1-1-2013

Using Calibrated Simulation to Quantify The energy Savings From Residential Passive Solar Design in Canada

Hayes E. Zirnhelt
Ryerson University

USING CALIBRATED SIMULATION TO QUANTIFY THE ENERGY SAVINGS FROM RESIDENTIAL PASSIVE SOLAR DESIGN IN CANADA

By

Hayes Emerson Zirnhelt

B.A.Sc Integrated Engineering, University of British Columbia, 2010

A thesis presented to

Ryerson University

in partial fulfillment

of the requirements

for the degree

of Master of Applied Science

in the Program of Building Science

Toronto, Ontario, Canada 2013

AUTHOR'S DECLARATION FOR ELECTRONIC SUBMISSION OF A THESIS

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I authorize Ryerson University to lend this thesis to other institutions or individuals for the purpose of scholarly research.

I further authorize Ryerson University to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

I understand that my thesis may be made electronically available to the public.

USING CALIBRATED SIMULATION TO QUANTIFY THE ENERGY SAVINGS FROM RESIDENTIAL PASSIVE SOLAR DESIGN IN CANADA

Master of Applied Science 2013 – Hayes Emerson Zirnhelt – Building Science Program
Ryerson University

Abstract

Energy savings from passive solar design applied to a typical Canadian house were quantified using calibrated whole building energy simulation. A detailed energy simulation model was created for a research house which represents a typical Canadian tract house with basic passive solar measures. The model was calibrated to measured furnace gas consumption data. Eight design scenarios were evaluated for eight climate locations. Design parameters included increased thermal mass, increased south window area, and high performance windows. In addition, an advanced house scenario was evaluated which featured optimized geometry, a further increase in south window area, high thermal mass, advanced glazing, and no north facing windows. For the typical house predicted solar heating fractions ranged from 20% to 34% with basic passive solar measures, and 35% to 52% for more aggressive passive solar measures. For the advanced house predicted solar fractions ranged from 40% to 69%.

Acknowledgements

I would like to thank my supervisor, Professor Russell Richman, for his generous support and guidance throughout this thesis research. I would also like to thank the Canadian Centre for Housing Technology (CCHT) for kindly providing detailed information and data required to produce a calibrated model of the CCHT Reference House. Thank you to Serious Windows and Pilkington North America for providing detailed optical data for their glazing. Also, I would like to acknowledge the funding provided by the Centre for Urban Energy at Ryerson which helped initiate this research.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AFUE – Annual fuel utilization efficiency
AMY – Actual metrological year
ASHRAE – American Society of Heating Refrigeration and Air Conditioning Engineers
CCHT – Canadian Centre for Housing Technology
CMHC – Canada Mortgage and Housing Corporation
CTF – Conduction transfer function
CV(RMSE) – Coefficient of variation of root mean square error
DHW – Domestic hot water
DOE – Department of Energy (US)
EMR – Energy, Mines and Resources Canada
GHG – Greenhouse gas emissions ($CO_{2\text{-}e}$)
HRV – Heat recovery ventilator
HVAC – Heating Ventilation and Air conditioning
ISO – International Standards Organization
LBNL – Lawrence Berkeley National Laboratory (US)
SHF – Solar heating fraction
SHGC – Solar heat gain coefficient
SSF – Solar savings fraction
NMBE – Normalized mean bias error
NRCan – Natural Resources Canada
NRC – National Research Council of Canada
TARP – Thermal Analysis Research Program
TMY – Typical meteorological year

Nomenclature

A_f	area of framing, m^2
A_w	area of wall, m^2
c	flow coefficient, $m^3/(s/Pa^n)$
C_s	stack coefficient, $(Pa/K)^n$
C_w	wind coefficient, $(Pa{\cdot}s^2/m^2)^n$
E	furnace gas consumption energy, GJ
h	height, m
n	pressure exponent
q''	heat flux, W/m^2
Q_s	stack airflow rate, m3/s
Q_w	wind airflow rate, m^3/s
R	thermal resistance (1/U), m^2K/W
s	shelter factor
Δt	change in time
ΔT	temperature difference, K
T	temperature, K
n	number of data points
U	heat transfer coefficient, W/m^2K
U_{eff}	effective overall heat transfer coefficient including thermal bridging, W/m^2K
U_f	overall heat transfer coefficient for framing, W/m^2K
U_{ins}	overall heat transfer coefficient for insulation, W/m^2K
V	volumetric flow rate, m^3/s
w	width, m

1. Introduction

With the choice now between "dangerous" and "extremely dangerous" levels of climate change (Anderson and Bows 2011), the need to reduce emissions from the building and construction sector has perhaps never been more urgent. Globally, it is predicted that the highest potential for economical climate change mitigation is through initiatives in the building sector (IPCC 2007). The operation of buildings accounts for 29% of Canada's total greenhouse gas (GHG) emissions (NRCan 2011), and over half of these emissions are from the residential sector. It is essential that the GHG emissions of Canadian houses are reduced and eventually eliminated.

In Canada, space heating accounts for over 60% of residential energy consumption (NRCan 2011). The space heating demand of new single-family residential buildings can be significantly reduced through the use of low energy design strategies. One of the most promising of these strategies is passive solar design. It has been suggested that passive solar design is the most effective means to reduce space-heating requirements in Canadian houses, when used in conjunction with insulation levels equivalent to the requirements of Canada's R-2000 program (Athienitis 2007).

The Canada Mortgage and Housing Corporation's passive solar house design book (1998, now out of print), suggested that one third to one half of the space heating requirement can be met with passive solar gain. Canada's potential to reduce energy consumption and associated GHG emissions, with passive solar design, ranks high relative to other countries, due to its predominantly cold and sunny climate (CMHC 1998). When coupled with earth sheltering, houses in the UK have been able to eliminate the need for an active heating system (Hockerton Housing Project 2010).

A limited number of studies have quantified the energy savings from passive solar design applied to a typical dwelling in Canada (eg. EMR 1984, CMHC 1998). Most passive solar design literature for cold climates is out of date, as much of the research was carried out several decades ago. In many cases the analysis was limited to statistically-based calculations, rather than hourly or sub-hourly time step based simulation that is common now (O'Brien et al. 2008). Understanding the potential of passive solar design has significance to policy and planning decisions for cities, regarding density and shading. Typical values for energy savings from passive solar design could be useful for informing house designers and justifying incentive programs designed to support/promote the adoption of low energy buildings. The purpose of this research is to evaluate the potential of passive solar design as a means to save energy in the residential sector, and to produce accurate estimates for typical energy savings from passive solar design for a common new house, throughout a range of nationally representative Canadian climates.

This thesis research adds to the work by CMHC (1998), with more locations and more emphasis on quantifying the effect of design variables. Dynamic simulations were carried out with the EnergyPlus simulation engine using a calibrated baseline model of a typical tract-built house. Several passive solar design options were evaluated for eight locations in Canada, these options include variations in size and type of glazing and the inclusion of additional thermal storage mass. Passive solar potential is quantified and expressed in terms of solar heating fraction and heating energy consumption.

2. Literature Review

2.1 Passive Solar

A passive solar building can be defined as a building that offsets a significant portion of its heating requirement using solar energy, where the solar collection system primarily operates in a passive manner, rather than through active systems which employ pumps or fans to circulate solar energy (this definition is consistent with Chan et al. 2010).

2.1.1 Background on Passive Solar Research

Most of the research on passive solar design in North America was conducted in the mid 1970's to mid 1980's largely in response to oil shortages. A majority of the research on passive solar originates from government sponsored work in the US (for an overview refer to Balcomb 1992). A majority of the effort to promote passive solar has been directed towards single family residential. It has been estimated that there are over 200,000 passive solar homes in the US (Balcomb 1992). Research in the US showed that large energy savings could be achieved with little or no additional capital cost (Balcomb 1992). This research has also produced the many of the simulation techniques, and design guidelines.

Passive solar research in Canada has been much less extensive. Barakat (1982) provides an overview of National Research Council of Canada (NRCC) studies. Many of these studies were test cell based. For experiments using simple test cells with only south facing glazing, found that 34% to 53% of the heating demand was being supplied by solar (Barakat 1984). These results are promising, as the test cells were much less insulated than modern buildings and had only regular double pane glazing and 38 x 89 mm insulated frame walls. Barakat (1984) concluded from these test cell studies that the energy savings from an eight fold increase in thermal mass were 'modest' and could be more practically accomplished via increased air circulation.

2.1.2 Site Considerations and Design Guidelines

Many guidelines exist for passive solar design (eg. Balcomb 1983, Chiras 2002, CMHC 1998, etc.). However, most are over a decade old, and some are out of print (eg. CMHC 1998). Many of these guidelines take the form of basic design principles, such as orientation for maximum solar gain, the use of thermal mass to reduce temperature fluctuations and advice on maximum south facing window areas.

An ideal site for passive solar would allow for south facing windows to receive no shading from nearby trees (or buildings) between 9am and 3pm on the winter solstice (CMHC 1998). The optimal orientation of a passive solar building in the northern hemisphere is due south (Jones 1992). CMHC (1998) offers the following guidelines for passive solar:

- The building should be oriented so that the aspect with the most window area faces +/- 15° of south, with southeast being preferred over southwest.
- Orientations of up to 30˚ from south can still provide considerable energy savings.
- Windows with high solar heat gain coefficients (SHGC) should be selected for south facing aspects.
- South facing window areas should not be higher than 8% of the total floor area, unless additional thermal mass is added, in which case up to 15% is recommended.

Guidelines differ on maximum south window area. Charron and Athienitis (2006) recommend 7% to 12% for basic designs, and no more than 20% for high mass designs, considerably higher values than recommended by CMHC 1998.

Guidelines around shading need to be carefully considered when aiming to maximize the energy performance of passive solar homes. According to Hastings (1995), a common premise in passive solar design is that fixed overhangs can provide shade from summer sun without restricting useful solar gain during the heating season. However, the lag between outdoor temperature and sun angle causes this assumption to be invalid. As described by Gusdorf et al. (2011 p. 1): "there is no net benefit to any configuration of fixed overhangs. This is because the overhangs block potentially useful solar energy in the spring shoulder seasons (March and April), and allow the sun to overheat a house in August and September." Movable shading, including awnings and roll shutters, provide a more optimal solution (discussed further in Section 2.2).

Although compact forms, such as a cube, have lower surface area and thus lower heat loss compared to complex geometries, a shallower north-south depth can allow for deeper solar penetration, and better facilitates increased south window area. The aspect ratio, a common metric used to describe building geometry, is the equatorial facing façade length divided by the perpendicular façade length. Chiras (2002) recommends an aspect ratio of 1.3 to 1.5, and Athienitis (2007) claims an aspect ratio of 1.2-1.3 is optimal.

Jones (1992) provides a detailed overview of thermal storage in passive solar buildings. Sensible heat storage is the most common and least expensive method for storing heat gains in passive solar buildings (Jones 1992). Sensible heat storage is commonly referred to as thermal mass. Materials with high specific heat capacity, density and conductivity are desired; with water, stone, concrete and masonry being the best performing options for thermal mass. Latent heat storage in phase change materials present another option, but are not yet widely available. Johnson (1981) recommends sizing thermal mass based on the diurnal heat capacity, a measure of heat storage and release over a daily cycle. For concrete the maximum occurs at 200 mm for mass exposed to direct sun. However, the diurnal heat capacity when the mass is not directly exposed to sun reaches a maximum at 75 mm. When using concrete for thermal mass, little additional benefit is achieved with thickness greater than 100 mm (Jones 1992). Covering concrete floors with carpet reduces the effectiveness of thermal storage by approximately 50%.

Early studies found effectiveness of thermal mass was not very sensitive to the surface solar absorptance (Jones 1992). Light coloured thermal mass is desirable as it reflects a higher portion of solar radiation onto other surfaces, increasing the effective surface area of mass, and enhances daylighting (Johnson 1992). Johnson (1992) illustrates this with the following example; for a building with off-white walls (solar absorptance of 0.2) and glazing area equal to 25% of the floor area, only 12% to 18% of the incoming solar radiation escapes. Multiple reflections and absorptions cause a typical room in a building to behave like an optical cavity.

2.1.3 Recent Passive Solar Literature

As discussed in Section 2.1.1, passive solar literature was prolific during the mid 1970's through to the mid 1980s. After this period, relatively few studies were published, however publications on passive solar have recently been increasing.

Hastings (1995) reviewed assumptions which are often incorrect yet remain used in passive solar design. One notable example is the assumption that passive solar is less feasible in northern or overcast climates. However, in such locations solar gains are typically better utilized by offsetting heating energy consumption without causing overheating (Hastings 1995).

Athienitis (1997) studied the interaction of radiant floor heating in direct gain passive solar heated buildings, concluding that control based on operative temperature results in increased thermal comfort and utilization of passive solar gains. Littlefair (1998) reviewed a range of tools and techniques to predict solar access in dense urban areas, in addition to methods for protecting solar access of existing buildings, most of which are based on sun angle. A largely unshaded site is essential to effective passive solar design. Simulations done for low and medium density housing developments, suggested passive solar savings diminish to less than half for non-ideal site layouts (NBA Tectonics 1988, cited in Littlefair 1998).

O'Brien et al. (2008) introduced the concept of design days for passive solar design, where specific days of interest for thermal performance and comfort are investigated in detail during the design process. These days include a cold cloudy (winter), cold sunny (winter), and a warm sunny day (shoulder season). Passive solar design was a key feature of the Alstonvale Net Zero Energy House, near Montreal, which was expected to achieve a passive solar heating fraction of approximately 60% (Candanedo and Athienitis 2009). Although this house went through design analysis, it was destroyed by fire shortly after construction; therefore no measured passive solar performance data exists. However, the simulation results indicate that passive solar continues to a promising energy saving feature in modern energy efficient homes. Chan et al. (2010) reviewed passive solar heating and cooling technologies, including Tombe walls, passive solar air heaters (SolarWall), solar chimneys, and double facades - technologies beyond the scope of the research presented here.

Hachem et al. (2011a) investigated passive and active solar potential for various geometric configurations of a two storey single-family dwelling, using simulation for Montreal. They estimate the mean incident solar radiation on south facing glazing units, and the reduction of solar radiation that occurs with various complex geometries such as L, H, and T shapes and a trapezoid. Hachem et al. (2011b) investigated parameters influencing the total solar potential of solar housing units in different neighborhood designs. Their study found that some complex geometries can provide higher potential for electricity generation, although this comes with a reduction in passive solar heating potential. Reductions in passive solar heating potential were calculated for various layouts and building geometries, and a methodology is presented to evaluate the solar potential of various neighborhood configurations. O'Brien et al. (2011) studied sensitivity of thermal zoning and interzonal airflow for modelling the energy performance and comfort of passive solar buildings. They conclude that assumptions for thermal zoning and interzonal airflow can have a significant impact on energy consumption and thermal comfort predictions.

2.1.4 Quantification of Passive Solar Energy Savings in Canada

Few studies have quantified the potential energy savings from passive solar across Canada. In 1984, EMR Canada studied energy efficient housing and solar orientation. They found that it is generally feasible to design new subdivisions so that a majority of lots have adequate solar exposure for passive solar, at little or no extra cost for land or services. Passive solar energy savings for increased south window area were quantified relative to a south facing baseline house. EMR Canada predicted of 7.3% and 7.5% in Edmonton and Toronto, for envelope insulation levels slightly lower than typically employed now in most Canadian climates. With much higher insulation levels, they estimated savings of 11.9% to 13.8% for Edmonton and Toronto respectively. Their study was limited to a monthly heat balance method, and did not include thermal storage, and limited temperature fluctuations to 2.75˚C, using ventilation to prevent any overheating.

