minimized at the optimal point (which is the calibrated value for heating capacity). In the case of the water heater, there is a direct correlation between the heater capacity and the slope of the temperature curve while the heating element is on. Therefore, the objective function calculates the difference in slope between the measured data during one of the water heater cycles with the slope of the temperature curve of the EnergyPlus output during a similar cycle. The MATLAB code used to calculate this error can be found in Appendix B.3 The value of water heater capacity at which the difference in slopes is minimized is the calibrated value for heater capacity. In this case, the calibration tool produced an optimized value of 6650 W for the water heater in the pilot house. Figure 21 shows both the measured and modeled temperatures of hot water being delivered to the heating coil during HVAC system operation. The modeled temperature represents the EnergyPlus output after the preceding calibrated values were entered.

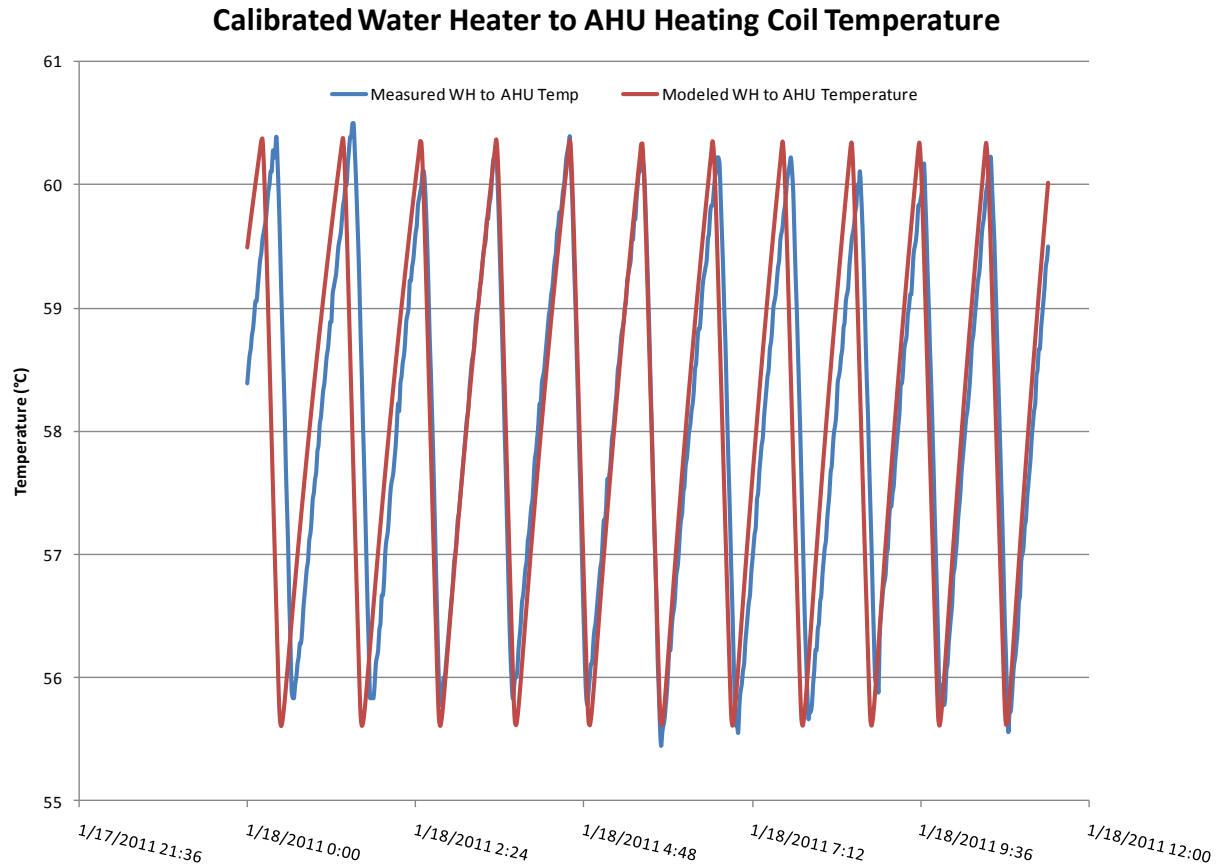


Figure 21: Comparison between measured and modeled hot water temperature delivered to the heating coil after calibration

4.5 HVAC System Calibration Procedure

Once the water heater is calibrated to deliver hot water the heating coil at the correct temperature, it becomes possible to calibrated the unknown parameters within the HVAC system model. Section 2.3 outlined the HVAC system as whole and went through the different components of the HVAC system and described them in a physical sense. There were certain parameters such as heating coil water flow rate and supply fan volumetric flow rate that were either determined directly from the measured data or calculated using the relationships described in Equation 2 through Equation 5. Even with this information known and the coil being supplied water at the correct temperature, there are still unknown parameters within the HVAC system that must be calibrated in order for the system in the model to deliver the same amount of

heat to the house as in the actual pilot house. Only once the HVAC heat gains are known can the building envelope parameters be calibrated with any degree of confidence.

Figure 22 contains sample text from the EnergyPlus IDF defining the heating coil. The only unknown parameter value that is required is the “U-Factor Times Area Value {W/K}” which is highlighted.

```
Coil:Heating:Water,
  AHU Heating Coil,      !- Name
  Always On,             !- Availability Schedule Name
  %UA%,                  !- U-Factor Times Area Value {W/K}
  0.000219175342,        !- Maximum Water Flow Rate {m3/s}
  AHU Heating Coil HW Inlet, !- Water Inlet Node Name
  AHU Heating Coil HW Outlet, !- Water Outlet Node Name
  AHU Mixed Air Outlet,   !- Air Inlet Node Name
  AHU Heating Coil Outlet, !- Air Outlet Node Name
  UFactorTimesAreaAndDesignWaterFlowRate, !- Performance Input Method
  autosize,              !- Rated Capacity {W}
  82.2,                  !- Rated Inlet Water Temperature {C}
  16.6,                  !- Rated Inlet Air Temperature {C}
  71.1,                  !- Rated Outlet Water Temperature {C}
  32.2,                  !- Rated Outlet Air Temperature {C}
  1.0;                   !- Rated Ratio for Air and Water Convection
```

Figure 22: Example text from EnergyPlus IDF for Coil:Heating:Water object

The U-Factor Times Area Value essentially defines how many Joules of energy are added to the air traveling through the heating coil as a function of the coil entering water temperature and flow rate (known) and the coil entering air temperature and flow rate (also known). The higher the value for this parameter, the more heat is transferred from the water to the air in the coil. Conservation of energy tells us that once the temperature of the coil apparatus reaches steady state, all of the heat lost from the water as it travels through the coil is added to the air passing through the coil. Fortunately, the pilot house is instrumented to measure the temperature of the water directly before and after it travels through the coil as well as water flow rate. We know from section 3.4.3 that the hot water circulation pump is a constant speed pump so it is either on or off. On the “Maximum Water Flow Rate” field in Figure 22, the value of $0.000219 \text{ m}^3/\text{s}$ comes from the measured data and does not change. With water flow rate, supply, and

return temperature known, the heating coil energy can be calculated using Equation 6. Similar to the water heater calibration, a period of time within the measured data when the HVAC system was operating continuously for a long period was chosen for the HVAC system calibration. Such a period took place on 1/18/2011 from approximately 12:01AM-11:25AM. The measured coil supply and return water temperatures are shown in Figure 23 for this time period.

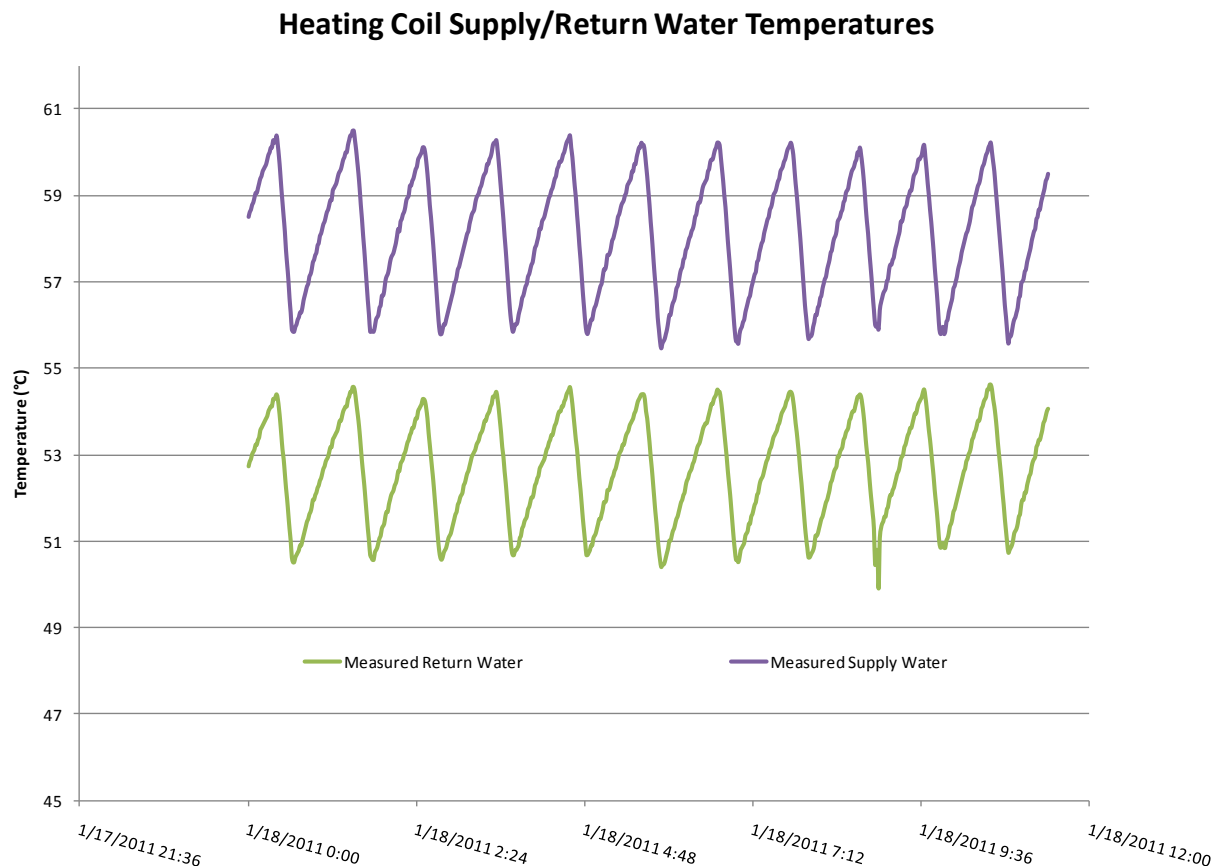


Figure 23: Measured supply and return water temperatures to the heating coil

You can see from the data that the heat removed from the water during this 12 hour period of time when the water heater cycled on and off about 10 times is fairly consistent with a drop in temperature of approximately 5.5-6°C across the coil. Again, the EnergyPlus-MATLAB calibration tool was used to calibrate the U-Factor Times Area Value in the EnergyPlus model. Since the actual heating coil energy could be calculated for each time step during the period shown in Figure 23, the objective

function in this case is the difference between the actual cumulative energy delivered and the cumulative energy delivered by the heating coil in the EnergyPlus model. The MATLAB code used to calculate the objective function value can be found in Appendix B.4. Fortunately, EnergyPlus has an output called “AHU:Air Loop Total Heating Coil Energy[J](TimeStep)” so this number is simply added up over the same time period and the difference in cumulative energy is the objective function value for each different “guess” at “U-Factor Times Area Value”. The value that produced the smallest objective function value turned out to be 224 W/K. Once this value was obtained, it was entered into the EnergyPlus model to look at the comparison between the measured and modeled heating coil supply and return water temperatures. Figure 24 shows the comparison.

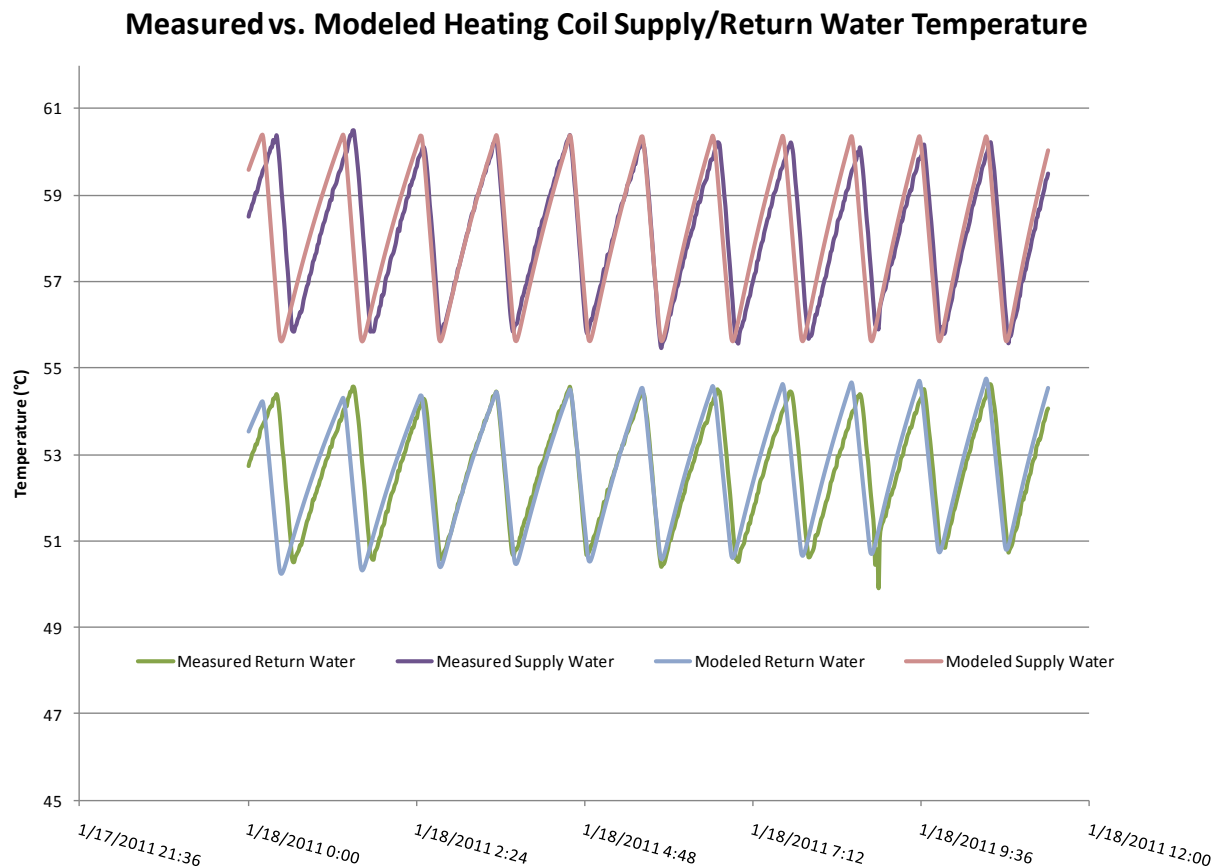


Figure 24: Water side results from the calibrated HVAC system model vs. the measured data

To check the validity of these results as well as the value obtained for supply fan volumetric flow rate by solving the system of equations in section 3.4.1, a comparison between the AHU supply and return air was also looked at. One potential flaw with using this comparison to validate the HVAC system calibration is that the return air temperature is a function of more than just the HVAC system, it relies rather heavily on the building envelope performance, internal gains, and outdoor weather conditions. Fortunately, in the case of the pilot house, the un-calibrated building model was close enough to produce return air that was fairly close to the measured return air temperature during the calibration period on 1/18/2011, so the results are encouraging. Figure 25 shows the comparison of measured vs. modeled AHU supply and return air during the calibration period.

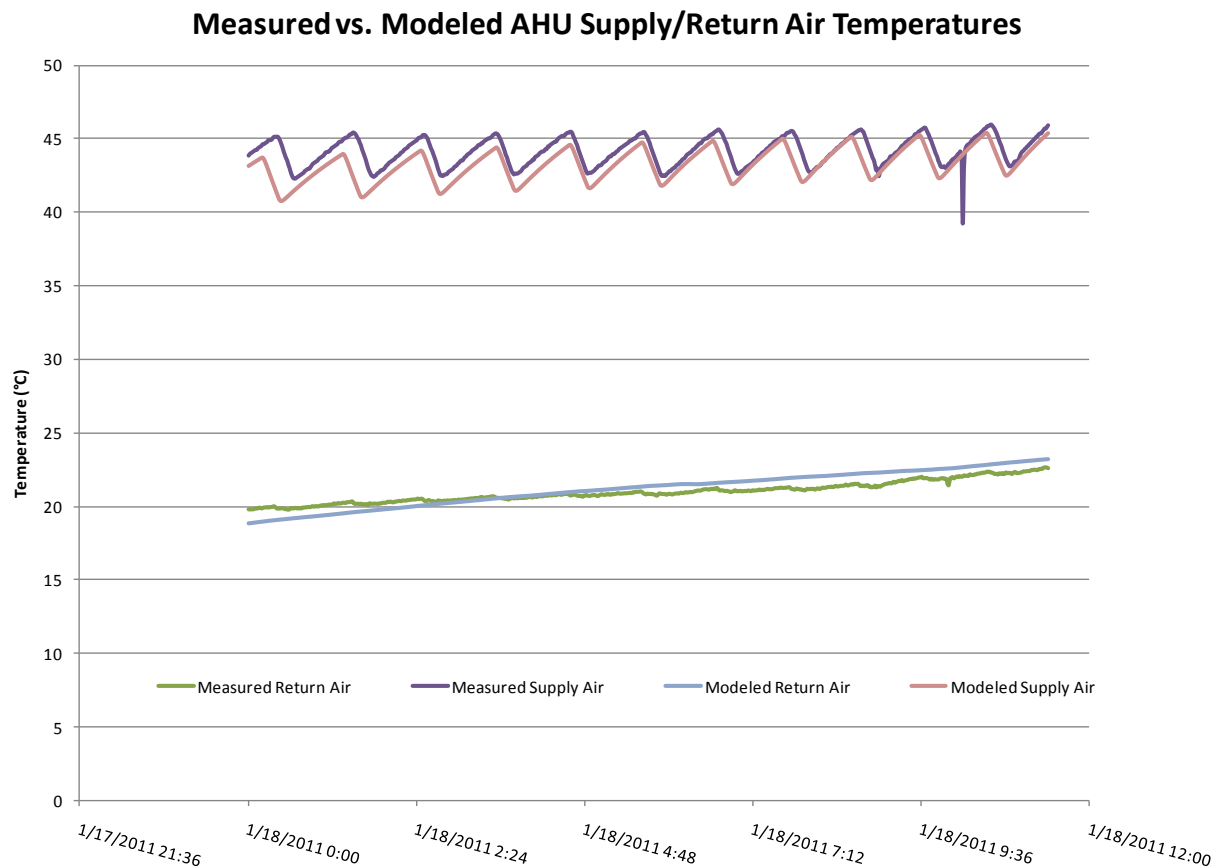


Figure 25: Air side results from the calibrated HVAC system model vs. the measured data

After adjusting for differences in return air temperature, the modeled supply air temperature is within approximately 1°C of the measured supply air temperature. Without knowing the exact supply fan flow rate, it would be near impossible to get this any closer. Not only does this result confirm the credibility of the HVAC system calibration, it also confirms that the calculated supply fan volumetric flow rate is very close the actual fan in the pilot house.

Everything described in this section so far has been restricted to calibrating the HVAC system so that the supply air is at the correct temperature and flow rate as related to the actual building. One thing that is not addressed by this calibration is the amount of the total supply air that is distributed to each floor of the house. There is only one thermostat in the house and there are no controllable supply ducts so the amount of air delivered to each floor is constant and must also be calibrated. Figure 26 contains an excerpt from the EnergyPlus IDF describing how the air is distributed within three thermal zones of the pilot house.

```
AirTerminal:SingleDuct:Uncontrolled,  
  FirstFloor Outlet,      !- Name  
  Always On,              !- Availability Schedule Name  
  FirstFloor Zone Equip Inlet, !- Zone Supply Air Node Name  
  %flow%;                 !- Maximum Air Flow Rate {m3/s}
```

```
AirTerminal:SingleDuct:Uncontrolled,  
  TopLevel Outlet,       !- Name  
  Always On,             !- Availability Schedule Name  
  TopLevel Zone Equip Inlet, !- Zone Supply Air Node Name  
  %flow2%;               !- Maximum Air Flow Rate {m3/s}
```

```
AirTerminal:SingleDuct:Uncontrolled,  
  Basement Outlet,       !- Name  
  Always On,             !- Availability Schedule Name  
  Basement Zone Equip Inlet, !- Zone Supply Air Node Name  
  0;                     !- Maximum Air Flow Rate {m3/s}
```

Figure 26: Example text from EnergyPlus IDF for AirTerminal:SingleDuct:Uncontrolled object

The two highlighted fields shown above are entered into the calibration tool during the building envelope calibration along with the parameters that will be described in the succeeding sections. The total

air flow rate is $0.234\text{m}^3/\text{s}$ and there is essentially no supply air entering the basement thermal zone, so the calibration tool determined what percentage of the total flow is distributed among the first and top levels of the house.

4.6 Building Envelope Calibration Procedure

Once the HVAC system model is properly calibrated to deliver heating to the house in a manner consistent with the actual building, it becomes possible to calibrate the building envelope which is the most complicated portion of the energy model calibration. Unlike the water heater and HVAC system, it is not possible to isolate individual building envelope parameters since they are truly inter-related in how they affect the performance of the building envelope. For this reason, calibration of the building envelope becomes a multivariable optimization problem. Although the calibration tool is designed to be universal in the number of variables that it can optimize simultaneously, the run time of the EnergyPlus model can make optimizing too many parameters impractical with the resources available for this project. This section will go through which building envelope parameters were chosen to be included in the optimization and how the objective function was calculated.

4.6.1 Building Envelope Calibration Input Parameters

As described in section 2.2, many characteristics of the building construction cannot be calculated exactly or looked up from a manufacturer. Theoretically, every unknown parameter for each layer of the building construction could be entered into the calibration tool to be optimized but this is impractical due to the fact that the run time would be astronomical and that this level of granularity would likely offer no better result than a simplified method of achieving the same building characteristics. The main two building envelope characteristics affected by the construction of the walls and roof are overall envelope thermal resistance and building mass. Also adding to the building mass are interior partitions, furniture, and any other object which can absorb and store heat within the envelope of the building. To account for building mass and its effects on the thermal conditions inside the zones of the house, EnergyPlus has an

“InternalMass” object. Figure 27 contains an excerpt from the EnergyPlus IDF file where the internal mass is defined.

```
!- ===== ALL OBJECTS IN CLASS: INTERNALMASS =====
```

```
InternalMass,  
  Top Floor Internal Mass, !- Name  
  Interior Furnishings,    !- Construction Name  
  TopLevel,               !- Zone Name  
  %mass%;                 !- Surface Area {m2}
```

```
InternalMass,  
  First Floor Internal Mass, !- Name  
  Interior Furnishings,    !- Construction Name  
  FirstFloor,              !- Zone Name  
  %mass%;                 !- Surface Area {m2}
```

```
InternalMass,  
  Basement Internal Mass, !- Name  
  Interior Furnishings,    !- Construction Name  
  Basement,               !- Zone Name  
  %mass%;                 !- Surface Area {m2}
```

Figure 27: Example text from EnergyPlus IDF for InternalMass object

As shown above, each zone has internal mass assigned to it. The physical characteristics of the internal mass are defined in a construction called “Interior Furnishings” which represents a composite value for all of the interior partitions, furniture, etc. The highlighted field is for surface area of the internal mass. This is essentially a way to increase or decrease the quantity of internal mass in the building and is therefore used as the variable to be entered into the calibration tool to adjust mass level to its optimal value. By using this method, we are essentially eliminating the density of each individual building construction material as unique parameters and wrapping them up into a single variable which can be adjusted to account for differing whole building mass levels.

In similar fashion to how the massing was combined into a single parameter, the building envelope thermal resistance can also be combined into a manageable number of parameters to be optimized by the calibration tool. There are three constructions where the vast majority of heat is lost through the building envelope, the exterior walls, exterior windows, and roof. These three constructions

are made up from many layers of building materials, each with their own characteristics as detailed in Table 4. Again, every physical characteristic of each layer could be entered in to the calibration tool to be optimized but this is highly impractical and likely fruitless. Instead, the thermal resistance for the building envelope is broken into three components, the exterior walls, the roof, and the windows. Each construction (with the exception of the exterior windows) is made up of many layers of materials in parallel so adjusting the thermal conductivity of just one layer has the same effect on the total construction as adjusting the thermal conductivity of each layer simultaneously. For the exterior windows, the thermal resistance is simply defined by one overall U-factor. Figure 28 contains an excerpt from the EnergyPlus IDF defining the exterior wall construction.

```
Construction,
  Exterior Wall,      !- Name
  Hardboard Siding,   !- Outside Layer
  1" Extruded Polystyrene, !- Layer 2
  5.5" Blown-in Blanket, !- Layer 3
  F04 Wall air space resistance, !- Layer 4
  G01a 19mm gypsum board; !- Layer 5
```

Figure 28: Example text from EnergyPlus IDF defining external wall construction

The exterior walls have a layer in the construction defined as “5.5” Blown-in Blanket” which is the insulation layer for the exterior wall. Figure 29 shows the physical characteristics of this layer.

```
Material,
  5.5" Blown-in Blanket, !- Name
  VeryRough,             !- Roughness
  0.1397,                 !- Thickness {m}
  %wallU%,                !- Conductivity {W/m-K}
  64,                    !- Density {kg/m3}
  1465,                   !- Specific Heat {J/kg-K}
  0.9,                    !- Thermal Absorptance
  0.7,                    !- Solar Absorptance
  0.7;                    !- Visible Absorptance
```

Figure 29: Physical characteristics for the exterior wall insulation

Most of the physical characteristics of the blown-in wall insulation were entered from the ASHRAE Handbook of Fundamentals and the absorptance values are defaults within EnergyPlus. This highlighted field “Conductivity” is the variable that is entered into the calibration tool to determine the optimal level of wall insulation. Figure 30 contains an excerpt from the EnergyPlus IDF defining the exterior wall construction.

```
Construction,
  Exterior Roof,      !- Name
  Shingles,          !- Outside Layer
  G05 25mm wood,      !- Layer 2
  Roof Insulation,    !- Layer 3
  G01a 19mm gypsum board; !- Layer 4
```

Figure 30: Example text from EnergyPlus IDF defining exterior roof construction

The exterior roof has a layer in the construction defined as “Roof Insulation” which is the insulation layer for the exterior roof. Figure 31 shows the physical characteristics of this layer.

```
Material,
  Roof Insulation,    !- Name
  VeryRough,          !- Roughness
  0.3048,             !- Thickness {m}
  %roofU%,            !- Conductivity {W/m-K}
  13,                 !- Density {kg/m3}
  837,                !- Specific Heat {J/kg-K}
  0.9,                !- Thermal Absorptance
  0.7,                !- Solar Absorptance
  0.7;                !- Visible Absorptance
```

Figure 31: Physical characteristics for the exterior roof insulation

Similar to the exterior wall insulation, most of the physical characteristics of the roof insulation were entered from the ASHRAE Handbook of Fundamentals and the absorptance values are defaults within EnergyPlus. Again, the highlighted field “Conductivity” is the variable that is entered into the calibration tool to determine the optimized value for roof insulation.

The last parameter that will be used in the calibration tool to define the overall building envelope thermal resistance is the exterior window overall U-factor. When more is known about the window

construction, there are options within EnergyPlus to define each glazing layer and the characteristics of each of those layers individually. Since that level of detail is not known nor needed for the pilot house study, the “WindowMaterial:SimpleGlazingSystem” object is used for the exterior windows. Figure 32 contains an excerpt from the EnergyPlus IDF defining the exterior window object.

```
WindowMaterial:SimpleGlazingSystem,  
Windows,                !- Name  
%windowU%,              !- U-Factor {W/m2-K}  
%SHGC%,                 !- Solar Heat Gain Coefficient  
0.72;                   !- Visible Transmittance
```

Figure 32: Example text from EnergyPlus IDF defining exterior window construction

The first highlighted field shown above is the “U-Factor” for the exterior windows. This is the variable that is entered into the calibration tool to determine the optimized value for thermal resistance of the exterior windows in the pilot house.

The second highlighted field shown in Figure 32 is for “Solar Heat Gain Coefficient” (SHGC). This parameter directly impacts the amount of solar radiation that is allowed to enter the space which in turn has a large impact on the heating loads during the day. For these reasons, the SHGC is another parameter that is entered into the calibration tool to be optimized.

Section 3.3 provides details related to how infiltration is defined in the EnergyPlus IDF. Building envelope infiltration is a very influential parameter for determining the heating loads on the building envelope. Figure 33 contains an excerpt from the IDF defining the zone infiltration. Note that there is no zone infiltration defined for the basement thermal zone because the basement zone does not have any exposure to the outside air conditions.


```

ZoneInfiltration:EffectiveLeakageArea,
  FirstFloor,      !- Name
  FirstFloor,      !- Zone Name
  Always On,       !- Schedule Name
  %infiltration%,  !- Effective Air Leakage Area {cm2}
  0.00029,         !- Stack Coefficient
  0.000137;        !- Wind Coefficient

```

```

ZoneInfiltration:EffectiveLeakageArea,
  TopFloor,        !- Name
  TopLevel,        !- Zone Name
  Always On,       !- Schedule Name
  %infiltration%,  !- Effective Air Leakage Area {cm2}
  0.00029,         !- Stack Coefficient
  0.000137;        !- Wind Coefficient

```

Figure 33: Example text from EnergyPlus IDF defining zone infiltration

The two highlighted fields shown above, “Effective Air Leakage Area,” directly impacts the thermal loads on the first floor and top level due to infiltration loads. This is the last building envelope parameter that is entered into the calibration tool to be optimized.

The final parameter that is entered into the calibration tool as a variable for optimization is something called the “ZoneCapacitanceMultiplier:ResearchSpecial:TemperatureCapacityMultiplier.” The EnergyPlus documentation does not give a true reason for the existence of this factor other than to say “This multiplier can be increased if the zone air capacitance needs to be increased for stability of the simulation or to allow modeling higher or lower levels of damping of behavior over time.” Further along in the documentation, the temperature capacity multiplier is described as follows: “This affects the transient calculations of zone air temperature. Values greater than 1.0 have the effect of smoothing or damping the rate of change in the temperature of zone air from time step to time step. Note that sensible heat capacity can also be modeled using internal mass surfaces.” It is not quite fully understood why the existence of this factor in the simulation has the impact that it does but without it the changes in zone air temperature from time step to time step are unrealistically high and would never allow the model to be calibrated. It appears that the short time step of the simulation has an effect on the transient calculations of temperature in the zone. For the reasons listed, this factor must also be included in the calibration. It is

important to point out, as noted in the documentation, that having the temperature capacity multiplier has the same effect on the model as increasing internal mass surface area, but also serves the purpose of stabilizing the transient temperature calculations. Figure 34 contains an excerpt from the IDF file showing how this factor is defined. The field to be optimized by the calibration tool is highlighted.

```
ZoneCapacitanceMultiplier:ResearchSpecial,
%multiplier%,      !- Temperature Capacity Multiplier
1,                  !- Humidity Capacity Multiplier
1;                  !- Carbon Dioxide Capacity Multiplier
```

Figure 34: Example text from EnergyPlus IDF defining temperature capacity multiplier

The preceding paragraphs describe the six salient parameters that are entered into the calibration tool related to the building envelope: mass, wall insulation, roof insulation, window U-factor, window SHGC, and infiltration. As shown in the figures, the parameters for optimization are each identified by the word between the percentage symbols, i.e. %...%. The optimizer within MATLAB requires that the parameters to be optimized are given an initial “guess” or expected value and then upper and lower limits. Several of these values and limits were identified throughout Chapter 3 and were based on published information or calculations. Table 14 contains a summary of all of the expected values, upper, and lower bounds for the parameters to be optimized by the calibration tool.

Table 14: Expected values, lower and upper bounds for building envelope parameters

<u>Parameter</u>	<u>Units</u>	<u>Expected Value</u>	<u>Lower Limit</u>	<u>Upper Limit</u>
Mass (each zone)	m ²	100	10	1000
Wall Insulation	R	27.5	14	35
Roof Insulation	R	42	29	48
Window U-Factor	U	0.6125	1.933	0.175
Window SHGC	N/A	0.6125	0.3	0.95
Infiltration (each zone)	cm ²	75	10	160
Temperature Capacity Multiplier	N/A	75	1	150

For most of these parameters, the expected values were based on some physical information or earlier testing data. In some cases (such as mass) there wasn't a whole lot of information to base the expected value on so the bounds were set to encompass a large range of feasible values. Once the results for the first few calibrations came in, the optimized values for mass tended to be similar with some variation so the expected values was adjusted to reduce the run time of the calibration.

4.6.2 Building Envelope Calibration Objective Functions

The calibration tool is intended to return an optimized a set of parameters (given to it by the user) by minimizing an objective function (also given to it by the user). The previous section went through all of the input parameters to be calibrated within the building envelope. Once these were determined, the objective function to be minimized had to be defined. In the case of the pilot house, there were many different options available for creating the objective functions, both in terms of the period of time and time interval to compute the error as well as the measured variables to be used to calculate error. The results section will discuss the effect that these different objective functions ended up having on how well the calibrated model was able to predict future building energy use. This section will look at how certain subsets of the measured data were used to calculate the objective function value. The concepts used here can be expanded or scaled back to run many different scenarios and compare results, therefore only two general scenarios will be covered in detail here. Any other objective functions used to produce results later in this report are generally slight modifications of these two scenarios.

4.6.2.1 Scenario 1: Computing the Objective Function Using Temperature Data

Data was gathered at the pilot house for a period of approximately five months (Jan-May, 2011). This data contained values at one minute intervals of all of the variables listed in Table 2. One way to evaluate how well the EnergyPlus model is mimicking reality as it relates to building envelope performance is to compare the measured zone air temperature to the predicted model zone air temperature over the same time period with the same weather and internal gains. Section 3.2 went into detail about

how the internal gains were simply read from the measured data and inputted into the EnergyPlus model. In a sense, there is no “guess work” related to internal gains from equipment since it is all being directly measured and scheduled into the model. Section 4.5 described how the HVAC system was calibrated to deliver the same amount of heat as the actual system in the house when in operation. The last step to assure that all of the internal gains being experienced in the pilot house are duplicated in the energy model is to force the HVAC system to turn on and off at the same time as the system in the pilot house. The state of the HVAC is known by looking at the measured data for heating coil water flow which is a non-zero number when the system is in operation. In theory, once all of the internal gains and outside weather conditions are known and inputted into the EnergyPlus model, the only difference between the zone air temperature outputted by the model and the measured zone air temperature should purely be a function of inaccuracies in the building envelope parameters. A truly calibrated model would output zone air temperature that is the same as the measured zone air temperature.

Using the reasoning above, the first building envelope calibration technique is to force the HVAC system in the model to turn on or off at the same time that the system was actually turning on and off in the pilot house. Once this is achieved, the objective function is simply the root-mean-square error (RMS error) between the simulated temperature and the measured temperature at each time step for the duration of the calibration period. The calibration tool varies all of the input parameters until it finds the optimal set of parameters that minimizes the RMS error in temperature.

The general approach taken to evaluate the accuracy of each calibration technique was to use a subset of the monitored data during the first 20 days to perform the calibration and then see how the calibrated model predicts energy use or zone air temperature during the following 4 months (where the data was known but not used during the calibration). Figure 35 shows the outside air temperature, solar radiation, and zone air temperature for the 20 day calibration period. The solar radiation curve clearly delineates where each day starts and stops and the approximate level of sun shine for each day. Note that the zone air temperature for approximately the first 8 days of the 20 day period is essentially drifting up and down based on the weather conditions. The reason for this is that the HVAC system was not operating

at all during this period and nobody was occupying the house; once this was discovered the system was turned back on as is fairly obvious by observing the zone air temperature for the remainder of the graph. This is also apparent in Figure 36 which shows the status of the HVAC system (a value of 1 indicates that the system is operating) overlaid with the zone air temperature. It is also clear to see that each spike in the zone air temperature represents one on/off cycle of the HVAC system.

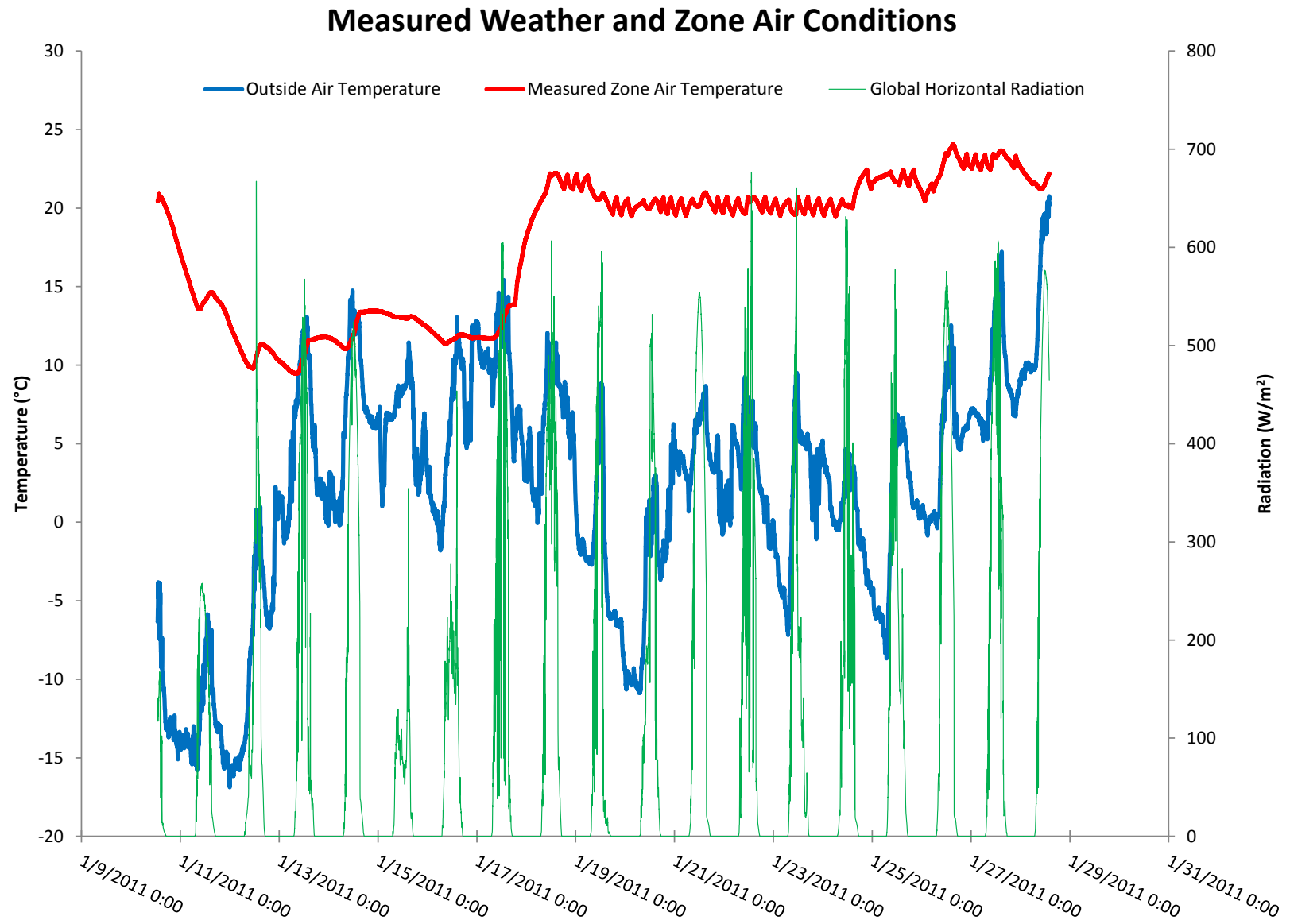


Figure 35: Measured weather and zone air temperatures for the 20 day period from 1/9/2011 through 1/28/2011

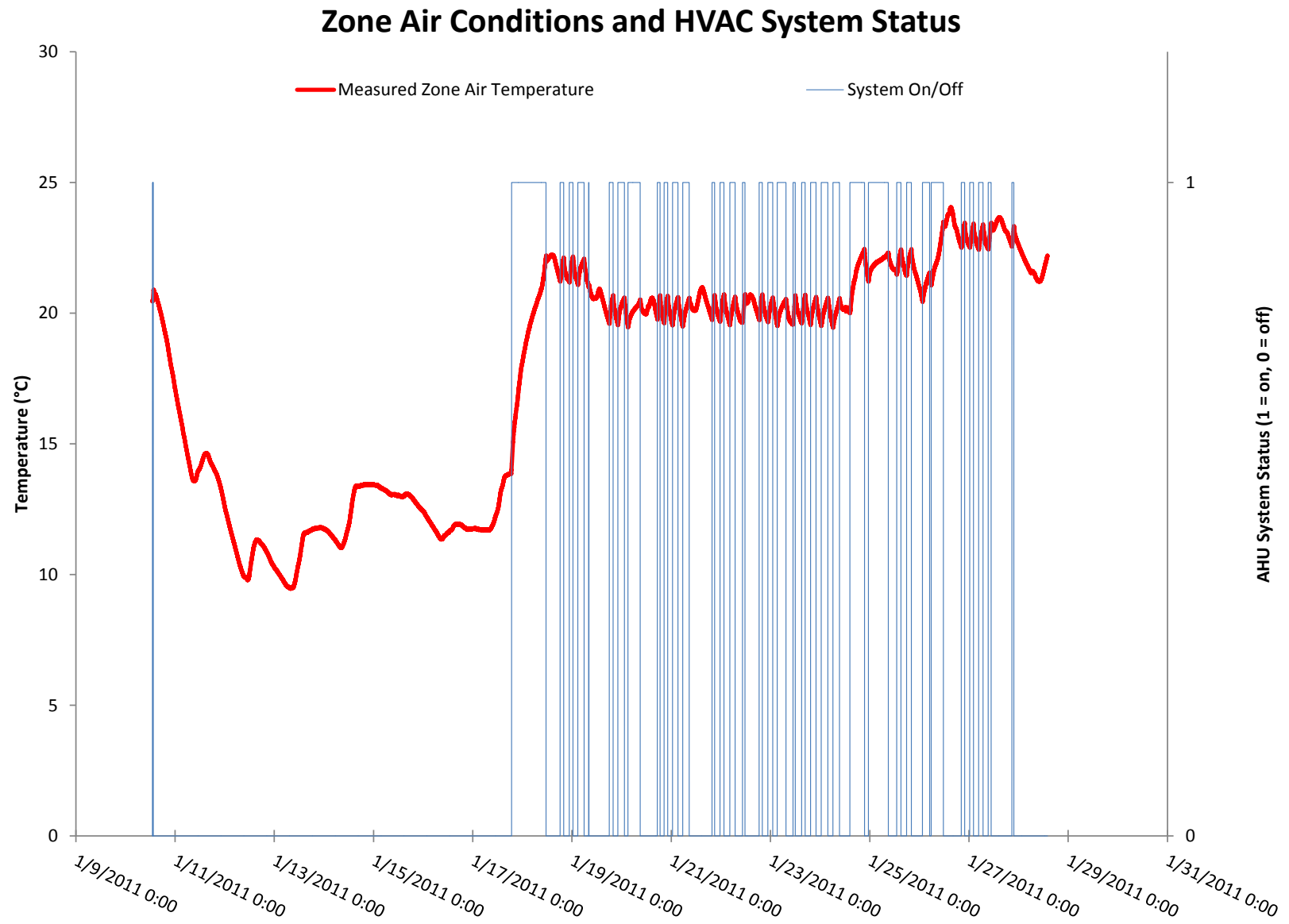


Figure 36: HVAC system status and zone air temperature during the same 20 day calibration period

For this example, the zone air temperature during the entire 20 day calibration period was used to compute the objective function value. As previously mentioned, this approach required that the HVAC system in the EnergyPlus model be forced on and off to replicate the system operation shown in Figure 36. There are several ways that this can be achieved within EnergyPlus, the method chosen for this study is described below.

The model of the HVAC system is such that if the supply fan is not operating for any reason, the entire system becomes inoperable. Figure 37 contain sample text from the EnergyPlus showing how the supply fan for the HVAC system is defined.

```
Fan:ConstantVolume,
  AHU Supply Fan,      !- Name
  Fan Availability Year, !- Availability Schedule Name
  0.3,                 !- Fan Efficiency
  370.5,               !- Pressure Rise {Pa}
  0.234,               !- Maximum Flow Rate {m3/s}
  1,                   !- Motor Efficiency
  1,                   !- Motor In Airstream Fraction
  AHU Heating Coil Outlet, !- Air Inlet Node Name
  AHU Supply Fan Outlet, !- Air Outlet Node Name
  General;             !- End-Use Subcategory
```

Figure 37: Example text from EnergyPlus IDF defining the supply fan

The highlighted field in Figure 37 is for the “Availability Schedule Name.” The availability schedule can essentially override all other system controls, so even if the thermostat is telling the system to run, if the system availability is “off” for the same time step, the system will not operate. Using this principal, a fractional minute time step fan availability schedule was created (using the procedure outlined in Appendix A.3) for the supply fan based on the measured heating coil flow rate. For each time step, if the measured heating coil flow was non-zero, the fan availability schedule was populated with a value of 1 (on) and for time steps with zero measured flow, the schedule was populated with a value of 0 (off). To assure that the system always operating when the fan was available, the thermostat set point was set to a value of 100°C. After the EnergyPlus model was created with this schedule and the expected values for the building envelope parameter values, it was run. Figure 38 shows the zone air temperature from the un-

calibrated EnergyPlus model, the measured zone air temperature, the outside air temperature, and the status of the HVAC system.

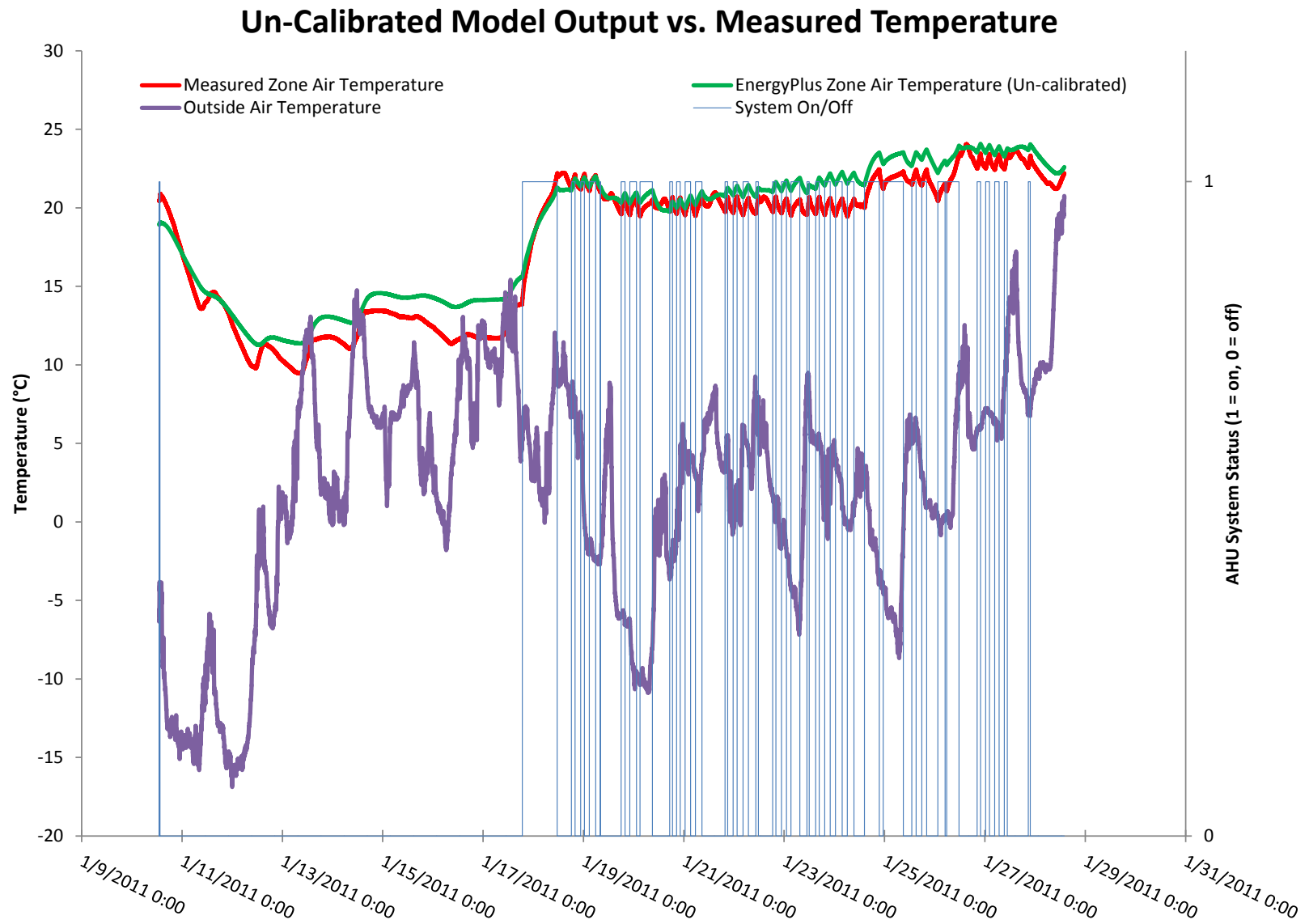


Figure 38: Zone air temperature output from the un-calibrated model

The graph clearly shows that the overall trend of the model output is similar to the measured data, but there are times when the modeled temperature is several degrees Celsius off from what it should be if the model were calibrated correctly. This un-calibrated model has an RMS error of 1.22°C , which, physically speaking, is the average error in measured temperature vs. modeled temperature. The results section of this report will look at how using different subsets of the measured data contained within this 20 day period to calibrate the EnergyPlus model produces optimized sets of building envelope parameters that vary in accuracy as it pertains to predicting a zone air temperature that matches the measured temperature.

4.6.2.2 Scenario 2: Computing the Objective Function Using Energy Consumption

An alternative method to calibrate the building envelope parameters is to compute the objective function by comparing measured to modeled HVAC system energy consumption during the calibration period. In scenario 1, the underlying theory is that if the outside weather conditions and all internal gains are known and present in the model during the calibration period, the modeled temperature in the zone should be the same as the measured temperature if the building envelope is calibrated. In this scenario, the outside weather conditions are known and the zone air temperature is known (i.e. thermostat set point) and inputted into the energy model, so the energy consumption of the HVAC system to maintain that set point should be the same as the measured energy consumption if the building envelope is calibrated.

As indicated above, instead of setting up the EnergyPlus model to force the HVAC system on and off based on a schedule derived from the measured data, this model will allow the HVAC system to operate as needed to maintain a zone air temperature set point which is derived from the measured zone air temperature data. Figure 39 shows the measured zone air temperature during the calibration period with a second line indicating the corresponding set point overlaid. Immediately after the graph, Table 15 shows the temperature set points that were programmed into the EnergyPlus model in tabular format.

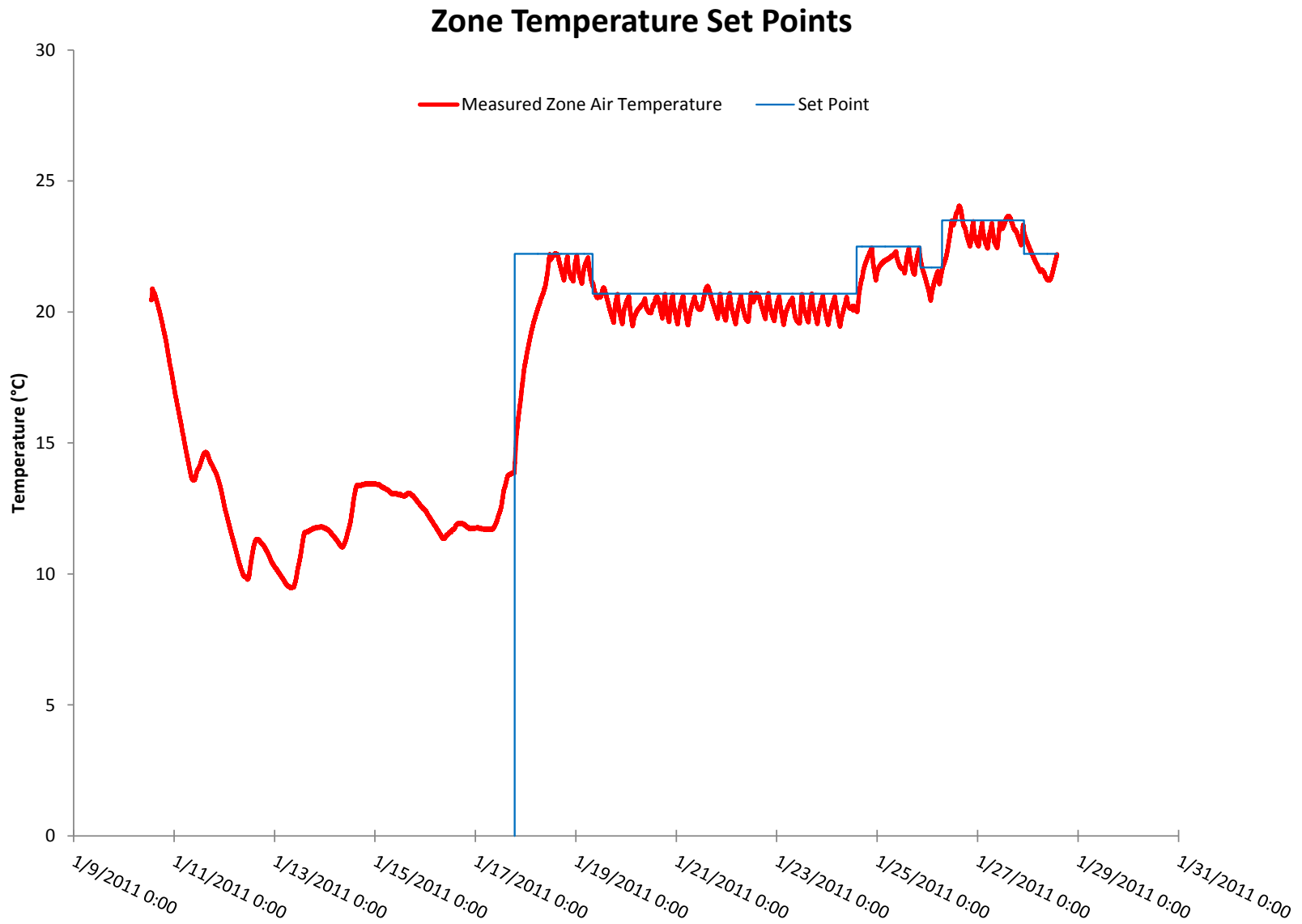


Figure 39: Measured zone air temperatures and thermostat set point

Table 15: EnergyPlus thermostat set points during calibration period

Date	Set Point (°C)
1/10/2011 13:00 - 1/17/2011 18:46	System Off
1/17/2011 18:47 - 1/19/2011 8:00	22.22
1/19/2011 8:01 - 1/24/2011 14:10	20.70
1/24/2011 14:11 - 1/25/2011 20:40	22.50
1/25/2011 20:41 - 1/26/2011 7:00	21.70
1/26/2011 7:01 - 1/27/2011 22:10	23.50
1/27/2011 22:11 - 1/28/2011 14:00	22.22

The graph in Figure 39 clearly shows that the system was not operating during the period from 1/10 13:00 – 1/17 18:46 because the measured zone air temperature is simply drifting as a function of the outside temperature, internal gains (non-HVAC), and solar radiation. Starting on 1/17 at 18:47, the system was turned back on and the set point was changed five times between this time and 1/27 at 22:11. The graph shows how the system cycles off when the set point is reached and then is allowed to drift down a certain amount before the system comes back on until the set point is reached again. This amount that the temperature is allowed to depart from the set point is known as the dead band and is approximately 1.112°C (2.0°F) in the pilot house. This number was used when creating the HVAC system controller in the Energy Management System feature of EnergyPlus.

Once the EnergyPlus model was created using these principals, it was allowed to run during the calibration period with the expected values for the building envelope parameters listed in Table 14. Figure 40 shows the output from this run with the measured temperature, modeled temperature, and temperature set point all visible.

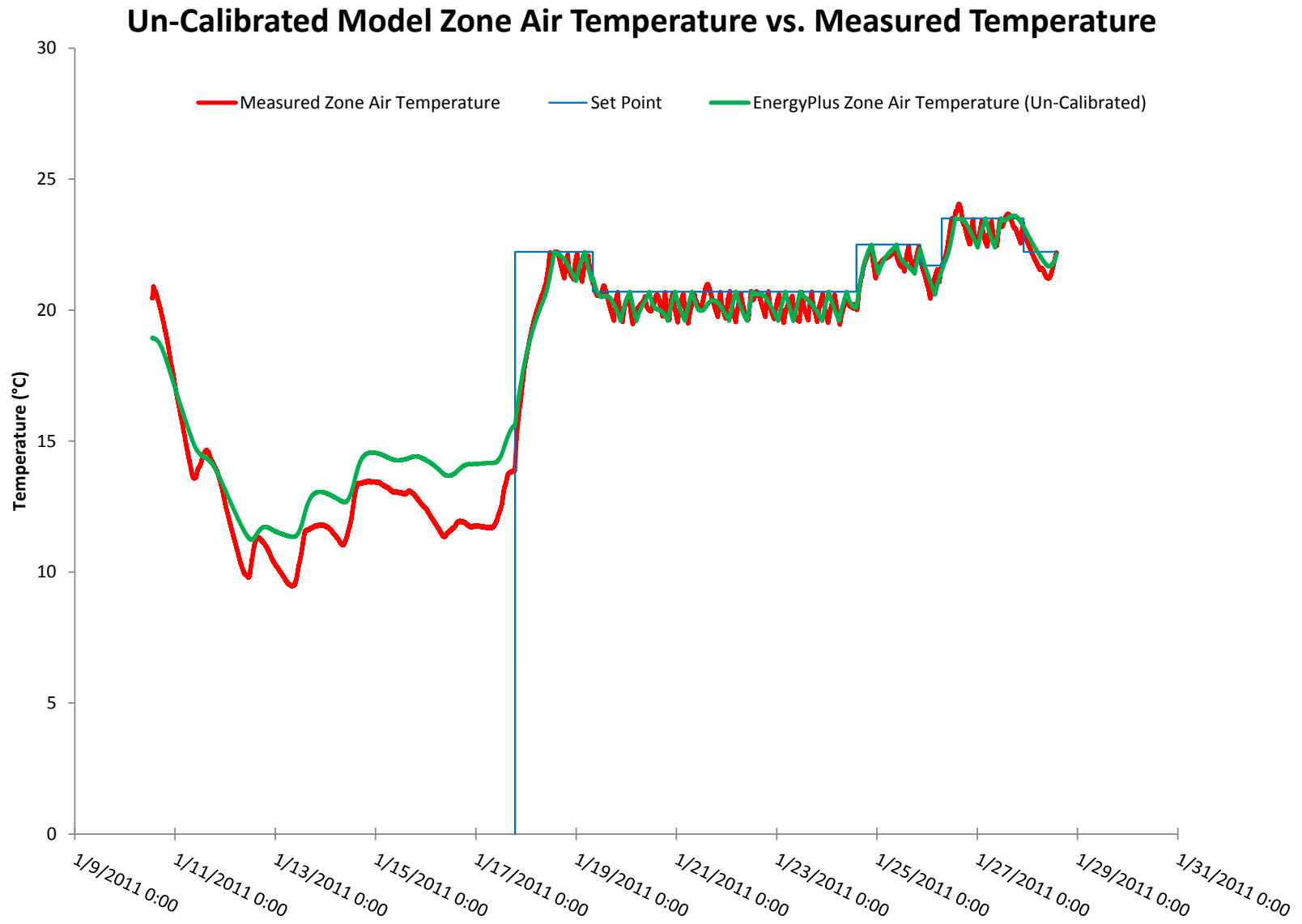


Figure 40: Measured/modeled zone air temperatures and thermostat set point for the un-calibrated model

The graph shows that the set point is being met and the dead band is set up properly to match the measured data. While this is not important for calculating the objective function value, it is an important verification that the model is set up to reproduce the same zone air conditions as the measured pilot house. Once the model is properly set up, the objective function can be calculated in order to calibrate the building envelope parameters.

The first method for calculating the objective function to be looked at is to compute the energy consumption of the HVAC system over set intervals during the calibration period, compare them to the measured energy consumption during the same intervals and compute the RMS error for energy consumption over the set of intervals. Since the system is not running for the first seven days of this time period, there is no energy consumption to compare so this period will be ignored. This example shows how the energy consumption will be compared using set one day intervals, it is important to note that the objective function can be computed for whatever interval is desired by the user. The results section of this report will investigate how different intervals produce different sets of optimized building envelope parameters and how accurate these calibrated models are at predicting future energy consumption. Figure 41 illustrates where the one day intervals begin and end for this example.

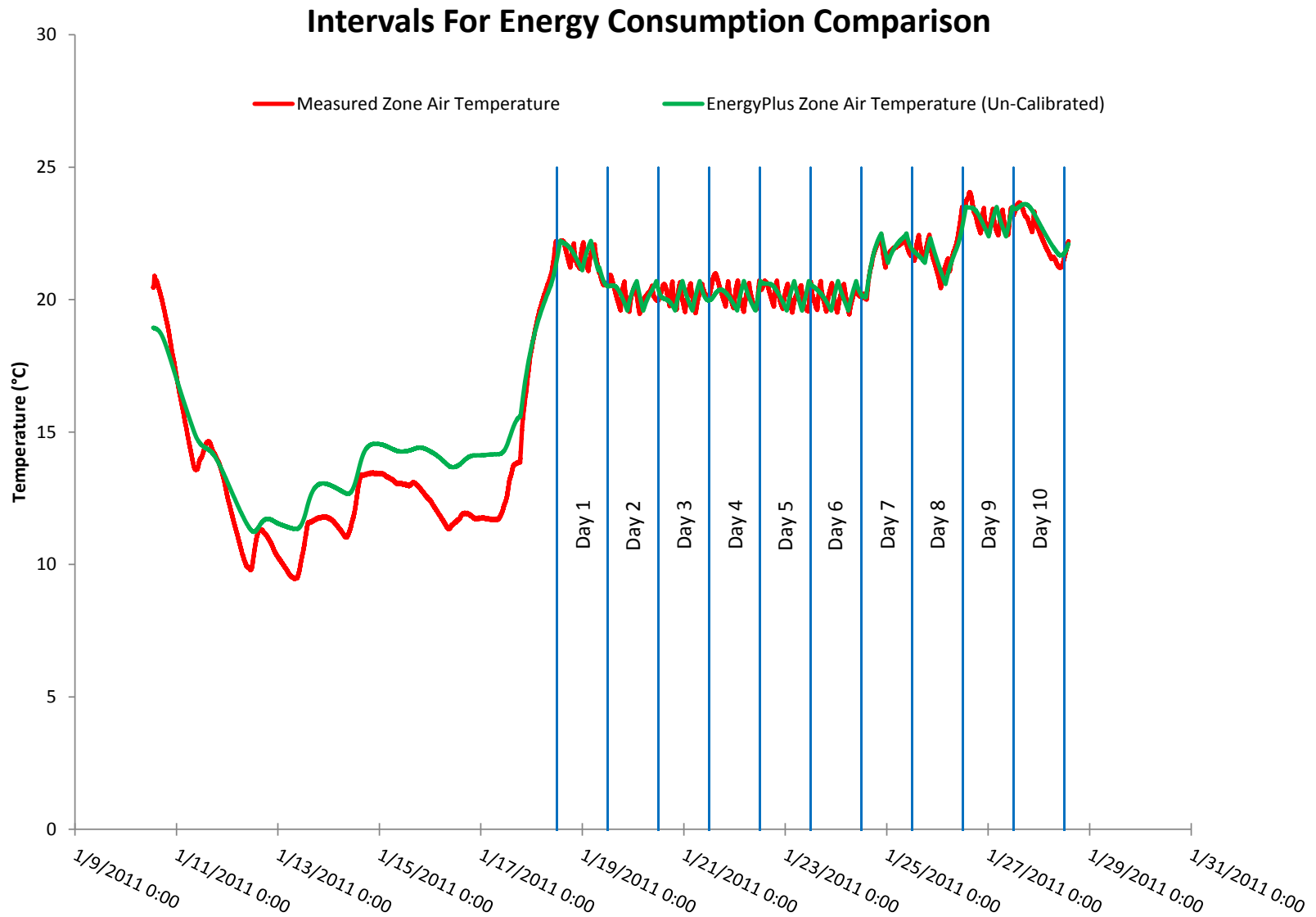


Figure 41: Beginning and end of one day intervals for computing energy consumption for comparison in the objective function

Figure 42 shows the energy consumption for the measured pilot house as well as the un-calibrated model for each of the ten days indicated in Figure 41.

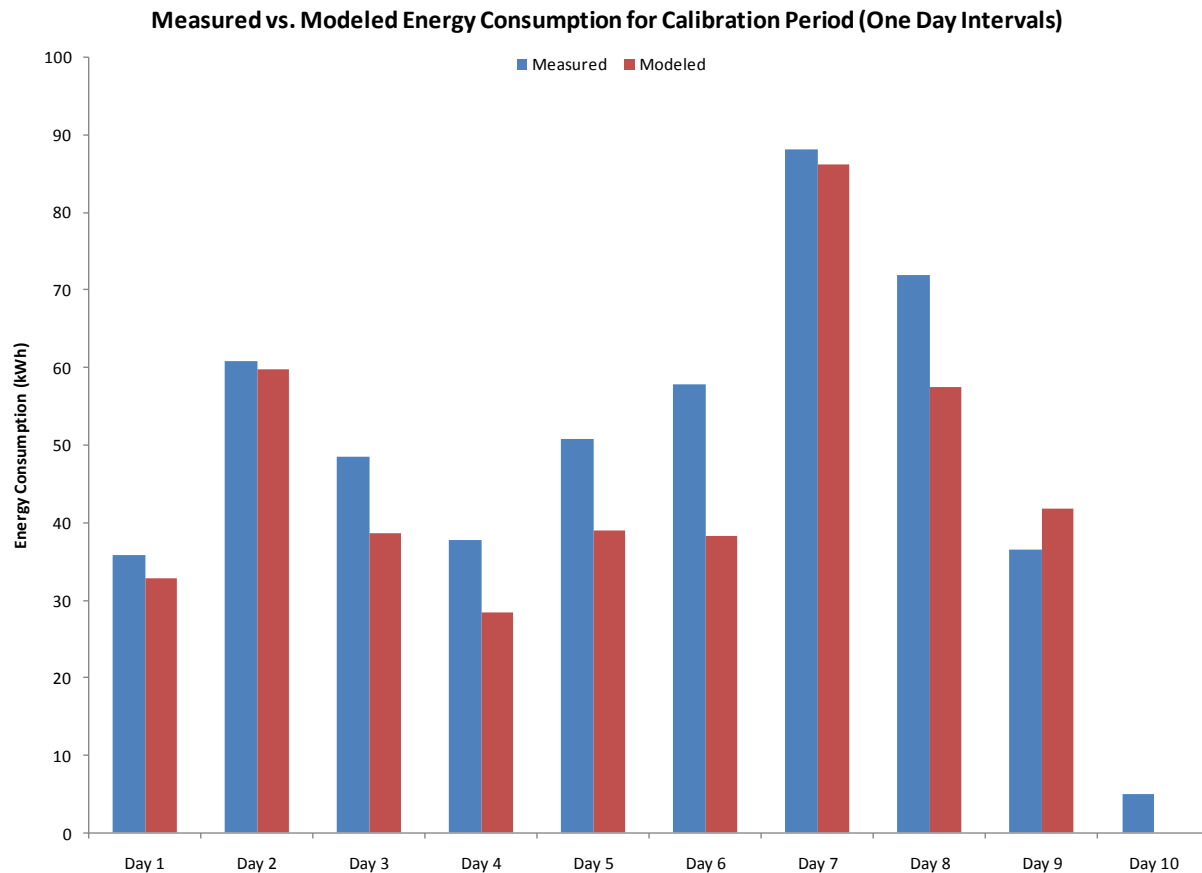


Figure 42: Measured vs. modeled energy consumption during the calibration period for the un-calibrated model

Figure 42 is a valuable visual indicator of how accurately the model mimics the actual pilot house. The objective function to be used by the calibration tool calculates the RMS error of the energy consumption for each interval over the total time period. The un-calibrated model has an RMS error of $3.5643(10^7)$ Joules (9.90 kWh). This means that the average error on a daily basis between the modeled and measured energy consumption is $3.5643(10^7)$ Joules for this 10 day period. To put some context to this number, the modeled energy consumption is approximately 14% less than the measured energy consumption during the total 10 day period. The results section of this report will investigate how using

different time interval lengths and overall calibration period length affect the accuracy of the calibration. The concepts described in the example within this section are applicable to produce these desired results.

There are some concerns with calculating the objective function value using the methods described above so an alternative method was also utilized to compare the different calibration techniques. These concerns grow as the period of monitoring for calibrations gets shorter, the number of set point changes increases, and the cycling time of the HVAC system increases. These are concerns because there must be enough HVAC system cycles within the interval being calculated to account for the fact that the system might be just starting or ending a cycle or somewhere mid-cycle. During such a long simulation, it is not feasible to expect that the HVAC system cycling within the model will remain in phase with the actual pilot house so it must be assumed that the cycles are not in phase. An example of where this could be an issue even if the building envelope is perfectly calibrated is when the interval for calculating energy consumption is the same as the system cycle time and the model and actual house are completely out of phase. In this case, either the model or measured data could go through the entire cycle with no energy consumption while the other could be operating the entire time which would produce an enormous error erroneously.

