Evaluation of building energy simulation software using residential homes

Robert Michael Madeja

University of Nevada, Las Vegas

Follow this and additional works at: https://digitalscholarship.unlv.edu/rtds

Repository Citation
https://digitalscholarship.unlv.edu/rtds/1881
EVALUATION OF BUILDING ENERGY SIMULATION
SOFTWARE USING RESIDENTIAL HOMES

by

Robert Michael Madeja

Bachelor of Science
University of South Florida
Tampa, Florida
2003

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science Degree in Mechanical Engineering
Department of Mechanical Engineering
Howard R. Hughes College of Engineering

Graduate College
University of Nevada, Las Vegas
December 2005

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.
The Thesis prepared by
Robert Michael Madeja

Entitled
Evaluation of Building Energy Simulation Software using Residential Homes.

is approved in partial fulfillment of the requirements for the degree of
Master of Science in Mechanical Engineering.

Examination Committee Chair
Dean of the Graduate College

Graduate College Faculty Representative
ABSTRACT

Evaluation of Building Energy Simulation Software Using Residential Homes

by

Robert Michael Madeja

Dr Samir F. Moujaes, Examination Committee Chair
Professor, Mechanical Engineering
University of Nevada, Las Vegas

Energy simulation software has been widely used by engineers and architects to predict the energy consumption of buildings during the design phase of new construction or remodel. Many of these programs are derived from cooling methodologies developed by ASHRAE. For this study, a widely used software package, Trace 700 was used to see how accurate it can be in predicting the energy consumption of the HVAC (Heating Ventilating and Air Conditioning) system of two residential homes. One home is classified as a Zero Energy Home (ZEH) because it employs advanced construction features which allow it to consume significantly less energy than a normal home. The baseline home is of the exact same dimensions and floor plan as the ZEH but uses more traditional construction practices. Trace was used to model both homes during for both cooling and heating. Weather data during the monitoring phase was taken from the vicinity and fed into Trace to create a more accurate representation of the conditions. The analytical results compared well to the experimental results gathered from the homes. In addition energy consumption between the ZEH and baseline home were compared.
TABLE OF CONTENTS

ABSTRACT ............................................................................................................................. iii
LIST OF FIGURES ................................................................................................. vi
LIST OF TABLES ........................................................................................................ vii
ACKNOWLEDGEMENTS .............................................................................................. viii

CHAPTER 1 INTRODUCTION AND BACKGROUND ....................................................1
1.1 Overview .................................................................................................................... 1
1.2 The Cooling Load Methodologies ........................................................................... 2
   1.2.1 TETD/TA Method ........................................................................................ 3
   1.2.2 Transfer Function Method ........................................................................... 5
   1.2.3 CLTD/CLF .................................................................................................... 7
   1.2.4 Methodology Updates .................................................................................. 8
1.3 Energy Simulations ................................................................................................... 9
1.4 Objective and Significance of Work ...................................................................... 11

CHAPTER 2 SIMULATION SOFTWARE .........................................................................12
2.1 Trace 700 ................................................................................................................ 12
   2.1.1 Methodology ................................................................................................ 13
   2.1.2 Design Analysis .......................................................................................... 15
   2.1.3 Energy Analysis .......................................................................................... 15

CHAPTER 3 TEST BUILDINGS..........................................................................................17
3.1 Overview ................................................................................................................... 17
3.2 The Zero Energy Home ......................................................................................... 20
   3.2.1 Wall Construction ....................................................................................... 23
   3.2.2 Roof Construction ....................................................................................... 26
   3.2.3 Window Construction ................................................................................ 27
   3.2.4 HVAC System ............................................................................................ 27
3.3 Baseline Home ......................................................................................................... 29
   3.3.1 Wall Construction ....................................................................................... 32
   3.3.2 Roof Construction ....................................................................................... 32
   3.3.3 Window Construction ................................................................................ 32
   3.3.4 HVAC System ............................................................................................ 33
3.4 Instrumentation ........................................................................................................ 33

CHAPTER 4 PEAK COOLING LOAD RESULTS ............................................................38
## LIST OF FIGURES

Figure 1  Difference between instantaneous heat gain and instantaneous cooling load ........................................................................ 3
Figure 2  Plan overview of baseline and zero energy home ..................................................................................................................... 18
Figure 4  Roof overview of baseline and zero energy home .................................................................................................................. 20
Figure 6  Front picture of the zero energy home ................................................................................................................................. 22
Figure 7  T-mass walls awaiting shipment to zero energy home construction site .................................................................................. 23
Figure 8  T-mass wall construction at zero energy home ......................................................................................................................... 24
Figure 9  Styrofoam insulation and connectors ................................................................................................................................. 25
Figure 10  T-mass wall cross-sections ..................................................................................................................................................... 25
Figure 11  Freus Unit Detail .................................................................................................................................................................... 28
Figure 12  ZEH Air Handler .................................................................................................................................................................. 29
Figure 13  Baseline home overview ....................................................................................................................................................... 30
Figure 14  Picture of front of baseline home .......................................................................................................................................... 31
Figure 15  Wattnode power meter ......................................................................................................................................................... 34
Figure 16  Gas meter and instantaneous water heater in zero energy home ............................................................................................ 35
Figure 17  Zero energy home weather station .................................................................................................................................. 36
Figure 18  Data Logger .............................................................................................................................................................................. 37
Figure 19  Wall peak cooling loads vs cooling methodology ............................................................................................................... 39
Figure 20  Roof peak cooling loads vs methodology .......................................................................................................................... 40
Figure 21  Glass transmission peak loads vs methodology ................................................................................................................... 41
Figure 22  Glass solar peak loads vs methodology .................................................................................................................................... 42
Figure 23  Partition peak loads vs methodology .................................................................................................................................... 43
Figure 24  Infiltration load vs methodology .......................................................................................................................................... 44
Figure 25  Total peak cooling loads vs methodology .......................................................................................................................... 45
Figure 26  Outdoor weather conditions for the cooling period monitored .................................................................................................. 48
Figure 27  Energy efficiency vs. outdoor air temperature for AC systems ............................................................................................... 49
Figure 28  Baseline home kWh vs time ................................................................................................................................................. 52
Figure 29  Baseline home experimental and simulated AC condenser kWh consumed .................................................................. 53
Figure 30  Zero energy home kWh vs time ............................................................................................................................................ 56
Figure 31  ZEH experimental and simulated AC condenser kWh consumed ............................................................................................ 57
Figure 33  Baseline home instantaneous therms used .......................................................................................................................... 62
Figure 34  Baseline home predicted and experimental therms used ...................................................................................................... 63
Figure 35  Zero energy home therms used vs time .............................................................................................................................. 65
Figure 36  Baseline home predicted and experimental therms used ...................................................................................................... 67
Figure 37  Annual AC kWh consumption ............................................................................................................................................. 69
Figure 38  Annual heating therms used ................................................................................................................................................ 70
LIST OF TABLES

Table 1  Component areas of zero energy home................................................................. 22
Table 2  Component areas of baseline home .................................................................  31
Table 3  Peak load time.................................................................................................... 46
Table 4  Baseline home kWh predicted vs experimental results ..................................... 54
Table 5  ZEH kWh predicted vs experimental results .....................................................  58
Table 6  Baseline home therms predicted vs experimental results ................................... 64
Table 7  ZEH therms actual vs predicted values.............................................................. 68
ACKNOWLEDGEMENTS

I would like to thank the thesis committee chair Dr. Samir Moujaes for getting me involved in and advising me not only on this project but many others. I have enjoyed working with him.

In addition I would like to thank Dr. Robert Boehm for leading Zero Energy Home Project and giving me the opportunity to work on it.

I would also like to thank the remainder of my thesis committee, Dr Mohamed Trabia and Dr. Samaan Ladkany

Special thanks goes to Rik Hurt for leading the team that made the houses fully operational.

I would finally like to thank the National Renewable Energy Laboratory (NREL) and Pinnacle Homes for funding and building the Zero Energy Home.
CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 Overview

Air Conditioning has literally changed the way society functions, giving us the freedom to work, play and relax in climate controlled environments. Areas of the globe that just 100 years ago were considered too hot and inhospitable to support a large population are now sprawling metropolises because of the mass use of air conditioning. However such a large use of air conditioning comes with a hefty price, in terms of energy consumption. For an air conditioning system to operate most efficiently it must be correctly sized. A system which is undersized or oversized will tend to operate inefficiently and use more energy than desired. To properly size a system for a particular building, the cooling loads present within the structure must be calculated. To calculate these loads ultimately the energy used by HVAC equipment to meet the use of one of the cooling load methodologies is necessary.

The current cooling methodologies available are the result of years of research and experimentation which has mostly be supported by ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) [1]. These cooling methodologies are not just employed to determine the peak loads needed size an air conditioning structure. They were also developed as a way to determine the loads present at each hour and in turn could be used to determine the energy needed to cool the
structure on a daily, monthly and annual basis. It is in fact these methodologies that form the basis for many of the whole building energy simulation programs [2]. As the cost of energy has risen so has the need to accurately predict the cooling loads and use them to design energy efficient structures. To try and create the most accurate results the cooling load methodologies have gone through many revisions and updates over the years.