More recently, CMHC (1998) quantified passive solar savings for a variety of house designs for several Canadian climates; Vancouver, Ottawa and Winnipeg finding solar heating fractions ranging from 13% (Winnipeg) to 67% (Vancouver), depending on the house design. CMHC defines the solar heating fraction as "the ratio of the useful solar gains to the house's annual heating consumption, calculated as if these gains were not present" (CMHC 1998 p.44). The details of the simulation methodology used is not described, however the DOE-2 simulation program was used. The DOE-2 program was developed during the 1990s. Recent simulation programs such as EnergyPlus feature more sophisticated simulation techniques, including sub-hourly timesteps (up to 60 per hour), and have undergone many revisions. Sub-hourly timesteps are essential to capturing the interactions with thermal mass, an important feature of advanced passive solar designs.

2.2 The Canadian Center for Housing Technology

The analysis for this thesis research was based on the Twin Houses at the Canadian Centre for Housing Technology (CCHT) site, which are architecturally representative of typical tract-built houses in Canada (CCHT 2010). One of the Twin Houses, referred to as the Reference House, remains unchanged and is used as a baseline for experiments carried out in the other house. The Twin Houses were built to the current version of the R-2000 standard in 1998, a voluntary energy performance standard in Canada (the R-2000 standard was updated in 2005 and 2012 (NRCan 2012)). The CCHT Reference House has insulation levels comparable to most current provincial building codes. In addition, the building has a relatively high air tightness rating (1.5 ACH@50) and uses a heat recovery ventilator. In order to ensure the Twin Houses are as identical as possible, they include simulated occupants, rather than real human occupants. A building automation system turns on and off appliances, hot water fixtures and lights according to a schedule, which represents a typical family of four. Light bulbs are used to simulate the heat released from occupants. The automated internal gains were based on a target electricity consumption of 20 kWh/day, a common input value used for simulation studies (Swinton et al. 2001).

Numerous studies have been carried out at the CCHT, primarily relating to energy conservation and include thermostat setback (Manning et al. 2007), electronically commutated furnace fan motors (Gusdorf et al. 2001), and combined heat and power systems (Swinton et al 2004).

Several studies related to passive solar have been carried out at the CCHT. Laouadi (2010) developed guidelines for solar shading devices based on research at the

CCHT, and also evaluated the heating and cooling energy savings of insulated exterior roll shutters, finding a heating energy savings of 7%. Gusdorf et al. (2011) studied the performance of summer awnings at the CCHT. Manning et al. (2008) compared the effect of high and low solar heat gain windows on heating and cooling energy consumption. Energy consumption as well as air temperatures and transmitted solar radiation were measured for a period of 28 days during January and February. Measured energy consumption differences were extrapolated, finding a predicted increase in furnace gas consumption of 10% when low solar heat gain windows were used, despite the lower solar heat gain windows having a slightly lower U value (1.62 W/m^2K compared to 1.76 W/m^2K). The heating energy savings from the high solar gain windows were found to be three times larger than the summer cooling energy savings from the low solar gain windows (their experiment did not employ any free cooling, therefore cooling energy is overestimated compared to an occupied house). Manning et al. (2008) suggest the need for calibrated simulation to extrapolate results from such experiments to predict energy savings for a wider range of climatic conditions.

2.3 Calibration of Whole Building Energy Simulation Models

The literature on calibrating building simulations to match measured data, focuses on the commercial sector (for a review refer to Reddy 2006). Calibration of commercial building models often involves "fine tuning" the parameters which have a high level of uncertainty, until a sufficient match is achieved between recorded and simulated energy consumption.

Calibration literature for residential single family dwellings is very limited. Judkoff et al. (1983) present a validation methodology aimed at simulation programs (as opposed to models), using three types of validation; inter-program comparison, analytical tests, and empirical validation. In this thesis the term ‘empirical validation’ is referred to as calibration. Judkoff et al. (1983) compared measured thermal performance in the SERI passive solar test house to simulation results from the DOE-2.1, BLAST-3.0, and SERIRES-l.0 simulation programs. Several important conclusions from their work are as follows:

- standard engineering assumptions for input (such as conductivity values from ASHRAE) can introduce prediction errors of 60%
- accurate temperature prediction does not ensure accurate load prediction
- even after measured data was used to eliminate most uncertainties, errors of 10% to 17% were still found, most of this they attribute to solar over prediction (these programs used the isotropic sky assumption)
- a validation methodology should account for hidden compensating errors.

More recently, Meldem and Winklemann (1995) calibrated the DOE-2 with measurements in the Pala Test Houses, passive solar test houses in California. They found excellent agreement between simulated and measured air temperatures for unconditioned low and high mass houses, ranging from 0.1 to 1˚C. Their high mass house has 100 mm of concrete added to the interior all exterior walls, and 100 mm concrete interzone partitions. These houses featured modest insulation compared to current Canadian standards, with a total thermal resistance for the walls of 1.79 W/m^2K.

3. Problem Definition

3.1 Objective and Justification

The objectives of this research are as follows:

1. To create a calibrated energy simulation model of a typical Canadian house.

2. To contribute to the quantification of the potential energy savings from passive solar design, for a broad range of Canadian climates.

This research will provide an update to earlier work which is now out dated due to advances in simulation software and changes building technology including advancements in window technology. The most thorough quantification of passive solar energy savings in Canada (CMHC 1998), only evaluated three climates. This research will provide a rigorous quantification of passive solar energy savings for eight locations, representing a broad range of Canadian climates.

3.2 Research Questions

The research questions for this thesis are as follows:

1. Which simulation parameters have the most influence on the accuracy of modelling the heating energy consumption of passive solar houses?
2. What are the energy savings for a typical Canadian tract house if passive solar design features are maximized?
3. What is the contribution that passive solar energy makes to the heating requirements of a typical Canadian tract house on a non-shaded site?

4. What level of energy savings can be achieved for a typical Canadian tract house redesigned according to passive solar guidelines and energy efficiency principles?

3.3 Scope

The scope of this research is limited to direct gain passive solar design. Direct gain is the considered simplest and most-cost effective passive solar design strategy (CMHC 1998). It is expected that the predicted energy saving from direct gain would be of similar magnitude to the energy savings to any of the other common passive solar strategies, such as: sunspaces, indirect gain (trombe wall variations), because results of a large scale monitoring project of 48 passive solar houses throughout the US showed no noticeable difference between the performance of the various passive solar strategies (Balcomb 1983). This study focuses on single-family dwellings, which are the most common dwelling type in Canada (NRCan 2011). Potential energy savings from passive solar is explored on a per house basis, assuming full solar access. Eight locations were selected for modeling to represent the range of Canadian climates and population centres: Vancouver, Prince George, Yellowknife, Edmonton, Winnipeg, Toronto, Ottawa, and Halifax.

The study is limited to houses heated with gas furnaces, as the reference house chosen is gas heated (the practical relevance of this limitation is that over 50% of Canadian houses use gas furnaces (NRCan 2011)). However, it is expected that the resulting heating loads would be similar for electrically heated houses provided that a means of mechanically driven air circulation is included (eg. ducted HRV). Any difference in air circulation and interzonal heat transfer would need to be considered when extrapolating the results from this study, as increased air circulation between zones results in better utilization of solar heat gain.

The analysis in this research is primarily limited to space heating energy consumption. Space cooling represents only 1.6% of total residential energy consumption in Canada (based on 2008 data, from NRCan 2010). Although this is a very small portion nationally, space cooling can be much more significant in specific climate locations in Canada and for some house designs, specifically those with large east and west facing windows or very large south facing windows. Summer overheating issues are not considered in this research because south facing windows can be shaded during the summer with shading devices such as awnings or roll shutters (Laouadi 2010) or other passive cooling measures. Overheating during the heating season is dealt with through passive ventilation at a zone level, during periods when the zone is occupied.

3.4 Methodology

This research uses calibrated whole building simulation to quantify passive solar energy savings.

3.4.1 Whole Building Energy Simulation with EnergyPlus

Building simulation has been credited with supporting building design optimization in addition to facilitating more detailed design analysis (Augenbroe 2002). Hundreds of simulation programs have been developed over the 50 year history of energy simulation (Crawley et al. 2008).

Some simpler simulation programs are based on a steady state monthly heat balance, for example HOT-2000, which is still widely used in Canada (NRCan 2008).

These simple steady state programs do not allow for accurate assessment of usable solar gains, especially for advanced buildings with high levels of insulation and increased thermal mass (Kisilewicz 2007). More advanced programs, such as EnergyPlus, use sub-hourly timesteps and can more accurately capture the behaviour of transient interactions such as heat storage in building surfaces (thermal mass).

EnergyPlus was chosen as the simulation platform due to its accuracy, flexibility and high level of input detail. EnergyPlus is a dynamic simulation program developed by the US Department of Energy and its partner agencies. It uses an integrated, modular simulation approach and a time step computation technique (Crawley 2004). EnergyPlus has been tested extensively and validated using standardized building energy simulation test methods (Crawley 2004, Hennigner and Witte 2007), and has been used in several passive solar studies (eg. O'Brien et al. 2011, Mirithane and Vale 2006, Hachem et al. 2011a,b).

With exception to the calibration, all simulations were carried out using Canadian Weather for Energy Calculations (CWEC) weather data, which is based on data from 1953 – 1995 and represents a "typical" weather year (Numerical Logistics 1999). Using historical weather data introduces potential error in the quantification of future energy savings due to changing climate trends, however to the best of the author's knowledge there is no standardized technique for including climate projections in energy simulations at this time.

3.4.2 Calibrated Simulation

A calibrated simulation model was created for a typical Canadian tract house with basic passive solar features. This model was used to evaluate the energy savings from this type of building in other Canadian climates. In addition the calibrated model formed the basis of the simulation models used to evaluate other passive solar measures. This approach allows for energy savings to be quantified from measured energy consumption data with a reasonable level of accuracy without requiring a full-scale experiment. Also, the analysis can be extrapolated to predict energy savings in other climates and with variation in design parameters. Calibration of the simulation model is essential to ensure that the results are accurate, especially when simulating changes in design parameters. It is particularly important that errors are minimal for the sub models related to the design parameters of study, as these errors can become magnified. For example, the over-prediction of solar heat gain through windows could double when the window area is doubled.

Calibration of building simulation models involves the "fine tuning" of parameters, which have a high level of uncertainty, until a sufficient match is achieved between recorded and simulated energy consumption. These parameters are varied over a range of possible or realistic values. However, simply matching simulated to measured annual energy consumption does not necessarily mean that a model is sufficiently calibrated. Further analysis is required to ensure that the match in annual data is not by chance. Error and uncertainty is unavoidable in the simulation model and simulation program. If there are errors which considerably overestimate and underestimate components of the energy balance, then the model may not be accurate enough for a given research project even though the simulated and measured annual energy consumption match. Therefore, simulation results must be compared to measured data at a resolution higher than annual consumption data.

ASHRAE provides guidance for the calibration of building energy simulation for the purpose of energy saving calculations in Guideline 14 (2002). This guideline suggests the use of two statistical metrics, the coefficient of variation of the root mean square error (CV(RMSE)) and the normalized mean bias error (NMBE). The CV(RMSE) and NMBE are calculated as shown in Equations 3-1 to 3-4.

CV(RMSE) = RMS (Error) / Average Measured Energy Consumption **(3-1)**

NMBE = $\sum$ Error / [Average Error * (n -1)] **(3-2)**

Where:

Error = Measured Energy Consumption – Simulated Energy Consumption **(3-3)**

computed for data points 0 to n.

RMS (Error) = $\{\text{Average }(\text{Error}^2)\}^{1/2}$ **(3-4)**

Guideline 14 (2002) specifies that in order to declare a model calibrated, the CV(RMSE) should be within +/- 30% using hourly data, or +/- 15% using monthly data and that the NMBE should be within +/-10% (hourly) or +/-5% (monthly). ASHRAE does not provide guidance on calibrating with daily values. Therefore, the daily calibration requirements were assumed to be the average of monthly and hourly, thus the maximum CV(RSME) target used in this research is 22.5% and the maximum NMBE target is 7.5%. ASHRAE (2002) prefers the use of hourly data for calibration to monthly as higher resolution data can provide more insight into the source of inaccuracies.

Daily data was available for an entire heating season for the CCHT Reference House. This was the primary justification for the use of daily calibration in this research.

Microsoft Excel™ was used for calibration calculations and to graph the measured daily furnace gas consumption against the simulated data for comparison. Passive solar energy savings vary over the heating season, therefore it was desirable that calibration is based on an entire heating season.

3.4.3 Metrics for Assessment

Solar heat gain contributes to the heating requirement of nearly all houses. This can include direct, ground, or sky reflected solar gain through windows, or solar gain elevating the exterior surface temperature of the building. This can lead to confusion when discussing the energy savings from passive solar and brings into question what is an appropriate baseline scenario to use.

The term solar fraction is often used in literature pertaining to both passive and active solar. The solar fraction is a standard metric in the active solar field and is defined as the fraction of the load met by solar. For direct gain passive solar, the solar fraction can be ambiguous because the heating load changes with increased window area. Two more precise metrics that have been used to describe the contribution of solar gains to the energy balance of a building are the solar heating fraction (SHF) and solar savings fraction (SSF) (Jones 1992).

The SSF is the fractional energy savings relative to "a similar non-solar building." Jones (1992) describes the most precise definition to this baseline being "a conventional building that satisfies the same architectural program as does the solar building but that has no solar collection area beyond the normal complement of windows" (Jones 1992, p.237). However, a simpler definition which is widely accepted is a building "in which the passive solar heating apertures are replaced by perfectly insulated walls" (Jones 1992, p.237).

The SHF has a less ambiguous definition. It is defined as the fractional energy savings relative to the heating energy requirement of the building for a scenario where there is no solar heat gain through the solar heating apertures, but there is heat loss through these apertures (Jones 1992). This is equivalent to the solar apertures being fully shaded. For this research the SHF metric is used because its definition is more precise than that of the solar savings fraction. In addition the SHF is more commonly used in closely related literature (eg. CMHC 1998).

The solar heating fraction was determined for each design scenario by also simulating a duplicate scenario were the solar gain is effectively switched off by setting the solar transmittance of the outer glazing layer to zero, and reflectance to 99.9%. This scenario, referred to as 'shaded' is then used to calculate the percent reduction in space heating energy consumption due to solar gain. This can be formulated as follows:

$$SHF = (E_{Shaded} - E_{Unshaded})/(E_{Shaded}) \quad \textbf{(3-5)}$$

4. Calibrated Simulation Model

This chapter describes the calibration of the reference case model to measured data from the CCHT Reference House. The reference case model was calibrated using measured daily gas consumption data from the CCHT Reference House for the 2002/2003 heating season and a validated weather file (AMY) from Weather Analytics which is based on real data from nearby weather stations and climate model data (Keller and Khuen 2011). Measured foundation temperature data was used to calibrate the ground heat transfer model, which produces average exterior foundation temperatures. Temperature data was also used as a constraint when adjusting furnace airflow to slave zones.