To account for the issue described above an alternative method is employed to calculate the objective function, a moving average. By using a moving average to calculate the objective function, it allows for many more data points to be added into the calculation of RMS error than in the case of set intervals with consecutive start and end points. When calculating the moving average, a “time step” and “window” are defined. For this example, a one hour time step and one day window are considered. In this case, the energy consumption is calculated for every hour during the calibration period and all of the energy consumed during the surrounding 24 hour period is included. To illustrate, the same model is used as in the previous “set interval” method, where the calibration period starts at on 1/18 at 12:00 and ends on 1/28 at 13:50. Since the window is defined as one day, the first data point for comparison is the energy consumption for both the model and the actual pilot house between 1/18 at 12:00 and 1/19 at 12:00. The second data point is the energy consumption between 1/18 at 13:00 and 1/19 at 13:00. This continues

until the final 24 hour window to be calculated, which is between 1/27 at 13:00 and 1/28 at 13:00.

Utilizing this method increases the number of data points in the RMS error calculation from 10 to 218.

Although the exact same EnergyPlus model was used, the RMS error changed from $3.5643(10^7)$ Joules (9.90 kWh) to $4.0315(10^7)$ Joules (11.2 kWh). This example was only for the case of 24 hour windows at one hour time steps. The same MATLAB code and methods could be modified to calculate a new RMS error for any window size and time step. The actual code used to calculate the objective function value can be found in Appendix B.12. Each of these different combinations will produce a different set of calibrated building envelope parameters. The accuracy of these calibration methods will be explored further in the results section of this report.

4.7 Sensitivity of Salient Building Envelope Parameters

Before looking at how variations of each of these calibrations methodologies produce different calibrated models, it is important to consider how sensitive the energy consumption of the home is to perturbations in each of the salient building envelope parameter values listed in Table 14. The table lists the expected values for each of the parameters based on information that was provided about the building, literature and the engineering judgment of the author. As suggested by (Manke and Hittle, 1996), a reasonable range to allow unknown parameters to vary is between 10% and 200% of their nominal values. The first sensitivity analysis was conducted for the calibration period from Jan 17 – Jan 28, 2011. The sensitivity of the total energy consumed by the home to perturbations in the salient building envelope parameters is shown on the following page in Figure 43. One concern with using just this period is that the very cold weather between Jan 17 and Jan 28 will skew the sensitivity of these parameters since the majority of the heating season is more mild than this period. An additional sensitivity analysis was run for the from Jan – May, 2011 to see if a longer simulation period results in significantly different sensitive building parameters. The results from this second analysis is presented in Figure 44.

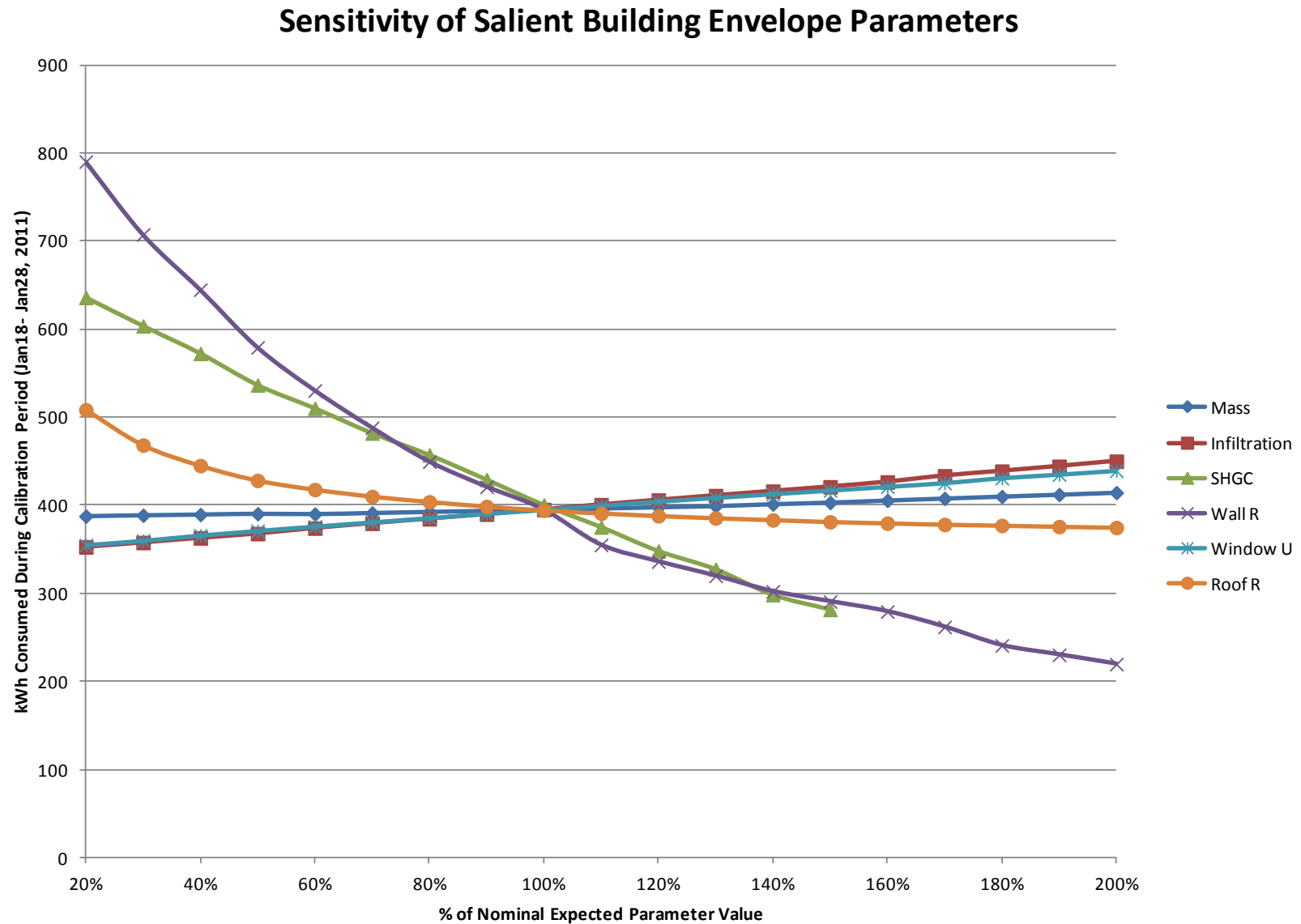


Figure 43: Effect of varying building envelope parameters on energy consumption for the period Jan 17-Jan 28, 2011

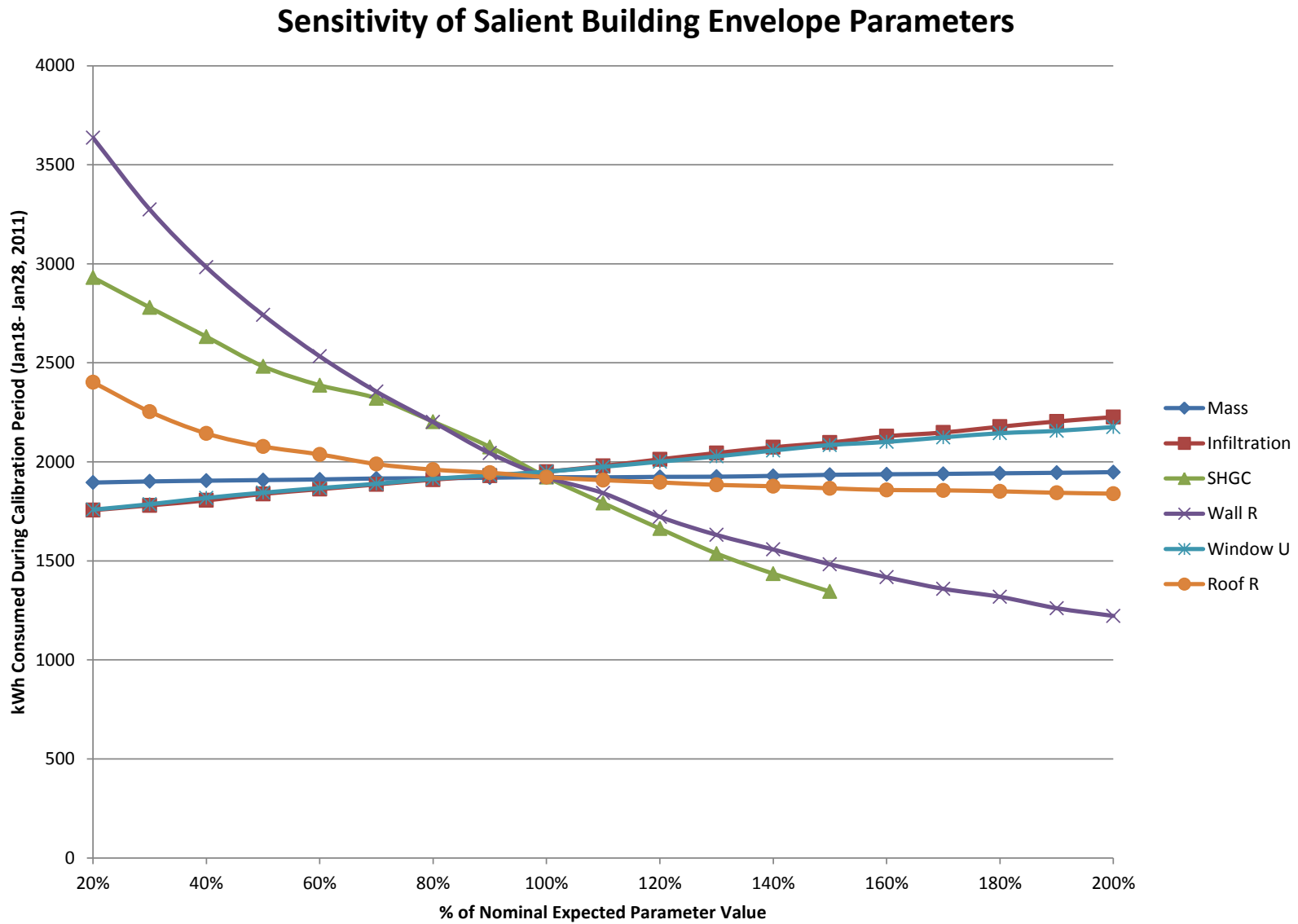


Figure 44: Effect of varying building envelope parameters on energy consumption for the period Jan - May, 2011

The total energy consumption when all of the building envelope parameters are at their nominal values is approximately 395 kWh during the calibration period and 1925 kWh during the Jan-May period.. Figure 43 and Figure 44 show how much this baseline energy consumptions changed as the six building envelopes are varied around their nominal values. As each individual parameter is varied, the other five parameters are fixed at their nominal values; this serves to isolate the sensitivity of each parameter. That graphs show that three of the five parameters have significantly more influence on the building's energy consumption during the two different periods than the other three parameters. The implications of this could potentially be far reaching and difficult to quantify. One implication is that the optimizer may only successfully be able to calibrate the more influential parameters since the less influential parameters could get lost in the noise generated by other less tangible errors within the energy model. Another less obvious implication is that certain parameters, while not very influential to the total energy consumption of the home over a multi-day period of time, may have a larger influence on certain predicted outputs of the model during shorter time steps. An example of this could be that while mass level does not greatly influence the total home energy consumption during the calibration period, and even less as the period increases, it could have a significant influence on how the model reacts to transients that would likely be observed in the actual space, and some potentially valuable information could be lost without the modeler being aware.

In general, the hierarchy of influential parameters does not changes during different time periods (i.e. different weather). Variations in wall and roof insulation values as well as the SHGC of the windows tend to exert the most influence over the total heating energy consumption of the home. There is, however, a change in how much absolute influence these parameters have on energy consumption. To illustrate this effect, Table 16 shows the effect on total energy consumption for both time periods of varying all of these salient building envelope parameters from 20% – 200% of their nominal values. The values in the table represent percentage of nominal energy consumption for each model run.

Table 16: Effect of variations to salient building envelope parameters on energy consumptions over different time periods

Percent of Nominal Parameter Value	Mass Jan	Mass Jan-May	Infiltration Jan	Infiltration Jan-May	SHGC Jan	SHGC Jan-May	Wall R Jan	Wall R Jan-May	Window U Jan	Window U Jan-May	Roof R Jan	Roof R Jan-May
20.00%	98.1%	98.6%	89.3%	90.0%	158.8%	152.4%	200.1%	189.1%	89.9%	90.2%	128.9%	124.9%
30.00%	98.4%	98.9%	90.5%	91.3%	150.8%	144.5%	179.1%	170.3%	91.1%	91.6%	118.8%	117.2%
40.00%	98.6%	99.1%	91.8%	92.6%	143.0%	136.9%	163.2%	155.1%	92.7%	93.2%	112.9%	111.5%
50.00%	98.8%	99.2%	93.1%	94.2%	134.0%	129.1%	146.6%	142.6%	93.9%	94.6%	108.6%	108.1%
60.00%	98.7%	99.4%	94.7%	95.5%	127.4%	124.1%	134.3%	131.7%	95.2%	95.7%	106.0%	106.0%
70.00%	99.0%	99.6%	96.0%	96.7%	120.4%	120.7%	123.6%	122.4%	96.4%	96.9%	104.0%	103.4%
80.00%	99.3%	99.7%	97.3%	97.9%	114.2%	114.5%	113.8%	114.5%	97.6%	98.1%	102.4%	102.0%
90.00%	99.6%	99.8%	98.7%	99.0%	107.2%	107.9%	106.6%	106.3%	98.9%	99.1%	101.1%	101.1%
100.00%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
110.00%	100.3%	99.9%	101.4%	101.5%	93.7%	93.2%	89.9%	95.8%	101.2%	101.3%	99.1%	99.2%
120.00%	100.7%	100.1%	102.7%	103.2%	87.0%	86.5%	85.1%	89.6%	102.4%	102.6%	98.4%	98.6%
130.00%	101.0%	100.1%	104.0%	104.8%	81.8%	79.9%	81.0%	84.8%	103.4%	103.9%	97.8%	98.0%
140.00%	101.6%	100.3%	105.3%	106.3%	74.6%	74.6%	76.5%	81.0%	104.5%	105.5%	97.2%	97.6%
150.00%	102.0%	100.6%	106.5%	107.5%	70.4%	70.0%	73.6%	77.1%	105.6%	106.9%	96.7%	97.1%
160.00%	102.6%	100.7%	107.9%	109.2%			70.7%	73.7%	106.6%	107.7%	96.3%	96.6%
170.00%	103.2%	100.8%	109.7%	110.1%			66.3%	70.7%	107.7%	108.9%	95.9%	96.5%
180.00%	103.7%	101.0%	111.0%	111.6%			61.0%	68.6%	109.1%	110.0%	95.6%	96.3%
190.00%	104.3%	101.1%	112.4%	113.0%			58.3%	65.6%	110.1%	110.6%	95.3%	95.9%
200.00%	104.9%	101.3%	113.9%	114.1%			55.6%	63.6%	111.2%	111.6%	95.0%	95.6%

Table 16 shows that for many of the parameters, their influence doesn't vary significantly depending on the time period when the model is run. The parameters where time period does affect their influence the most are also the most influential parameters overall, wall insulation, roof insulation and SHGC. The analysis shows that as the insulation values and SHGC decrease from their expected nominal values in the cold weather case, the energy consumption increases more dramatically than for the 5 month period which is to be expected. Overall, these results reduce concern that using a shorter period of building monitoring to calibrate the energy model skews the results of the calibration.

CHAPTER 5 MODEL CALIBRATION RESULTS AND PREDICTED ENERGY CONSUMPTION

The report up to this point has detailed various ways to process the measured data so that it could be used in the EnergyPlus simulation directly and indirectly. A procedure was also detailed describing how certain measurements and EnergyPlus output variables could be compared in a calibration tool which automatically “tunes” certain model parameters to minimize an objective function (like temperature error or energy consumption error). In order to get to this stage, the water heater model and HVAC system model were also calibrated separately as outlined in procedures in sections 4.3 and 4.5. Once the model was completely set up to replicate the pilot house as closely as possible, the focus shifted to seeing what sets of building envelope parameter values were produced by a variety of calibration methods and how accurate those calibrated models are able to predict future energy use. The ultimate goal of looking at these variations is to see what level of instrumentation and monitoring is truly necessary to reach the level of accuracy that the energy modeler desires. To move towards this end, this section investigates the differences in calibration results by using a variety of subsets of the measured data in the calibration process.

5.1 Calibration Period and Prediction Period

As previously stated, data was gathered at the pilot house from Jan 10, 2011 through May 31, 2011 at one minute intervals. The HVAC system was operating in heating mode for the duration of the monitored period. For this study, the data from 1/10-1/28 was designated as the “calibration period” so all of the different calibration scenarios were chosen from this subset of the monitored data (but not necessarily all of it). The four months after the calibration period were designated as the “prediction period.” For this period, in order to accurately compare the model building performance to the actual pilot house, the measured weather data was used to create a weather file for the simulation, the measured plug/lighting loads were scheduled into the model, and the temperature set points actually observed in the pilot house were also scheduled into the model. Once these items were implemented into the model, the

different sets of calibrated building parameters were also inputted into the model and it was allowed to run for the four months of the prediction period where the modeled energy consumption could be compared to the measured consumption over the same time period. During the four month prediction period there were five times when the data acquisition system was either not operating properly or wasn't measuring all of the variables required to be used for this study. These outages occurred from 1/28 – 2/3, 2/24 – 2/28, 3/10 – 4/7, 4/9 – 4/11, and 5/5 – 5/17. Due to the lack of full data during these outages, the associated days were not included in the computation of energy consumption. After omitting these days, there were approximately 70 days during the heating season that were used to compare the accuracy of the calibrated models. Figure 45 - Figure 48 show the measured zone air temperature during the entire prediction period (February – May) with a second line indicating the corresponding set point overlaid. Immediately after the graph, Table 17 shows the temperature set points that were programmed into the EnergyPlus model during the prediction period. With these set points entered and the plug loads also entered, the calibrated models were allowed to run through this period using the weather file generated from the monitored data and the resulting outputs were used to compute the modeled energy consumption.

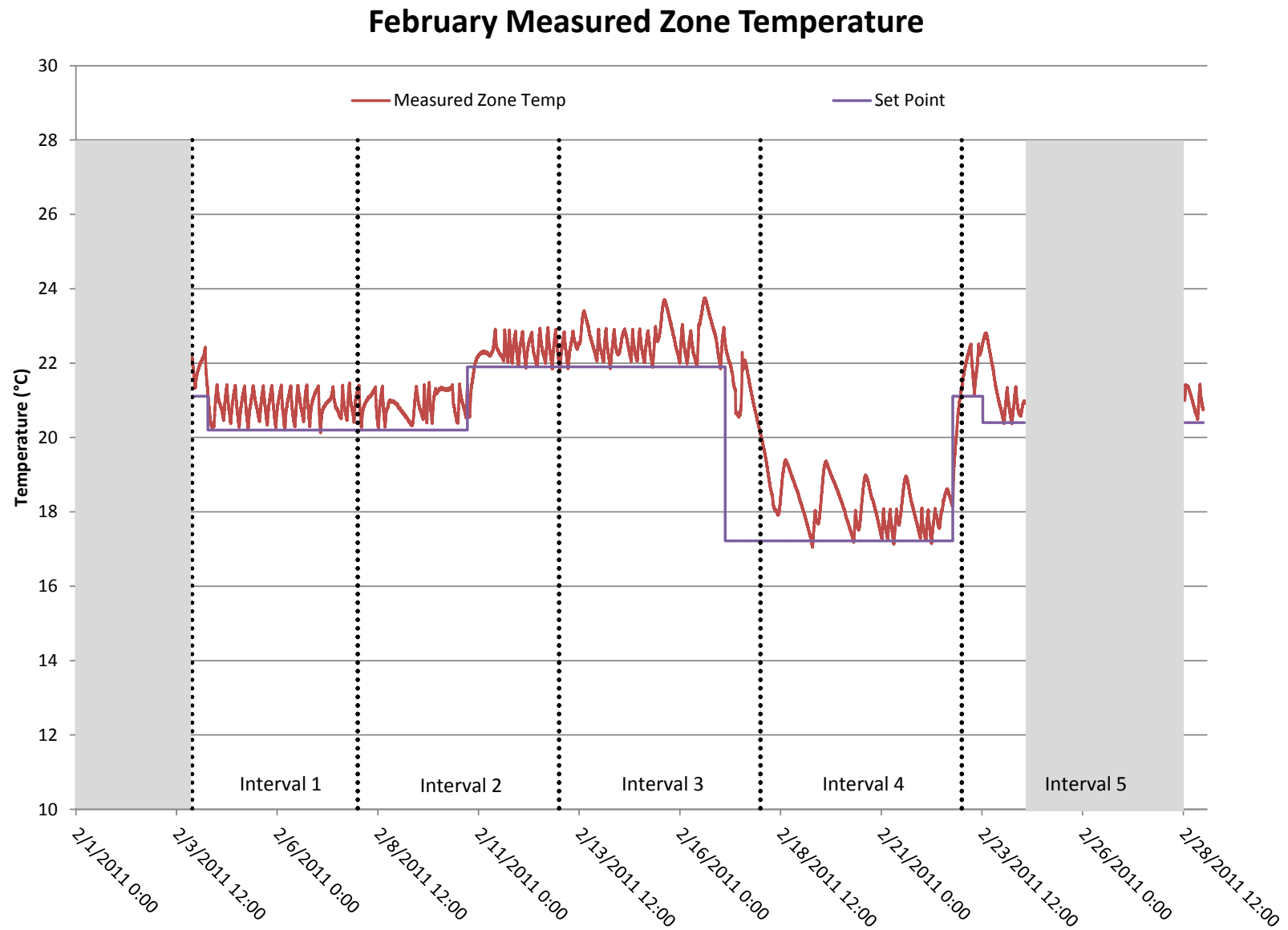


Figure 45: Measured zone air temperature and thermostat set points for the month of February

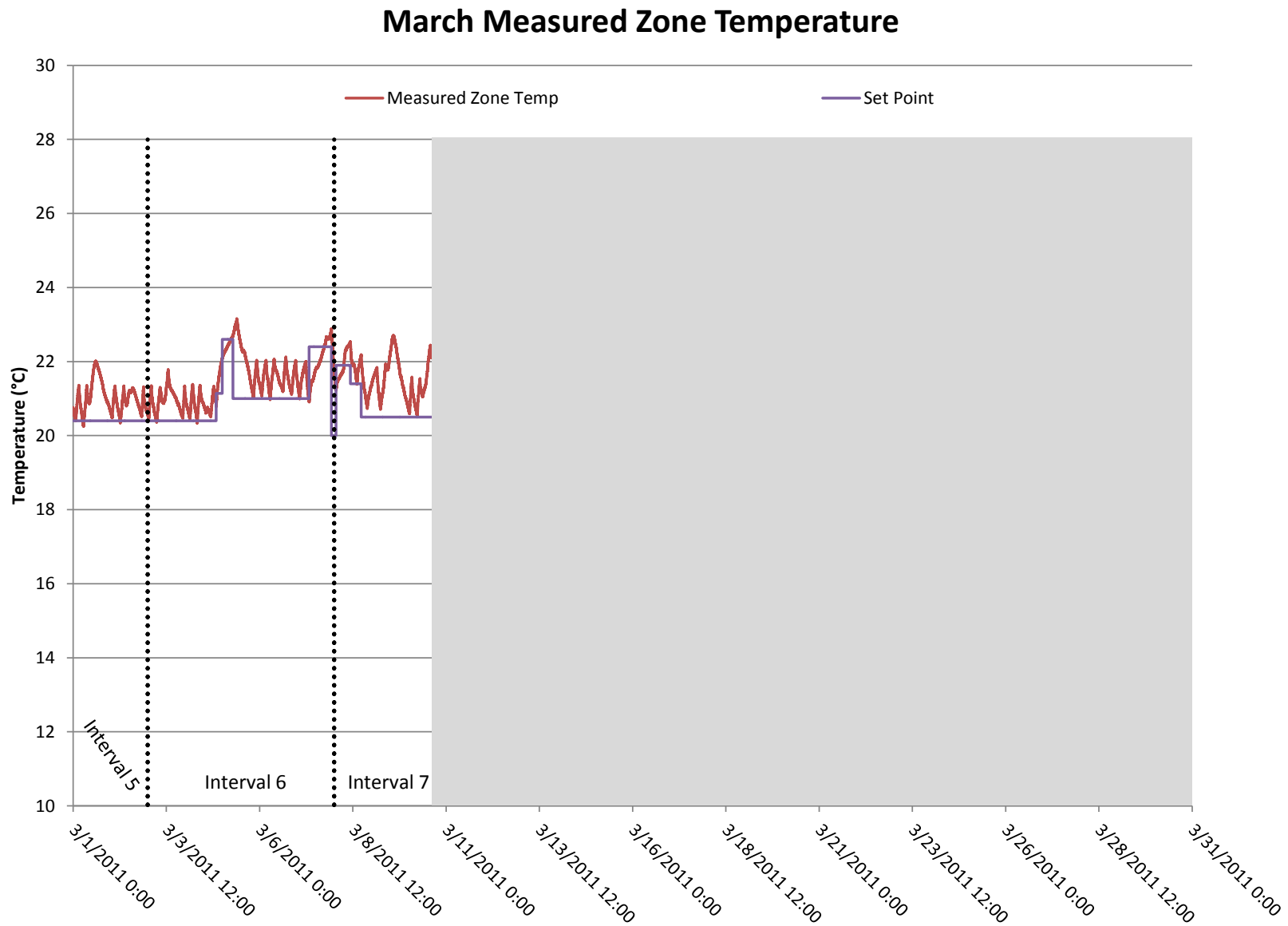


Figure 46: Measured zone air temperature and thermostat set points for the month of March

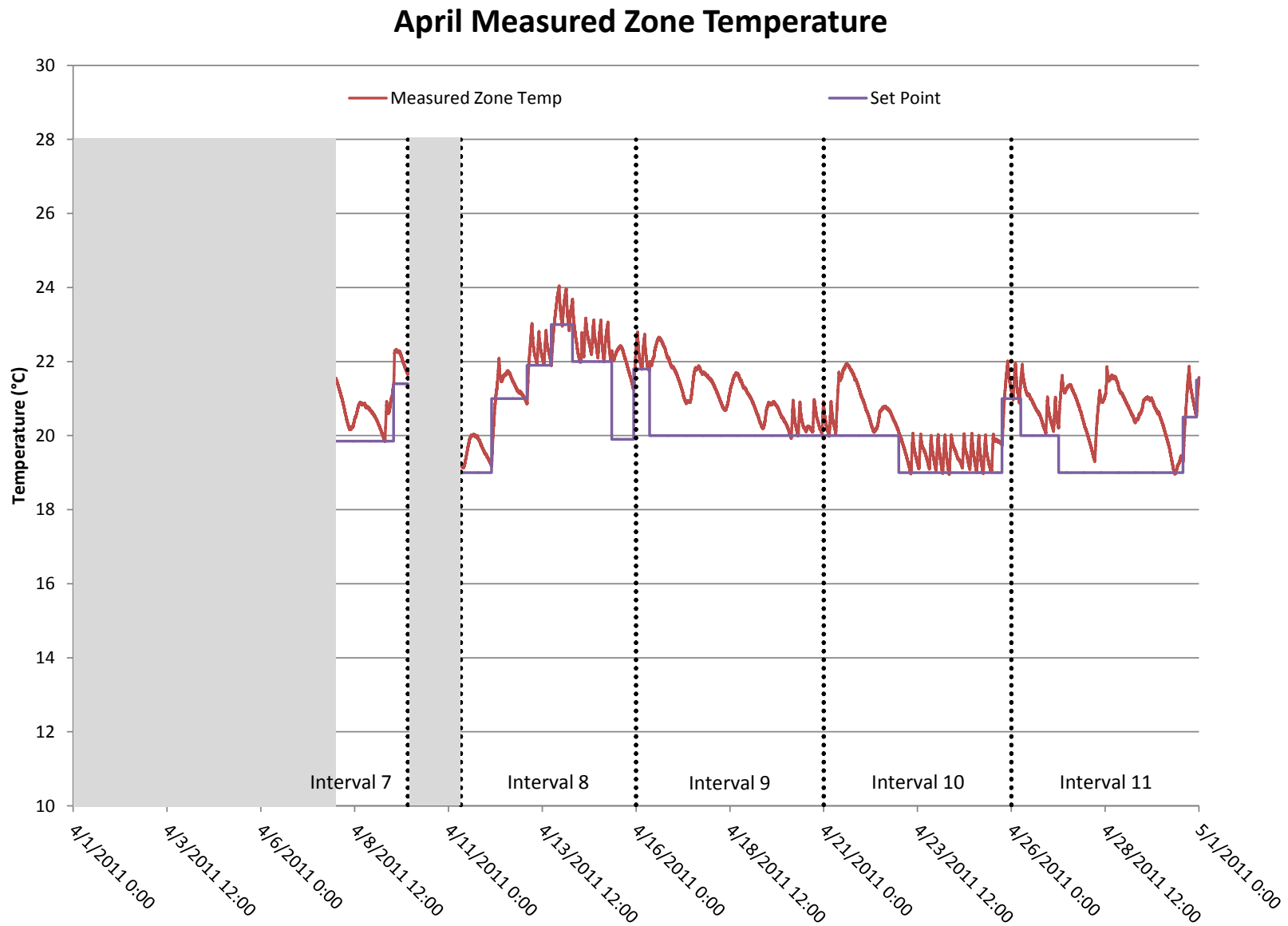


Figure 47: Measured zone air temperature and thermostat set points for the month of April

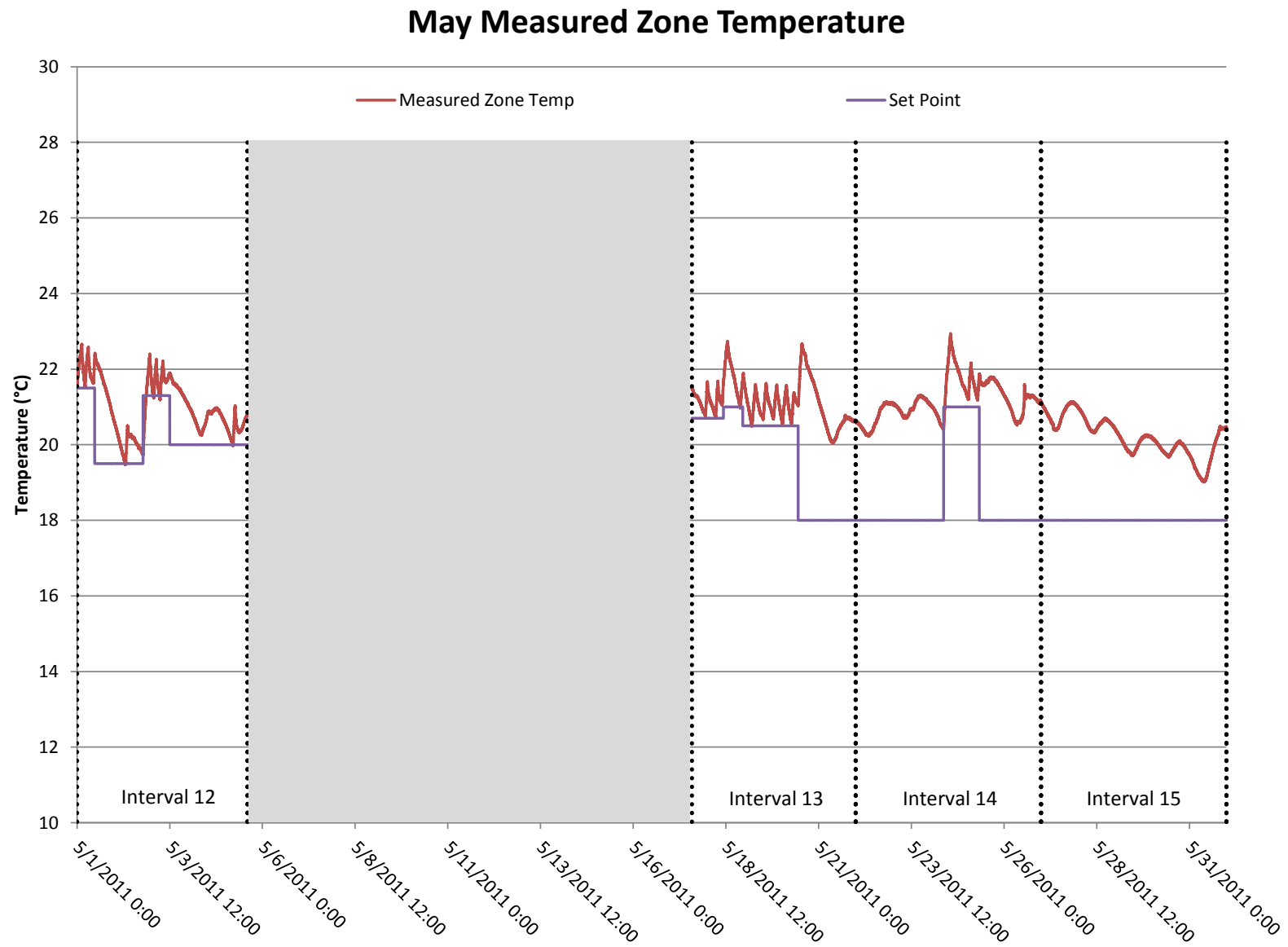


Figure 48: Measured zone air temperature and thermostat set points for the month of May

Table 17: EnergyPlus thermostat set points during prediction period

Date	Set Point (°C)
2/3/2011 9:22:00 PM - 2/4/2011 6:40:00 AM	21.11
2/4/2011 6:41:00 AM - 2/10/2011 5:22:00 PM	20.2
2/10/2011 5:23:00 PM - 2/17/2011 3:00:00 AM	21.9
2/17/2011 3:01:00 AM - 2/22/2011 6:37:00 PM	17.22
2/22/2011 6:38:00 PM - 2/23/2011 12:31:00 PM	21.11
2/23/2011 12:32:00 PM - 2/24/2011 1:25:00 PM	20.4
2/24/2011 1:25:00 PM - 2/28/2011 12:59:00 PM	Data Acquisition System Down
2/28/2011 1:00:00 PM - 3/4/2011 8:04:00 PM	20.4
3/4/2011 8:05:00 PM - 3/4/2011 11:59:00 PM	21.14
3/4/2011 12:00:00 AM - 3/5/2011 6:51:00 AM	22.6
3/5/2011 6:52:00 AM - 3/7/2011 7:50:00 AM	21
3/7/2011 7:51:00 AM - 3/7/2011 10:13:00 PM	22.4
3/7/2011 10:14:00 PM - 3/8/2011 1:10:00 AM	20
3/8/2011 1:11:00 AM - 3/8/2011 10:26:00 AM	21.9
3/8/2011 10:27:00 AM - 3/8/2011 5:21:00 PM	21.4
3/8/2011 5:22:00 PM - 3/10/2011 2:41:00 PM	20.5
3/10/2011 2:42:00 PM - 4/8/2011 12:00:00 AM	Data Acquisition System Down
4/8/2011 12:01:00 AM - 4/9/2011 12:57:00 PM	19.85
4/9/2011 12:57:00 PM - 4/9/2011 10:05:00 PM	21.4
4/9/2011 10:06:00 PM - 4/11/2011 7:59:00 AM	Data Acquisition System Down
4/11/2011 8:00:00 AM - 4/12/2011 3:36:00 AM	19
4/12/2011 3:37:00 AM - 4/13/2011 2:17:00 AM	21
4/13/2011 2:18:00 AM - 4/13/2011 5:45:00 PM	21.9
4/13/2011 5:46:00 PM - 4/14/2011 7:21:00 AM	23
4/14/2011 7:22:00 AM - 4/15/2011 8:27:00 AM	22
4/15/2011 8:28:00 AM - 4/15/2011 10:30:00 PM	19.9
4/15/2011 10:31:00 PM - 4/16/2011 8:39:00 AM	21.8
4/16/2011 8:40:00 AM - 4/22/2011 11:59:00 PM	21
4/23/2011 12:00:00 AM - 4/25/2011 6:00:00 PM	19
4/25/2011 6:01:00 PM - 4/26/2011 6:00:00 AM	21
4/26/2011 6:01:00 AM - 4/27/2011 6:13:00 AM	20
4/27/2011 6:14:00 AM - 4/30/2011 1:45:00 PM	19
4/30/2011 1:46:00 PM - 4/30/2011 10:20:00 PM	20.5
4/30/2011 10:21:00 PM - 5/1/2011 11:24:00 AM	21.5
5/1/2011 11:25:00 AM - 5/2/2011 6:42:00 PM	19.5
5/2/2011 6:43:00 PM - 5/3/2011 12:00:00 PM	21.3
5/3/2011 12:01:00 PM - 5/5/2011 2:22:00 PM	20
5/5/2011 2:23:00 PM - 5/17/2011 1:59:00 PM	Data Acquisition System Down
5/17/2011 2:00:00 PM - 5/18/2011 10:23:00 AM	20.7
5/18/2011 10:24:00 AM - 5/18/2011 10:53:00 PM	21
5/18/2011 10:54:00 PM - 5/20/2011 10:44:00 AM	20.5
5/20/2011 10:45:00 AM - 5/24/2011 8:54:00 AM	18
5/24/2011 8:55:00 AM - 5/25/2011 8:00:00 AM	21
5/25/2011 8:01:00 AM - 5/31/2011 11:59:00 PM	18

In addition to using the overall absolute energy consumption during the entire prediction period as the metric to compare the accuracy of the calibration techniques, the prediction period was broken into fifteen 5-day intervals where the energy consumption was computed for each interval and compared to the measured energy consumption during the same 5-day period. Two additional metrics that are very commonly used in standards such as ASHRAE-14 (ASHRAE, 2002) and the FEMP M&V Guidelines (U.S. DOE, 2008) as acceptance criteria for the validity of a model calibration are (NMBE) and CV(RSME). The NMBE indicates how well the model is able to predict energy consumption compared to the measured data but it does not take into account situations when a positive error can cancel out a negative error to produce zero net error. The CV(RSME) is used to take into account the overall uncertainty of the models ability to predict energy consumption. Equation 9 and Equation 10 show the equations to calculate NMBE and CV(RSME) respectively. For this study, the length of each interval, i , is 5 days and the quantity of intervals, n , is 15.

Equation 9: Normalized mean bias error calculation

$$NMBE = \frac{\sum_n (y_i - \hat{y}_i)}{(n-1)\bar{y}} * 100$$

Equation 10: Coefficient of variation of the root mean square error calculation

$$CV(RSME) = \sqrt{\frac{\sum_n (y_i - \hat{y}_i)^2}{(n-1)}} * 100 * \bar{y}$$

Where:

n = number of calculation intervals

y = measured energy consumption during the calculation interval i

\hat{y} = simulated energy consumption during the calculation interval i

\bar{y} = average measured energy consumption for n intervals

Each of the fifteen intervals is marked off with dotted vertical lines and labels on Figure 45 - Figure 48. Breaking the prediction period into several smaller intervals allows the modeler to see how accurate the calibrated models are during periods of varying weather conditions and can serve as a good

diagnostic tool to further refine the model to increase accuracy. The period from February to May is a good time of year to see how accurate the models are for a wide variety of weather conditions.

5.2 Calibration Scenarios

This section presents the results from different calibration scenarios using various subsets of the measured data and the two objective functions described in section 4.6.2. The results include the optimized set of building envelope parameters for each case as well as a graphical presentation of how closely the zone air temperature predicted by the calibrated models compared to the measured air temperatures. Additionally, the predicted energy consumption of each calibrated model compared to the measured energy consumption is presented.

5.2.1 Scenario 1: No Internal Gains, Temperature Used as Objective Function

There was a period of time (approximately 7 days) at the beginning of the calibration period when the pilot house was not occupied, plug and lighting loads were approximately zero, and the HVAC system was turned off. The house was basically allowed to “float” purely as a function of outside weather conditions. Naturally, there was no energy consumed during this period so zone air temperature was used as the objective function in the calibration tool. Since only temperature and weather conditions were used in this model calibration, it could be a feasible experiment for energy modelers or auditors to perform on a house when trying to calibrate the parameters defining the building envelope. Figure 49 contains a graph of the total calibration period with the portion used for the scenario 1 calibration grayed out.

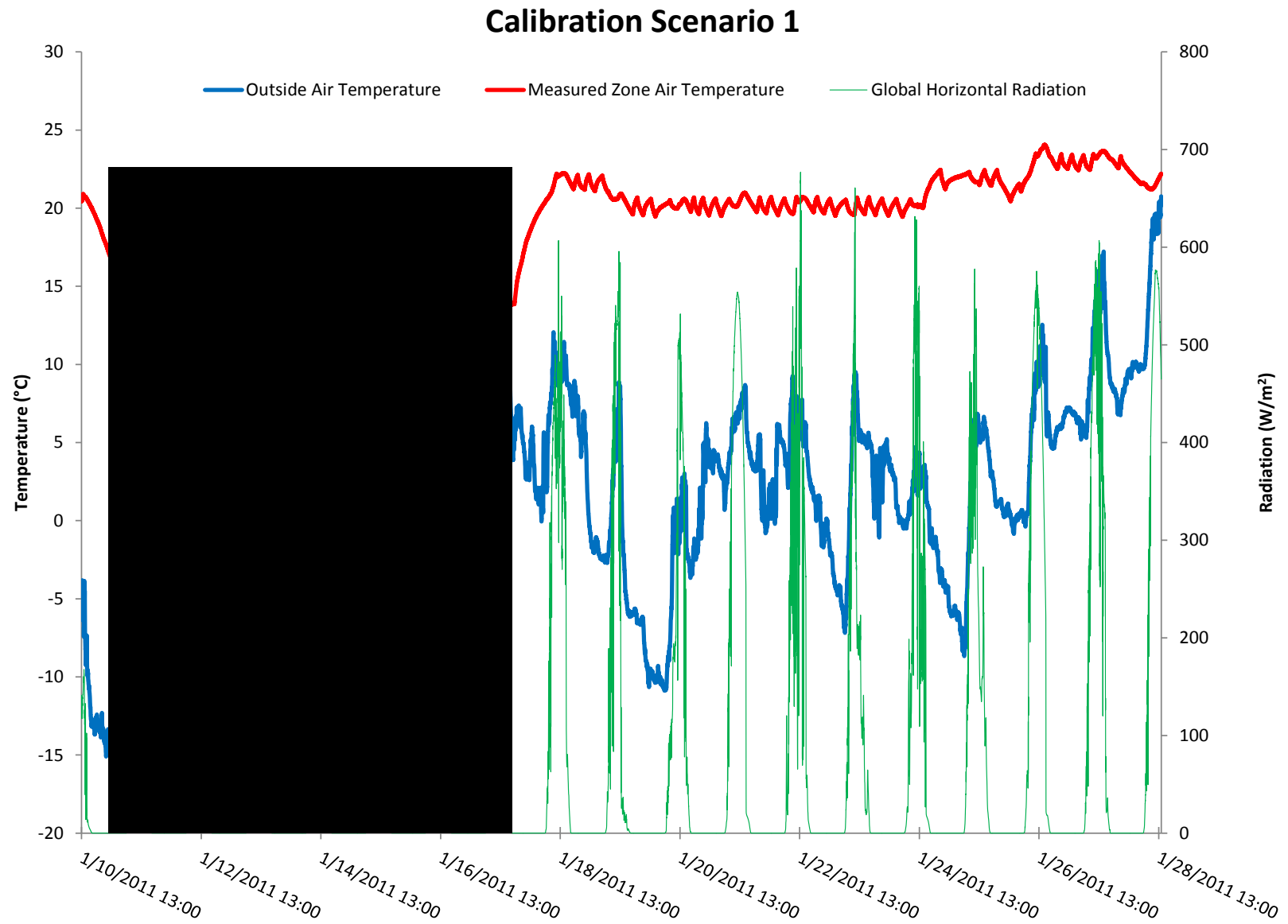


Figure 49: Shaded region shows the portion of the calibration period used for scenario 1

From this figure, it is clear to see that the house temperature is essentially floating as a function of the outdoor temperature and solar radiation. It is also clear that it takes a few days for the house to “lose” the heat that was in its mass after the HVAC system was turned off. There was an approximately 12 hour “warm up” period before error calculations began to allow differences in initial conditions between the model and actual house to stabilize. In order to speed up the run time of the calibration, the wall insulation, roof insulation, and window U-factor were varied as a function of a single “scaling factor.” Instead of allowing the calibration tool to vary all three insulation values independently, it was allowed to vary a single factor which would scale up or down all three insulations together between their lower and upper bounds. In addition to the insulation value, the other parameters that were entered into the calibration tool were mass, infiltration, temperature capacity multiplier, and SHGC. After allowing the calibration tool to run through its optimization, Table 18 shows the values of the optimized parameters and the RMS error associated with the output from this calibrated model.

Table 18: Scenario 1 calibrated building envelope parameters

<u>Parameter</u>	<u>Calibrated Value</u>	<u>Units</u>
Mass (each zone)	290	m ²
Wall Insulation	15	R
Roof Insulation	31	R
Window U-Factor	1.66	W/m ² K
Window SHGC	0.40	N/A
Infiltration (each zone)	10	cm ²
Temperature Capacity Multiplier	66	N/A
RMS Error	0.52	°C

After the calibrated values were entered into the EnergyPlus model, it was run again and the resulting model temperatures during the calibration period are shown in Figure 50. This graph essentially shows how closely the calibration tool was able to get the modeled temperature curve to match the measured temperature curve by varying all of the building envelope parameters.

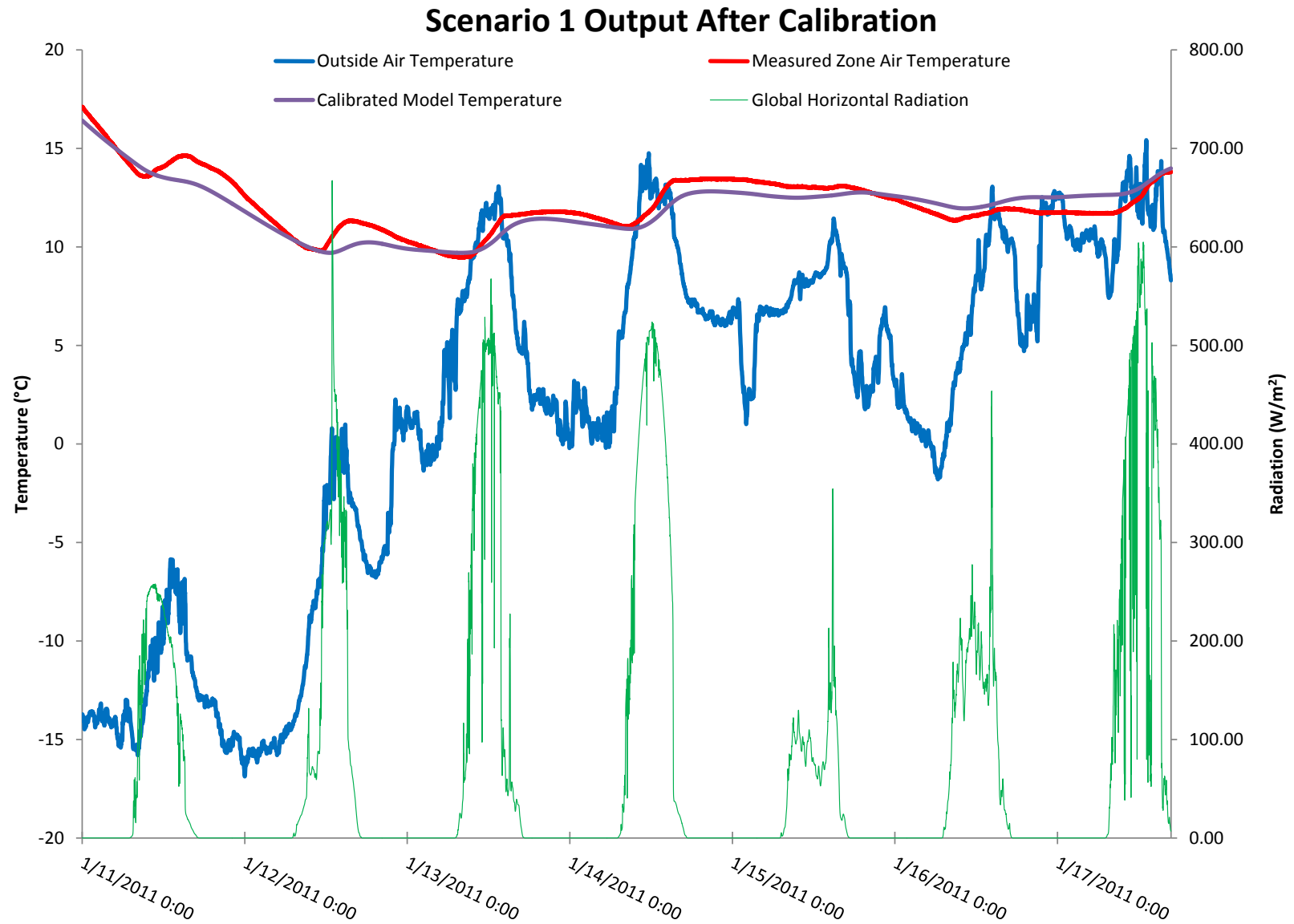


Figure 50: Scenario 1 calibrated model output

Once the calibrated parameters were found using this technique, the model was run through the prediction period and allowed to maintain the set points listed in Table 17. Table 19 below shows the modeled vs. measured energy consumption, absolute error for the whole period, NMBE and the CV(RMSE) for each of the 15 five-day intervals delineated throughout Figure 45 - Figure 48.

Table 19: Modeled vs. measured energy consumption during prediction period for scenario 1

Date	Modeled Energy Consumption (J)	Modeled Energy Consumption (kWh)	Measured Energy Consumption (J)	Measured Energy Consumption (kWh)
Interval 1 (2/3 - 2/7)	1324204114	368	988073772	274
Interval 2 (2/8 - 2/12)	2119041731	589	1487459017	413
Interval 3 (2/13 - 2/17)	548066786	152	440348842	122
Interval 4 (2/18 - 2/22)	407855799	113	343816038	96
Interval 5 (2/23 - 3/2)	650404632	181	455335926	126
Interval 6 (3/3 - 3/7)	1210025284	336	1009809048	281
Interval 7 (3/8 - 4/9)	800818064	222	484740114	135
Interval 8 (4/11 - 4/15)	846766521	235	552698905	154
Interval 9 (4/16 - 4/20)	317590267	88	137480540	38
Interval 10 (4/21 - 4/25)	666487111	185	402296736	112
Interval 11 (4/26 - 4/30)	410234390	114	318844567	89
Interval 12 (5/1 - 5/5)	573173968	159	316510908	88
Interval 13 (5/17 - 5/21)	595436058	165	395305784	110
Interval 14 (5/22 - 5/26)	230193603	64	134359199	37
Interval 15 (5/27 - 5/31)	0	0	0	0
Total	10700298330	2972	7467079396	2074
Absolute Error	43.3%			
NMBE	46.4%			
CV(RSME)	54.2%			

This same information is displayed in a bar-graph format on the following page in Figure 51. Additionally, the modeled zone air temperature vs. measured zone air temperature for the four months of the prediction period is presented in Figure 52 - Figure 55.

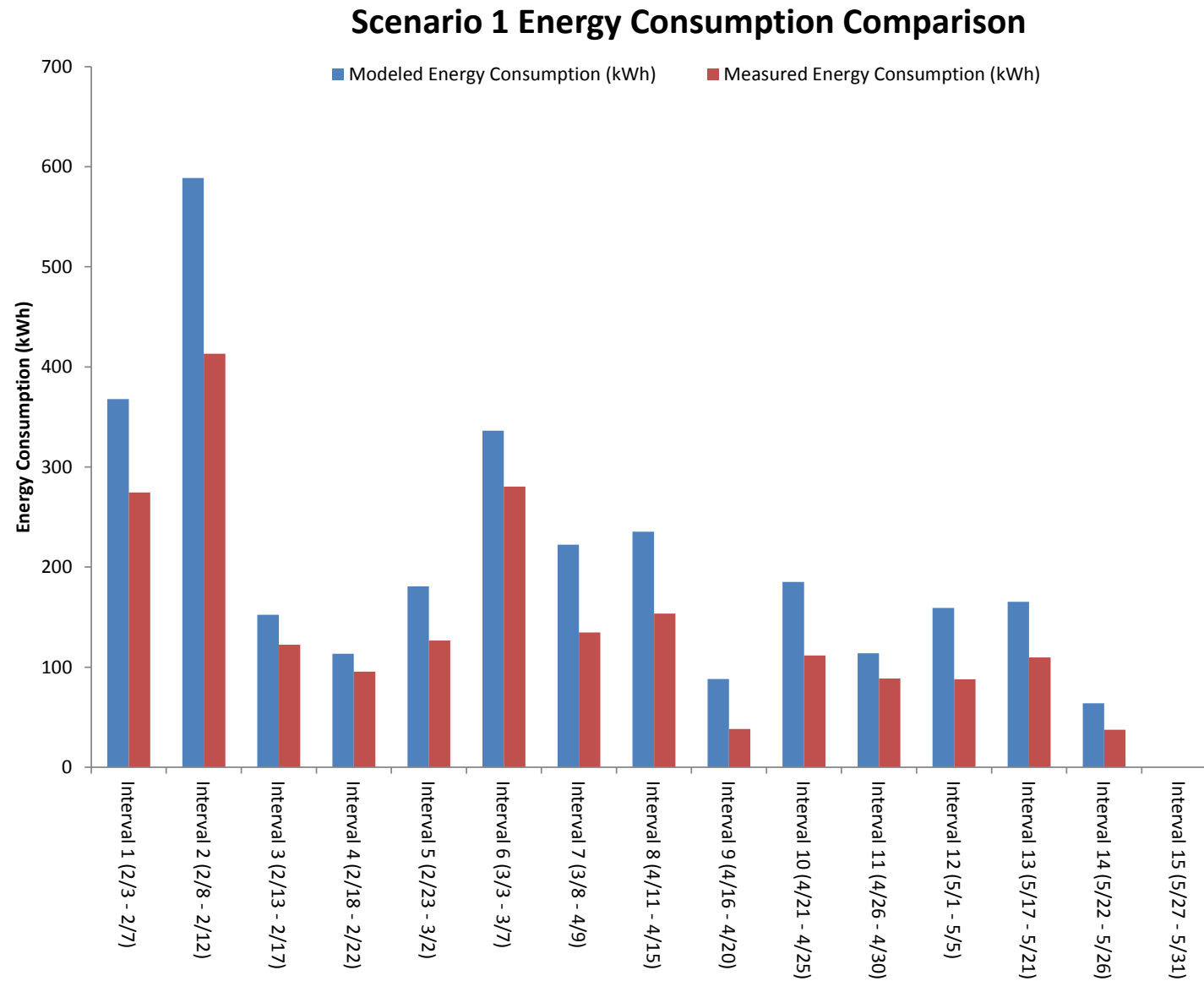


Figure 51: Graphical representation of energy consumption comparison for calibration scenario 1

February Calibrated Model Performance

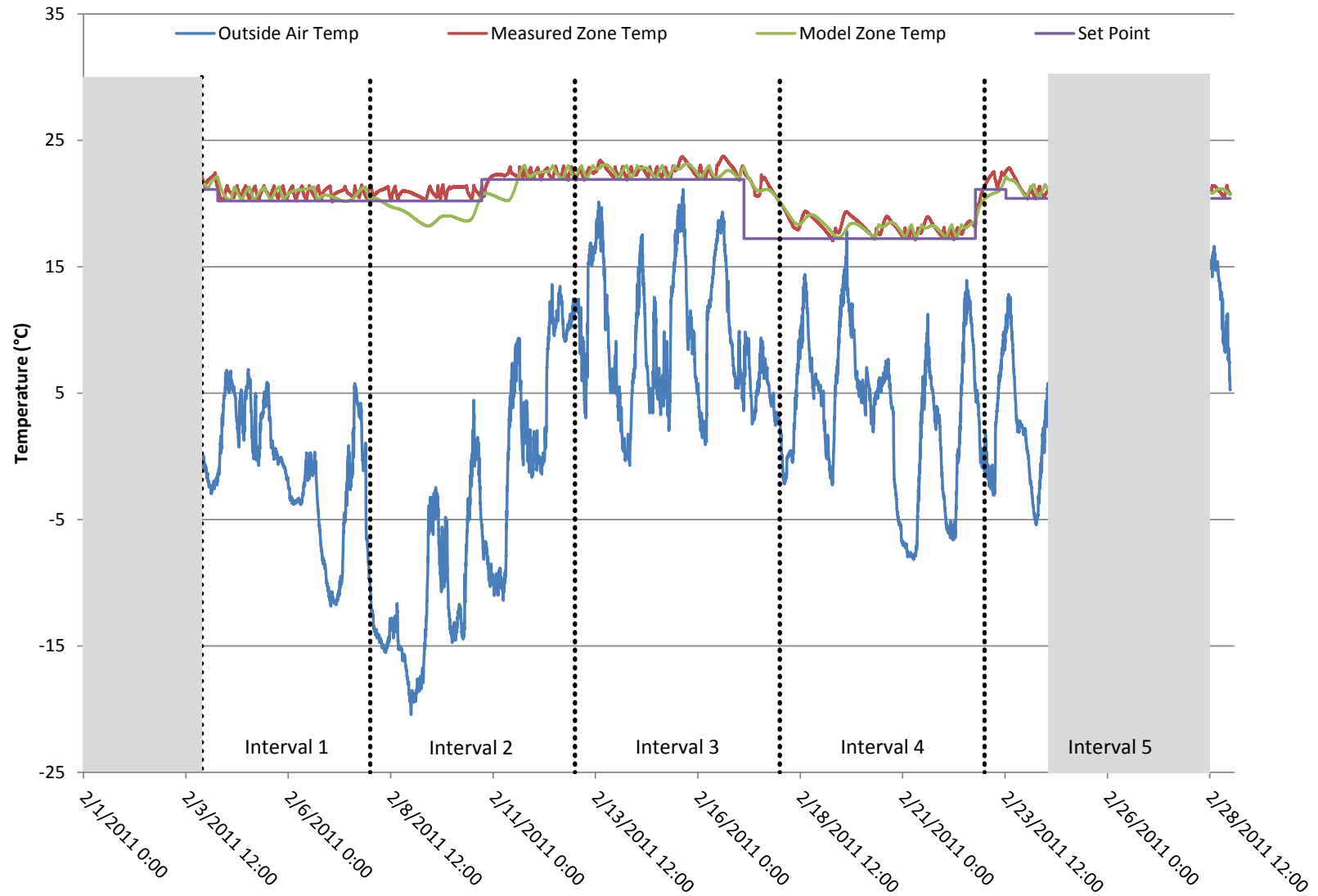


Figure 52: Measured vs. modeled zone air temperatures during February for calibration scenario 1

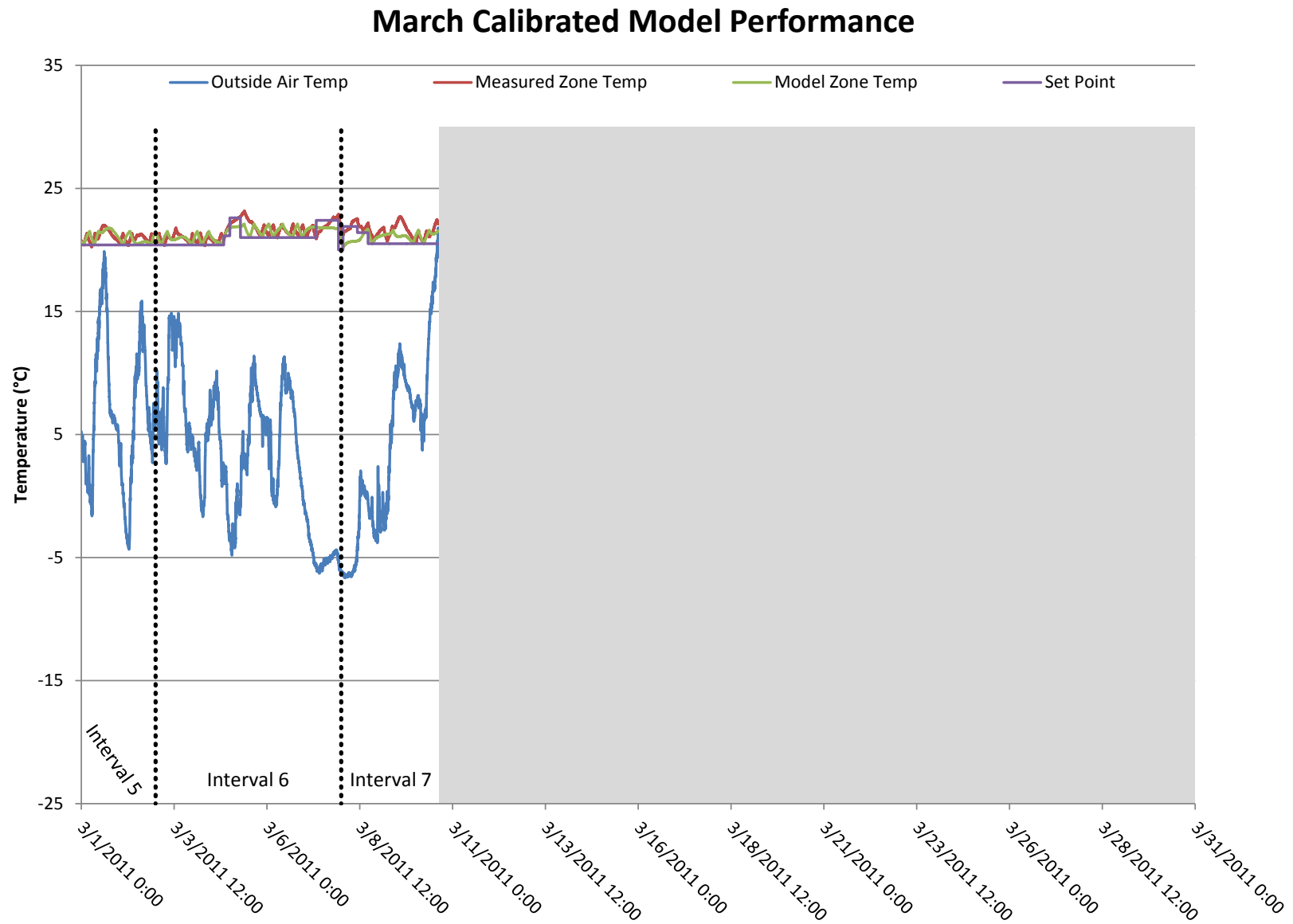


Figure 53: Measured vs. modeled zone air temperatures during March for calibration scenario 1

April Calibrated Model Performance

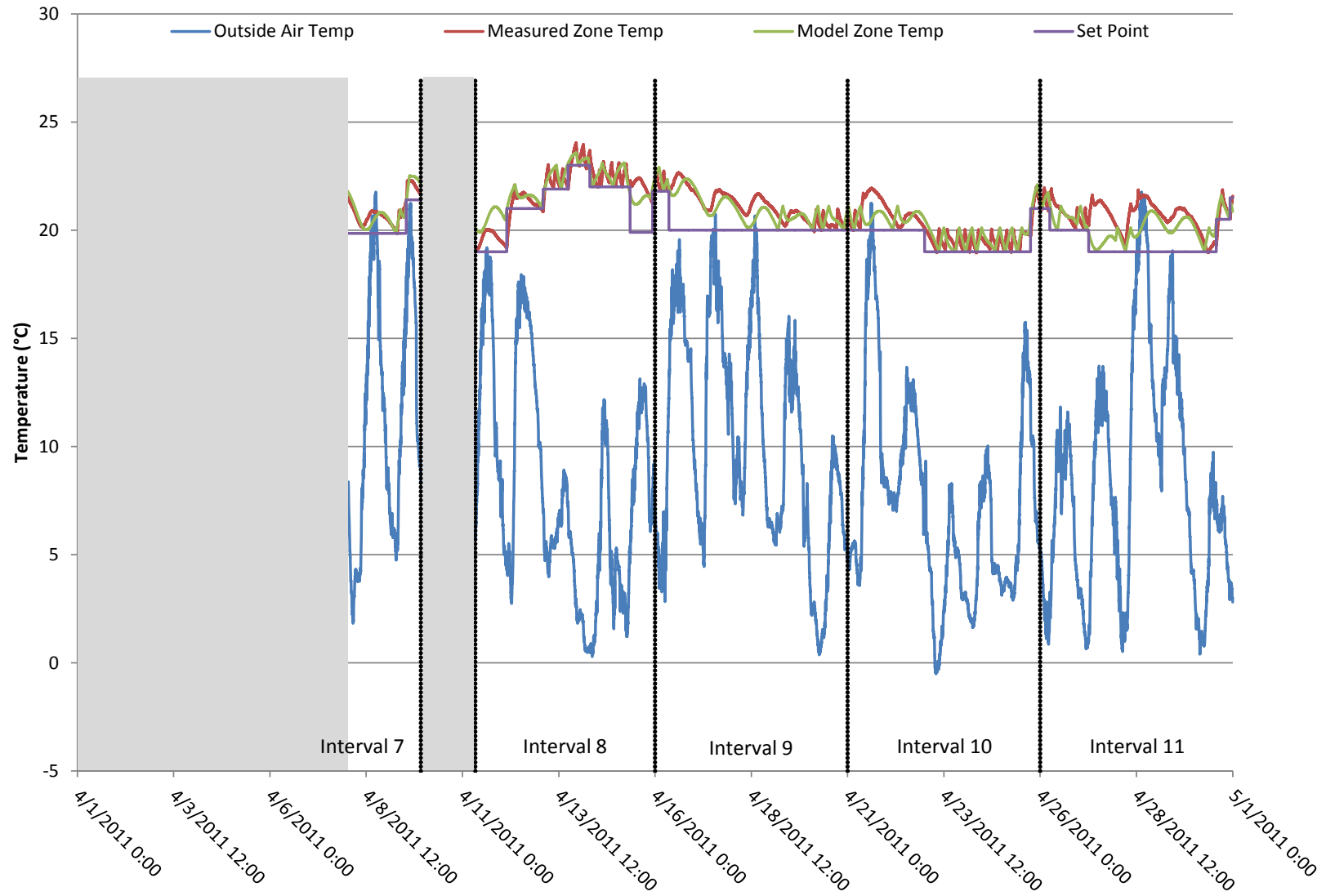


Figure 54: Measured vs. modeled zone air temperatures during April for calibration scenario 1

May Calibrated Model Performance

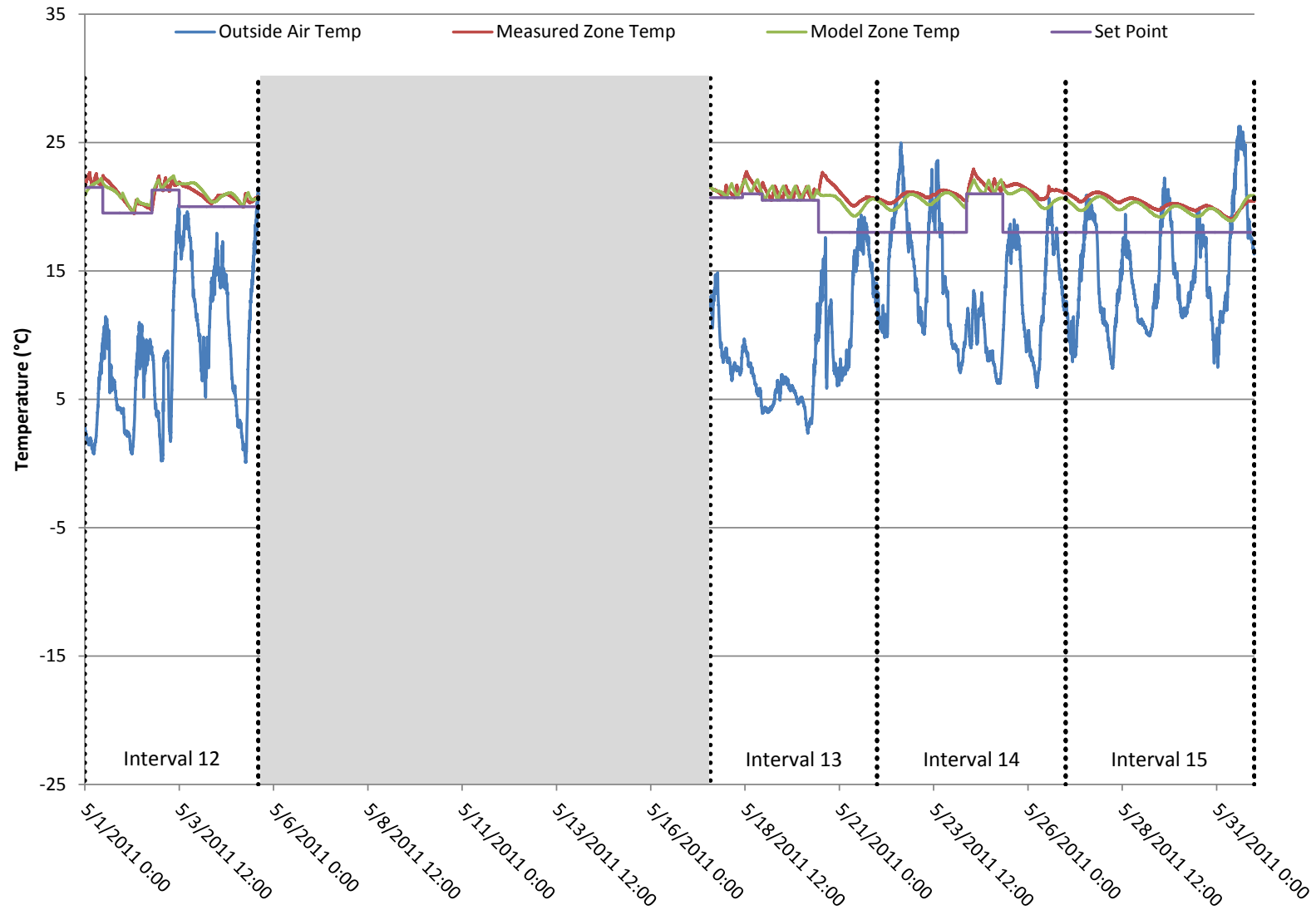


Figure 55: Measured vs. modeled zone air temperatures during May for calibration scenario

5.2.2 Scenario 2: HVAC System Normal Operation, Temperature Used as Objective Function

After the initial 7 day period when the HVAC system was turned off, it was turned back on for the remainder of the calibration period. Therefore, there were 11 days of measured data when the system was operating and the house was occupied for a portion of the time. For this calibration, the plug/light loads were scheduled into EnergyPlus and the HVAC system was forced on in the model when the system in the pilot house was operating, regardless of the zone air temperature in the model. The schedule created to drive the HVAC system in the model was based on the status of hot water flow in the AHU heating coil loop, i.e. a non-zero flow indicated that the system was operating. By forcing the internal gains on the energy model, the zone air temperature should theoretically match the measured air temperature when the building envelope parameters are properly calibrated. For this reason, the error between measured and modeled air temperature is used to calculate the objective function. The shaded portion of Figure 56 illustrates the period of time when the calibration was run for scenario 2.