1.2 The Cooling Load Methodologies

In the early part of the 20th century the basic way to calculate the cooling load in a building was by using the simple steady state energy equation.

\[ q = AU(\Delta T) \]  

(1)

Where:

- **q** = Cooling Load (btu/hr)
- **A** = Area (ft²)
- **U** = Heat Transfer Coefficient (btu/h·ft²·°F)
- **ΔT** = Difference Between Indoor and Outdoor Temperature

Using this relation only computes the instantaneous heat gain and does not give an accurate representation of the effect of thermal storage within a structure. The thermal mass of a structure can have a significant impact on when the peak loads of the building will occur. It has been shown that for a building of large mass there will be significant reduction in the cooling load as well as an increase in the time lag in which the peak loads occur when compared to a building of lesser mass [3]. In essence the instantaneous heat gain is not necessarily the cooling load present within a structure. To more accurately account for this heat storage and time lag ASHRAE commissioned several...
Research Projects (RP) over the past 40 years. These projects produced the methodologies that are currently used today. Figure 1 shows a basic representation of how each methodology treats instantaneous heat gain vs Instantaneous cooling load [4].

Figure 1 Difference between instantaneous heat gain and instantaneous cooling load

1.2.1 TETD/TA Method

One of the first cooling load calculations to be introduced was the Total Equivalent Temperature Difference/Time Averaging method (TETD/TA). This method was first introduced into the 1967 ASHRAE fundamentals handbook, and in the subsequent 1972 update. Except for some tabular data the method itself remains virtually unchanged from the original 1967 handbook [5].

The basic premise of the TETD/TA method is to first determine all heat gains and estimate the convective and radiative fractions. Heat gain due to conduction through exterior surfaces is estimated using an equivalent temperature difference (TETD) which is given by.
\[ \text{TETD} = t_{ea} - t_i + (DF)(t_{eTL} - t_{ea}) \]  

(2)

Where:

- \( t_{ea} \) = daily average sol-air temperature
- \( t_i \) = sol-air temperature for current hour
- \( DF \) = decrement factor (obtained from tables)
- \( t_{eTL} \) = sol-air temperature TL hours ago

The basic equation to determine the heat gain through walls and roofs is as follows.

\[
q = UA(\text{TETD})
\]

(3)

Solar heat gain through windows is divided into conduction heat gain and radiation heat gain. Conduction heat gain through windows is assumed to be quasi-steady state and is based on simple steady state relationship as shown in equation 1. Radiation heat gain through windows is based on an hourly solar heat gain factor (SHGF).

A time averaging period is estimated for each zone based on the perceived thermal characteristics of the zone. The cooling load due to radiative heat gain is then calculated as the average radiative heat gain over the time averaging period. The total cooling load is then calculated as the sum of all convective heat gains for the hour and the time-averaged radiative heat gain using the following relation.

\[
Q_s = \sum_{n=1}^{\infty} \left[ q_{s,n}(1 - rf_{n}) \right] + \sum_{n=1}^{\infty} \left[ \sum_{\tau=0}^{\infty} \left( q_{s,n} rf_{n} \right) \tau / \theta \right] + \sum_{\beta=1}^{\infty} (q_{sc,\beta})
\]

(4)

Where:

- \( q_s \) = each of \( n \) heat gain elements with radiant fraction (rf) determined from tables.
- \( \theta \) = number of hours over which to average radiant heat gain fractions
- \( \tau \) = hourly steps back in time to \( \theta-1 \)
One of the drawbacks of the TETD/TA method is that it is only geared toward peak load calculation and cannot be used to determine the rate of heat extraction.

1.2.2 Transfer Function Method

The next methodology to be widely adopted when it was first published in the 1972 ASHRAE Handbook was the Transfer Function Method (TFM). The Transfer function method is based upon work done in 1967 which attempted to characterize the interplay of heat exchange between various surfaces and sources of heat gain. Response factors were developed by modeling the surface heat flux to triangular unit temperature excitation pulses on the outer and inner surfaces [6]. In addition room thermal response factors were also calculated to describe the dynamic thermal characteristics of the room [7]. Experimental validation of this method has also been completed to check both the predicted loads, as well as the ability to predict the performance of air conditioning systems [8, 9].

With the Transfer Function Method, a general mathematical relationship which defines load as a function of heat gain and time is determined for each heat gain component in a room. This relationship is then used to quickly calculate loads for each hour. The mathematical relationship is expressed in what is called a Room Transfer Function Equation

\[ Q_\theta = v_0 q_\theta + v_1 q_{\theta-\delta} + v_2 q_{\theta-2\delta} - w_1 Q_{\theta-\delta} - w_2 Q_{\theta-2\delta} \]

(5)

Where

\( q = \) heat gain at hour \( \theta \) (btu/hr)

\( Q = \) Cooling load at hour \( \theta \) (btu/hr)
\( v \) and \( w \) = Room Transfer Coefficients. Values of these coefficients vary for each type of heat gain and room due to the different heat transfer processes involved in converting each kind of heat gain into a load. ASHRAE has published tables of these coefficients for different heat gain components, room types, and building weights.

\( \delta \) = time interval (1 h)

The Room Transfer Function Equation says that the cooling load for the current hour \((Q_\delta)\) is a function of the heat gain for the current and preceding two hours, plus the loads for the preceding two hours. Because loads for the preceding hours are themselves dependent on a series of heat gains for prior hours, this hour's load is really dependent on the effects of heat gains from many preceding hours[10].

Since there is a delay between the time heat gain occurs at the outer surface of a wall or roof and the time the heat gain reaches the interior surface of the wall or roof. Thus, the heat gain calculation must consider the transient heat transfer through the wall or roof. The transfer function principles can therefore be applied to determine the heat gain through a wall or roof as well as the conversion of the heat gain into a load. The heat gain at the interior surface of the wall using a Conduction Transfer Function Equation which is written as:

\[
q_e = A \left[ \sum b_n (t_{e,\theta-n\delta}) - \sum d_n \left( \frac{q_{e,\theta-n\delta}}{A} \right) + t_{en} \sum c_n \right] 
\]

Where:

\( q_{e,\theta-n\delta} \) = heat gain through wall, roof, partition etc, at time \( \theta-n\delta \), (btu/hr)

\( A \) = indoor surface area of wall or roof (ft²)

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
\[ \theta = \text{time, h} \]
\[ \delta = \text{time interval, h} \]
\[ n = \text{summation index (each summation has as many terms as there are nonzero values of the coefficients).} \]

\[ t_{e,\theta-n\delta} = \text{sol air temperature at time } \theta-n\delta \text{ (°F)} \]

\[ t_{rc} = \text{constant indoor room temperature (°F)} \]

\[ b_{ncnd} = \text{conduction Transfer Function coefficients} \]

The procedure for calculating window heat gains begins with profiles of solar heat gain (SHG) for reference glass. If external shading devices are used, the fraction of the window shaded from direct sunlight must be calculated each hour. The total SHG is then a sum of the Total Solar Heat Gain (TSHG) and the Absorbed Solar Heat Gain (ASHG). Once the total heat gains from all sources, walls, windows, etc. the appropriate room transfer function can be applied to convert the heat gain to cooling load.

1.2.3 CLTD/CLF

The transfer function method as is shown is complicated and tedious with respect to the sheer amount of arithmetic needed. The transfer function method is almost always used with the aid of a computer, however when introduced, access to computers was very limited. Engineers in particular needed a method which could easily be calculated by hand. To meet these needs ASHRAE commissioned RP-138, which resulted in the development of a one step procedure called the Cooling Load Temperature Difference/Cooling Load Factor method (CLTD/CLF) [11]. The basic premise of this method is to use a CLTD or CLF to calculate the cooling load in one step with the following equation.
\[ q = UA(\text{CLTD}) \] (7)

The CLTDs and CLFs can be obtained from tables based upon such factors as building envelop surfaces and internal load sources. The CLTD/CLF method is actually derived from the transfer function method. The CLTDs and CLFs were tabulated by running the transfer function method for various structures and then backing out the constants by dividing by the respective U-factors.

In order to get better accuracy both the Transfer function method and ultimately the CLTD/CLF method have been updated over the years. More specifically the weighting factors and eventually the CLTD tables have been retooled to account for a wide range of parameters. These updates have been the result of several ASHRAE sponsored research projects.

1.2.4 Methodology Updates

The first such project, RP-359 [11], sought to update the CLTD/CLF tables by creating new weighting factors, which would also update the transfer function method, to account for a wider range of zones. In particular one of the goals was to allow engineers to characterize their buildings in terms other than “heavy”, “medium”, or “light”. The result was a set of weighting factors that classified zones in terms of seven of their physical factors and according to their dynamic response factors[12]. In addition some unexpected results were obtained, including the revelation that a lightweight zone may in fact see a longer delay in the conversion of heat gain to cooling load than a similar yet more massive zone.[13]

Many of these unexpected results from RP-359 led many to question the limited range of design variables selected for determining the weighting factors. To resolve the
situation and fill the gaps left by RP-359 ASHRAE commissioned RP-472. RP-472 increased the physical parameters from seven to 14 which includes: zone floor plan, zone height, number of exterior walls, interior shading, furniture, glass fraction, exterior wall construction, zone location, mid-floor construction, slab construction, floor covering, roof type, and ceiling type. Using these parameters 200,640 useful yet unique zone types could be classified and their respective weighting factors determined [14, 15]. The principal tool used to calculate the zone dynamic response and create the weighting factors was the DOE 2.1C program. The DOE program was modified to improve the radiative transfer calculations and boundary conditions [16]. In addition RP-472 also updated the categorization of wall and roof structures for easier use in the CLTD method. In total 41 wall groups and 42 roof groups were categorized on bases of their dynamic thermal response[17].