4.1 Overview of the Calibration Process

Calibration is defined not only by good agreement between simulated and measured heating energy consumption for an annual period, but also by agreement at a finer temporal resolution. In this case, daily comparisons were deemed to be most appropriate. In addition to matching heating energy consumption, which is the main parameter of interest, simulated temperatures are matched with measured data wherever possible. All model input parameters were tested parametrically to determine their significance. Significant input parameters are based on known or measured data wherever possible, or best assumptions available from literature review (uncertain parameters are used in the final stage of calibration).

As the CCHT houses undergo extensive research, data was available to define most major modelling parameters, such as internal gains, measured furnace efficiency, and actual furnace fan flow rate. A principle focus of the calibration process involved systematically identifying and fixing minor errors, and adding more detail to components of the model that had a significant effect on the annual heating energy consumption. The calibration procedure is a highly iterative process. Throughout this process parameters with a high level of uncertainty are noted. These ‘adjustable’ parameters are later used in the “fine tuning” stage, by varying their input values within the range of uncertainty to achieve a better match in heating energy consumption. Such ‘adjustable’ parameters included the furnace airflow rates to each zone, wind driven infiltration parameters, the monthly basement air temperature profile assumption (used the by the *Basement* program) and the soil properties. An overview of the calibration processed developed and used for this research is shown in **Error! Reference source not ound.**.

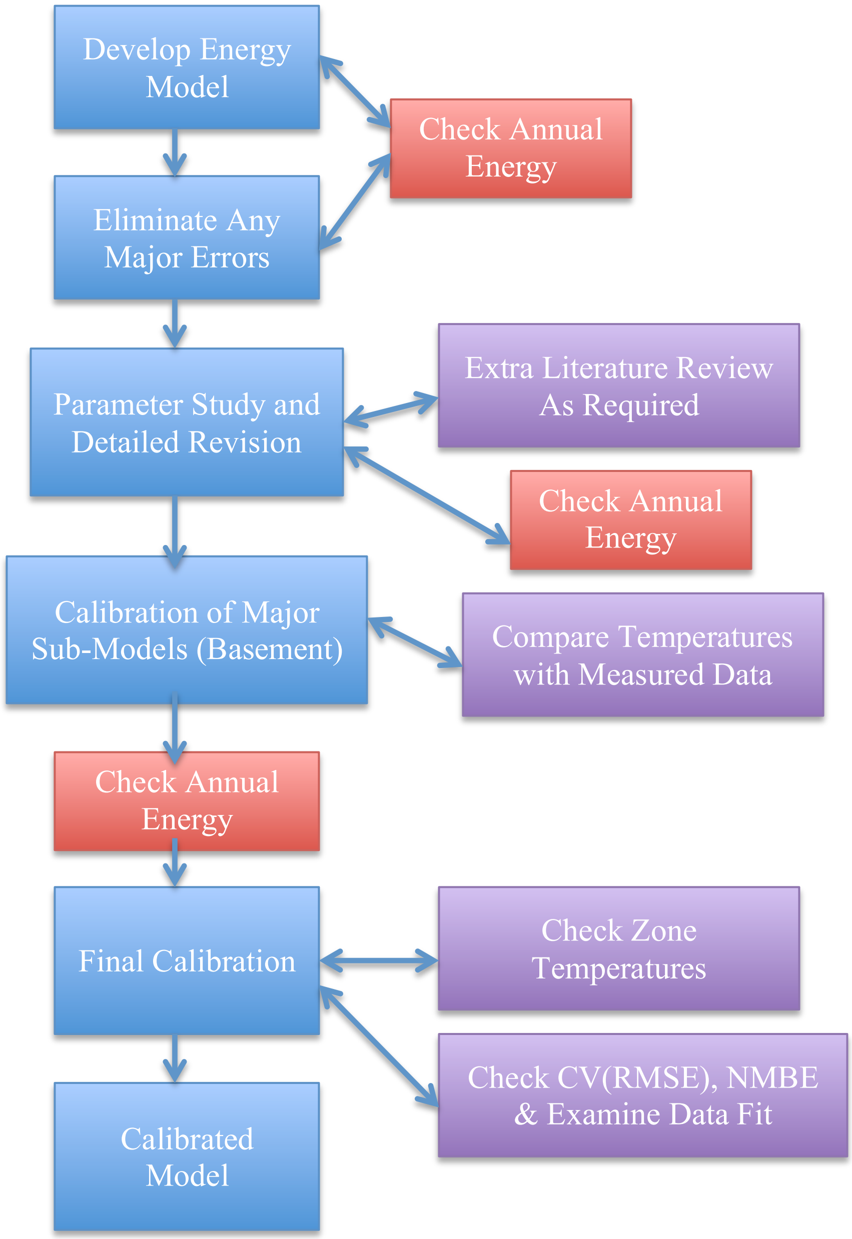

Figure 1: Calibration Process

Three versions of the model are discussed throughout this chapter: the first version was a single zone model (one living space zone, and separate basement, attic and garage zones) described fully in a preliminary version of this research (Zirnhelt and Richman 2011), secondly a more detailed single zone model was created, and the final version of the model is a detailed multi-zone model featuring a more sophisticated solar distribution, interzonal airflow, and many minor revisions. EnergyPlus has undergone several revisions over the course of this thesis research, the first single zone model was created using version 6.0, for the second model version 7.0 was used, and version 7.2 was used for the final model.

4.2 Description of the CCHT House

For this research, a detailed calibrated model of the CCHT Reference House was created in EnergyPlus and used as a reference case for the passive solar design options considered. The architecture of the CCHT houses is shown below in Figure 2. It includes a double car garage and a heated basement. The design includes many jogs and a complex roofline – features that are common in new construction in North America, but not ideal for low energy design.

Figure 2: CCHT Twin Houses View From South East (CCHT 2010)

Important features of the CCHT houses are summarized below in Table 1.

Table 1 - Key Features of the CCHT Twin Houses

Feature	Value
Floor Area (Living Space)	208 m^2
Total Window Area	35 m^2
South Facing Window Area	16.2 m^2
Window Type	double glazed, low-e, argon filled, insulated spacer
Window Properties	SHGC = 0.52[a], U = 1.76 W/m^2K
Attic R Insulation R Value	8.08 m^2K/W[b]
Above Grade Wall Insulation R Value	2.61 m^2K/W – walls without windows 2.36 m^2K/W – walls with windows
Basement Interior Insulation R Value	1.75 m^2K/W
Basement Slab	75 mm concrete, un-insulated
Air tightness rating (at 50 Pa)	1.5 ACH
Gas Furnace Efficiency	80.2%
Heat Recovery Ventilator Efficiency	84%
Internal Gains	19.35 kWh/day

[a] Overall window properties, including frame

[b] R values include thermal bridging

The floor plan for the CCHT house is shown in Figures 3 and 4.

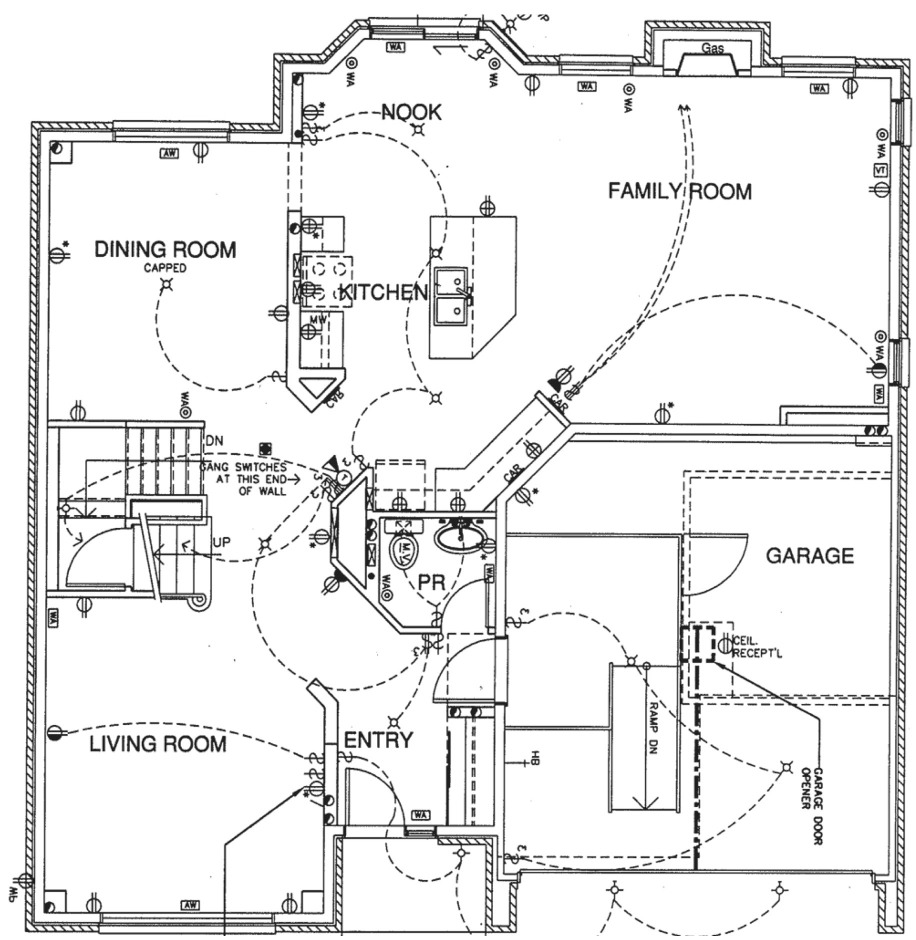

Figure 3: CCHT Twin Houses First Floor (Minto 1998, from M. Armstrong email communication)

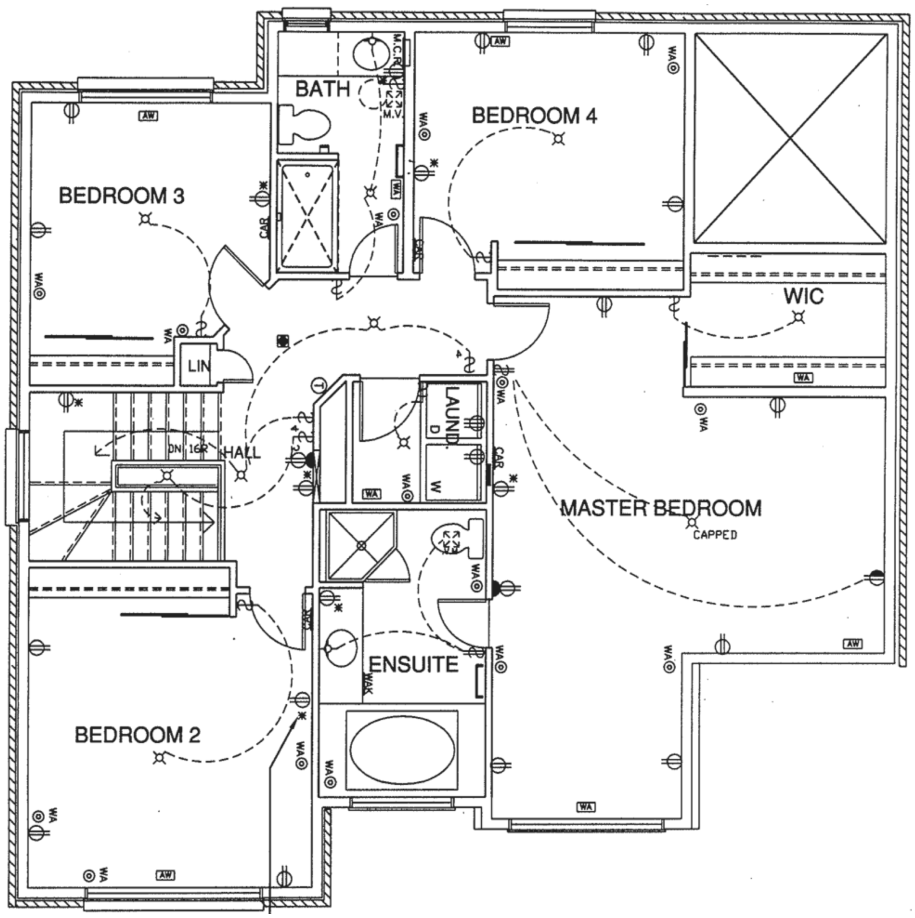

Figure 4: CCHT Twin Houses Second Floor (Minto 1998, from M. Armstrong email communication)

4.3 Important Sub-Models

4.3.1 Geometric Representation and Thermal Zoning

The geometric representation of the CCHT Reference House is based on the as-built drawings provided by M. Armstrong (email communication May 2011). Walls are not represented by any physical thickness in EnergyPlus. According to the EnergyPlus Engineering Reference Manual (2012) the choice of interior, exterior or centred dimensions has little impact of the simulation model. Dimensions to the exterior of the thermal envelope were used, rather than to the exterior of the rain screen brick veneer.

Minor geometric simplifications were made to reduce the number of surfaces modelled without reducing the building's surface area, such as shifting some of the minor inset wall elements outwards to combine with the surrounding walls. This was primarily done on the North façade, where the impact on solar gain would not be affected significantly. The as-modelled geometry is shown in Figure 5.

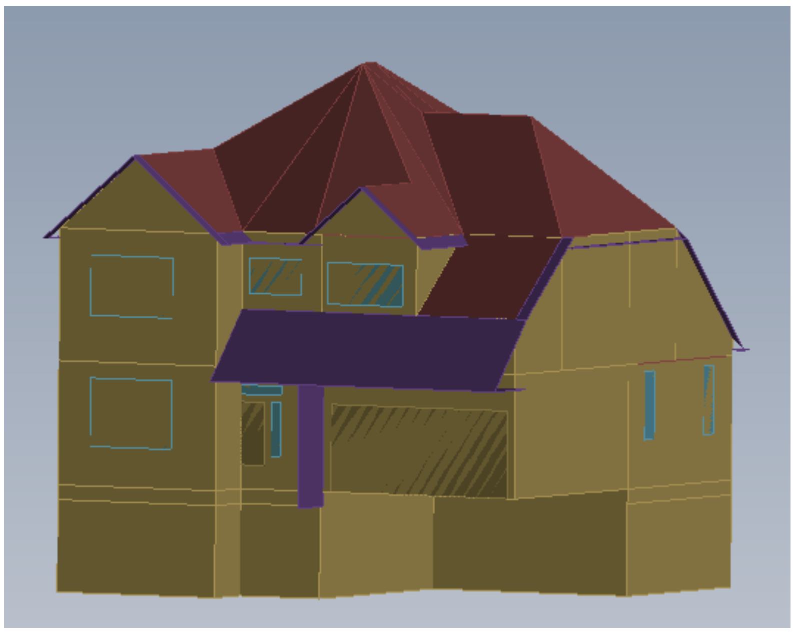

Figure 5: CCHT As Modelled - Isometric View From South (Note – Ground Plane is Not Shown)

The purple surfaces shown in Figure 5 (above) are shading surface. These surfaces also reflect solar gain, therefore reflectance values were assigned as described in Section 4.3.6.

Originally the CCHT Reference house was modelled as four zones, with the entire living spaced modelled as one zone (referred to in this research as single zone) . The basement, which is heated, was modelled as a slave zone (further described in Section 4.3.8). The garage and attic were the remaining two zones, which are unheated.