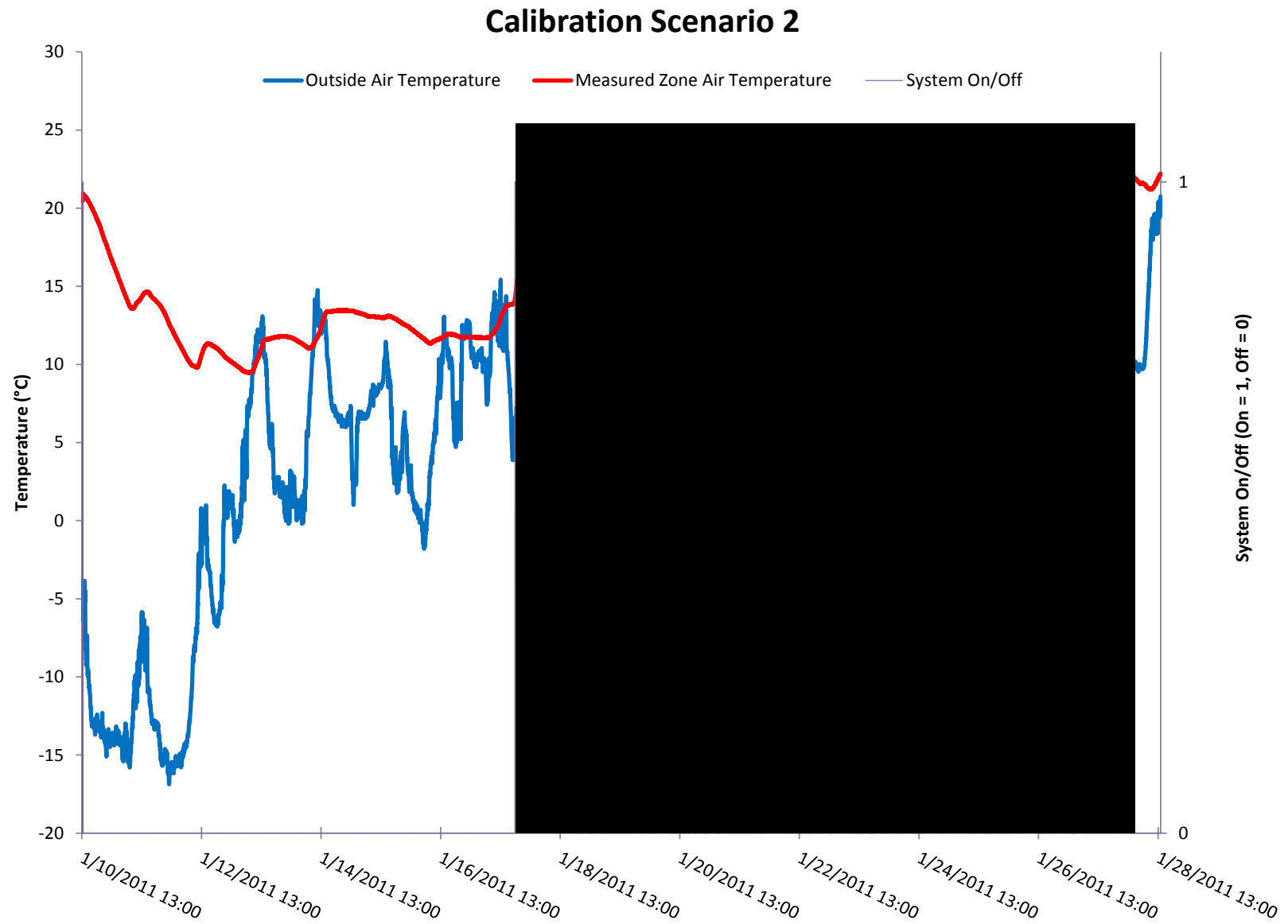


Figure 56: Shaded region shows the portion of the calibration period used for scenario 2

From this figure, one can see that the HVAC system is constantly cycling on and off in order to maintain the thermostat set point which changes several times between approximately 20-25°C. It is clearly visible how the measured zone air temperature spikes each time the HVAC system cycles on and shuts off when the set point is met. There are other small spikes that occur when the system is off which correspond to times when there are spikes in solar radiation. The parameters entered into the calibration tool in this case are the same as in calibration scenario 1 with one addition. Since in this case the HVAC system has a major impact on the internal gains experienced in each zone, the distribution of air between the two main floors is important. The overall supply air volumetric flow rate is 0.234 m³/s, so the last parameter to be calibrated is the fraction of this that is split between the two main thermal zones of the pilot house. Table 20 shows the values of the optimized parameters and the RMS error associated with the output from this calibrated model.

Table 20: Scenario 2 calibrated building envelope parameters

<u>Parameter</u>	<u>Calibrated Value</u>	<u>Units</u>
Mass (each zone)	123	m ²
Wall Insulation	23	R
Roof Insulation	39	R
Window U-Factor	0.82	W/m ² K
Window SHGC	0.56	N/A
Infiltration (each zone)	112	cm ²
% Supply Air to Main Floor	55	%
RMS Error	0.51	°C

After the calibrated values were entered into the EnergyPlus model, it was run again and the resulting model temperatures during the calibration period are shown in Figure 57.

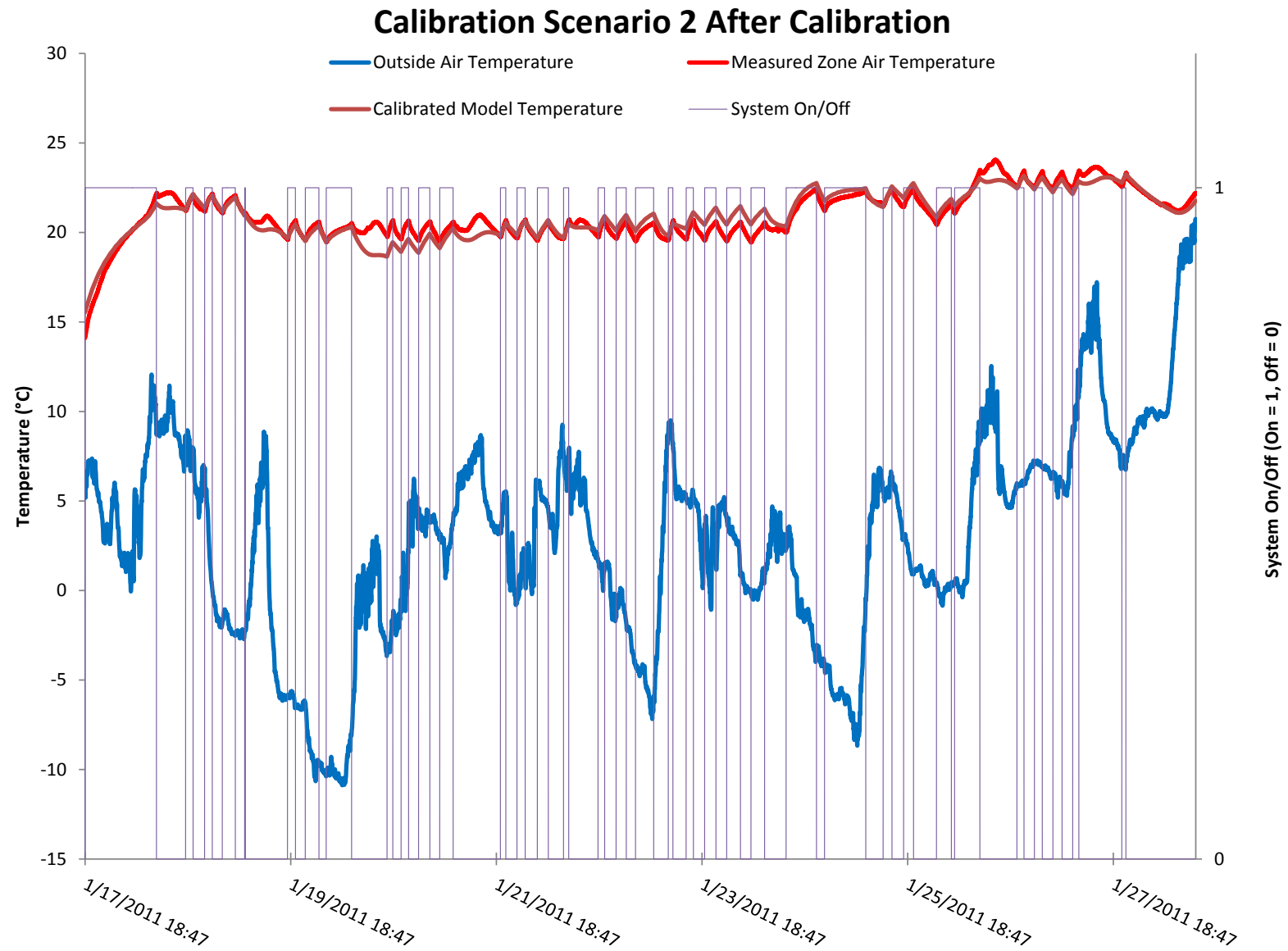


Figure 57: Scenario 2 calibrated model output

Table 21 below shows the modeled vs. measured energy consumption, absolute error for the whole period, NMBE and the CV(RSME) for the same five-day intervals as in scenario 1.

Table 21: Modeled vs. measured energy consumption during prediction period for scenario 2

Date	Modeled Energy Consumption (J)	Modeled Energy Consumption (kWh)	Measured Energy Consumption (J)	Measured Energy Consumption (kWh)
Interval 1 (2/3 - 2/7)	1123020774	312	988073772	274
Interval 2 (2/8 - 2/12)	1825775255	507	1487459017	413
Interval 3 (2/13 - 2/17)	300118686	83	440348842	122
Interval 4 (2/18 - 2/22)	215335975	60	343816038	96
Interval 5 (2/23 - 3/2)	352760417	98	455335926	126
Interval 6 (3/3 - 3/7)	959065197	266	1009809048	281
Interval 7 (3/8 - 4/9)	603014076	168	484740114	135
Interval 8 (4/11 - 4/15)	619566647	172	552698905	154
Interval 9 (4/16 - 4/20)	171580047	48	137480540	38
Interval 10 (4/21 - 4/25)	500829948	139	402296736	112
Interval 11 (4/26 - 4/30)	276583756	77	318844567	89
Interval 12 (5/1 - 5/5)	419198326	116	316510908	88
Interval 13 (5/17 - 5/21)	462747303	129	395305784	110
Interval 14 (5/22 - 5/26)	145791319	40	134359199	37
Interval 15 (5/27 - 5/31)	0	0	0	0
Total	7975387725	2215	7467079396	2074
Absolute Error	6.8%			
NMBE	7.3%			
CV(RSME)	25.7%			

As in scenario 1, the results are displayed in a bar-graph format on the following page in Figure 58. Additionally, the modeled zone air temperature vs. measured zone air temperature for the four months of the prediction period is presented in Figure 59 - Figure 62.

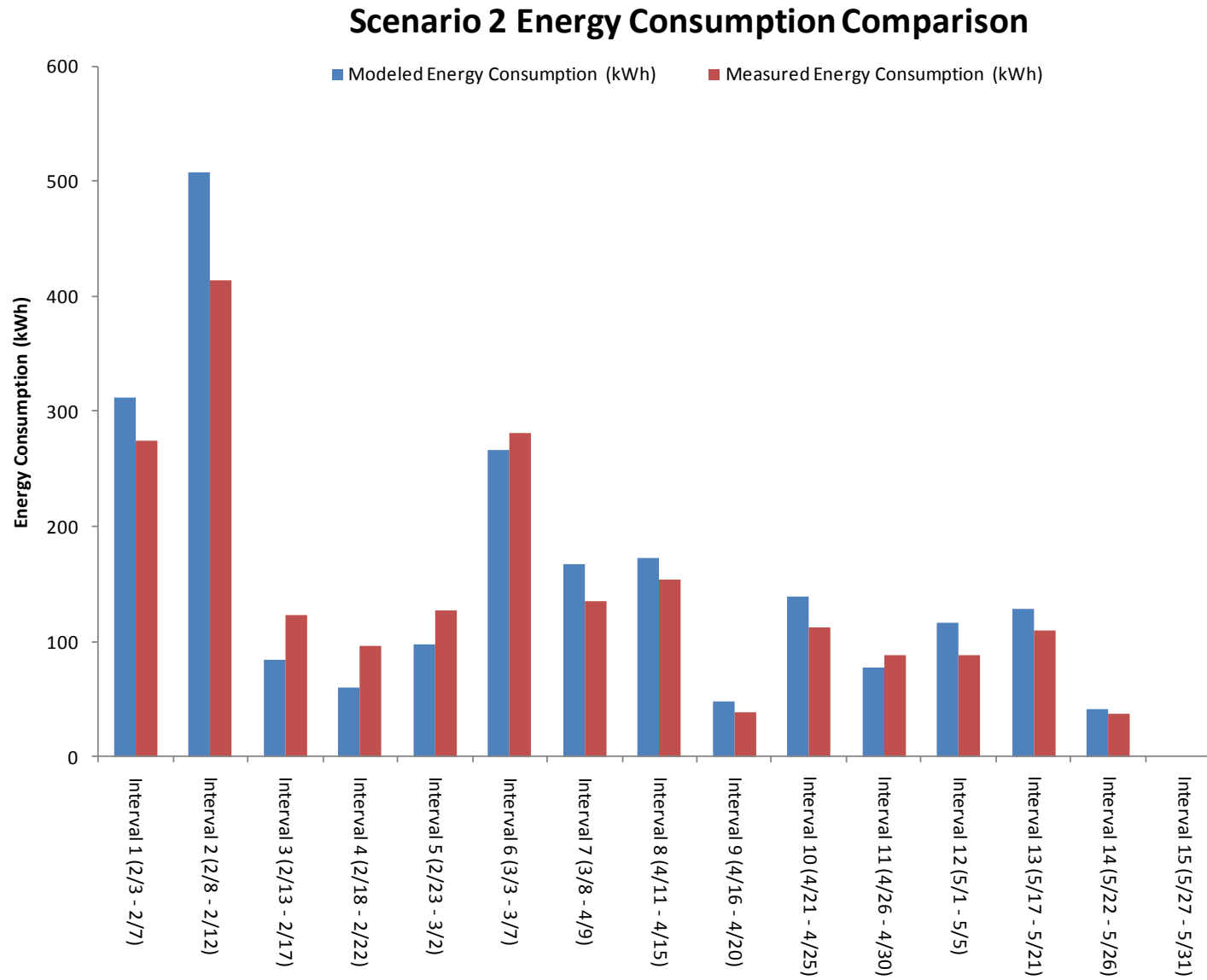


Figure 58: Graphical representation of energy consumption comparison for calibration scenario 2

February Calibrated Model Performance

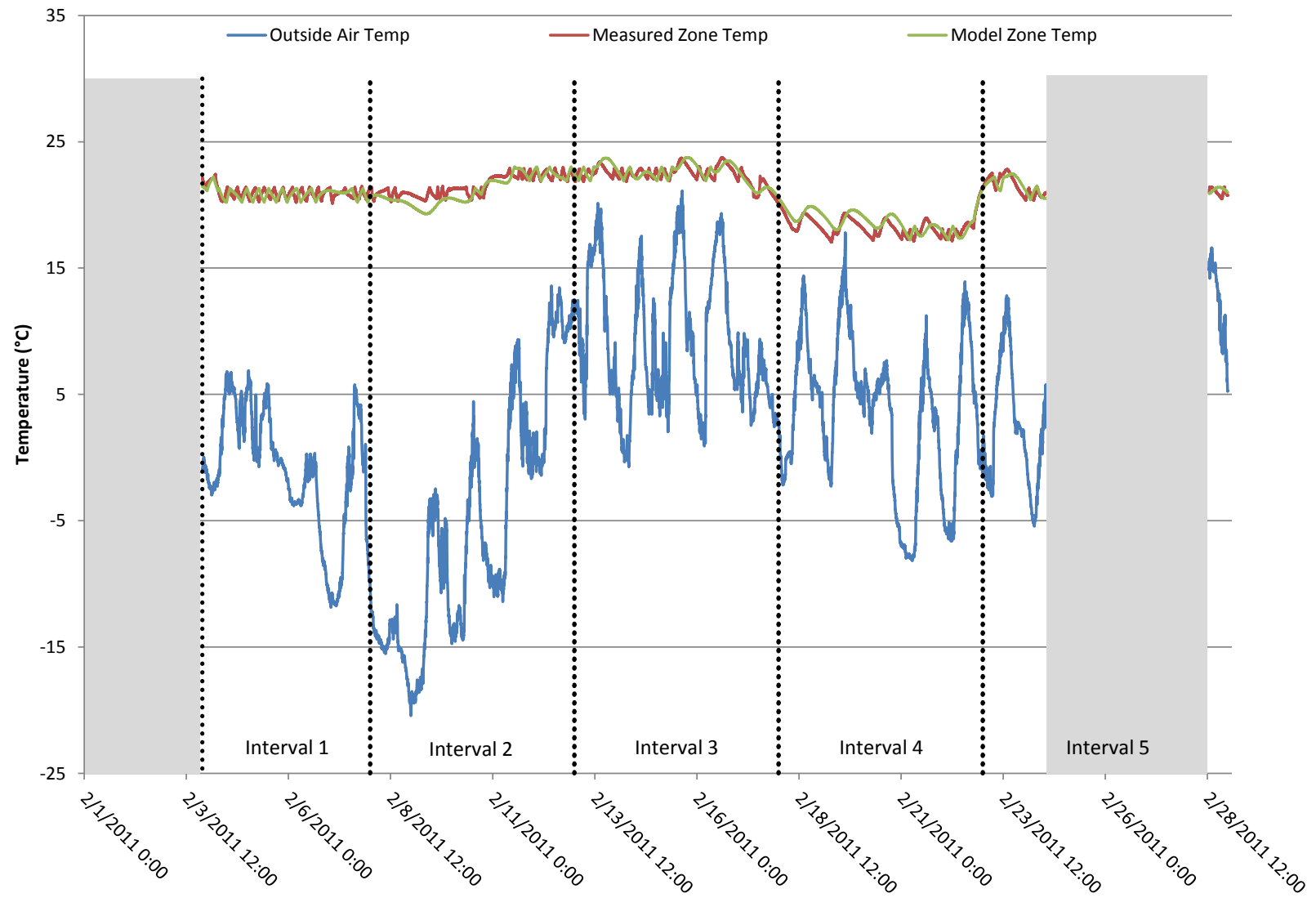


Figure 59: Measured vs. modeled zone air temperatures during February for calibration scenario 2

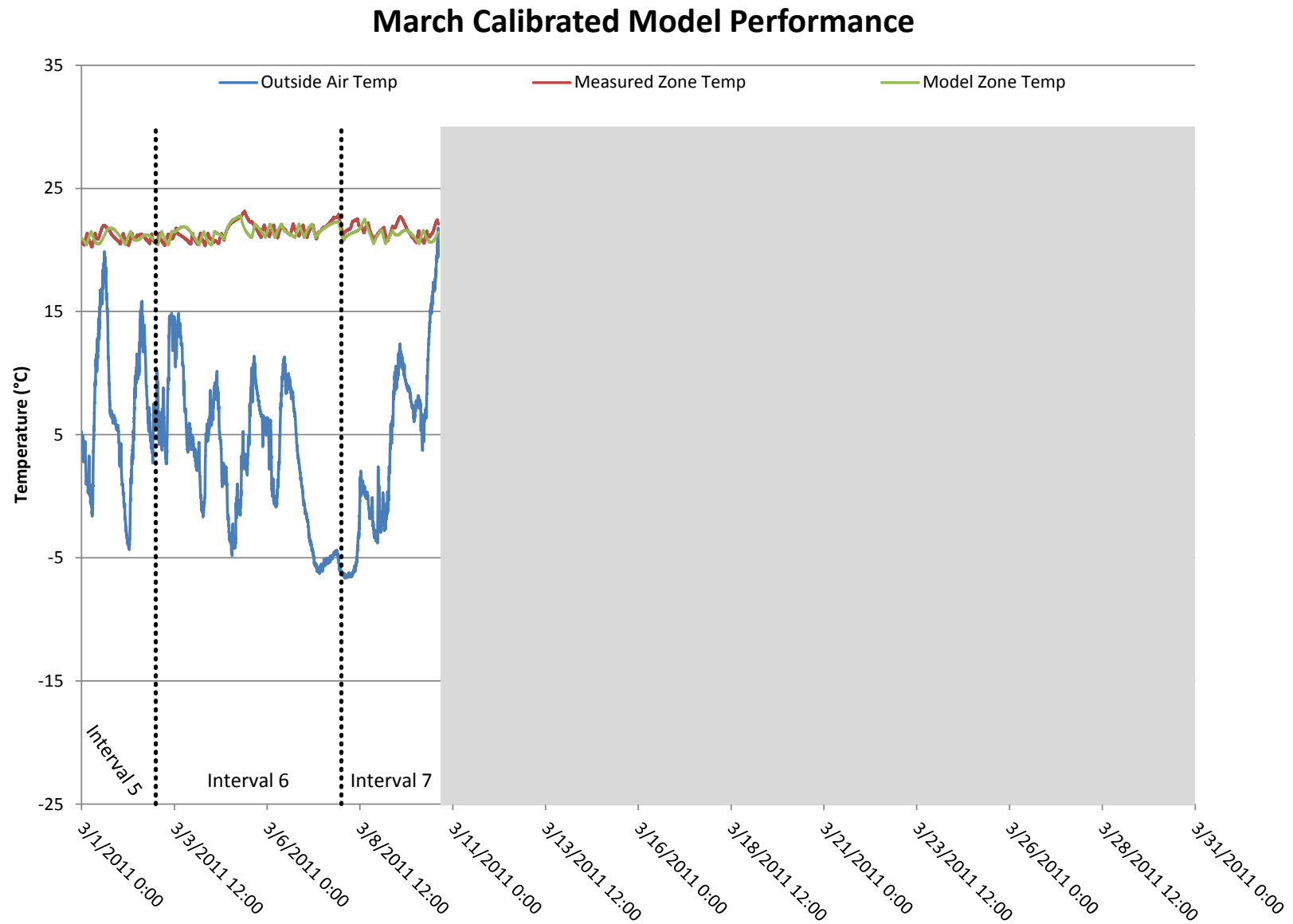


Figure 60: Measured vs. modeled zone air temperatures during March for calibration scenario 2

April Calibrated Model Performance

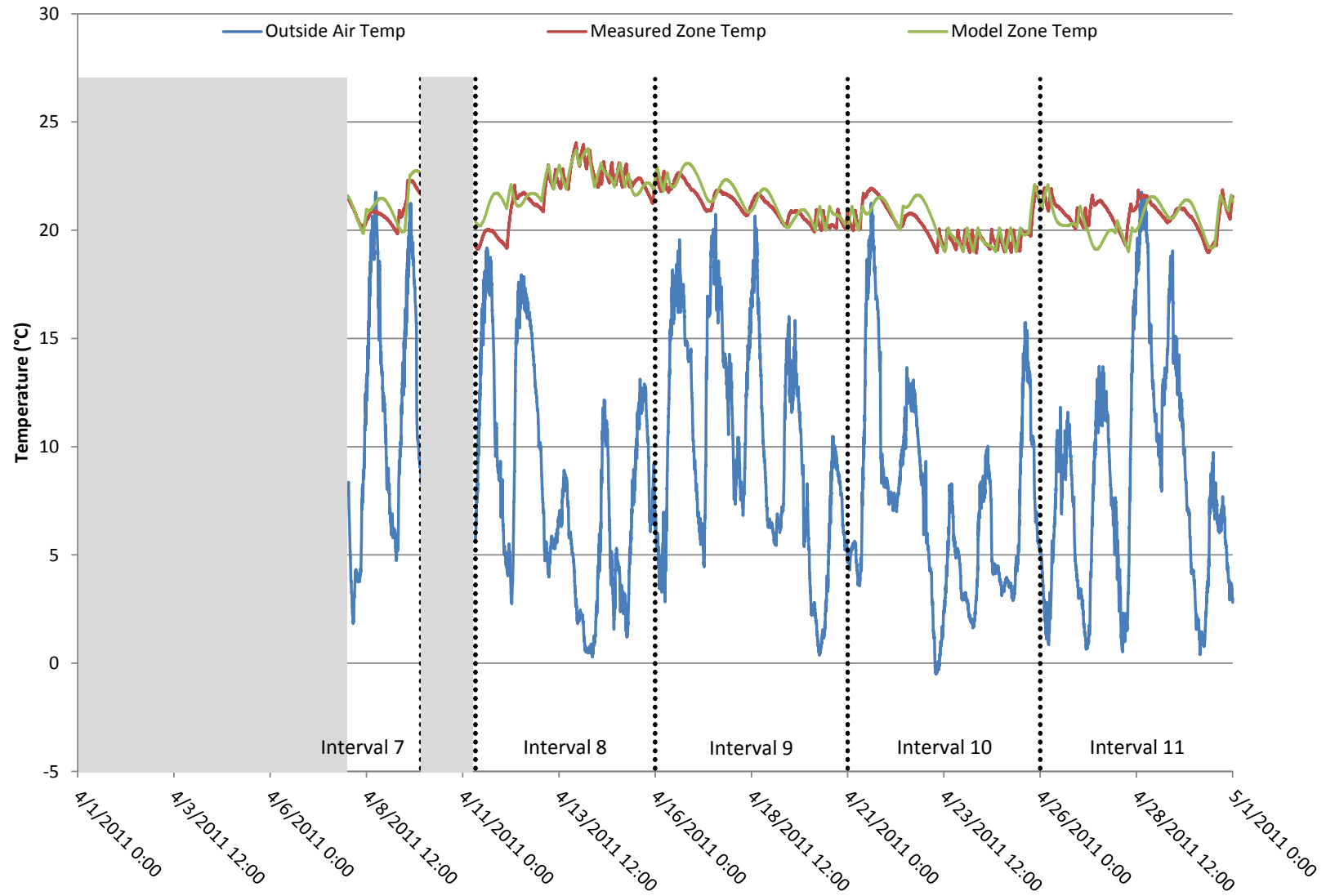


Figure 61: Measured vs. modeled zone air temperatures during April for calibration scenario 2

May Calibrated Model Performance

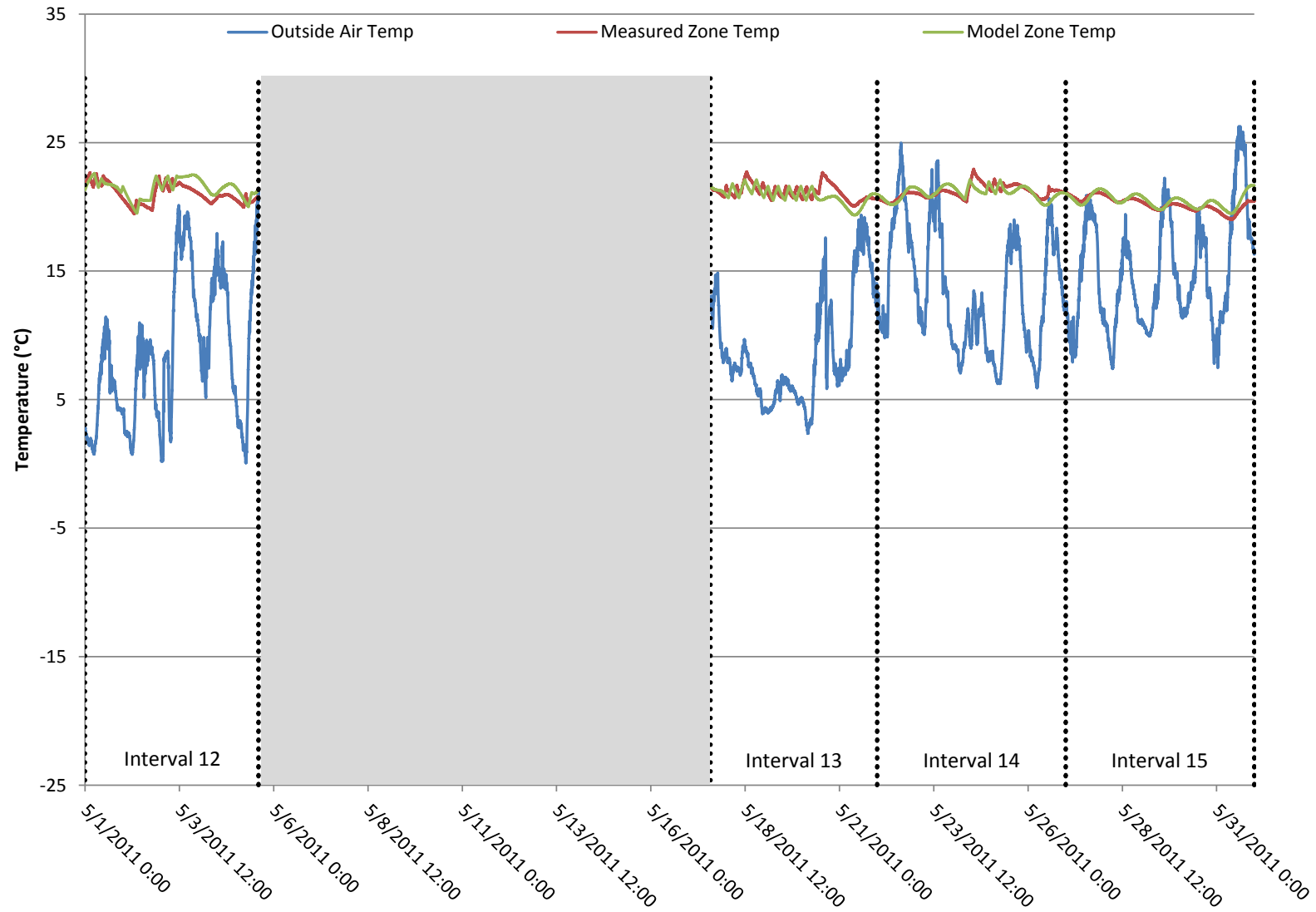


Figure 62: Measured vs. modeled zone air temperatures during May for calibration scenario 2

5.2.3 Scenario 3: No Internal Gains for a Portion of the Calibration Period, Temperature Used as Objective Function

In a sense, this calibration scenario is a combination of the first two. The whole calibration period is used, so the portion of the time when the HVAC system was not operating as well as the portion of time when it was operating were both used to compute the objective function value for temperature error. For this case, the parameters entered into the calibration tool were the same as in calibration scenario 2 described in section 5.2.2. Table 22 shows the values of the optimized parameters and the RMS error associated with the output from the calibrated model.

Table 22: Scenario 3 calibrated building envelope parameters

<u>Parameter</u>	<u>Calibrated Value</u>	<u>Units</u>
Mass (each zone)	129	m ²
Wall Insulation	20	R
Roof Insulation	36	R
Window U-Factor	1.05	W/m ² K
Window SHGC	0.33	N/A
Infiltration (each zone)	15	cm ²
% Supply Air to Main Floor	69	%
RMS Error	0.63	°C

After the calibrated values were entered into the EnergyPlus model, it was run again and the resulting model temperatures during the calibration period are shown in Figure 63.

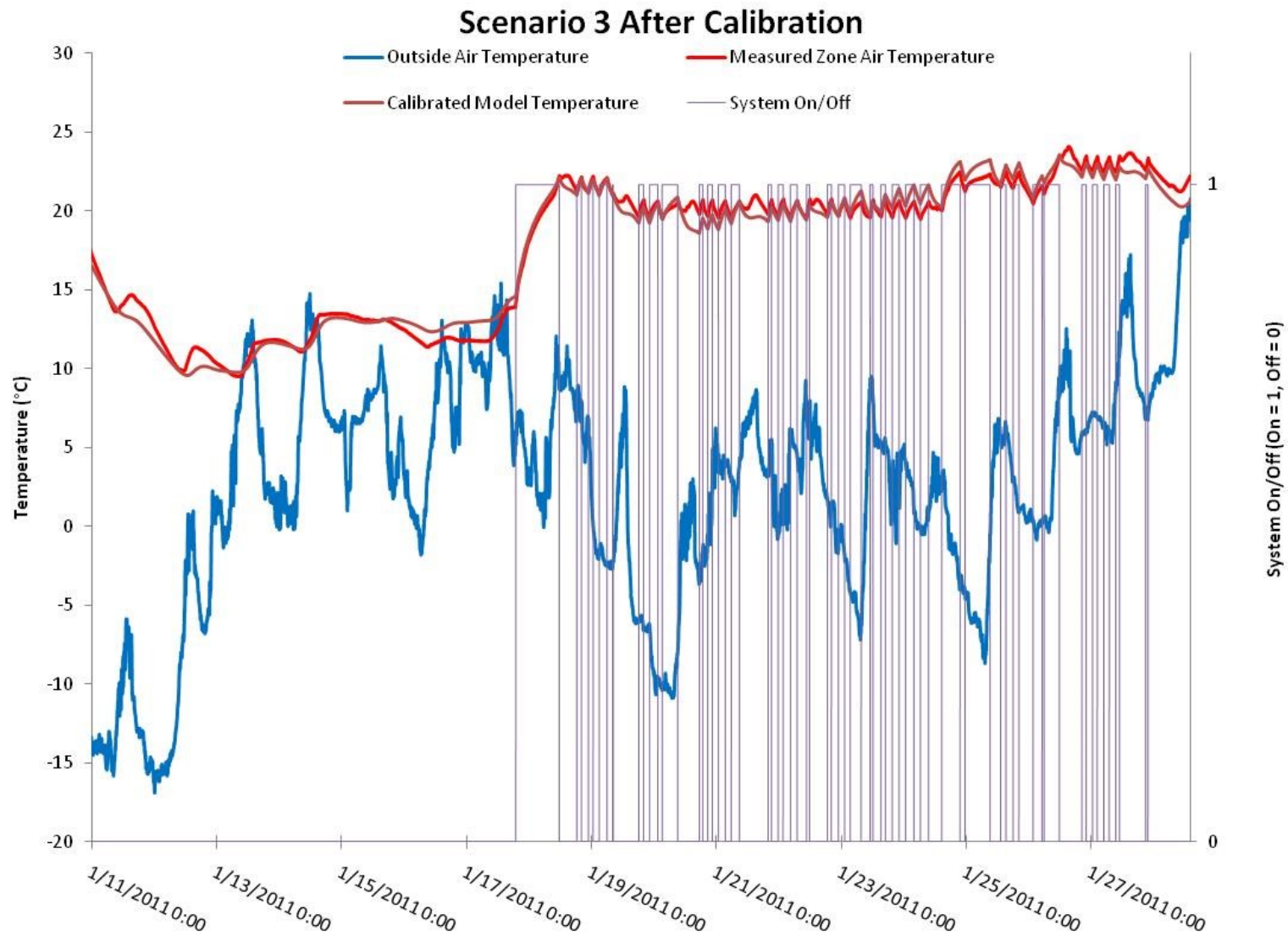


Figure 63: Scenario 3 calibrated model output

Table 23 below shows the modeled vs. measured energy consumption, absolute error for the whole period NMBE and the CV(RSME) for the same five-day intervals as in the previous scenarios.

Table 23: Modeled vs. measured energy consumption during prediction period for scenario 3

Date	Modeled Energy Consumption (J)	Modeled Energy Consumption (kWh)	Measured Energy Consumption (J)	Measured Energy Consumption (kWh)
Interval 1 (2/3 - 2/7)	977980539	272	988073772	274
Interval 2 (2/8 - 2/12)	1737029051	483	1487459017	413
Interval 3 (2/13 - 2/17)	386131134	107	440348842	122
Interval 4 (2/18 - 2/22)	307666322	85	343816038	96
Interval 5 (2/23 - 3/2)	411289218	114	455335926	126
Interval 6 (3/3 - 3/7)	947034129	263	1009809048	281
Interval 7 (3/8 - 4/9)	589643699	164	484740114	135
Interval 8 (4/11 - 4/15)	615861628	171	552698905	154
Interval 9 (4/16 - 4/20)	200443459	56	137480540	38
Interval 10 (4/21 - 4/25)	450141444	125	402296736	112
Interval 11 (4/26 - 4/30)	299622696	83	318844567	89
Interval 12 (5/1 - 5/5)	394980185	110	316510908	88
Interval 13 (5/17 - 5/21)	415255068	115	395305784	110
Interval 14 (5/22 - 5/26)	152172800	42	134359199	37
Interval 15 (5/27 - 5/31)	0	0	0	0
Total	7885251370	2190	7467079396	2074
Absolute Error	5.6%			
NMBE	6.0%			
CV(RSME)	17.1%			

As in the other scenarios, the results are displayed in a bar-graph format on the following page in Figure 64. Additionally, the modeled zone air temperature vs. measured zone air temperature for the four months of the prediction period is presented in Figure 65 - Figure 68.

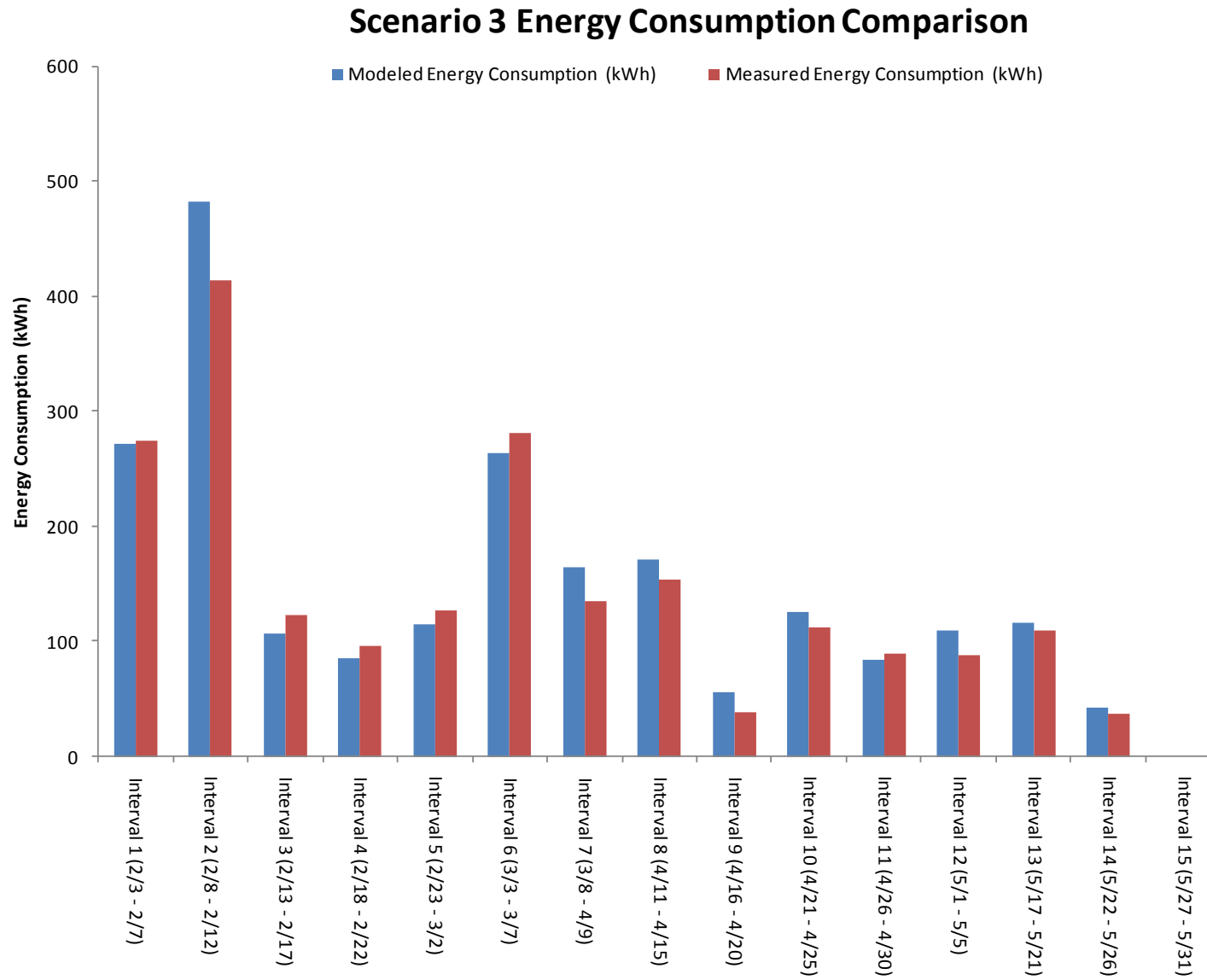


Figure 64: Graphical representation of energy consumption comparison for calibration scenario

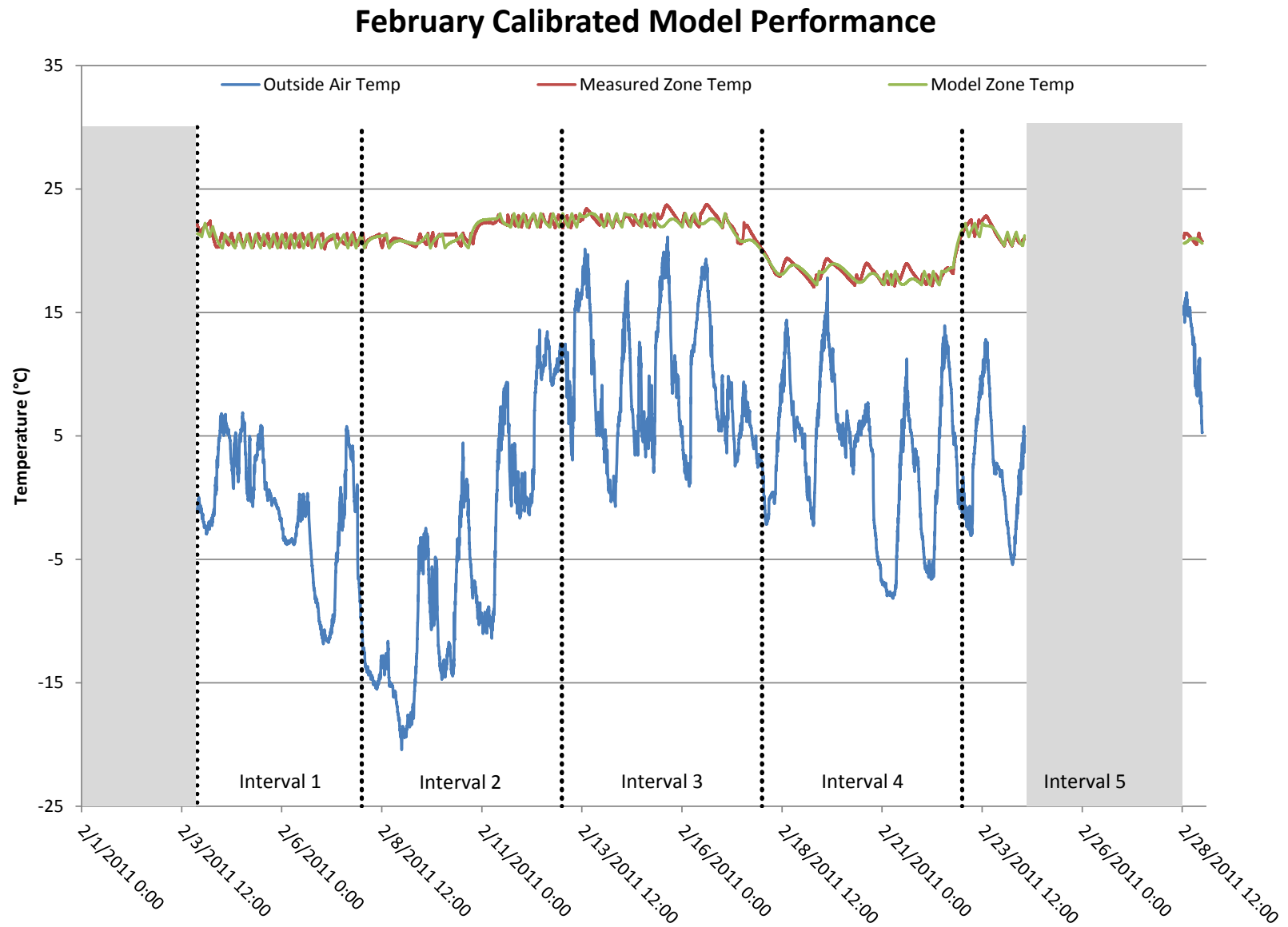


Figure 65: Measured vs. modeled zone air temperatures during February for calibration scenario 3

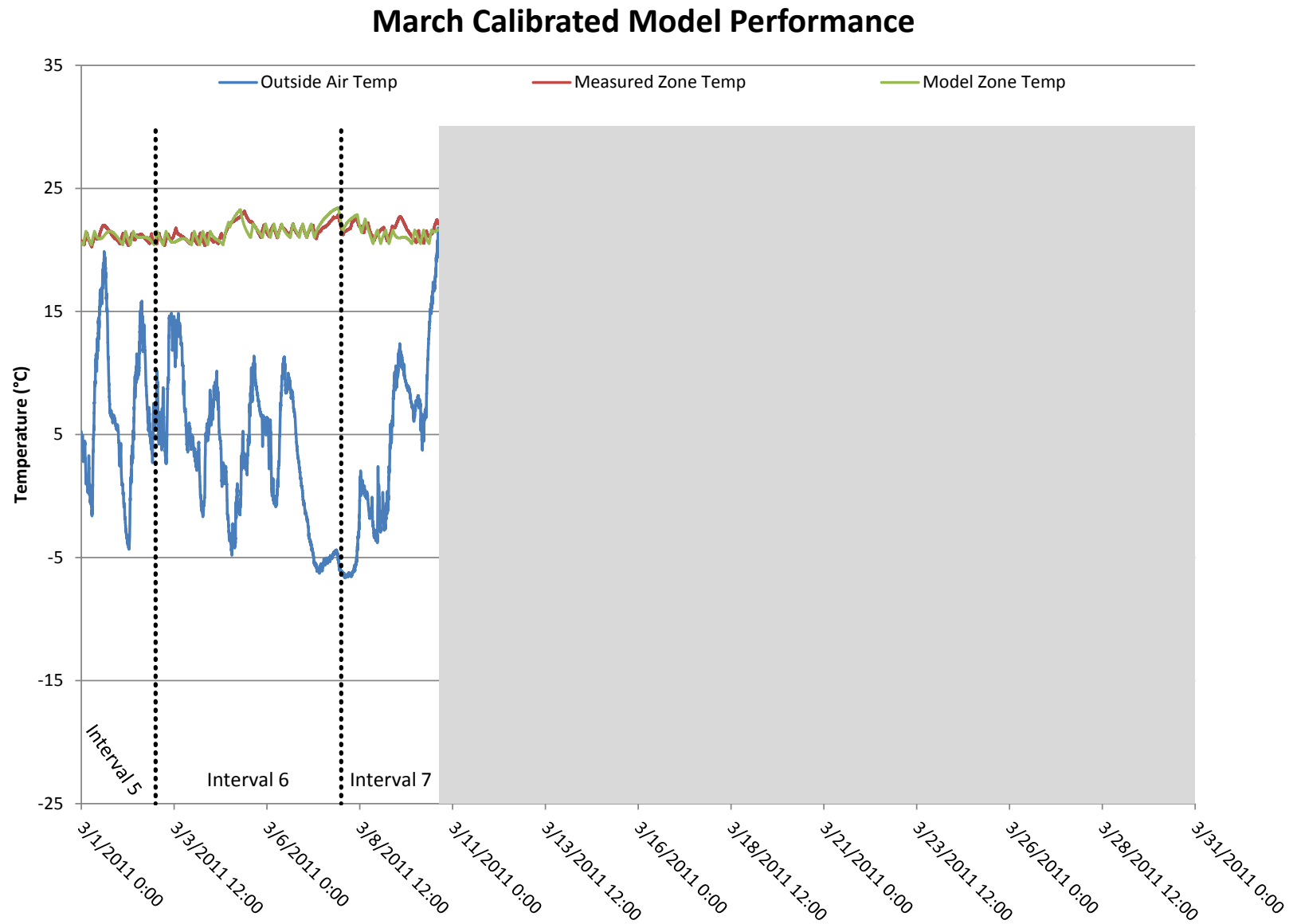


Figure 66: Measured vs. modeled zone air temperatures during March for calibration scenario 3

April Calibrated Model Performance

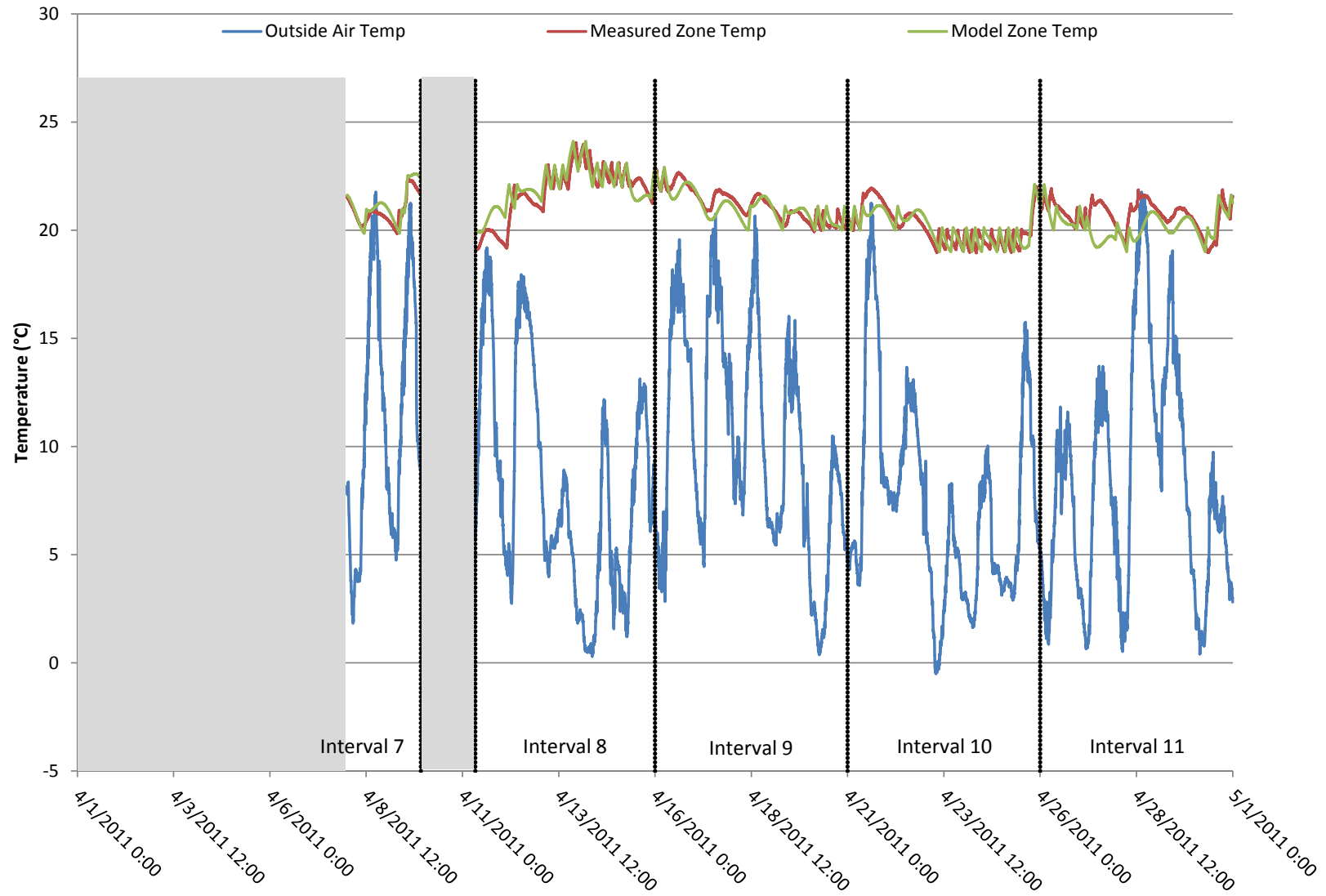


Figure 67: Measured vs. modeled zone air temperatures during April for calibration scenario 3

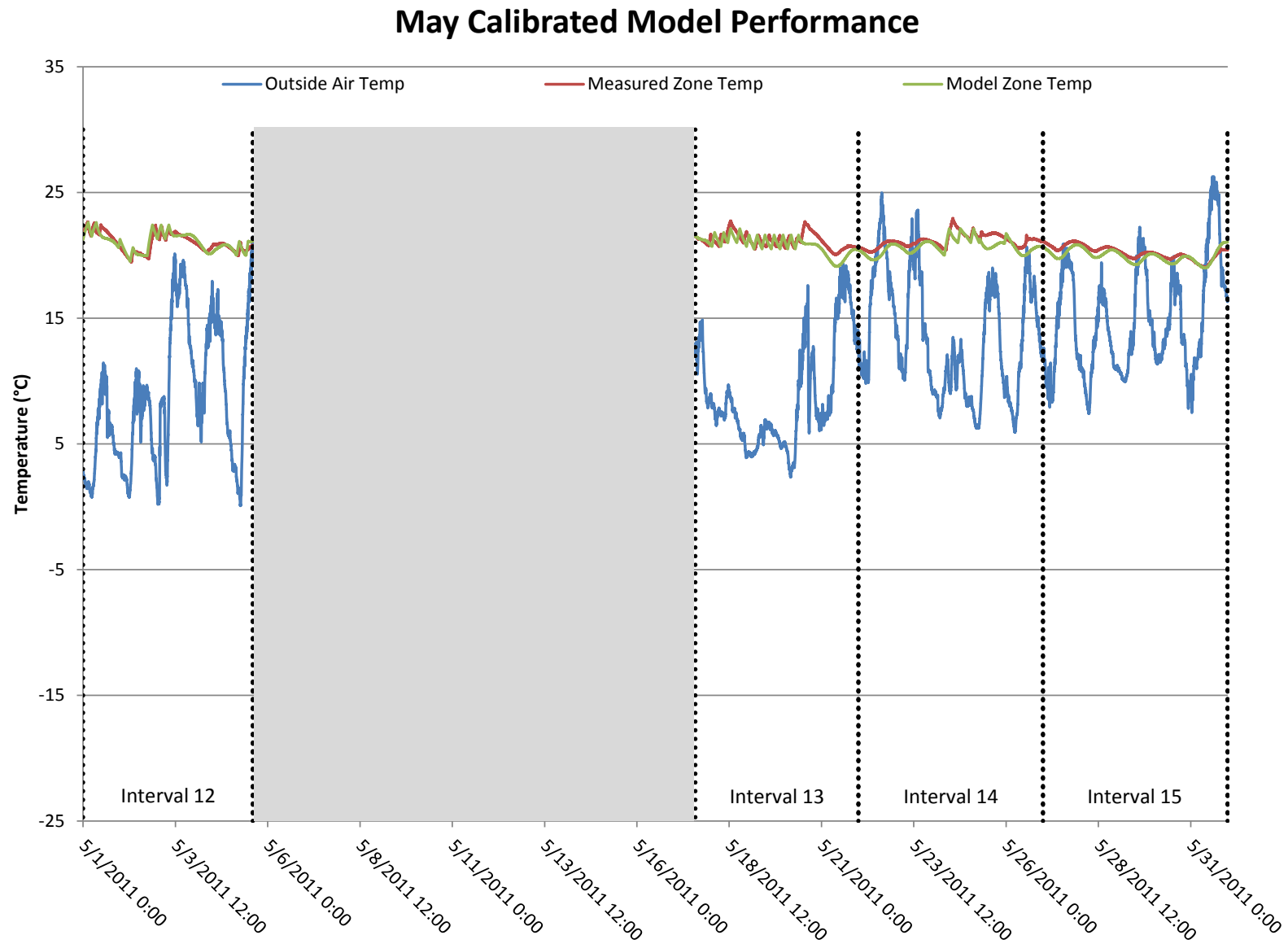


Figure 68: Measured vs. modeled zone air temperatures during May for calibration scenario 3

5.2.4 Scenario 4: Energy Consumption Used as Objective Function during Fixed Intervals

In this calibration scenario, the objective function used in the calibration tool was the difference between the energy consumed by the pilot house and the modeled energy consumption during both one day and half day intervals over the portion of the calibration period when the HVAC system was operational. This constitutes 10 one day intervals or 20 half day intervals available for comparison. Instead of forcing the HVAC system to turn on and off as observed in the measured data and then comparing temperatures, in this case the system is allowed to run in order to maintain the same temperature set points observed in the pilot house via the measured temperature data. Table 15 contains the actual set point values that were scheduled into the EnergyPlus model during these 10 days. For this case, the parameters entered into the calibration tool to be optimized are the same as the parameters used in scenarios 2 and 3. In theory, once the building envelope parameters are properly calibrated, the energy required to maintain the scheduled temperature set points should match very closely the measured energy consumption in the pilot house. Figure 69 and Figure 70 shows the measured zone air temperature during the calibration period along with a line representing the corresponding temperature set point. The vertical lines show the start and end points for each one day interval and half day interval used in the calculation of energy consumption.

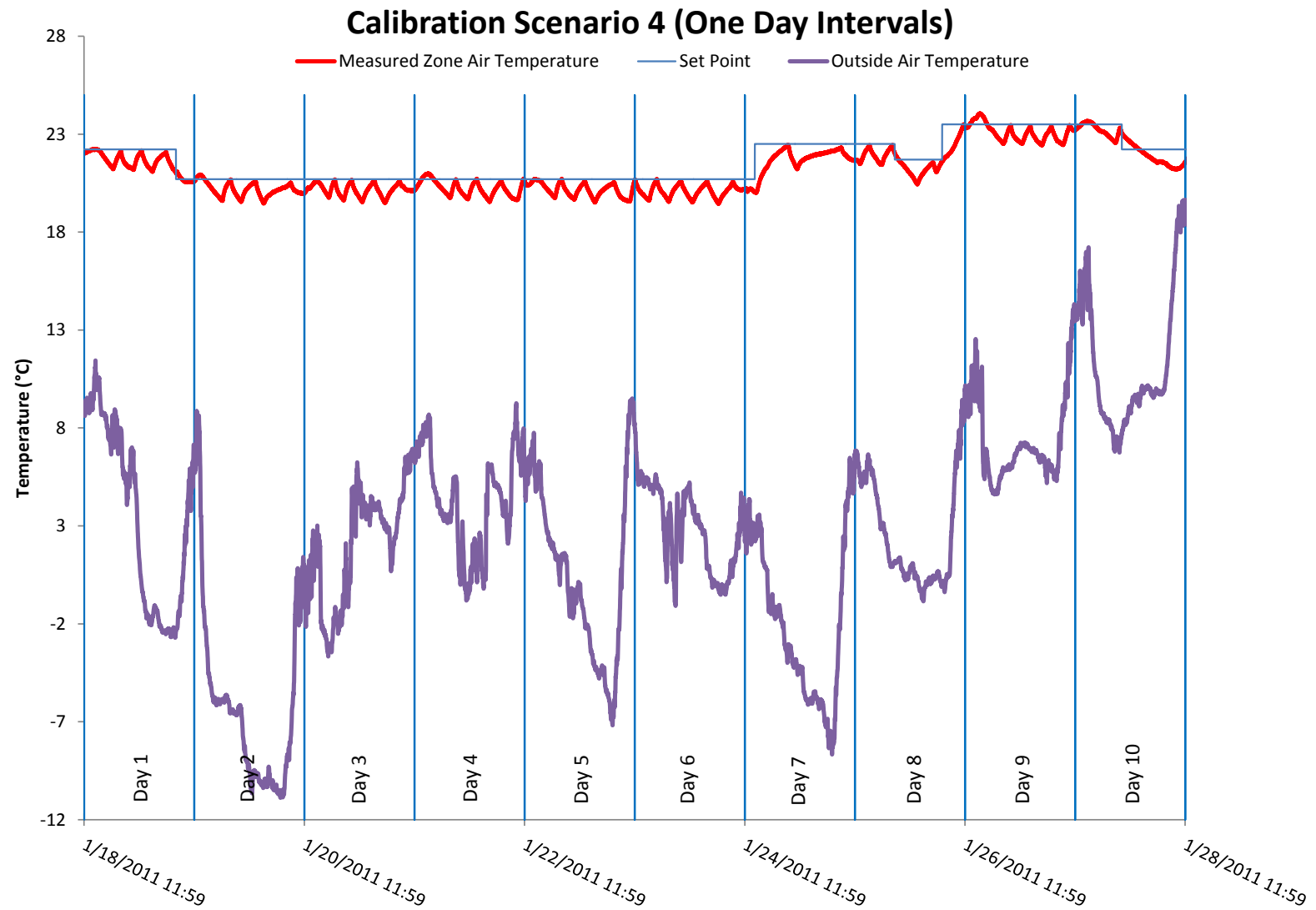


Figure 69: Period of time used for calibration scenario 4a, including temperature information and one day intervals for energy consumption calculation

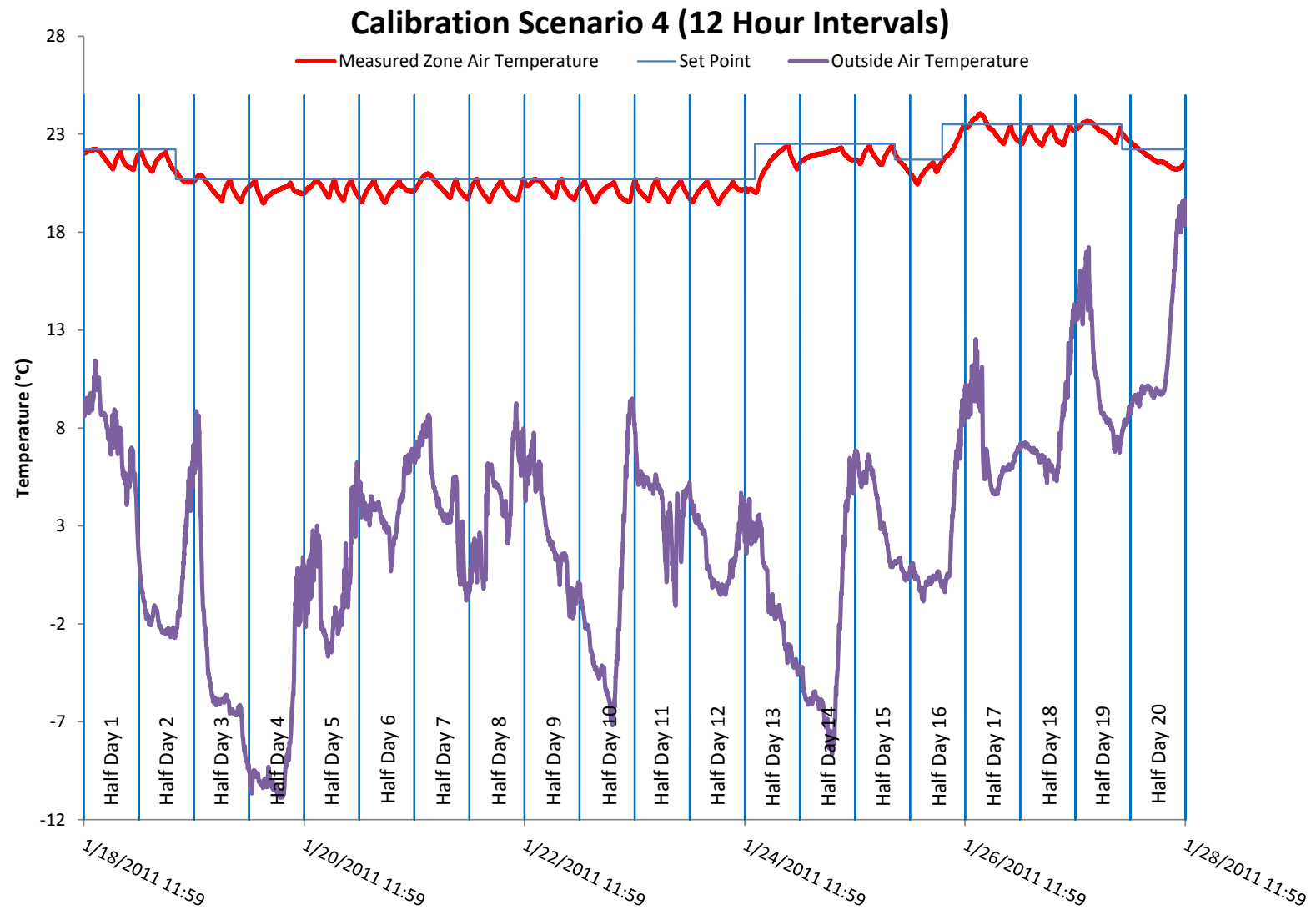


Figure 70: Period of time used for calibration scenario 4b, including temperature information and half day intervals for energy consumption calculation

Table 24 and Table 25 shows the values of the optimized parameters and the RMS error associated with the output from this calibrated model. Figure 71 and Figure 72 shows the measured energy consumption vs. the energy consumption of the calibrated model once the parameters from Table 24 and Table 25 were inputted into the model. Each of the days and half days indicated in Figure 71 and Figure 72 corresponds to the days delineated in Figure 69 and Figure 70. It is easy to see the correlation between days with lower outside air temperatures or higher zone air temperature set point and the energy consumed.