ASHRAE later commissioned RP-626 in order to incorporate the results of both RP-359 and RP-472 into a new heating and cooling load calculation manual. To keep up with the rising use of personal computers RP-626 also allowed the weighting factors developed in RP-472 to be available on software that could quickly access the large database [18]. In addition new CLTD/CLF tables were created using those weighting factors and the entire method itself was made more computer friendly [19]

1.3 Energy Simulations

In recent years HVAC engineers have been tasked at the design stage to perform a whole building energy analysis to better design an energy efficient system. No longer can engineers simply rely on designing their system using simply peak load calculations. However the cooling load methodologies are an important part of energy analysis as they
are the first step in building energy simulation [20]. However since energy analysis requires hour by hour calculation it is almost impossible for it to be completed without the use of a computer. With the increase of computing speed and available access the majority of building load and ultimately building energy simulation has been done using the computer [21].

As stated before the first step in any building energy simulation is the calculation of the cooling loads present in the building. Not only must the peak cooling loads be calculated, but the cooling loads present for each hour within the year. To accomplish this task calculations would have to be performed 8,760 times. Therefore to help engineers, various computer programs have been written to perform the required calculations and compile a full years energy consumption. Many of these programs have been built around the Transfer Function Method, although many can utilize the TETD/TA method for peak design. The transfer function method is often the basis of these programs not only because it can accurately predict time lags in peak loads, but also because it can accurately model room heat extraction. One of the first programs developed for energy analysis was the Post Office Program, which uses weighting factors based on the transfer function method. Several popular energy analysis programs evolved from this Post Office Program, including DOE 2, as well as some commercial programs such as Trace and HAP (Hourly Analysis Program)[21].

Once the loads in the building have been calculated for the entire year the next process that must be simulated is how the air conditioning system extracts this heat. First the secondary systems are modeled based upon mass, energy, and moisture balances at the various components (coils, fans, etc) and junctions (mixing boxes, diverters) in the
distribution system. Equations representing these balances are solved by algorithms within the program. Next most of the equipment such as chillers and boilers must be modeled. For the most part this equipment is modeled by curve fits of manufactures data. Most energy analysis programs will allow the user to build their own equipment within the system so an accurate analysis can be performed [23].

1.4 Objective and Significance of Work

Calculation of building cooling loads and the energy needed to meet those loads is of great importance to the design engineer. Many engineers will utilize computer software which can quickly perform both building load and energy simulations. One such widely used program is Trane’s Trace 700 Comprehensive Building Load and Energy software package. For this study Trace 700 will be used to simulate a Zero Energy Home (ZEH) and its companion baseline home. These two homes are of the exact same floor plan and orientation however the ZEH utilizes several energy saving features and represents a heavyweight structure, while the baseline home represents a lightweight structure.

The intent of this study is to analyze and compare the results of using the various options available to each program. In addition the second intent of this study will be to make use of the experimental data which will be obtained from these two homes and compare it to the analytical results generated by program. This will show how well the program is able to handle simulating both a light weight and heavy weight structure. In addition this study will help to show how well simulations can help predict energy savings of low energy buildings. Finally comparisons can be made to see how well the ZEH is in lowering its energy consumption in relation to its baseline home companion.
CHAPTER 2

SIMULATION SOFTWARE

For this study Trace 700 was used to model a zero energy home and a baseline home of which the design and construction is further discussed in chapter 3. This chapter provides a brief description of the software used to perform the building load and energy simulations.

2.1 Trace 700

TRACE (Trane Air-Conditioning Economics) 700 is a computer program developed by the Trane Company for use on a personal computer. The main purpose of the program is to assist engineers in designing HVAC systems and perform whole building economic analysis. Unlike other energy programs such as DOE-2, Trace does not use a full 8760 hours worth of weather data to perform its calculations. Rather Trace uses a set of 24 hour of weather conditions for each month of the year totaling 288 hours. In the design phase the program will use a set of weather data that corresponds to the most extreme weather cases in order for the equipment to handle the peak loads at all times. For the energy analysis phase the program will use a set of data that corresponds to typical hourly observations that more realistically assess the energy consumption of the equipment during the 99.6% of the time that the equipment is not running at full load. The weather data for both of these sets can be modified by the user.
For the cooling/heating calculation methods Trace 700 offers the user the choice of 6 different types of methodologies. While each methodology offered by trace is unique in its own right they are all based upon the two basic methodologies, the transfer function method and the TETD method.

2.1.1 Methodology

For the cooling/heating calculation methods Trace 700 offers the user the choice of 6 different types of methodologies. While each methodology offered by trace is unique in its own right they are all based upon the two basic methodologies, the transfer function method and the TETD method[24].

The methodology options based upon the transfer function method each vary by using different weighting factors. The following is a brief description of Trace's methodology options based off the transfer function method:

Trane CLTD-CLF (TFM) - Trane calls this the CLTD-CLF method, but is essentially the same as the ASHRAE standard TFM. Transfer functions calculate both the heat gain and room load just as the CLTD/CLF tables were produced in the 1985 ASHRAE Handbook of Fundamentals. The differences between the tabular data and the exact transfer function method will vary based on the degree of difference in the assumptions between the two methods. For example, the wall CLTD tables are organized into several generic groups based on wall time delay and amplitude characteristics and, as such, are representative averages. In addition, the room delay was calculated only for rooms of medium weight. The TFM method, on the other hand, calculates the wall heat gains using the wall heat gain transfer function for each particular wall, and the room load transfer function coefficients for the calculated or entered weight of the particular room.

13

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
RP359 - This method is based on the results of ASHRAE Research Project Number 359. The heat gain calculations are based on the transfer function method, while the room load calculations are based on room transfer coefficients or weighting factors generated for specific combinations of building components. This method uses the same algorithms as the CLTD-CLF method, only the room load coefficients differ.

CEC-DOE2 - This room load method duplicates the Precalculated Weighting Factors in the DOE2.1c energy analysis program, and is based on the original ASHRAE weighting factors for light, medium, and heavy construction.

The second set of methodology options was created by using and modifying the TETD method. The following is a brief description of Trace's methodology options based off the TETD method:

TETD-TA1 - The heat gain calculations are based on the transfer function method described in the appendix of the ASHRAE Handbook of Fundamentals. The room load calculations are based on the time-averaging technique. The TETD tables from the 1972 ASHRAE Handbook of Fundamentals were originally calculated using the exact response factor method that is best approximated by the transfer function method used here.

TETD-TA2 - The heat gain calculations are based on the "approximate" TETD heat gain method that uses a "lambda" and "delta" to describe the amplitude and time delay characteristics for a particular wall or roof slab. The heat gains for this method are less exact than those used for TETD method described for TETD-TA1.

TETD-PO Same as TETD-TA2 except the room load calculations are based on the Post Office RMRG weighting factors used in the original versions of TRACE. These
factors are independent of room construction and vary only according to the type of heat gain

2.1.2 Design Analysis

In the design stage of the program the user can input the physical characteristics of the building. This would include components such as wall, window, roof, size, and orientation. In addition the internal loads of the building such as lights, people, and equipment can be modeled as well. The type of cooling/heating system that will be used within the structure can be chosen. The program will then determine the peak loads within the structure using a methodology chosen by the user. After the peak loads have been determined the program will size the various cooling/heating coils and plants as well as the fans needed to deliver the required CFM to the space.

2.1.3 Energy Analysis

Trace 700 also offers the user the ability to create and modify certain components within an extensive library. The user can create various construction types such as building materials, walls, roofs, windows. Schedules and energy rate structures can also be created in the library. Trace also offers the ability for the users to create their own HVAC equipment. Cooling and heating system efficiencies can be modeled by building system curves within Trace’s library. Creating an accurate representation of the equipment as it operates under partial load conditions in the energy analysis part of the program.

In the energy analysis part of the program the equipment and building is modeled on a monthly basis. Using the analysis weather data set the program will take the hourly data for that particular month and calculate the energy usage for weekday, Saturday and Sunday. The energy usage is then multiplied by how many times the weekday, Saturday,
and Sunday occur in that particular month. This result is then used as the monthly energy usage.
CHAPTER 3

TEST BUILDINGS

For this study two homes built in Las Vegas, Nevada were used as test buildings to simulate within Trace and HAP, and compare the results with experimental data. One home is a zero energy home (ZEH) which incorporates the latest technology and construction techniques that will allow the home to significantly reduce its energy demand. The other home is a baseline home which utilizes normal construction techniques that are currently being used for most new homes in the Las Vegas area. In addition these two homes have been extensively outfitted with various sensors and monitoring equipment to record the performance of both buildings. This test data will be used to compare with the simulated results. This chapter will summarize the design, construction and instrumentation of both buildings.

3.1 Overview

The ZEH and the baseline home are both single family one story homes of approximately 1610 sq ft of livable space. During the testing phase both of these homes are to serve as model homes for the developing subdivision. They will therefore be unoccupied but will be subject to the foot traffic of visitors as they tour the homes. The HVAC systems will be left on to maintain a comfortable climate inside.
The two homes are built next to each other have the same floor plan with the front facing north. However each plan is flipped relative to each other, meaning that the east and west facing walls are opposite to each other. Figures 2 and 3 give a better perspective as to how the two homes are positioned next to each other within the subdivision.

![Diagram of baseline and zero energy homes](image)

**Figure 2**  Plan overview of baseline and zero energy home
The roof lines of both homes are somewhat different to each other as well. The roof on the (ZEH) has been altered to give it more north to south exposure for the solar PV panels and solar hot water heater. The baseline home’s roof has a more east to west exposure. Figure 4 offers a better perspective of how the rooflines of both homes are constructed.
While both homes are designed to look and seem the same there is actually a great difference in the way the ZEH and the baseline home are constructed. These details, which can be indistinguishable when first entering each home, affect the way each home operates and consumes energy. The next two sections will offer more detail into the construction properties of each home.