For the final version of the model, the living space was divided into multiple zones for the following reasons:

1. To allow for the use of the interior solar distribution option, which requires zones to be convex (defined by a straight line passing through the zone not intersecting more than two surfaces).
2. To account for temperature differences between zones, to allow for potential overheating can be more accurately quantified, and to improve the accuracy of the heat balance.
3. To allow for the addition of passive ventilation at the zone level, linked to the occupancy schedule to limit overheating during the heating season (further described in Section 5.2.3).

Thermal zoning is often considered to be an 'art' (O'Brien et al. 2011). No standardized procedure exists for defining the number or location of thermal zones. However, a five zone model is generally considered sufficient for accurately predicting the energy consumption and assessing the potential for overheating in passive solar houses (O'Brien et al. 2011). For the baseline model eight heated zones were created in order to satisfy the non-convex zone requirement of the interior solar distribution. Two zones on the second floor (South 2b and 2c; refer to Figures 6 and 7) were modelled effectively as one zone by defining a high air exchange between them (1 m^3/s.) These zones are connected by large openings, but did not satisfy the non-convex zone requirement unless modelled as separate zones. The building was divided into zones by floor level, and along major partition walls were possible. When determining zone boundaries, consideration was given to the size of openings between spaces. The south of the building was divided into more zones, due to the higher expected temperature variations due to the solar exposure. Figures 6 and 7 below show the final CCHT floor plan as modelled, and the thermal zoning.

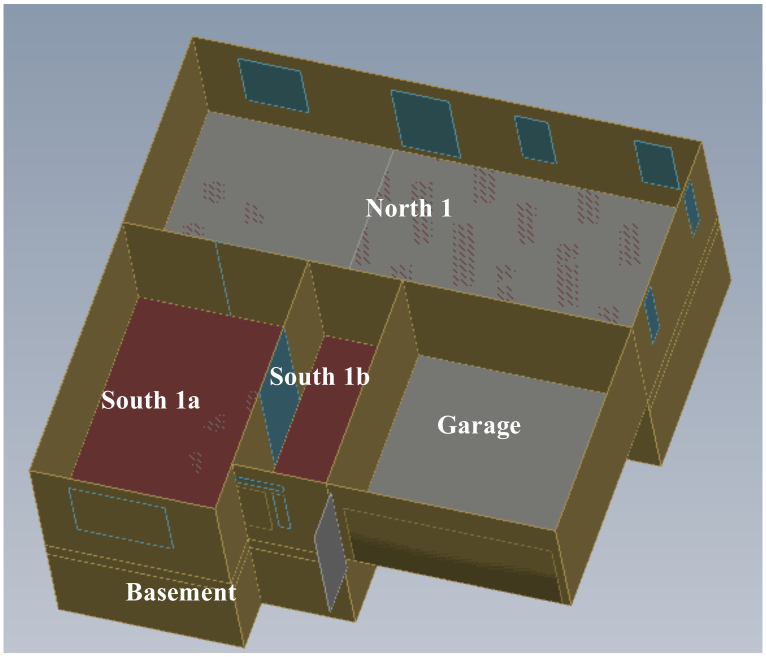

Figure 6: Final CCHT Zoning First Floor

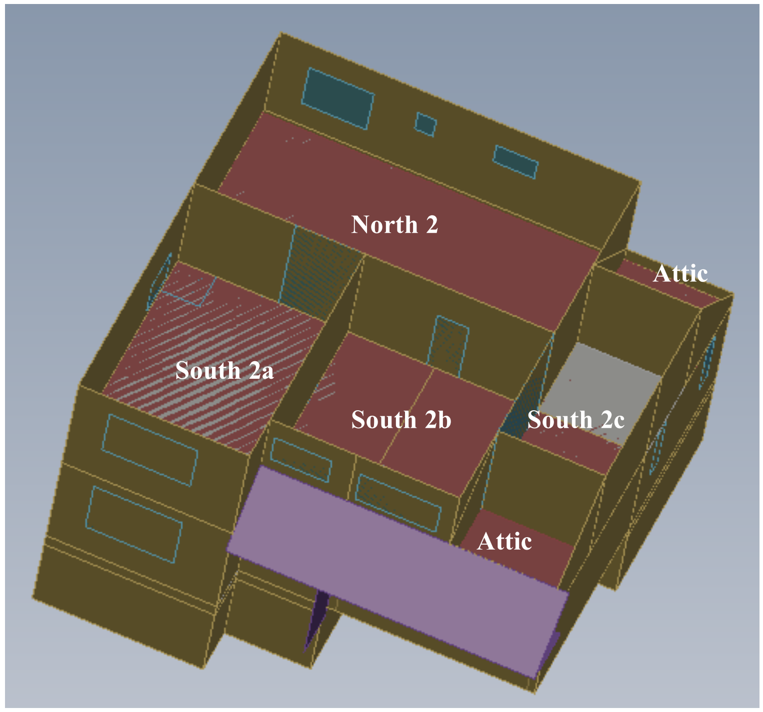

Figure 7: Final CCHT Zoning Second Floor

EnergyPlus will automatically calculate the zone air volumes based on the input geometry, however the actual zone air volumes are often much smaller due to the space occupied by partition walls, furnishings, and exterior walls if geometry is input based on exterior dimensions. For the multi-zone model a 0.6% difference in predicted furnace gas consumption was observed when manually calculated zone volumes were entered (including all walls, and approximate values for included furnishings such as counters, appliances etc.).

4.3.2 Construction Assemblies

Figures 8 to 10 show typical envelope construction assemblies used in the CCHT house. Wall insulation is fiberglass batt, and ceiling insulation is blown cellulose.

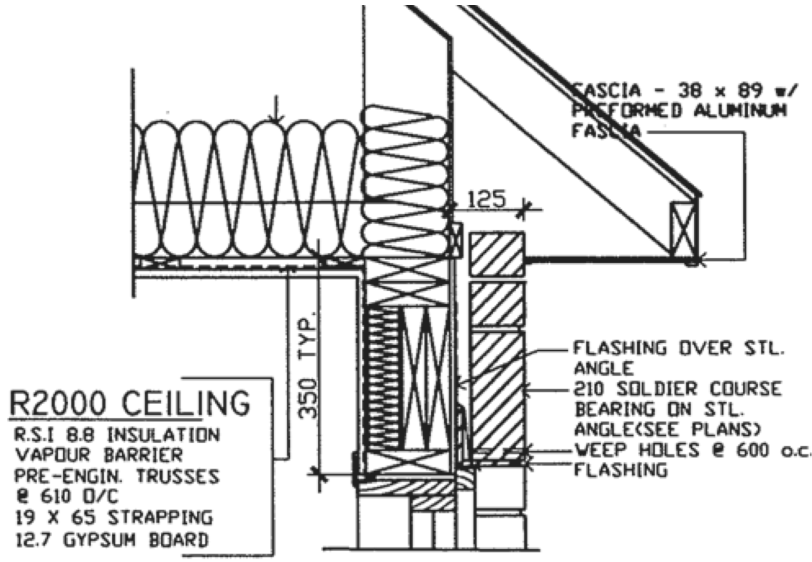

Figure 8: Ceiling and Window Header Detail (Minto 1998, from M. Armstrong email communication)

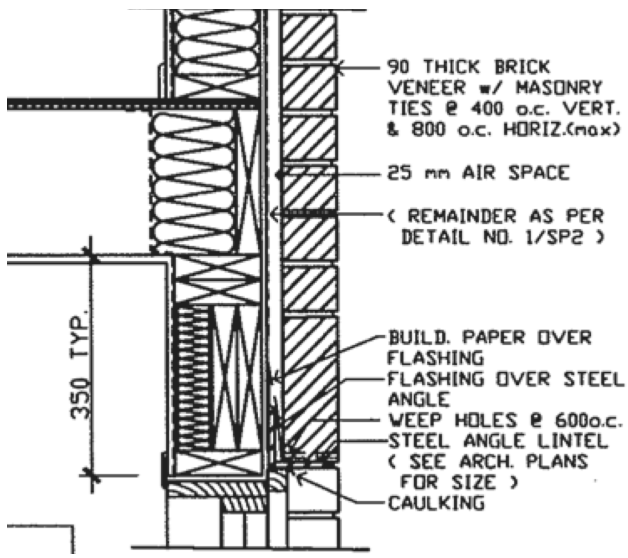

Figure 9: Wall and Second Floor Junction Detail (Minto 1998, from M. Armstrong email communication)

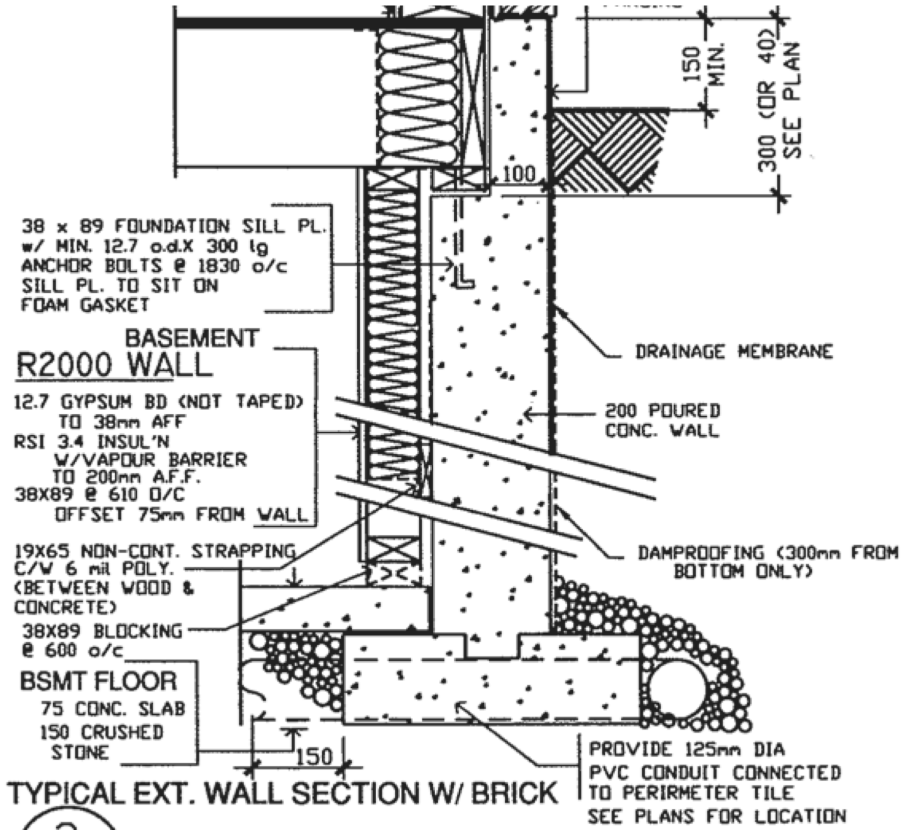

Figure 10: Below Grade Wall Detail (Minto 1998, from M. Armstrong email communication)

All materials were modelled using average input parameters from ASHRAE (2009 F.26) for density, specific heat capacity and thermal conductivity. Using ASHRAE's values led to lower calculated thermal resistance values than the nominal overall values listed in the project drawings; it is expected that the lower values are more realistic of field conditions, whereas the values given in the drawings are likely based on manufacturer's data from laboratory testing. Density and heat capacity originally were modelled using values for fiberglass insulation, however in the final model an area weighted average for fiberglass and wood framing was used. The vented exterior rain screen cavity and the drained interior foundation cavity were both modelled as an air gap with simple thermal resistance (and no thermal mass), which was assumed to be 50% less than that of a sealed cavity. This approach is recommended by BRANZ (2004).

Interior partitions in the CCHT Houses are typical hollow stud walls. The partition walls were originally modelled as two sheets of gypsum drywall separated by an air cavity. For the final version of the model the properties at the centre of the partition wall assembly was entered as an area weighed average of the properties for wood framing and air for 15% framing. This allowed for the thermal mass of the studs to be included in the model. This changed the predicted heating energy consumption by only 0.1%.

Thermal bridging through the wood framing members was accounted for by calculating a one dimensional area-weighted equivalent heat transfer coefficient by combining the thermal resistance of the framing with the insulation in parallel according to the Isothermal Planes method (ASHRAE 2009 F.27.3). This is formulated as follows:

$$U_{eff} = U_f \text{ x } (A_f / A_w) + U_{ins} \text{ x } (A_f / A_w) \quad \textbf{(4-1)}$$

This is then converted into a thermal conductivity value for input into EnergyPlus. Two-dimensional edge effects were neglected. Thermal bridging was accounted for in all major construction assemblies, with the above grade walls divided into walls, with windows and without – to account for extra framing members required around windows. The fraction of framing for each wall type was based on a representative wall of each type, and a framing diagram created using stud spacing from the 'as built' drawings assuming standard framing techniques. All framing members were taken into account (studs, cripples, jacks, double top plate, single bottom plate and corner posts). Only accounting for studs when calculating the fraction of thermal bridging, could lead to severe underestimation. For example, the framing fraction if only typical vertical studs are considered is 9.5% (for the CCHT stud spacing of 400 mm.) However, using the more detailed approach, described previously, results in significantly higher framing fractions, as shown in Table 2 below.

Table 2 - Thermal Resistance Values with and without Thermal Bridging

Assembly	R value- insulation (m^2K/W)	Thermal bridging	R value - insulation & framing (m^2K/W)
Wall with windows	3.22	23.2%	2.61
With no windows	3.22	15.1%	2.36
Below grade wall	2.06	11.1%	1.75
Attic	8.80	6.3%[a]	8.08

[a] Attic thermal bridging is only in 225 mm of 368 mm

During updates made in the final model, a calculation error was discovered related to the percent thermal bridging for the walls with windows. This value was changed from 15.5% to 23.2%, and lead to a 3.9% increase in heating energy consumption, highlighting the sensitivity of thermal bridging.

4.3.3 Conduction and Thermal Storage Algorithm

Thermal storage is an essential component of passive solar design. Conductive heat flow through thermally massive materials exhibits dynamic behaviour, which must be accurately modelled to assess the effectiveness of most passive solar designs. The most commonly used computational method for modelling transient thermal conduction is the conduction transfer function (CTF). Recently, other options for modelling conduction have been added to EnergyPlus, such as the finite difference method and a combined heat air and moisture algorithm.

The conduction transfer function is based on the basic time series approach, known as the response factor equation, which relates heat flux at a surface of an element to an infinite series of temperature histories at both sides of the element. The conduction transfer function solves the time series equation by replacing the higher order terms with flux history terms. The basic conduction transfer function solution is shown below in Equation 4-2 (EnergyPlus Engineering Reference 2012).

$$q''_{ko}(t) = \sum_{j=0}^{\infty} X_j T_{o,t-j\delta} - \sum_{j=0}^{\infty} Y_j T_{i,t-j\delta} \tag{4-2}$$

Where X, and Y are the response factors, which are solved in EnergyPlus with the state space method. The state space method has been shown to be within 1% of an analytical solution for heat flux at the surface of slab (EnergyPlus Engineering Reference 2012). During final calibration, the conduction finite difference solution algorithm was tested and compared to the CTF algorithm. The impact on the heating energy consumption was negligible (approximately 0.01%), however simulation time increased to over one hour from approximately seven minutes.

4.3.4 Window Model

Windows are an essential component of a passive solar building. It is essential to accurately model the solar heat gain through them, in addition to the conduction-based heat loss and/or gain. Window heat loss can be a large portion of the heat balance, especially for designs with increased window area.