Table 24: Scenario 4a calibrated building envelope parameters for fixed one day intervals

<u>Parameter</u>	<u>Calibrated Value</u>	<u>Units</u>
Mass (each zone)	105	m ²
Wall Insulation	23	R
Roof Insulation	39	R
Window U-Factor	0.76	W/m ² K
Window SHGC	0.59	N/A
Infiltration (each zone)	150	cm ²
% Supply Air to Main Floor	55	%
RMS Error	1.61E+07	J

Table 25: Scenario 4b calibrated building envelope parameters for fixed half day intervals

<u>Parameter</u>	<u>Calibrated Value</u>	<u>Units</u>
Mass (each zone)	184	m ²
Wall Insulation	25	R
Roof Insulation	40	R
Window U-Factor	0.72	W/m ² K
Window SHGC	0.5	N/A
Infiltration (each zone)	158	cm ²
% Supply Air to Main Floor	73	%
RMS Error	1.44E+07	J

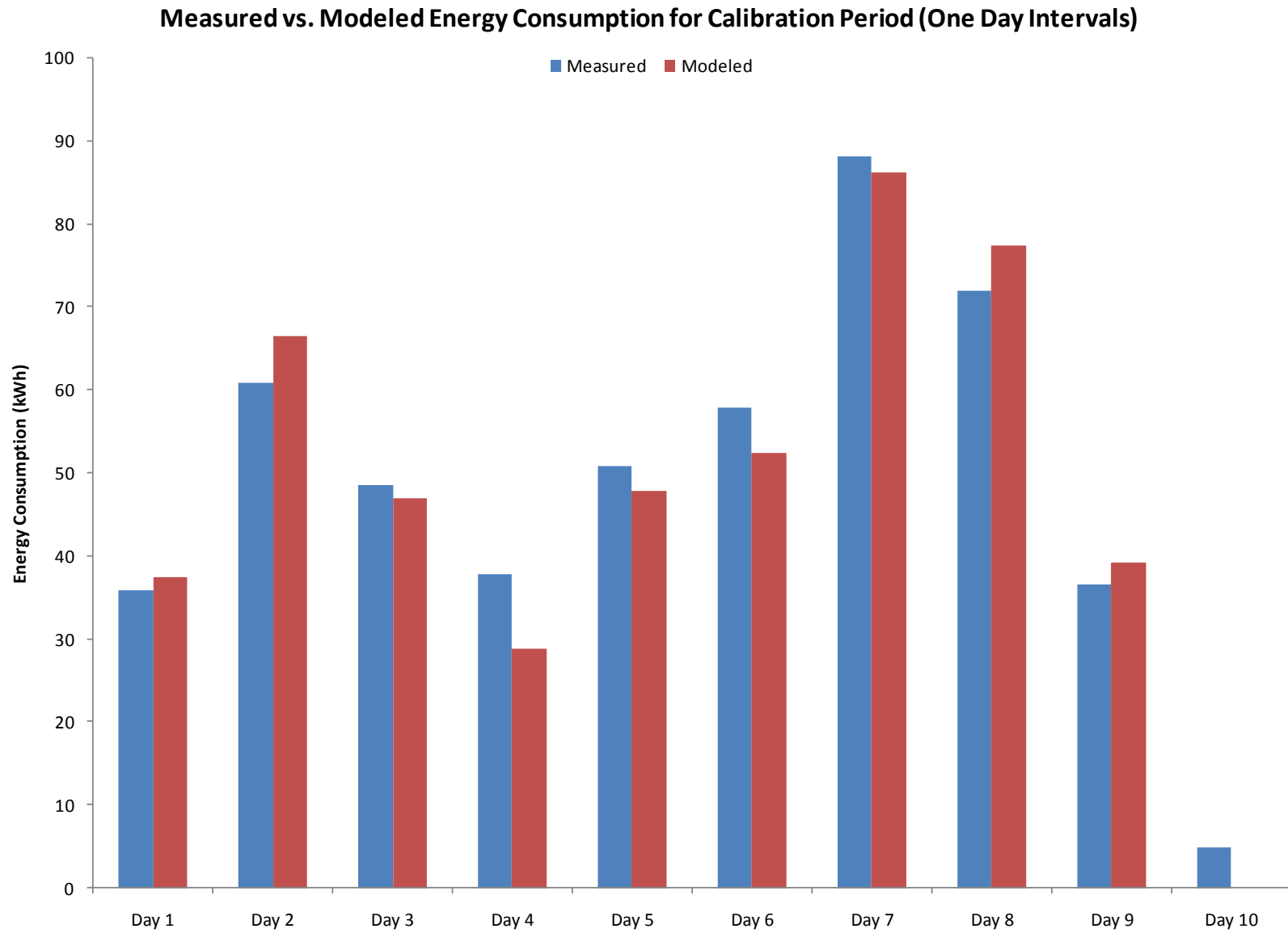


Figure 71: Energy consumption comparison during calibration period using optimized parameters

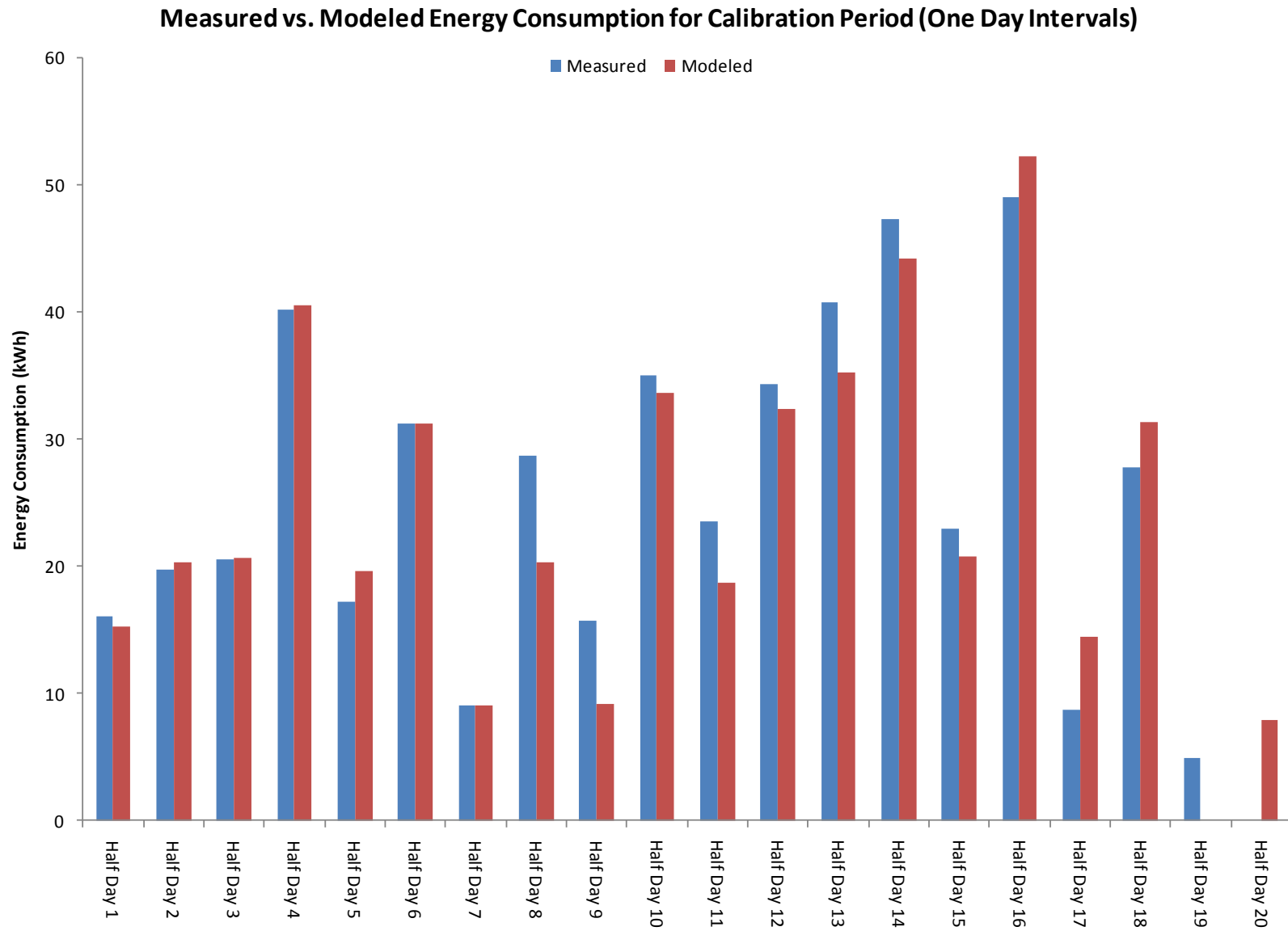


Figure 72: Energy consumption comparison during calibration period using optimized parameters

Table 26 below shows the modeled vs. measured energy consumption, absolute error for the whole period, NMBE and the CV(RSME) for the fixed, one day interval calibration.

Table 26: Modeled vs. measured energy consumption during prediction period for scenario 4a (one day intervals)

Date	Modeled Energy Consumption (J)	Modeled Energy Consumption (kWh)	Measured Energy Consumption (J)	Measured Energy Consumption (kWh)
Interval 1 (2/3 - 2/7)	1100705398	306	988073772	274
Interval 2 (2/8 - 2/12)	1814974686	504	1487459017	413
Interval 3 (2/13 - 2/17)	291719896	81	440348842	122
Interval 4 (2/18 - 2/22)	206382208	57	343816038	96
Interval 5 (2/23 - 3/2)	353377935	98	455335926	126
Interval 6 (3/3 - 3/7)	941391051	261	1009809048	281
Interval 7 (3/8 - 4/9)	616106515	171	484740114	135
Interval 8 (4/11 - 4/15)	608859446	169	552698905	154
Interval 9 (4/16 - 4/20)	164938718	46	137480540	38
Interval 10 (4/21 - 4/25)	479579239	133	402296736	112
Interval 11 (4/26 - 4/30)	266592995	74	318844567	89
Interval 12 (5/1 - 5/5)	406102880	113	316510908	88
Interval 13 (5/17 - 5/21)	477311941	133	395305784	110
Interval 14 (5/22 - 5/26)	136391489	38	134359199	37
Interval 15 (5/27 - 5/31)	0	0	0	0
Total	7864434397	2185	7467079396	2074
Absolute Error	5.3%			
NMBE	5.7%			
CV(RSME)	25.2%			

As in the other scenarios, the results are displayed in a bar-graph format on the following page in Figure 73. Additionally, the modeled zone air temperature vs. measured zone air temperature for the four months of the prediction period is presented in Figure 74 - Figure 77.

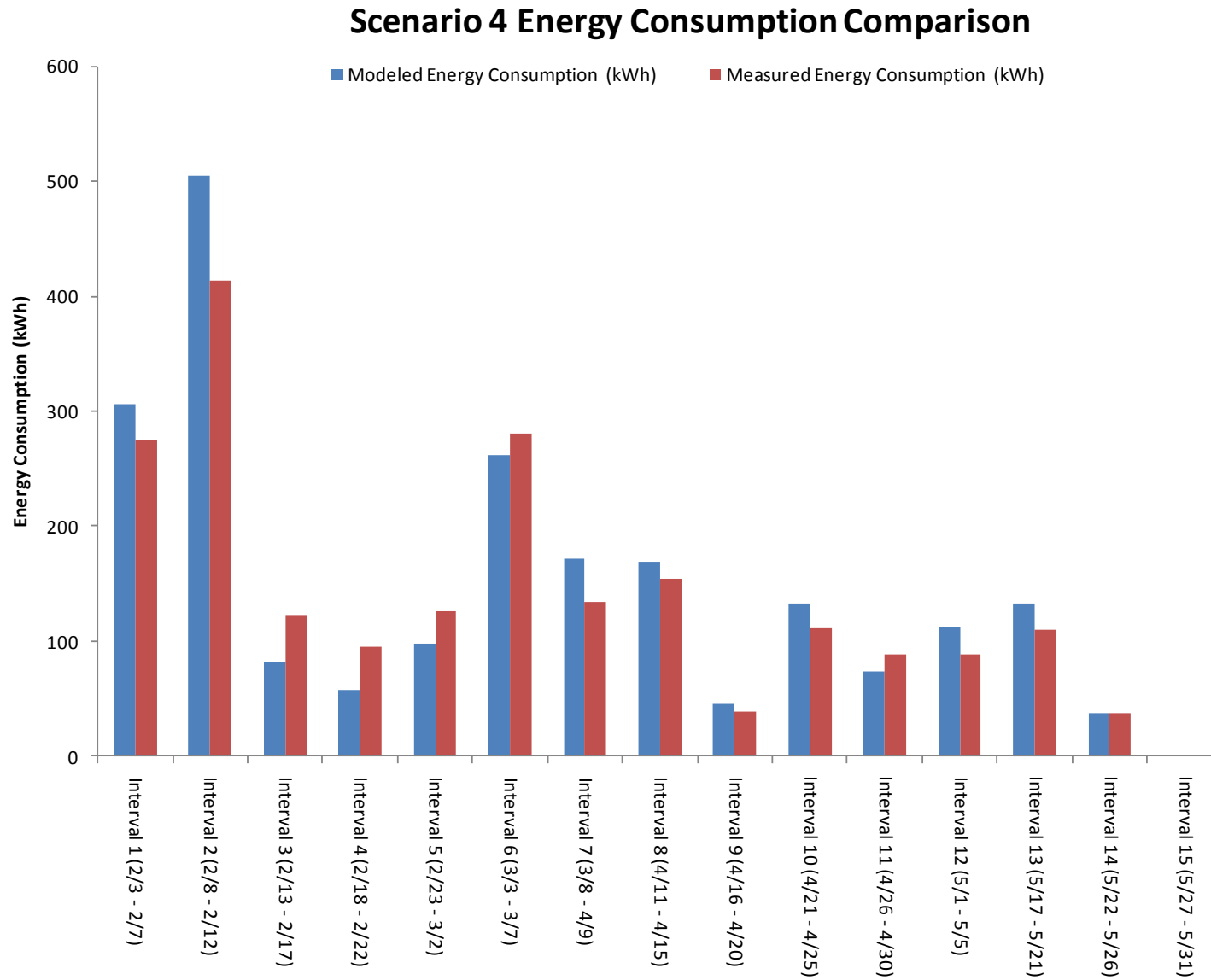


Figure 73: Graphical representation of energy consumption comparison for calibration scenario 4a (one day intervals)

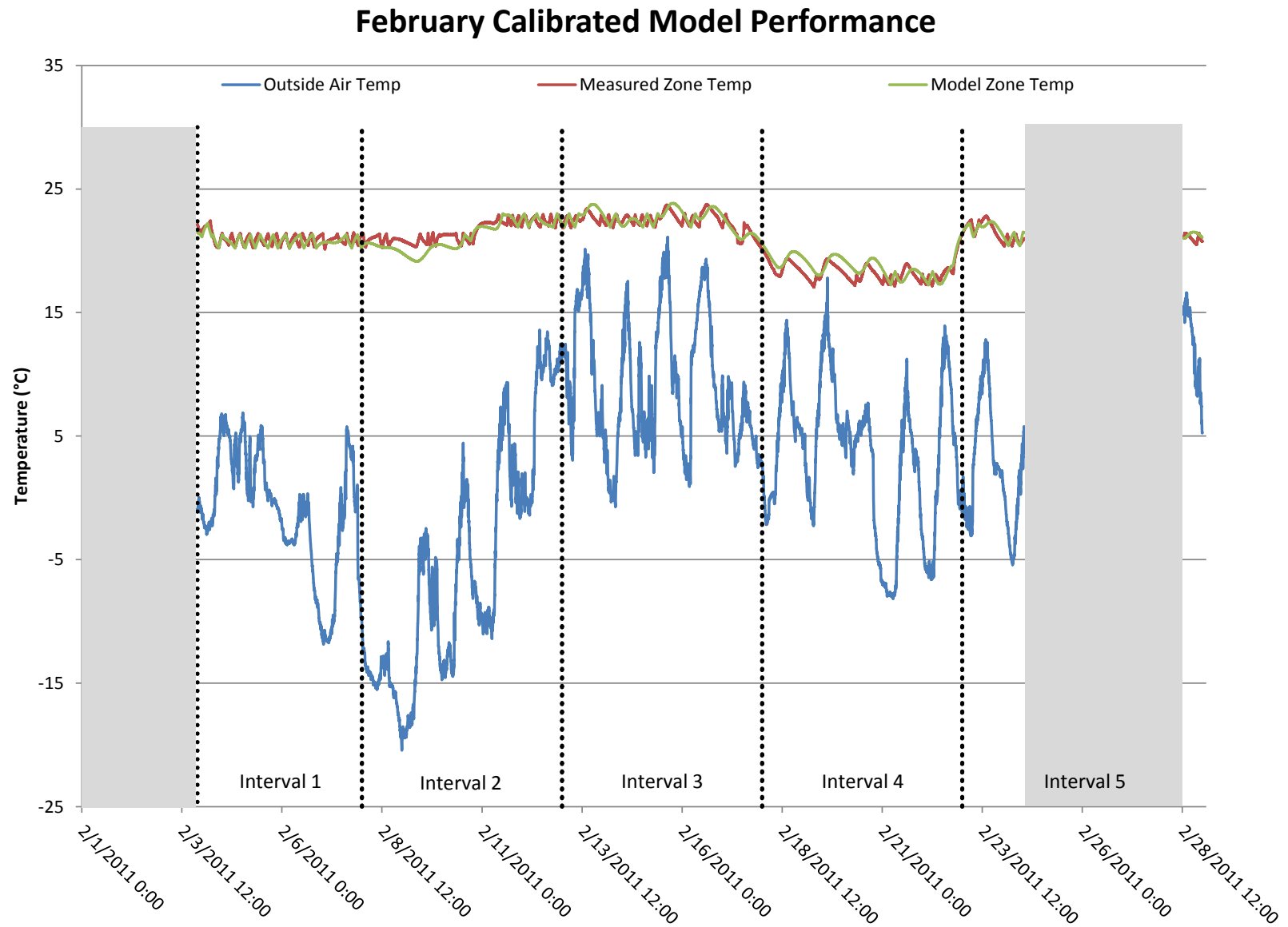


Figure 74: Measured vs. modeled zone air temperatures during February for calibration scenario 4a (one day intervals)

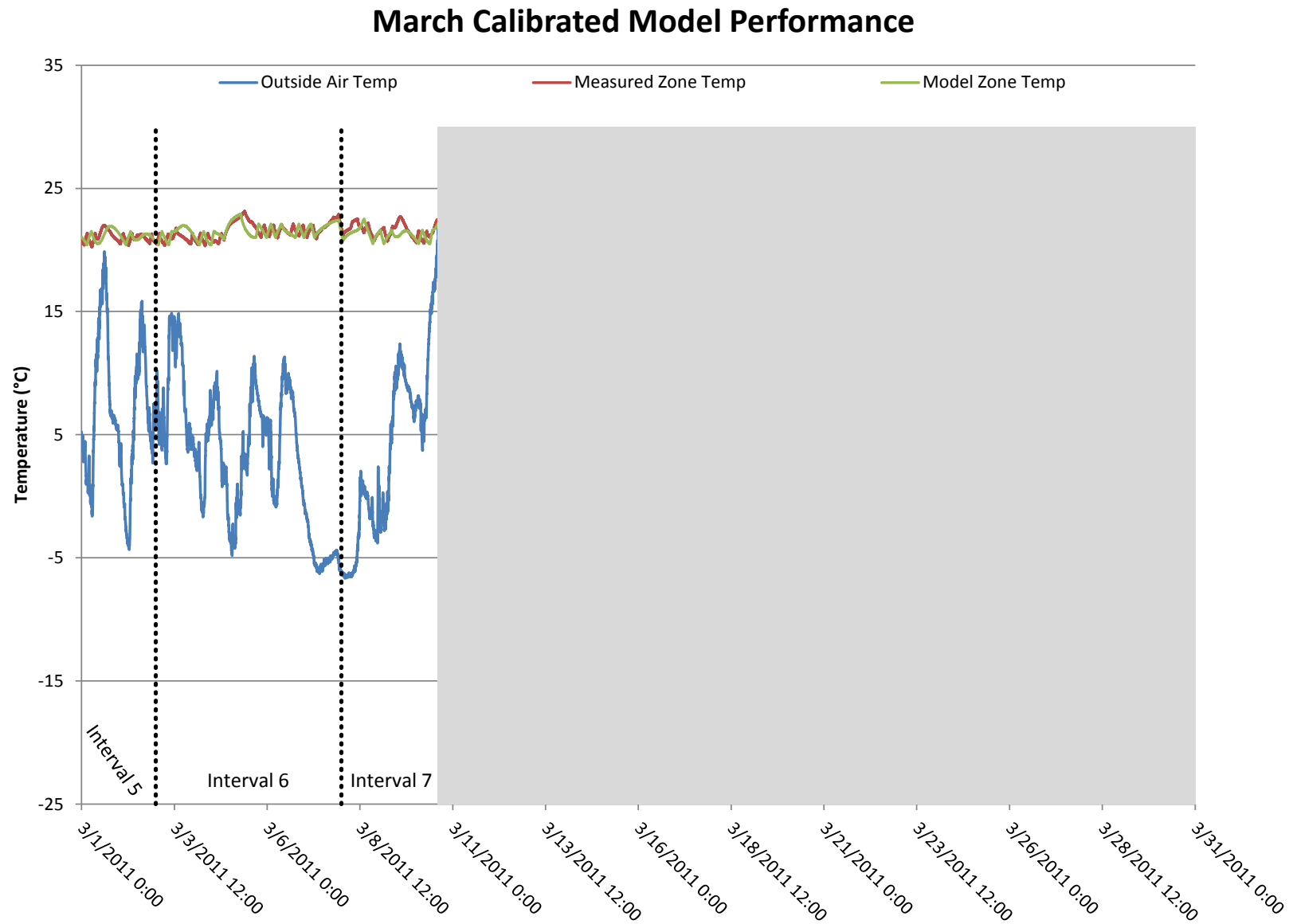


Figure 75: Measured vs. modeled zone air temperatures during March for calibration scenario 4a (one day intervals)

April Calibrated Model Performance

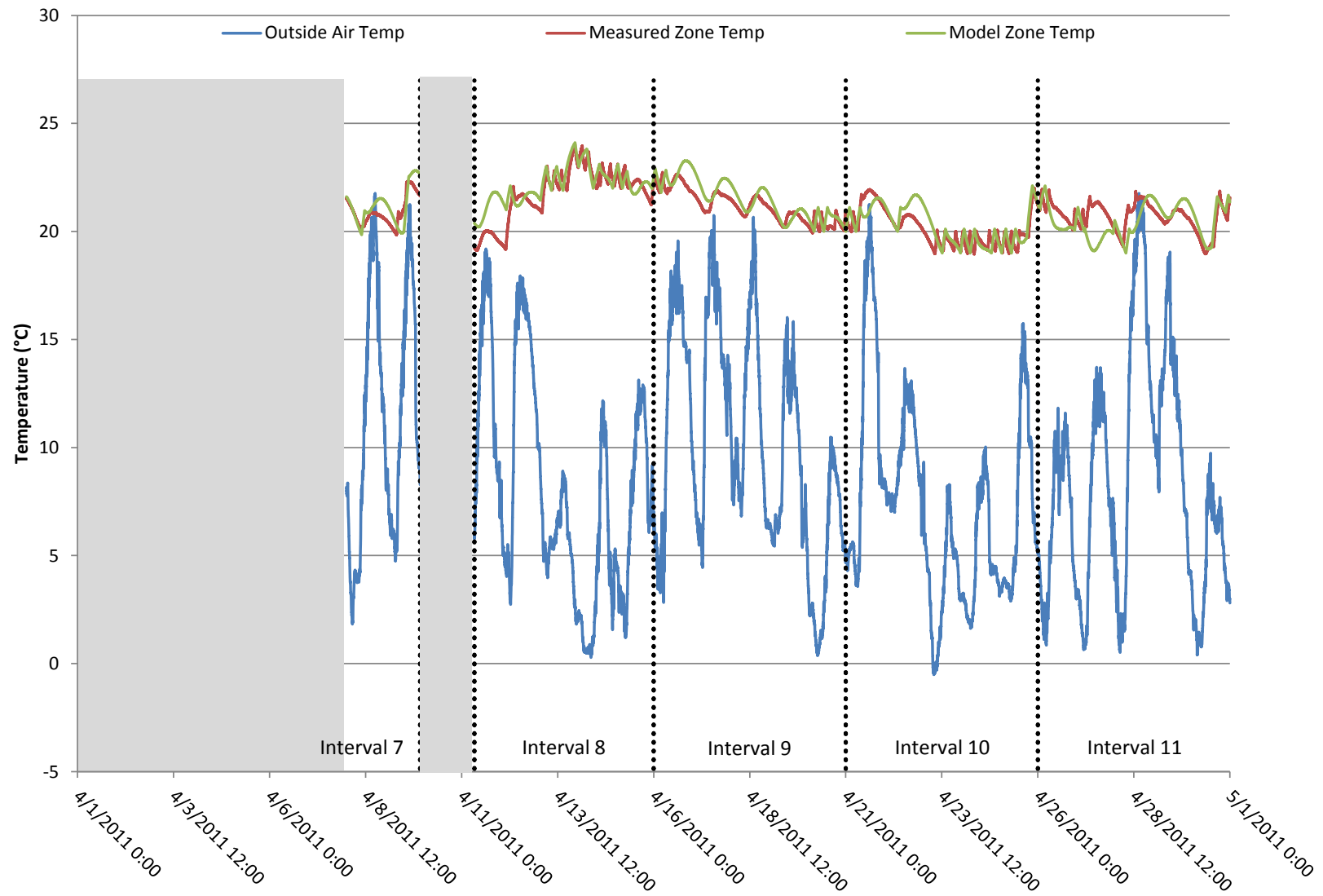


Figure 76: Measured vs. modeled zone air temperatures during April for calibration scenario 4a (one day intervals)

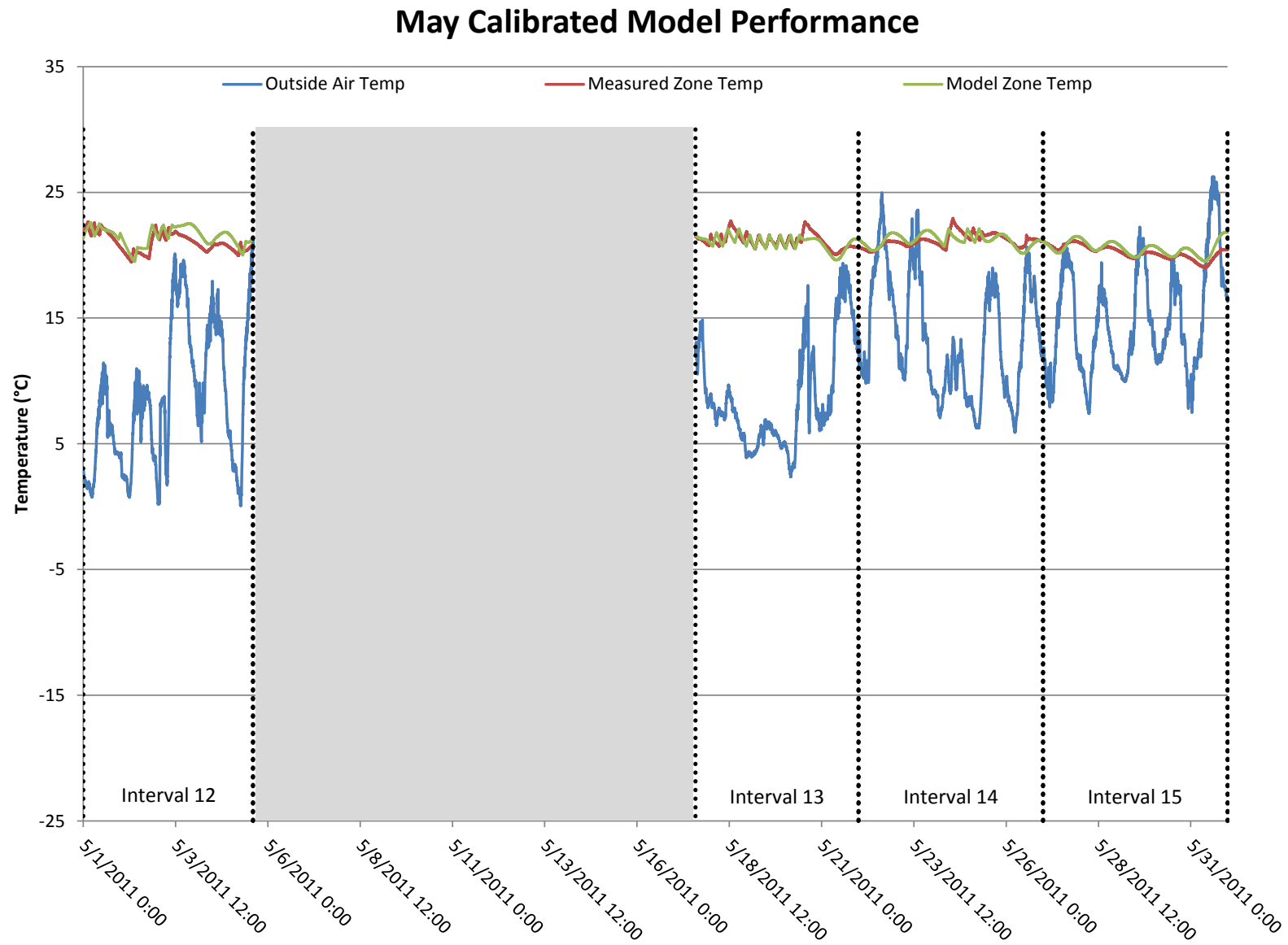


Figure 77: Measured vs. modeled zone air temperatures during May for calibration scenario 4a (one day intervals)

Table 27 below shows the modeled vs. measured energy consumption, absolute error for the whole period, NMBE and the CV(RSME) for the fixed, half day interval calibration.

Table 27: Modeled vs. measured energy consumption during prediction period for scenario 4b (half day intervals)

Date	Modeled Energy Consumption (J)	Modeled Energy Consumption (kWh)	Measured Energy Consumption (J)	Measured Energy Consumption (kWh)
Interval 1 (2/3 - 2/7)	926903112	257	988073772	274
Interval 2 (2/8 - 2/12)	1764750742	490	1487459017	413
Interval 3 (2/13 - 2/17)	324812930	90	440348842	122
Interval 4 (2/18 - 2/22)	232583967	65	343816038	96
Interval 5 (2/23 - 3/2)	350680172	97	455335926	126
Interval 6 (3/3 - 3/7)	889362946	247	1009809048	281
Interval 7 (3/8 - 4/9)	541267057	150	484740114	135
Interval 8 (4/11 - 4/15)	565703393	157	552698905	154
Interval 9 (4/16 - 4/20)	158680857	44	137480540	38
Interval 10 (4/21 - 4/25)	408861323	114	402296736	112
Interval 11 (4/26 - 4/30)	284538969	79	318844567	89
Interval 12 (5/1 - 5/5)	339642044	94	316510908	88
Interval 13 (5/17 - 5/21)	407294737	113	395305784	110
Interval 14 (5/22 - 5/26)	131537636	37	134359199	37
Interval 15 (5/27 - 5/31)	0	0	0	0
Total	7326619885	2035	7467079396	2074
Absolute Error	1.9%			
NMBE	2.0%			
CV(RSME)	19.9%			

As in the other scenarios, the results are displayed in a bar-graph format on the following page in Figure 78. Additionally, the modeled zone air temperature vs. measured zone air temperature for the four months of the prediction period is presented in Figure 79 - Figure 82.

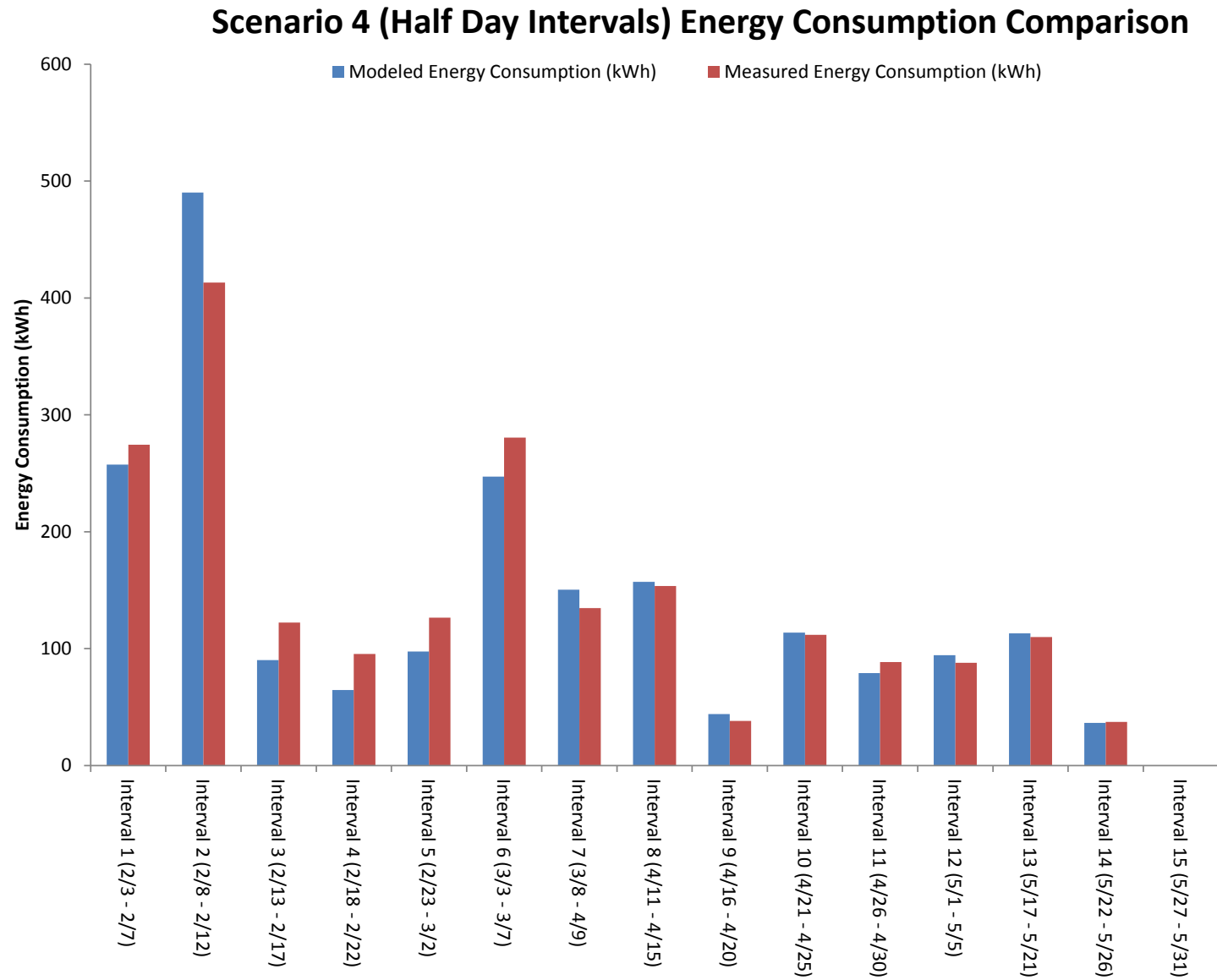


Figure 78: Graphical representation of energy consumption comparison for calibration scenario 4b (half day intervals)

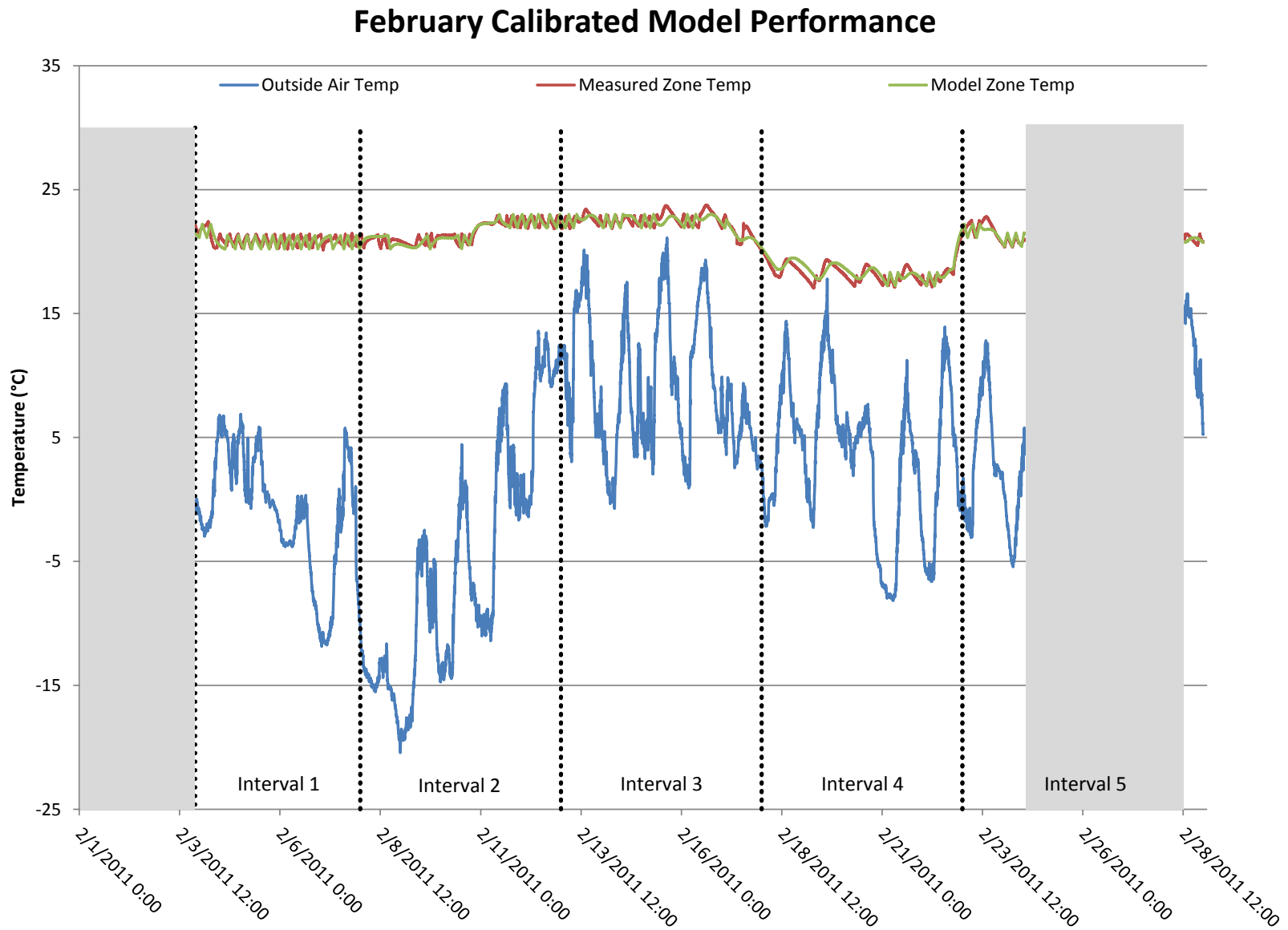


Figure 79: Measured vs. modeled zone air temperatures during February for calibration scenario 4b (half day intervals)

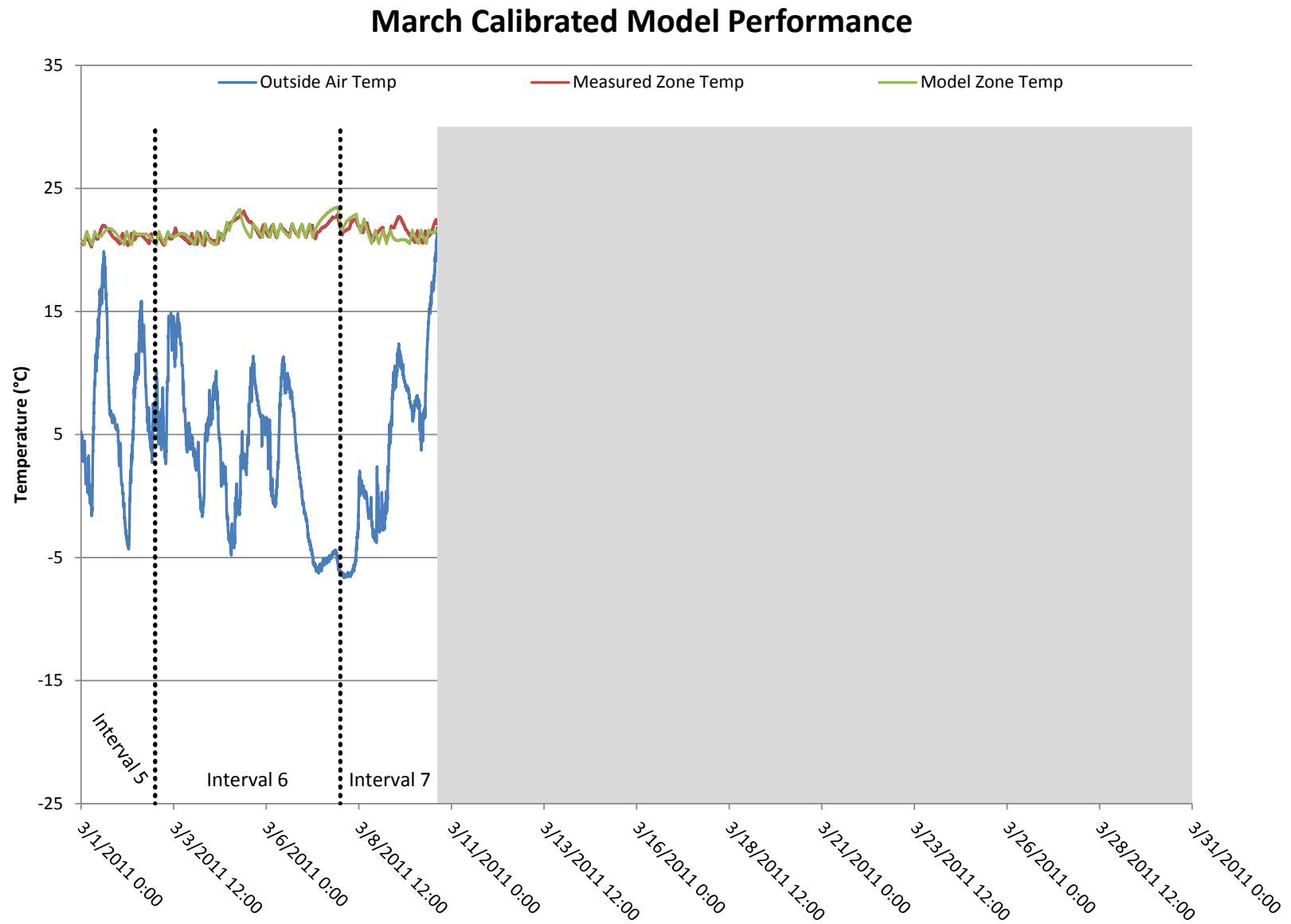


Figure 80: Measured vs. modeled zone air temperatures during March for calibration scenario 4b (half day intervals)

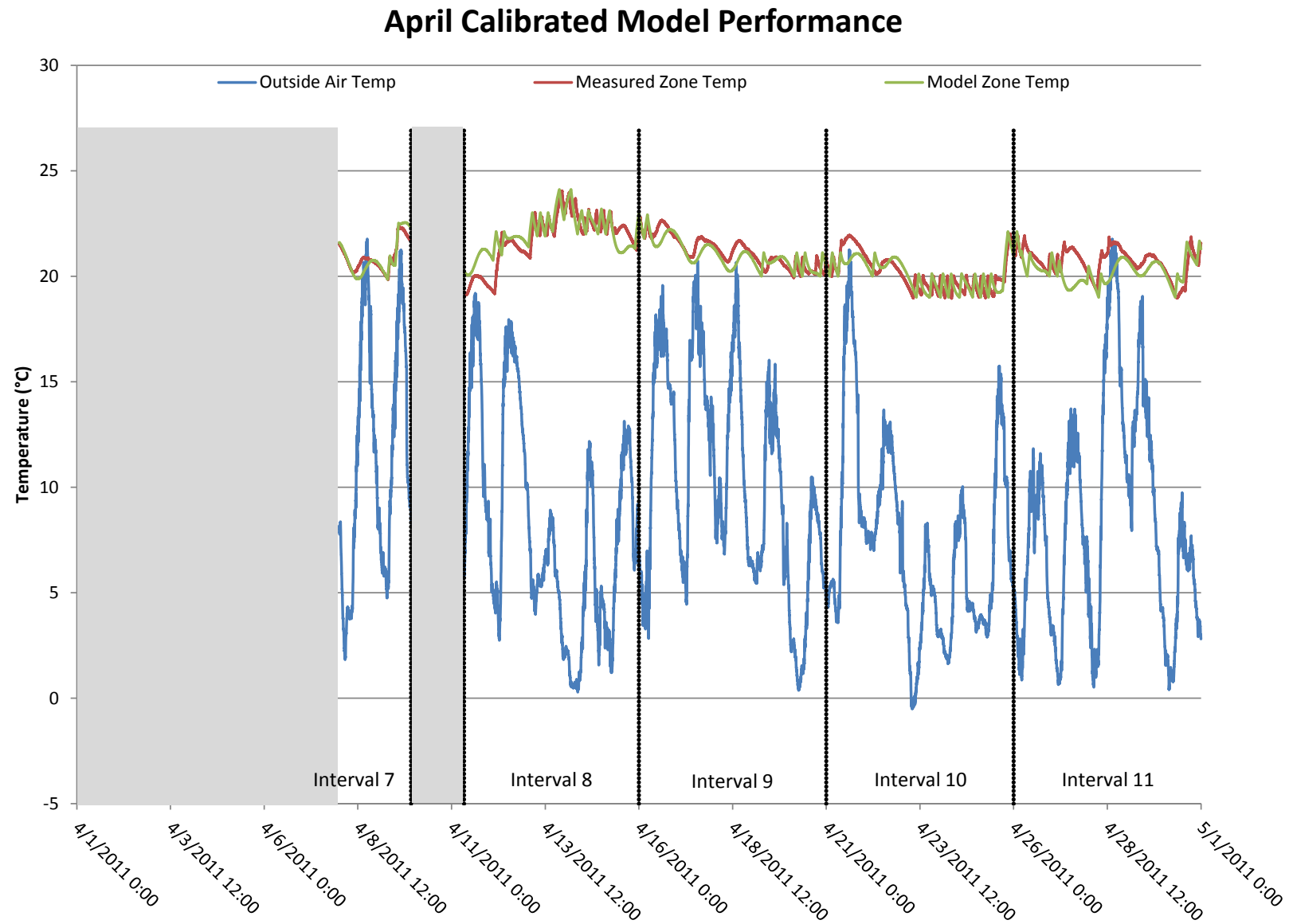


Figure 81: Measured vs. modeled zone air temperatures during April for calibration scenario 4b (half day intervals)

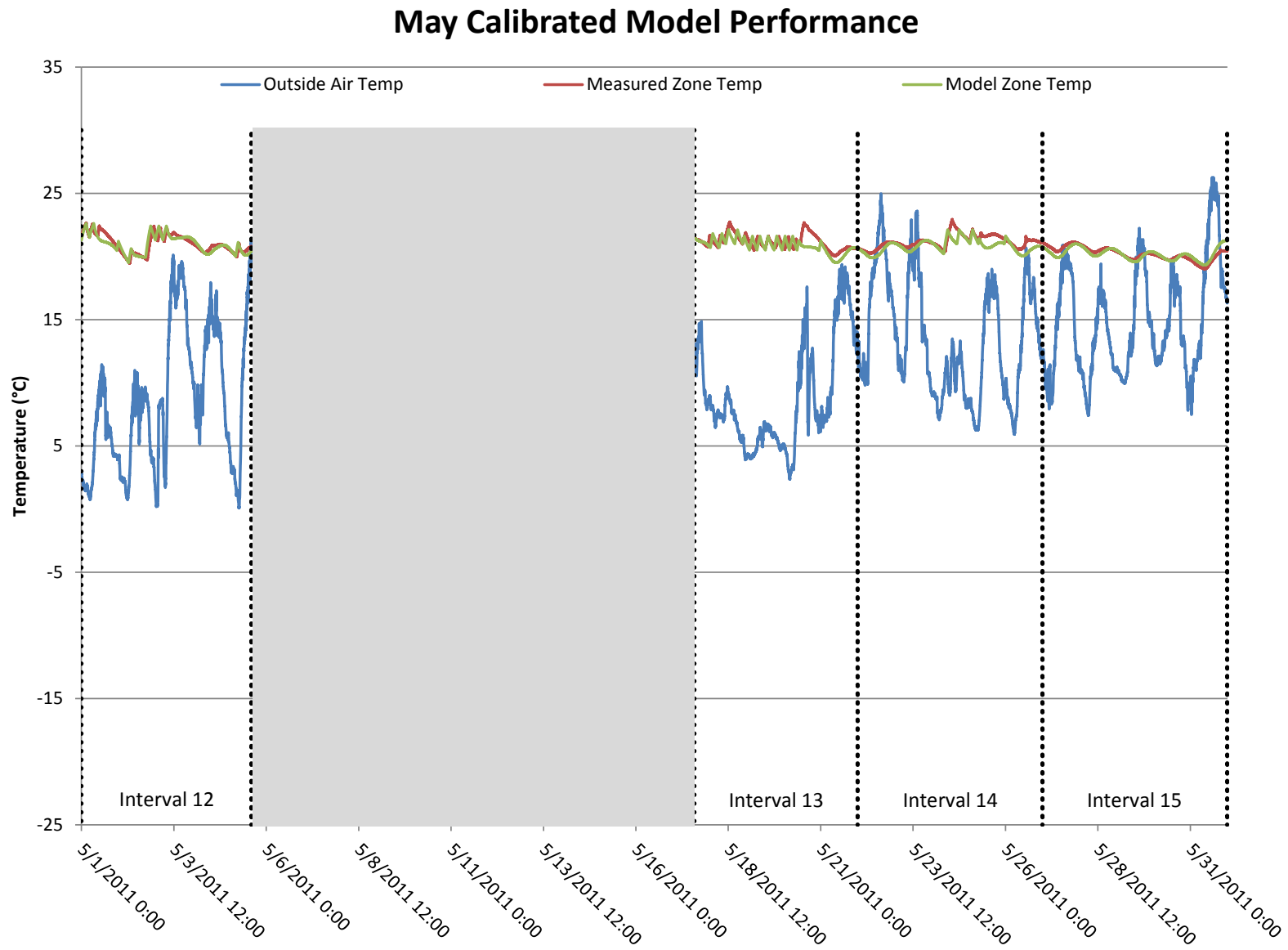


Figure 82: Measured vs. modeled zone air temperatures during May for calibration scenario 4b (half day intervals)

5.2.5 Scenario 5: Energy Consumption Used as Objective Function during Moving One Day Intervals at One Hour Time Steps

Scenario 5 is essentially identical to scenario 4 with one exception. To calculate the RMS error in the objective function in scenario 4 there are 10 data points available (one for each day's energy consumption). Instead of using 10 consecutive fixed, one day periods of time, scenario 5 uses a moving "window" of time that gets computed every hour during the 10 day calibration period. As described in section 4.6.2.2, this method allows for many more data points to be used in calculating the objective function, which may or may not have an impact of the calibrated set of building envelope parameters outputted by the calibration tool. The objective of using the moving intervals is to see if the results change and also to see how those different results are able to predict future energy consumption as compared with the fixed, one day and half day interval calibration. The same 10 day period was used in the calibration as was used in scenario 4 and shown in Figure 69 and the same parameters were inputted into the calibration tool. This calibration was run twice using two different "window" sizes; one day and half day. Table 28 and shows the values of the optimized parameters and the RMS error associated with the output from this calibrated model.

Table 28: Scenario 5a calibrated building envelope parameters (one day windows)

<u>Parameter</u>	<u>Calibrated Value</u>	<u>Units</u>
Mass (each zone)	23	m ²
Wall Insulation	23	R
Roof Insulation	39	R
Window U-Factor	0.78	W/m ² K
Window SHGC	0.55	N/A
Infiltration (each zone)	155	cm ²
% Supply Air to Main Floor	61	%
RMS Error	2.91E+07	J

Table 29: Scenario 5b calibrated building envelope parameters (half day windows)

<u>Parameter</u>	<u>Calibrated Value</u>	<u>Units</u>
Mass (each zone)	173	m ²
Wall Insulation	21	R
Roof Insulation	37	R
Window U-Factor	0.98	W/m ² K
Window SHGC	0.69	N/A
Infiltration (each zone)	157	cm ²
% Supply Air to Main Floor	67	%
RMS Error	2.40E+07	J

There is really no meaningful graphical means to display how well the final calibrated model lines up with the energy consumption during the calibration period since the energy is being calculated over 200 times for each hour of the simulation. Other than providing the RMS error in Joules as shown in Table 28 and Table 29, it may be useful to state that the total error between the modeled and measured energy consumption during the calibration period for the calibrated model is 3.6% for one day windows and 1.64% for half day windows.

Table 30 below shows the modeled vs. measured energy consumption, error for the whole period, NMBE and the CV(RMSE) for the moving one day interval.

Table 30: Modeled vs. measured energy consumption during prediction period for scenario 5a (one day window)

Date	Modeled Energy Consumption (J)	Modeled Energy Consumption (kWh)	Measured Energy Consumption (J)	Measured Energy Consumption (kWh)
Interval 1 (2/3 - 2/7)	1088916414	302	988073772	274
Interval 2 (2/8 - 2/12)	1765141238	490	1487459017	413
Interval 3 (2/13 - 2/17)	296928387	82	440348842	122
Interval 4 (2/18 - 2/22)	268992175	75	343816038	96
Interval 5 (2/23 - 3/2)	345092755	96	455335926	126
Interval 6 (3/3 - 3/7)	938852130	261	1009809048	281
Interval 7 (3/8 - 4/9)	606499375	168	484740114	135
Interval 8 (4/11 - 4/15)	603804082	168	552698905	154
Interval 9 (4/16 - 4/20)	204860414	57	137480540	38
Interval 10 (4/21 - 4/25)	460149522	128	402296736	112
Interval 11 (4/26 - 4/30)	295809664	82	318844567	89
Interval 12 (5/1 - 5/5)	394406525	110	316510908	88
Interval 13 (5/17 - 5/21)	451316412	125	395305784	110
Interval 14 (5/22 - 5/26)	124997571	35	134359199	37
Interval 15 (5/27 - 5/31)	0	0	0	0
Total	7845766664	2179	7467079396	2074
Absolute Error	5.1%			
NMBE	5.4%			
CV(RSME)	21.9%			

As in the other scenarios, the results are displayed in a bar-graph format on the following page in Figure 83. Additionally, the modeled zone air temperature vs. measured zone air temperature for the four months of the prediction period is presented in Figure 84 - Figure 87.

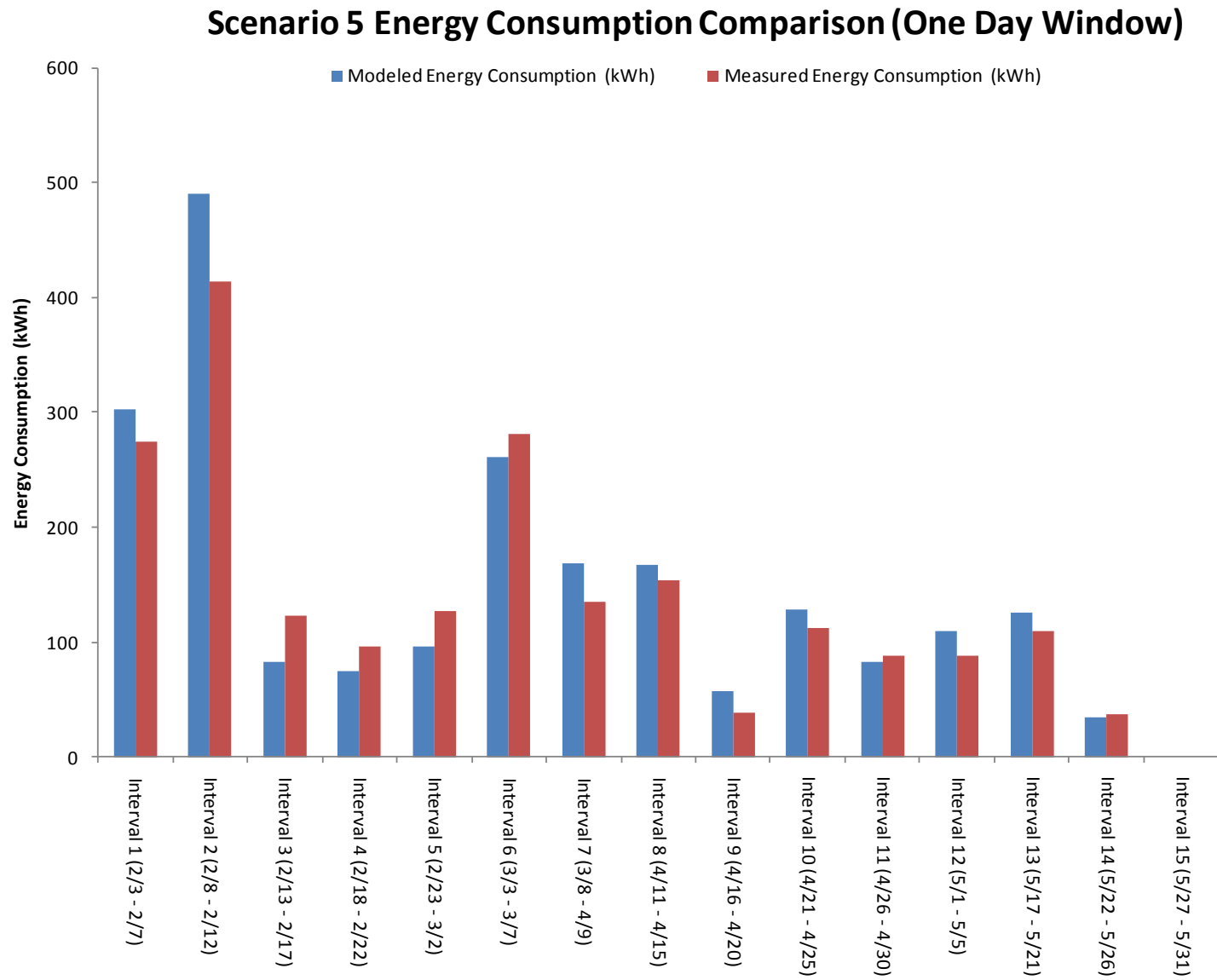


Figure 83: Graphical representation of energy consumption comparison for calibration scenario 5a (one day window)

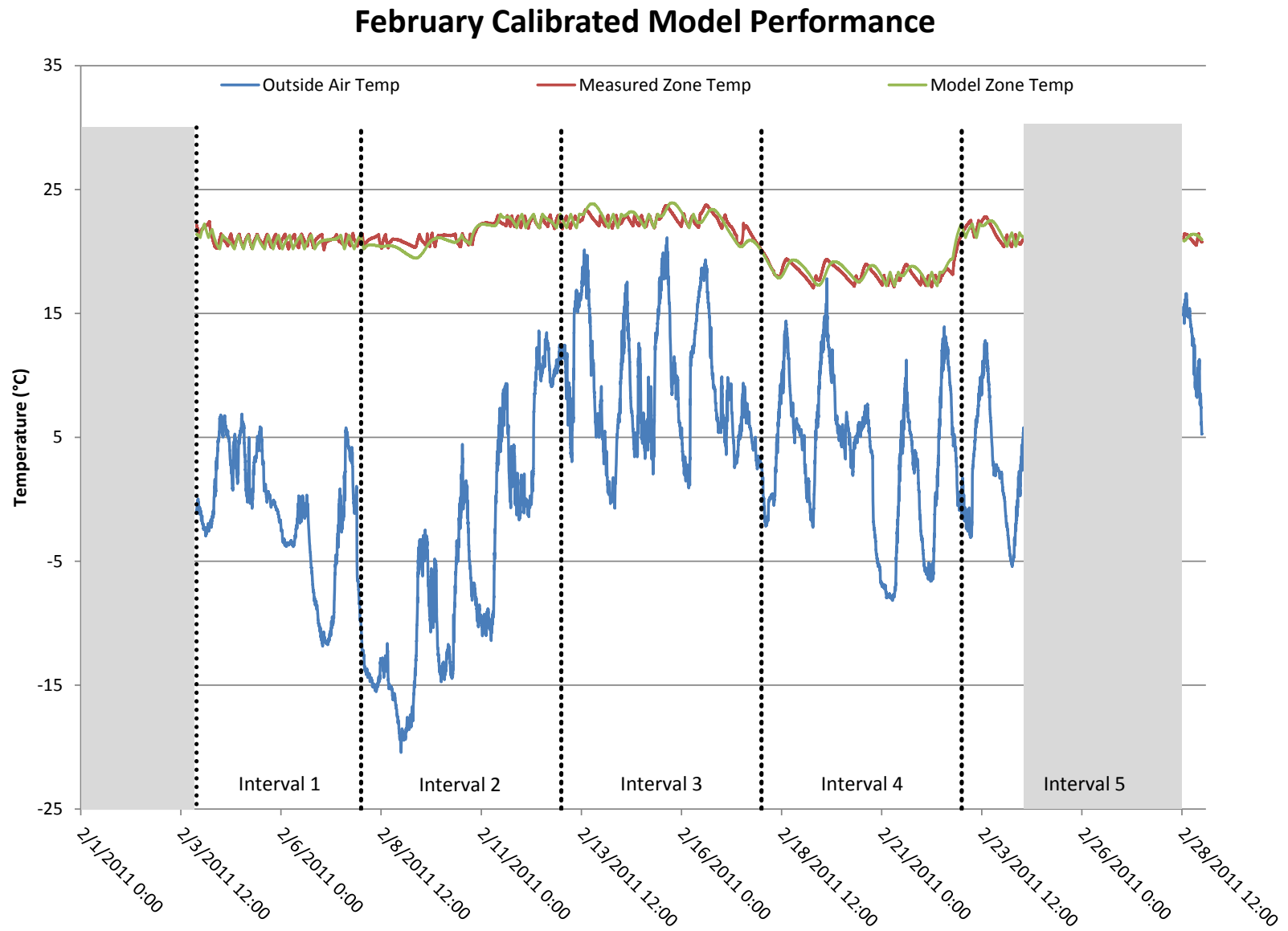


Figure 84: Measured vs. modeled zone air temperatures during February for calibration scenario 5a (one day window)

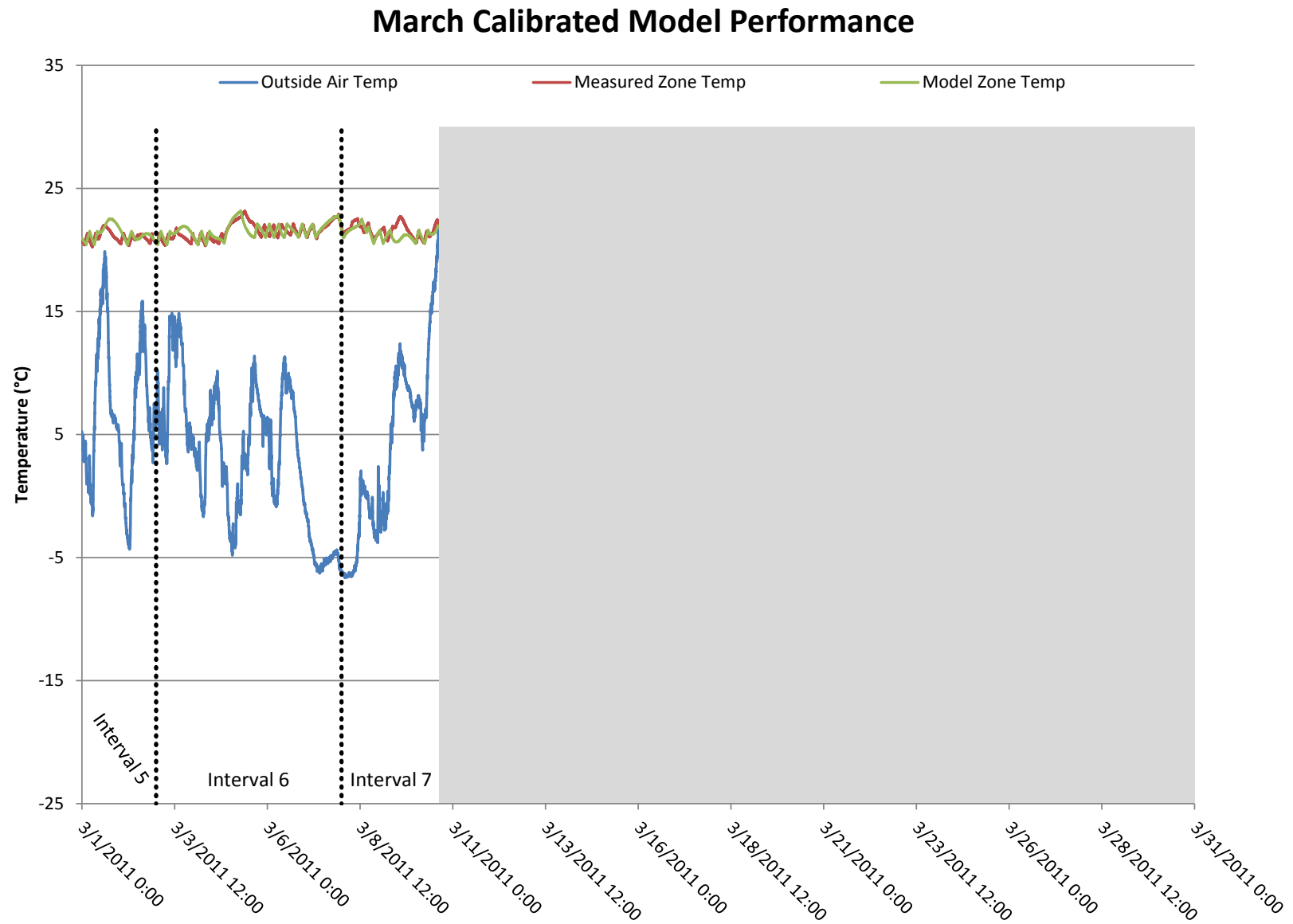


Figure 85: Measured vs. modeled zone air temperatures during March for calibration scenario 5a (one day window)

April Calibrated Model Performance

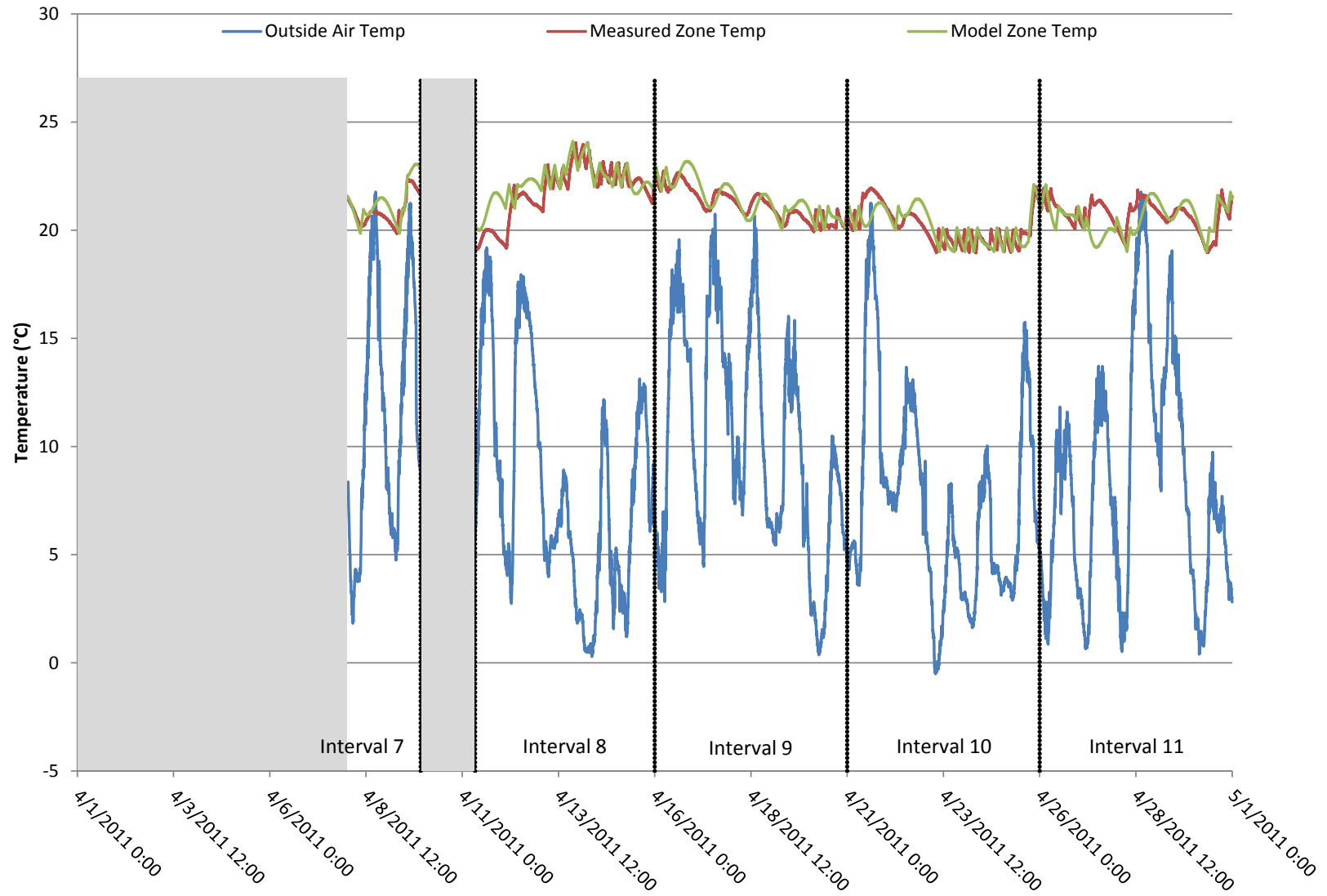


Figure 86: Measured vs. modeled zone air temperatures during April for calibration scenario 5a (one day window)

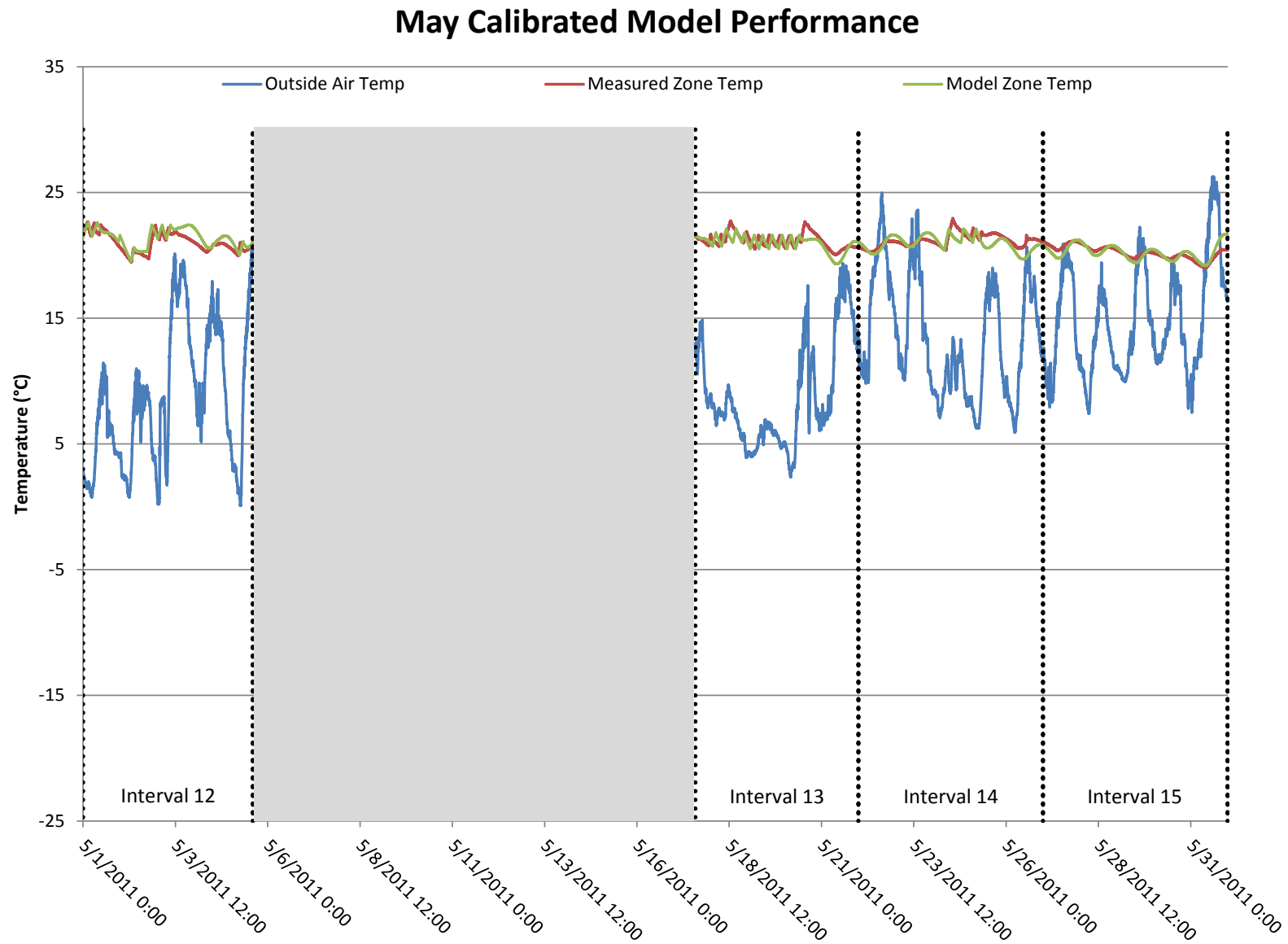


Figure 87: Measured vs. modeled zone air temperatures during May for calibration scenario 5a (one day window)

Table 31 below shows the modeled vs. measured energy consumption, error for the whole period, NMBE and the CV(RMSE) for the moving half day interval.