3.2 The Zero Energy Home

A ZEH is defined as a home which produces at least as much energy as it consumes annually. To accomplish this a ZEH combines state of the art, energy efficient construction and appliances with commercially available renewable energy systems such
as solar water heating and solar electricity [25]. For a more detailed view the plan well as a picture of the front of the ZEH is shown in figure 5 and 6.

Figure 5 Zero Energy Home Plan
Figure 6 Front picture of the zero energy home

For simulation purposes each of the various areas of the construction components was broken down by the direction they face. Table 1 shows a summary of these areas.

Table 1 Component areas of zero energy home

<table>
<thead>
<tr>
<th>Direction</th>
<th>Wall Area $\text{ft}^2$</th>
<th>Glass Area $\text{ft}^2$</th>
<th>Roof Area $\text{ft}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>189.1</td>
<td>23</td>
<td>895</td>
</tr>
<tr>
<td>S</td>
<td>353.8</td>
<td>121</td>
<td>1233</td>
</tr>
<tr>
<td>E</td>
<td>645</td>
<td>57</td>
<td>260.2</td>
</tr>
<tr>
<td>W</td>
<td>578</td>
<td>14</td>
<td>166.2</td>
</tr>
<tr>
<td>Partitions</td>
<td>349</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2114.9</td>
<td>215</td>
<td>2554.4</td>
</tr>
</tbody>
</table>
To gain a better understanding of the efficient construction of the home as well as how it was modeled in the simulation programs it is necessary to break down and explain the various features of the home.

3.2.1 Wall Construction

One of the unique features of the ZEH is that unlike other homes in the Las Vegas area, which are built out of wood framing, the ZEH is built out of concrete walls. These insulated concrete walls, known as T-mass walls, are designed by Dow Corning. These walls can be poured off site and then shipped to the location where the home is to be erected. Figure 7 and 8 shows completed sections of wall being shipped to the zero energy home and then erected.

Figure 7 T-mass walls awaiting shipment to zero energy home construction site
The main feature of the T-mass wall is its ability to effectively use the Thermal Mass effect of concrete to offset the cooling loads to off peak hours when power rates are lower. The large mass of the concrete allows the wall to absorb and store more heat than a frame wall and then radiate it back to the outside when the ambient temperature has dropped during later hours of the day. The Styrofoam insulation shown in figure 9 is between the two layers of concrete help to stop the flow of heat to the inside of the home.
The Styrofoam is connected to the concrete with connectors made up of 76% glass fibers and 24% vinyl ester polymer. The connectors have a low thermal conductivity and do not cause thermal bridges or energy/vapor leaks, and are effective in eliminating thermal loss through the wall. The T-mass wall is designed to work well in an area such as Las Vegas where there are large temperature swings between night and day. This can lead to a substantially larger equivalent performance R-value when compared to the actual R-value based upon the material properties. Figure 10 shows a cross section of the wall with the insulation between the two layers of concrete.
The concrete used in this wall is taken to have a density of 130 lb/ft\(^3\) and a conductivity of 1.04 btu/hr-ft\(^2\)-F per inch. The specific heat is taken to be 0.22 btu/lb*F. The outer wall has 2 inches of concrete while the inner wall is composed of 4 inches of concrete. The interior insulation is composed of 2 inches of styrofoam extruded polystyrene and polyisocyanurate rigid board insulations. The insulation is rated to have an R-value of 5 hr-ft\(^2\)-F/btu per inch, and a specific heat of 0.27 btu/lb*F. The wall was also has 0.5 inch of stucco on the exterior. Including interior and exterior film coefficients the Overall R-value of the T-mass Wall was found to be 11.7 hr-ft\(^2\)-F/btu. The overall weight of this wall was found to be 75 lb/ft\(^2\).

3.2.2 Roof Construction

The roof of the home is of the sealed attic design. The insulation is applied directly to the upper side of the ceiling drywall. The insulation itself is a combination of netted and blown in cellulose which has a total R value of 38. The roof is constructed of ceramic tile shingles over \(\frac{1}{2}\) inch plywood. The roof framing is 2X8ft 24in on center, taking into account the effect of framing the overall U value is 0.04 btu/hr-ft\(^2\)-F or an overall R-value of 28. The slope of the roof is approximately 68 degrees. Because of the many vaulted ceilings within the home an average height of the attic had to be approximated at around 4ft. Taking into account this air space and the \(\frac{1}{2}\) inch Gypsum board ceiling the R-value can rise to an R value of 35. The overall weight of this roof is 10.8 lb/ ft\(^2\).

The plywood sheathing facing the interior of the attic utilizes a radiant barrier system. Reflective aluminum foil, which has an extremely low emissive, is located on the underside of the plywood sheathing. The radiant barrier has the ability to significantly reduce the amount of radiant heat that will enter the attic and ultimately the home.
3.2.3 Window Construction

The windows of the ZEH are of the low emissivity design. While construction codes now demand that new homes have low e windows, the ZEH exceeds these codes. All windows in the ZEH are double pane, including the patio doors located in the master bedroom and the living room. The patio doors have a U-value of 0.34 btu/hr-ft²-F, a Solar Heat Gain Coefficient (SHGC) of 0.21 and a Visible Transmittance (VT) of 0.35. The remaining windows on average have a U-value of 0.33 btu/hr-ft²-F, a SHGC of 0.21 and a VT of 0.35. To reduce the amount of solar transmittance through the windows the ZEH has 1 ft eaves overhanging from the roof for shading. There is also a patio cover extending out approximately 8ft to shade all patio doors.

3.2.4 HVAC System

The HVAC system is single zone split system design. A single air handler supplies conditioned air to the entire home, and is controlled by a single thermostat located within the front foyer. The condensing unit, which is located outside, is an evaporatively cooled unit built by Freus rated at 3 tons. The unit works by spraying water over the condensing coils as the condensing fan supplies air to the coils. This allows the refrigerant to expel more heat by taking advantage of the use of the cooling due to evaporation. Figure 11 shows a detailed view of the Freus unit.
When compared to traditionally air cooled condensers the Freus unit can operate more efficiently when the outdoor ambient temperature rises. This can be especially effective in hot dry climates such as Las Vegas. Unlike most residential systems, which are rated by their Seasonal Energy Efficiency Ratio (SEER), the Freus unit is rated by the Energy Efficiency Ratio (EER). At an outdoor ambient air condition of 95 F Dry Bulb (DB) the Freus unit has an EER of about 18. As the temperature increases to 105 the EER drops to about 17.

The ZEH utilizes a hydronic heating design instead of the normal residential gas furnace. A hot water coil located in the air handler shown in figure 12 is connected to an instantaneous or tankless natural gas water heater located in the garage.
The entire air handling system including the ducting is located within in the conditioned space. The ducts themselves are flex type with an outer insulation of R-6. By running the ducting through interior soffits instead of the attic there will be no heat gain through the ducting system. In addition any air losses through leakage in the ducts will eventually make its way to the conditioned space instead of being lost in the attic. The heat gain on the coils and air handling system will also be reduced because it is located in a heavily insulated section and is isolated from the main attic where the most extremes in temperatures occur.

3.3 Baseline Home

The baseline home represents the typical single family residential track home which is currently being built in southern Nevada. This home meets all the design and codes set
by Clark County, Nevada. In comparing this home to the ZEH the results will show how well the ZEH can perform in relation to a typical home which is being widely built. For a more detailed view the plan and front of the baseline home is shown in figure 13 and 14.

Figure 13 Baseline home overview
For simulation purposes each of the various areas of the construction components were broken down by the direction they face. Table 2 shows a summary of these areas.

Table 2 Component areas of baseline home

<table>
<thead>
<tr>
<th>Direction</th>
<th>Wall Area $\text{ft}^2$</th>
<th>Glass Area $\text{ft}^2$</th>
<th>Roof Area $\text{ft}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>189.1</td>
<td>23</td>
<td>166.2</td>
</tr>
<tr>
<td>S</td>
<td>438</td>
<td>127</td>
<td>(NW) 96.7</td>
</tr>
<tr>
<td>E</td>
<td>474</td>
<td>14</td>
<td>1114.5</td>
</tr>
<tr>
<td>W</td>
<td>502.5</td>
<td>57</td>
<td>1100</td>
</tr>
<tr>
<td>Partitions</td>
<td>349</td>
<td>220</td>
<td>2477.4</td>
</tr>
<tr>
<td>Total</td>
<td>1952.6</td>
<td>220</td>
<td>2477.4</td>
</tr>
</tbody>
</table>
To gain a better understanding of the efficient construction of the home as well as how it was modeled in the simulation programs it is necessary to break down and explain the various features of the home.

3.3.1 Wall Construction

The wall construction in the baseline home is based upon frame construction, 2 X 4ft 12 in on center. The insulation installed between the framing is R-13 Blanket and Batt insulation. The exterior is covered by 1 inch of stucco and the interior by 0.5 inch of dry wall. Including interior and exterior film coefficients as well and taking into account the loss due to the effect of framing the R-value for this normal wall was found to be 12.22 hr-ft\(^{-2}\)-F/btu. The overall weight of this wall is found to be 14.6 lb/ft\(^2\).

3.3.2 Roof Construction

The roof of the home is of the sealed attic design. The insulation is applied directly to the upper side of the ceiling drywall. The insulation itself is a combination of netted and blown in cellulose which has a total R value of 29. The roof is constructed of ceramic tile shingles over \(\frac{1}{2}\) inch plywood. The roof framing is 2X8ft 24in on center, taking into account the effect of framing the overall U value is 0.04 btu/hr-ft\(^2\)-F or an overall R-value of 25. The slope of the roof is approximately 68 degrees. Because of the many vaulted ceilings within the home an average height of the attic had to be approximated at around 4ft. Taking into account this air space and the \(\frac{1}{2}\) inch Gypsum board ceiling the R-value can rise to an R value of 27. The overall weight of this roof is 10.8 lb/ft\(^2\).