There are two main options for modelling windows in EnergyPlus. The simple window model only requires the U value and SHGC for input, whereas the detailed model requires transmittance, reflectance and emissivity data for each layer. The simple window model generates a single layer window using the U value and SHGC ratings. The simple model was used for the first version of the study (Zirnhelt and Richman 2011). The detailed window model was used for the second version of the single zone model. For the reference case, a quadruple pane window was used to test the window modelling options in EnergyPlus, an 11% reduction in predicted furnace gas consumption (for January) occurred when the detailed model was used.

The detailed window model uses spectral average data from WINDOW or OPTICS (LBNL n.d.). The input data for the optical calculations are as follows:

- Solar Transmittance at Normal Incidence
- Front Side Solar Reflectance at Normal Incidence
- Back Side Solar Reflectance at Normal Incidence
- Visible Transmittance at Normal Incidence
- Front Side Visible Reflectance at Normal Incidence
- Back Side Visible Reflectance at Normal Incidence
- Infrared Transmittance at Normal Incidence
- Front Side Infrared Hemispherical Emissivity
- Back Side Infrared Hemispherical Emissivity
- Conductivity (W/m-K)

The model accounts for multiple internal reflections that occur as light passes through the glazing system. Transmission, reflection and absorption is calculated as a function of wavelength, EnergyPlus automatically generates angular optical properties from spectral average input. The model is illustrated below in Figure 11, for a detailed list of equations refer to EnergyPlus Engineering Reference (2012 p.222).

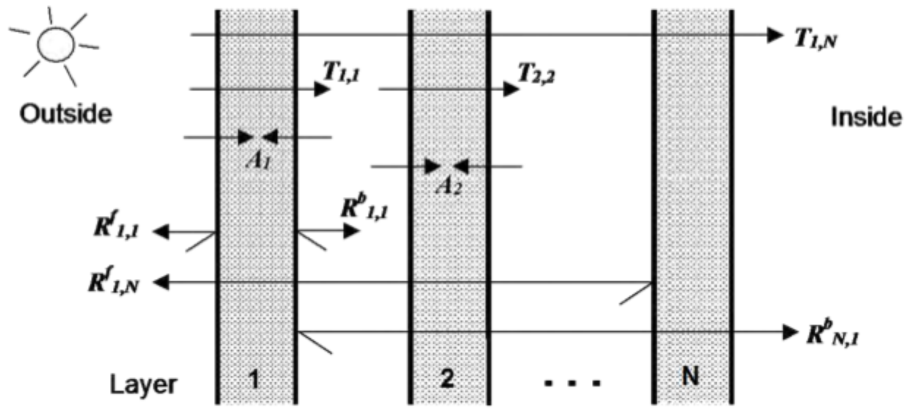

Figure 11: Solar Gain Model (EnergyPlus Engineering Reference 2012, p.222)

Shading from the window reveal and frame, in addition to sill solar reflectance, were included in the final model. EnergyPlus can calculate the solar interactions for the three dimensional geometry of window frames, sills and reveals. These geometric considerations are shown below in Figure 12. The outside reveal depth is 125 mm (Gusdorf et al. 2011) and includes the brick veneer. This depth is enough to shade a considerable portion of the windows during early spring, when heat gain is still desired. Entering the detailed reveal, sill and frame projection parameters resulted in a 4.4% difference in heating energy consumption.

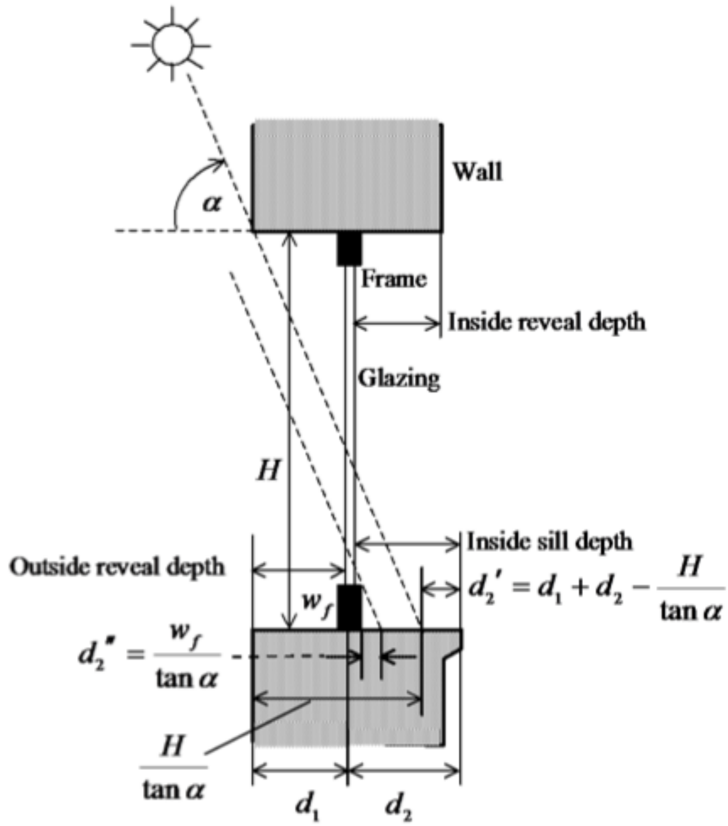

Figure 12: Shading and Reflections due to Window Placement (EnergyPlus Engineering Reference p. 281)

Room side convection from the glazing is calculated in accordance with ISO 15099, and assumes the room air is still. This inherent modelling simplification causes an underestimation of window heat loss as in reality convection currents often develop along window surfaces due to the colder temperatures. EnergyPlus accounts for the inside surface temperature of the window, the fluid properties of the air at the window height and the zone conditions. For a detailed explanation and list of equations refer to EnergyPlus Engineering Reference (2012 p. 264).

4.3.5 Solar Distribution

EnergyPlus provides five options for modelling solar distribution. The simplest (MinimalShadowing) option assumes that all direct solar radiation that enters the building falls on the floor, where a portion is absorbed and the remainder is reflected. The direct solar reflected by the floor is added to the transmitted diffuse radiation, which is evenly distributed amongst all surfaces interior surfaces in the zone.

Initially, the FullExterior option was used, which is similar to the MinimalShadowing option but takes into account shading from exterior surfaces such as overhangs and building self shading. During the calibration stage of the second version of the model, the solar distribution was changed to FullExteriorWithReflections to increase accuracy by adding the following details:

- solar radiation (both direct and diffuse) that is reflected from shadowing surfaces such as overhangs
- the reduction of ground reflected radiation due to the presence of surfaces which shade the ground (ground is not considered unobstructed as in other cases)
- solar reflected from other parts of the building (EnergyPlus Engineering Reference 2012)

During calibration of the second single zone model it was noted that the addition of the 'WithReflections' model increased the energy consumption by 1.1% or 0.75 GJ with only a minor increase in simulation time.

The most advanced option for modelling the solar distribution in EnergyPlus is the FullInteriorAndExteriorWithReflections option, this model calculates the amount of direct solar radiation that falls on each interior surface by projecting sun rays through the exterior windows. This option can only be used for models with convex zones. Initially this option seemed to increase simulation time considerably. Prior to creation of the multi-zone model the effect of the interior solar distribution option was investigated, for the Advanced house model (described in Section 5.1.2), as this model features convex zones. Simulated furnace gas consumption was reduced by 0.8% when the interior solar distribution model was used, however the simulation time increased by a factor of three. It was unknown if this difference would be larger or smaller for the CCHT house, therefore the floor plan was divided into thermal zones in way that would satisfy the convex zone criteria so that the interior solar distribution could be used. For the final multi-zone CCHT model the difference was much smaller, a 0.1% increase in gas consumption with the interior distribution option and no noticeable change in simulation time. The interior solar distribution option was used in all final simulations.

4.3.6 Solar Absorption

Early research in passive solar concluded that energy savings are not very sensitive to the solar absorptance of interior surfaces (Jones 1992). As such, for the initial models it was assumed that the effect of accurate solar absorptance would not have a large effect on the simulation results as much of the radiation reflected by interior surfaces will land on other surfaces, provided window areas are not too large. However, further review of solar absorptance was undertaken for the final model to eliminate any potential error associated with this assumption, especially for cases with higher window areas.

Literature review was carried out to identify more accurate absorptance values for the materials used in the CCHT house, and these values were updated for the multi-zone model. The updated values used for solar absorptance are given in Table 3 below, and along with a summary of the relevant literature.

Table 3 - Solar Absorption Input Values

Surface	Solar Absorptance Value	Justification and Reference
White carpet	0.55	Value for light carpet (Haggard et al., 2009)
Gypsum drywall – off white painted	0.35	Solar absorptance values for DOE-2 (DOE-2 n.d.) recommend 0.3 for semi-gloss white; Reagan and Acklam (1979) measured 0.35 for 'bone' colour paint on stucco, 0.36 used in SERI Test House (Burch et al., 1985)
Tile – mixed colour	0.55	Assumption based on Reagan and Acklam (1979) – value determined based on "medium" category as the tiles are a medium to dark, yet very smooth
Brick – red, exterior	0.55	Haggard et al. (2009)
Asphalt roofing – dark grey	0.8	0.8 based on values from Haggard et al. (2009)

Shading, such as overhangs, can reflect ground reflected radiation and direct beam radiation onto windows depending on the window location and sun angle. Shading surfaces can be assigned reflectance values (note for opaque surfaces: the sum of reflectance and absorptance is equal to 1). The values used for shading objects are summarized in Table 4.

Table 4 - Solar Reflectance Values for Shading Surfaces

Shading Surface	Reflectance Value	Justification and reference
Overhangs	0.65	0.65, consistent with the above values for off white paint as the soffits of the CCHT house are white
Vertical garage fin	0.45	Value for red brick, (Haggard et al. 2009)
South projected roof above garage	0.2	Value for asphalt roofing (Haggard et al. 2009)

4.3.7 Infiltration Model

During the initial modelling, it was observed that the energy consumption of the CCHT house is highly sensitive to the choice of infiltration model. Initially, infiltration was modelled using the design flow rate model, which uses coefficients to modify a set air change rate based on changes in temperature and wind speed. Little guidance is provided in the EnergyPlus documentation on how to select appropriate coefficients, however the coefficients from DOE and BLAST (two EnergyPlus predecessors) are provided. An increase in predicted heating energy consumption of 28% was observed when the DOE coefficients were replaced with the BLAST coefficients. Due to this uncertainty a different method of modelling infiltration was required.

Detailed blower door test results for the CCHT Reference House, were provided by the CCHT (Armstrong email communication), which allowed infiltration to be modelled with the ASHRAE (2009) enhanced model (ZoneInfiltration:FlowCoefficient), which is based on the AIM-2 model (originally formulated by Walker and Wilson 1998, described in ASHRAE 2009 F.16.23). The enhanced model uses an empirically tested superposition technique to combine wind and stack effect, shown below in Equation 4-3.

$$Q = (Q_w^2 + Q_s^2)^{1/2} \quad \textbf{(4-3)}$$

Where the airflow from wind and stack are calculated using Equations 4-4 and 4-5.

$$Q_s = c\ C_s \Delta t^n \qquad \textbf{(4-4)}$$

$$Q_w = c\ C_w (sU)^{2n} \qquad \textbf{(4-5)}$$

The flow coefficient and pressure exponent, c and n, were determined using the results from the blower door test (2005 data). The shelter factor is an empirical coefficient given by ASHRAE (2009) based on 5 categories for 'shelter class', for the CCHT house a value of 0.7 was chosen initially, based on "typical shelter caused by buildings across the street". However, there is some uncertainty associated with this parameter, as a difference in judgment could lead to a value of 0.9 if class 4 is chosen ("typical shelter for an isolated rural house), thus the potential flexibility of this parameter was considered during calibration.

The enhanced infiltration model is a single zone infiltration model, therefore it was necessary to allocate a fraction of the total infiltration to each zone for the final multi-zone CCHT reference model. It was assumed that 70% of the total infiltration occurs around windows and door frame edges, and the remaining infiltration is proportional to exposed exterior envelope area. Each zone fraction of total infiltration was calculated as a weighted average according to the fraction of total fenestration frame length in a given zone (multiplied by a weighting factor of 70%), and the fraction of total exposed exterior envelope area for the zone. This approach is similar to that used by Villi et al. (2012), with the 70% value based on findings from field measurements of Finnish house by Kalamees et al. (2008).

4.3.8 HVAC System

The main simulation components involved in the HVAC system included air terminals, which regulate the maximum air flow rate to each heated zone, the furnace fan, heating coil, and heat recovery ventilator. Fresh air is circulated through the HVAC ducting, after passing through a heat recovery ventilator (HRV). A schematic for HVAC system is provided in Figure 13 (earlier model versions) and Figure 14 (later versions). The CCHT Reference house has a typical residential forced-air gas furnace system. There is one centrally located thermostat (located in the control zone). The remaining zones are slave zones, the heat delivered to these zones is determined by a pre-set constant fraction of furnace airflow and is only available when heat is required in the control zone. The actual thermostat set point is 22˚C, with a 2˚C dead band below the set point. According to measurements by Manning et al. (2007) an average of 21˚C is maintained near the thermostat location. EnergyPlus does not include a simulation object for a thermostat dead band, therefore 21˚C was used.

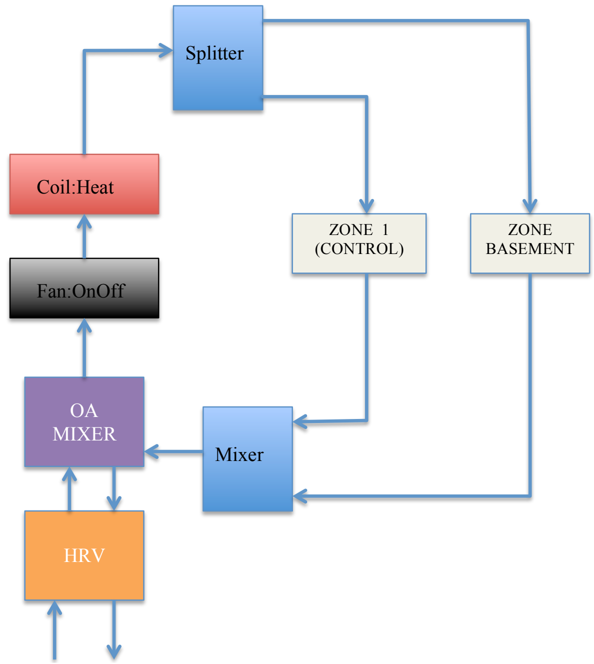

Figure 13: HVAC Diagram for Single Zone Model (Early Version)

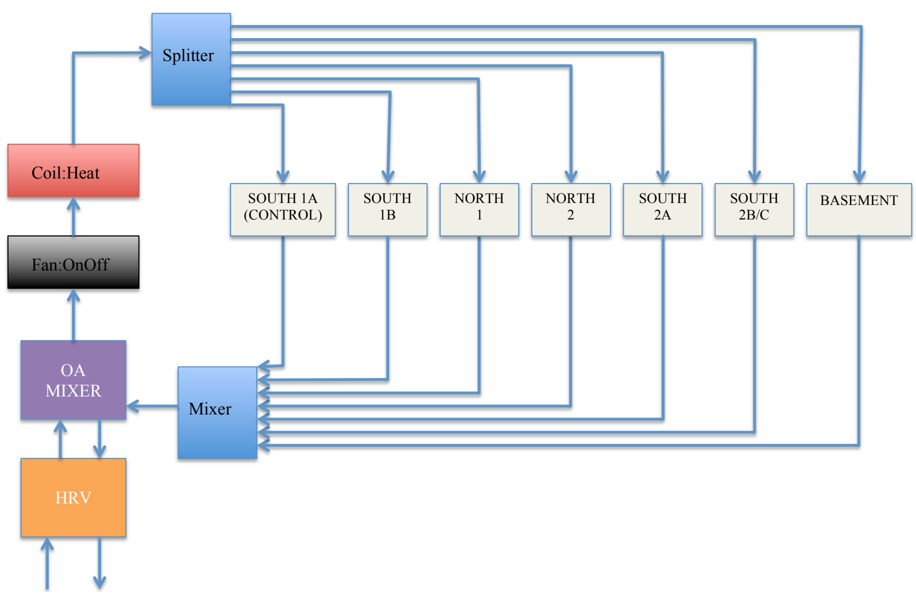

Figure 14: HVAC Diagram for Multi-zone Model (Latest Version)

The main input for the furnace heating coil is the coil efficiency, which is 80.2% according to CCHT measurements for the 2002 / 2003 heating season. The fraction of total furnace airflow to each zone was determined initially by the floor area of the zone, and then later adjusted during calibration to match measured temperature data where possible (for the basement and south 2a zones) or expected zone temperatures where data was not available.