Table 31: Modeled vs. measured energy consumption during prediction period for scenario 5b (half day window)

Date	Modeled Energy Consumption (J)	Modeled Energy Consumption (kWh)	Measured Energy Consumption (J)	Measured Energy Consumption (kWh)
Interval 1 (2/3 - 2/7)	1051697257	292	988073772	274
Interval 2 (2/8 - 2/12)	1819552554	505	1487459017	413
Interval 3 (2/13 - 2/17)	272638488	76	440348842	122
Interval 4 (2/18 - 2/22)	175743803	49	343816038	96
Interval 5 (2/23 - 3/2)	300441253	83	455335926	126
Interval 6 (3/3 - 3/7)	882753961	245	1009809048	281
Interval 7 (3/8 - 4/9)	583351048	162	484740114	135
Interval 8 (4/11 - 4/15)	549320094	153	552698905	154
Interval 9 (4/16 - 4/20)	130044172	36	137480540	38
Interval 10 (4/21 - 4/25)	411686840	114	402296736	112
Interval 11 (4/26 - 4/30)	247027941	69	318844567	89
Interval 12 (5/1 - 5/5)	344437604	96	316510908	88
Interval 13 (5/17 - 5/21)	444714176	124	395305784	110
Interval 14 (5/22 - 5/26)	98310615	27	134359199	37
Interval 15 (5/27 - 5/31)	0	0	0	0
Total	7311719807	2031	7467079396	2074
Absolute Error	2.1%			
NMBE	2.2%			
CV(RSME)	25.8%			

As in the other scenarios, the results are displayed in a bar-graph format on the following page in Figure 88. Additionally, the modeled zone air temperature vs. measured zone air temperature for the four months of the prediction period is presented in Figure 89 - Figure 92.

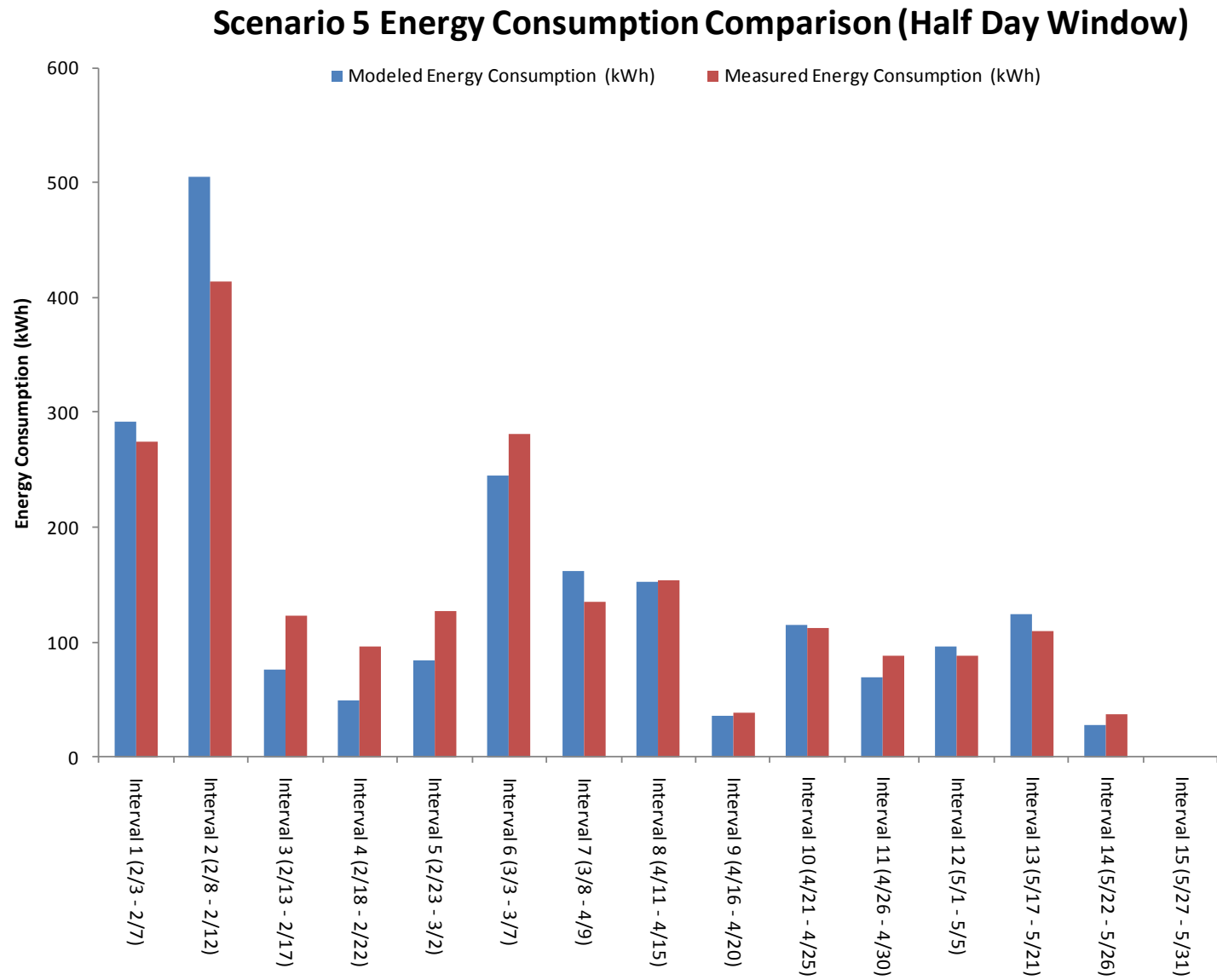


Figure 88: Graphical representation of energy consumption comparison for calibration scenario 5b (half day window)

February Calibrated Model Performance

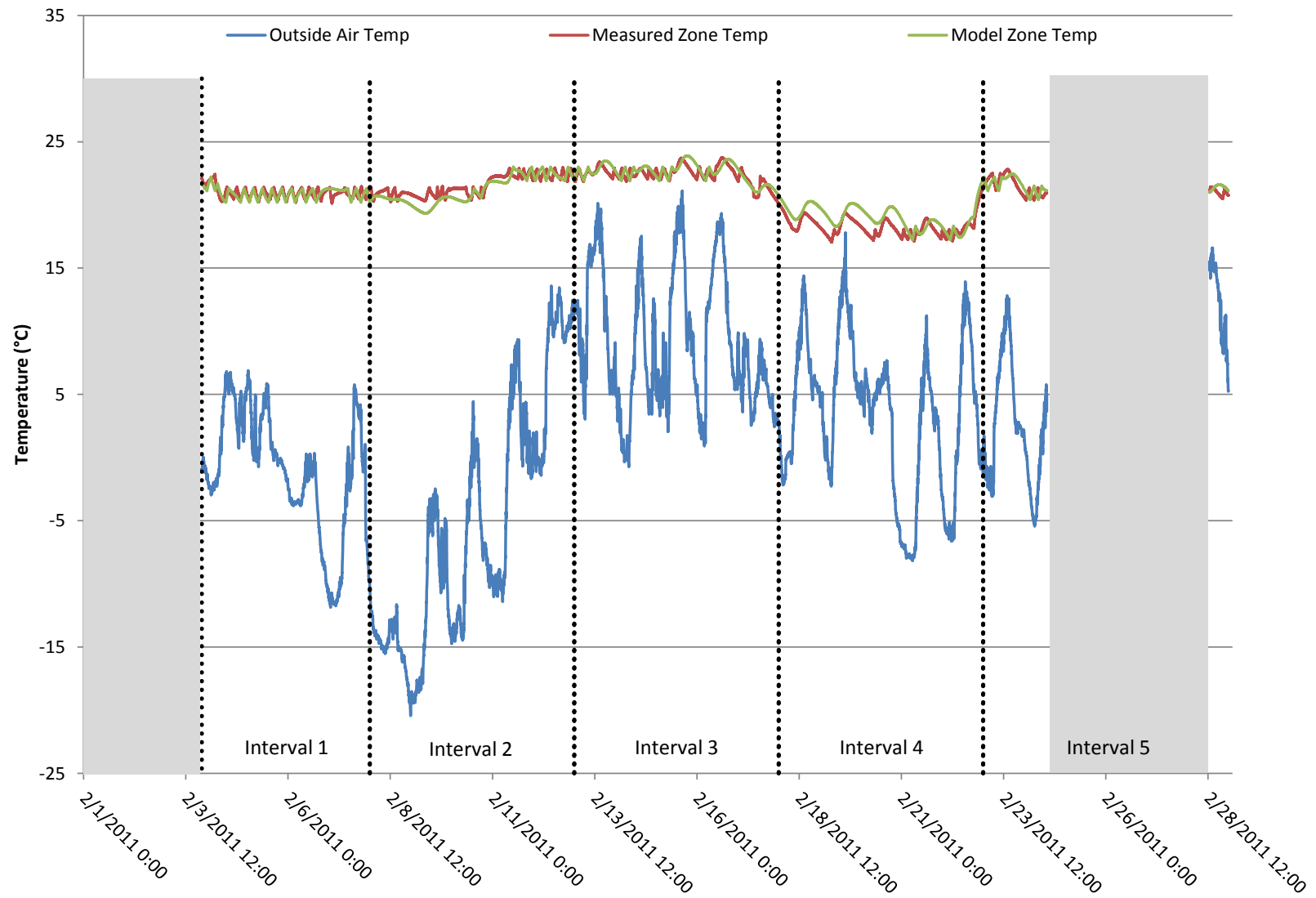


Figure 89: Measured vs. modeled zone air temperatures during February for calibration scenario 5b (half day window)

March Calibrated Model Performance

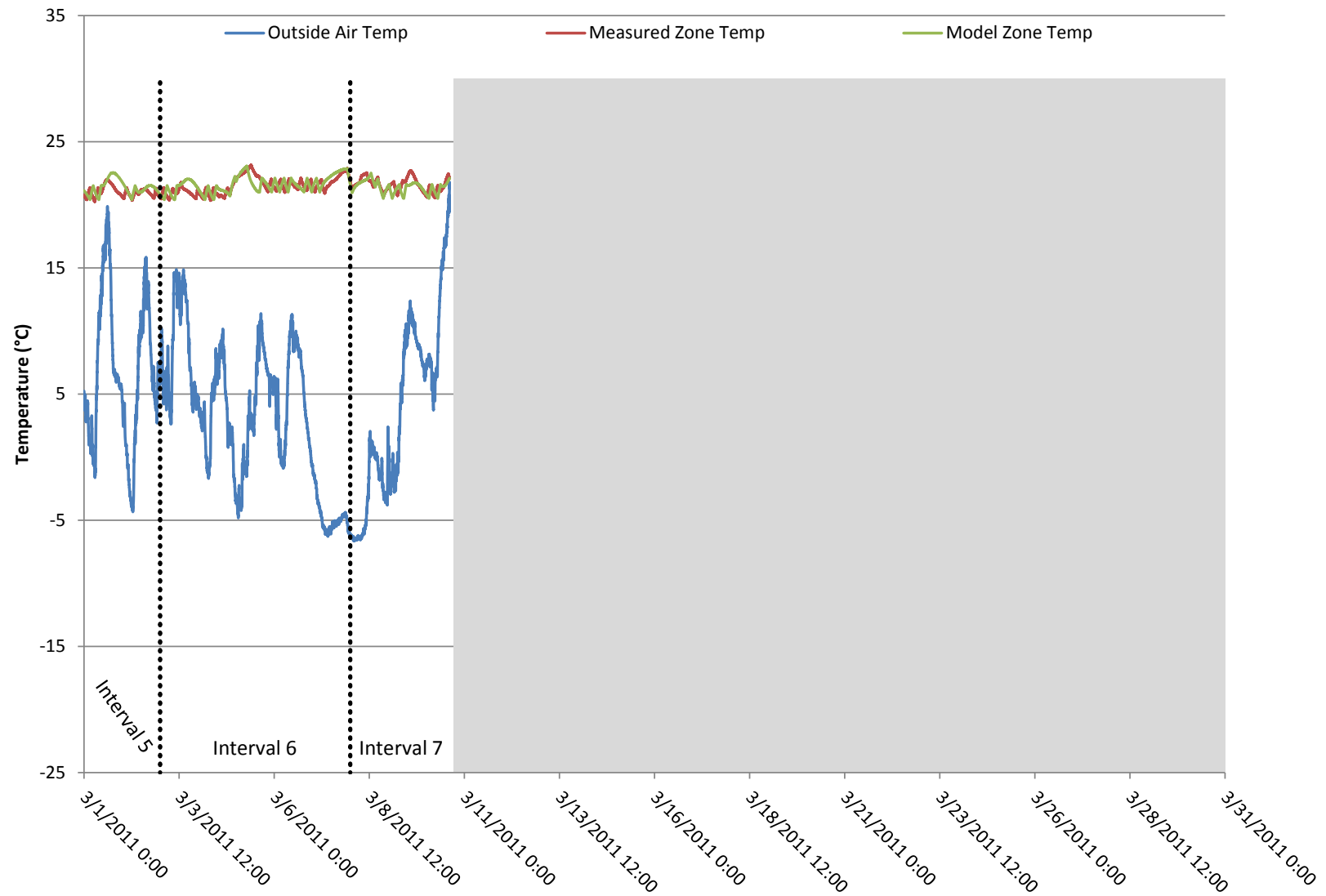


Figure 90: Measured vs. modeled zone air temperatures during March for calibration scenario 5b (half day window)

April Calibrated Model Performance

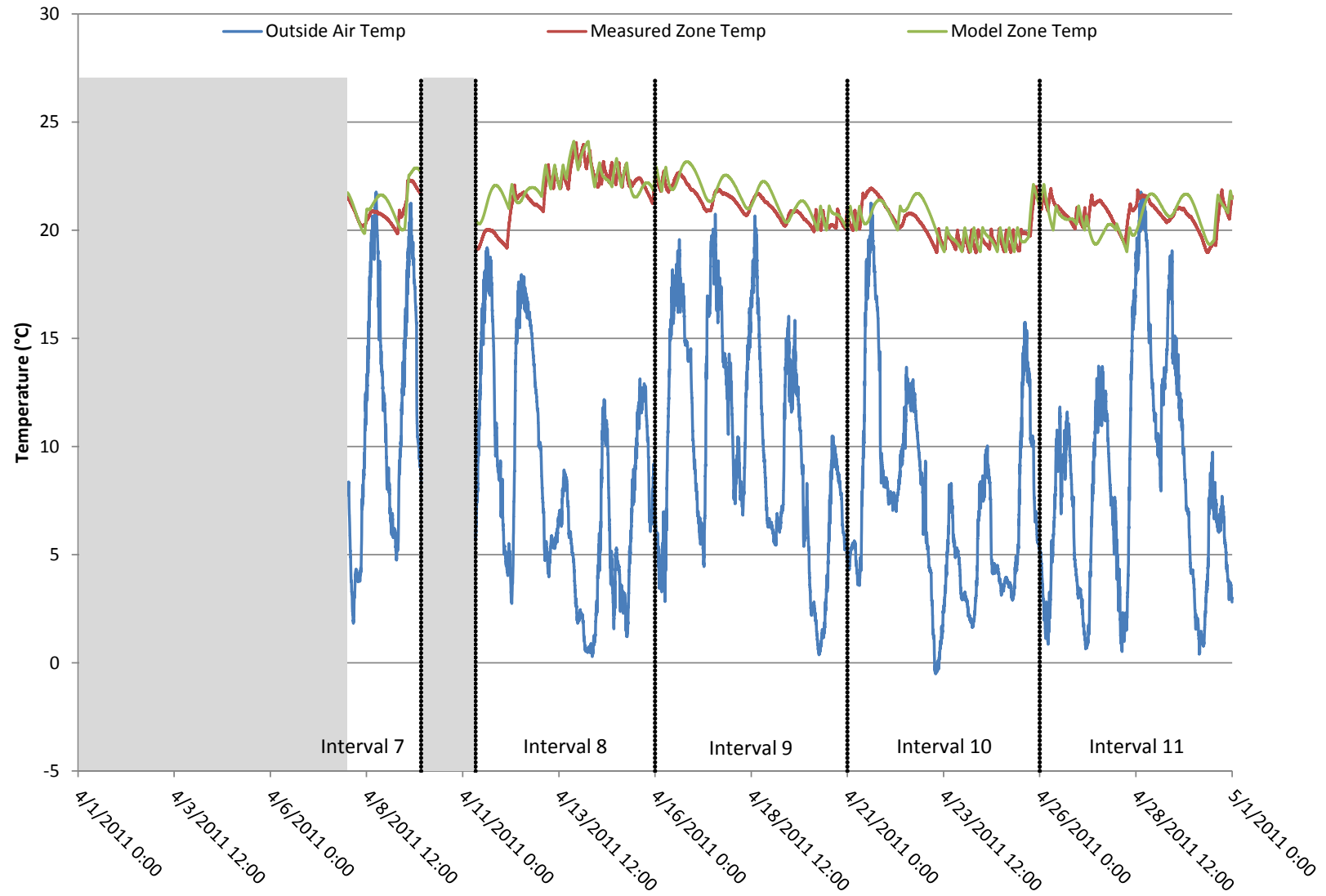


Figure 91: Measured vs. modeled zone air temperatures during April for calibration scenario 5b (half day window)

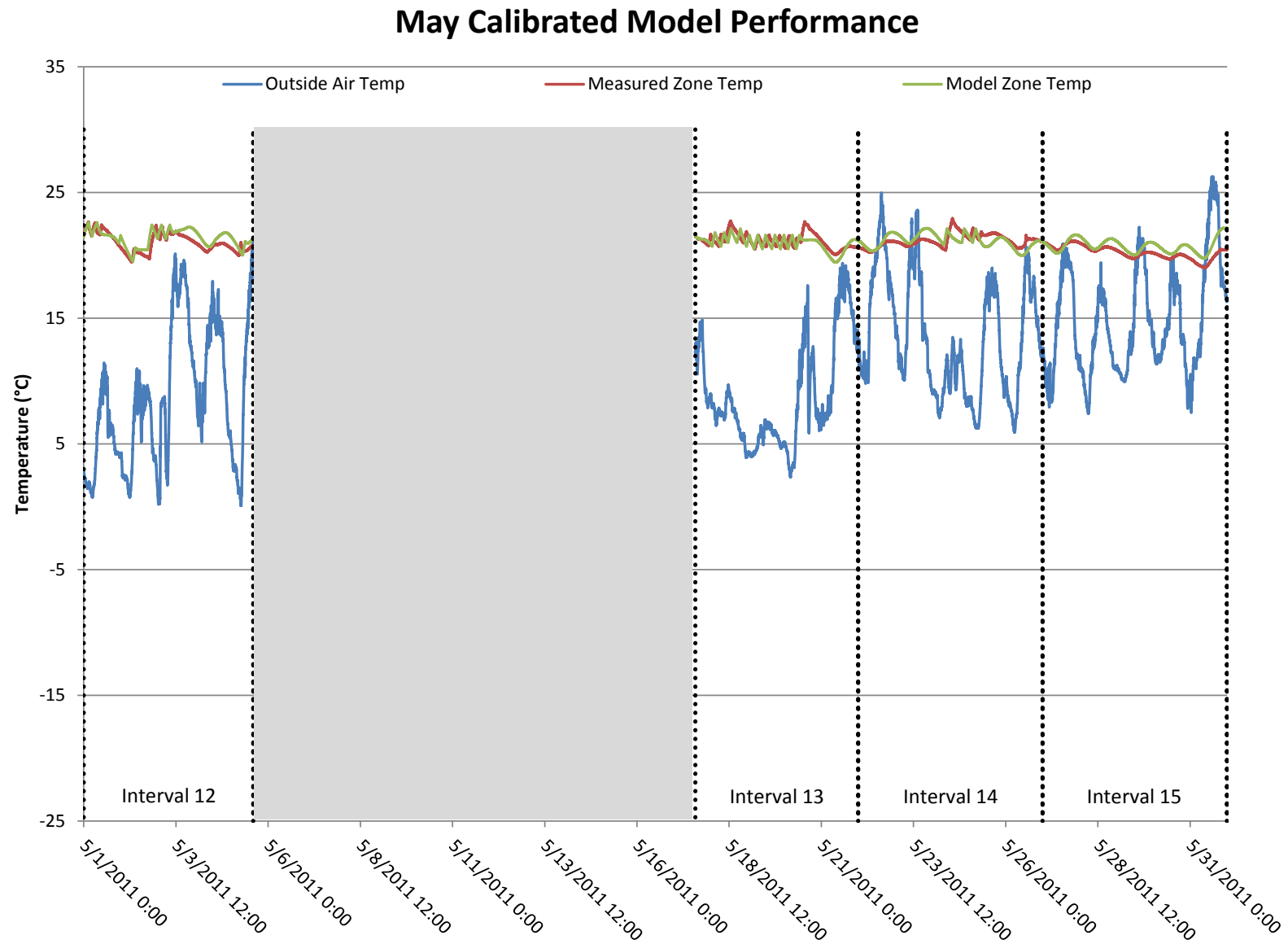


Figure 92: Measured vs. modeled zone air temperatures during May for calibration scenario 5b (half day window)

5.3 Calibration Scenario Comparison

The previous sections detail several different approaches to calibrating the energy model using measured data. After being run in the calibration tool, each of these different techniques produce a different set of optimized or calibrated building envelope parameters. These calibrated parameters were then entered into the energy model and each case was run for the prediction period of the study to determine how well each model was able to match the measured energy consumption of the building during the same time period. Table 32 contains a summary of all of the values for each scenario as well as the absolute error over the entire prediction period, the NMBE, and the CV(RMSE) using the 5 day intervals during the prediction period between the measured and predicted building energy consumption.

Table 32: Calibrated building envelope parameters and associated performance for each calibration scenario

Parameter	Units	Uncalibrated Model	Scenario 1	Scenario 2	Scenario 3	Scenario 4a	Scenario 4b	Scenario 5a	Scenario 5b
Mass (each zone)	m ²	100	290	123	129	105	184	23	173
Wall Insulation	R	28	15	23	20	23	25	23	21
Roof Insulation	R	42	31	39	36	39	40	39	37
Window U-Factor	W/m ² K	0.61	1.66	0.81	1.05	0.76	0.72	0.78	0.98
Window SHGC	N/A	0.61	0.40	0.56	0.33	0.59	0.50	0.60	0.69
Infiltration (each zone)	cm ²	75	10	112	15	150	158	155	157
Total Error	%	14.7	43.3	6.8	5.6	5.3	1.9	5.1	2.1
NMBE	%	15.8	46.4	7.3	6.0	5.7	2.0	5.4	2.2
CV(RMSE)	%	25.5	54.2	25.7	17.1	25.2	19.9	21.9	25.8

The calibrated values for building mass varied somewhat for the different calibration scenarios. The largest outlier was in scenario 1 which produced a much higher value for building mass than the other cases. Figure 93 contains a graphical representation of the different calibrated values for building mass to show how they compare relative to each other.

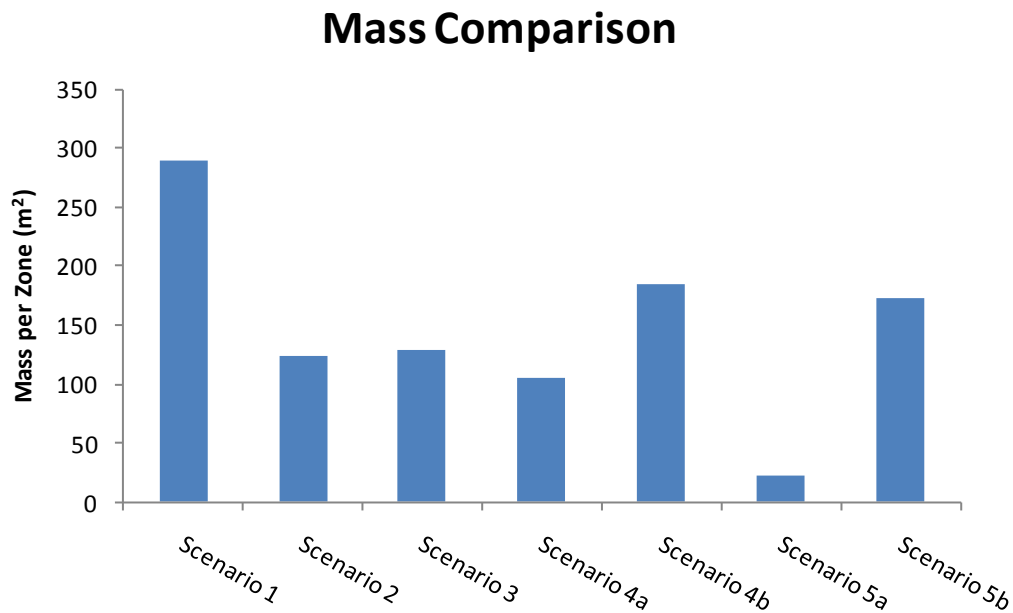


Figure 93: Building mass comparison for the different calibration scenarios

The thermal resistance of the building envelope (wall/roof insulation and window U-factor), envelope leakiness (infiltration) and SHGC are all inter-related in that their sum contributes to the heating load on the building as a function of outside weather conditions (including heat gain from solar radiation). Therefore, there is usually a correlation between the calibrated values for each of these parameters in each scenario. Normally a higher thermal resistance (less heat loss) will correspond with a higher infiltration value (higher heat loss) and/or a lower SHGC (less heat gain). The opposite also holds true. This general trend can be seen by looking at Figure 94 - Figure 98, which contain graphical representations of the calibrated values for the building wall/roof insulation, window U-factor, window SHGC, and infiltration.

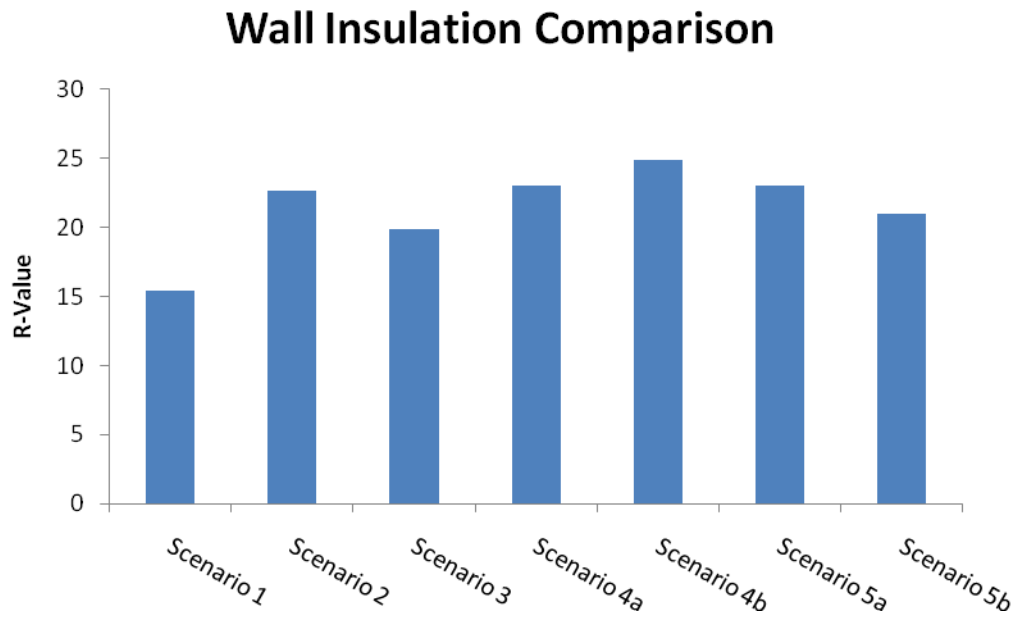


Figure 94: Wall insulation level comparison for the different calibration scenarios

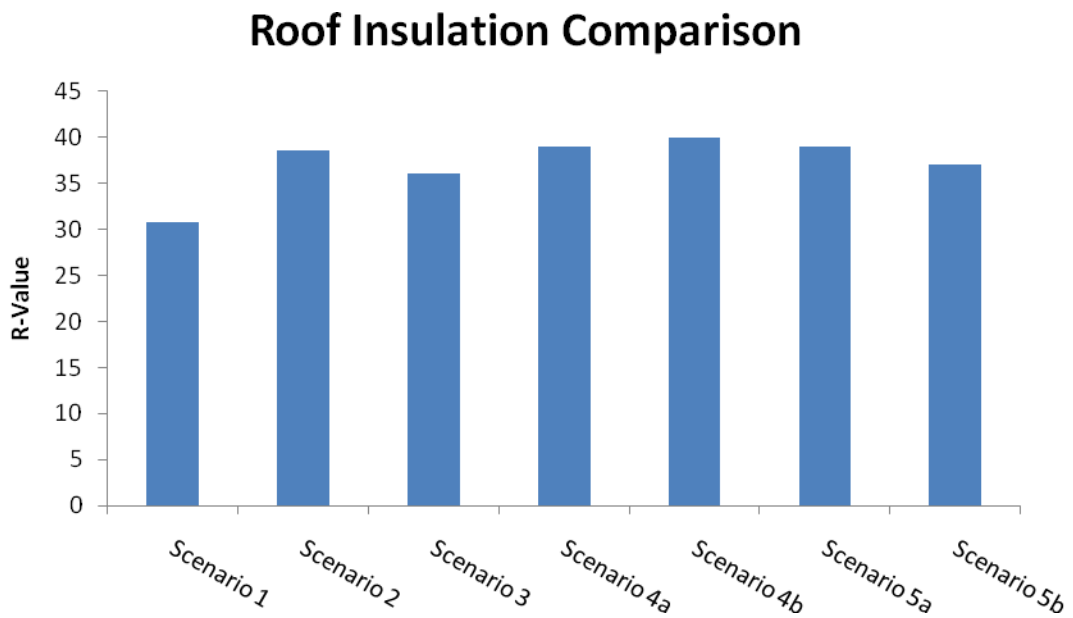


Figure 95: Roof insulation level comparison for the different calibration scenarios

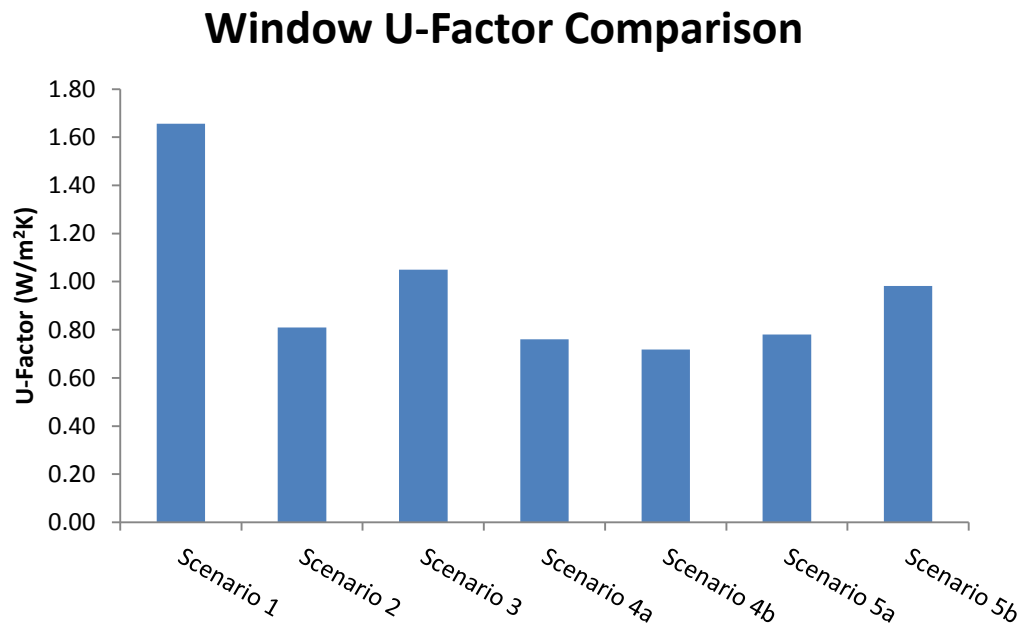


Figure 96: Window U-factor comparison for the different calibration scenarios

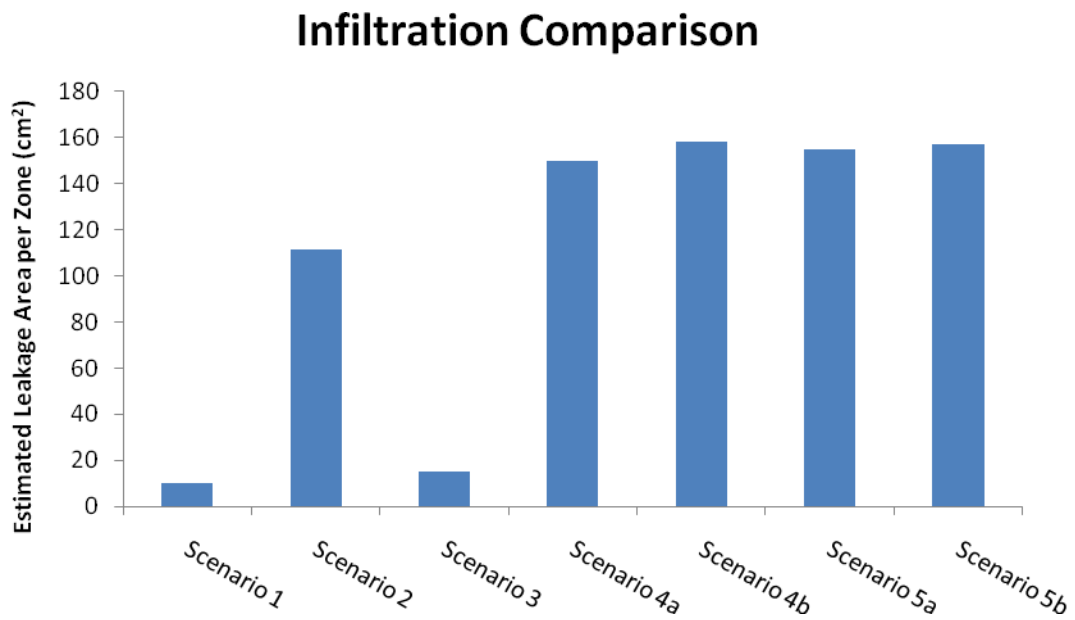


Figure 97: Infiltration value comparison for the different calibration scenarios

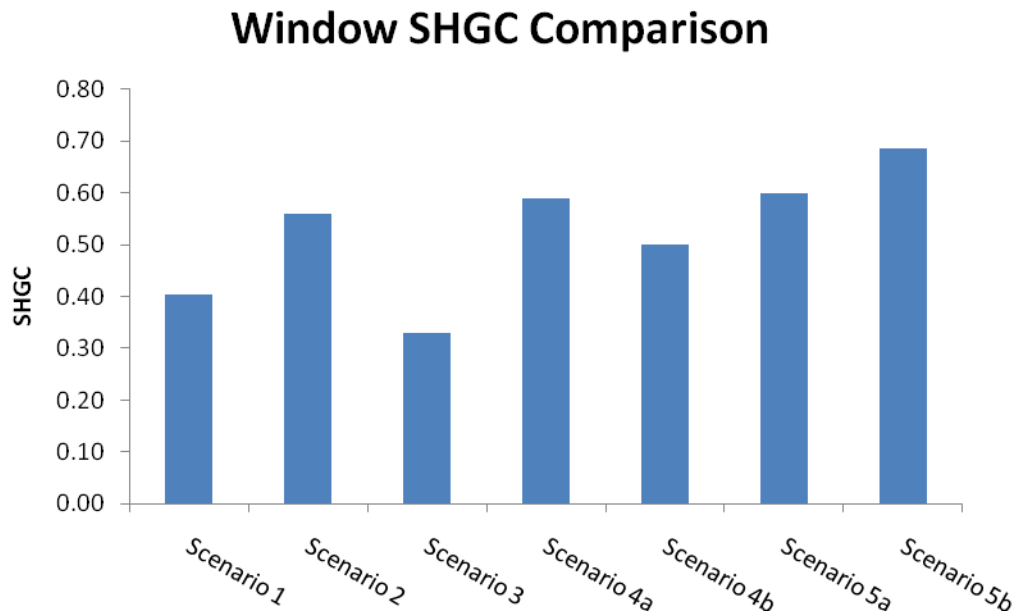


Figure 98: SHGC value comparison for the different calibration scenarios

As previously mentioned, the NMBE and CV(RMSE) are two widely used statistical metrics used to determine if a building energy model is to be considered calibrated. ASHRAE-14 has two recommended sets of acceptable values for these metrics depending on the calibration type. If monthly utility data are used, the thresholds for NBME and CV(RMSE) are 5% and 15%, respectively. If hourly data are used for the calibration, the values increase to 10% and 30%. While these metrics are useful in determining that validity of the calibrations performed in this report, in some ways it is like comparing apples to oranges. The following points indicate how some of the approaches studied in this report differ from the whole building prescriptive path described in AHSRAE-14 (and other M&V guidelines).

- The whole building prescriptive path uses simulation tools that perform hourly calculation for the simulation period (usually one year). This study uses an EnergyPlus model performing calculations at sub- hourly time steps over an approximately 3-week period during the heating season.
- The whole building prescriptive path calibrates the model by minimizing error between monthly utility data and simulated whole building energy use for the period of one year.

In some cases, calibrations are done by minimizing error based on measured and simulated hourly data for the year. This study looks at several approaches to calibrating the model. The approaches range from minimizing error between the measured and simulated zone air temperature for each minute of the three-week calibration period to minimizing the error in daily energy consumption between the measured and simulated building during a ten day time span. The resulting calibrated models are then compared.

- The whole building prescriptive path only considers NMBE and CV(RMSE) for the data used during the calibration to determine if a model is calibrated or not. The model's ability to accurately predict future energy consumption when the data is unknown is not considered. This study considers the calibrated model's ability to predict future energy consumption (i.e. how well can it match data beyond what was used to calibrate the model).
- As the name implies, the whole building prescriptive path combines occupant behavior (plug & lighting loads, set points, etc.), HVAC system performance, and building envelope performance into a single monthly energy use for the calibration. This study greatly reduces the uncertainty of occupant behavior and HVAC performance because these things are directly measured and scheduled into the model. The calibration (and calculation of NMBE & CV(RMSE)) are mostly focused on building envelope parameters and how they affect performance.

For the reasons outlined above, it would not be fully legitimate to adopt either of the NMBE and CV(RMSE) acceptance thresholds listed in ASHRAE-14 or any other M&V guideline as hard lines to declare the different models in this report as “calibrated.” With this noted, the metrics are still valuable for both confidence in the model's ability to predict future energy consumption and to compare the different results to each other.

Clearly, scenario 1 largely overestimates the future energy consumption of the home by nearly 2:1 on an absolute scale, and could not be considered calibrated by any metric. Additionally, the two other

temperature calibrated scenarios are also rather inconsistent and difficult to explain with regard to the calibrated parameters they produced. There are several possible reasons for the inaccuracy of the calibrations. Some things that can be ruled out are inaccurate modeling of the internal gains and occupant behavior because the house was totally unoccupied during this period and the same schedules were used during the prediction period in all scenarios. Furthermore, the overall model inaccuracy cannot be attributed to HVAC system modeling errors because the HVAC system was inoperative during the calibration period and the same HVAC system model was used for all scenarios during the prediction period. In the author's opinion, the most likely source of the calibration inaccuracy rests in the way that zone air temperature was measured vs. how it is reported in the EnergyPlus output file. The zone air temperature sensor was located in one location within the house; very near the thermostat on the first floor. The zone air temperature reported in the EnergyPlus output file assumes that the air is perfectly mixed in the zone. The extent to which this error contributes to poor calibration is likely a function of how well the HVAC system mixes the air within the zone so that the temperature being measured by the data acquisition is similar to the EnergyPlus output temperature. It is very difficult to account for this phenomenon without extensive further studying, but its effect may have led the optimizer to choose a set of building envelope parameters that were not representative of the home which resulted in a model that was very poor in its ability to predict future energy consumption. Due to the uncertainty surrounding this phenomenon, the remainder of this report will focus on the energy calibrations. Using energy consumption as the metric for comparison has the benefit of "filtering" out these unintended differences between the measured local temperature and model output.

As indicated in Table 32, the NMBE for all of the energy calibration scenarios during the prediction period using 5-day intervals was between 2.0% and 5.7% and the CV(RMSE) was between 19.9% and 25.8%. While this can't be said with absolute certainty, given that these metrics are computed for the models ability to *predict* energy consumption (vs. reproduce energy consumption) and would be lower if whole building energy consumption was considered (since plug and lighting loads are known), they would very likely fall well within the "acceptable" range and be considered calibrated models.

Assuming that all of the energy calibrated models would be considered “calibrated” by most existing guidelines, the great concern is the range of building envelope parameters contained within these six calibrated models and presented in Figure 93 - Figure 98. The question that should be asked is although all six models are calibrated, which is actually correct, if any?

5.4 Time/Seasonal Sensitivity of Calibration Results

The previous section only considered the effect of using different objective functions in the calibration tool to produce an optimized set of building envelope parameters. Each case was calibrated during a short period of time in late January and then the resulting calibrated models were compared based on their ability to predict energy consumption over the next several months. There is added value in looking at how using different time periods to calibrate the model could produce different sets of calibrated model parameters. Since 5 months of data were available for this study, this section compares the calibrated building envelope parameters resulting from using each of these months separately as well as the entire 5 month period for the calibration. For all cases; the fixed, half day energy consumption objective function was used to compare the different months. During the total 5 month period, the data acquisition system was operating properly and gathering data for approximately 75 total days. Approximately 20 days of data were available for the months of February and April, 18 days for May and 7 days for March. Table 33 lists all of the calibrated building envelope parameters for each of the time periods for which the model was calibrated; also shown are the model parameters.

Table 33: Calibrated building envelope parameters for various calibration periods

Parameter	Units	Original Calibration					
		Period	Feb	Mar	Apr	May	Whole Period
Mass (each zone)	m ²	184	69	275	276	209	254
Wall Insulation	R	25	31	33	20	32	26
Roof Insulation	R	40	45	47	36	46	42
Window U-Factor	W/m ² K	0.72	0.34	0.23	1.05	0.30	0.56
Window SHGC	N/A	0.50	0.35	0.94	0.52	0.44	0.46
Infiltration (each zone)	cm ²	158	115	78	108	155	160

As illustrated in Figure 43 and Figure 44, the parameters with the most influence over building energy consumption are wall R-value, SHGC, and to a lesser extent the roof R-value. It is also worth noting that the incremental change in energy consumption (sensitivity) for each additional R-1 for both the roof insulation and wall insulation diminishes after the R-value reaches a certain point. These results show that as the outside air temperature increases the mass value tends to increase. SHGC tends to be similar regardless of outside air temperature with the exception of March (which only had 7 days of data). The other sensitive parameters, wall and roof R-Value, are also relatively consistent during most time periods with the exception of April which was a bit of an outlier. The infiltration values were also fairly consistent with the exception of March. Further inspection of the weather and building operation data may reveal the reasons for this outlier. To aid in analyzing these results, Figure 99 consolidates the average daily temperature and solar radiation for the entire 5-month period into one graphic. Understanding the outside conditions during each month as well as the portion of the month that was missing data might aid in understanding the variation in calibrated building envelope parameters. The calibration period during January is highlighted on the figure.

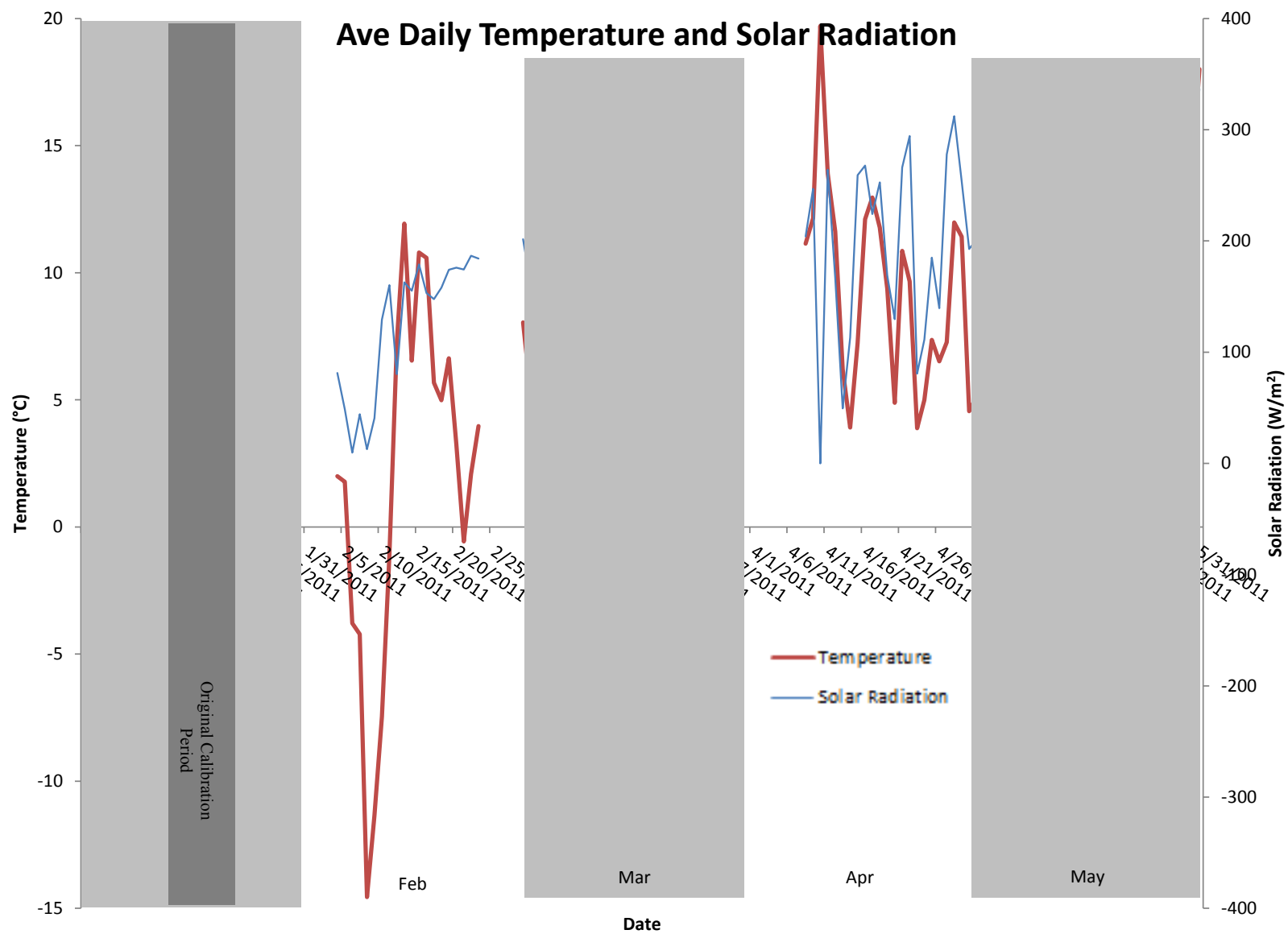


Figure 99: Weather conditions during 5 month monitoring period

The one value (outside of March) in Table 33 that stands out as a significant outlier is the mass value when February is used to calibrate the model. The sensitivity analysis showed that mass is much less influential than insulation and SHGC on energy consumption so it's hard to say if there is any significance in this result but looking at the weather data reveals a potential explanation. Variations in the average daily temperature during the month of February were far more significant than any of the other periods used for calibration. The closest comparable period was the original calibration period during January, which coincidentally also had the second smallest mass value. Although this period was most similar to Feb, the average daily temperature only fluctuated between $\sim -5^{\circ}\text{C}$ to 9°C compared to a much more pronounced $\sim -15^{\circ}\text{C}$ to 12°C during Feb. There was no other calibration period that was close to this level of variation. It makes some sense that the calibrated mass value would tend to be smaller during periods of high fluctuation, as the building gains and loses heat at a higher rate than during periods of lower temperature fluctuations. During the swing season months (April & May in this case), the average daily temperature is significantly higher and fluctuates less than during the colder time periods and the calibrated mass value is also higher. Since the heating load on the house is much lower and steadier over the fixed 12 hour time periods that the model was calibrated using, it makes sense that the calibrated mass value would increase. Higher mass in this case is essentially dampening the variations in energy consumption to match the steadier heating load on the building. During the colder months which saw wild temperature fluctuations, the calibrated mass value tended to decrease; allowing the building to respond to these large changes in heating load more rapidly. With more rapid response to changing loads on the building, the error in modeled vs. measured energy consumption over fixed 12 hour intervals was minimized.

When the entire 5 month set of data is used to calibrate the model, the calibrated values of the most influential building envelope parameters are nearly identical to the values produced during the original calibration period in January. This is encouraging in that with the correct calibration procedure, baseline energy model and monitoring; an accurately calibrated model could potentially be created using

only a short period of monitored data. The 5-month calibration values also tend to land between the months with most extreme weather vs. the more mild and steady weather months. The results shown in this and previous sections indicate that the time period used for calibrating an energy model in this fashion should contain a representative weather profile for the entire heating or cooling season. This could be accomplished by monitoring for a longer portion of the season or by monitoring for several shorter periods of varying weather and averaging the results or multiple calibrations.

CHAPTER 6 SUMMARY, CONCLUSIONS, AND FUTURE WORK

The information presented throughout this thesis and its appendices provide an energy modeler with the tools and knowledge necessary to create a customized EnergyPlus model for a house with a weather station and data acquisition system recording measurements at the house. The tools are intended to be general in nature and may require modification to suit each users specific needs for the building to be studied. Additionally, a tool which utilizes MATLAB and EnergyPlus has been presented and is capable of optimizing a user-defined set of EnergyPlus parameters by either maximizing or minimizing a user-defined objective function.

The uniqueness of this study was that an extensive suite of instrumentation producing measured data was available to the author to be used in an EnergyPlus model running at sub-hourly time steps. Most studies to date looking at different ways to calibrate energy models and evaluate the validity of those models use either monthly or hourly utility bill data for comparison and calibration. Additionally, the energy models calculate energy use at one hour simulation time steps. The vast majority of calibration studies have focused on commercial size buildings where occupant behavior and building operation (plug & lighting loads, set points, etc.) account for a large portion of the building energy consumption. Naturally, this has led to procedures that focus more on calibrating building schedules to produce simulation results that closely match measured data and less on the building envelope performance. Generally, NMBE and CV(RMSE) between the energy model results and the measured monthly or hourly energy use during the period of calibration are used to determine if the model is to be considered “calibrated” at an acceptable level. Without revealing exactly how the model was “tuned” to produce an acceptable result; these methods leave the author questioning how much confidence there should be that the model is truly calibrated, or just that all of the “knobs” were tuned to produce a final result that meets the criteria. Whether or not all of the “individual knobs” were all tuned to represent their true values is very hard to know with so many variables to consider.

In general, residential building energy consumption is more of a function of envelope performance than occupant behavior. For this reason and the availability of detailed monitored data, this study looked at alternative methods to approaching the calibration problem which would hopefully result in more confidence that the “individual knobs” were tuned to represent their actual values. The general approach taken was to reduce the number of unknown parameters as much as possible by directly inputting known values that were monitored such as weather conditions, plug and lighting loads, thermostat set points, and HVAC system performance. Once these schedules were directly inputted into the model, the calibration tool was given a set of building envelope parameters to optimize based on different subsets of the monitored data (periods of time when the HVAC system was off, on, and both on and off) and different objective functions to minimize (i.e. RMS error between measured vs. modeled zone air temperature or RMS error between measured and modeled energy consumption during fixed and moving intervals). Each of these calibration runs produced different sets of optimized building envelope parameters which needed to be evaluated. To evaluate the effectiveness of each calibration approach, simulations were run for each different model for the 4 months after the 1 month used in the calibration. The 4 months were broken into 5-day intervals and the calibrated models were compared to each other based on the NMBE and CV(RMSE) between the measured and predicted energy use.

The results from these runs indicated that several different calibration approaches or scenarios performed very similarly to each other and would all likely be considered acceptably “calibrated” based on current M&V guidelines; although they also produced fairly different sets of building envelope parameters. This brings into question whether or not the current acceptability criteria for whether or not a model is to be considered calibrated can really be applied to residential buildings. It becomes much more difficult to calibrate an energy model once the ability to “tune” schedules and occupant behavior is removed from the equation. Additionally, the validity of using a certain set of data to calibrate an energy model and then using the same data to calculate the acceptance metrics is something that should be called into question by the energy modeling community. One of the objectives of this thesis was to develop a calibration procedure for a house using monitored data to produce the most accurate model possible.

While several promising approaches were developed and presented, there is still significant doubt as to whether or not the results from any single approach can be considered better or more accurate than the other approaches. There is a significant amount of additional work that should be considered in order to reach the aforementioned goal. This includes:

- An extensive uncertainty analysis should be conducted to determine where the most error is being introduced into the model calibration, and energy use prediction. This includes studying the uncertainty within the data acquisition system, uncertainty in the assumptions made when creating the EnergyPlus model, uncertainty in the models used within EnergyPlus to calculate energy consumption, and uncertainty in the assumptions made by equations used in the weather converter program. This is a non-trivial problem which should include a sensitivity analysis to determine how each of these errors impacts the results of the calibration. As mentioned earlier, a study to evaluate the impact of using just a single zone air temperature sensor in the calibration when the EnergyPlus model assumes perfectly mixed air would be very beneficial but would require further monitoring.
- More HVAC systems should be considered to see how that would change or add to the HVAC calibration procedure. The system installed in the pilot house was relatively simple; more complex systems should be studied and further procedures using the calibration tool should be developed for these different systems.
- Once an uncertainty analysis is conducted, more calibration scenarios should be considered. Ideally, a longer period of continuous monitored data would become available to increase the variety of calibration scenarios and increase the length of the model prediction period.
- More scenarios should be considered where modeler reduces the amount of data used in the calibration and the results of these calibrations can be compared to the results of the

calibrations where all of the detailed data are used. These scenarios should mimic what is likely to be available to energy modelers or home energy raters in practical, real world situations.

- The guidelines used to determine whether or not a residential energy model is to be considered calibrated should be re-evaluated and perhaps new metrics should be investigated that serve as a better indication of how accurate an energy modeler can expect a model to be.

While future work to further advance upon what was discovered in this thesis is recommended, enough knowledge was gained from the work already done to make several recommendations to the residential energy modeling community. Adopting calibration tools such as the one developed and presented in this thesis could go a long way to standardize modeling methods and calibration procedures across the industry. Energy modeling tends to still be more of an art than a science, but with a relatively small amount of instrumentation and extra time spent to learn, this trend can be changed. By monitoring for short periods during a few different times of year and using the data gathered for calibration, a significant increase in model confidence is achievable with relative ease and a small investment with the proper knowledge. With the proper package of portable instrumentation, an energy modeler can employ the multi-step calibration approach of first calibrating the HVAC system and then the building envelope without spending too much time on site. For residential buildings, a sub-hourly simulation time-step for a shorter period is recommended over a one hour time-step simulation for a longer period. The low building mass and fast cycling rates of residential HVAC equipment make capturing transient effects very difficult if longer time-step simulation is used. While an annual, hourly simulation may be able to accurately predict annual energy consumption; much more information about how the space reacts to different events is possible with a shorter time-step simulation (if calibrated properly). The benefits of this information extend beyond simply predicting annual energy consumption.

Based on the results from this study, several of the energy objective function approaches are capable of producing a calibrated building envelope model; but the fixed, half day interval objective

function was the most consistent and is recommended for use going forward with this tool. This said, it is also recommended that the temperature objective function approach gets additional attention. It is inherently cheaper and easier to deploy the temperature logging devices and state devices required to gather the data needed for the temperature objective function calibration than the energy objective function calibration. Therefore, it is worth continuing to try to find a solution to the issues presented in the thesis related to the temperature approach. There is also the added benefit of collecting comfort information when using temperature rather than energy.

The final recommendation is to use this calibration procedure and tool to help develop a residential specific calibration acceptance criteria, similar to ASHRAE Guideline 14, by performing a series of field case studies. Multiple buildings should be chosen with varying characteristics (location, building type, HVAC system, etc.), and outfitted with a fairly extensive package of instrumentation. Several calibrated building energy models should be created and calibrated using varying amounts of the measured data using the tools developed in this thesis and these calibrated models should be used to recommend energy conservation measures for each building to be implemented. The models should then be used to predict energy savings due to these conservation measures and once they are implemented, the actual energy savings should be compared to what was predicted by each of the models pre-implementation. The information gathered should then be used to inform the acceptance criteria guidelines and further recommendations can be made pertaining to the amount of instrumentation required to reach certain levels of confidence in the calibrated energy models.

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APPENDIX A ENERGYPLUS SCHEDULE CREATION PROCEDURE

This appendix goes through a detailed procedure explaining how to take the one minute data file from the pilot house and turn the information into schedules that can be read by EnergyPlus. There are a few specific examples presented for different types of schedules (generally those that were used specifically by the model in this thesis), but the concepts contained in this appendix can be applied rather generally to any schedules the user wishes to import into the model.

A.2 Fraction Schedules

Fraction schedules will be used to define the internal gains in the EnergyPlus model. Table 34 lists the measured variables that contribute to the internal gains in the pilot house. As shown, this house has the energy use broken down into 13 sub-meters, or one for each electric circuit (or group of circuits) at the house. Each of these sub-meters records the energy consumed at one minute intervals.

Table 34: Measured variables contributing to internal gains

Variable	Type	Unit
Basement Energy	Energy	Wh
Oven Energy	Energy	Wh
Garage Energy	Energy	Wh
Living Room Energy	Energy	Wh
Master Bedroom Energy	Energy	Wh
Inverter Energy	Energy	Wh
Master Bathroom Energy	Energy	Wh
Kitchen/Dining Room Lighting Energy	Energy	Wh
Dishwasher Energy	Energy	Wh
Clothes Dryer Energy	Energy	Wh
Kitchen/Dining Room Receptacle Energy	Energy	Wh
Main Floor Energy	Energy	kWh
Clothes Washer Energy	Energy	kWh

At the highest level of detail each of these measurements could be given its own minute by minute schedule and assigned to the thermal zone where it is located. Unfortunately, there is only one method of implementing minute schedules in EnergyPlus and it requires every minute of the year to be

populated with a value, even if the simulation run period is only for one week. Doing this would result in over 500,000 lines added to the IDF file for each sub-metered internal gain, or 6.5+ million lines to the IDF file in total. It is the author's experience that having just one minute by minute schedule in the IDF file significantly slows down the computing process, therefore it would be in the users best interest to limit the minute schedules to only those that are absolutely necessary, or of interest for a particular study.

There are a couple of different ways to reduce the size and run time of the EnergyPlus model with respect to the internal gains schedules. First, the user could group internal gains together by the thermal zone they reside in. In the case of the pilot house, this would reduce the number of internal gain schedules to from 13 to 3. Hypothetically, the gains could also be grouped into a single schedule based on the whole house energy use and then distributed to each thermal zone defined in the EnergyPlus model. This zone fraction of internal gains would have to be based on the results of a walkthrough survey of lights, plug loads, and appliances by the modeler or simply dividing the loads evenly into the zones. In all cases, reducing the number of schedules by grouping internal gains together will result in a reduction of model accuracy. The amount of accuracy lost will depend on each situation individually and also in the skill of the modeler to make proper assumptions and estimations. The other way that the user could reduce the size and run time of the model would be to reduce the time step of the internal gain schedule. As discussed above, one extreme would be to have the internal gain scheduled for each minute of the year (which is the also smallest simulation time step allowable by EnergyPlus). The other extreme would be to have a single value for internal gains throughout the year. A large number of options exist between these two extremes and the correct interval for internal gains scheduling depends on the information available and needs of the modeler.

For the pilot house, internal gains were consolidated into three groups; one in each of the thermal zones in the house with one hour time step. When a one hour time step is used, there are at least two different ways this can be achieved in EnergyPlus. The EnergyPlus Input-Output Reference document goes into great detail on how to create all different types of schedules, this document will show specifically how these internal gains schedules were created using the data gathered in this specific case.

A.2.1 Defining the Schedule:File in the IDF

In this instance, the Schedule:File object was used for the internal gains schedule. This option is EnergyPlus can only be used when hourly schedules are desired. There must be a value for every hour of the year (8760 entries), so if data only exists for a few weeks when the simulation is to be run, the rest of the hours of the year still need to be populated with a value. The nice thing about this type of schedule is that it can reference an external file where the values are located, so the desired measured data can be saved as a comma separated value (.csv) file and then referenced by the EnergyPlus IDF. Figure 100 shows an excerpt of the IDF file where the Schedule:File is defined.

```
Schedule:File,  
  MainFloorGains,      !- Name  
  Fraction,            !- Schedule Type Limits Name  
  C:\Documents and Settings\cwassmer\Desktop\MainFloorGains.txt, !- File Name  
  1,                   !- Column Number  
  0,                   !- Rows to Skip at Top  
  8760,                !- Number of Hours of Data  
  Tab;                 !- Column Separator
```

Figure 100: Example text from the EnergyPlus IDF file defining Shedule:File

This example can be used for any hourly schedule that is desired. Each schedule must have a unique name and the file path will vary depending on the user. If a temperature schedule is to be used, the “Schedule Type Limits Name” should change from “Fraction” to “Temperature.” In this example, the MainFloorGains fraction schedule is derived from the consolidated values of: oven energy, living room energy, kitchen/dining room lighting energy, kitchen/dining room receptacle energy, and dishwasher energy. This is based on the electric circuits that correspond with the main floor thermal zone defined in the EnergyPlus model. Naturally, this will be different for each individual building being modeled depending on what actually exists at that site.

A.2.2 Defining the Internal Gains as Electric Equipment in the IDF

Within the Internal Gains group of EnergyPlus is an ElectricEquipment object where the internal gains scheduled above are inputted. Figure 101 shows an excerpt of the IDF file where the ElectricEquipment is defined for the main floor internal gains.

```
ElectricEquipment,  
  First Floor Light and Plug Loads, !- Name  
  FirstFloor, !- Zone or ZoneList Name  
  MainFloorGains, !- Schedule Name  
  EquipmentLevel, !- Design Level Calculation Method  
  349, !- Design Level {W}  
  , !- Watts per Zone Floor Area {W/m2}  
  , !- Watts per Person {W/person}  
  0, !- Fraction Latent  
  0.7, !- Fraction Radiant  
  0, !- Fraction Lost  
  General; !- End-Use Subcategory
```

Figure 101: Example text from the EnergyPlus IDF file defining ElectricEquipment

In this example, the object is given a unique name for the first floor gains and references the “MainFloorGains” schedule. In this case, the Design Level is 349 Watts. This value represents the maximum aggregated value of average power for all of the hours during the period that the data was being taken. In the schedule, the hour when the average power draw was 349 Watts would be assigned a value of 1 and every other hour of the year would be assigned a value between 0 and 1 which is calculated from the average power draw for that hour divided by 349 Watts. This example can be replicated for as many different internal gain objects are desired by the user. Again, this will depend on each specific case and the needs of the user. Another variable that is chosen under the discretion of the user is the fraction radiant and fraction latent. The radiant fraction is the percentage of the power consumed by the lights/appliances/plug loads, etc. that ends up being added to the zone as sensible heat gains and the fraction latent is percentage that gets added to the zone as latent heat gains. In this case, the radiant fraction was left at its default value of 0.7.

A.2.3 Defining the File Containing the Schedule Values for Hourly Internal Gains

In Figure 100, the “File Name” field contains the file path that points to where the .txt file resides with the actual values for the MainFloorGains schedule. The previous paragraph describes what these values (fractions) represent in the context of internal gains in the main floor zone. The actual .txt file, which in this example is “MainFloorGains.txt,” is simply a tab delimited file containing 8760 lines with a single value on each line; there is no header in the file. The first line of the .txt file contains the fraction value for the first hour of the year and continues to the last hour of the year. Although this example is specifically for scheduling hourly internal gains for one zone in the model; the concept can be carried forward to any hourly schedule desired using the measured data.

A.2.4 Lapses in Measured Data, Missing Data Points

Similar to the case with the weather file, there will inevitably be missing records within the measured internal gains data. There are really only two options for filling in the missing data and which to use is at the discretion of the modeler. In all cases, the code that is written to aggregate internal gains and write the tab delimited .txt file should be able to detect when a record is missing and deal with it depending on the needs of the modeler. One case would be for the modeler to ignore hours with missing data in any analysis done on the EnergyPlus output. Naturally, this would require the modeler to know which hours have errors in the data and deal with them accordingly depending on his/her needs. If the modeler decides to throw out the results from the times where there are missing data, the hourly schedule values for those hours with missing data should all be 0. In the case where the modeler would like to run the simulation through periods where internal gain data is missing, the hourly schedule should populate the missing records with a best “guess” at values for those hours. One reasonable way to do this would be to populate the missing day (or days) hourly values with an average of the preceding and succeeding existing values for that hour. For example, if last data point before the lapse is on Jan 7th during the 10:00AM - 11:00AM hour with a value of 0.4 and resumes on Jan 10th during the 10:00AM - 11:00AM hour with a value of 0.6, the code that create the schedule should populate the schedule with values of 0.5

for the 10:00AM – 11:00AM hour on both Jan 8th and Jan 9th. This is just one way to populate missing data that will allow the model to run without crashing. Entire studies have been done related to this issue and there really is no consensus among the modeling community.

A.2.5 Using Fraction Schedules for Domestic Water Use

Table 35 contains all of the variables related to domestic water usage; they are all either flow rates or temperatures. In the pilot house, there are two flowmeters and thermocouples installed on two branches of the hot water supply and one flowmeter and thermocouple installed on the cold water supply.

Table 35: Variables related to domestic water use

Variable	Type	Unit
Domestic Hot Water Supply Temperature (East)	Temperature	°F
Domestic Hot Water Supply Temperature (West)	Temperature	°F
Domestic Cold Water Supply Temperature	Temperature	°F
Domestic Cold Water Supply Flow	Flow	gallon
Domestic Hot Water Supply Flow (East)	Flow	gallon
Domestic Hot Water SupplyFlow (West)	Flow	gallon

By using a combination of these measurements, it is possible to compute the domestic water usage at the house and know the temperature of the water delivered at the appliance, although a certain amount of pre-processing of the data is required before anything could be inputted into the EnergyPlus model. Similar to defining internal gains, there is a fairly vast range of “level of detail” that use user could go to depending on the instrumentation installed in the house. At one extreme, there could be flowmeters/thermocouples installed at each appliance on both the hot and cold supply lines recording data on a minute or even sub-minute interval. Alternatively, there could be flowmeters measuring whole house hot/cold water usage which could be read off once a month (or once a year) along with a spot temperature measurement of the hot and cold water supply. For purposes of this example, one hour time steps are used and the water usage is split into two branches (east and west).

To define domestic water use, 4 different schedules are required regardless of time step. The flow rate fraction schedule for each water use branch is a schedule with values for each time step representing

a fraction of a maximum defined flow rate (which can be read from the data file). The target temperature schedule contains values for the temperature of the water delivered at the appliance/equipment; this value must be calculated from the measured hot/cold flow rate and temperatures depending on how the EnergyPlus model is set up and the physical layout of the house being modeled (this will be partially up to the modeler to determine based on judgment and research on the installed appliances). As the name suggests, the hot water supply temperature schedule contains values of temperature for the hot water supply, which comes directly from the measured data and processed into whatever time step is desired. Similarly, the cold water supply temperature schedule is the same but for cold water from the water main.

```
WaterUse:Equipment,
  EastSideWaterUse,    !- Name
  General,             !- End-Use Subcategory
  0.00325,             !- Peak Flow Rate {m3/s}
  EastSideWaterFlow,   !- Flow Rate Fraction Schedule Name
  EastSideWaterTemp,   !- Target Temperature Schedule Name
  HotWaterTemp,        !- Hot Water Supply Temperature Schedule Name
  ColdWaterTemp,       !- Cold Water Supply Temperature Schedule Name
  TopLevel;           !- Zone Name
```

Figure 102 contains an excerpt from the EnergyPlus IDF defining one branch of the water use in the house. The schedules are described above and can be created using the same methodology defined in section A.2.3. The “Peak Flow Rate” shown in the IDF example is the maximum measured value of water flow rate after being calculated for the “EastSideWaterUse.”

```
WaterUse:Equipment,
  EastSideWaterUse,    !- Name
  General,             !- End-Use Subcategory
  0.00325,             !- Peak Flow Rate {m3/s}
  EastSideWaterFlow,   !- Flow Rate Fraction Schedule Name
  EastSideWaterTemp,   !- Target Temperature Schedule Name
  HotWaterTemp,        !- Hot Water Supply Temperature Schedule Name
  ColdWaterTemp,       !- Cold Water Supply Temperature Schedule Name
  TopLevel;           !- Zone Name
```

Figure 102: Example text from EnergyPlus IDF defining domestic water use

Similar to defining the internal gains, the same logic applies to dealing with lapses in the measured data as was described in A.2.4.