3.3.3 Window Construction

The windows of the baseline home are of low-e design to meet code. All windows are double pane, including the patio doors located in the master bedroom and the living room.
The patio doors have a U-value of 0.65 btu/hr-ft²-F, a SHGC of 0.41 and a VT of 0.60. The remaining windows on average have a U-value of 0.58 btu/hr-ft²-F, a SHGC of 0.35 and a VT of 0.57. There are 1 ft eaves overhanging from the roof shading all the windows. There is also a patio cover extending out approximately 8 ft to shade the patio doors in the living room, however the patio doors in the master bedroom only have the standard 1 ft overhang.

3.3.4 HVAC System

The HVAC system is single zone split system design. A single air handler supplies conditioned air to the entire home, and is controlled by a single thermostat located within the front foyer. The condensing unit, which is located outside, is a typical air cooled unit. The condenser is a 4 ton unit with a SEER rating of 12.4.

Heating is accomplished by a residential natural gas furnace which is located within the air handling unit. The air handler itself is located within the attic space along with the entire ducting system. The ducts themselves are flex ducts with an outer insulation of R-6.

3.4 Instrumentation

In order to compare the performance of the baseline home to the ZEH to the simulated results each home has been outfitted with a variety of sensing and monitoring devices. This section will give a general overview of how both homes have instrumented.

The main types of inputs used for this study are from the gas flow meters, the power meters, and the weather station. The gas flow meters will monitor how much natural gas each home consumes for heating. The power meters monitor how much power in kilowatt hours (kWh) the condensing unit (compressor and fan) of the air conditioning
system uses. The weather station gives accurate outdoor conditions for use in the simulation.

The power meters are Wattnode Model 1P-240 3Y-308 shown in figure 15 manufactured by Continental Control Systems LLC. The Wattnodes output a certain number of pulses for each kWh used, and a conversion factor supplied by the manufacturer can be used to convert to actual power consumption in kWh.

![Wattnode power meter](image)

Figure 15 Wattnode power meter

The natural gas meters are 200CFGM meters manufactured by E-MON. They measure the natural gas in cubic feet, and output one pulse for each cubic foot of gas consumed. Therefore it is not necessary to apply a conversion factor to the results given by the meters. In the baseline home the gas meter is installed in the attic where the natural gas furnace is located. In the zero energy home the gas meter is installed in the garage at the instantaneous water heater, since this is what provides heating to the home by circulating hot water to a coil in the air handler. Figure 16 shows the gas meter installed at the instantaneous water heater.
Figure 16 Gas meter and instantaneous water heater in zero energy home

The weather station is also located at the peak of the zero energy home’s roof and is shown in figure 17. The weather station records outdoor dry bulb temperature and relative humidity.
The power meters, gas meters and weather station are wired directly to a data logger, which is located in each garage. The data logger compiles and stores the data at 15 minute intervals from each sensor for easy access. Figure 18 provides an example of the data logger installed in the zero energy home garage.
Figure 18 Data logger
CHAPTER 4

PEAK COOLING LOAD RESULTS

This chapter presents analytical results of the peak loads of both the zero energy and baseline home from the Trace 700 programs. The peak loads is the maximum load that the air conditioning system will see at a certain point of the year. These peak loads are often used to properly size the air conditioning unit, as for the rest of the year the system will see less of a load. For this section each cooling methodology was used to predict the peak loads within each structure. The peak loads have been broken up into there respective components so that the two homes could be better compared to see which component is the most effective at reducing the load placed upon the AC system.

Figure 19 shows the results of the peak loads associated with walls of each home. As is shown the T-mass walls effectively reduce the walls when compared to the standard R-13 walls of the baseline home. This shows that the thermal mass of the walls effectively reduces the amount of heat transmitted through them even though the actual R-value of the two walls is very close to each other. There is also a larger difference in the calculated values of the baseline home walls, which are not as thermally massive, when comparing the methodologies based upon the Transfer function method (Trane TFM,RP-359, CEC DOE2) to the methodologies based upon the TETD method (TETD-TA1, TA2, PO). For the most part the TETD based methodologies predict a higher load when compared to the transfer function based methodologies for the less massive baseline
home wall. However for the T-mass walls of the zero energy home overall each methodology predicts very similar loads.

![Wall Peak Loads](image)

**Figure 19** Wall peak cooling loads vs cooling methodology

Figure 20 shows the peak loads associated with the roof of each home. As expected every methodology predicts a large reduction in the amount of cooling load from the roof for the ZEH. This is due to its higher insulation rating located within the attic. When comparing the methodologies the TETD methods all predict lower peak loads for the ZEH roof, while predicting higher peak loads for the baseline home roof.
Figure 20 Roof peak cooling loads vs methodology

Figure 21 shows the peak loads associated with conduction of heat through the windows of each home. Since the zero energy home uses windows that have a lower U-value than the windows the lower peak load from glass transmission predicted by each methodology is expected. There is no clear difference in how each method predicted the amount of load for each building. From the results it shows that if a certain method such as RP-359 predicted a larger load for the baseline home when compared to other methodologies, then it also predicted a larger load with respect to the ZEH. The lowest predicted load for both the zero energy and baseline home glass transmission is the standard Trane transfer function method.

40
Figure 21 shows the peak loads associated with solar loads transmitted through the windows. Since the ZEH contains windows which are of lower - e value when compared to the baseline home the large reduction in the amount of solar load that is transmitted is expected. The solar loads predicted by the TETD methods are greater than 20% in some cases when compared to the solar loads predicted by the transfer function methods. Since the TETD methods default is to only use 1 hour for time averaging. This means that this is instantaneous load without any time lag reducing the radiant portion of the load. Even with this conservative estimate given by the TETD methods the ZEH, with its low-e windows, has a small solar load when compared to the baseline home. This shows that the home is capable of reducing the large swings in instantaneous load.
The TFM based Rp-359 does predict a significantly larger load for the baseline home when compared to the other transfer function based methods. When looking at the ZEH Rp-359 does become more similar when compared to the other transfer function based methods.

![Glass Solar](image)

**Figure 22** Glass solar peak loads vs methodology

Figure 23 shows the peak loads associated with heat transmission through partitions. The partitions are located between the garage and the conditioned space and are constructed in the same manner as the outside walls of their respective house. The only difference is that instead of a layer of stucco on the outer wall, there is a layer of drywall facing the garage. The results show that the T-mass walls of the ZEH are very effective
at reducing the amount of load entering the house when compared to the traditional frame wall.

![Graph showing partition peak loads vs methodology.](image)

Figure 23 Partition peak loads vs methodology

Figure 24 shows the cooling load associated with infiltration. For the ZEH the infiltration was set at around 0.1 air changes per hour, while the baseline home was set at 0.3 air changes per hour. The amount of infiltration will also be subject to how often the air handler fan is running, as this will pressurize the home.
Figure 24 Infiltration load vs methodology

Figure 25 shows the total peak loads present within the two homes. This is what would be used to size the HVAC system in the home. It should be noted however that these loads do not include any cooling loads due to people as the homes are unoccupied for the simulation and testing phase. If included, the cooling load from occupants could increase the load by as much as a full ton of cooling (12,000 btu/hr) for a home of this size.

The total peak loads do include loads associated with lighting. The baseline home has approximately 1100 Watts of lighting which is on at all times. The lights are mostly incandescent with 100% of there load transmitted to the conditioned space. The ZEH utilizes compact fluorescent lighting in all its fixtures, comprising about 250 Watts total.
Compact fluorescents, unlike incandescent bulbs, turn most of the electricity they consume into usable light instead of heat. On average there is up to a 75% reduction in the amount of heat transmitted to the space when compared to a traditional incandescent bulb.

Each methodology predicts over a 50% reduction in the amount of cooling load in the ZEH when compared to the baseline home. When comparing all the methodologies it seems that there is very little difference between the TETD methods and TFMs predictions of the ZEH loads. However with the baseline home results the TETD methods predict loads that are about 10% higher. There is an exception with the RP-359 method. For the baseline home this method predicts a load more in line with the TETD methods.

![Total Cooling Loads](image)

**Figure 25** Total peak cooling loads vs methodology

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Table 3 shows at what hour and month the each of the methodologies predicts the peak cooling loads will occur for both homes. The results that the peak loads occur at the same time for both the ZEH and the baseline home. In some instances the peak loads for the baseline home are predicted to occur 1 hour after the ZEH. The TETD based methods all predict peak loads occurring

<table>
<thead>
<tr>
<th>Method</th>
<th>Trane TFM</th>
<th>CEC DOE 2</th>
<th>RP359</th>
<th>TETD TA1</th>
<th>TETD TA2</th>
<th>TETD PO</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZEH</td>
<td>7/17</td>
<td>7/17</td>
<td>7/17</td>
<td>7/16</td>
<td>7/15</td>
<td>7/15</td>
</tr>
<tr>
<td>Baseline Home</td>
<td>7/17</td>
<td>7/18</td>
<td>7/17</td>
<td>7/16</td>
<td>7/15</td>
<td>7/15</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
CHAPTER 5

ENERGY CONSUMPTION RESULTS AND DISCUSSION

This chapter provides both experimental and simulated results. More directly it reports on the energy consumption of the HVAC system as it pertains to electricity and natural gas of both the Baseline and Zero Energy Home. The results are broken up into cooling results and heating results. Two weeks of experimental data was taken from each period and Trace 700 was used to try to compare to the experimental data.