The reference house uses a Venmar heat recovery ventilator. Input parameters were determined from product documentation. The HRV used has a sensible effectiveness of 84%, and 0% latent effectiveness. Defrosting is accomplished via exhaust air circulation which is active at -5˚C.

Fan Model

The CCHT furnace fan provides warm air at 622 L/s when the furnace heating coil is on, and circulates air at 454 L/s when the furnace heating coil is off. The circulation mode distributes the fresh air to each zone and also helps distribute solar heat from the south zones to cooler zones. Originally the fan was simulated to cycle on and off with the furnace heating coil and capturing the behaviour of the circulation mode was unnecessary due to the fully mixed air inherent in the zone air balance. However, this was not the case for the final multi-zone model. A cycling fan could not be modelled in conjunction with the outdoor air system (which integrates ventilation through the HRV) due to limitations in the program. As such, continual fan operation was simulated.

Based on detailed hourly furnace gas consumption data provided by M. Armstrong of the CCHT (email communication), during January (2003) the furnace fan ran at high speed 94% of the time. Given this, modelling the furnace fan as a constant volume fan running at high speed was deemed to be a valid approximation. The implications of this assumption are that interzonal airflow due to fan driven air circulation is overestimated by 5 to 26 L/s depending on the zone, during periods where the fan would actually be in circulation mode.

The furnace fan has a considerable impact on the furnace gas consumption. Gusdorf et al. (2002) evaluated two types of fan motors in the CCHT houses, and found that the more efficient (ECM) fan motor resulted in a 14% increase in gas consumption due to reduced electrical heat gain. The CCHT Reference house uses a furnace fan with a permanent split capacitor motor (PCM), which is relatively inefficient but provides significant heat gains. The fan electricity power consumption is approximately 350 W for circulation and 490 W for heating mode. Due to size of the furnace fan heat gains it was necessary to ensure these gains were accurately modelled. For the multi-zone model, the gains were added to the airstream so that they are distributed in the correct proportions to each of the zones.

The fan model used (Fan:OnOff) includes the following input parameters:

- overall fan efficiency
- motor efficiency
- fraction of motor heat gains in airstream
- pressure rise

Phillips (1998) recorded fan pressure rises of 75 to 175 Pa for Canadian furnaces installed after 1990. Additional pressure rise due to dirty filters ranged from 20 to 100 Pa, and an average of 21 Pa was observed for systems with AC coils. Phillips (1998) recommends 175 Pa as a realistic value for furnace AFUE rating, this value was used in the model due to the absence of furnace pressure rise data for the CCHT Reference house. In the first two version of the model, 125 Pa was used, based on a study on US furnaces (Lutz et al. 2004). However, for the final model this was changed to 175 Pa to be consistent with measured data from Phillips (1998). A 1.2% difference in furnace gas consumption occurred when the pressure was changed from 125 Pa to 175 Pa, when the furnace fan heat gains were modelled as general equipment heat gain. This can be explained by the heat generated by the air pressure increase from the fan. Although in reality the furnace fan pressure rise affects the airflow rate, in EnergyPlus airflow is a set input parameter, therefore only fan energy consumption is affected by a change in furnace fan pressure.

It was assumed that 100% of the motor heat gains are transferred to the airstream. Although, in reality some of these gains will be transferred to the zone surrounding the fan, it is expected that this amount is small. The overall fan efficiency was calculated based on the flow rate and total power in as follows:

Power to Fluid = Volume Flow Rate * Fan Pressure Rise **(4-6)**

Overall Fan Efficiency = Power to Fluid / Electrical Power In **(4-7)**

(EnergyPlus Input/Output Reference 2012)

The value used for electrical power in is the measured power draw of the CCHT furnace fan and the HRV supply fan electricity input (M. Armstrong email communication). The HRV supply fan gains were combined with the furnace fan to simplify the model input.

4.3.9 Interzonal Airflow

The significance of interzonal airflow is highlighted by the following example. For a case with a 3.3˚C temperature difference Balcomb and Jones (1985) show that heat transfer from natural convection through a 914 mm door can be five times greater than the heat transfer through a standard un-insulated partition wall 3 m x 6 m. Balcomb et al. (1977, cited in O'Brien et al. 2011) report airflow rates of 0.3 to 1.05 m^3/s through doors during sunny periods, equating to a heat transfer of up to 6kW.

Balcomb and Jones (1985) studied airflow inside 15 passive solar buildings, and determined the following empirical equation for volumetric airflow rate through doorways:

$$V = 0.0368\ w\ (h^3\ \Delta T)^{1/2} \qquad \textbf{(4-8)}$$

For a standard 813 mm door with a height of 2030 mm, a temperature difference of 1˚C results in 87 L/s of airflow, and a temperature difference of 2˚C results in 122 L/s of airflow.

Airflow Network

EnergyPlus features a detailed airflow network model that accounts for the effect of buoyancy, wind pressure, wind direction (EnergyPlus Engineering Reference 2012) and mechanical air distribution systems. The EnergyPlus airflow network model has been validated with data from the ORNL test facility. Gu (2007) found that the predicted airflows were within 4.1% of measured data. For a test building the predicted air conditioning energy requirement was approximately 12% less than measured data for a case with supply leaks (Gu 2007).

Several airflow network models were developed and tested for the following situations encountered in this study:

- interzonal airflow due to buoyancy
- interzonal airflow due to HVAC air distribution

    - surface level infiltration in relation to both internal and external air pressures and flows
- zone level passive ventilation through operable windows

Interzonal airflows are very complex. Although, the airflow network model in EnergyPlus is quite detailed, often uncertainty of input parameters limits the accuracy of the calculation. It would not be realistic to capture the dynamics of all of the interzonal airflow in the CCHT house. The following parameters have significant uncertainty, which would limit the accuracy of the airflow network model:

- actual location of cracks are unknown
- duct leakage
- actual discharge coefficients of openings are unknown

In addition, the author found that the solution algorithm used in the airflow network has limitations with regard to the selection input variables (also confirmed by Lixing Gu (EnergyPlus Support) email communication November 30th 2012). The airflow network solution would not converge for many of the desired values for the input variables, and that very high convergence tolerance values were required. After over two weeks of model development and troubleshooting, it was determined that the airflow network model was not suitable for this study. For the multi-zone model, only the interzonal airflow part of the airflow network would converge and even for this case much higher convergence tolerance parameters than the default values were required, which brings into question the accuracy of the airflow network model.

Empirical Approach to Interzonal Airflow

In the final model, a stronger empirical approach was taken to simulate heat transfer due to interzonal airflow. EnergyPlus contains simplified airflow modelling options, including objects such as the zone cross mixing object, which exchanges heat between zones based on an airflow rate, which can be turned on at a given temperature difference. The limitation of this approach is that only one cross mixing object is allowed per zone. Another simplified approach is that taken by Meldem and Winklemann (1995), where heat transfer from airflow through an internal opening (such as a hallway) is modelled using an overall heat transfer coefficient. The advantage of this approach is that the heat transfer rate is proportional to temperature difference.

To overcome the limitation of only one zone cross mixing object per zone, the heat transfer coefficient approach was used for smaller interzonal openings. As with most simulation programs, omitting a surface is equivalent to omitting the heat transfer that would occur through the surface, therefore a surface was required for each of the interzonal openings (doorways, hallways, staircase). The openings were modelled as glass, with very high transmittance, high emissivity, high long wave transmittance and very low thermal resistance.

A significant amount of air exchange already occurs between the zones from the continuous operation of the furnace fan. During circulation mode this is equivalent to an airflow rate of 15 to 71 L/s per zone, depending on the size of the zone. All zones have a return air vent, except for the first floor south zones (South 1a/b). Because the furnace fan was modelled with it containing a continuous flow rate of 622 L/s (high speed), the base interzonal airflow is overestimated when the furnace coil is off by approximately 5 to 26

L/s per zone. The final interzonal airflow input parameters are summarized below in Table 5.

Table 5 – Interzonal Airflow Input Values

Object / Zone	Value	Justification and reference
Zone cross mixing – South 1a & North 1	44.8 L/s continuous	South 1a & b have no air return duct, based on the initial furnace airflow rates this amount of air would return to North 1 via South 1a, when furnace operates
Zone cross mixing – South 2a & North 2	189 L/s when $\Delta T > 2^{\circ}C$	Calculated using empirical formula from Balcomb and Jones (1985) (described above)
Zone cross mixing – South 2b & South 2c	1000 L/s	These two zones are the modelled as fully mixed (both zones describe the master bedroom, which was only separated so that the interior solar distribution could be used)
U value – South 1a to South 1b	11 W/m^2k	Meldem and Winklemann (1995) – this is a medium sized hallway
U value – South 2b to North 2	11 W/m^2k	Meldem and Winklemann (1995) – this is a small doorway
U value – South 1a to South 2a	20 W/m^2k	Staircase, it was assumed that the heat transfer through a horizontal opening would be considerably higher than that of a vertical opening

It was observed that these airflow heat exchanges had a very small direct effect on the simulated annual energy consumption, typically around 0.1% or less, with the exception of the cross mixing between zones South 1a & North 1 which resulted in a difference of 0.6%. This can be explained by the base level of interzonal airflow that is already occurring due to the continuous operation of the furnace fan, and the HVAC set up where only one zone is controlled. Interzonal airflows occurring between slave zones do not have a large effect on the heat loss of the control zone. A more noticeable effect was noticed on air temperature of the south facing slave zones, with reductions in peak temperatures of approximately 2˚C occurring with the addition of interzonal airflow.

4.3.10 Ground Contact Heat Transfer

Although ground contact heat transfer is not directly related to passive solar, it is a large source of heat loss for typical Canadian houses with heated basements, such as the CCHT reference house. During initial modelling it was found that ground temperature assumptions have a large influence on energy consumption, this was also observed by Purdy and Beausoleil-Morrison (2001) who also modelled the CCHT house. Because of this, and the significant variability in ground temperatures across Canadian climates, Basement was used to calculate 3 dimensional ground contact heat transfer. Basement is a pre-processor auxiliary program for EnergyPlus, which produces monthly temperature profiles for the exterior of the foundation wall and floor slab using a finite difference model (EnergyPlus Auxiliary Programs 2012). These temperatures are used in the one-dimensional conduction equations used in the energy balance calculations carried out by EnergyPlus.

One of the most sensitive input parameters for Basement is the monthly interior temperature profile. The results of long-term basement temperature measurements for the CCHT Reference House are presented in Armstrong et al. (2011). Graphs from Armstrong et al. (2011) were interpolated to develop a monthly basement air temperature profile, and an average exterior foundation temperature profile used to calibrate Basement. Basement does not allow for interior foundation insulation, therefore to account for the interior insulation in the CCHT house, the thermal resistance of the interior foundation insulation was combined with, and entered as, the horizontal convective heat transfer coefficient in the basement input. Soil properties were estimated through the calibration procedure, outlined in Section 4.5.

Originally the garage slab was modelled as adiabatic, for the final model this assumption was revised and the EnergyPlus Slab auxiliary program was used to estimate the sub-slab temperatures. Convergence of the solution algorithm could not be achieved using the calibrated soil properties used in *Basement*, therefore default input parameters had to be used. The reason for this instability in the *Slab* program is unknown. Similar to *Basement*, the results of Slab are highly dependent on the zone air temperature profile. The air temperature in the garage varies widely as it is unheated, therefore the simulation was run several times to iteratively determine the monthly air temperature profile input. The addition of Slab results into the simulation model, increased the heating energy consumption by 0.1%

4.3.9 Convection Algorithms

Convective heat transfer from surfaces plays an important role in the discharging of heat stored in thermal mass, and is therefore important to model accurately when estimating the savings from passive solar houses. EnergyPlus offers many choices for convection algorithms, many of which come from EnergyPlus's predecessor programs (eg. DOE-2, TARP). The most detailed of these options is the adaptive convection algorithm, an algorithm which selects the most appropriate convection model from a range of models including many recent studies (EnergyPlus Engineering Reference 2012). For exterior convection, the adaptive convection algorithm chooses the most appropriate algorithm from over 20 options, depending on the direction of heat flow, the wind direction, wind speed and type of surface. In all algorithms when the weather file indicates the occurrence of rain, a convective heat transfer coefficient of 1000 W/m^{2}K is used for all surfaces exposed to wind.

The adaptive convection algorithm for interior convection functions in a similar way to its exterior counterpart. However, it is more detailed and has many more algorithms to choose from, taking into account the expected flow regime based on HVAC system type as well as the surface type (exterior wall, partition, ceiling, floor, etc). The assumption for forced HVAC air distribution is limited to ceiling air diffusers; there are no algorithm options for floor heat registers so airflow regimes are assumed to be driven by simple buoyancy. This results in the convective heat transfer coefficients being underestimated in regions close to the heat registers. However, it is not expected that this has a large effect on the overall results.

For the first single zone model, the TARP algorithm was used for interior convection and the DOE-2 algorithm was used for exterior convection. After further review of the model and EnergyPlus documentation, both of these were changed to the Adaptive Convection Algorithm. Changing the inside convection algorithm reduced furnace gas consumption by 8%, this is likely explained by the increase heat transfer (i.e. effectiveness) in and out of heat storage surfaces. When the outside convection algorithm was changed a 5% increase occurred, which is likely caused by more accurate consideration of wind effects.

4.4 Other Simulation Inputs and Assumptions

This section provides a summary of other simulation inputs and assumptions made which were expected to have a relatively small contribution to the overall heat balance.

4.4.1 Internal Gains

Internal gains were modelled using a time schedule, a power level (W), an assigned zone, and fractions to portion the internal gain amongst the various possible heat transfer mechanisms. These include latent, radiant, convective, and in some cases fraction lost. The internal gains were modelled based on the original internal gains schedule for the CCHT houses (Swinton et al. 2001). However in the final model, detailed measured data for a sample day in January 2003 were used. In the final model, after reviewing the detailed internal gain data, 723 W of continuous heat gain was added to the garage, for the control and monitoring equipment installed in the reference house. Such discrepancies, led to an increase of 7.7% in heating energy consumption.