A.3 Minute Schedules

All of the examples described in section A.2 could also be defined as minute schedules. As described earlier, defining a minute schedule requires over 500,000 lines to be added to the IDF file for each minute schedule to be added. Nonetheless, sometimes it is desirable to include a minute schedule for purposes of looking at effects that cannot be picked up by using hourly data. Alternatively, the modeler may be interested in seeing how much (if any) accuracy is lost by reducing data to hourly instead of minute by minute. Given that minute data is available with the data acquisition system installed in the pilot house, this section will detail how to translate the measured data file into a minute schedule in the EnergyPlus IDF.

The EnergyPlus InputOutput Reference document goes into more detail than this document about how to create virtually any schedule desired. This document will serve as a condensed instruction on how to create minute schedules using the measured data available for the specific project defined in the scope of this work.

When defining schedules within EnergyPlus, there is a hierarchy of schedules within the system starting with the Schedule:Day:List. This type of schedule is one of 3 different ways to define a daily schedule, but the only one capable of defining a daily schedule down to the minute. Within the Schedule:Day:List object, there are 1440 lines available for values representing all minutes starting at 12:00 AM and ending at 11:59 PM. Figure 103 contains sample text from the EnergyPlus IDF for a daily schedule with values listed at each minute. Note that for brevity in the figure, the example text is truncated after the first 19 entries; the actual IDF file would have 1440 entries with a semi-colon after the final entry for this day.

```

Schedule:Day:List,
Setpoint Day 1,      !- Name
Temperature,         !- Schedule Type Limits Name
No,                  !- Interpolate to Timestep
1,                    !- Minutes per Item
20,                   !- Value 1
20,                   !- N3
20,                   !- N4
20,                   !- N5
20,                   !- N6
20,                   !- N7
20,                   !- N8
20,                   !- N9
20,                   !- N10
21,                   !- N11
21,                   !- N12
21,                   !- N13
21,                   !- N14
20,                   !- N15
20,                   !- N16
20,                   !- N17
20,                   !- N18
20,                   !- N19
20,                   !- N20

```

Figure 103: Example text from EnergyPlus IDF defining a minute time step daily schedule

This is an example for a temperature set point schedule. Here, the temperature set point is 20°C from 12:00AM-12:08AM then changes to 21°C from 12:09AM-12:14AM and changes back to 20°C from 12:15AM until the end of the day (this example stops at 12:20AM but in the real IDF would continue to 11:59PM). For each day of the year where a unique schedule is desired, there must be a new Schedule:Day:List with a unique name for that day. Therefore, a full year's worth of one minute schedules required 365 Schedule:Day:List objects. In Figure 103, the schedule name is Setpoint Day 1 and the schedule type is Temperature. When a one minute time step is desired, the Minutes per Item field should be 1 as in this example.

After the day schedules are defined with all of the set point temperature values, the next schedule in the hierarchy is the weekly schedule. Similar to the day schedule, the Schedule:Week:Daily schedule is

defined uniquely for each week of the year. Figure 104 contains sample text from the EnergyPlus IDF where the weekly schedules are defined.

```
Schedule:Week:Daily,  
  Setpoint Week 1,      !- Name  
  Setpoint Day 1,      !- Sunday Schedule:Day Name  
  Setpoint Day 1,      !- Monday Schedule:Day Name  
  Setpoint Day 1,      !- Tuesday Schedule:Day Name  
  Setpoint Day 1,      !- Wednesday Schedule:Day Name  
  Setpoint Day 1,      !- Thursday Schedule:Day Name  
  Setpoint Day 1,      !- Friday Schedule:Day Name  
  Setpoint Day 1,      !- Saturday Schedule:Day Name  
  Setpoint Day 1,      !- Holiday Schedule:Day Name  
  Setpoint Day 1,      !- SummerDesignDay Schedule:Day Name  
  Setpoint Day 1,      !- WinterDesignDay Schedule:Day Name  
  Setpoint Day 1,      !- CustomDay1 Schedule:Day Name  
  Setpoint Day 1;      !- CustomDay2 Schedule:Day Name  
  
Schedule:Week:Daily,  
  Setpoint Week 2,      !- Name  
  Setpoint Day 2,      !- Sunday Schedule:Day Name  
  Setpoint Day 3,      !- Monday Schedule:Day Name  
  Setpoint Day 4,      !- Tuesday Schedule:Day Name  
  Setpoint Day 5,      !- Wednesday Schedule:Day Name  
  Setpoint Day 6,      !- Thursday Schedule:Day Name  
  Setpoint Day 7,      !- Friday Schedule:Day Name  
  Setpoint Day 8,      !- Saturday Schedule:Day Name  
  Setpoint Day 1,      !- Holiday Schedule:Day Name  
  Setpoint Day 1,      !- SummerDesignDay Schedule:Day Name  
  Setpoint Day 1,      !- WinterDesignDay Schedule:Day Name  
  Setpoint Day 1,      !- CustomDay1 Schedule:Day Name  
  Setpoint Day 1;      !- CustomDay2 Schedule:Day Name
```

Figure 104: Example text from EnergyPlus IDF defining a weekly schedule

For each week of the year, there must be a new Schedule:Week:Daily object with a unique schedule name. This example is for 2011 so Jan 1st lands on a Saturday. Setpoint Day 1 represents Jan 1st, and Setpoint Day 2 represents Jan 2nd, etc. all the way through Setpoint Day 365 representing December 31st. For any year, there are always 53 unique week schedules since one there is always a partial week on the calendar. In this example, since the first day of the year is on a Saturday, Setpoint Week 1 has Setpoint Day 1 as its “Saturday Schedule: Day Name.” Since the other days of the week, holiday, design

days and custom days are not used, they are simply filled in with Setpoint Day 1 which is used as a filler since EnergyPlus requires these fields be filled in. Setpoint Week 2 starts with its Sunday Schedule: Day Name as Setpoint Day 2, which is January 2nd. Figure 104 is truncated to only show the first two weeks of the year; in the actual IDF, there are 53 Schedule:Week:Daily objects using all 365 Setpoint Day schedules sequentially as the days fall on the calendar for the year 2011. Since Jan 1st falls on a different day of the week each year, these Schedule:Week:Daily objects will always be different depending on the year.

The final schedule in the hierarchy is the year schedule. The year schedule contains all of the weekly schedule which in turn contain all of the daily minute schedules for the item being scheduled (which is temperature setpoint in this case). Therefore, when the one minute time step schedule is being referenced in other parts of the IDF, it is the year schedule name that is pointed to. Figure 105 shows sample text from the IDF defining the year schedule for a temperature set point.

```

Schedule:Year,
  Setpoint Year,      !- Name
  Temperature,        !- Schedule Type Limits Name
  Setpoint Week 1,    !- Schedule:Week Name 1
  1,                  !- Start Month 1
  1,                  !- Start Day 1
  1,                  !- End Month 1
  1,                  !- End Day 1
  Setpoint Week 2,    !- Schedule:Week Name 2
  1,                  !- Start Month 2
  2,                  !- Start Day 2
  1,                  !- End Month 2
  8,                  !- End Day 2
  Setpoint Week 3,    !- Schedule:Week Name 3
  1,                  !- Start Month 3
  9,                  !- Start Day 3
  1,                  !- End Month 3
  15,                 !- End Day 3
  Setpoint Week 4,    !- Schedule:Week Name 4
  1,                  !- Start Month 4
  16,                 !- Start Day 4
  1,                  !- End Month 4
  22,                 !- End Day 4

```

Figure 105: Example text from EnergyPlus IDF defining a year schedule

The Schedule:Year object shown in this example has a unique name “Setpoint Year” which contains all of the temperature set point values for each minute of the year. This is the schedule where each weekly schedule previously populated with daily schedules is defined by start month, start day, end month and end day. As stated earlier, January 1st, 2011 is a Saturday so the Setpoint Week 1 schedule only contains one day. This is reflected in the year schedule where the start day and month and end day and month for Setpoint Week 1 are all 1. The rest of the weeks defined in the year schedules are correlated to start month/start day and end month/end day for the remainder of the year. All of these values will be different depending on the specific year.

This section illustrates how to create all of the different schedules required when a one minute time interval is desired. In the examples shown throughout, a set point temperature was used as the

variable but this does not change the steps involved in creating a similar schedule for fractions, availability, etc.

In cases where there are lapses in the measured data and it is being used to create a minute schedule, the data should be pre-processed to fill in the lapses so that there are no missing fields in the IDF file (this would cause an EnergyPlus crash). The techniques used to fill in missing data are really up to the user based on his/her goals for the simulation and are discussed in section A.2.4. These same techniques can be applied to minute interval data in the same way that they were applied to hourly data.

APPENDIX B MATLAB CODE

This appendix contains all of the MATLAB code that was written to create the calibration, the schedule creation tools, and the weather file creation tool. In general, the top level programs are listed first and the functions and scripts called by the top level program come next.

B.1 Top Level Optimizer

This script starts the optimizer. Variations of this script can be used for the water heater calibration, HVAC system calibration, and building envelope calibration.

```
clear all
inputs = [.5,.5,.5,.5,.5]; %Initial guesses at EnergyPlus parameters
lb = [0,0,0,0,0]; %Lower bounds of EnergyPlus parameters
ub = [1,1,1,1,1]; %Upper bounds of EnergyPlus parameters
options = psoptimset('TolFun',1e-2); %Options for optimizer
[inputs,fval,exitflag,output] =
patternsearch(@FixedIntervalObjectFun,inputs,[],[],[],[],lb,ub,[],options)
%Launches the optimizer for objective function "ObjectFunction." To run
different objective functions, this would be replaced with the objective
function desired.
```

B.2 Building Envelope Objective Function

The following function is used to calculate the objective function value for the optimizer.

Depending on which error calculation is used at the end of the function, this code can be used for any of the building envelope calibration scenarios.

```
function error = ObjectiveFunction(inputs)

delete('IDFiterate2.csv'); %Clears CSV file from previous iteration from the
working directory
IDFbaseline = loadIDF('IDFToken2.idf'); %Loads the IDF file with the
parameters to be calibrated formatted as: %parameter%

SHGC = inputs(1) %Assigns input 1 from the optimizer as the SHGC parameter
SHGC = 0.3 + SHGC*(.95-.3) %Scales up SHGC value to its nominal value
SHGC = num2cell(SHGC);

Rmultiplier = inputs(2) %Assigns input 2 from the optimizer as the insulation
parameter
windowU = 1.054 - Rmultiplier*.879 %Scales up window U-Factor value to its
nominal value
windowU = num2cell(windowU);
wallU = .189 - Rmultiplier*.081 %Scales up wall R-value to its nominal value
wallU = num2cell(wallU);
```

```

roofU = .048 - Rmultiplier*.012 %Scales up Roof R-value to its nominal value
roofU = num2cell(roofU);

infiltration = inputs(3) %Assigns input 3 from the optimizer as the
infiltration parameter
infiltration = 40 + infiltration*(160-40) %Scales up infiltration value to
its nominal value
infiltration = num2cell(infiltration);

mass = inputs(4) %Assigns input 4 from the optimizer as the building mass
parameter
mass = 10 + mass*(300-10) %Scales up building mass value to its nominal value
mass = num2cell(mass);

flow = inputs(5) %Assigns input 5 from the optimizer as the flow percentage
parameter
flow = flow*(.234) %Scales up first floor air flow value to its nominal value
flow2 = .234 - flow; %Scales up second floor air flow value to its nominal
value
flow = num2cell(flow);
flow2 = num2cell(flow2);

IDFiterate = replaceTokens(IDFbaseline,{'%infiltration%'},infiltration); %The
replacTokens function replaces the token in the IDF file with the value
assigned to each parameter by the optimizer
IDFiterate = replaceTokens(IDFiterate,{'%mass%'},mass);
IDFiterate = replaceTokens(IDFiterate,{'%roofU%'},roofU);
IDFiterate = replaceTokens(IDFiterate,{'%SHGC%'},SHGC);
IDFiterate = replaceTokens(IDFiterate,{'%windowU%'},windowU);
IDFiterate = replaceTokens(IDFiterate,{'%wallU%'},wallU);
IDFiterate = replaceTokens(IDFiterate,{'%flow%'},flow);
IDFiterate = replaceTokens(IDFiterate,{'%flow2%'},flow2);

saveIDF('IDFiterate.idf', IDFiterate);
ePlusBinPath = 'C:\EnergyPlusV6-0-0\RunEPlusChris1';
runEPlus('IDFiterate', 'Warner_All_Weather', ePlusBinPath); %This script runs
the current iteration with the IDF file written by the optimizer

DataRead; %This script reads the measured data from the CSV file and
calculates the relevant values from the data
ProcessResults; %This script reads the EnergyPlus output from the current
iteration of the optimizer

startRecord = 11460; %Starting timestep for calculation of the objective
function
endRecord = 25970; %Ending timestep for calculation of the objective function
window = 1440; %If moving average is being used for the objective function,
this defines the size of the moving window, if fixed intervals are being used
this line is commented out
timestep = 60; %If moving average is being used for the objective function,
this defines the size of the step for the moving window, if fixed intervals
are being used this line is commented out

error =
calcIntervalError(dataStruct,HVACPower,coilEnergy,startRecord,endRecord,720)

```

```
%This function calculates the value of the objective function based on the
output of the current iteration, the measured data and the size of the
interval, if moving average or temperature is being used, this line is
commented out.
error =
movingAverage(dataStruct,HVACPower,coilEnergy,startRecord,endRecord,timestep,
window); %This function calculates the value of the objective function based
on the output of the current iteration, the measured data, the size of the
moving interval, and the size of the time step of the moving interval, if
fixed interval or temperature are being used, this line is commented out.
RMSerror = calcError(dataStruct,measuredVariable,startRecord,endRecord) %This
function calculates the value of the objective function based on the output
of the current iteration, and the measured data, if fixed interval or moving
average are being used, this line is commented out.

End
```

B.3 Water Heater Objective Function

The following function is used to calculate the objective function value for the water heater calibration optimization.

```
function error = HVACObjectfun(inputs)

delete('HVACiterate.csv');
HVACbaseline = loadIDF('HVACToken.idf');

setpoint = inputs(1)
setpoint = num2cell(setpoint);
deadband = inputs(2)
deadband = num2cell(deadband);
capacity = inputs(1)
capacity = num2cell(capacity);

HVACiterate = replaceTokens(HVACbaseline,{'%setpoint%'},setpoint);
HVACiterate = replaceTokens(HVACbaseline,{'%capacity%'},capacity);
HVACiterate = replaceTokens(HVACiterate,{'%deadband%'},deadband);

saveIDF('HVACiterate.idf', HVACiterate);
ePlusBinPath = 'C:\EnergyPlusV6-0-0\RunEPlus';
runEPlus('HVACiterate', 'Chris', ePlusBinPath);
dataFile = 'C:\Documents and Settings\cwassmer\My Documents\My
Dropbox\Cecile\Matlab\CR1000_Min_Fix.dat';

DataRead;
ProcessHVACResults;

startRecord = 10742;
endRecord = 11426;

error = calcWHerror(dataStruct,WHtoAHU,startRecord,endRecord);
```

end

B.4 HVAC System Objective Function

The following function is used to calculate the objective function value for the HVAC system calibration optimization.

```
function error = HVACObjectfun(inputs)

delete('HVACiterate.csv');
HVACbaseline = loadIDF('HVACToken.idf');

UA = inputs(1)
UA = num2cell(UA);

HVACiterate = replaceTokens(HVACbaseline, {'%UA%'}, UA);

saveIDF('HVACiterate.idf', HVACiterate);
ePlusBinPath = 'C:\EnergyPlusV6-0-0\RunEPlus';
runEPlus('HVACiterate', 'Chris', ePlusBinPath);

DataRead;
ProcessHVACResults;
startRecord = 10000;
endRecord = 25000;
error = calcHVACError(dataStruct, coilEnergy, startRecord, endRecord)

end
```

B.5 Load IDF Function

This function reads an IDF file from the working directory and imports it into the MATLAB workspace. The following code was written by Chad Corbin at the University of Colorado.

```
%*****
%
% FUNCTION
%   cellArray = loadIDF(fileName)
%
% DESCRIPTION
%   Function to load and parse an EnergyPlus IDF file into a cell array of
%   strings.
%
% ARGUMENTS
%   fileName:   A string representing the path to the IDF file. Relative or
%               absolute.
%
% RETURNS
%   cellArray:  A cell array of strings containing each line of the IDF
%               file in a separate element.
```

```

%
% AUTHOR
%   Chad Corbin
%   University of Colorado at Boulder
%   charles.corbin@colorado.edu
%
%
% CREATED
%   05.May.2009
%
% SEE ALSO fopen fclose textscan
%
%*****

function cellArray = loadIDF(fileName)

    if nargin ~= 1

        error('Function loadIDF(fileName) requires 1 argument. ');
        return;

    end

    if ~ischar(fileName)

        error('Argument fileName must be a string. ');
        return;

    end

    disp(['Loading: ', fileName]);
    fileID = fopen(fileName);
    tmp =
textscan(fileID, '%s', 'MultipleDelimsAsOne', 0, 'Delimiter', ',', 'Whitespace', '');
    cellArray = tmp{1};
    fclose(fileID);

% end function

```

B.6 Replace Tokens Function

This function replaces the tokens within the EnergyPlus IDF file with the values selected either by the user or the optimizer. The following code was written by Chad Corbin at the University of Colorado.

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Chad Corbin
% charles.corbin@colorado.edu
%
% Replaces the text in the cellArray specified by the tokens array with the
% values contained in the values array.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```



```

function newCellArray = replaceTokens(cellArray, tokens, values)

    lenC = length(cellArray);
    lenT = length(tokens);
    lenV = length(values);
    newCellArray = cellArray;

    if lenT ~= lenV

        warning('The token array and value array are not the same size. No
substitutions were made.');
```

return;

```

    end

    newValues = values;

    for j=1:lenT

        if isnumeric(values{j})

            newValues{j} = num2str(values{j});

        end

    end

    newCellArray = regexprep(cellArray, tokens, newValues);
end %function

```

B.7 Save IDF Function

The following function saves the file that had the tokens replaces as a new IDF. The following code was written by Chad Corbin at the University of Colorado.

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Chad Corbin
% charles.corbin@colorado.edu
%
% Saves the cellArray to the location specified in fileName, adding a line
% break at each array element.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function saveIDF(fileName, cellArray)

    if nargin ~= 2

        error('Function loadIDF(fileName, cellArray) requies 2 argument.');
```

return;

```

end

disp(['Saving: ', fileName]);
fileID = fopen(fileName, 'w');
fprintf(fileID, '%s\r\n', cellArray{:});
fclose(fileID);

end % function

```

B.8 Run EnergyPlus Function

The following function calls the EnergyPlus program to run with the new IDF file written by the saveIDF function and a weather file. The output files from the EnergyPlus run are placed in the working directory. The following code was written by Chad Corbin at the University of Colorado.

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Chad Corbin
% charles.corbin@colorado.edu
%
% Runs energyplus using the IDF file in the location specified by
% simulationFile, and optionally using the EPS file in the location
% specified by weatherFile.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [status, result] = runEPlus(simulationFile, weatherFile,
ePlusBinPath)

    cmd = [ePlusBinPath, ' ', simulationFile];

    if nargin >= 2

        cmd = [cmd, ' ', weatherFile];

    end

    disp(['Running: ', cmd]);
    [status, result] = system(cmd);

    if ~isempty(regexpi(result, 'EnergyPlus Terminated')) || status ~= 0

        throw(MException('EnergyPlus:Error', result));

    end

end % function

```

B.9 Data Read Script

The following script imports all of the measured data into MATLAB from a CSV file where the data file is saved. Each of the variables in the data file is assigned a name that is then placed in the MATLAB workspace for use by the other MATLAB scripts and functions. There are also some new variables such as “coilEnergy”, “MainFloorGains”, “TopFloorGains”, and “BasementGains” that are calculated within this script from the other variables in the data file.

```
dataFile = 'I:\Writing\Common Files\CR1000_Min_Fix.dat'; %Specifies the
location of the CSV file containing the monitored data
[Date,Time,Record,BatteryVolt,GlobalHoriz,WindSpeed,OutsideAirTemp,OutsideAir
RH,MainFloorTemp,MainFloorRH,ERVMainBath,ERV2ndBath,WaterHeaterTop,WaterHeate
rtMid,WaterHeaterBot,ERVExhaust,ERVFresh,AHURet,AHUSupply,AHUtoWH,WHtoAHU,HWS
upplyEastTemp,HWSupplyWestTemp,ColdWaterSupply,TopFloorTemp,FridgeTemp,Freeze
rTemp,DishTemp,ColdWaterSupplyFlow,HWSupplyFlowWest,HWSupplyFlowEast,AHULoopF
low,NaturalGasFlow,BasementPower,OverPower,GaragePower,LivingRoomPower,Master
BRPower,InverterPos,InverterNeg,BathPowerPos,BathPowerNeg,KitLightRecepPower,
DishPower,DryerPower,KitchenRecepPower,GridL1Power,GridL2Power,MainFloorRecep
tPower,WasherPower,HVACPower]=textread(dataFile,'%s %s %f %f %f %f %f %f %f
%f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f
%f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f
', 'headerlines',4);
[Year,Month,Day]=datevec(Date);
DateVector=datevec(Time,'HH:MM');
Hour=DateVector(:,4);
Hour = Hour + 1;
Minute=DateVector(:,5);
OutsideAirTemp = (OutsideAirTemp-32)/1.8;
WindSpeed = WindSpeed*.44704;
MainFloorTemp = (MainFloorTemp-32)/1.8;
StartHour = Hour(1);
StartMinute = Minute(1);
StartDay = Day(1);
StartMonth = Month(1);
WHtoAHU = (WHtoAHU-32)/1.8;
AHUSupply = (AHUSupply-32)/1.8;
AHUtoWH = (AHUtoWH-32)/1.8;
CoilFlow = AHULoopFlow*.0630902;
Cp=4186;
coilEnergy = 60*Cp*bsxfun(@times,CoilFlow,WHtoAHU-AHUtoWH);
numrecords = length(MainFloorReceptPower);
for n = 1:numrecords
    if n == 1
        MainFloorReceptPowerFix(n) = 0;
        HVACPowerFix(n) = 0;
        WasherPowerFix(n) = 0;
    else
        MainFloorReceptPowerFix(n) = 1000*(MainFloorReceptPower(n) -
MainFloorReceptPower(n-1));
        HVACPowerFix(n) = 1000*(HVACPower(n)-HVACPower(n-1))-(55/60);
        WasherPowerFix(n) = 1000*(WasherPower(n)-WasherPower(n-1));
    end
end
```

```

    if BathPowerNeg(n) == 99999
        BathPowerNeg(n) = 0;
        BathPowerPos(n) = 0;
        KitLightRecepPower(n) = 0;
        KitchenRecepPower(n) = 0;
        DishPower(n) = 0;
        DryerPower(n) = 0;
    end
    if HVACPowerFix(n) < 0
        HVACPowerFix(n) = 0;
    end
    if coilEnergy(n) < 0
        coilEnergy(n) = 0;
    end
end

MainFloorReceptPower = transpose(MainFloorReceptPowerFix);
HVACPower = transpose(HVACPowerFix);
WasherPower = transpose(WasherPowerFix);
clear MainFloorReceptPowerFix;
clear HVACPowerFix;
clear WasherPowerFix;
MainFloorGains = MainFloorReceptPower + MasterBRPower + BathPowerNeg +
BathPowerPos;
TopFloorGains = KitLightRecepPower + KitchenRecepPower + DishPower +
OverPower + LivingRoomPower;
BasementGains = WasherPower + DryerPower + BasementPower;

```

B.10 Process Results Script

The following script reads the output from a specified EnergyPlus run and writes desired variables into the MATLAB workspace for use by other MATLAB functions and scripts.

```

fileName = 'IDFiterate.csv'; %Defines the EnergyPlus output file to be
processed

fileID = fopen(fileName);

%Puts all Energy+ output into one cell array
tmp = textscan(fileID, '%s', 'MultipleDelimsAsOne', 1, 'Delimiter',
'\r', 'BufSize', 4095*16);
cellArray = tmp{1};
fclose('all');
% Get the first row in the file. This is the header row that defines
% the columns of the results
tmp = textscan(cellArray{1}, '%s', 'Delimiter', ',', 'BufSize', 4095*16);
names = tmp{1};

% i is the number of records
leni = length(cellArray);

% j is the number of fields
lenj = length(names);

```

```

%Gets rid of special charactors
for h = 1:lenj
    names{h}=genvarname(names{h});
end

for i=2:leni;

    tmp = textscan(cellArray{i}, '%s', 'Delimiter',
    ',', 'BufSize', 4095*16);
    row = tmp{1};
    j=75; %This variable assigns which column in the EnergyPlus output
    file will be written to the "dataStruct" structure.
    if j>length(row) || isempty(row{j});
        v = -99999;
    else
        v = str2double(row{j});
    end
    dataStruct.(names{j})(i-1) = v;
end

```

B.11 Interval Error Calculation Function

The following function takes the output from the EnergyPlus run, the measured data, starting record, ending record, and size of interval as arguments and calculates the RMS error between the measured energy consumption and the simulated energy consumption based on these input parameters.

```

function error =
calcIntervalError(dataStruct,measuredVariable,measuredVariable2,startRecord,e
ndRecord,timestep)

compareArray(:,1) = measuredVariable(startRecord:endRecord,1);
compareArray(:,2) = measuredVariable2(startRecord:endRecord,1);
compareArray(:,3) =
transpose(dataStruct.AHU0x3AAirLoopTotalHeatingEnergy0x5BJ0x5D0x28TimeStep0x2
9(1,startRecord+6539:endRecord+6539));

lenn=length(compareArray);
count = 0;
modelCount = 0;
numIntervals = fix(lenn/timestep);
m = 1;

for i = 1:numIntervals

    cumMeasured = 0;
    cumModelEnergy = 0;

    for n = m:i*timestep;
        if compareArray(n,1)<1;
            count = count;
        else

```

```

        count = count+1;
        AHUEnergy = compareArray(n,1)*3600;
        coilEnergy = compareArray(n,2);
        cumMeasured = cumMeasured + AHUEnergy + coilEnergy;
    end
    if compareArray(n,3)<1;
        modelCount = modelCount;
    else
        modelCount = modelCount+1;
        cumModelEnergy = cumModelEnergy + compareArray(n,3);
    end
end

Output(i,1) = cumMeasured;
Output(i,2) = cumModelEnergy;

m = (i*timestep)+1;

end

count
modelCount
sqError = 0;
for i = 1:numIntervals
    sqError = sqError + (Output(i,1)-Output(i,2))^2;
end
error = sqrt(sqError/numIntervals);
end

```

B.12 Moving Average Calculation Function

The following function takes the output from the EnergyPlus run, the measured data, starting record, ending record, size of the moving average window, and time step between each moving average calculation as arguments and calculates the RMS error between the measured energy consumption and the simulated energy consumption based on these input parameters.

```

function error =
movingAverage(dataStruct,measuredVariable,measuredVariable2,startRecord,endRe
cord,timestep>window)

compareArray(:,1) = measuredVariable(startRecord:endRecord,1);
compareArray(:,2) = measuredVariable2(startRecord:endRecord,1);
compareArray(:,3) =
transpose(dataStruct.AHU0x3AAirLoopTotalHeatingEnergy0x5BJ0x5D0x28TimeStep0x2
9(1,startRecord+6539:endRecord+6539));

lenn=length(compareArray);

NumIterations = fix(lenn/timestep);

```

```

while NumIterations*timestep+(window-timestep)>lenn
    NumIterations = NumIterations-1;
end

NumIterations;

index = 1;

for i = 1:NumIterations
    cumModelEnergy = 0;
    cumMeasuredEnergy = 0;

    for n = index:(index+window-1)
        AHUEnergy = compareArray(n,1)*3600;
        coilEnergy = compareArray(n,2);
        cumMeasuredEnergy = cumMeasuredEnergy + AHUEnergy + coilEnergy;
        cumModelEnergy = cumModelEnergy + compareArray(n,3);
    end

    Output(i,1) = cumMeasuredEnergy;
    Output(i,2) = cumModelEnergy;

    index = index + timestep;
end

sqError = 0;

for m = 1:NumIterations
    sqError = sqError + (Output(m,1)-Output(m,2))^2;
end

error = sqrt(sqError/NumIterations)

end

```

B.13 Temperature RMSE Function

The following function takes the output from the EnergyPlus run, the measured data, starting record, and ending record and calculates the RMSE between the measured temperature and simulated temperature at every minute between the starting and ending point.

```

function RMSError =
calcError(dataStruct,measuredVariable,startRecord,endRecord)

compareArray(:,1) = measuredVariable(startRecord:endRecord,1);
compareArray(:,2) =
transpose(dataStruct.FIRSTFLOOR0x3AZoneMeanAirTemperature0x5BC0x5D0x28TimeSte
p0x29(1,startRecord+6539:endRecord+6539));

lenn=length(compareArray);
count = 0;

```

```

cumError = 0;

for n = 1:lenn;
    if compareArray(n,1)==0;
        count = count;
    else
        count = count+1;
        sqError = (compareArray(n,1)-compareArray(n,2))^2;
        cumError = cumError+sqError;
    end
end

RMSError = sqrt(cumError/count);

End

```

B.14 Water Heater Error Function

The following function calculates the error for the water heater optimizer.

```

function error =
calcWHerror(dataStruct,measuredVariable,startRecord,endRecord)

compareArray(:,1) = measuredVariable(startRecord:endRecord,1);
compareArray(:,2) =
transpose(dataStruct.AHUHEATINGCOILHWINLET0x3ASystemNodeTemp0x5BC0x5D0x28Time
Step0x2(1,startRecord+6539:endRecord+6539));

lenn=length(compareArray);

measuredAverage = sum(compareArray(:,1))/lenn;
modelAverage = sum(compareArray(:,2))/lenn;
tempError = sqrt((measuredAverage-modelAverage)^2);

measuredSlope = .094907; %degrees C per minute
[Y,minIndex] = min(compareArray(1:lenn-20,2));
modelSlope = (compareArray(minIndex+12,2)-compareArray(minIndex+2,2))/10;
slopeError = 5*sqrt((measuredSlope-modelSlope)^2);

measuredDeadband = max(compareArray(:,1))-min(compareArray(:,1));
modelDeadband = max(compareArray(:,2))-min(compareArray(:,2));
deadbandError = sqrt((measuredDeadband-modelDeadband)^2);

error = deadbandError+slopeError+tempError

end

```

B.15 HVAC System Error Function

The following function calculates the error for the HVAC system optimizer.

```

function error =
calcHVACError(dataStruct,measuredVariable,startRecord,endRecord)

```



```

compareArray(:,1) = measuredVariable(startRecord:endRecord,1);
compareArray(:,2) =
transpose(dataStruct.AHU0x3AAirLoopTotalHeatingCoilEnergy0x5BJ0x5D0x28TimeSte
p0x29(1,startRecord+6539:endRecord+6539));

lenn=length(compareArray);
cumError = 0;
count = 0;

for n = 1:lenn;

    if compareArray(n,1)==0;
        count = count;
    elseif compareArray(n-1,1)==0;
        count = count;
    else
        sqError = (compareArray(n,1)-compareArray(n,2))^2;
        cumError = cumError+sqError;
        count = count + 1;
    end
end

error = sqrt(cumError/count);

end

```

B.16 Create Internal Gains Schedule

The following function uses variables in the workspace of MATLAB to write a CSV file to the working directory that can be read by the EnergyPlus IDF. This function was used to create internal gain schedules after combining several of the plug/lighting load variables by zone.

```

function Schedule = createSchedule(startHour,variable,fileName)
clear Schedule;
numrecords = length(variable);
endHour = startHour + numrecords/60;
index = 1;
for n = 1:8760
    if n < startHour
        Schedule(n,:) = 0;
    elseif n > endHour-1
        Schedule(n,:) = 0;
    else
        Schedule(n,:) = sum(variable(index:index+59,1));
        index = index + 60;
    end
end
ScheduleMax = max(Schedule)
ScheduleFraction = Schedule/ScheduleMax;
csvwrite(fileName,ScheduleFraction);

```

B.17 Weather File Creation

The following script creates the .def and .txt weather files needed by the weather converter program included with EnergyPlus. Data is read from the CSV file that has been entered into the MATLAB workspace by using the “DataRead” script and the following code uses these data to save the two required files for the weather converter program. After the weather converter program is run, the EPW file can be used for all EnergyPlus simulations.

```
WindDir = linspace(90,90,1+max(Record))';
Weather = [Month, Day, Hour, Minute, OutsideAirTemp, OutsideAirRH,
GlobalHoriz, WindSpeed, WindDir];
[numrecords,numcategories] = size(Weather);
clear Weather
numdummyrecords = (StartHour-1)*60 + StartMinute;
index = 1;
hourfill = 1;
minutefill = 0;

for index = 1:numdummyrecords
    if minutefill<60
        Weather(index,:) = [Month(1), Day(1), hourfill, minutefill,
MainFloorTemp(1), MainFloorRH(1),0, WindSpeed(1), WindDir(1)];
        minutefill = minutefill+1;
    else
        minutefill = 0;
        hourfill = hourfill+1;
        Weather(index,:) = [Month(1), Day(1), hourfill, minutefill,
MainFloorTemp(1), MainFloorRH(1),0, WindSpeed(1), WindDir(1)];
        minutefill = minutefill+1;
    end
end

Weather(numdummyrecords+1:numdummyrecords+numrecords,:)= [Month, Day, Hour,
Minute, OutsideAirTemp, OutsideAirRH, GlobalHoriz, WindSpeed, WindDir];

WeatherTxtFileName = strcat(WeatherFileName, '.txt');
csvwrite(WeatherTxtFileName,Weather);
WeatherDefFileName = strcat(WeatherFileName, '.def');
Line1 = char('&location');
Line2 = char('City=' 'Warner House' '');
Line3 = char('StateProv=' 'Boulder, CO' '');
Line4 = char('Country=' 'USA' '');
Line5 = char('InWMO=' ' ');
Line6 = char('InLat=40.02');
Line7 = char('InLong=-105.28');
Line8 = char('InElev=1646');
Line9 = char('InTime=-7');
Line10 = char('/');
Line11 = char('&miscdata');
Line12 = char('Comments1=' 'Warner House Test Weather File' '');
Line13 = char('/');
```

```

Line14 = char('&wthdata');
Line15 = char('NumInHour=60');
Line16 = char('InputFileType=''CUSTOM'');
Line17 = char('InFormat=''DELIMITED'');
Line18 =
char('DataElements=Month,Day,Hour,Minute,DryBulb,Relative_Humidity,glohorrad,
Wind_Speed,WindDir');
Line19 = char('DataUnits=x,x,x,x,'C','%', 'wh/m2','m/s','deg');
Line20 = char('DataConversionFactors=1,1,1,1,1,1,1,1,1,1');
Line21 = char('DelimiterChar=', '');
Line22 = char('/');
Line23 = char('&datacontrol');
Line24 = char('NumRecordsToSkip=0');
Line25 = char('/');
WeatherDefFile
=char(Line1,Line2,Line3,Line4,Line5,Line6,Line7,Line8,Line9,Line10,Line11,Line12,Line13,Line14,Line15,Line16,Line17,Line18,Line19,Line20,Line21,Line22,Line23,Line24,Line25);
dlmwrite(WeatherDefFileName,WeatherDefFile, '');

```

APPENDIX C ENERGYPLUS FILE FOR PILOT HOUSE

This appendix contains the EnergyPlus file for the pilot house. This IDF is for the model that is used during the 4 month prediction period. When the IDF is being used for the temperature calibration (scenarios 1-3), the procedures described in section 4.6.2.1 and appendix A.3 should be implemented into the IDF in place of the Energy Management System.

!-Generator IDFEditor 1.38a

!-Option SortedOrder

!-NOTE: All comments with '!' are ignored by the IDFEditor and are generated automatically.

!- Use '!' comments if they need to be retained when using the IDFEditor.

!- ===== ALL OBJECTS IN CLASS: VERSION =====

Version,

6.0; !- Version Identifier

!- ===== ALL OBJECTS IN CLASS: SIMULATIONCONTROL =====

SimulationControl,

Yes, !- Do Zone Sizing Calculation

Yes, !- Do System Sizing Calculation

Yes, !- Do Plant Sizing Calculation

Yes, !- Run Simulation for Sizing Periods

Yes; !- Run Simulation for Weather File Run Periods

!- ===== ALL OBJECTS IN CLASS: BUILDING =====

Building,

Untitled, !- Name

0.0, !- North Axis {deg}

City, !- Terrain

0.04, !- Loads Convergence Tolerance Value

0.4, !- Temperature Convergence Tolerance Value {deltaC}

FullExterior, !- Solar Distribution

25; !- Maximum Number of Warmup Days

!- ===== ALL OBJECTS IN CLASS: ZONEAIRHEATBALANCEALGORITHM =====

=====

ZoneAirHeatBalanceAlgorithm,

ThirdOrderBackwardDifference; !- Algorithm

!- ===== ALL OBJECTS IN CLASS:

ZONECAPACITANCEMULTIPLIER:RESEARCHSPECIAL =====

ZoneCapacitanceMultiplier:ResearchSpecial,

66, !- Temperature Capacity Multiplier

1, !- Humidity Capacity Multiplier

1; !- Carbon Dioxide Capacity Multiplier

!- ===== ALL OBJECTS IN CLASS: TIMESTEP =====

Timestep,

60; !- Number of Timesteps per Hour

!- ===== ALL OBJECTS IN CLASS: SITE:LOCATION =====

Site:Location,

Boulder (CO), !- Name

40.015913, !- Latitude {deg}

```

-105.292509,      !- Longitude {deg}
-7.0,             !- Time Zone {hr}
1648.00;          !- Elevation {m}
!- ===== ALL OBJECTS IN CLASS: SIZINGPERIOD:WEATHERFILEDAYS
=====
SizingPeriod:WeatherFileDays,
  Heating DD,      !- Name
  1,               !- Begin Month
  11,              !- Begin Day of Month
  1,               !- End Month
  11,              !- End Day of Month
  Monday,          !- Day of Week for Start Day
  Yes,             !- Use Weather File Daylight Saving Period
  Yes;            !- Use Weather File Rain and Snow Indicators
!- ===== ALL OBJECTS IN CLASS: RUNPERIOD =====
RunPeriod,
,                 !- Name
1,               !- Begin Month
7,               !- Begin Day of Month
5,               !- End Month
31,              !- End Day of Month
Friday,          !- Day of Week for Start Day
No,              !- Use Weather File Holidays and Special Days
Yes,             !- Use Weather File Daylight Saving Period
No,              !- Apply Weekend Holiday Rule
Yes,             !- Use Weather File Rain Indicators
Yes,             !- Use Weather File Snow Indicators
1;               !- Number of Times Runperiod to be Repeated
!- ===== ALL OBJECTS IN CLASS: RUNPERIODCONTROL:DAYLIGHTSAVINGTIME
=====
! Daylight Saving Period in US
RunPeriodControl:DaylightSavingTime,
  2nd Sunday in March, !- Start Date
  1st Sunday in November; !- End Date
!- ===== ALL OBJECTS IN CLASS: SITE:WATERMAINSTEMPERATURE
=====
Site:WaterMainsTemperature,
  Correlation,      !- Calculation Method
,                  !- Temperature Schedule Name
9.69,              !- Annual Average Outdoor Air Temperature {C}
28.1;              !- Maximum Difference In Monthly Average Outdoor Air Temperatures {deltaC}
!- ===== ALL OBJECTS IN CLASS: SCHEDULETYPELIMITS =====
ScheduleTypeLimits,
  Any Number;      !- Name
ScheduleTypeLimits,
  Fraction,         !- Name
  0.0,              !- Lower Limit Value
  1.0,              !- Upper Limit Value
  CONTINUOUS;      !- Numeric Type
ScheduleTypeLimits,
  Temperature,     !- Name

```

```

-60,          !- Lower Limit Value
200,          !- Upper Limit Value
CONTINUOUS;    !- Numeric Type
ScheduleTypeLimits,
  On/Off,      !- Name
  0,          !- Lower Limit Value
  1,          !- Upper Limit Value
  DISCRETE;    !- Numeric Type
ScheduleTypeLimits,
  Control Type, !- Name
  0,          !- Lower Limit Value
  4,          !- Upper Limit Value
  DISCRETE;    !- Numeric Type
ScheduleTypeLimits,
  Humidity,    !- Name
  10,          !- Lower Limit Value
  90,          !- Upper Limit Value
  CONTINUOUS;  !- Numeric Type
ScheduleTypeLimits,
  Number;      !- Name
!
! -----
! New objects created from ExpandObjects
! -----
!
ScheduleTypeLimits,
  HVACTemplate Any Number; !- Name
!- ===== ALL OBJECTS IN CLASS: SCHEDULE:COMPACT =====
Schedule:Compact,
  Always On,    !- Name
  Any Number,   !- Schedule Type Limits Name
  Through: 12/31, !- Field 1
  For: AllDays, !- Field 2
  Until: 24:00, !- Field 3
  1.0;          !- Field 4
Schedule:Compact,
  Always Off,   !- Name
  Fraction,     !- Schedule Type Limits Name
  Through: 12/31, !- Field 1
  For: AllDays, !- Field 2
  Until: 24:00, !- Field 3
  0.0;          !- Field 4
Schedule:Compact,
  Heating_Setpoint_Schedule, !- Name
  Temperature, !- Schedule Type Limits Name
  Through: 1/16, !- Field 1
  For: AllDays, !- Field 2
  Until: 24:00, !- Field 3
  0,            !- Field 4
  Through: 1/17, !- Field 5
  For: AllDays, !- Field 6

```

Until: 18:48, !- Field 7
 0, !- Field 8
 Until: 24:00, !- Field 9
 21.11, !- Field 10
 Through: 1/18, !- Field 11
 For: AllDays, !- Field 12
 Until: 24:00, !- Field 13
 21.11, !- Field 14
 Through: 1/19, !- Field 15
 For: AllDays, !- Field 16
 Until: 8:00, !- Field 17
 21.11, !- Field 18
 Until: 24:00, !- Field 19
 19.44, !- Field 20
 Through: 1/23, !- Field 21
 For: AllDays, !- Field 22
 Until: 24:00, !- Field 23
 19.44, !- Field 24
 Through: 1/24, !- Field 25
 For: AllDays, !- Field 26
 Until: 10:18, !- Field 27
 19.44, !- Field 28
 Until: 24:00, !- Field 29
 21.11, !- Field 30
 Through: 1/25, !- Field 31
 For: AllDays, !- Field 32
 Until: 18:32, !- Field 33
 21.11, !- Field 34
 Until: 24:00, !- Field 35
 20.83, !- Field 36
 Through: 1/26, !- Field 37
 For: AllDays, !- Field 38
 Until: 1:49, !- Field 39
 20.83, !- Field 40
 Until: 24:00, !- Field 41
 22.78, !- Field 42
 Through: 1/27, !- Field 43
 For: AllDays, !- Field 44
 Until: 19:28, !- Field 45
 22.78, !- Field 46
 Until: 24:00, !- Field 47
 21.11, !- Field 48
 Through: 1/28, !- Field 43
 For: AllDays, !- Field 44
 Until: 14:00, !- Field 45
 21.11, !- Field 46
 Until: 24:00, !- Field 47
 0, !- Field 48
 Through: 2/2, !- Field 49
 For: AllDays, !- Field 50
 Until: 24:00, !- Field 51

0, !- Field 52
 Through: 2/3, !- Field 49
 For: AllDays, !- Field 50
 Until: 20:21, !- Field 51
 0, !- Field 52
 Until: 24:00, !- Field 57
 21.11, !- Field 58
 Through: 2/4, !- Field 53
 For: AllDays, !- Field 54
 Until: 6:40, !- Field 55
 21.11, !- Field 56
 Until: 24:00, !- Field 57
 20.2, !- Field 58
 Through: 2/9, !- Field 59
 For: AllDays, !- Field 60
 Until: 24:00, !- Field 61
 20.2, !- Field 62
 Through: 2/10, !- Field 63
 For: AllDays, !- Field 64
 Until: 17:22, !- Field 65
 20.22, !- Field 66
 Until: 24:00, !- Field 67
 21.9, !- Field 68
 Through: 2/16, !- Field 69
 For: AllDays, !- Field 70
 Until: 24:00, !- Field 71
 21.9, !- Field 72
 Through: 2/17, !- Field 73
 For: AllDays, !- Field 74
 Until: 3:00, !- Field 75
 21.9, !- Field 76
 Until: 24:00, !- Field 79
 17.22, !- Field 80
 Through: 2/21, !- Field 81
 For: AllDays, !- Field 82
 Until: 24:00, !- Field 83
 17.22, !- Field 84
 Through: 2/22, !- Field 85
 For: AllDays, !- Field 86
 Until: 18:37, !- Field 87
 17.22, !- Field 88
 Until: 24:00, !- Field 89
 21.11, !- Field 90
 Through: 2/23, !- Field 91
 For: AllDays, !- Field 92
 Until: 12:31, !- Field 93
 21.11, !- Field 94
 Until: 24:00, !- Field 95
 20.4, !- Field 96
 Through: 2/24, !- Field 91
 For: AllDays, !- Field 92

Until: 13:25, !- Field 93
 20.4, !- Field 94
 Until: 24:00, !- Field 95
 0, !- Field 96
 Through: 2/27, !- Field 97
 For: AllDays, !- Field 98
 Until: 24:00, !- Field 99
 0, !- Field 100
 Through: 2/28, !- Field 97
 For: AllDays, !- Field 98
 Until: 12:00, !- Field 99
 0, !- Field 100
 Until: 24:00, !- Field 99
 20.4, !- Field 100
 Through: 3/3, !- Field 97
 For: AllDays, !- Field 98
 Until: 24:00, !- Field 99
 20.4, !- Field 100
 Through: 3/4, !- Field 101
 For: AllDays, !- Field 102
 Until: 20:05, !- Field 103
 20.4, !- Field 104
 Until: 24:00, !- Field 105
 21.14, !- Field 106
 Through: 3/5, !- Field 107
 For: AllDays, !- Field 108
 Until: 6:51, !- Field 109
 22.6, !- Field 110
 Until: 24:00, !- Field 111
 21.0, !- Field 112
 Through: 3/6, !- Field 113
 For: AllDays, !- Field 114
 Until: 24:00, !- Field 115
 21.0, !- Field 116
 Through: 3/7, !- Field 117
 For: AllDays, !- Field 118
 Until: 7:50, !- Field 119
 21.0, !- Field 120
 Until: 22:13, !- Field 121
 22.4, !- Field 122
 Until: 24:00, !- Field 123
 20.0, !- Field 124
 Through: 3/8, !- Field 125
 For: AllDays, !- Field 126
 Until: 1:10, !- Field 127
 20.0, !- Field 128
 Until: 10:26, !- Field 129
 21.9, !- Field 130
 Until: 17:21, !- Field 131
 21.4, !- Field 132
 Until: 24:00, !- Field 133

20.5, !- Field 134
 Through: 3/9, !- Field 125
 For: AllDays, !- Field 126
 Until: 24:00, !- Field 127
 20.5, !- Field 128
 Through: 3/10, !- Field 125
 For: AllDays, !- Field 126
 Until: 14:41, !- Field 127
 20.5, !- Field 128
 Until: 24:00, !- Field 127
 0, !- Field 128
 Through: 4/6, !- Field 135
 For: AllDays, !- Field 136
 Until: 24:00, !- Field 137
 0,
 Through: 4/7, !- Field 125
 For: AllDays, !- Field 126
 Until: 21:49, !- Field 127
 0, !- Field 128
 Until: 24:00, !- Field 127
 19.85, !- Field 128
 Through: 4/8, !- Field 139
 For: AllDays, !- Field 140
 Until: 24:00, !- Field 141
 19.85, !- Field 142
 Through: 4/9, !- Field 143
 For: AllDays, !- Field 144
 Until: 12:57, !- Field 145
 19.85, !- Field 146
 Until: 22:05, !- Field 147
 21.4, !- Field 148
 Until: 24:00, !- Field 149
 0, !- Field 150
 Through: 4/10, !- A153
 For: AllDays, !- A154
 Until: 24:00, !- A155
 0, !- A156
 Through: 4/11, !- A157
 For: AllDays, !- A158
 Until: 5:56, !- A159
 0, !- A160
 Until: 6:25, !- A161
 20.0, !- A162
 Until: 24:00, !- A163
 19.0, !- A164
 Through: 4/12, !- A165
 For: AllDays, !- A166
 Until: 3:36, !- A167
 19.0, !- A168
 Until: 24:00, !- A169
 21.0, !- A170

Through: 4/13, !- A171
 For: AllDays, !- A172
 Until: 2:17, !- A173
 21.0, !- A174
 Until: 17:45, !- A175
 21.9, !- A176
 Until: 24:00, !- A177
 23.0, !- A178
 Through: 4/14, !- A179
 For: AllDays, !- A180
 Until: 7:21, !- A181
 23.0, !- A182
 Until: 24:00, !- A183
 22.0, !- A184
 Through: 4/15, !- A185
 For: AllDays, !- A186
 Until: 8:27, !- A187
 22.0, !- A188
 Until: 22:30, !- A189
 19.9, !- A190
 Until: 24:00, !- A191
 21.8, !- A192
 Through: 4/16, !- A193
 For: AllDays, !- A194
 Until: 8:39, !- A195
 21.8, !- A196
 Until: 24:00, !- A197
 20.0, !- A198
 Through: 4/22, !- A199
 For: AllDays, !- A200
 Until: 24:00, !- A201
 20.0, !- A202
 Through: 4/24, !- A203
 For: AllDays, !- A204
 Until: 24:00, !- A205
 19.0, !- A206
 Through: 4/25, !- A207
 For: AllDays, !- A208
 Until: 18:00, !- A209
 19.0, !- A210
 Until: 24:00, !- A211
 21.0, !- A212
 Through: 4/26, !- A213
 For: AllDays, !- A214
 Until: 6:00, !- A215
 21.0, !- A216
 Until: 24:00, !- A217
 20.0, !- A218
 Through: 4/27, !- A219
 For: AllDays, !- A220
 Until: 6:13, !- A221

20.0, !- A222
 Until: 24:00, !- A223
 19.0, !- A224
 Through: 4/28, !- A225
 For: AllDays, !- A226
 Until: 24:00, !- A231
 19.0, !- A232
 Through: 4/29, !- A233
 For: AllDays, !- A234
 Until: 24:00, !- A235
 19.0, !- A236
 Through: 4/30, !- A237
 For: AllDays, !- A238
 Until: 13:45, !- A239
 19.0, !- A240
 Until: 22:20, !- A241
 20.5, !- A242
 Until: 24:00, !- A243
 21.5, !- A244
 Through: 5/1, !- A245
 For: AllDays, !- A246
 Until: 11:24, !- A247
 21.5, !- A248
 Until: 24:00, !- A249
 19.0, !- A250
 Through: 5/2, !- A251
 For: AllDays, !- A252
 Until: 18:42, !- A253
 19.5, !- A254
 Until: 24:00, !- A255
 21.3, !- A256
 Through: 5/3, !- A257
 For: AllDays, !- A258
 Until: 12:00, !- A259
 21.3, !- A260
 Until: 24:00, !- A261
 20.0, !- A262
 Through: 5/5, !- A263
 For: AllDays, !- A264
 Until: 14:22, !- A265
 20.0, !- A266
 Until: 24:00, !- A265
 0, !- A266
 Through: 5/16, !- A263
 For: AllDays, !- A264
 Until: 24:00, !- A265
 0, !- A266
 Through: 5/17, !- A267
 For: AllDays, !- A268
 Until: 11:00, !- A269
 0, !- A270

Until: 24:00, !- A271
 20.7, !- A272
 Through: 5/18, !- A273
 For: AllDays, !- A274
 Until: 10:23, !- A275
 20.7, !- A276
 Until: 22:53, !- A277
 21.0, !- A278
 Until: 24:00, !- A277
 20.5, !- A278
 Through: 5/19, !- A279
 For: AllDays, !- A280
 Until: 24:00, !- A281
 20.5, !- A282
 Through: 5/20, !- A283
 For: AllDays, !- A284
 Until: 10:44, !- A285
 20.5, !- A286
 Until: 24:00, !- A287
 19.0, !- A288
 Through: 5/23, !- A289
 For: AllDays, !- A290
 Until: 24:00, !- A291
 19.0, !- A292
 Through: 5/24, !- A293
 For: AllDays, !- A294
 Until: 8:54, !- A295
 19.0, !- A296
 Until: 24:00, !- A297
 21.0, !- A298
 Through: 5/25, !- A299
 For: AllDays, !- A300
 Until: 8:00, !- A301
 21.0, !- A302
 Until: 24:00, !- A303
 18.0, !- A304
 Through: 12/31, !- A305
 For: AllDays, !- A306
 Until: 24:00, !- A307
 18.0; !- A308
 Schedule:Compact,
 HVACTemplate-Always 1, !- Name
 HVACTemplate Any Number, !- Schedule Type Limits Name
 Through: 12/31, !- Field 1
 For: AllDays, !- Field 2
 Until: 24:00, !- Field 3
 1; !- Field 4
 Schedule:Compact,
 HVACTemplate-Always 4, !- Name
 HVACTemplate Any Number, !- Schedule Type Limits Name
 Through: 12/31, !- Field 1

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For: AllDays,      !- Field 2
Until: 24:00,      !- Field 3
4;                !- Field 4
Schedule:Compact,
HVACTemplate-Always 20, !- Name
HVACTemplate Any Number, !- Schedule Type Limits Name
Through: 12/31,      !- Field 1
For: AllDays,        !- Field 2
Until: 24:00,        !- Field 3
20;                 !- Field 4
Schedule:Compact,
HVACTemplate-Always 25, !- Name
HVACTemplate Any Number, !- Schedule Type Limits Name
Through: 12/31,      !- Field 1
For: AllDays,        !- Field 2
Until: 24:00,        !- Field 3
25;                 !- Field 4
Schedule:Compact,
HVACTemplate-Always 12.8,!- Name
HVACTemplate Any Number, !- Schedule Type Limits Name
Through: 12/31,      !- Field 1
For: AllDays,        !- Field 2
Until: 24:00,        !- Field 3
12.8;               !- Field 4
Schedule:Compact,
Hot Water Setpoint Temp Schedule, !- Name
Any Number,          !- Schedule Type Limits Name
THROUGH: 12/31,      !- Field 1
FOR: AllDays,        !- Field 2
UNTIL: 24:00,        !- Field 3
60.5;               !- Field 4
Schedule:Compact,
HVACTemplate-Always 60, !- Name
HVACTemplate Any Number, !- Schedule Type Limits Name
Through: 12/31,      !- Field 1
For: AllDays,        !- Field 2
Until: 24:00,        !- Field 3
60;                 !- Field 4
!- ===== ALL OBJECTS IN CLASS: SCHEDULE:FILE =====
Schedule:File,
MainFloorGains,      !- Name
Fraction,            !- Schedule Type Limits Name
I:\Writing\Prediction Period\MainFloorGains.txt, !- File Name
1,                   !- Column Number
0,                   !- Rows to Skip at Top
8760,                !- Number of Hours of Data
Tab;                 !- Column Separator
Schedule:File,
BasementGains,       !- Name
Fraction,            !- Schedule Type Limits Name
I:\Writing\Prediction Period\BasementGains.txt, !- File Name

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1,          !- Column Number
0,          !- Rows to Skip at Top
8760,       !- Number of Hours of Data
Tab;        !- Column Separator
Schedule:File,
  TopFloorGains,    !- Name
  Fraction,         !- Schedule Type Limits Name
  I:\Writing\Prediction Period\TopFloorGains.txt, !- File Name
  1,               !- Column Number
  0,               !- Rows to Skip at Top
  8760,           !- Number of Hours of Data
  Tab;            !- Column Separator
!- ===== ALL OBJECTS IN CLASS: MATERIAL =====
Material,
  F08 Metal surface, !- Name
  Smooth,           !- Roughness
  0.0008,          !- Thickness {m}
  45.28,           !- Conductivity {W/m-K}
  7824,            !- Density {kg/m3}
  500;             !- Specific Heat {J/kg-K}
Material,
  G01a 19mm gypsum board, !- Name
  MediumSmooth,     !- Roughness
  0.019,           !- Thickness {m}
  0.16,            !- Conductivity {W/m-K}
  800,             !- Density {kg/m3}
  1090;            !- Specific Heat {J/kg-K}
Material,
  M15 200mm heavyweight concrete, !- Name
  MediumRough,      !- Roughness
  0.2032,          !- Thickness {m}
  1.95,            !- Conductivity {W/m-K}
  2240,            !- Density {kg/m3}
  900;             !- Specific Heat {J/kg-K}
Material,
  G05 25mm wood,    !- Name
  MediumSmooth,     !- Roughness
  0.0254,          !- Thickness {m}
  0.15,            !- Conductivity {W/m-K}
  608,             !- Density {kg/m3}
  1630;            !- Specific Heat {J/kg-K}
Material,
  Basement Floor,   !- Name
  MediumRough,      !- Roughness
  0.1524,          !- Thickness {m}
  1.874,           !- Conductivity {W/m-K}
  2242,            !- Density {kg/m3}
  879,             !- Specific Heat {J/kg-K}
  0.9,             !- Thermal Absorptance
  0.7,             !- Solar Absorptance
  0.7;             !- Visible Absorptance

```

Material,

Hardboard Siding, !- Name
MediumRough, !- Roughness
0.016, !- Thickness {m}
0.216, !- Conductivity {W/m-K}
1000, !- Density {kg/m3}
837, !- Specific Heat {J/kg-K}
0.9, !- Thermal Absorptance
0.7, !- Solar Absorptance
0.7; !- Visible Absorptance

Material,

1" Extruded Polystyrene, !- Name
Smooth, !- Roughness
0.0254, !- Thickness {m}
2.306, !- Conductivity {W/m-K}
32, !- Density {kg/m3}
1465, !- Specific Heat {J/kg-K}
0.9, !- Thermal Absorptance
0.7, !- Solar Absorptance
0.7; !- Visible Absorptance

Material,

5.5" Blown-in Blanket, !- Name
VeryRough, !- Roughness
0.1397, !- Thickness {m}
.1518, !- Conductivity {W/m-K}
64, !- Density {kg/m3}
1465, !- Specific Heat {J/kg-K}
0.9, !- Thermal Absorptance
0.7, !- Solar Absorptance
0.7; !- Visible Absorptance

Material,

Shingles, !- Name
Rough, !- Roughness
0.00635, !- Thickness {m}
0.035, !- Conductivity {W/m-K}
1922, !- Density {kg/m3}
1256, !- Specific Heat {J/kg-K}
0.9, !- Thermal Absorptance
0.7, !- Solar Absorptance
0.7; !- Visible Absorptance

Material,

Roof Insulation, !- Name
VeryRough, !- Roughness
0.3048, !- Thickness {m}
.0434, !- Conductivity {W/m-K}
13, !- Density {kg/m3}
837, !- Specific Heat {J/kg-K}
0.9, !- Thermal Absorptance
0.7, !- Solar Absorptance
0.7; !- Visible Absorptance

Material,


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Internal Mass,      !- Name
MediumSmooth,      !- Roughness
0.15,              !- Thickness {m}
0.12,              !- Conductivity {W/m-K}
540,               !- Density {kg/m3}
1210,              !- Specific Heat {J/kg-K}
0.9,               !- Thermal Absorptance
0.7,               !- Solar Absorptance
0.7;               !- Visible Absorptance
!- ===== ALL OBJECTS IN CLASS: MATERIAL:AIRGAP =====
Material:AirGap,
  F04 Wall air space resistance, !- Name
  0.15;                !- Thermal Resistance {m2-K/W}
!- ===== ALL OBJECTS IN CLASS: WINDOWMATERIAL:SIMPLEGLAZINGSYSTEM
=====
WindowMaterial:SimpleGlazingSystem,
  Windows,            !- Name
  .7175,              !- U-Factor {W/m2-K}
  .4928,              !- Solar Heat Gain Coefficient
  0.72;               !- Visible Transmittance
!- ===== ALL OBJECTS IN CLASS: CONSTRUCTION =====
Construction,
  Exterior Floor,     !- Name
  Basement Floor;     !- Outside Layer
Construction,
  Interior Floor,     !- Name
  G01a 19mm gypsum board, !- Outside Layer
  G05 25mm wood;      !- Layer 2
Construction,
  Exterior Wall,      !- Name
  Hardboard Siding,   !- Outside Layer
  1" Extruded Polystyrene, !- Layer 2
  5.5" Blown-in Blanket, !- Layer 3
  F04 Wall air space resistance, !- Layer 4
  G01a 19mm gypsum board; !- Layer 5
Construction,
  Interior Wall,      !- Name
  G01a 19mm gypsum board, !- Outside Layer
  G01a 19mm gypsum board; !- Layer 2
Construction,
  Exterior Roof,      !- Name
  Shingles,           !- Outside Layer
  G05 25mm wood,      !- Layer 2
  Roof Insulation,    !- Layer 3
  G01a 19mm gypsum board; !- Layer 4
Construction,
  Interior Ceiling,   !- Name
  G05 25mm wood,     !- Outside Layer
  G01a 19mm gypsum board; !- Layer 2
Construction,
  Exterior Door,      !- Name

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    F08 Metal surface,      !- Outside Layer
    I01 25mm insulation board; !- Layer 2
Construction,
    Interior Door,          !- Name
    G05 25mm wood;          !- Outside Layer
Construction,
    Foundation Walls,       !- Name
    M15 200mm heavyweight concrete; !- Outside Layer
Construction,
    Simple Windows,         !- Name
    Windows;                !- Outside Layer
Construction,
    Interior Furnishings,    !- Name
    Internal Mass;          !- Outside Layer
!- ===== ALL OBJECTS IN CLASS: GLOBALGEOMETRYRULES =====
GlobalGeometryRules,
    UpperLeftCorner,        !- Starting Vertex Position
    Counterclockwise,      !- Vertex Entry Direction
    Relative,              !- Coordinate System
    Relative,              !- Daylighting Reference Point Coordinate System
    Relative;              !- Rectangular Surface Coordinate System
!- ===== ALL OBJECTS IN CLASS: ZONE =====
Zone,
    Basement,              !- Name
    0.0,                   !- Direction of Relative North {deg}
    -6.397911,             !- X Origin {m}
    -5.150398,             !- Y Origin {m}
    -2.234184,             !- Z Origin {m}
    ,                      !- Type
    1;                     !- Multiplier
Zone,
    FirstFloor,            !- Name
    0.0,                   !- Direction of Relative North {deg}
    -6.397911,             !- X Origin {m}
    -5.150398,             !- Y Origin {m}
    0.326136,              !- Z Origin {m}
    ,                      !- Type
    1;                     !- Multiplier
Zone,
    TopLevel,              !- Name
    0.0,                   !- Direction of Relative North {deg}
    -6.397911,             !- X Origin {m}
    -5.150398,             !- Y Origin {m}
    2.886456,              !- Z Origin {m}
    ,                      !- Type
    1;                     !- Multiplier
!- ===== ALL OBJECTS IN CLASS: BUILDINGSURFACE:DETAILED =====
BuildingSurface:Detailed,
    7B2034,                !- Name
    Floor,                 !- Surface Type
    Exterior Floor,        !- Construction Name

```

Basement, !- Zone Name
 Ground, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 , !- View Factor to Ground
 12, !- Number of Vertices
 10.968449963194, !- Vertex 1 X-coordinate {m}
 10.391795956877, !- Vertex 1 Y-coordinate {m}
 0.000000000000, !- Vertex 1 Z-coordinate {m}
 12.594601351525, !- Vertex 2 X-coordinate {m}
 5.311718431658, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 11.675349227914, !- Vertex 3 X-coordinate {m}
 5.017462466151, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 12.047040973818, !- Vertex 4 X-coordinate {m}
 3.856301888958, !- Vertex 4 Y-coordinate {m}
 0.000000000000, !- Vertex 4 Z-coordinate {m}
 7.982978953643, !- Vertex 5 X-coordinate {m}
 2.555380778293, !- Vertex 5 Y-coordinate {m}
 0.000000000000, !- Vertex 5 Z-coordinate {m}
 7.611287207739, !- Vertex 6 X-coordinate {m}
 3.716541355486, !- Vertex 6 Y-coordinate {m}
 0.000000000000, !- Vertex 6 Z-coordinate {m}
 3.982660404012, !- Vertex 7 X-coordinate {m}
 2.555004649536, !- Vertex 7 Y-coordinate {m}
 0.000000000000, !- Vertex 7 Z-coordinate {m}
 4.354352149916, !- Vertex 8 X-coordinate {m}
 1.393844072343, !- Vertex 8 Y-coordinate {m}
 0.000000000000, !- Vertex 8 Z-coordinate {m}
 0.000000000000, !- Vertex 9 X-coordinate {m}
 0.000000000000, !- Vertex 9 Y-coordinate {m}
 0.000000000000, !- Vertex 9 Z-coordinate {m}
 -0.371691760461, !- Vertex 10 X-coordinate {m}
 1.161160602395, !- Vertex 10 Y-coordinate {m}
 0.000000000000, !- Vertex 10 Z-coordinate {m}
 -0.758745286192, !- Vertex 11 X-coordinate {m}
 1.037263353760, !- Vertex 11 Y-coordinate {m}
 0.000000000000, !- Vertex 11 Z-coordinate {m}
 -2.384896674523, !- Vertex 12 X-coordinate {m}
 6.117340878979, !- Vertex 12 Y-coordinate {m}
 0.000000000000, !- Vertex 12 Z-coordinate {m}
 BuildingSurface:Detailed,
 67B266, !- Name
 Wall, !- Surface Type
 Foundation Walls, !- Construction Name
 Basement, !- Zone Name
 Ground, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure

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NoWind,          !- Wind Exposure
0.0,             !- View Factor to Ground
4,              !- Number of Vertices
-0.371691760461, !- Vertex 1 X-coordinate {m}
1.161160602395,  !- Vertex 1 Y-coordinate {m}
2.560320000000,  !- Vertex 1 Z-coordinate {m}
-0.371691760461, !- Vertex 2 X-coordinate {m}
1.161160602395,  !- Vertex 2 Y-coordinate {m}
0.000000000000,  !- Vertex 2 Z-coordinate {m}
0.000000000000,  !- Vertex 3 X-coordinate {m}
0.000000000000,  !- Vertex 3 Y-coordinate {m}
0.000000000000,  !- Vertex 3 Z-coordinate {m}
0.000000000000,  !- Vertex 4 X-coordinate {m}
0.000000000000,  !- Vertex 4 Y-coordinate {m}
2.560320000000;  !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
64FA54,          !- Name
Wall,            !- Surface Type
Foundation Walls, !- Construction Name
Basement,        !- Zone Name
Ground,          !- Outside Boundary Condition
,               !- Outside Boundary Condition Object
NoSun,           !- Sun Exposure
NoWind,          !- Wind Exposure
0.0,             !- View Factor to Ground
4,              !- Number of Vertices
7.611287207739,  !- Vertex 1 X-coordinate {m}
3.716541355486,  !- Vertex 1 Y-coordinate {m}
2.560320000000,  !- Vertex 1 Z-coordinate {m}
7.611287207739,  !- Vertex 2 X-coordinate {m}
3.716541355486,  !- Vertex 2 Y-coordinate {m}
0.000000000000,  !- Vertex 2 Z-coordinate {m}
7.982978953643,  !- Vertex 3 X-coordinate {m}
2.555380778293,  !- Vertex 3 Y-coordinate {m}
0.000000000000,  !- Vertex 3 Z-coordinate {m}
7.982978953643,  !- Vertex 4 X-coordinate {m}
2.555380778293,  !- Vertex 4 Y-coordinate {m}
2.560320000000;  !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
432CE9,          !- Name
Wall,            !- Surface Type
Foundation Walls, !- Construction Name
Basement,        !- Zone Name
Ground,          !- Outside Boundary Condition
,               !- Outside Boundary Condition Object
NoSun,           !- Sun Exposure
NoWind,          !- Wind Exposure
0.0,             !- View Factor to Ground
4,              !- Number of Vertices
-0.758745286192, !- Vertex 1 X-coordinate {m}
1.037263353760,  !- Vertex 1 Y-coordinate {m}

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2.560320000000,      !- Vertex 1 Z-coordinate {m}
-0.758745286192,     !- Vertex 2 X-coordinate {m}
1.037263353760,      !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
-0.371691760461,     !- Vertex 3 X-coordinate {m}
1.161160602395,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
-0.371691760461,     !- Vertex 4 X-coordinate {m}
1.161160602395,      !- Vertex 4 Y-coordinate {m}
2.560320000000;      !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
227BEE,               !- Name
Wall,                 !- Surface Type
Foundation Walls,     !- Construction Name
Basement,             !- Zone Name
Ground,               !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
NoSun,                !- Sun Exposure
NoWind,               !- Wind Exposure
0.0,                  !- View Factor to Ground
4,                    !- Number of Vertices
11.675349227914,      !- Vertex 1 X-coordinate {m}
5.017462466151,       !- Vertex 1 Y-coordinate {m}
2.560320000000,       !- Vertex 1 Z-coordinate {m}
11.675349227914,      !- Vertex 2 X-coordinate {m}
5.017462466151,       !- Vertex 2 Y-coordinate {m}
0.000000000000,       !- Vertex 2 Z-coordinate {m}
12.594601351525,      !- Vertex 3 X-coordinate {m}
5.311718431658,       !- Vertex 3 Y-coordinate {m}
0.000000000000,       !- Vertex 3 Z-coordinate {m}
12.594601351525,      !- Vertex 4 X-coordinate {m}
5.311718431658,       !- Vertex 4 Y-coordinate {m}
2.560320000000;      !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
B5E520,               !- Name
Wall,                 !- Surface Type
Foundation Walls,     !- Construction Name
Basement,             !- Zone Name
Ground,               !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
NoSun,                !- Sun Exposure
NoWind,               !- Wind Exposure
0.0,                  !- View Factor to Ground
4,                    !- Number of Vertices
2.999985502208,       !- Vertex 1 X-coordinate {m}
7.841061350609,       !- Vertex 1 Y-coordinate {m}
2.560320000000,       !- Vertex 1 Z-coordinate {m}
2.999985502208,       !- Vertex 2 X-coordinate {m}
7.841061350609,       !- Vertex 2 Y-coordinate {m}
0.000000000000,       !- Vertex 2 Z-coordinate {m}
-2.384896674523,      !- Vertex 3 X-coordinate {m}