Trace 700 only gives results of energy consumption in terms of months. Therefore to get around this limitation the program was “tricked” into running the simulation on a daily basis. For better accuracy weather data from each monitoring day was taken directly from the weather station located at the ZEH and was fed into Trace 700. The weather data for each 24 hour period was inputted into Trace’s weather library of monthly 24 hour data. This means that the program will simulate day 1 as January and day 2 as February and so on. Since Trace will take the results and multiply it by the number of days that falls in the month the results could be determined by simply dividing out the number of days in the month. To further modify the program a calendar was built in which all days fall on a weekday so that the program will treat each simulated day equally. This will allow for better accuracy when dividing out by the monthly day to get the daily energy consumption.
5.1 Cooling Results

The cooling results were taken for a two week period during the end of September and beginning of October 2005. Figure 26 displays the weather during the cooling monitoring period.

Figure 26 Outdoor weather conditions for the cooling period monitored.

These are the weather conditions which were fed into the Trace 700 program. The weather during this period offers a range of conditions. For the most part during the day temperatures remained above 76°F, which is the maintained temperature of the two homes. During the nighttime however temperatures do approach 50°F, especially during the second half of the monitoring period. The second half of the monitoring period is also marked with large temperature swings between night and day when, for example,
during the same day a high temperature and low temperature of 92°F and 58°F respectively were reached. The first half of the monitoring period however, sees a relatively small temperature swing, with temperatures never going above 90°F or below 60°F.

The largest consumer of energy during the cooling monitoring period for both homes is the condenser fan and compressor which are located outside in the condenser. The power consumption of these components is related to the outdoor temperature. As the temperature rises the less efficient the condenser will become and the more power it will consume. To try and model this data from the manufacturers of the condenser systems of both the baseline and zero energy home were taken and an equipment profile was built in the Trace 700 program. Figure 27 shows the energy efficiency of the systems installed at each home [26],[27].

![Figure 27 Energy efficiency vs. outdoor air temperature for AC systems.](image)

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
5.1.1 Baseline Home Results

The baseline home during the monitoring period was used as a model home which is subjected to foot traffic as people enter and leave the home to tour it. The home is unoccupied with the only interior loads being the lights which constitute approximately 1100 W which transmit 100% of their load to the space. These lights are on approximately from 9am to 6pm daily. The homes thermostats were set to maintain a temperature of 76°F at all times during the monitoring period. These factors were all considered and modeled within the Trace program to create a more accurate representation of the loads being handled by the AC equipment during this time period.

Figure 28 presents the energy consumption of the baseline home condenser and its fan as a function of time. Also shown is the outdoor ambient condition for that time period. The energy is represented as kWh and is recorded by the data logger at 15 minute intervals. In essence this will show when the peak amount of kWh is being used. As expected it occurs during the mid day when there are large temperature extremes.

To a certain extent there seems to be a degree of thermal storage within the structure, in particular looking at October 8th. A high of 91°F is reached during the late afternoon of October 7th but the air conditioner did not cycle on until mid afternoon on the 8th. This means that the air conditioner did not see these loads as instantaneous rather it took some time for the loads to transmit the structure and cause the air conditioner to turn on. This can be attributed to the fact that the house is often shut with very few people inside. If there are several visitors touring the home they do not stay long enough to affect the internal heat gain of the structure.
Three days that saw a large use of the air conditioner were October 1-3rd. These days were marked with high average temperatures often above 70°F even during the night hours. It should be noted that all the peaks of electricity consumption occur at around 1:30pm. Also of interest is that during the October 1-3 timeframe the instantaneous kWh actually reduce as the air conditioner stays on to continually meet the load which is present due to the higher average temperature. This shows that as the air conditioner continually turns on and off it consumes more power as the compressor power consumption is the highest at startup. This is why a system must be properly sized as an oversized system will quickly meet the load and cycle on and off too frequently. This is the case here because the 4 ton system, while sized for a family occupying the home during extreme outdoor summer conditions, is oversized for an empty home with little internal loads.
The results from figure 28 can be added to give a total kWh consumed per each day of the monitoring period. Figure 29 presents these results as well as the results from the Trace 700 simulations.
The results show that during the first week of the monitoring period Trace 700 closely follows the actual power consumption of the AC condenser. However during relatively large or small values of energy consumption Trace has trouble duplicating the actual results.

Trace is actually predicting a larger thermal mass for the structure than is actually present. As there are large temperature swings between the monitoring days, the home will respond in turn by using either a large or small amount of energy. Trace predicts that the home will store the heat it gains during warm days and release it slowly during cold days.

Trace does seem to follow along with the rise and fall of energy use. The rise in energy use can be seen until an eventual peak is reached on October 2nd. The fall in energy consumption that begins on the 3rd and bottoms around the 5th and 6th of October is also followed by Trace. The difference between trace and the experimental results is in
the magnitude. The difference between the experimental results and Trace 700's results is shown in table 4.

<table>
<thead>
<tr>
<th>Monitoring Day</th>
<th>Monitoring A Experimental kWh</th>
<th>Monitoring B Trace 700 kWh</th>
<th>A-B</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/28/2005</td>
<td>14.78</td>
<td>11.35</td>
<td>3.43</td>
<td>23.20</td>
</tr>
<tr>
<td>9/29/2005</td>
<td>10.00</td>
<td>11.52</td>
<td>-1.52</td>
<td>15.19</td>
</tr>
<tr>
<td>9/30/2005</td>
<td>12.72</td>
<td>11.54</td>
<td>1.18</td>
<td>9.24</td>
</tr>
<tr>
<td>10/1/2005</td>
<td>18.56</td>
<td>15.37</td>
<td>3.20</td>
<td>17.22</td>
</tr>
<tr>
<td>10/2/2005</td>
<td>23.30</td>
<td>17.02</td>
<td>6.28</td>
<td>26.96</td>
</tr>
<tr>
<td>10/3/2005</td>
<td>20.73</td>
<td>12.26</td>
<td>8.47</td>
<td>40.85</td>
</tr>
<tr>
<td>10/4/2005</td>
<td>6.43</td>
<td>8.60</td>
<td>-2.17</td>
<td>33.83</td>
</tr>
<tr>
<td>10/5/2005</td>
<td>4.73</td>
<td>6.61</td>
<td>-1.88</td>
<td>39.67</td>
</tr>
<tr>
<td>10/6/2005</td>
<td>3.34</td>
<td>7.35</td>
<td>-4.01</td>
<td>120.03</td>
</tr>
<tr>
<td>10/7/2005</td>
<td>6.31</td>
<td>13.21</td>
<td>-6.90</td>
<td>109.43</td>
</tr>
<tr>
<td>10/8/2005</td>
<td>10.82</td>
<td>10.90</td>
<td>-0.08</td>
<td>0.76</td>
</tr>
<tr>
<td>10/9/2005</td>
<td>7.79</td>
<td>7.28</td>
<td>0.51</td>
<td>6.50</td>
</tr>
<tr>
<td>10/10/2005</td>
<td>5.01</td>
<td>6.03</td>
<td>-1.02</td>
<td>20.25</td>
</tr>
<tr>
<td>10/11/2005</td>
<td>2.40</td>
<td>8.08</td>
<td>-5.68</td>
<td>236.53</td>
</tr>
<tr>
<td>10/12/2005</td>
<td>6.93</td>
<td>10.19</td>
<td>-3.26</td>
<td>47.05</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>153.84</strong></td>
<td><strong>157.30</strong></td>
<td><strong>-3.46</strong></td>
<td><strong>2.25</strong></td>
</tr>
</tbody>
</table>

The percent difference is the largest on October 11th, and is the smallest on October 8th. When adding up the entire monitoring period the difference between the actual and simulated results drops dramatically. For half of a month of monitoring Trace 700 overestimated the amount energy usage by about 2.25%.

For the most part the largest difference between the results occurs on the coldest days of the monitoring period. This may occur because Trace does not have sufficient data for the condenser unit to accurately predict its energy consumption. Manufacturers usually
only give power consumption data at between 75°F and 115°F. Since on some of these
colder days the AC was on when the outdoor temperature was below 75°F Trace could
not interpolate what the power consumption would be. For this case it would have just
taken the lowest value for which data was supplied, which was 75°F. At this temperature
the power consumption would be slightly higher than what would have actually occurred.

5.1.2 Zero Energy Home Results

The ZEH during the monitoring period served as a model home which was open to
the public for tours. The home is otherwise unoccupied during this period with the only
internal loads present are the lights. The ZEH has been outfitted with compact
fluorescent lights instead of the usual incandescent bulbs. In total there are
approximately 250 watts of fluorescent lights which were modeled as 100% of their loads
going to the space. These lights are on approximately from 9am to 6pm daily.

Figure 30 presents the energy consumption of the baseline home condenser and its
fan as a function of time. Also shown is the outdoor ambient condition for that time
period. The energy is represented as kWh and is recorded by the data logger at 15 minute
intervals.

When comparing figure 30 with figure 38 of the baseline home, the first noticeable
difference is in the magnitude of kWh. The maximum instantaneous kWh for the ZEH is
about 0.2, while for the baseline home it was about 0.8. These maximums occurred both
on October 1\textsuperscript{st}, showing that given the same weather conditions the ZEH substantially
reduced its HVAC energy consumption.