The CCHT Houses include simulated heat gain from people, using incandescent light bulbs. Using guidelines from EnergyPlus's Engineering Reference manual, it was assumed that 90% of this heat gain is radiant, and the remaining 10% is convective. The reference house includes 450 W of lights, and all standard appliances (stove, washer, dryer, fridge). It was assumed that 70% of the dryer energy input is lost (vented), the dryer is located in the middle of the house therefore some heat will transferred through the house from the ducting, and from the dryer itself (i.e. the remaining 30%). Domestic hot water consumption was difficult to allocate to the various heat transfer mechanisms. No literature was found to guide how the DHW consumption gains should be allocated. It was assumed that 60% of the hot water energy input is lost (down the drain), and 20% is latent heat gain.

4.4.2 Timesteps

Even though the standard weather data used for energy simulation is only available on hourly intervals, using timesteps of less than one hour does considerably increases simulation accuracy. This is because EnergyPlus interpolates weather conditions between timesteps, and the transient response of a building and its systems can occur over relatively short time periods. For example, internal gains and the effect of thermal mass often require an increase in frequency of timesteps to accurately capture their contribution to the overall heat balance (EnergyPlus Input Output Reference 2012).

More timesteps per hour typically increases accuracy, but can also significantly increase simulation time. For the first model, 4 timesteps per hour were used. This was later increased to 10 timesteps per hour for the second version of the model, and for the remaining model development. Twenty timesteps per hour was tested for the second version of the model, and found to reduce the estimated gas consumption by 0.6 – 0.8%, however this doubled the simulation time. For the final calibration stage and simulation 30 timesteps per hour was used, with a resulting typical simulation time of approximately 8 minutes.

4.4.3 Shadow Calculation Frequency

Shading is calculated based on the building geometry and sun angles. The default option in EnergyPlus updates the shadow size every 20 days based on changes to the sun angle. A 10 day update was tested for the multi-zone version of reference case and it was found that the effect was very small (less than 0.1%) and the simulation time increase was slight (13 seconds or 6%). Due to the relatively small impact on simulation time, a 10 day update frequency was used for the multi-zone model.

4.4.4 Ground Reflectance

The ground reflectance was modelled using monthly values, based on recommendations from Thevenard and Haddad (2006). Monthly average ground reflectivity was assumed to be 0.26, which is a typical value for green grass. The SnowModifier object was used to change the ground reflectivity to 0.65 when snow is present, based on the snow fall indicators included in the weather files. Uncertainty in these values was considered during calibration. Snow indicators were not available in the AMY weather file used for calibration, thus were added from the TMY weather file.

4.5 Calibration Process

This section provides a more detailed account of the calibration of major sub models and the final calibration process (as shown in the calibration process flow chart, Figure 1).

4.5.1 Initial Calibration

Calibration was based on comparison of daily furnace gas consumption data measured at the CCHT house in the 2002/2003 heating season. The data set provided by the CCHT included 203 data points, which spans the heating season but does not include every day as some data points were missing. The furnace gas consumption at the CCHT is measured as a volume flow rate, and was converted by the CCHT to an energy value using a heating value for natural gas of 37.3 MJ/m^3 provided by the gas utility (M. Armstrong personal communication December 20th 2011).

Because of the significant effect of ground heat transfer, the model was first calibrated with on-site ground temperature data. The foundation wall temperature profile was developed based on data measured at five depths along the foundation wall from Armstrong et al. (2011) and approximated as a sinusoidal function using the maximum and minimum temperatures measured for the corresponding calibration year. Monthly values were used for the building surface ground temperature input in EnergyPlus. The heat transfer from the foundation walls was modelled using these temperatures and the basement floor was assumed to be 14.5˚C; equal to the temperature measured at the bottom of a stud on the interior side of the foundation wall. This assumption was made based on the lack of further data, with the plan to further verify during the calibration. After this step, each major component of the model was reviewed, and various simulation outputs (such as mass flow rates, basement temperature set point, heat transfer through windows, walls etc.) were examined. After simulated gas consumption was close to measured data (approx. +/- 5%), the EnergyPlus Basement auxiliary program was calibrated then added, as it is required for the other locations examined (as illustrated in Figure 1, Section 4.1).

4.5.2 Basement Calibration

Basement calibration parameters include thermal properties of the soil, which can vary considerably, concrete thermal properties parameters, and basement air temperatures. Because the basement air temperature was measured 30cm below the ceiling, stratification was not accounted for. Therefore, it was assumed that the fully mixed temperatures, which EnergyPlus simulates, could be slightly cooler than the measured values. This was taken into consideration when “fine tuning” the basement duct size. The final combination of parameters that gave the best calibration statistics resulted in basement temperatures approximately 0.5 to 1˚C cooler than measured. The final calibrated basement temperatures are shown below in Figure 15, along with a sine curve generated from the interpolated average maximum and minimum measured foundation temperatures from Armstrong et al. (2011).

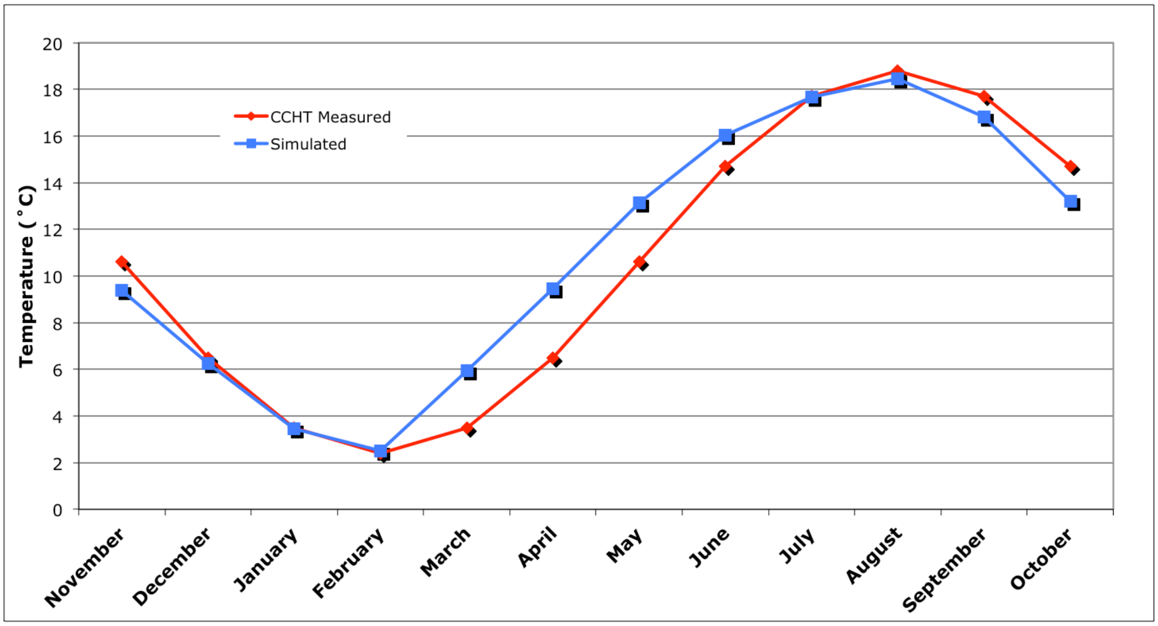

Figure 15: Calibrated Foundation Temperatures

4.5.3 Calibrating Air Terminal Flow Rates

Whenever possible zone air temperatures should be calibrated to measured data. For this research, limited temperature data was available. Temperature data for the basement air temperature was measured by Armstrong et al. (2011).

The highest temperatures typically occur in the south upstairs bedroom (South 2a Zone) as shown in a 10 day temperature profile for February 2006 (Manning et al. 2008). These measured temperatures were compared with the simulated temperatures for this zone and used to ensure that air terminal size ratios and heat transfer due to interzonal airflow were realistically approximated. Although weather data and gas consumption data from 2003 is used, and the measured temperatures are for 2006, it is expected that similar temperatures will occur in either year on sunny days.

Temperatures measured at mid-room height during February 2006 (Manning et al. 2008) varies between approximately 20.1˚C and 27.2˚C. The simulated temperatures correlate well for a February week with several sunny days, reporting simulated temperatures varying between approximately 20.2˚C to 27.8˚C for the multi-zone model before calibration. It is important to note the simulated air temperatures using the airflow network model for interzonal heat transfer did not match the measured values nearly as well as for the multi-zone model without the airflow network. This indicates that the interzonal airflow due to buoyancy does not have a large impact on the overall energy balance. Also, during sunny periods the furnace coil is typically off, and the fan would be operating in circulation mode. However, as modelled, the fan is always in heating mode, hence the air circulation between each zones is overestimated when the furnace coil is off, which may account for some of the interzonal buoyancy and convection driven airflow that occurs in reality.

4.5.4 Calibration Parameters

A list of input parameters with the highest uncertainty was created during model development. During the final stage of calibration these parameters were varied within a range of values recommended by literature to 'fine tune' the calibration until the lowest CV(RMSE) value was reached. These parameters are shown below in Table 6, along with the range of possible values and final input value.

Table 6 - Calibration Parameters for Fine Tuning

Parameter	Range	Source	Final
Ground Solar Reflectance (no snow)	0.2 to 0.35	(Thevenard and Haddad 2006)	0.26
Ground Solar Reflectance (snow)	0.5 to 0.7	(Thevenard and Haddad 2006)	0.65
Shelter factor	0.6 to 0.9	ASHRAE (2009)	0.85
Garage infiltration	1.5 – 3 (tested)	Ranges from CCHT airtightness rating to near typical value for houses	3 ACH @50
DHW fraction lost	0.5 to 0.6	Assumption	0.6

4.5.5 Calibration Evaluation

As discussed in Section 3.4.2, to the best of the author's knowledge there are no existing standards for daily calibration. The CV(RMSE) and NMBE values for the three versions of the model are summarized below in Table 7. The first version being a simple single zone model which used the simple window model and several minor input errors. The second version being a more detailed single zone model using the detailed layer by layer window model and many revisions. The final version is a detailed multi-zone model which includes interzonal airflow.

Table 7 – Evaluation of Calibrated Model

Model Version	CV(RMSE) [target = 22.5%]	NMBE [target = 7.5%]	Heating (GJ)
Version 1	22.9%	-0.58%	0.57%
Version 2	18.4%	-0.08%	0.08%
Version 3 (final)	17.1%	0.06%	-0.06%

The proposed CV(RMSE) target of 22.5% was not met for the first version of the model, however it likely could have been met with the same modelling approach if the input errors that were later discovered were eliminated. For the second and final versions of the model the CV(RMSE) target was exceeded considerably. In all cases the NMBE target of 7.5% was exceeded by an order of magnitude. The NMBE was not found to be a very relevant metric in this research. The daily simulated furnace gas consumption for the final calibrated model is shown with the measured data below in Figure 16 (for an enlarged version refer to Appendix A).

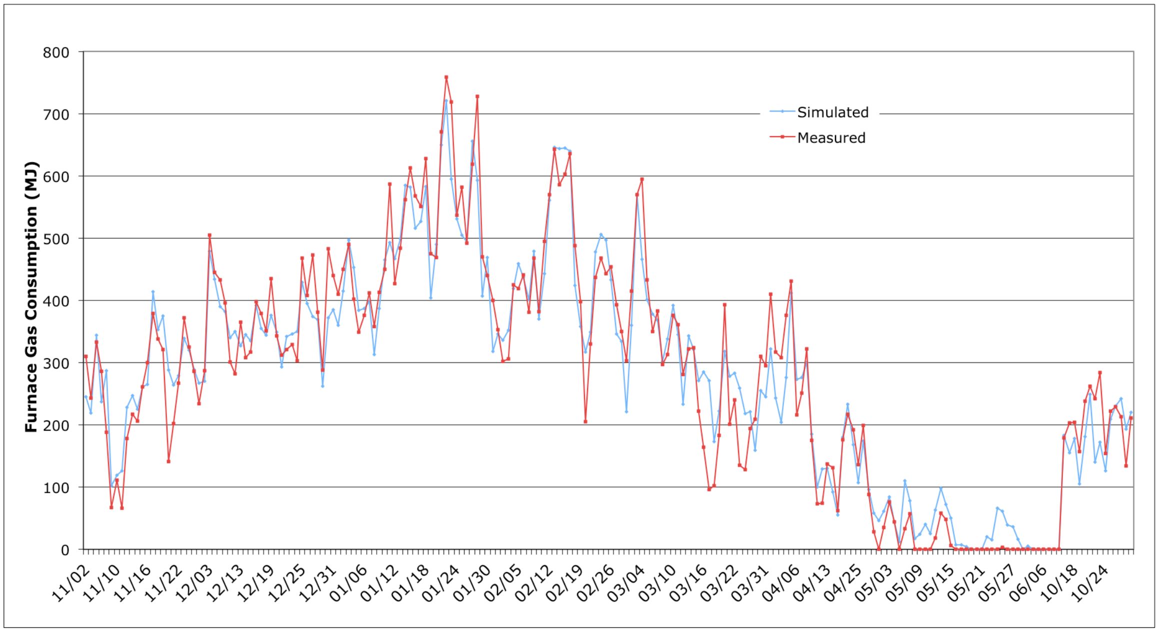

Figure 16: Measured and Simulated Daily Furnace Gas Consumption

Comparisons of measured and simulated gas consumption for model versions 1 and 2 are given in Appendix A.

4.6 Conclusions from Calibration

Energy simulation requires careful selection of input parameters, and model choices. Many input parameters were found to significantly affect the simulation results. Model choices and parameters that were found to have the largest influence on the simulated furnace gas consumption are summarized below in Table 8.

Table 8 - Important Simulation Parameters and their Effect on Furnace Gas Consumption

Simulation Parameter / Model Choice	Percent Change in Furnace Gas Cons.
Initial infiltration model: Design flow rate (Changed from DOE-2 to BLAST coefficients)	+ 28%
Initial infiltration model: Design flow rate (Changed from BLAST to default EnergyPlus coefficients)	- 13%
Enhanced Infiltration model (relative to BLAST coeffs)	- 3%
Window model (changed from simple to detailed, tested for quadruple pane window)	- 11%
Internal gains update (added monitoring equipment in garage, changed dryer fraction lost, dishwasher)	- 7.7%
Convection algorithm interior	- 8%
Convection algorithm exterior	+ 5%
Thermal bridging calculation error	+ 4.4%

The choice of infiltration model is critical in accurately predicting the heating energy consumption. The choice of window model is also very important, especially when modelling passive solar. It is important to include all framing members when quantifying thermal bridging and to separate walls with windows from those without. Internal gains provide a considerable portion of the heat balance. The adaptive convection algorithm provides a more sophisticated treatment of convection with no noticeable increase in simulation time.

Modelling the interior solar distribution using ray projection had a relatively small effect on the results compared to the exterior distribution option which assumes all beam radiation lands on the floor, and is then evenly redistributed according to surface properties. However, given that it did not increase simulation time, its use is justified in this research.

Using the conduction transfer function model is an appropriate choice for modelling high mass passive solar houses, as no noticeable difference in simulation results occurred when the conduction finite difference algorithm was used.

Other solar parameters such as the shadow position update frequency, solar absoptance and reflectance values had only a minor influence on simulation results. However, for many minor parameters detailed consideration seems appropriate if simulation time is not affected considerably and if the parameter is of particular interest to the study.