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6.117340878979,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
-2.384896674523,     !- Vertex 4 X-coordinate {m}
6.117340878979,      !- Vertex 4 Y-coordinate {m}
2.560320000000;      !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
911E99,               !- Name
Wall,                 !- Surface Type
Foundation Walls,     !- Construction Name
Basement,             !- Zone Name
Ground,               !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
NoSun,                !- Sun Exposure
NoWind,               !- Wind Exposure
0.0,                  !- View Factor to Ground
4,                    !- Number of Vertices
4.354352149916,       !- Vertex 1 X-coordinate {m}
1.393844072343,       !- Vertex 1 Y-coordinate {m}
2.560320000000,       !- Vertex 1 Z-coordinate {m}
4.354352149916,       !- Vertex 2 X-coordinate {m}
1.393844072343,       !- Vertex 2 Y-coordinate {m}
0.000000000000,       !- Vertex 2 Z-coordinate {m}
3.982660404012,       !- Vertex 3 X-coordinate {m}
2.555004649536,       !- Vertex 3 Y-coordinate {m}
0.000000000000,       !- Vertex 3 Z-coordinate {m}
3.982660404012,       !- Vertex 4 X-coordinate {m}
2.555004649536,       !- Vertex 4 Y-coordinate {m}
2.560320000000;      !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
D9932B,               !- Name
Wall,                 !- Surface Type
Foundation Walls,     !- Construction Name
Basement,             !- Zone Name
Ground,               !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
NoSun,                !- Sun Exposure
NoWind,               !- Wind Exposure
0.0,                  !- View Factor to Ground
4,                    !- Number of Vertices
12.047040973818,      !- Vertex 1 X-coordinate {m}
3.856301888958,       !- Vertex 1 Y-coordinate {m}
2.560320000000,       !- Vertex 1 Z-coordinate {m}
12.047040973818,      !- Vertex 2 X-coordinate {m}
3.856301888958,       !- Vertex 2 Y-coordinate {m}
0.000000000000,       !- Vertex 2 Z-coordinate {m}
11.675349227914,      !- Vertex 3 X-coordinate {m}
5.017462466151,       !- Vertex 3 Y-coordinate {m}
0.000000000000,       !- Vertex 3 Z-coordinate {m}
11.675349227914,      !- Vertex 4 X-coordinate {m}
5.017462466151,       !- Vertex 4 Y-coordinate {m}
2.560320000000;      !- Vertex 4 Z-coordinate {m}

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BuildingSurface:Detailed,
 4EF62C, !- Name
 Wall, !- Surface Type
 Foundation Walls, !- Construction Name
 Basement, !- Zone Name
 Ground, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 4, !- Number of Vertices
 7.982978953643, !- Vertex 1 X-coordinate {m}
 2.555380778293, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 7.982978953643, !- Vertex 2 X-coordinate {m}
 2.555380778293, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 12.047040973818, !- Vertex 3 X-coordinate {m}
 3.856301888958, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 12.047040973818, !- Vertex 4 X-coordinate {m}
 3.856301888958, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}

BuildingSurface:Detailed,
 538EE9, !- Name
 Wall, !- Surface Type
 Foundation Walls, !- Construction Name
 Basement, !- Zone Name
 Ground, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 4, !- Number of Vertices
 -2.384896674523, !- Vertex 1 X-coordinate {m}
 6.117340878979, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 -2.384896674523, !- Vertex 2 X-coordinate {m}
 6.117340878979, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 -0.758745286192, !- Vertex 3 X-coordinate {m}
 1.037263353760, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 -0.758745286192, !- Vertex 4 X-coordinate {m}
 1.037263353760, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}

BuildingSurface:Detailed,
 A7951A, !- Name
 Wall, !- Surface Type
 Foundation Walls, !- Construction Name
 Basement, !- Zone Name

Ground, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 4, !- Number of Vertices
 12.594601351525, !- Vertex 1 X-coordinate {m}
 5.311718431658, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 12.594601351525, !- Vertex 2 X-coordinate {m}
 5.311718431658, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 10.968449963194, !- Vertex 3 X-coordinate {m}
 10.391795956877, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 10.968449963194, !- Vertex 4 X-coordinate {m}
 10.391795956877, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}
 BuildingSurface:Detailed,
 6A0646, !- Name
 Wall, !- Surface Type
 Foundation Walls, !- Construction Name
 Basement, !- Zone Name
 Ground, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 4, !- Number of Vertices
 3.982660404012, !- Vertex 1 X-coordinate {m}
 2.555004649536, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 3.982660404012, !- Vertex 2 X-coordinate {m}
 2.555004649536, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 7.611287207739, !- Vertex 3 X-coordinate {m}
 3.716541355486, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 7.611287207739, !- Vertex 4 X-coordinate {m}
 3.716541355486, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}
 BuildingSurface:Detailed,
 AFD051, !- Name
 Ceiling, !- Surface Type
 Interior Ceiling, !- Construction Name
 Basement, !- Zone Name
 Surface, !- Outside Boundary Condition
 6B7DCC, !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground

12, !- Number of Vertices
 -2.384896674523, !- Vertex 1 X-coordinate {m}
 6.117340878979, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 -0.758745286192, !- Vertex 2 X-coordinate {m}
 1.037263353760, !- Vertex 2 Y-coordinate {m}
 2.560320000000, !- Vertex 2 Z-coordinate {m}
 -0.371691760461, !- Vertex 3 X-coordinate {m}
 1.161160602395, !- Vertex 3 Y-coordinate {m}
 2.560320000000, !- Vertex 3 Z-coordinate {m}
 0.000000000000, !- Vertex 4 X-coordinate {m}
 0.000000000000, !- Vertex 4 Y-coordinate {m}
 2.560320000000, !- Vertex 4 Z-coordinate {m}
 4.354352149916, !- Vertex 5 X-coordinate {m}
 1.393844072343, !- Vertex 5 Y-coordinate {m}
 2.560320000000, !- Vertex 5 Z-coordinate {m}
 3.982660404012, !- Vertex 6 X-coordinate {m}
 2.555004649536, !- Vertex 6 Y-coordinate {m}
 2.560320000000, !- Vertex 6 Z-coordinate {m}
 7.611287207739, !- Vertex 7 X-coordinate {m}
 3.716541355486, !- Vertex 7 Y-coordinate {m}
 2.560320000000, !- Vertex 7 Z-coordinate {m}
 7.982978953643, !- Vertex 8 X-coordinate {m}
 2.555380778293, !- Vertex 8 Y-coordinate {m}
 2.560320000000, !- Vertex 8 Z-coordinate {m}
 12.047040973818, !- Vertex 9 X-coordinate {m}
 3.856301888958, !- Vertex 9 Y-coordinate {m}
 2.560320000000, !- Vertex 9 Z-coordinate {m}
 11.675349227914, !- Vertex 10 X-coordinate {m}
 5.017462466151, !- Vertex 10 Y-coordinate {m}
 2.560320000000, !- Vertex 10 Z-coordinate {m}
 12.594601351525, !- Vertex 11 X-coordinate {m}
 5.311718431658, !- Vertex 11 Y-coordinate {m}
 2.560320000000, !- Vertex 11 Z-coordinate {m}
 10.968449963194, !- Vertex 12 X-coordinate {m}
 10.391795956877, !- Vertex 12 Y-coordinate {m}
 2.560320000000, !- Vertex 12 Z-coordinate {m}
 BuildingSurface:Detailed,
 D5C5F2, !- Name
 Wall, !- Surface Type
 Foundation Walls, !- Construction Name
 Basement, !- Zone Name
 Ground, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 4, !- Number of Vertices
 0.000000000000, !- Vertex 1 X-coordinate {m}
 0.000000000000, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}

```

0.000000000000,    !- Vertex 2 X-coordinate {m}
0.000000000000,    !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
4.354352149916,    !- Vertex 3 X-coordinate {m}
1.393844072343,    !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
4.354352149916,    !- Vertex 4 X-coordinate {m}
1.393844072343,    !- Vertex 4 Y-coordinate {m}
2.560320000000;    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
F1A629,            !- Name
Wall,              !- Surface Type
Foundation Walls,  !- Construction Name
Basement,          !- Zone Name
Ground,            !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
NoSun,             !- Sun Exposure
NoWind,            !- Wind Exposure
0.0,               !- View Factor to Ground
4,                 !- Number of Vertices
5.481966235958,    !- Vertex 1 X-coordinate {m}
8.635552457480,    !- Vertex 1 Y-coordinate {m}
2.560320000000,    !- Vertex 1 Z-coordinate {m}
5.481966235958,    !- Vertex 2 X-coordinate {m}
8.635552457480,    !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
2.999985502208,    !- Vertex 3 X-coordinate {m}
7.841061350609,    !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
2.999985502208,    !- Vertex 4 X-coordinate {m}
7.841061350609,    !- Vertex 4 Y-coordinate {m}
2.560320000000;    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
7A4952,            !- Name
Wall,              !- Surface Type
Interior Wall,     !- Construction Name
Basement,          !- Zone Name
Adiabatic,         !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
NoSun,             !- Sun Exposure
NoWind,            !- Wind Exposure
0.0,               !- View Factor to Ground
4,                 !- Number of Vertices
3.929214866969,    !- Vertex 1 X-coordinate {m}
4.938159907627,    !- Vertex 1 Y-coordinate {m}
2.560320000000,    !- Vertex 1 Z-coordinate {m}
3.929214866969,    !- Vertex 2 X-coordinate {m}
4.938159907627,    !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
2.999985502208,    !- Vertex 3 X-coordinate {m}
7.841061350609,    !- Vertex 3 Y-coordinate {m}

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```

0.000000000000,      !- Vertex 3 Z-coordinate {m}
2.999985502208,      !- Vertex 4 X-coordinate {m}
7.841061350609,      !- Vertex 4 Y-coordinate {m}
2.560320000000;      !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
40C49A,                !- Name
Wall,                  !- Surface Type
Foundation Walls,      !- Construction Name
Basement,              !- Zone Name
Ground,                !- Outside Boundary Condition
,                      !- Outside Boundary Condition Object
NoSun,                 !- Sun Exposure
NoWind,                !- Wind Exposure
0.0,                   !- View Factor to Ground
4,                     !- Number of Vertices
10.968449963194,      !- Vertex 1 X-coordinate {m}
10.391795956877,      !- Vertex 1 Y-coordinate {m}
2.560320000000,        !- Vertex 1 Z-coordinate {m}
10.968449963194,      !- Vertex 2 X-coordinate {m}
10.391795956877,      !- Vertex 2 Y-coordinate {m}
0.000000000000,        !- Vertex 2 Z-coordinate {m}
5.481966235958,       !- Vertex 3 X-coordinate {m}
8.635552457480,       !- Vertex 3 Y-coordinate {m}
0.000000000000,        !- Vertex 3 Z-coordinate {m}
5.481966235958,       !- Vertex 4 X-coordinate {m}
8.635552457480,       !- Vertex 4 Y-coordinate {m}
2.560320000000;       !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
3E1AA3,                !- Name
Wall,                  !- Surface Type
Interior Wall,          !- Construction Name
Basement,              !- Zone Name
Adiabatic,             !- Outside Boundary Condition
,                      !- Outside Boundary Condition Object
NoSun,                 !- Sun Exposure
NoWind,                !- Wind Exposure
0.0,                   !- View Factor to Ground
4,                     !- Number of Vertices
5.481966235958,       !- Vertex 1 X-coordinate {m}
8.635552457480,       !- Vertex 1 Y-coordinate {m}
2.560320000000,        !- Vertex 1 Z-coordinate {m}
5.481966235958,       !- Vertex 2 X-coordinate {m}
8.635552457480,       !- Vertex 2 Y-coordinate {m}
0.000000000000,        !- Vertex 2 Z-coordinate {m}
6.411195600718,       !- Vertex 3 X-coordinate {m}
5.732651014498,       !- Vertex 3 Y-coordinate {m}
0.000000000000,        !- Vertex 3 Z-coordinate {m}
6.411195600718,       !- Vertex 4 X-coordinate {m}
5.732651014498,       !- Vertex 4 Y-coordinate {m}
2.560320000000;       !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,

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6B7DCC, !- Name
 Floor, !- Surface Type
 Interior Floor, !- Construction Name
 FirstFloor, !- Zone Name
 Surface, !- Outside Boundary Condition
 AFD051, !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 12, !- Number of Vertices
 10.968449963194, !- Vertex 1 X-coordinate {m}
 10.391795956877, !- Vertex 1 Y-coordinate {m}
 0.000000000000, !- Vertex 1 Z-coordinate {m}
 12.594601351525, !- Vertex 2 X-coordinate {m}
 5.311718431658, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 11.675349227914, !- Vertex 3 X-coordinate {m}
 5.017462466151, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 12.047040973818, !- Vertex 4 X-coordinate {m}
 3.856301888958, !- Vertex 4 Y-coordinate {m}
 0.000000000000, !- Vertex 4 Z-coordinate {m}
 7.982978953643, !- Vertex 5 X-coordinate {m}
 2.555380778293, !- Vertex 5 Y-coordinate {m}
 0.000000000000, !- Vertex 5 Z-coordinate {m}
 7.611287207739, !- Vertex 6 X-coordinate {m}
 3.716541355486, !- Vertex 6 Y-coordinate {m}
 0.000000000000, !- Vertex 6 Z-coordinate {m}
 3.982660404012, !- Vertex 7 X-coordinate {m}
 2.555004649536, !- Vertex 7 Y-coordinate {m}
 0.000000000000, !- Vertex 7 Z-coordinate {m}
 4.354352149916, !- Vertex 8 X-coordinate {m}
 1.393844072343, !- Vertex 8 Y-coordinate {m}
 0.000000000000, !- Vertex 8 Z-coordinate {m}
 0.000000000000, !- Vertex 9 X-coordinate {m}
 0.000000000000, !- Vertex 9 Y-coordinate {m}
 0.000000000000, !- Vertex 9 Z-coordinate {m}
 -0.371691760461, !- Vertex 10 X-coordinate {m}
 1.161160602395, !- Vertex 10 Y-coordinate {m}
 0.000000000000, !- Vertex 10 Z-coordinate {m}
 -0.758745286192, !- Vertex 11 X-coordinate {m}
 1.037263353760, !- Vertex 11 Y-coordinate {m}
 0.000000000000, !- Vertex 11 Z-coordinate {m}
 -2.384896674523, !- Vertex 12 X-coordinate {m}
 6.117340878979, !- Vertex 12 Y-coordinate {m}
 0.000000000000, !- Vertex 12 Z-coordinate {m}
 BuildingSurface:Detailed,
 A4C974, !- Name
 Wall, !- Surface Type
 Exterior Wall, !- Construction Name
 FirstFloor, !- Zone Name

Outdoors, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 SunExposed, !- Sun Exposure
 WindExposed, !- Wind Exposure
 , !- View Factor to Ground
 4, !- Number of Vertices
 12.594601351525, !- Vertex 1 X-coordinate {m}
 5.311718431658, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 12.594601351525, !- Vertex 2 X-coordinate {m}
 5.311718431658, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 12.023125292197, !- Vertex 3 X-coordinate {m}
 7.097002819092, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 12.023125292197, !- Vertex 4 X-coordinate {m}
 7.097002819092, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}
 BuildingSurface:Detailed,
 B204CE, !- Name
 Wall, !- Surface Type
 Exterior Wall, !- Construction Name
 FirstFloor, !- Zone Name
 Outdoors, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 SunExposed, !- Sun Exposure
 WindExposed, !- Wind Exposure
 , !- View Factor to Ground
 4, !- Number of Vertices
 3.982660404012, !- Vertex 1 X-coordinate {m}
 2.555004649536, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 3.982660404012, !- Vertex 2 X-coordinate {m}
 2.555004649536, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 7.611287207739, !- Vertex 3 X-coordinate {m}
 3.716541355486, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 7.611287207739, !- Vertex 4 X-coordinate {m}
 3.716541355486, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}
 BuildingSurface:Detailed,
 648845, !- Name
 Ceiling, !- Surface Type
 Interior Ceiling, !- Construction Name
 FirstFloor, !- Zone Name
 Surface, !- Outside Boundary Condition
 83FFDB, !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground

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8,                !- Number of Vertices
-2.384896674523,  !- Vertex 1 X-coordinate {m}
6.117340878979,   !- Vertex 1 Y-coordinate {m}
2.560320000000,   !- Vertex 1 Z-coordinate {m}
-0.758745286192,  !- Vertex 2 X-coordinate {m}
1.037263353760,   !- Vertex 2 Y-coordinate {m}
2.560320000000,   !- Vertex 2 Z-coordinate {m}
-0.371691760461,  !- Vertex 3 X-coordinate {m}
1.161160602395,   !- Vertex 3 Y-coordinate {m}
2.560320000000,   !- Vertex 3 Z-coordinate {m}
0.000000000000,   !- Vertex 4 X-coordinate {m}
0.000000000000,   !- Vertex 4 Y-coordinate {m}
2.560320000000,   !- Vertex 4 Z-coordinate {m}
4.354352149916,   !- Vertex 5 X-coordinate {m}
1.393844072343,   !- Vertex 5 Y-coordinate {m}
2.560320000000,   !- Vertex 5 Z-coordinate {m}
3.982660404012,   !- Vertex 6 X-coordinate {m}
2.555004649536,   !- Vertex 6 Y-coordinate {m}
2.560320000000,   !- Vertex 6 Z-coordinate {m}
12.594601351525,  !- Vertex 7 X-coordinate {m}
5.311718431658,   !- Vertex 7 Y-coordinate {m}
2.560320000000,   !- Vertex 7 Z-coordinate {m}
10.968449963194,  !- Vertex 8 X-coordinate {m}
10.391795956877,  !- Vertex 8 Y-coordinate {m}
2.560320000000;    !- Vertex 8 Z-coordinate {m}
BuildingSurface:Detailed,
F6A76D,            !- Name
Wall,              !- Surface Type
Exterior Wall,     !- Construction Name
FirstFloor,        !- Zone Name
Outdoors,          !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
SunExposed,        !- Sun Exposure
WindExposed,       !- Wind Exposure
,                  !- View Factor to Ground
4,                !- Number of Vertices
-0.758745286192,  !- Vertex 1 X-coordinate {m}
1.037263353760,   !- Vertex 1 Y-coordinate {m}
2.560320000000,   !- Vertex 1 Z-coordinate {m}
-0.758745286192,  !- Vertex 2 X-coordinate {m}
1.037263353760,   !- Vertex 2 Y-coordinate {m}
0.000000000000,   !- Vertex 2 Z-coordinate {m}
-0.371691760461,  !- Vertex 3 X-coordinate {m}
1.161160602395,   !- Vertex 3 Y-coordinate {m}
0.000000000000,   !- Vertex 3 Z-coordinate {m}
-0.371691760461,  !- Vertex 4 X-coordinate {m}
1.161160602395,   !- Vertex 4 Y-coordinate {m}
2.560320000000;    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
C200C2,           !- Name
Wall,             !- Surface Type

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Exterior Wall,      !- Construction Name
FirstFloor,        !- Zone Name
Outdoors,          !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
SunExposed,        !- Sun Exposure
WindExposed,       !- Wind Exposure
,                  !- View Factor to Ground
4,                 !- Number of Vertices
7.611287207739,    !- Vertex 1 X-coordinate {m}
3.716541355486,    !- Vertex 1 Y-coordinate {m}
2.560320000000,    !- Vertex 1 Z-coordinate {m}
7.611287207739,    !- Vertex 2 X-coordinate {m}
3.716541355486,    !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
7.982978953643,    !- Vertex 3 X-coordinate {m}
2.555380778293,    !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
7.982978953643,    !- Vertex 4 X-coordinate {m}
2.555380778293,    !- Vertex 4 Y-coordinate {m}
2.560320000000;    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
63A98A,            !- Name
Wall,              !- Surface Type
Exterior Wall,     !- Construction Name
FirstFloor,        !- Zone Name
Outdoors,          !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
SunExposed,        !- Sun Exposure
WindExposed,       !- Wind Exposure
,                  !- View Factor to Ground
4,                 !- Number of Vertices
11.675349227914,   !- Vertex 1 X-coordinate {m}
5.017462466151,    !- Vertex 1 Y-coordinate {m}
2.560320000000,    !- Vertex 1 Z-coordinate {m}
11.675349227914,   !- Vertex 2 X-coordinate {m}
5.017462466151,    !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
12.594601351525,   !- Vertex 3 X-coordinate {m}
5.311718431658,    !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
12.594601351525,   !- Vertex 4 X-coordinate {m}
5.311718431658,    !- Vertex 4 Y-coordinate {m}
2.560320000000;    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
4DCE52,            !- Name
Wall,              !- Surface Type
Exterior Wall,     !- Construction Name
FirstFloor,        !- Zone Name
Outdoors,          !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
SunExposed,        !- Sun Exposure

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WindExposed,      !- Wind Exposure
,                !- View Factor to Ground
4,              !- Number of Vertices
7.982978953643,   !- Vertex 1 X-coordinate {m}
2.555380778293,   !- Vertex 1 Y-coordinate {m}
2.560320000000,   !- Vertex 1 Z-coordinate {m}
7.982978953643,   !- Vertex 2 X-coordinate {m}
2.555380778293,   !- Vertex 2 Y-coordinate {m}
0.000000000000,   !- Vertex 2 Z-coordinate {m}
12.047040973818,  !- Vertex 3 X-coordinate {m}
3.856301888958,   !- Vertex 3 Y-coordinate {m}
0.000000000000,   !- Vertex 3 Z-coordinate {m}
12.047040973818,  !- Vertex 4 X-coordinate {m}
3.856301888958,   !- Vertex 4 Y-coordinate {m}
2.560320000000;   !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
56F7F0,          !- Name
Wall,            !- Surface Type
Exterior Wall,   !- Construction Name
FirstFloor,      !- Zone Name
Outdoors,        !- Outside Boundary Condition
,                !- Outside Boundary Condition Object
SunExposed,      !- Sun Exposure
WindExposed,     !- Wind Exposure
,                !- View Factor to Ground
4,              !- Number of Vertices
-2.384896674523, !- Vertex 1 X-coordinate {m}
6.117340878979,  !- Vertex 1 Y-coordinate {m}
2.560320000000,  !- Vertex 1 Z-coordinate {m}
-2.384896674523, !- Vertex 2 X-coordinate {m}
6.117340878979,  !- Vertex 2 Y-coordinate {m}
0.000000000000,  !- Vertex 2 Z-coordinate {m}
-1.509562612919, !- Vertex 3 X-coordinate {m}
3.382807719690,  !- Vertex 3 Y-coordinate {m}
0.000000000000,  !- Vertex 3 Z-coordinate {m}
-1.509562612919, !- Vertex 4 X-coordinate {m}
3.382807719690,  !- Vertex 4 Y-coordinate {m}
2.560320000000;  !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
6D525F,          !- Name
Wall,            !- Surface Type
Exterior Wall,   !- Construction Name
FirstFloor,      !- Zone Name
Outdoors,        !- Outside Boundary Condition
,                !- Outside Boundary Condition Object
SunExposed,      !- Sun Exposure
WindExposed,     !- Wind Exposure
,                !- View Factor to Ground
4,              !- Number of Vertices
12.047040973818, !- Vertex 1 X-coordinate {m}
3.856301888958,  !- Vertex 1 Y-coordinate {m}

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2.560320000000,    !- Vertex 1 Z-coordinate {m}
12.047040973818,   !- Vertex 2 X-coordinate {m}
3.856301888958,    !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
11.675349227914,   !- Vertex 3 X-coordinate {m}
5.017462466151,    !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
11.675349227914,   !- Vertex 4 X-coordinate {m}
5.017462466151,    !- Vertex 4 Y-coordinate {m}
2.560320000000;    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
1D30FA,             !- Name
Wall,               !- Surface Type
Exterior Wall,      !- Construction Name
FirstFloor,         !- Zone Name
Outdoors,           !- Outside Boundary Condition
,                   !- Outside Boundary Condition Object
SunExposed,         !- Sun Exposure
WindExposed,        !- Wind Exposure
,                   !- View Factor to Ground
4,                  !- Number of Vertices
4.354352149916,     !- Vertex 1 X-coordinate {m}
1.393844072343,     !- Vertex 1 Y-coordinate {m}
2.560320000000,     !- Vertex 1 Z-coordinate {m}
4.354352149916,     !- Vertex 2 X-coordinate {m}
1.393844072343,     !- Vertex 2 Y-coordinate {m}
0.000000000000,     !- Vertex 2 Z-coordinate {m}
3.982660404012,     !- Vertex 3 X-coordinate {m}
2.555004649536,     !- Vertex 3 Y-coordinate {m}
0.000000000000,     !- Vertex 3 Z-coordinate {m}
3.982660404012,     !- Vertex 4 X-coordinate {m}
2.555004649536,     !- Vertex 4 Y-coordinate {m}
2.560320000000;     !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
B0EF72,             !- Name
Wall,               !- Surface Type
Exterior Wall,      !- Construction Name
FirstFloor,         !- Zone Name
Outdoors,           !- Outside Boundary Condition
,                   !- Outside Boundary Condition Object
SunExposed,         !- Sun Exposure
WindExposed,        !- Wind Exposure
,                   !- View Factor to Ground
4,                  !- Number of Vertices
5.481966235958,     !- Vertex 1 X-coordinate {m}
8.635552457480,     !- Vertex 1 Y-coordinate {m}
2.560320000000,     !- Vertex 1 Z-coordinate {m}
5.481966235958,     !- Vertex 2 X-coordinate {m}
8.635552457480,     !- Vertex 2 Y-coordinate {m}
0.000000000000,     !- Vertex 2 Z-coordinate {m}
2.999985502208,     !- Vertex 3 X-coordinate {m}

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7.841061350609,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
2.999985502208,      !- Vertex 4 X-coordinate {m}
7.841061350609,      !- Vertex 4 Y-coordinate {m}
2.560320000000;      !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
AEA51E,               !- Name
Wall,                 !- Surface Type
Exterior Wall,        !- Construction Name
FirstFloor,           !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
4,                    !- Number of Vertices
-0.371691760461,      !- Vertex 1 X-coordinate {m}
1.161160602395,      !- Vertex 1 Y-coordinate {m}
2.560320000000,      !- Vertex 1 Z-coordinate {m}
-0.371691760461,      !- Vertex 2 X-coordinate {m}
1.161160602395,      !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
0.000000000000,      !- Vertex 3 X-coordinate {m}
0.000000000000,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
0.000000000000,      !- Vertex 4 X-coordinate {m}
0.000000000000,      !- Vertex 4 Y-coordinate {m}
2.560320000000;      !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
868AEF,               !- Name
Wall,                 !- Surface Type
Exterior Wall,        !- Construction Name
FirstFloor,           !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
4,                    !- Number of Vertices
0.000000000000,      !- Vertex 1 X-coordinate {m}
0.000000000000,      !- Vertex 1 Y-coordinate {m}
2.560320000000,      !- Vertex 1 Z-coordinate {m}
0.000000000000,      !- Vertex 2 X-coordinate {m}
0.000000000000,      !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
4.354352149916,      !- Vertex 3 X-coordinate {m}
1.393844072343,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
4.354352149916,      !- Vertex 4 X-coordinate {m}
1.393844072343,      !- Vertex 4 Y-coordinate {m}
2.560320000000;      !- Vertex 4 Z-coordinate {m}

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BuildingSurface:Detailed,
 807F9E, !- Name
 Wall, !- Surface Type
 Exterior Wall, !- Construction Name
 FirstFloor, !- Zone Name
 Outdoors, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 SunExposed, !- Sun Exposure
 WindExposed, !- Wind Exposure
 , !- View Factor to Ground
 4, !- Number of Vertices
 2.999985502208, !- Vertex 1 X-coordinate {m}
 7.841061350609, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 2.999985502208, !- Vertex 2 X-coordinate {m}
 7.841061350609, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 -2.384896674523, !- Vertex 3 X-coordinate {m}
 6.117340878979, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 -2.384896674523, !- Vertex 4 X-coordinate {m}
 6.117340878979, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}

BuildingSurface:Detailed,
 857B3C, !- Name
 Wall, !- Surface Type
 Interior Wall, !- Construction Name
 FirstFloor, !- Zone Name
 Adiabatic, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 4, !- Number of Vertices
 4.198304203847, !- Vertex 1 X-coordinate {m}
 4.097528031430, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 4.198304203848, !- Vertex 2 X-coordinate {m}
 4.097528031430, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 2.999985502208, !- Vertex 3 X-coordinate {m}
 7.841061350609, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 2.999985502208, !- Vertex 4 X-coordinate {m}
 7.841061350609, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}

BuildingSurface:Detailed,
 79D76B, !- Name
 Wall, !- Surface Type
 Exterior Wall, !- Construction Name
 FirstFloor, !- Zone Name

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Outdoors,          !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
SunExposed,        !- Sun Exposure
WindExposed,       !- Wind Exposure
,                  !- View Factor to Ground
4,                 !- Number of Vertices
-1.509562612919,   !- Vertex 1 X-coordinate {m}
3.382807719690,    !- Vertex 1 Y-coordinate {m}
2.560320000000,    !- Vertex 1 Z-coordinate {m}
-1.509562612919,   !- Vertex 2 X-coordinate {m}
3.382807719690,    !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
-0.758745286192,   !- Vertex 3 X-coordinate {m}
1.037263353760,    !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
-0.758745286192,   !- Vertex 4 X-coordinate {m}
1.037263353760,    !- Vertex 4 Y-coordinate {m}
2.560320000000;    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
7BD755,            !- Name
Wall,              !- Surface Type
Interior Wall,     !- Construction Name
FirstFloor,        !- Zone Name
Adiabatic,         !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
NoSun,             !- Sun Exposure
NoWind,            !- Wind Exposure
0.0,               !- View Factor to Ground
4,                 !- Number of Vertices
2.423868842322,    !- Vertex 1 X-coordinate {m}
4.641913508940,    !- Vertex 1 Y-coordinate {m}
2.560320000000,    !- Vertex 1 Z-coordinate {m}
2.423868842322,    !- Vertex 2 X-coordinate {m}
4.641913508940,    !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
-1.509562612919,   !- Vertex 3 X-coordinate {m}
3.382807719690,    !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
-1.509562612919,   !- Vertex 4 X-coordinate {m}
3.382807719690,    !- Vertex 4 Y-coordinate {m}
2.560320000000;    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
78BC65,            !- Name
Wall,              !- Surface Type
Exterior Wall,     !- Construction Name
FirstFloor,        !- Zone Name
Outdoors,          !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
SunExposed,        !- Sun Exposure
WindExposed,       !- Wind Exposure
,                  !- View Factor to Ground

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4,                !- Number of Vertices
10.968449963194,  !- Vertex 1 X-coordinate {m}
10.391795956877,  !- Vertex 1 Y-coordinate {m}
2.560320000000,    !- Vertex 1 Z-coordinate {m}
10.968449963194,  !- Vertex 2 X-coordinate {m}
10.391795956877,  !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
7.061144620940,    !- Vertex 3 X-coordinate {m}
9.141053231910,    !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
7.061144620940,    !- Vertex 4 X-coordinate {m}
9.141053231910,    !- Vertex 4 Y-coordinate {m}
2.560320000000;    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
FE88A4,            !- Name
Wall,              !- Surface Type
Interior Wall,      !- Construction Name
FirstFloor,         !- Zone Name
Adiabatic,          !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
NoSun,              !- Sun Exposure
NoWind,             !- Wind Exposure
0.0,                !- View Factor to Ground
4,                !- Number of Vertices
7.039811148412,    !- Vertex 1 X-coordinate {m}
5.501825742920,    !- Vertex 1 Y-coordinate {m}
2.560320000000,    !- Vertex 1 Z-coordinate {m}
7.039811148412,    !- Vertex 2 X-coordinate {m}
5.501825742920,    !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
7.611287207739,    !- Vertex 3 X-coordinate {m}
3.716541355486,    !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
7.611287207739,    !- Vertex 4 X-coordinate {m}
3.716541355486,    !- Vertex 4 Y-coordinate {m}
2.560320000000;    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
662777,            !- Name
Wall,              !- Surface Type
Exterior Wall,      !- Construction Name
FirstFloor,         !- Zone Name
Outdoors,           !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
SunExposed,         !- Sun Exposure
WindExposed,        !- Wind Exposure
,                  !- View Factor to Ground
4,                !- Number of Vertices
12.023125292197,    !- Vertex 1 X-coordinate {m}
7.097002819092,    !- Vertex 1 Y-coordinate {m}
2.560320000000,    !- Vertex 1 Z-coordinate {m}
12.023125292197,    !- Vertex 2 X-coordinate {m}

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7.097002819092,      !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
10.968449963194,     !- Vertex 3 X-coordinate {m}
10.391795956877,     !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
10.968449963194,     !- Vertex 4 X-coordinate {m}
10.391795956877,     !- Vertex 4 Y-coordinate {m}
2.560320000000;      !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
412ACD,              !- Name
Wall,                !- Surface Type
Interior Wall,        !- Construction Name
FirstFloor,           !- Zone Name
Adiabatic,            !- Outside Boundary Condition
,                    !- Outside Boundary Condition Object
NoSun,                !- Sun Exposure
NoWind,               !- Wind Exposure
0.0,                  !- View Factor to Ground
4,                    !- Number of Vertices
8.115819949944,       !- Vertex 1 X-coordinate {m}
5.846260094125,       !- Vertex 1 Y-coordinate {m}
2.560320000000,       !- Vertex 1 Z-coordinate {m}
8.115819949944,       !- Vertex 2 X-coordinate {m}
5.846260094125,       !- Vertex 2 Y-coordinate {m}
0.000000000000,       !- Vertex 2 Z-coordinate {m}
12.023125292197,      !- Vertex 3 X-coordinate {m}
7.097002819092,       !- Vertex 3 Y-coordinate {m}
0.000000000000,       !- Vertex 3 Z-coordinate {m}
12.023125292197,      !- Vertex 4 X-coordinate {m}
7.097002819092,       !- Vertex 4 Y-coordinate {m}
2.560320000000;       !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
3E389E,              !- Name
Wall,                !- Surface Type
Exterior Wall,        !- Construction Name
FirstFloor,           !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                    !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                    !- View Factor to Ground
4,                    !- Number of Vertices
7.061144620940,       !- Vertex 1 X-coordinate {m}
9.141053231910,       !- Vertex 1 Y-coordinate {m}
2.560320000000,       !- Vertex 1 Z-coordinate {m}
7.061144620940,       !- Vertex 2 X-coordinate {m}
9.141053231910,       !- Vertex 2 Y-coordinate {m}
0.000000000000,       !- Vertex 2 Z-coordinate {m}
5.481966235958,       !- Vertex 3 X-coordinate {m}
8.635552457480,       !- Vertex 3 Y-coordinate {m}
0.000000000000,       !- Vertex 3 Z-coordinate {m}

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5.481966235958, !- Vertex 4 X-coordinate {m}
 8.635552457480, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}
 BuildingSurface:Detailed,
 9F010D, !- Name
 Wall, !- Surface Type
 Interior Wall, !- Construction Name
 FirstFloor, !- Zone Name
 Adiabatic, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 4, !- Number of Vertices
 7.792448131007, !- Vertex 1 X-coordinate {m}
 6.856469796283, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 7.792448131007, !- Vertex 2 X-coordinate {m}
 6.856469796283, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 7.061144620940, !- Vertex 3 X-coordinate {m}
 9.141053231910, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 7.061144620940, !- Vertex 4 X-coordinate {m}
 9.141053231910, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}
 BuildingSurface:Detailed,
 83A11D, !- Name
 Wall, !- Surface Type
 Interior Wall, !- Construction Name
 FirstFloor, !- Zone Name
 Adiabatic, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 4, !- Number of Vertices
 5.481966235958, !- Vertex 1 X-coordinate {m}
 8.635552457480, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 5.481966235958, !- Vertex 2 X-coordinate {m}
 8.635552457480, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 6.213269746025, !- Vertex 3 X-coordinate {m}
 6.350969021853, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 6.213269746025, !- Vertex 4 X-coordinate {m}
 6.350969021853, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}
 BuildingSurface:Detailed,
 53C718, !- Name

Roof, !- Surface Type
 Exterior Roof, !- Construction Name
 FirstFloor, !- Zone Name
 Outdoors, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 SunExposed, !- Sun Exposure
 WindExposed, !- Wind Exposure
 0.0, !- View Factor to Ground
 4, !- Number of Vertices
 7.611287207739, !- Vertex 1 X-coordinate {m}
 3.716541355486, !- Vertex 1 Y-coordinate {m}
 2.560320000000, !- Vertex 1 Z-coordinate {m}
 7.982978953643, !- Vertex 2 X-coordinate {m}
 2.555380778293, !- Vertex 2 Y-coordinate {m}
 2.560320000000, !- Vertex 2 Z-coordinate {m}
 12.047040973818, !- Vertex 3 X-coordinate {m}
 3.856301888958, !- Vertex 3 Y-coordinate {m}
 2.560320000000, !- Vertex 3 Z-coordinate {m}
 11.675349227914, !- Vertex 4 X-coordinate {m}
 5.017462466151, !- Vertex 4 Y-coordinate {m}
 2.560320000000; !- Vertex 4 Z-coordinate {m}
 BuildingSurface:Detailed,
 83FFDB, !- Name
 Floor, !- Surface Type
 Interior Floor, !- Construction Name
 TopLevel, !- Zone Name
 Surface, !- Outside Boundary Condition
 648845, !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 8, !- Number of Vertices
 10.968449963194, !- Vertex 1 X-coordinate {m}
 10.391795956877, !- Vertex 1 Y-coordinate {m}
 0.000000000000, !- Vertex 1 Z-coordinate {m}
 12.594601351525, !- Vertex 2 X-coordinate {m}
 5.311718431658, !- Vertex 2 Y-coordinate {m}
 0.000000000000, !- Vertex 2 Z-coordinate {m}
 3.982660404012, !- Vertex 3 X-coordinate {m}
 2.555004649536, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 4.354352149916, !- Vertex 4 X-coordinate {m}
 1.393844072343, !- Vertex 4 Y-coordinate {m}
 0.000000000000, !- Vertex 4 Z-coordinate {m}
 0.000000000000, !- Vertex 5 X-coordinate {m}
 0.000000000000, !- Vertex 5 Y-coordinate {m}
 0.000000000000, !- Vertex 5 Z-coordinate {m}
 -0.371691760461, !- Vertex 6 X-coordinate {m}
 1.161160602395, !- Vertex 6 Y-coordinate {m}
 0.000000000000, !- Vertex 6 Z-coordinate {m}
 -0.758745286192, !- Vertex 7 X-coordinate {m}


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1.037263353760,      !- Vertex 7 Y-coordinate {m}
0.000000000000,      !- Vertex 7 Z-coordinate {m}
-2.384896674523,     !- Vertex 8 X-coordinate {m}
6.117340878979,      !- Vertex 8 Y-coordinate {m}
0.000000000000;      !- Vertex 8 Z-coordinate {m}
BuildingSurface:Detailed,
A38E22,               !- Name
Wall,                 !- Surface Type
Exterior Wall,        !- Construction Name
TopLevel,             !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
4,                    !- Number of Vertices
-0.758745286191,     !- Vertex 1 X-coordinate {m}
1.037263353758,     !- Vertex 1 Y-coordinate {m}
2.133600000000,     !- Vertex 1 Z-coordinate {m}
-0.758745286192,     !- Vertex 2 X-coordinate {m}
1.037263353760,     !- Vertex 2 Y-coordinate {m}
0.000000000000,     !- Vertex 2 Z-coordinate {m}
-0.371691760461,     !- Vertex 3 X-coordinate {m}
1.161160602395,     !- Vertex 3 Y-coordinate {m}
0.000000000000,     !- Vertex 3 Z-coordinate {m}
-0.371691760460,     !- Vertex 4 X-coordinate {m}
1.161160602391,     !- Vertex 4 Y-coordinate {m}
2.133599999999;     !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
E00FE4,               !- Name
Wall,                 !- Surface Type
Exterior Wall,        !- Construction Name
TopLevel,             !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
5,                    !- Number of Vertices
11.791747180372,     !- Vertex 1 X-coordinate {m}
7.819825278395,     !- Vertex 1 Y-coordinate {m}
4.800600000000,     !- Vertex 1 Z-coordinate {m}
12.594601351525,     !- Vertex 2 X-coordinate {m}
5.311718431658,     !- Vertex 2 Y-coordinate {m}
2.133600000000,     !- Vertex 2 Z-coordinate {m}
12.594601351525,     !- Vertex 3 X-coordinate {m}
5.311718431658,     !- Vertex 3 Y-coordinate {m}
0.000000000000,     !- Vertex 3 Z-coordinate {m}
10.968449963194,     !- Vertex 4 X-coordinate {m}
10.391795956877,     !- Vertex 4 Y-coordinate {m}
0.000000000000,     !- Vertex 4 Z-coordinate {m}

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10.968449963194,    !- Vertex 5 X-coordinate {m}
10.391795956877,    !- Vertex 5 Y-coordinate {m}
2.133600000000;      !- Vertex 5 Z-coordinate {m}
BuildingSurface:Detailed,
D0776F,              !- Name
Wall,                !- Surface Type
Exterior Wall,       !- Construction Name
TopLevel,            !- Zone Name
Outdoors,            !- Outside Boundary Condition
,                    !- Outside Boundary Condition Object
SunExposed,          !- Sun Exposure
WindExposed,         !- Wind Exposure
,                    !- View Factor to Ground
5,                   !- Number of Vertices
-2.384896674523,     !- Vertex 1 X-coordinate {m}
6.117340878979,      !- Vertex 1 Y-coordinate {m}
2.133600000000,      !- Vertex 1 Z-coordinate {m}
-2.384896674523,     !- Vertex 2 X-coordinate {m}
6.117340878979,      !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
-0.758745286192,     !- Vertex 3 X-coordinate {m}
1.037263353760,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
-0.758745286191,     !- Vertex 4 X-coordinate {m}
1.037263353758,      !- Vertex 4 Y-coordinate {m}
2.133600000000,      !- Vertex 4 Z-coordinate {m}
-1.561599457345,     !- Vertex 5 X-coordinate {m}
3.545370200497,      !- Vertex 5 Y-coordinate {m}
4.800600000000;      !- Vertex 5 Z-coordinate {m}
BuildingSurface:Detailed,
2685F3,              !- Name
Wall,                !- Surface Type
Exterior Wall,       !- Construction Name
TopLevel,            !- Zone Name
Outdoors,            !- Outside Boundary Condition
,                    !- Outside Boundary Condition Object
SunExposed,          !- Sun Exposure
WindExposed,         !- Wind Exposure
,                    !- View Factor to Ground
4,                   !- Number of Vertices
-0.371691760460,     !- Vertex 1 X-coordinate {m}
1.161160602391,      !- Vertex 1 Y-coordinate {m}
2.133599999999,      !- Vertex 1 Z-coordinate {m}
-0.371691760461,     !- Vertex 2 X-coordinate {m}
1.161160602395,      !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
0.000000000000,      !- Vertex 3 X-coordinate {m}
0.000000000000,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
0.000000000000,      !- Vertex 4 X-coordinate {m}
0.000000000000,      !- Vertex 4 Y-coordinate {m}

```

```

2.133599999999;      !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
BC7656,              !- Name
Wall,                !- Surface Type
Exterior Wall,       !- Construction Name
TopLevel,            !- Zone Name
Outdoors,            !- Outside Boundary Condition
,                    !- Outside Boundary Condition Object
SunExposed,          !- Sun Exposure
WindExposed,         !- Wind Exposure
,                    !- View Factor to Ground
4,                   !- Number of Vertices
4.354352158592,      !- Vertex 1 X-coordinate {m}
1.393844045238,      !- Vertex 1 Y-coordinate {m}
2.1335999999994,     !- Vertex 1 Z-coordinate {m}
4.354352149916,      !- Vertex 2 X-coordinate {m}
1.393844072343,      !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
3.982660404012,      !- Vertex 3 X-coordinate {m}
2.555004649536,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
3.982660404012,      !- Vertex 4 X-coordinate {m}
2.555004649534,      !- Vertex 4 Y-coordinate {m}
2.133600000000;      !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
909C61,              !- Name
Wall,                !- Surface Type
Exterior Wall,       !- Construction Name
TopLevel,            !- Zone Name
Outdoors,            !- Outside Boundary Condition
,                    !- Outside Boundary Condition Object
SunExposed,          !- Sun Exposure
WindExposed,         !- Wind Exposure
,                    !- View Factor to Ground
6,                   !- Number of Vertices
0.268355212723,      !- Vertex 1 X-coordinate {m}
6.966656508242,      !- Vertex 1 Y-coordinate {m}
4.800599950547,      !- Vertex 1 Z-coordinate {m}
1.388875201354,      !- Vertex 2 X-coordinate {m}
7.325339053168,      !- Vertex 2 Y-coordinate {m}
3.369466501462,      !- Vertex 2 Z-coordinate {m}
1.388875201354,      !- Vertex 3 X-coordinate {m}
7.325339053168,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
-2.384896674523,     !- Vertex 4 X-coordinate {m}
6.117340878979,      !- Vertex 4 Y-coordinate {m}
0.000000000000,      !- Vertex 4 Z-coordinate {m}
-2.384896674523,     !- Vertex 5 X-coordinate {m}
6.117340878979,      !- Vertex 5 Y-coordinate {m}
2.133600000000,      !- Vertex 5 Z-coordinate {m}
-1.545259977315,     !- Vertex 6 X-coordinate {m}

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6.386111655425,      !- Vertex 6 Y-coordinate {m}
2.133600000000;      !- Vertex 6 Z-coordinate {m}
BuildingSurface:Detailed,
2068E8,              !- Name
Wall,                !- Surface Type
Exterior Wall,       !- Construction Name
TopLevel,            !- Zone Name
Outdoors,            !- Outside Boundary Condition
,                    !- Outside Boundary Condition Object
SunExposed,          !- Sun Exposure
WindExposed,         !- Wind Exposure
,                    !- View Factor to Ground
5,                  !- Number of Vertices
2.266198377420,      !- Vertex 1 X-coordinate {m}
0.725418419636,      !- Vertex 1 Y-coordinate {m}
4.800600000000,      !- Vertex 1 Z-coordinate {m}
0.000000000000,      !- Vertex 2 X-coordinate {m}
0.000000000000,      !- Vertex 2 Y-coordinate {m}
2.133599999999,      !- Vertex 2 Z-coordinate {m}
0.000000000000,      !- Vertex 3 X-coordinate {m}
0.000000000000,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
4.354352149916,      !- Vertex 4 X-coordinate {m}
1.393844072343,      !- Vertex 4 Y-coordinate {m}
0.000000000000,      !- Vertex 4 Z-coordinate {m}
4.354352158592,      !- Vertex 5 X-coordinate {m}
1.393844045238,      !- Vertex 5 Y-coordinate {m}
2.133599999994;      !- Vertex 5 Z-coordinate {m}
BuildingSurface:Detailed,
8249AA,              !- Name
Roof,                !- Surface Type
Exterior Roof,       !- Construction Name
TopLevel,            !- Zone Name
Outdoors,            !- Outside Boundary Condition
,                    !- Outside Boundary Condition Object
SunExposed,          !- Sun Exposure
WindExposed,         !- Wind Exposure
,                    !- View Factor to Ground
4,                  !- Number of Vertices
1.091652461540,      !- Vertex 1 X-coordinate {m}
4.394685839888,      !- Vertex 1 Y-coordinate {m}
4.800600000000,      !- Vertex 1 Z-coordinate {m}
-0.371691760460,      !- Vertex 2 X-coordinate {m}
1.161160602391,      !- Vertex 2 Y-coordinate {m}
2.133599999999,      !- Vertex 2 Z-coordinate {m}
0.000000000000,      !- Vertex 3 X-coordinate {m}
0.000000000000,      !- Vertex 3 Y-coordinate {m}
2.133599999999,      !- Vertex 3 Z-coordinate {m}
2.266198377420,      !- Vertex 4 X-coordinate {m}
0.725418419636,      !- Vertex 4 Y-coordinate {m}
4.800600000000;      !- Vertex 4 Z-coordinate {m}

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BuildingSurface:Detailed,
7D693C,           !- Name
Roof,             !- Surface Type
Exterior Roof,    !- Construction Name
TopLevel,         !- Zone Name
Outdoors,         !- Outside Boundary Condition
,                !- Outside Boundary Condition Object
SunExposed,       !- Sun Exposure
WindExposed,      !- Wind Exposure
,                !- View Factor to Ground
4,               !- Number of Vertices
-1.561599457345,  !- Vertex 1 X-coordinate {m}
3.545370200497,  !- Vertex 1 Y-coordinate {m}
4.800600000000,  !- Vertex 1 Z-coordinate {m}
-0.758745286191, !- Vertex 2 X-coordinate {m}
1.037263353758,  !- Vertex 2 Y-coordinate {m}
2.133600000000,  !- Vertex 2 Z-coordinate {m}
-0.371691760460, !- Vertex 3 X-coordinate {m}
1.161160602391,  !- Vertex 3 Y-coordinate {m}
2.133599999999,  !- Vertex 3 Z-coordinate {m}
1.091652461540,  !- Vertex 4 X-coordinate {m}
4.394685839888,  !- Vertex 4 Y-coordinate {m}
4.800600000000;   !- Vertex 4 Z-coordinate {m}

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BuildingSurface:Detailed,
9ACDF3,          !- Name
Roof,            !- Surface Type
Exterior Roof,   !- Construction Name
TopLevel,        !- Zone Name
Outdoors,        !- Outside Boundary Condition
,               !- Outside Boundary Condition Object
SunExposed,      !- Sun Exposure
WindExposed,     !- Wind Exposure
,               !- View Factor to Ground
4,              !- Number of Vertices
1.091652461540,  !- Vertex 1 X-coordinate {m}
4.394685839888,  !- Vertex 1 Y-coordinate {m}
4.800600000000,  !- Vertex 1 Z-coordinate {m}
-1.545259977315, !- Vertex 2 X-coordinate {m}
6.386111655425,  !- Vertex 2 Y-coordinate {m}
2.133600000000,  !- Vertex 2 Z-coordinate {m}
-2.384896674523, !- Vertex 3 X-coordinate {m}
6.117340878979,  !- Vertex 3 Y-coordinate {m}
2.133600000000,  !- Vertex 3 Z-coordinate {m}
-1.561599457345, !- Vertex 4 X-coordinate {m}
3.545370200497,  !- Vertex 4 Y-coordinate {m}
4.800600000000;   !- Vertex 4 Z-coordinate {m}

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BuildingSurface:Detailed,
4278FA,          !- Name
Roof,            !- Surface Type
Exterior Roof,   !- Construction Name
TopLevel,        !- Zone Name

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Outdoors,          !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
SunExposed,        !- Sun Exposure
WindExposed,       !- Wind Exposure
,                  !- View Factor to Ground
3,                 !- Number of Vertices
0.268355212723,    !- Vertex 1 X-coordinate {m}
6.966656508242,    !- Vertex 1 Y-coordinate {m}
4.800599950547,    !- Vertex 1 Z-coordinate {m}
-1.545259977315,   !- Vertex 2 X-coordinate {m}
6.386111655425,    !- Vertex 2 Y-coordinate {m}
2.133600000000,    !- Vertex 2 Z-coordinate {m}
1.091652461540,    !- Vertex 3 X-coordinate {m}
4.394685839888,    !- Vertex 3 Y-coordinate {m}
4.800600000000;    !- Vertex 3 Z-coordinate {m}
BuildingSurface:Detailed,
ED5DDA,           !- Name
Roof,             !- Surface Type
Exterior Roof,    !- Construction Name
TopLevel,         !- Zone Name
Outdoors,         !- Outside Boundary Condition
,                 !- Outside Boundary Condition Object
SunExposed,       !- Sun Exposure
WindExposed,      !- Wind Exposure
,                 !- View Factor to Ground
4,                 !- Number of Vertices
1.091652461540,    !- Vertex 1 X-coordinate {m}
4.394685839888,    !- Vertex 1 Y-coordinate {m}
4.800600000000,    !- Vertex 1 Z-coordinate {m}
1.770384571385,    !- Vertex 2 X-coordinate {m}
6.133508360644,    !- Vertex 2 Y-coordinate {m}
3.369466524378,    !- Vertex 2 Z-coordinate {m}
1.388875201354,    !- Vertex 3 X-coordinate {m}
7.325339053168,    !- Vertex 3 Y-coordinate {m}
3.369466501462,    !- Vertex 3 Z-coordinate {m}
0.268355212723,    !- Vertex 4 X-coordinate {m}
6.966656508242,    !- Vertex 4 Y-coordinate {m}
4.800599950547;    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
442D04,           !- Name
Roof,             !- Surface Type
Exterior Roof,    !- Construction Name
TopLevel,         !- Zone Name
Outdoors,         !- Outside Boundary Condition
,                 !- Outside Boundary Condition Object
SunExposed,       !- Sun Exposure
WindExposed,      !- Wind Exposure
,                 !- View Factor to Ground
3,                 !- Number of Vertices
2.212172418531,    !- Vertex 1 X-coordinate {m}
4.753368374686,    !- Vertex 1 Y-coordinate {m}

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4.800600000000,      !- Vertex 1 Z-coordinate {m}
1.770384571385,      !- Vertex 2 X-coordinate {m}
6.133508360644,      !- Vertex 2 Y-coordinate {m}
3.369466524378,      !- Vertex 2 Z-coordinate {m}
1.091652461540,      !- Vertex 3 X-coordinate {m}
4.394685839888,      !- Vertex 3 Y-coordinate {m}
4.800600000000;      !- Vertex 3 Z-coordinate {m}
BuildingSurface:Detailed,
9D062D,               !- Name
Roof,                 !- Surface Type
Exterior Roof,        !- Construction Name
TopLevel,             !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
4,                    !- Number of Vertices
2.266198377420,      !- Vertex 1 X-coordinate {m}
0.725418419636,      !- Vertex 1 Y-coordinate {m}
4.800600000000,      !- Vertex 1 Z-coordinate {m}
4.354352158592,      !- Vertex 2 X-coordinate {m}
1.393844045238,      !- Vertex 2 Y-coordinate {m}
2.133599999994,      !- Vertex 2 Z-coordinate {m}
3.982660404012,      !- Vertex 3 X-coordinate {m}
2.555004649534,      !- Vertex 3 Y-coordinate {m}
2.133600000000,      !- Vertex 3 Z-coordinate {m}
1.091652461540,      !- Vertex 4 X-coordinate {m}
4.394685839888,      !- Vertex 4 Y-coordinate {m}
4.800600000000;      !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
521949,              !- Name
Wall,                 !- Surface Type
Exterior Wall,        !- Construction Name
TopLevel,             !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
7,                    !- Number of Vertices
3.982660404012,      !- Vertex 1 X-coordinate {m}
2.555004649534,      !- Vertex 1 Y-coordinate {m}
2.133600000000,      !- Vertex 1 Z-coordinate {m}
3.982660404012,      !- Vertex 2 X-coordinate {m}
2.555004649536,      !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
12.594601351525,     !- Vertex 3 X-coordinate {m}
5.311718431658,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
12.594601351525,     !- Vertex 4 X-coordinate {m}

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5.311718431658,      !- Vertex 4 Y-coordinate {m}
2.133600000000,      !- Vertex 4 Z-coordinate {m}
11.799206361900,     !- Vertex 5 X-coordinate {m}
5.057109567744,      !- Vertex 5 Y-coordinate {m}
2.133600000000,      !- Vertex 5 Z-coordinate {m}
9.912320425879,      !- Vertex 6 X-coordinate {m}
4.453110474660,      !- Vertex 6 Y-coordinate {m}
4.192499305555,      !- Vertex 6 Z-coordinate {m}
8.025434486024,      !- Vertex 7 X-coordinate {m}
3.849111393555,      !- Vertex 7 Y-coordinate {m}
2.133600000000;      !- Vertex 7 Z-coordinate {m}
BuildingSurface:Detailed,
E6F090,               !- Name
Roof,                 !- Surface Type
Exterior Roof,        !- Construction Name
TopLevel,             !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
3,                    !- Number of Vertices
9.912320425879,      !- Vertex 1 X-coordinate {m}
4.453110474660,      !- Vertex 1 Y-coordinate {m}
4.192499305555,      !- Vertex 1 Z-coordinate {m}
11.799206361900,     !- Vertex 2 X-coordinate {m}
5.057109567744,      !- Vertex 2 Y-coordinate {m}
2.133600000000,      !- Vertex 2 Z-coordinate {m}
9.292524431914,      !- Vertex 3 X-coordinate {m}
6.389345761088,      !- Vertex 3 Y-coordinate {m}
4.192499305555;      !- Vertex 3 Z-coordinate {m}
BuildingSurface:Detailed,
A4F367,               !- Name
Roof,                 !- Surface Type
Exterior Roof,        !- Construction Name
TopLevel,             !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
3,                    !- Number of Vertices
9.292524431914,      !- Vertex 1 X-coordinate {m}
6.389345761088,      !- Vertex 1 Y-coordinate {m}
4.192499305555,      !- Vertex 1 Z-coordinate {m}
8.025434486024,      !- Vertex 2 X-coordinate {m}
3.849111393555,      !- Vertex 2 Y-coordinate {m}
2.133600000000,      !- Vertex 2 Z-coordinate {m}
9.912320425879,      !- Vertex 3 X-coordinate {m}
4.453110474660,      !- Vertex 3 Y-coordinate {m}
4.192499305555;      !- Vertex 3 Z-coordinate {m}

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BuildingSurface:Detailed,
4504ED,           !- Name
Roof,             !- Surface Type
Exterior Roof,    !- Construction Name
TopLevel,         !- Zone Name
Outdoors,         !- Outside Boundary Condition
,                 !- Outside Boundary Condition Object
SunExposed,       !- Sun Exposure
WindExposed,      !- Wind Exposure
,                 !- View Factor to Ground
7,               !- Number of Vertices
1.091652461540,   !- Vertex 1 X-coordinate {m}
4.394685839888,   !- Vertex 1 Y-coordinate {m}
4.800600000000,   !- Vertex 1 Z-coordinate {m}
3.982660404012,   !- Vertex 2 X-coordinate {m}
2.555004649534,   !- Vertex 2 Y-coordinate {m}
2.133600000000,   !- Vertex 2 Z-coordinate {m}
8.025434486024,   !- Vertex 3 X-coordinate {m}
3.849111393555,   !- Vertex 3 Y-coordinate {m}
2.133600000000,   !- Vertex 3 Z-coordinate {m}
9.292524431914,   !- Vertex 4 X-coordinate {m}
6.389345761088,   !- Vertex 4 Y-coordinate {m}
4.192499305555,   !- Vertex 4 Z-coordinate {m}
11.799206361900,  !- Vertex 5 X-coordinate {m}
5.057109567744,   !- Vertex 5 Y-coordinate {m}
2.133600000000,   !- Vertex 5 Z-coordinate {m}
12.594601351525,  !- Vertex 6 X-coordinate {m}
5.311718431658,   !- Vertex 6 Y-coordinate {m}
2.133600000000,   !- Vertex 6 Z-coordinate {m}
11.791747180372,  !- Vertex 7 X-coordinate {m}
7.819825278395,   !- Vertex 7 Y-coordinate {m}
4.800600000000,   !- Vertex 7 Z-coordinate {m}
BuildingSurface:Detailed,
E0FF91,          !- Name
Roof,             !- Surface Type
Exterior Roof,    !- Construction Name
TopLevel,         !- Zone Name
Outdoors,         !- Outside Boundary Condition
,                 !- Outside Boundary Condition Object
SunExposed,       !- Sun Exposure
WindExposed,      !- Wind Exposure
,                 !- View Factor to Ground
5,               !- Number of Vertices
3.663623140022,   !- Vertex 1 X-coordinate {m}
5.217983057066,   !- Vertex 1 Y-coordinate {m}
4.800600000000,   !- Vertex 1 Z-coordinate {m}
2.840325922844,   !- Vertex 2 X-coordinate {m}
7.789953735548,   !- Vertex 2 Y-coordinate {m}
2.133600000000,   !- Vertex 2 Z-coordinate {m}
2.356509015692,   !- Vertex 3 X-coordinate {m}
7.635082174758,   !- Vertex 3 Y-coordinate {m}

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2.133600000000,      !- Vertex 3 Z-coordinate {m}
1.770384571385,      !- Vertex 4 X-coordinate {m}
6.133508360644,      !- Vertex 4 Y-coordinate {m}
3.369466524378,      !- Vertex 4 Z-coordinate {m}
2.212172418531,      !- Vertex 5 X-coordinate {m}
4.753368374686,      !- Vertex 5 Y-coordinate {m}
4.800600000000;      !- Vertex 5 Z-coordinate {m}
BuildingSurface:Detailed,
6CB5CC,               !- Name
Wall,                 !- Surface Type
Exterior Wall,        !- Construction Name
TopLevel,             !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
5,                    !- Number of Vertices
2.840325922844,      !- Vertex 1 X-coordinate {m}
7.789953735548,      !- Vertex 1 Y-coordinate {m}
2.133600000000,      !- Vertex 1 Z-coordinate {m}
2.840325922844,      !- Vertex 2 X-coordinate {m}
7.789953735548,      !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
1.388875201354,      !- Vertex 3 X-coordinate {m}
7.325339053168,      !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
1.388875201354,      !- Vertex 4 X-coordinate {m}
7.325339053168,      !- Vertex 4 Y-coordinate {m}
3.369466501462,      !- Vertex 4 Z-coordinate {m}
2.356509015692,      !- Vertex 5 X-coordinate {m}
7.635082174758,      !- Vertex 5 Y-coordinate {m}
2.133600000000;      !- Vertex 5 Z-coordinate {m}
BuildingSurface:Detailed,
920ECC,               !- Name
Roof,                 !- Surface Type
Exterior Roof,        !- Construction Name
TopLevel,             !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
3,                    !- Number of Vertices
1.770384571385,      !- Vertex 1 X-coordinate {m}
6.133508360644,      !- Vertex 1 Y-coordinate {m}
3.369466524378,      !- Vertex 1 Z-coordinate {m}
2.356509015692,      !- Vertex 2 X-coordinate {m}
7.635082174758,      !- Vertex 2 Y-coordinate {m}
2.133600000000,      !- Vertex 2 Z-coordinate {m}
1.388875201354,      !- Vertex 3 X-coordinate {m}

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7.325339053168, !- Vertex 3 Y-coordinate {m}
 3.369466501462; !- Vertex 3 Z-coordinate {m}
 BuildingSurface:Detailed,
 E2981C, !- Name
 Wall, !- Surface Type
 Interior Wall, !- Construction Name
 TopLevel, !- Zone Name
 Adiabatic, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 6, !- Number of Vertices
 2.212172418531, !- Vertex 1 X-coordinate {m}
 4.753368374686, !- Vertex 1 Y-coordinate {m}
 4.800600000000, !- Vertex 1 Z-coordinate {m}
 2.311599960561, !- Vertex 2 X-coordinate {m}
 4.442757920286, !- Vertex 2 Y-coordinate {m}
 4.470311804888, !- Vertex 2 Z-coordinate {m}
 2.311599960561, !- Vertex 3 X-coordinate {m}
 4.442757920286, !- Vertex 3 Y-coordinate {m}
 0.000000000000, !- Vertex 3 Z-coordinate {m}
 1.388875201354, !- Vertex 4 X-coordinate {m}
 7.325339053168, !- Vertex 4 Y-coordinate {m}
 0.000000000000, !- Vertex 4 Z-coordinate {m}
 1.388875201354, !- Vertex 5 X-coordinate {m}
 7.325339053168, !- Vertex 5 Y-coordinate {m}
 3.369466501462, !- Vertex 5 Z-coordinate {m}
 1.770384571385, !- Vertex 6 X-coordinate {m}
 6.133508360644, !- Vertex 6 Y-coordinate {m}
 3.369466524378; !- Vertex 6 Z-coordinate {m}
 BuildingSurface:Detailed,
 1954C6, !- Name
 Roof, !- Surface Type
 Exterior Roof, !- Construction Name
 TopLevel, !- Zone Name
 Outdoors, !- Outside Boundary Condition
 , !- Outside Boundary Condition Object
 SunExposed, !- Sun Exposure
 WindExposed, !- Wind Exposure
 , !- View Factor to Ground
 4, !- Number of Vertices
 11.791747180372, !- Vertex 1 X-coordinate {m}
 7.819825278395, !- Vertex 1 Y-coordinate {m}
 4.800600000000, !- Vertex 1 Z-coordinate {m}
 10.968449963194, !- Vertex 2 X-coordinate {m}
 10.391795956877, !- Vertex 2 Y-coordinate {m}
 2.133600000000, !- Vertex 2 Z-coordinate {m}
 2.840325922844, !- Vertex 3 X-coordinate {m}
 7.789953735548, !- Vertex 3 Y-coordinate {m}
 2.133600000000, !- Vertex 3 Z-coordinate {m}

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3.663623140022,      !- Vertex 4 X-coordinate {m}
5.217983057066,      !- Vertex 4 Y-coordinate {m}
4.800600000000;       !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
A4B067,               !- Name
Wall,                 !- Surface Type
Exterior Wall,        !- Construction Name
TopLevel,             !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
4,                     !- Number of Vertices
10.968449963194,      !- Vertex 1 X-coordinate {m}
10.391795956877,      !- Vertex 1 Y-coordinate {m}
2.133600000000,       !- Vertex 1 Z-coordinate {m}
10.968449963194,      !- Vertex 2 X-coordinate {m}
10.391795956877,      !- Vertex 2 Y-coordinate {m}
0.000000000000,       !- Vertex 2 Z-coordinate {m}
2.840325922844,       !- Vertex 3 X-coordinate {m}
7.789953735548,       !- Vertex 3 Y-coordinate {m}
0.000000000000,       !- Vertex 3 Z-coordinate {m}
2.840325922844,       !- Vertex 4 X-coordinate {m}
7.789953735548,       !- Vertex 4 Y-coordinate {m}
2.133600000000;       !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
AFB673,               !- Name
Wall,                 !- Surface Type
Interior Wall,        !- Construction Name
TopLevel,             !- Zone Name
Adiabatic,            !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
NoSun,                !- Sun Exposure
NoWind,               !- Wind Exposure
0.0,                  !- View Factor to Ground
5,                     !- Number of Vertices
2.840325922844,       !- Vertex 1 X-coordinate {m}
7.789953735548,       !- Vertex 1 Y-coordinate {m}
2.133600000000,       !- Vertex 1 Z-coordinate {m}
2.840325922844,       !- Vertex 2 X-coordinate {m}
7.789953735548,       !- Vertex 2 Y-coordinate {m}
0.000000000000,       !- Vertex 2 Z-coordinate {m}
3.763050682051,       !- Vertex 3 X-coordinate {m}
4.907372602666,       !- Vertex 3 Y-coordinate {m}
0.000000000000,       !- Vertex 3 Z-coordinate {m}
3.763050682052,       !- Vertex 4 X-coordinate {m}
4.907372602667,       !- Vertex 4 Y-coordinate {m}
4.470311805555,       !- Vertex 4 Z-coordinate {m}
3.663623140022,      !- Vertex 5 X-coordinate {m}
5.217983057066,      !- Vertex 5 Y-coordinate {m}

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4.800600000000;      !- Vertex 5 Z-coordinate {m}
!- ===== ALL OBJECTS IN CLASS: FENESTRATIONSURFACE:DETAILED
=====

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```

FenestrationSurface:Detailed,
529444,      !- Name
GlassDoor,   !- Surface Type
Simple Windows, !- Construction Name
521949,      !- Building Surface Name
,            !- Outside Boundary Condition Object
,            !- View Factor to Ground
,            !- Shading Control Name
,            !- Frame and Divider Name
,            !- Multiplier
4,           !- Number of Vertices
8.896304907973, !- Vertex 1 X-coordinate {m}
4.127880237174, !- Vertex 1 Y-coordinate {m}
2.438400000000, !- Vertex 1 Z-coordinate {m}
8.896304907974, !- Vertex 2 X-coordinate {m}
4.127880237175, !- Vertex 2 Y-coordinate {m}
0.304800000000, !- Vertex 2 Z-coordinate {m}
10.928335918288, !- Vertex 3 X-coordinate {m}
4.778340791799, !- Vertex 3 Y-coordinate {m}
0.304800000000, !- Vertex 3 Z-coordinate {m}
10.928335918288, !- Vertex 4 X-coordinate {m}
4.778340791799, !- Vertex 4 Y-coordinate {m}
2.438400000000; !- Vertex 4 Z-coordinate {m}

```

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FenestrationSurface:Detailed,
4622F7,      !- Name
Window,       !- Surface Type
Simple Windows, !- Construction Name
521949,      !- Building Surface Name
,            !- Outside Boundary Condition Object
,            !- View Factor to Ground
,            !- Shading Control Name
,            !- Frame and Divider Name
,            !- Multiplier
4,           !- Number of Vertices
4.490668150849, !- Vertex 1 X-coordinate {m}
2.717619806125, !- Vertex 1 Y-coordinate {m}
1.828800000000, !- Vertex 1 Z-coordinate {m}
4.490668150849, !- Vertex 2 X-coordinate {m}
2.717619806125, !- Vertex 2 Y-coordinate {m}
1.219200000000, !- Vertex 2 Z-coordinate {m}
5.071248439511, !- Vertex 3 X-coordinate {m}
2.903465678875, !- Vertex 3 Y-coordinate {m}
1.219200000000, !- Vertex 3 Z-coordinate {m}
5.071248439511, !- Vertex 4 X-coordinate {m}
2.903465678875, !- Vertex 4 Y-coordinate {m}
1.828800000000; !- Vertex 4 Z-coordinate {m}