Like the baseline home the ZEH used more energy during the first half of the
monitoring period when there was a higher average outdoor temperature. The results also
show that there is a much larger amount of thermal storage in the structure due to its heavier weight construction. When there are large temperature swings the home does not respond with large swings in temperature consumption. This occurs during the first half of the monitoring period when the amount of electrical consumption by the AC system remains constant. However a more dramatic example of this thermal storage is seen happening on October 7th and 8th. When the outdoor temperature goes from 60°F to a high of over 90°F there is not a noticeable peak in energy consumption as there is in baseline home. In general the peaks of energy consumption for each day occur at 2:45pm, over an hour after the peaks of the baseline home. This shows that the thermal mass of the home is capable of helping to shift the loads to a later hour in the day.

![Zero Energy Home Condenser KWh vs time](image)

Figure 30 Zero energy home kWh vs time
Also of interest is that at start up the condenser of the ZEH does not use as much power as the baseline home. The peak of energy consumption occurs after the condenser has been on for some time. This is beneficial when the system is under partial load condition as it will not use as much energy when quickly cycling on and off.

The results from figure 30 can be added to give a total kWh consumed per each day of the monitoring period. Figure 31 presents these results as well as the results from the Trace 700 simulations.

![Graph](image)

Figure 31 ZEH experimental and simulated AC condenser kWh consumed.

The results show that trace was able to follow along closely with the results of the first week of the monitoring period. Trace is accurately predicting the amount of thermal storage in the structure for the first week but it overestimates the thermal mass in the second half of the monitoring period.
As the average outdoor temperature drops off after October 3rd, Trace does not follow along with the magnitude of fall of energy consumption. As with the baseline home Trace has trouble in predicting relatively small values in energy consumption. It does show it can follow along with the peaks and valleys of the energy consumption associated with the second week, it simply overestimates the magnitude. The percent difference between the experimental results and Trace 700’s results is shown in table 5.

Table 5 ZEH kWh predicted vs experimental results

<table>
<thead>
<tr>
<th>Monitoring Day</th>
<th>A Experimental kWh</th>
<th>B Trace 700 kWh</th>
<th>A-B</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/28/2005</td>
<td>4.19</td>
<td>2.33</td>
<td>1.85</td>
<td>44.27</td>
</tr>
<tr>
<td>9/29/2005</td>
<td>4.63</td>
<td>2.56</td>
<td>2.07</td>
<td>44.72</td>
</tr>
<tr>
<td>9/30/2005</td>
<td>3.61</td>
<td>3.38</td>
<td>0.22</td>
<td>6.16</td>
</tr>
<tr>
<td>10/1/2005</td>
<td>4.88</td>
<td>4.67</td>
<td>0.21</td>
<td>4.34</td>
</tr>
<tr>
<td>10/2/2005</td>
<td>4.87</td>
<td>5.98</td>
<td>-1.11</td>
<td>22.73</td>
</tr>
<tr>
<td>10/3/2005</td>
<td>4.31</td>
<td>3.93</td>
<td>0.38</td>
<td>8.87</td>
</tr>
<tr>
<td>10/4/2005</td>
<td>1.50</td>
<td>2.55</td>
<td>-1.05</td>
<td>69.55</td>
</tr>
<tr>
<td>10/5/2005</td>
<td>0.78</td>
<td>1.63</td>
<td>-0.85</td>
<td>108.85</td>
</tr>
<tr>
<td>10/6/2005</td>
<td>0.43</td>
<td>1.62</td>
<td>-1.20</td>
<td>281.06</td>
</tr>
<tr>
<td>10/7/2005</td>
<td>1.76</td>
<td>2.94</td>
<td>-1.17</td>
<td>66.60</td>
</tr>
<tr>
<td>10/8/2005</td>
<td>2.00</td>
<td>2.85</td>
<td>-0.85</td>
<td>42.33</td>
</tr>
<tr>
<td>10/9/2005</td>
<td>1.17</td>
<td>1.40</td>
<td>-0.23</td>
<td>19.89</td>
</tr>
<tr>
<td>10/10/2005</td>
<td>0.56</td>
<td>0.86</td>
<td>-0.29</td>
<td>52.19</td>
</tr>
<tr>
<td>10/11/2005</td>
<td>0.40</td>
<td>1.42</td>
<td>-1.02</td>
<td>255.89</td>
</tr>
<tr>
<td>10/12/2005</td>
<td>1.19</td>
<td>2.03</td>
<td>-0.84</td>
<td>70.89</td>
</tr>
<tr>
<td>Total</td>
<td>36.26</td>
<td>40.13</td>
<td>-3.87</td>
<td>10.67</td>
</tr>
</tbody>
</table>

Like the baseline home the largest percent difference occurs when the actual energy consumption is at its lowest, in particular October 6th and 11th. When energy consumption is relatively high the difference between the actual results and the Trace 700
results become small. Adding up the entire energy consumption for the monitoring period Trace 700 over predicts the energy consumption by about 11%.

As with the baseline home there may not be enough information on the condenser unit for its power consumption under outdoor temperatures of 75°F for Trace to model it correctly. There is also an added factor in that the Freus unit's energy consumption will be directly linked to the outdoor relative humidity, or wet bulb temperature. Generally the lower the wet bulb temperatures the better the system will perform. If the manufacturer tested this unit in a different climate with different humidity conditions then the data fed into Trace could be erroneous for the Las Vegas area.

5.2 Heating Results

The heating results were taken for an 11 day period during the end of October and beginning of November 2005. Figure 32 displays the weather during the cooling monitoring period.
These were the conditions that were fed into the Trace program. As is shown the average daily temperature was for the most part below 80°F, with the exception of November 1st and 2nd. Nightly temperatures hover around just under the 50°F mark. Also of note is the large spike in relative humidity at the start of the monitoring period due to rain in the vicinity.

For the heating monitoring period the simulated results were compared to the amount of natural gas expressed in therms consumed by each home’s heating system. In the case of the baseline home, this would be the natural gas furnace. The AFUE (Annual Fuel Utilization Efficiency) of this furnace was taken to be about 83% for modeling within Trace. The ZEH’s hydronic heating system was modeled as a small boiler and fan coil arrangement with the boiler also having an AFUE of about 85%.
5.2.1 Baseline Home Results

The baseline home during the heating monitoring period was used as a model home which is subjected to foot traffic as people enter and leave the home to tour it. The home is otherwise unoccupied with the only interior loads being the incandescent lights which constitute approximately 1100 Watts of power which transmit 100% of there load to the space. These lights are on approximately from 10 am to 5pm daily. The homes thermostat was set to heating to maintain a temperature of 75 F at all times during the monitoring period. These factors were all considered and modeled within the Trace program.

Figure 33 presents the energy consumption of the baseline home furnace. Also shown is the outdoor ambient condition for that time period. The energy is represented in therms and is recorded by the data logger at 15 minute intervals. Also shown is the outdoor ambient condition for that time period.

As expected the furnace only operates during the night time period when outdoor temperatures reach there lowest. There is really no peak in the therms used. The system turns on and quickly reaches a maximum in the amount of therms it consumes. There is a fair amount of cycling on and off as the system quickly meets the heating load and raises the temperature of the home to its set point. This can be expected with this type of system. The furnace is essentially an air to air heat exchanger type furnace in which the supply temperature is almost constant and relatively high. Couple that with a constant volume fan that is properly sized for cooling yet oversized for heating and the homes temperature will rise quickly.
There is also not much of a thermal storage effect in the home during heating. The home needs heat exactly when the outdoor temperature is at its lowest. There is very little storage from the heat gained during the day. The home will rapidly lose its heat during the nighttime period, and then quickly gain it back as the temperature rises during the daytime period.

Figure 33 Baseline home instantaneous therms used.

Taking the results from figure 33 and integrating the total therms used per day can be calculated. Figure 34 presents the total therms both actual and predicted by Trace used by the heating system per day.
The results show the Trace was able to follow along rather well with the rise and fall of heating needed. It seems that the efficiency of the system was modeled correctly. It seems that Trace might be simply over estimating how quickly the home will gain and lose heat. In this case it might be overestimating once again the thermal mass of the home. The difference between the predicated and the actual therms used is shown in table 6.
Table 6 Baseline home therms predicted vs experimental results

<table>
<thead>
<tr>
<th>Monitoring Day</th>
<th>A Experimental Therms</th>
<th>B Trace 700 Therms</th>
<th>A-B</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/28/2005</td>
<td>0.4928</td>
<td>0.83</td>
<td>-0.33</td>
<td>67.57</td>
</tr>
<tr>
<td>10/29/2005</td>
<td>0.77324</td>
<td>0.80</td>
<td>-0.03</td>
<td>3.92</td>
</tr>
<tr>
<td>10/30/2005</td>
<td>0.73207</td>
<td>0.60</td>
<td>0.14</td>
<td>18.48</td>
</tr>
<tr>
<td>10/31/2005</td>
<td>0.67015</td>
<td>0.64</td>
<td>0.03</td>
<td>5.00</td>
</tr>
<tr>
<td>11/1/2005</td>
<td>0.69077</td>
<td>0.55</td>
<td>0.15</td>
<td>21.08</td>
</tr>
<tr>
<td>11/2/2005</td>
<td>0.63922</td>
<td>0.50</td>
<td>0.14</td>
<td>21.26</td>
</tr>
<tr>
<td>11/3/2005</td>
<td>0.25975</td>
<td>0.40</td>
<td>-0.14</td>
<td>53.99</td>
</tr>
<tr>
<td>11/4/2005</td>
<td>0.8666</td>
<td>0.85</td>
<td>0.02</td>
<td>2.47</td>
</tr>
<tr>
<td>11/5/2005</td>
<td>1.14441</td>
<td>0.96</td>
<td>0.19</td>
<td>16.41</td>
</tr>
<tr>
<td>11/6/2005</td>
<td>1.21568</td>
<td>0.90</td>
<td>0.32</td>
<td>25.97</td>
</tr>
<tr>
<td>11/7/2005</td>
<td>0.8351</td>
<td>0.78</td>
<td>0.05</td>
<td>6.20</td>
</tr>
<tr>
<td>Total</td>
<td>8.31979</td>
<td>7.80</td>
<td>0.52</td>
<td>6.29</td>
</tr>
</tbody>
</table>

There is a large difference between the experimental and simulated results on a day to day basis, most notably on October 28th. However if the entire monitoring period is taken into account the percent difference drops to about 6%.