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FenestrationSurface:Detailed,
F872D5,      !- Name

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Window,                !- Surface Type
Simple Windows,        !- Construction Name
521949,                !- Building Surface Name
,                      !- Outside Boundary Condition Object
,                      !- View Factor to Ground
,                      !- Shading Control Name
,                      !- Frame and Divider Name
,                      !- Multiplier
4,                    !- Number of Vertices
5.506683656006,        !- Vertex 1 X-coordinate {m}
3.042850083437,        !- Vertex 1 Y-coordinate {m}
1.828800000000,        !- Vertex 1 Z-coordinate {m}
5.506683656007,        !- Vertex 2 X-coordinate {m}
3.042850083437,        !- Vertex 2 Y-coordinate {m}
1.219200000000,        !- Vertex 2 Z-coordinate {m}
6.087263944668,        !- Vertex 3 X-coordinate {m}
3.228695956187,        !- Vertex 3 Y-coordinate {m}
1.219200000000,        !- Vertex 3 Z-coordinate {m}
6.087263944667,        !- Vertex 4 X-coordinate {m}
3.228695956187,        !- Vertex 4 Y-coordinate {m}
1.828800000000;        !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
3F8C93,                !- Name
Window,                !- Surface Type
Simple Windows,        !- Construction Name
521949,                !- Building Surface Name
,                      !- Outside Boundary Condition Object
,                      !- View Factor to Ground
,                      !- Shading Control Name
,                      !- Frame and Divider Name
,                      !- Multiplier
4,                    !- Number of Vertices
6.522699161163,        !- Vertex 1 X-coordinate {m}
3.368080360749,        !- Vertex 1 Y-coordinate {m}
1.828800000000,        !- Vertex 1 Z-coordinate {m}
6.522699161163,        !- Vertex 2 X-coordinate {m}
3.368080360749,        !- Vertex 2 Y-coordinate {m}
1.219200000000,        !- Vertex 2 Z-coordinate {m}
7.103279449825,        !- Vertex 3 X-coordinate {m}
3.553926233499,        !- Vertex 3 Y-coordinate {m}
1.219200000000,        !- Vertex 3 Z-coordinate {m}
7.103279449825,        !- Vertex 4 X-coordinate {m}
3.553926233499,        !- Vertex 4 Y-coordinate {m}
1.828800000000;        !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
5A83AA,                !- Name
Window,                !- Surface Type
Simple Windows,        !- Construction Name
E00FE4,                !- Building Surface Name
,                      !- Outside Boundary Condition Object
,                      !- View Factor to Ground

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,                !- Shading Control Name
,                !- Frame and Divider Name
,                !- Multiplier
4,                !- Number of Vertices
12.284858229938,    !- Vertex 1 X-coordinate {m}
6.279352245985,    !- Vertex 1 Y-coordinate {m}
1.828800000000,    !- Vertex 1 Z-coordinate {m}
12.284858229938,    !- Vertex 2 X-coordinate {m}
6.279352245985,    !- Vertex 2 Y-coordinate {m}
1.219200000000,    !- Vertex 2 Z-coordinate {m}
12.099012356986,    !- Vertex 3 X-coordinate {m}
6.859932534582,    !- Vertex 3 Y-coordinate {m}
1.219200000000,    !- Vertex 3 Z-coordinate {m}
12.099012356986,    !- Vertex 4 X-coordinate {m}
6.859932534582,    !- Vertex 4 Y-coordinate {m}
1.828800000000;    !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
E7197B,            !- Name
Window,            !- Surface Type
Simple Windows,    !- Construction Name
E00FE4,            !- Building Surface Name
,                  !- Outside Boundary Condition Object
,                  !- View Factor to Ground
,                  !- Shading Control Name
,                  !- Frame and Divider Name
,                  !- Multiplier
4,                  !- Number of Vertices
11.464038957733,    !- Vertex 1 X-coordinate {m}
8.843581853953,    !- Vertex 1 Y-coordinate {m}
1.828800000000,    !- Vertex 1 Z-coordinate {m}
11.464038957733,    !- Vertex 2 X-coordinate {m}
8.843581853953,    !- Vertex 2 Y-coordinate {m}
1.219200000000,    !- Vertex 2 Z-coordinate {m}
11.278193084781,    !- Vertex 3 X-coordinate {m}
9.424162142550,    !- Vertex 3 Y-coordinate {m}
1.219200000000,    !- Vertex 3 Z-coordinate {m}
11.278193084781,    !- Vertex 4 X-coordinate {m}
9.424162142550,    !- Vertex 4 Y-coordinate {m}
1.828800000000;    !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
BABE81,            !- Name
Window,            !- Surface Type
Simple Windows,    !- Construction Name
909C61,            !- Building Surface Name
,                  !- Outside Boundary Condition Object
,                  !- View Factor to Ground
,                  !- Shading Control Name
,                  !- Frame and Divider Name
,                  !- Multiplier
4,                  !- Number of Vertices
0.834421025744,    !- Vertex 1 X-coordinate {m}

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7.147856244499,      !- Vertex 1 Y-coordinate {m}
2.438400000000,      !- Vertex 1 Z-coordinate {m}
0.834421025744,      !- Vertex 2 X-coordinate {m}
7.147856244499,      !- Vertex 2 Y-coordinate {m}
1.219200000000,      !- Vertex 2 Z-coordinate {m}
-0.326739551449,     !- Vertex 3 X-coordinate {m}
6.776164498594,      !- Vertex 3 Y-coordinate {m}
1.219200000000,      !- Vertex 3 Z-coordinate {m}
-0.326739551449,     !- Vertex 4 X-coordinate {m}
6.776164498594,      !- Vertex 4 Y-coordinate {m}
2.438400000000;      !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
C5C8B7,              !- Name
Window,              !- Surface Type
Simple Windows,      !- Construction Name
6CB5CC,              !- Building Surface Name
,                    !- Outside Boundary Condition Object
,                    !- View Factor to Ground
,                    !- Shading Control Name
,                    !- Frame and Divider Name
,                    !- Multiplier
4,                   !- Number of Vertices
2.259745634248,      !- Vertex 1 X-coordinate {m}
7.604107862596,      !- Vertex 1 Y-coordinate {m}
1.828800000000,      !- Vertex 1 Z-coordinate {m}
2.259745634248,      !- Vertex 2 X-coordinate {m}
7.604107862596,      !- Vertex 2 Y-coordinate {m}
0.609600000000,      !- Vertex 2 Z-coordinate {m}
1.679165345652,      !- Vertex 3 X-coordinate {m}
7.418261989644,      !- Vertex 3 Y-coordinate {m}
0.609600000000,      !- Vertex 3 Z-coordinate {m}
1.679165345652,      !- Vertex 4 X-coordinate {m}
7.418261989644,      !- Vertex 4 Y-coordinate {m}
1.828800000000;      !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
55FD1A,              !- Name
Window,              !- Surface Type
Simple Windows,      !- Construction Name
D0776F,              !- Building Surface Name
,                    !- Outside Boundary Condition Object
,                    !- View Factor to Ground
,                    !- Shading Control Name
,                    !- Frame and Divider Name
,                    !- Multiplier
4,                   !- Number of Vertices
-1.654522393821,     !- Vertex 1 X-coordinate {m}
3.835660344795,      !- Vertex 1 Y-coordinate {m}
1.828800000000,      !- Vertex 1 Z-coordinate {m}
-1.654522393821,     !- Vertex 2 X-coordinate {m}
3.835660344795,      !- Vertex 2 Y-coordinate {m}
1.219200000000,      !- Vertex 2 Z-coordinate {m}

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-1.468676520869,    !- Vertex 3 X-coordinate {m}
3.255080056199,    !- Vertex 3 Y-coordinate {m}
1.219200000000,    !- Vertex 3 Z-coordinate {m}
-1.468676520869,    !- Vertex 4 X-coordinate {m}
3.255080056199,    !- Vertex 4 Y-coordinate {m}
1.828800000000;    !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
CCA052,             !- Name
Window,             !- Surface Type
Simple Windows,     !- Construction Name
D0776F,             !- Building Surface Name
,                   !- Outside Boundary Condition Object
,                   !- View Factor to Ground
,                   !- Shading Control Name
,                   !- Frame and Divider Name
,                   !- Multiplier
4,                  !- Number of Vertices
-1.269821436810,    !- Vertex 1 X-coordinate {m}
2.633859147398,    !- Vertex 1 Y-coordinate {m}
1.828800000000,    !- Vertex 1 Z-coordinate {m}
-1.269821436810,    !- Vertex 2 X-coordinate {m}
2.633859147398,    !- Vertex 2 Y-coordinate {m}
1.219200000000,    !- Vertex 2 Z-coordinate {m}
-1.083975563858,    !- Vertex 3 X-coordinate {m}
2.053278858802,    !- Vertex 3 Y-coordinate {m}
1.219200000000,    !- Vertex 3 Z-coordinate {m}
-1.083975563858,    !- Vertex 4 X-coordinate {m}
2.053278858802,    !- Vertex 4 Y-coordinate {m}
1.828800000000;    !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
25A651,             !- Name
Window,             !- Surface Type
Simple Windows,     !- Construction Name
868AEF,             !- Building Surface Name
,                   !- Outside Boundary Condition Object
,                   !- View Factor to Ground
,                   !- Shading Control Name
,                   !- Frame and Divider Name
,                   !- Multiplier
4,                  !- Number of Vertices
1.306305643798,    !- Vertex 1 X-coordinate {m}
0.418153221326,    !- Vertex 1 Y-coordinate {m}
1.828800000000,    !- Vertex 1 Z-coordinate {m}
1.306305643798,    !- Vertex 2 X-coordinate {m}
0.418153221326,    !- Vertex 2 Y-coordinate {m}
0.914400000000,    !- Vertex 2 Z-coordinate {m}
3.048046506118,    !- Vertex 3 X-coordinate {m}
0.975690851017,    !- Vertex 3 Y-coordinate {m}
0.914400000000,    !- Vertex 3 Z-coordinate {m}
3.048046506118,    !- Vertex 4 X-coordinate {m}
0.975690851017,    !- Vertex 4 Y-coordinate {m}

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1.828800000000;      !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
C8F3FD,              !- Name
Window,              !- Surface Type
Simple Windows,      !- Construction Name
4DCE52,              !- Building Surface Name
,                    !- Outside Boundary Condition Object
,                    !- View Factor to Ground
,                    !- Shading Control Name
,                    !- Frame and Divider Name
,                    !- Multiplier
4,                    !- Number of Vertices
9.756470303965,      !- Vertex 1 X-coordinate {m}
3.123081843326,      !- Vertex 1 Y-coordinate {m}
1.828800000000,      !- Vertex 1 Z-coordinate {m}
9.756470303965,      !- Vertex 2 X-coordinate {m}
3.123081843326,      !- Vertex 2 Y-coordinate {m}
0.914400000000,      !- Vertex 2 Z-coordinate {m}
10.917630881158,     !- Vertex 3 X-coordinate {m}
3.494773589231,      !- Vertex 3 Y-coordinate {m}
0.914400000000,      !- Vertex 3 Z-coordinate {m}
10.917630881157,     !- Vertex 4 X-coordinate {m}
3.494773589231,      !- Vertex 4 Y-coordinate {m}
1.828800000000;      !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
D3E073,              !- Name
Door,                !- Surface Type
Exterior Door,       !- Construction Name
B204CE,              !- Building Surface Name
,                    !- Outside Boundary Condition Object
,                    !- View Factor to Ground
,                    !- Shading Control Name
,                    !- Frame and Divider Name
,                    !- Multiplier
4,                    !- Number of Vertices
5.361538589428,      !- Vertex 1 X-coordinate {m}
2.996388597797,      !- Vertex 1 Y-coordinate {m}
2.286000000000,      !- Vertex 1 Z-coordinate {m}
5.361538589428,      !- Vertex 2 X-coordinate {m}
2.996388597797,      !- Vertex 2 Y-coordinate {m}
0.152400000000,      !- Vertex 2 Z-coordinate {m}
6.232409022323,      !- Vertex 3 X-coordinate {m}
3.275157407225,      !- Vertex 3 Y-coordinate {m}
0.152400000000,      !- Vertex 3 Z-coordinate {m}
6.232409022323,      !- Vertex 4 X-coordinate {m}
3.275157407225,      !- Vertex 4 Y-coordinate {m}
2.286000000000;      !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
C1C4D1,              !- Name
Window,              !- Surface Type
Simple Windows,      !- Construction Name

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B204CE,          !- Building Surface Name
,                !- Outside Boundary Condition Object
,                !- View Factor to Ground
,                !- Shading Control Name
,                !- Frame and Divider Name
,                !- Multiplier
4,               !- Number of Vertices
4.998675909055,  !- Vertex 1 X-coordinate {m}
2.880234927202,  !- Vertex 1 Y-coordinate {m}
2.286000000000,  !- Vertex 1 Z-coordinate {m}
4.998675909055,  !- Vertex 2 X-coordinate {m}
2.880234927202,  !- Vertex 2 Y-coordinate {m}
0.152400000000,  !- Vertex 2 Z-coordinate {m}
5.288966053354,  !- Vertex 3 X-coordinate {m}
2.973157863678,  !- Vertex 3 Y-coordinate {m}
0.152400000000,  !- Vertex 3 Z-coordinate {m}
5.288966053354,  !- Vertex 4 X-coordinate {m}
2.973157863678,  !- Vertex 4 Y-coordinate {m}
2.286000000000;  !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
B9E2AD,          !- Name
Window,          !- Surface Type
Simple Windows,   !- Construction Name
B204CE,          !- Building Surface Name
,                !- Outside Boundary Condition Object
,                !- View Factor to Ground
,                !- Shading Control Name
,                !- Frame and Divider Name
,                !- Multiplier
4,               !- Number of Vertices
6.304981558397,  !- Vertex 1 X-coordinate {m}
3.298388141344,  !- Vertex 1 Y-coordinate {m}
2.286000000000,  !- Vertex 1 Z-coordinate {m}
6.304981558397,  !- Vertex 2 X-coordinate {m}
3.298388141344,  !- Vertex 2 Y-coordinate {m}
0.152400000000,  !- Vertex 2 Z-coordinate {m}
6.595271702696,  !- Vertex 3 X-coordinate {m}
3.391311077820,  !- Vertex 3 Y-coordinate {m}
0.152400000000,  !- Vertex 3 Z-coordinate {m}
6.595271702696,  !- Vertex 4 X-coordinate {m}
3.391311077820,  !- Vertex 4 Y-coordinate {m}
2.286000000000;  !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
FD39E3,          !- Name
Window,          !- Surface Type
Simple Windows,   !- Construction Name
662777,          !- Building Surface Name
,                !- Outside Boundary Condition Object
,                !- View Factor to Ground
,                !- Shading Control Name
,                !- Frame and Divider Name

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,                !- Multiplier
4,                !- Number of Vertices
11.340141709098,    !- Vertex 1 X-coordinate {m}
9.230635379684,     !- Vertex 1 Y-coordinate {m}
2.133600000000,     !- Vertex 1 Z-coordinate {m}
11.340141709098,    !- Vertex 2 X-coordinate {m}
9.230635379684,     !- Vertex 2 Y-coordinate {m}
0.914400000000,     !- Vertex 2 Z-coordinate {m}
11.154295836146,    !- Vertex 3 X-coordinate {m}
9.811215668281,     !- Vertex 3 Y-coordinate {m}
0.914400000000,     !- Vertex 3 Z-coordinate {m}
11.154295836146,    !- Vertex 4 X-coordinate {m}
9.811215668281,     !- Vertex 4 Y-coordinate {m}
2.133600000000;     !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
2D44D1,            !- Name
Window,            !- Surface Type
Simple Windows,     !- Construction Name
56F7F0,            !- Building Surface Name
,                  !- Outside Boundary Condition Object
,                  !- View Factor to Ground
,                  !- Shading Control Name
,                  !- Frame and Divider Name
,                  !- Multiplier
4,                  !- Number of Vertices
-2.013204928619,    !- Vertex 1 X-coordinate {m}
4.956180301786,     !- Vertex 1 Y-coordinate {m}
2.133600000000,     !- Vertex 1 Z-coordinate {m}
-2.013204928619,    !- Vertex 2 X-coordinate {m}
4.956180301786,     !- Vertex 2 Y-coordinate {m}
0.914400000000,     !- Vertex 2 Z-coordinate {m}
-1.827359055667,    !- Vertex 3 X-coordinate {m}
4.375600013190,     !- Vertex 3 Y-coordinate {m}
0.914400000000,     !- Vertex 3 Z-coordinate {m}
-1.827359055667,    !- Vertex 4 X-coordinate {m}
4.375600013190,     !- Vertex 4 Y-coordinate {m}
2.133600000000;     !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
BFC72E,            !- Name
Window,            !- Surface Type
Simple Windows,     !- Construction Name
B0EF72,            !- Building Surface Name
,                  !- Outside Boundary Condition Object
,                  !- View Factor to Ground
,                  !- Shading Control Name
,                  !- Frame and Divider Name
,                  !- Multiplier
4,                  !- Number of Vertices
4.531266013381,     !- Vertex 1 X-coordinate {m}
8.331229840521,     !- Vertex 1 Y-coordinate {m}
2.407920000000,     !- Vertex 1 Z-coordinate {m}

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4.531266013381,      !- Vertex 2 X-coordinate {m}
8.331229840521,      !- Vertex 2 Y-coordinate {m}
1.188720000000,      !- Vertex 2 Z-coordinate {m}
3.950685724785,      !- Vertex 3 X-coordinate {m}
8.145383967568,      !- Vertex 3 Y-coordinate {m}
1.188720000000,      !- Vertex 3 Z-coordinate {m}
3.950685724785,      !- Vertex 4 X-coordinate {m}
8.145383967568,      !- Vertex 4 Y-coordinate {m}
2.407920000000;      !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
6BAE45,              !- Name
Window,              !- Surface Type
Simple Windows,      !- Construction Name
3E389E,              !- Building Surface Name
,                    !- Outside Boundary Condition Object
,                    !- View Factor to Ground
,                    !- Shading Control Name
,                    !- Frame and Divider Name
,                    !- Multiplier
4,                  !- Number of Vertices
6.561845572747,      !- Vertex 1 X-coordinate {m}
8.981225781171,      !- Vertex 1 Y-coordinate {m}
2.255520000000,      !- Vertex 1 Z-coordinate {m}
6.561845572747,      !- Vertex 2 X-coordinate {m}
8.981225781171,      !- Vertex 2 Y-coordinate {m}
1.036320000000,      !- Vertex 2 Z-coordinate {m}
5.981265284151,      !- Vertex 3 X-coordinate {m}
8.795379908219,      !- Vertex 3 Y-coordinate {m}
1.036320000000,      !- Vertex 3 Z-coordinate {m}
5.981265284151,      !- Vertex 4 X-coordinate {m}
8.795379908219,      !- Vertex 4 Y-coordinate {m}
2.255520000000;      !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
A2BE82,              !- Name
Window,              !- Surface Type
Simple Windows,      !- Construction Name
2068E8,              !- Building Surface Name
,                    !- Outside Boundary Condition Object
,                    !- View Factor to Ground
,                    !- Shading Control Name
,                    !- Frame and Divider Name
,                    !- Multiplier
3,                  !- Number of Vertices
2.252673418394,      !- Vertex 1 X-coordinate {m}
0.721088996009,      !- Vertex 1 Y-coordinate {m}
4.097927297775,      !- Vertex 1 Z-coordinate {m}
0.457073581739,      !- Vertex 2 X-coordinate {m}
0.146310917418,      !- Vertex 2 Y-coordinate {m}
1.984756272630,      !- Vertex 2 Z-coordinate {m}
3.899076513342,      !- Vertex 3 X-coordinate {m}
1.248108651605,      !- Vertex 3 Y-coordinate {m}

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1.995133375705;      !- Vertex 3 Z-coordinate {m}
FenestrationSurface:Detailed,
682F54,              !- Name
Window,              !- Surface Type
Simple Windows,      !- Construction Name
2068E8,              !- Building Surface Name
,                    !- Outside Boundary Condition Object
,                    !- View Factor to Ground
,                    !- Shading Control Name
,                    !- Frame and Divider Name
,                    !- Multiplier
4,                  !- Number of Vertices
0.435435218541,      !- Vertex 1 X-coordinate {m}
0.139384398174,      !- Vertex 1 Y-coordinate {m}
1.969793086800,      !- Vertex 1 Z-coordinate {m}
0.435435218541,      !- Vertex 2 X-coordinate {m}
0.139384398174,      !- Vertex 2 Y-coordinate {m}
0.457200000000,      !- Vertex 2 Z-coordinate {m}
3.918916940709,      !- Vertex 3 X-coordinate {m}
1.254459645010,      !- Vertex 3 Y-coordinate {m}
0.457200000000,      !- Vertex 3 Z-coordinate {m}
3.918916940709,      !- Vertex 4 X-coordinate {m}
1.254459645010,      !- Vertex 4 Y-coordinate {m}
1.969793086800;      !- Vertex 4 Z-coordinate {m}
!- ===== ALL OBJECTS IN CLASS: INTERNALMASS =====
InternalMass,
Top Floor Internal Mass, !- Name
Interior Furnishings,   !- Construction Name
TopLevel,               !- Zone Name
184.42;                 !- Surface Area {m2}
InternalMass,
First Floor Internal Mass, !- Name
Interior Furnishings,   !- Construction Name
FirstFloor,             !- Zone Name
184.42;                 !- Surface Area {m2}
InternalMass,
Basement Internal Mass, !- Name
Interior Furnishings,   !- Construction Name
Basement,               !- Zone Name
184.42;                 !- Surface Area {m2}
!- ===== ALL OBJECTS IN CLASS: SHADING:BUILDING:DETAILED =====
Shading:Building:Detailed,
44F23B,                 !- Name
,                       !- Transmittance Schedule Name
15,                     !- Number of Vertices
-2.415250595988,        !- Vertex 1 X-coordinate {m}
-2.595393350464,        !- Vertex 1 Y-coordinate {m}
2.886456000000,         !- Vertex 1 Z-coordinate {m}
-1.764790040656,        !- Vertex 2 X-coordinate {m}
-4.627424360552,        !- Vertex 2 Y-coordinate {m}
2.886456000000,         !- Vertex 2 Z-coordinate {m}

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-1.443596698836,    !- Vertex 3 X-coordinate {m}
-4.782630844533,    !- Vertex 3 Y-coordinate {m}
2.886456000000,     !- Vertex 3 Z-coordinate {m}
-1.104087828234,    !- Vertex 4 X-coordinate {m}
-4.892120306497,    !- Vertex 4 Y-coordinate {m}
2.886456000000,     !- Vertex 4 Z-coordinate {m}
-0.752734572904,    !- Vertex 5 X-coordinate {m}
-4.953805843444,    !- Vertex 5 Y-coordinate {m}
2.886456000000,     !- Vertex 5 Z-coordinate {m}
-0.396233834539,    !- Vertex 6 X-coordinate {m}
-4.966511709965,    !- Vertex 6 Y-coordinate {m}
2.886456000000,     !- Vertex 6 Z-coordinate {m}
-0.041380627447,    !- Vertex 7 X-coordinate {m}
-4.929995728316,    !- Vertex 7 Y-coordinate {m}
2.886456000000,     !- Vertex 7 Z-coordinate {m}
0.305061436517,     !- Vertex 8 X-coordinate {m}
-4.844953904397,    !- Vertex 8 Y-coordinate {m}
2.886456000000,     !- Vertex 8 Z-coordinate {m}
0.636489064488,     !- Vertex 9 X-coordinate {m}
-4.713007161670,    !- Vertex 9 Y-coordinate {m}
2.886456000000,     !- Vertex 9 Z-coordinate {m}
0.946585143394,     !- Vertex 10 X-coordinate {m}
-4.536670445850,    !- Vertex 10 Y-coordinate {m}
2.886456000000,     !- Vertex 10 Z-coordinate {m}
1.229439146084,     !- Vertex 11 X-coordinate {m}
-4.319304789268,    !- Vertex 11 Y-coordinate {m}
2.886456000000,     !- Vertex 11 Z-coordinate {m}
1.479659787804,     !- Vertex 12 X-coordinate {m}
-4.065053248552,    !- Vertex 12 Y-coordinate {m}
2.886456000000,     !- Vertex 12 Z-coordinate {m}
1.692477785749,     !- Vertex 13 X-coordinate {m}
-3.778761936686,    !- Vertex 13 Y-coordinate {m}
2.886456000000,     !- Vertex 13 Z-coordinate {m}
1.863836763071,     !- Vertex 14 X-coordinate {m}
-3.465887654602,    !- Vertex 14 Y-coordinate {m}
2.886456000000,     !- Vertex 14 Z-coordinate {m}
1.213376207739,     !- Vertex 15 X-coordinate {m}
-1.433856644514,    !- Vertex 15 Y-coordinate {m}
2.886456000000;     !- Vertex 15 Z-coordinate {m}
Shading:Building:Detailed,
CFBFD0,              !- Name
,                    !- Transmittance Schedule Name
4,                  !- Number of Vertices
-11.220552496222,   !- Vertex 1 X-coordinate {m}
-15.336595486396,   !- Vertex 1 Y-coordinate {m}
6.575425000000,     !- Vertex 1 Z-coordinate {m}
-11.220552496222,   !- Vertex 2 X-coordinate {m}
-15.336595486396,   !- Vertex 2 Y-coordinate {m}
0.000000000000,     !- Vertex 2 Z-coordinate {m}
-13.472541078190,   !- Vertex 3 X-coordinate {m}
-5.282850875938,    !- Vertex 3 Y-coordinate {m}

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0.000000000000,      !- Vertex 3 Z-coordinate {m}
-13.472541078190,    !- Vertex 4 X-coordinate {m}
-5.282850875938,     !- Vertex 4 Y-coordinate {m}
6.575425000000;      !- Vertex 4 Z-coordinate {m}
Shading:Building:Detailed,
EA613B,               !- Name
,                     !- Transmittance Schedule Name
4,                   !- Number of Vertices
3.818938284227,      !- Vertex 1 X-coordinate {m}
-13.547186485484,    !- Vertex 1 Y-coordinate {m}
7.137400000000,      !- Vertex 1 Z-coordinate {m}
3.818938284227,      !- Vertex 2 X-coordinate {m}
-13.547186485484,    !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
2.832638412974,      !- Vertex 3 X-coordinate {m}
-8.117896293712,     !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
2.832638412974,      !- Vertex 4 X-coordinate {m}
-8.117896293712,     !- Vertex 4 Y-coordinate {m}
7.137400000000;      !- Vertex 4 Z-coordinate {m}
Shading:Building:Detailed,
433CC0,              !- Name
,                     !- Transmittance Schedule Name
4,                   !- Number of Vertices
2.832638412974,      !- Vertex 1 X-coordinate {m}
-8.117896293712,     !- Vertex 1 Y-coordinate {m}
7.137400000000,      !- Vertex 1 Z-coordinate {m}
2.832638412974,      !- Vertex 2 X-coordinate {m}
-8.117896293712,     !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
3.818938284227,      !- Vertex 3 X-coordinate {m}
-7.938722331431,     !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
3.818938284227,      !- Vertex 4 X-coordinate {m}
-7.938722331431,     !- Vertex 4 Y-coordinate {m}
7.137400000000;      !- Vertex 4 Z-coordinate {m}
Shading:Building:Detailed,
FB1995,              !- Name
,                     !- Transmittance Schedule Name
4,                   !- Number of Vertices
3.818938284227,      !- Vertex 1 X-coordinate {m}
-7.938722331431,     !- Vertex 1 Y-coordinate {m}
7.137400000000,      !- Vertex 1 Z-coordinate {m}
3.818938284227,      !- Vertex 2 X-coordinate {m}
-7.938722331431,     !- Vertex 2 Y-coordinate {m}
0.000000000000,      !- Vertex 2 Z-coordinate {m}
3.590523037864,      !- Vertex 3 X-coordinate {m}
-6.681363699562,     !- Vertex 3 Y-coordinate {m}
0.000000000000,      !- Vertex 3 Z-coordinate {m}
3.590523037864,      !- Vertex 4 X-coordinate {m}
-6.681363699562,     !- Vertex 4 Y-coordinate {m}

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7.137400000000;    !- Vertex 4 Z-coordinate {m}
Shading:Building:Detailed,
C7CF76,            !- Name
,                  !- Transmittance Schedule Name
4,                  !- Number of Vertices
3.590523037864,    !- Vertex 1 X-coordinate {m}
-6.681363699562,   !- Vertex 1 Y-coordinate {m}
7.137400000000,    !- Vertex 1 Z-coordinate {m}
3.590523037864,    !- Vertex 2 X-coordinate {m}
-6.681363699562,   !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
6.731576713253,    !- Vertex 3 X-coordinate {m}
-6.110751202126,   !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
6.731576713253,    !- Vertex 4 X-coordinate {m}
-6.110751202126,   !- Vertex 4 Y-coordinate {m}
7.137400000000;    !- Vertex 4 Z-coordinate {m}
Shading:Building:Detailed,
5319FD,           !- Name
,                  !- Transmittance Schedule Name
4,                  !- Number of Vertices
6.731576713253,    !- Vertex 1 X-coordinate {m}
-6.110751202126,   !- Vertex 1 Y-coordinate {m}
7.137400000000,    !- Vertex 1 Z-coordinate {m}
6.731576713253,    !- Vertex 2 X-coordinate {m}
-6.110751202126,   !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
6.351073799746,    !- Vertex 3 X-coordinate {m}
-4.016194773137,   !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
6.351073799746,    !- Vertex 4 X-coordinate {m}
-4.016194773137,   !- Vertex 4 Y-coordinate {m}
7.137400000000;    !- Vertex 4 Z-coordinate {m}
Shading:Building:Detailed,
33E5EA,           !- Name
,                  !- Transmittance Schedule Name
4,                  !- Number of Vertices
6.351073799746,    !- Vertex 1 X-coordinate {m}
-4.016194773137,   !- Vertex 1 Y-coordinate {m}
7.137400000000,    !- Vertex 1 Z-coordinate {m}
6.351073799746,    !- Vertex 2 X-coordinate {m}
-4.016194773137,   !- Vertex 2 Y-coordinate {m}
0.000000000000,    !- Vertex 2 Z-coordinate {m}
12.425443637433,   !- Vertex 3 X-coordinate {m}
-2.912707949403,   !- Vertex 3 Y-coordinate {m}
0.000000000000,    !- Vertex 3 Z-coordinate {m}
12.425443637433,   !- Vertex 4 X-coordinate {m}
-2.912707949403,   !- Vertex 4 Y-coordinate {m}
7.137400000000;    !- Vertex 4 Z-coordinate {m}
!- ===== ALL OBJECTS IN CLASS: ELECTRICEQUIPMENT =====
ElectricEquipment,

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First Floor Light and Plug Loads, !- Name
FirstFloor,      !- Zone or ZoneList Name
MainFloorGains,  !- Schedule Name
EquipmentLevel,  !- Design Level Calculation Method
349,             !- Design Level {W}
,               !- Watts per Zone Floor Area {W/m2}
,               !- Watts per Person {W/person}
0,              !- Fraction Latent
0.7,            !- Fraction Radiant
0,              !- Fraction Lost
General;         !- End-Use Subcategory
ElectricEquipment,
  Basement Light and Plug Loads, !- Name
  Basement,      !- Zone or ZoneList Name
  BasementGains, !- Schedule Name
  EquipmentLevel, !- Design Level Calculation Method
  2905.4,        !- Design Level {W}
  ,              !- Watts per Zone Floor Area {W/m2}
  ,              !- Watts per Person {W/person}
  0,             !- Fraction Latent
  0.7,           !- Fraction Radiant
  0,             !- Fraction Lost
  General;       !- End-Use Subcategory
ElectricEquipment,
  Top Level Light and Plug Loads, !- Name
  TopLevel,      !- Zone or ZoneList Name
  TopFloorGains, !- Schedule Name
  EquipmentLevel, !- Design Level Calculation Method
  1838.6,        !- Design Level {W}
  ,              !- Watts per Zone Floor Area {W/m2}
  ,              !- Watts per Person {W/person}
  0,             !- Fraction Latent
  0.7,           !- Fraction Radiant
  0,             !- Fraction Lost
  General;       !- End-Use Subcategory
!- ===== ALL OBJECTS IN CLASS: ZONEINFILTRATION:EFFECTIVELEAKAGEAREA
=====
ZoneInfiltration:EffectiveLeakageArea,
  FirstFloor,    !- Name
  FirstFloor,    !- Zone Name
  Always On,     !- Schedule Name
  158.14,        !- Effective Air Leakage Area {cm2}
  0.00029,       !- Stack Coefficient
  0.000137;      !- Wind Coefficient
ZoneInfiltration:EffectiveLeakageArea,
  TopFloor,      !- Name
  TopLevel,      !- Zone Name
  Always On,     !- Schedule Name
  158.14,
  0.00029,       !- Stack Coefficient
  0.000137;      !- Wind Coefficient

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!- ===== ALL OBJECTS IN CLASS: SIZING:ZONE =====
Sizing:Zone,
  Basement,      !- Zone Name
  12.8,          !- Zone Cooling Design Supply Air Temperature {C}
  50,            !- Zone Heating Design Supply Air Temperature {C}
  0.008,         !- Zone Cooling Design Supply Air Humidity Ratio {kg-H2O/kg-air}
  0.008,         !- Zone Heating Design Supply Air Humidity Ratio {kg-H2O/kg-air}
  Flow/Person,   !- Outdoor Air Method
  0.00944,       !- Outdoor Air Flow per Person {m3/s}
  ,             !- Outdoor Air Flow per Zone Floor Area {m3/s-m2}
  ,             !- Outdoor Air Flow per Zone {m3/s}
  1.1,          !- Zone Heating Sizing Factor
  ,             !- Zone Cooling Sizing Factor
  ,             !- Cooling Design Air Flow Method
  ,             !- Cooling Design Air Flow Rate {m3/s}
  ,             !- Cooling Minimum Air Flow per Zone Floor Area {m3/s-m2}
  ,             !- Cooling Minimum Air Flow {m3/s}
  ,             !- Cooling Minimum Air Flow Fraction
  DesignDay,    !- Heating Design Air Flow Method
  0,            !- Heating Design Air Flow Rate {m3/s}
  ,            !- Heating Maximum Air Flow per Zone Floor Area {m3/s-m2}
  ,            !- Heating Maximum Air Flow {m3/s}
  0;           !- Heating Maximum Air Flow Fraction
Sizing:Zone,
  TopLevel,     !- Zone Name
  12.8,         !- Zone Cooling Design Supply Air Temperature {C}
  50,           !- Zone Heating Design Supply Air Temperature {C}
  0.008,        !- Zone Cooling Design Supply Air Humidity Ratio {kg-H2O/kg-air}
  0.008,        !- Zone Heating Design Supply Air Humidity Ratio {kg-H2O/kg-air}
  Flow/Person,  !- Outdoor Air Method
  0.00944,      !- Outdoor Air Flow per Person {m3/s}
  ,            !- Outdoor Air Flow per Zone Floor Area {m3/s-m2}
  ,            !- Outdoor Air Flow per Zone {m3/s}
  1.1,         !- Zone Heating Sizing Factor
  ,            !- Zone Cooling Sizing Factor
  ,            !- Cooling Design Air Flow Method
  ,            !- Cooling Design Air Flow Rate {m3/s}
  ,            !- Cooling Minimum Air Flow per Zone Floor Area {m3/s-m2}
  ,            !- Cooling Minimum Air Flow {m3/s}
  ,            !- Cooling Minimum Air Flow Fraction
  DesignDay,   !- Heating Design Air Flow Method
  0,           !- Heating Design Air Flow Rate {m3/s}
  ,           !- Heating Maximum Air Flow per Zone Floor Area {m3/s-m2}
  ,           !- Heating Maximum Air Flow {m3/s}
  0;          !- Heating Maximum Air Flow Fraction
Sizing:Zone,
  FirstFloor,   !- Zone Name
  12.8,         !- Zone Cooling Design Supply Air Temperature {C}
  50,           !- Zone Heating Design Supply Air Temperature {C}
  0.008,        !- Zone Cooling Design Supply Air Humidity Ratio {kg-H2O/kg-air}
  0.008,        !- Zone Heating Design Supply Air Humidity Ratio {kg-H2O/kg-air}

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Flow/Person,      !- Outdoor Air Method
0.00944,          !- Outdoor Air Flow per Person {m3/s}
,                !- Outdoor Air Flow per Zone Floor Area {m3/s-m2}
,                !- Outdoor Air Flow per Zone {m3/s}
1.1,             !- Zone Heating Sizing Factor
,                !- Zone Cooling Sizing Factor
,                !- Cooling Design Air Flow Method
,                !- Cooling Design Air Flow Rate {m3/s}
,                !- Cooling Minimum Air Flow per Zone Floor Area {m3/s-m2}
,                !- Cooling Minimum Air Flow {m3/s}
,                !- Cooling Minimum Air Flow Fraction
DesignDay,       !- Heating Design Air Flow Method
0,               !- Heating Design Air Flow Rate {m3/s}
,                !- Heating Maximum Air Flow per Zone Floor Area {m3/s-m2}
,                !- Heating Maximum Air Flow {m3/s}
0;              !- Heating Maximum Air Flow Fraction
!- ===== ALL OBJECTS IN CLASS: SIZING:SYSTEM =====
Sizing:System,
  AHU,           !- AirLoop Name
  Sensible,      !- Type of Load to Size On
  autosize,      !- Design Outdoor Air Flow Rate {m3/s}
  0.3,           !- Minimum System Air Flow Ratio
  7,             !- Preheat Design Temperature {C}
  0.008,         !- Preheat Design Humidity Ratio {kg-H2O/kg-Air}
  11,            !- Precool Design Temperature {C}
  0.008,         !- Precool Design Humidity Ratio {kg-H2O/kg-Air}
  12.8,         !- Central Cooling Design Supply Air Temperature {C}
  50,            !- Central Heating Design Supply Air Temperature {C}
  NonCoincident, !- Sizing Option
  No,            !- 100% Outdoor Air in Cooling
  No,            !- 100% Outdoor Air in Heating
  0.008,         !- Central Cooling Design Supply Air Humidity Ratio {kg-H2O/kg-Air}
  0.008,         !- Central Heating Design Supply Air Humidity Ratio {kg-H2O/kg-Air}
  DesignDay,     !- Cooling Design Air Flow Method
  0,             !- Cooling Design Air Flow Rate {m3/s}
  DesignDay,     !- Heating Design Air Flow Method
  0;             !- Heating Design Air Flow Rate {m3/s}
!- ===== ALL OBJECTS IN CLASS: SIZING:PLANT =====
Sizing:Plant,
  Hot Water Loop, !- Plant or Condenser Loop Name
  Heating,        !- Loop Type
  82,             !- Design Loop Exit Temperature {C}
  10;             !- Loop Design Temperature Difference {deltaC}
!- ===== ALL OBJECTS IN CLASS: THERMOSTATSETPOINT:SINGLEHEATING
=====
ThermostatSetpoint:SingleHeating,
  Heating Thermostat, !- Name
  HVACTemplate-Always 20; !- Setpoint Temperature Schedule Name
!- ===== ALL OBJECTS IN CLASS: AIRTERMINAL:SINGLEDUCT:UNCONTROLLED
=====
AirTerminal:SingleDuct:Uncontrolled,

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FirstFloor Outlet,      !- Name
Always On,              !- Availability Schedule Name
FirstFloor Zone Equip Inlet, !- Zone Supply Air Node Name
.1718;                  !- Maximum Air Flow Rate {m3/s}
AirTerminal:SingleDuct:Uncontrolled,
  TopLevel Outlet,      !- Name
  Always On,            !- Availability Schedule Name
  TopLevel Zone Equip Inlet, !- Zone Supply Air Node Name
.0622;                  !- Maximum Air Flow Rate {m3/s}
AirTerminal:SingleDuct:Uncontrolled,
  Basement Outlet,      !- Name
  Always On,            !- Availability Schedule Name
  Basement Zone Equip Inlet, !- Zone Supply Air Node Name
0;                      !- Maximum Air Flow Rate {m3/s}
!- ===== ALL OBJECTS IN CLASS: ZONEHVAC:EQUIPMENTLIST =====
ZoneHVAC:EquipmentList,
  BasementEquipment,    !- Name
  AirTerminal:SingleDuct:Uncontrolled, !- Zone Equipment 1 Object Type
  Basement Outlet,      !- Zone Equipment 1 Name
  1,                    !- Zone Equipment 1 Cooling Sequence
  1;                    !- Zone Equipment 1 Heating or No-Load Sequence
ZoneHVAC:EquipmentList,
  TopLevelEquipment,    !- Name
  AirTerminal:SingleDuct:Uncontrolled, !- Zone Equipment 1 Object Type
  TopLevel Outlet,      !- Zone Equipment 1 Name
  1,                    !- Zone Equipment 1 Cooling Sequence
  1;                    !- Zone Equipment 1 Heating or No-Load Sequence
ZoneHVAC:EquipmentList,
  FirstFloorEquipment,  !- Name
  AirTerminal:SingleDuct:Uncontrolled, !- Zone Equipment 1 Object Type
  FirstFloor Outlet,    !- Zone Equipment 1 Name
  1,                    !- Zone Equipment 1 Cooling Sequence
  1;                    !- Zone Equipment 1 Heating or No-Load Sequence
!- ===== ALL OBJECTS IN CLASS: ZONEHVAC:EQUIPMENTCONNECTIONS =====
ZoneHVAC:EquipmentConnections,
  FirstFloor,           !- Zone Name
  FirstFloorEquipment,  !- Zone Conditioning Equipment List Name
  FirstFloor Zone Equip Inlet, !- Zone Air Inlet Node or NodeList Name
  ,                     !- Zone Air Exhaust Node or NodeList Name
  FirstFloor Zone Air Node, !- Zone Air Node Name
  FirstFloor Return Outlet, !- Zone Return Air Node Name
ZoneHVAC:EquipmentConnections,
  TopLevel,             !- Zone Name
  TopLevelEquipment,    !- Zone Conditioning Equipment List Name
  TopLevel Zone Equip Inlet, !- Zone Air Inlet Node or NodeList Name
  ,                     !- Zone Air Exhaust Node or NodeList Name
  TopLevel Zone Air Node, !- Zone Air Node Name
  TopLevel Return Outlet, !- Zone Return Air Node Name
ZoneHVAC:EquipmentConnections,
  Basement,             !- Zone Name

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BasementEquipment,    !- Zone Conditioning Equipment List Name
Basement Zone Equip Inlet, !- Zone Air Inlet Node or NodeList Name
,                      !- Zone Air Exhaust Node or NodeList Name
Basement Zone Air Node, !- Zone Air Node Name
Basement Return Outlet; !- Zone Return Air Node Name
!- ===== ALL OBJECTS IN CLASS: FAN:CONSTANTVOLUME =====
Fan:ConstantVolume,
  AHU Supply Fan,      !- Name
  Always On,           !- Availability Schedule Name
  0.3,                 !- Fan Efficiency
  370.5,               !- Pressure Rise {Pa}
  0.234,               !- Maximum Flow Rate {m3/s}
  1,                   !- Motor Efficiency
  1,                   !- Motor In Airstream Fraction
  AHU Heating Coil Outlet, !- Air Inlet Node Name
  AHU Supply Fan Outlet, !- Air Outlet Node Name
  General;             !- End-Use Subcategory
!- ===== ALL OBJECTS IN CLASS: COIL:HEATING:WATER =====
Coil:Heating:Water,
  AHU Heating Coil,    !- Name
  Always On,           !- Availability Schedule Name
  224,                 !- U-Factor Times Area Value {W/K}
  0.000219175342,      !- Maximum Water Flow Rate {m3/s}
  AHU Heating Coil HW Inlet, !- Water Inlet Node Name
  AHU Heating Coil HW Outlet, !- Water Outlet Node Name
  AHU Mixed Air Outlet, !- Air Inlet Node Name
  AHU Heating Coil Outlet, !- Air Outlet Node Name
  UFactorTimesAreaAndDesignWaterFlowRate, !- Performance Input Method
  autosize,            !- Rated Capacity {W}
  82.2,                !- Rated Inlet Water Temperature {C}
  16.6,                !- Rated Inlet Air Temperature {C}
  71.1,                !- Rated Outlet Water Temperature {C}
  32.2,                !- Rated Outlet Air Temperature {C}
  1.0;                 !- Rated Ratio for Air and Water Convection
!- ===== ALL OBJECTS IN CLASS: CONTROLLER:WATERCOIL =====
Controller:WaterCoil,
  AHU Heating Coil Controller, !- Name
  Temperature,                !- Control Variable
  Normal,                     !- Action
  Flow,                       !- Actuator Variable
  AHU Heating Coil Outlet, !- Sensor Node Name
  AHU Heating Coil HW Inlet, !- Actuator Node Name
  autosize,                   !- Controller Convergence Tolerance {deltaC}
  0.000219175342,             !- Maximum Actuated Flow {m3/s}
  0;                           !- Minimum Actuated Flow {m3/s}
!- ===== ALL OBJECTS IN CLASS: CONTROLLER:OUTDOORAIR =====
Controller:OutdoorAir,
  AHU OA Controller,    !- Name
  AHU Relief Air Outlet, !- Relief Air Outlet Node Name
  AHU Air Loop Inlet,    !- Return Air Node Name
  AHU Mixed Air Outlet, !- Mixed Air Node Name

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AHU Outside Air Inlet,  !- Actuator Node Name
autosize,              !- Minimum Outdoor Air Flow Rate {m3/s}
autosize,              !- Maximum Outdoor Air Flow Rate {m3/s}
NoEconomizer,          !- Economizer Control Type
ModulateFlow,          !- Economizer Control Action Type
,                      !- Economizer Maximum Limit Dry-Bulb Temperature {C}
,                      !- Economizer Maximum Limit Enthalpy {J/kg}
,                      !- Economizer Maximum Limit Dewpoint Temperature {C}
,                      !- Electronic Enthalpy Limit Curve Name
,                      !- Economizer Minimum Limit Dry-Bulb Temperature {C}
NoLockout,             !- Lockout Type
ProportionalMinimum;   !- Minimum Limit Type
!- ===== ALL OBJECTS IN CLASS: AIRLOOPHVAC:CONTROLLERLIST =====
AirLoopHVAC:ControllerList,
  AHU OA System Controllers, !- Name
  Controller:OutdoorAir, !- Controller 1 Object Type
  AHU OA Controller; !- Controller 1 Name
AirLoopHVAC:ControllerList,
  AHU Controllers, !- Name
  Controller:WaterCoil, !- Controller 1 Object Type
  AHU Heating Coil Controller; !- Controller 1 Name
!- ===== ALL OBJECTS IN CLASS: AIRLOOPHVAC =====
AirLoopHVAC,
  AHU, !- Name
  AHU Controllers, !- Controller List Name
  AHU Availability Managers, !- Availability Manager List Name
  0.234, !- Design Supply Air Flow Rate {m3/s}
  AHU Branches, !- Branch List Name
  , !- Connector List Name
  AHU Air Loop Inlet, !- Supply Side Inlet Node Name
  AHU Return Air Outlet, !- Demand Side Outlet Node Name
  AHU Supply Path Inlet, !- Demand Side Inlet Node Names
  AHU Supply Fan Outlet; !- Supply Side Outlet Node Names
!- ===== ALL OBJECTS IN CLASS:
AIRLOOPHVAC:OUTDOORAIRSYSTEM:EQUIPMENTLIST =====
AirLoopHVAC:OutdoorAirSystem:EquipmentList,
  AHU OA System Equipment, !- Name
  OutdoorAir:Mixer, !- Component 1 Object Type
  AHU OA Mixing Box; !- Component 1 Name
!- ===== ALL OBJECTS IN CLASS: AIRLOOPHVAC:OUTDOORAIRSYSTEM
=====
AirLoopHVAC:OutdoorAirSystem,
  AHU OA System, !- Name
  AHU OA System Controllers, !- Controller List Name
  AHU OA System Equipment; !- Outdoor Air Equipment List Name
!- ===== ALL OBJECTS IN CLASS: OUTDOORAIR:MIXER =====
OutdoorAir:Mixer,
  AHU OA Mixing Box, !- Name
  AHU Mixed Air Outlet, !- Mixed Air Node Name
  AHU Outside Air Inlet, !- Outdoor Air Stream Node Name
  AHU Relief Air Outlet, !- Relief Air Stream Node Name

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    AHU Air Loop Inlet;    !- Return Air Stream Node Name
!- ===== ALL OBJECTS IN CLASS: AIRLOOPHVAC:ZONESPLITTER =====
AirLoopHVAC:ZoneSplitter,
    AHUAirLoopHVAC:ZoneSplitter, !- Name
    AHU Supply Path Inlet, !- Inlet Node Name
    FirstFloor Zone Equip Inlet, !- Outlet 1 Node Name
    TopLevel Zone Equip Inlet, !- Outlet 2 Node Name
    Basement Zone Equip Inlet; !- Outlet 3 Node Name
!- ===== ALL OBJECTS IN CLASS: AIRLOOPHVAC:SUPPLYPATH =====
AirLoopHVAC:SupplyPath,
    AHU Supply Path,    !- Name
    AHU Supply Path Inlet, !- Supply Air Path Inlet Node Name
    AirLoopHVAC:ZoneSplitter,!- Component 1 Object Type
    AHUAirLoopHVAC:ZoneSplitter; !- Component 1 Name
!- ===== ALL OBJECTS IN CLASS: AIRLOOPHVAC:ZONEMIXER =====
AirLoopHVAC:ZoneMixer,
    AHUAirLoopHVAC:ZoneMixer,!- Name
    AHU Return Air Outlet, !- Outlet Node Name
    FirstFloor Return Outlet,!- Inlet 1 Node Name
    TopLevel Return Outlet, !- Inlet 2 Node Name
    Basement Return Outlet; !- Inlet 3 Node Name
!- ===== ALL OBJECTS IN CLASS: AIRLOOPHVAC:RETURNPATH =====
AirLoopHVAC:ReturnPath,
    AHU Return Path,    !- Name
    AHU Return Air Outlet, !- Return Air Path Outlet Node Name
    AirLoopHVAC:ZoneMixer, !- Component 1 Object Type
    AHUAirLoopHVAC:ZoneMixer;!- Component 1 Name
!- ===== ALL OBJECTS IN CLASS: BRANCH =====
Branch,
    AHU Main Branch,    !- Name
    autosize,    !- Maximum Flow Rate {m3/s}
    ,    !- Pressure Drop Curve Name
    AirLoopHVAC:OutdoorAirSystem, !- Component 1 Object Type
    AHU OA System,    !- Component 1 Name
    AHU Air Loop Inlet, !- Component 1 Inlet Node Name
    AHU Mixed Air Outlet, !- Component 1 Outlet Node Name
    Passive,    !- Component 1 Branch Control Type
    Coil:Heating:Water, !- Component 2 Object Type
    AHU Heating Coil,    !- Component 2 Name
    AHU Mixed Air Outlet, !- Component 2 Inlet Node Name
    AHU Heating Coil Outlet, !- Component 2 Outlet Node Name
    Passive,    !- Component 2 Branch Control Type
    Fan:ConstantVolume, !- Component 3 Object Type
    AHU Supply Fan,    !- Component 3 Name
    AHU Heating Coil Outlet, !- Component 3 Inlet Node Name
    AHU Supply Fan Outlet, !- Component 3 Outlet Node Name
    Active;    !- Component 3 Branch Control Type
Branch,
    Water Heater Use Branch, !- Name
    autosize,    !- Maximum Flow Rate {m3/s}
    ,    !- Pressure Drop Curve Name

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WaterHeater:Mixed, !- Component 1 Object Type
 Water Heater, !- Component 1 Name
 Water Heater Use Inlet Node, !- Component 1 Inlet Node Name
 Water Heater Use Outlet Node, !- Component 1 Outlet Node Name
 PASSIVE; !- Component 1 Branch Control Type
 Branch,
 Water Heater Use Outlet Branch, !- Name
 autosize, !- Maximum Flow Rate {m3/s}
 , !- Pressure Drop Curve Name
 Pipe:Adiabatic, !- Component 1 Object Type
 Water Heater Use Outlet Pipe, !- Component 1 Name
 Water Heater Use Outlet Pipe Inlet Node, !- Component 1 Inlet Node Name
 Water Heater Use Loop Outlet Node, !- Component 1 Outlet Node Name
 PASSIVE; !- Component 1 Branch Control Type
 Branch,
 Demand Inlet Branch, !- Name
 autosize, !- Maximum Flow Rate {m3/s}
 , !- Pressure Drop Curve Name
 Pipe:Adiabatic, !- Component 1 Object Type
 Demand Inlet Pipe, !- Component 1 Name
 Demand Inlet Node, !- Component 1 Inlet Node Name
 Demand Pipe-DHW Node, !- Component 1 Outlet Node Name
 PASSIVE; !- Component 1 Branch Control Type
 Branch,
 Heating Coil Branch, !- Name
 autosize, !- Maximum Flow Rate {m3/s}
 , !- Pressure Drop Curve Name
 Coil:Heating:Water, !- Component 1 Object Type
 AHU Heating Coil, !- Component 1 Name
 AHU Heating Coil HW Inlet, !- Component 1 Inlet Node Name
 AHU Heating Coil HW Outlet, !- Component 1 Outlet Node Name
 Active; !- Component 1 Branch Control Type
 Branch,
 Demand Outlet Branch, !- Name
 autosize, !- Maximum Flow Rate {m3/s}
 , !- Pressure Drop Curve Name
 Pipe:Adiabatic, !- Component 1 Object Type
 Demand Outlet Pipe, !- Component 1 Name
 Demand DHW-Pipe Node, !- Component 1 Inlet Node Name
 Demand Outlet Node, !- Component 1 Outlet Node Name
 PASSIVE; !- Component 1 Branch Control Type
 Branch,
 Water Heater Use Inlet Branch, !- Name
 autosize, !- Maximum Flow Rate {m3/s}
 , !- Pressure Drop Curve Name
 Pump:ConstantSpeed, !- Component 1 Object Type
 Heating Coil Pump, !- Component 1 Name
 Heating Coil Pump Input Node, !- Component 1 Inlet Node Name
 Heating Coil Pump Output Node, !- Component 1 Outlet Node Name
 ACTIVE; !- Component 1 Branch Control Type
 Branch,

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Bypass,          !- Name
autosize,        !- Maximum Flow Rate {m3/s}
,               !- Pressure Drop Curve Name
Pipe:Adiabatic,   !- Component 1 Object Type
Bypass Pipe,     !- Component 1 Name
Bypass Inlet Node, !- Component 1 Inlet Node Name
Bypass Outlet Node, !- Component 1 Outlet Node Name
Bypass;          !- Component 1 Branch Control Type
!- ===== ALL OBJECTS IN CLASS: BRANCHLIST =====
BranchList,
  AHU Branches,    !- Name
  AHU Main Branch; !- Branch 1 Name
BranchList,
  Water Heater Use Branches, !- Name
  Water Heater Use Inlet Branch, !- Branch 1 Name
  Water Heater Use Branch, !- Branch 2 Name
  Water Heater Use Outlet Branch; !- Branch 3 Name
BranchList,
  Demand Branches,    !- Name
  Demand Inlet Branch, !- Branch 1 Name
  Heating Coil Branch, !- Branch 2 Name
  Bypass,             !- Branch 3 Name
  Demand Outlet Branch; !- Branch 4 Name
!- ===== ALL OBJECTS IN CLASS: CONNECTOR:SPLITTER =====
Connector:Splitter,
  Water Heater Use Splitter, !- Name
  Water Heater Use Inlet Branch, !- Inlet Branch Name
  Water Heater Use Branch; !- Outlet Branch 1 Name
Connector:Splitter,
  Demand Splitter,    !- Name
  Demand Inlet Branch, !- Inlet Branch Name
  Heating Coil Branch, !- Outlet Branch 1 Name
  Bypass;            !- Outlet Branch 2 Name
!- ===== ALL OBJECTS IN CLASS: CONNECTOR:MIXER =====
Connector:Mixer,
  Water Heater Use Mixer, !- Name
  Water Heater Use Outlet Branch, !- Outlet Branch Name
  Water Heater Use Branch; !- Inlet Branch 1 Name
Connector:Mixer,
  Demand Mixer,      !- Name
  Demand Outlet Branch, !- Outlet Branch Name
  Heating Coil Branch, !- Inlet Branch 1 Name
  Bypass;            !- Inlet Branch 2 Name
!- ===== ALL OBJECTS IN CLASS: CONNECTORLIST =====
ConnectorList,
  Water Heater Use Connectors, !- Name
  Connector:Splitter, !- Connector 1 Object Type
  Water Heater Use Splitter, !- Connector 1 Name
  Connector:Mixer, !- Connector 2 Object Type
  Water Heater Use Mixer; !- Connector 2 Name
ConnectorList,

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Demand Connectors,    !- Name
Connector:Splitter,   !- Connector 1 Object Type
Demand Splitter,      !- Connector 1 Name
Connector:Mixer,      !- Connector 2 Object Type
Demand Mixer;         !- Connector 2 Name
!- ===== ALL OBJECTS IN CLASS: OUTDOORAIR:NODELIST =====
OutdoorAir:NodeList,
  AHU Outside Air Inlet; !- Node or NodeList Name 1
!- ===== ALL OBJECTS IN CLASS: PIPE:ADIABATIC =====
Pipe:Adiabatic,
  Water Heater Use Outlet Pipe, !- Name
  Water Heater Use Outlet Pipe Inlet Node, !- Inlet Node Name
  Water Heater Use Loop Outlet Node; !- Outlet Node Name
Pipe:Adiabatic,
  Demand Inlet Pipe,    !- Name
  Demand Inlet Node,    !- Inlet Node Name
  Demand Pipe-DHW Node; !- Outlet Node Name
Pipe:Adiabatic,
  Demand Outlet Pipe,   !- Name
  Demand DHW-Pipe Node, !- Inlet Node Name
  Demand Outlet Node;   !- Outlet Node Name
Pipe:Adiabatic,
  Bypass Pipe,          !- Name
  Bypass Inlet Node,    !- Inlet Node Name
  Bypass Outlet Node;   !- Outlet Node Name
!- ===== ALL OBJECTS IN CLASS: PUMP:CONSTANTSPEED =====
Pump:ConstantSpeed,
  Heating Coil Pump,    !- Name
  Heating Coil Pump Input Node, !- Inlet Node Name
  Heating Coil Pump Output Node, !- Outlet Node Name
  0.000219175342,      !- Rated Flow Rate {m3/s}
  35000,                !- Rated Pump Head {Pa}
  55,                   !- Rated Power Consumption {W}
  0.9,                  !- Motor Efficiency
  ,                     !- Fraction of Motor Inefficiencies to Fluid Stream
  Intermittent;         !- Pump Control Type
!- ===== ALL OBJECTS IN CLASS: WATERHEATER:MIXED =====
WaterHeater:Mixed,
  Water Heater,         !- Name
  0.1893,               !- Tank Volume {m3}
  Hot Water Setpoint Temp Schedule, !- Setpoint Temperature Schedule Name
  5.2,                  !- Deadband Temperature Difference {deltaC}
  82,                   !- Maximum Temperature Limit {C}
  Cycle,                !- Heater Control Type
  6650,                 !- Heater Maximum Capacity {W}
  ,                     !- Heater Minimum Capacity {W}
  ,                     !- Heater Ignition Minimum Flow Rate {m3/s}
  ,                     !- Heater Ignition Delay {s}
  NaturalGas,           !- Heater Fuel Type
  0.9,                  !- Heater Thermal Efficiency
  ,                     !- Part Load Factor Curve Name

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,           !- Off Cycle Parasitic Fuel Consumption Rate {W}
,           !- Off Cycle Parasitic Fuel Type
,           !- Off Cycle Parasitic Heat Fraction to Tank
,           !- On Cycle Parasitic Fuel Consumption Rate {W}
,           !- On Cycle Parasitic Fuel Type
,           !- On Cycle Parasitic Heat Fraction to Tank
Zone,       !- Ambient Temperature Indicator
,           !- Ambient Temperature Schedule Name
Basement,   !- Ambient Temperature Zone Name
,           !- Ambient Temperature Outdoor Air Node Name
1,          !- Off Cycle Loss Coefficient to Ambient Temperature {W/K}
1,          !- Off Cycle Loss Fraction to Zone
1,          !- On Cycle Loss Coefficient to Ambient Temperature {W/K}
1,          !- On Cycle Loss Fraction to Zone
,           !- Peak Use Flow Rate {m3/s}
,           !- Use Flow Rate Fraction Schedule Name
,           !- Cold Water Supply Temperature Schedule Name
Water Heater Use Inlet Node, !- Use Side Inlet Node Name
Water Heater Use Outlet Node, !- Use Side Outlet Node Name
1,          !- Use Side Effectiveness
,           !- Source Side Inlet Node Name
,           !- Source Side Outlet Node Name
,           !- Source Side Effectiveness
autosize,   !- Use Side Design Flow Rate {m3/s}
,           !- Source Side Design Flow Rate {m3/s}
1.5;        !- Indirect Water Heating Recovery Time {hr}
!- ===== ALL OBJECTS IN CLASS: PLANTLOOP =====
PlantLoop,
Hot Water Loop, !- Name
Water,          !- Fluid Type
Heating Coil Loop Operation, !- Plant Equipment Operation Scheme Name
Water Heater Use Loop Outlet Node, !- Loop Temperature Setpoint Node Name
100,           !- Maximum Loop Temperature {C}
3,             !- Minimum Loop Temperature {C}
autosize,      !- Maximum Loop Flow Rate {m3/s}
,             !- Minimum Loop Flow Rate {m3/s}
autocalculate, !- Plant Loop Volume {m3}
Heating Coil Pump Input Node, !- Plant Side Inlet Node Name
Water Heater Use Loop Outlet Node, !- Plant Side Outlet Node Name
Water Heater Use Branches, !- Plant Side Branch List Name
Water Heater Use Connectors, !- Plant Side Connector List Name
Demand Inlet Node, !- Demand Side Inlet Node Name
Demand Outlet Node, !- Demand Side Outlet Node Name
Demand Branches, !- Demand Side Branch List Name
Demand Connectors, !- Demand Side Connector List Name
Sequential,      !- Load Distribution Scheme
,               !- Availability Manager List Name
SingleSetpoint, !- Plant Loop Demand Calculation Scheme
None,           !- Common Pipe Simulation
None;          !- Pressure Simulation Type
!- ===== ALL OBJECTS IN CLASS: PLANTEQUIPMENTLIST =====

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PlantEquipmentList,
  Heating Coil Plant Equipment, !- Name
  WaterHeater:Mixed,    !- Equipment 1 Object Type
  Water Heater;        !- Equipment 1 Name
!- ===== ALL OBJECTS IN CLASS: PLANTEQUIPMENTOPERATION:HEATINGLOAD
=====

PlantEquipmentOperation:HeatingLoad,
  Heating Coil Control Scheme, !- Name
  0,          !- Load Range 1 Lower Limit {W}
  1E+15,      !- Load Range 1 Upper Limit {W}
  Heating Coil Plant Equipment; !- Range 1 Equipment List Name
!- ===== ALL OBJECTS IN CLASS: PLANTEQUIPMENTOPERATIONSCHEMES
=====

PlantEquipmentOperationSchemes,
  Heating Coil Loop Operation, !- Name
  PlantEquipmentOperation:HeatingLoad, !- Control Scheme 1 Object Type
  Heating Coil Control Scheme, !- Control Scheme 1 Name
  Always On;          !- Control Scheme 1 Schedule Name
!- ===== ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:SENSOR
=====

EnergyManagementSystem:Sensor,
  heating_setpoint,    !- Name
  Heating_Setpoint_Schedule, !- Output:Variable or Output:Meter Index Key Name
  Schedule Value;      !- Output:Variable or Output:Meter Name
EnergyManagementSystem:Sensor,
  thermostat_temp,    !- Name
  FirstFloor,        !- Output:Variable or Output:Meter Index Key Name
  Zone Mean Air Temperature; !- Output:Variable or Output:Meter Name
!- ===== ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:ACTUATOR
=====

EnergyManagementSystem:Actuator,
  HVACstatus,        !- Name
  AHU,               !- Actuated Component Unique Name
  AirLoopHVAC,       !- Actuated Component Type
  Availability Status; !- Actuated Component Control Type
!- ===== ALL OBJECTS IN CLASS:
ENERGYMANAGEMENTSYSTEM:PROGRAMCALLINGMANAGER =====
EnergyManagementSystem:ProgramCallingManager,
  EMS-based Setpoint Managers, !- Name
  AfterPredictorAfterHVACManagers, !- EnergyPlus Model Calling Point
  AHU_Operation_Schedule; !- Program Name 1
!- ===== ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:PROGRAM
=====

EnergyManagementSystem:Program,
  AHU_Operation_Schedule, !- Name
  SET Toffset = 0.556,    !- Program Line 1
  SET ForceOff = 1.0,    !- Program Line 2
  SET CycleOn = 2.0,     !- A4
  SET AHU_TurnOn = heating_setpoint, !- A5
  SET AHU_TurnOff = heating_setpoint + (2*Toffset), !- A6
  IF thermostat_temp < AHU_TurnOn, !- A7

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SET HVACstatus = CycleOn, !- A8
RETURN,          !- A9
ELSEIF thermostat_temp > AHU_TurnOff, !- A10
SET HVACstatus = ForceOff, !- A11
ENDIF;           !- A12
!- ===== ALL OBJECTS IN CLASS: SETPOINTMANAGER:SCHEDULED =====
! NOTE: Heating supply air setpoint is placed on Supply Path Inlet node to allow separate heating and
cooling setpoints.
! SetpointManager:MixedAir <system name> Heating Coil Air Temp Manager adjusts this setpoint for
fan heat and places it on the Heating Coil Outlet
SetpointManager:Scheduled,
    AHU Heating Supply Air Temp Manager, !- Name
    Temperature,          !- Control Variable
    HVACTemplate-Always 60, !- Schedule Name
    FIRSTFLOOR ZONE AIR NODE; !- Setpoint Node or NodeList Name
SetpointManager:Scheduled,
    Hot Water Loop Set Point Manager, !- Name
    Temperature,          !- Control Variable
    Hot Water Setpoint Temp Schedule, !- Schedule Name
    Water Heater Use Loop Outlet Node; !- Setpoint Node or NodeList Name
!- ===== ALL OBJECTS IN CLASS: SETPOINTMANAGER:MIXEDAIR =====
SetpointManager:MixedAir,
    AHU Heating Coil Air Temp Manager, !- Name
    Temperature,          !- Control Variable
    FIRSTFLOOR ZONE AIR NODE; !- Reference Setpoint Node Name
    AHU Heating Coil Outlet, !- Fan Inlet Node Name
    AHU Supply Fan Outlet, !- Fan Outlet Node Name
    AHU Heating Coil Outlet; !- Setpoint Node or NodeList Name
!- ===== ALL OBJECTS IN CLASS: OUTPUT:VARIABLEDICTIONARY =====
Output:VariableDictionary,
    IDF;          !- Key Field
!- ===== ALL OBJECTS IN CLASS: OUTPUT:SCHEDULES =====
Output:Schedules,
    Hourly;       !- Key Field
!- ===== ALL OBJECTS IN CLASS: OUTPUT:VARIABLE =====
Output:Variable,
    *,            !- Key Value
    System Node Temp, !- Variable Name
    Timestep;     !- Reporting Frequency
Output:Variable,
    *,            !- Key Value
    Outdoor Dry Bulb, !- Variable Name
    Timestep;     !- Reporting Frequency
Output:Variable,
    *,            !- Key Value
    Zone Mean Air Temperature, !- Variable Name
    Timestep;     !- Reporting Frequency
Output:Variable,
    *,            !- Key Value
    Pump Mass Flow Rate, !- Variable Name
    Timestep;     !- Reporting Frequency

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Output:Variable,
*,                !- Key Value
Water Heater Tank Temperature, !- Variable Name
Timestep;         !- Reporting Frequency
Output:Variable,
*,                !- Key Value
Zone/Sys Thermostat Heating Setpoint, !- Variable Name
Timestep;         !- Reporting Frequency
Output:Variable,
*,                !- Key Value
Air Loop Fan Heating Energy, !- Variable Name
Timestep;         !- Reporting Frequency
Output:Variable,
*,                !- Key Value
Air Loop Total Heating Energy, !- Variable Name
Timestep;         !- Reporting Frequency
Output:Variable,
*,                !- Key Value
Air Loop Heating Coil Hot Water Consumption, !- Variable Name
Timestep;         !- Reporting Frequency
Output:Variable,
*,                !- Key Value
Air Loop Total Heating Coil Energy, !- Variable Name
Timestep;         !- Reporting Frequency
Output:Variable,
*,                !- Key Value
Water Heating Coil U-Factor Times Area Value, !- Variable Name
Timestep;         !- Reporting Frequency
Output:Variable,
*,                !- Key Value
Debug Plant Loop Bypass Fraction, !- Variable Name
Timestep;         !- Reporting Frequency
Output:Variable,
*,                !- Key Value
System Node Volume Flow Rate Standard Density, !- Variable Name
Timestep;         !- Reporting Frequency
!- ===== ALL OBJECTS IN CLASS: OUTPUT:SQLITE =====
Output:SQLite,
SimpleAndTabular;    !- Option Type

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