5.2.2 Zero Energy Home Results

The ZEH during the heating monitoring period was used as a model home which is subjected to foot traffic as people enter and leave the home to tour it. The home is otherwise unoccupied with the only interior loads being the lights which constitute approximately 250 Watts of fluorescent lights which transmit 100% of there load to the space. These lights are approximately on from 10 am to 5pm daily. The homes thermostat was set to heating to maintain a temperature of 75 F at all times during the monitoring period. These factors were all considered and modeled within the Trace program.
Figure 35 presents the energy consumption of the ZEH Instantaneous water heater which supplies heat to the home. Also shown is the outdoor ambient condition for that time period. The energy is represented in therms and is recorded by the data logger at 15 minute intervals. Also shown is the outdoor ambient condition for that time period.

![Zero Energy Home Therms Used](image)

**Figure 35 Zero energy home therms used vs time.**

What is noticeable about the results is that unlike the baseline home there is a peak in therms consumed in the ZEH. This peak usually occurs between 7 and 8am. This peak can be the result of the change in temperature of the water entering and leaving the instantaneous hot water heater. During the nighttime period the temperature of the air coming in from the return ducts is colder than the hot water coming back from the hot water
coil will also be colder and require more heat, and thus more therms, to warm it back up to a suitable temperature. These peaks during the night time period may also be due to the fact that the pipes between the hot water coil and instantaneous hot water heater are uninsulated. These pipes might be losing heat in the unconditioned garage and attic, requiring the heater to use extra energy.

What is also of interest is how the heating system remains on for a longer period of time than the baseline home system. The ZEH system does not heat the home as rapidly as in the baseline home. The supply air coming off the hot water coil will be less than a normal residential furnace. Also the air handling unit is sized to deliver less air than the unit in the baseline home simply because it is sized for a cooling load that is significantly less than the baseline home.

The thermal mass of the home may also be influencing this larger consumption of gas. During the day the home does not gain as much heat from the outside so the system must turn on much earlier to maintain the heating set point. Also during the night and morning hours the home's thermal mass seems to store the "cold". Like many cement structures it takes a while to heat, and force out the cold which has set in over the night hours. The home will not quickly succumb to the fast rise in temperature that is seen as the day begins.

The results from figure 35 can be integrated and the total daily therms consumed can be calculated. Figure 36 presents the total therms both actual and predicted by Trace used by the heating system per day.
The results show that Trace was able to predict the rise and fall of the therms consumed as heating was used. However it is interesting to note that for this case Trace has never predicted a value that was more than the experimental value. Trace is always predicting that the consumption of therms will always be less than what is actually occurring. The program has modeled the heating system of the ZEH to be more efficient than the way it is actually operating. Table 6 gives the percent difference between the predicted and experimental results.
Table 7 ZEH therms actual vs predicted values

<table>
<thead>
<tr>
<th>Monitoring Day</th>
<th>A Experimental Therms</th>
<th>B Trace 700 Therms</th>
<th>A-B</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/28/2005</td>
<td>1.01038</td>
<td>0.77</td>
<td>0.24</td>
<td>23.70</td>
</tr>
<tr>
<td>10/29/2005</td>
<td>0.9297</td>
<td>0.77</td>
<td>0.16</td>
<td>17.41</td>
</tr>
<tr>
<td>10/30/2005</td>
<td>0.79387</td>
<td>0.56</td>
<td>0.24</td>
<td>29.70</td>
</tr>
<tr>
<td>10/31/2005</td>
<td>0.78356</td>
<td>0.55</td>
<td>0.24</td>
<td>30.23</td>
</tr>
<tr>
<td>11/1/2005</td>
<td>0.79387</td>
<td>0.41</td>
<td>0.38</td>
<td>47.99</td>
</tr>
<tr>
<td>11/2/2005</td>
<td>0.85573</td>
<td>0.37</td>
<td>0.48</td>
<td>56.37</td>
</tr>
<tr>
<td>11/3/2005</td>
<td>0.71139</td>
<td>0.28</td>
<td>0.43</td>
<td>60.55</td>
</tr>
<tr>
<td>11/4/2005</td>
<td>1.06193</td>
<td>0.71</td>
<td>0.35</td>
<td>32.87</td>
</tr>
<tr>
<td>11/5/2005</td>
<td>1.165</td>
<td>0.85</td>
<td>0.32</td>
<td>27.32</td>
</tr>
<tr>
<td>11/6/2005</td>
<td>1.3999</td>
<td>0.85</td>
<td>0.55</td>
<td>39.63</td>
</tr>
<tr>
<td>11/7/2005</td>
<td>1.25782</td>
<td>0.75</td>
<td>0.51</td>
<td>40.37</td>
</tr>
<tr>
<td>Total</td>
<td>10.76315</td>
<td>6.87</td>
<td>3.90</td>
<td>36.22</td>
</tr>
</tbody>
</table>

As shown there quite a large difference between the actual and predicted values on a day to day basis. The largest difference once again occurs on November 3rd. For the total monitoring period the percent difference drops to about 34%. Trace is predicting that the home uses a little over a third less natural gas then the heating system actually consumes.

5.3 Annual Energy Consumption

Using the Trace program an annual energy analysis was performed. Using the standard weather tape for Las Vegas provided by Trace yearly consumption of both electricity and natural gas was calculated for both homes. In addition the annual energy analysis was performed using each methodology. The results are presented in figures 37 and 38.
The results follow the peak load analysis done in chapter 4. For the most part the TETD based methods will predict a larger consumption of energy than the TFM based methods as they are predicting a larger load that must be satisfied. The TFM based RP-359 however again displays that it will predict a larger consumption of energy on the same level with the TETD methods. For the heating analysis Trace does not allow the user to use RP-359. Instead it offers a basic method which only takes into account the temperature difference between the inside and outside. UATD method predicts energy consumption on the same level as the TETD methods.

Figure 37 Annual AC KW-hr consumption

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Figure 38 Annual heating therms used
CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

For this study the main focus was to see if a widely used building load and energy analysis software package, Trace 700, could accurately be used to predict the energy consumption of two differently constructed homes. On a day to day basis Trace has trouble effectively predicting the energy consumption of the HVAC system of both homes. However, for the entire monitoring period the difference between the actual results and predicted falls dramatically. This shows that for over an extended time Trace can quite accurately predict the energy consumption of a building. This is useful because for the most part interest lies in determining the energy consumption on a monthly and yearly basis. This is because for most billing purposes energy is charged on a monthly basis.

When looking at how accurately the predictions are between the homes it is clear that Trace more accurately modeled the baseline home. Trace did predict that there would be an extensive energy savings with the ZEH but not on the same magnitude as what actually occurred. The results were off by about 11% for both heating and cooling. What is surprising is that in heating Trace actually under predicted the amount of energy consumed by heating. However it did show a dramatic reduction in the amount of cooling energy needed in the ZEH. Trace might see more accurate results with much
larger building as it was designed for. However even with these two smaller buildings it can be shown that Trace can be an effective tool in designing energy efficient structures, especially large expensive structures.

When comparing the actual results from both ZEH and the baseline home it is apparent that when it comes to cooling the ZEH is incredibly energy efficient. In terms of electrical energy alone, the ZEH AC system consumes 75% less than the baseline home. When taking into account the amount of cooling that will be needed in the Las Vegas area this will add up to substantial savings. In heating however the ZEH heating system consumes slightly more natural gas than then baseline home. This may be due to certain inefficiencies within the system. The airflow might not be enough over the heating coil, and the pipes may be losing heat due to not being insulated.

6.2 Recommendations

In order to get more accurate results from trace it might be necessary to get more accurate information as to how the air conditioning equipment performs under partial load conditions as well as under varying outdoor conditions. Determining how the equipment works when conditions are under 75°F could improve the results of this study as well as future studies. There could be a some occasions where the air conditioning equipment is on even when it is relatively cold outside due to greater internal loads such as people, lights, and electronic equipment.

It also might be helpful to perform an air leakage test on the homes to determine how much air is infiltrating the homes. In addition the piping and airflow in the ZEH heating system should be checked to make sure that it is working as designed.
A longer study could also lead to more in depth results and conclusions. 3 months of cooling data and 3 months of heating data would show how Trace could perform on a more long term basis. This will also show how much more efficiently the ZEH can perform in relation to the baseline home.
REFERENCES


[26] Freus Manufacturer Specifications

[27] Lennox Operational Manual Specifications

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
VITA

Graduate College
University of Nevada, Las Vegas

Robert Michael Madeja

Home Address
433 Drake Street
Henderson, Nevada 89015

Degrees
Bachelor of Science, Mechanical Engineering, 2003
University of South Florida, Tampa

Thesis Title: Evaluation of Building Energy Simulation Software Using Residential Homes

Thesis Examination Committee
Chairperson, Dr. Samir F. Moujaes, Ph.D., P.E.
Committee Member, Dr. Robert F. Boehm, Ph.D., P.E.
Committee Member, Dr. Mohamed B. Trabia, Ph.D.
Graduate Faculty Representative, Dr. Samaan Ladkany, Ph.D., P.E.