Using the airflow network for the CCHT house was found to be impractical (version 7.2 of EnergyPlus). Assumptions regarding natural interzonal airflow did not have a big impact on the simulation results in this study (approx. less than 1%), which is most likely due to the high rate of forced air circulation between zones.

While a considerable improvement in the calibration (according to the CV(RMSE)) was achieved between the first and second version, only a relatively small difference was achieved by upgrading to the more detailed multi-zone model. It is expected that the proposed CV(RMSE) target of 22.5% for daily calibration would be easily met when calibrated other residential energy models. For this research it was feasible to achieve a CV(RMSE) value of 18.4% with a single zone model, and 17.1% with the multi-zone model. There are some limitations with projecting how calibration of the CCHT reference house model applies to other single family dwellings, as for many other situations less detailed input and calibration data would be available.

5. Passive Solar Simulations

5.1 Scope

The scope of the passive solar options evaluated covers a range of design options applied to the CCHT house to represent a typical Canadian tract house, and one Advanced passive solar design which features higher insulation levels than currently prescribed by provincial building codes, and a very high south facing window area.

5.1.1 Passive Solar for a Typical Canadian House

Eight passive solar design options for the CCHT house were evaluated, including two amounts of thermal storage mass, two south facing window areas (SWA) and two types of glazing as outlined in Table 9.

Table 9 - Passive Solar Design Options Evaluated

Parameter	Variation	Description
Thermal Mass	Sun Tempered	CCHT house - regular light frame construction, main floor 50% tiled
	High Mass	100 mm concrete added to interior of above grade walls, partition walls, and interior floors
South Window Area (SWA)	Regular	CCHT house - 7.7% of floor area (16.2 m^2)
	High	15.4% of floor area (32.4 m^2), 2x regular case
Glazing Type	2x Glazed	CCHT house - Low emissivity, argon filled, hollow vinyl frame, U = 1.76 W/m^2K, SHGC = 0.52[a]
	Advanced Glazing	3x glazed, low emissivity, krypton filled, high solar heat gain, insulated fiberglass frame, U = 1.07 W/m^2K, SHGC = 0.45[a]

[a] U and SHGC for whole window including frame, no dividers, using WINDOW 6 NFRC Standard

Each basic parameter option is based on the CCHT house as is. Concrete was chosen as the thermal mass material as it is an effect thermal storage medium, and can be integrated into a building as a structural element. Jones (1992) provides a detailed overview on thermal mass thickness and concludes that adding more than 100 mm of concrete for thermal mass has little benefit. The increased window area corresponds to the maximum recommended south window area to floor area ratio for high mass designs according to CMHC (1998). The advanced glazing selected, Serious 7H, is a commonly used window for passive solar houses, including Passive House projects (Allyson Landers, Serious Energy, email communication Aug. 8th 2011). This window has a much lower U value than the existing CCHT windows, but has a lower SHGC. The frames for this window are insulated fibreglass.

5.1.2 Advanced Passive Solar House

An advanced passive solar building was developed and modeled in order to quantify the solar fraction for a higher performance building of the same floor area. This building has a compact shape, a more optimal solar geometry, shown in Figure 17, and increased insulation. North windows have been eliminated for the advanced design, and south windows are increased to a maximum area recommended by passive solar guidelines.

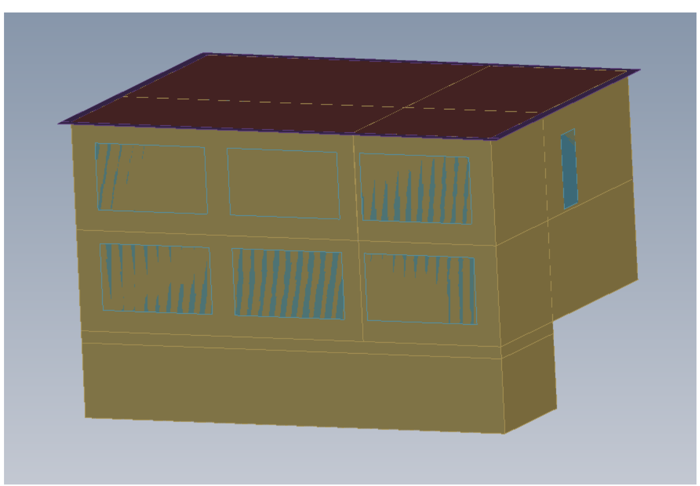

Figure 17: Advanced House View from South

Other input parameters are consistent with the CCHT houses such as the floor area, for the living space, garage and basement. It also has two stories and a basement, with the garage moved to the north façade. The floors in the south zones are tile, to enhance solar absorption and increase thermal mass of these zones, while the north zones have carpeted floors. The key parameters for the improved case are summarized below in Table 10.

Table 10 - Key Parameters for Advanced House

Parameter	Value	Justification
South facing window area (SWA)	42 m^2 (20% of floor area, 50% WWR approx.)	Near practical maximum for frame wall, coincides with maximum recommended value from Charron and Athienitis (2006)
Insulation	50 mm extruded polystyrene (R = 1.47 m^2K/W) added to above grade walls and roof	Approx. 50% increase in wall insulation, feasible upgrade to existing assembly
Aspect ratio	1.34	Within recommended range from (Chiras 2002)
Glazing	U = 1.07 W/m^2K, SHGC = 0.45	Consistent with typical house advanced glazing scenario
Thermal Mass	100 mm concrete added to interior of above grade walls, and interior floors	Consistent with typical house high mass scenario

The Advanced house has small 0.3 m overhangs, consistent with the CCHT house. These overhangs are not enough to shade for summer sun, and additional shading features would be required. As discussed in Section 2, large overhangs can reduce useful passive solar gain during the spring when there can still be a considerable requirement for heating. Therefore, only modest overhangs, which do not provide significant shading, were included in the simulation. It may be desirable to add awnings or roll shutters during to reduce cooling energy consumption and overheating during the summer (as described in Laouadi 2010).

5.2 Simulation

5.2.1 Addition of Thermal Mass

Thermal mass was added as the second layer (from inside surface) so the surface finish would be the same as in the reference case. For example, the interior floors have the 100 mm concrete thermal mass layer underneath tile or carpet depending on the floor type, which replaces the OSB and airspace. The key input parameters used to simulate concrete as added thermal mass are given below in Table 11.

Table 11 - Thermal Mass Properties

Material Property	Value	Source
Conductivity (W/m-K)	1.3	ASHRAE 2009 F.26 mid range values
Density (kg/m^3)	2240	
Specific heat capacity (J/kg-K)	900	

Adding a layer of concrete to the existing assemblies to increase thermal mass results in a small increase in the overall thermal resistance of the wall. The base exterior wall assembly (R = 3.01 W/m^{2}K) is increased by 3% (0.08 W/m^{2}K) when the concrete thermal mass layer is added.

5.2.2 Glazing Size and Type

The high south window area scenarios (SWA) have twice the glazing of the regular (CCHT as is) scenarios. Glazing is entered into EnergyPlus by entering the edge of glass coordinates. It was assumed that no extra dividers are required for the larger windows. The south door was replaced with a window to represent a fully glazed door, this was required in order for the south envelope to realistically fit the required increase in window area. The geometry for the high SWA scenarios is shown below in Figure 18.

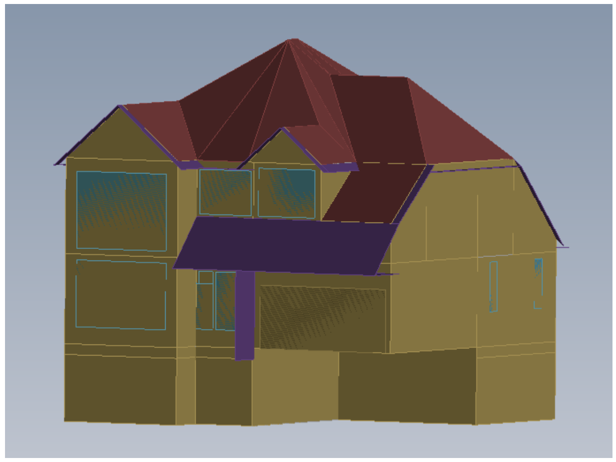

Figure 18: CCHT High SWA

The advanced glazing was modelled in a consistent way to the existing CCHT glazing, described in Section 4.3.1. A high profile frame was chosen, which is 71 mm, however, it was modelled as 80 mm to be consistent with the CCHT frame dimensions, and to simplify model input. EnergyPlus's detailed window model was used, with inputs based on WINDOW 6 results for the 7H glazing and THERM files provided by Serious Energy (Cain Hathaway, email communication).

5.2.3 Passive Ventilation to Prevent Overheating

During the course of this research it was decided that passive ventilation should be included in the simulation model to prevent overheating during the heating season. In reality, this is not done for the CCHT house (i.e. no occupants exist to open windows, etc.), however, for typical houses occupants will open windows when they find the conditions too warm, releasing excess heat gain and cooling the building. The concern with neglecting this phenomenon is that the energy savings from passive solar could be overestimated if the simulated thermal mass reaches a higher temperature then it would in reality, and as a result the building remains above the thermostat set point for a longer time period. Accurately modelling the venting of excess solar gain was also a primary motivation for adding thermal zones during model development/calibration.

Ventilation was added at the zone level and scheduled according to the zone occupancy schedules based on the simulated occupancy schedule used in the CCHT house. Ventilation was active in a given zone when the temperature in any occupied zone exceeded 25˚C, and a temperature difference of more than 0.1˚C existed between the zone air temperature and the outdoor temperature. A flow rate of outdoor air of 500 L/s was assumed. This value is based on a typical flow rate observed by Balcomb and Jones (1985) for airflow between zones when significant temperature differences occur. It is highly uncertain what actual ventilation rates would occur when windows are opened, however an accurate value is not relevant to the simulation objective in this case. Rather it is important to ensure that the value used does cool the zone effectively but not overcool it.

In most cases overheating occurs during times for which the zone is not occupied, when this occurs it would be both unrealistic and undesirable to vent excess heat. It is unrealistic to expect windows to be opened when a house is unoccupied, unless there is a mechanical system in place to do so. Allowing temperatures to rise during unoccupied periods allows for more heat storage, which results in the building remaining warmer for longer periods and reduces furnace operation time. This approach, of linking venting excess heat gain with the occupancy schedule differs from other recent literature (eg. O'Brien et al. 2011), which tend to assume ventilation is always available and desired.

The occupancy schedule is shown below in Figure 19, this schedule also determines the time and zones where venting is available.

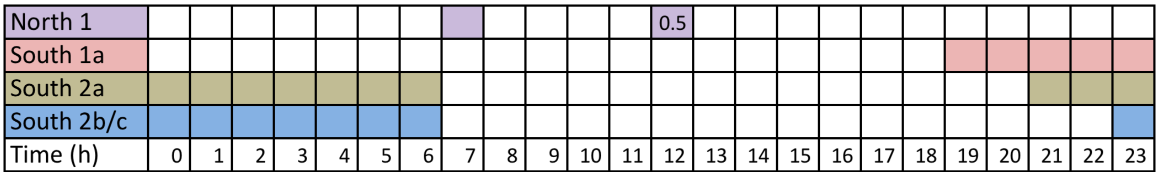

Figure 19: Occupancy Schedule

5.3 Simulation of Advanced Passive Solar House

The Advanced house scenario was originally modelled as two thermal zones with no venting of excess solar gain. During the course of this research it was decided that neglecting the special temperature distribution in the building through the one zone, fully mixed approach, and not venting excess solar gains was likely not realistic. As a result, the Advanced house simulation model was updated to include eight heated zones. Zone level ventilation was added to prevent excessive overheating during occupied periods, as described in Section 5.2.3. Generally, the simulation methodology used is consistent with the typical house scenarios. Due to the change in overall dimensions, it was necessary to modify the zone sizes. The zone floor areas for the ground level are close to those of the CCHT house, however the south zones are much shallower in the advance house due to the more rectangular geometry and the position of the garage. The thermostat was relocated to the North 1, as the change in geometry caused the centre of the building (which is where the thermostat was previously located) to be in the North 1 zone. In addition, it is assumed that a more advanced passive solar house would feature architectural programing, which allows for greater temperature swings in the south facing rooms. Figure 20, shows the zoning and floor plan of the Advanced house.

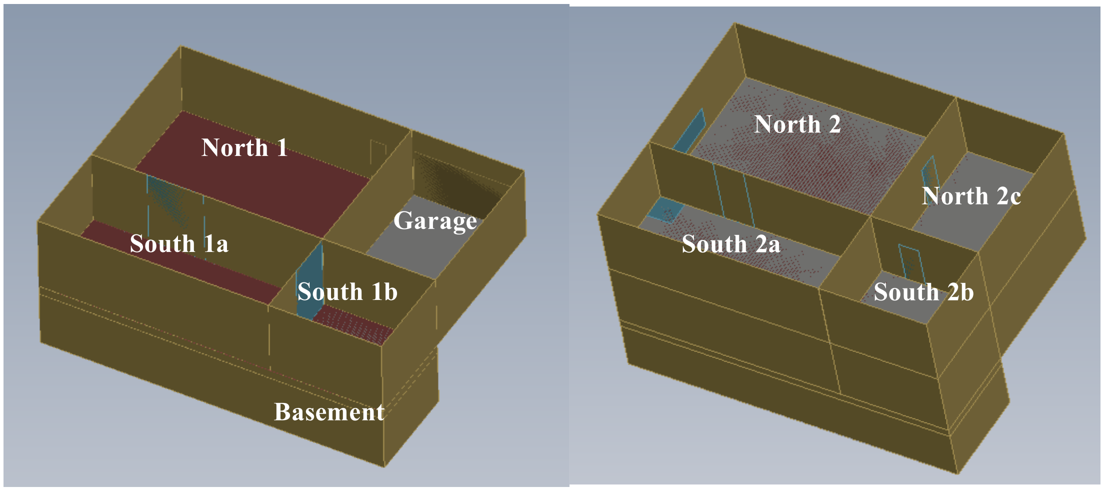

Figure 20: Floor Plan and Thermal Zones for Advanced House

Insulation levels were not increased for the basement walls, and walls between the house and garage, as this walls have much less heat loss than the other parts of the envelope. The window typology simulated contains one intermediate mullion per window, however in reality some windows would likely have two and others would have none.

Zone air temperatures were verified initially (simulating using the Ottawa weather file), and furnace airflow rates to each zone were adjusted to ensure the temperature in each slave zone did not fall below 19˚C, and had an approximate average of 20˚C, or higher for south zones.

5.4 Results

5.4.1 Thermal Performance

Table 12 summarizes the results for all scenarios and locations by providing the minimum, maximum and average values for SHF, and space heating energy consumption.

Table 12 - Results Summary

	SHF	Space Heating Gas Consumption (GJ)	Space Heating Gas Consumption Intensity (kWh/m^2.yr)
Average	38%	59.9	80.0
Maximum	69% (Ottawa)	134.4 (Yellowknife)	179.5
Minimum	17% (Yellowknife)	15.5 (Vancouver	20.7

* based on 208m^2 floor area (excludes basement)

In all scenarios and cities the south facing windows had a net energy gain over the heating season; as shown in Figures 21 and 22, increasing south facing window area always resulted in lower heating energy consumption. Figures 21 and 22, below, show the detailed simulated space heating energy consumption for each city considered, in GJ of natural gas. The locations are arranged in order of increasing heating degree days (HDD). The first scenario, referred to as Sun Tempered, is the reference case model of the CCHT house simulated for the respective climate.

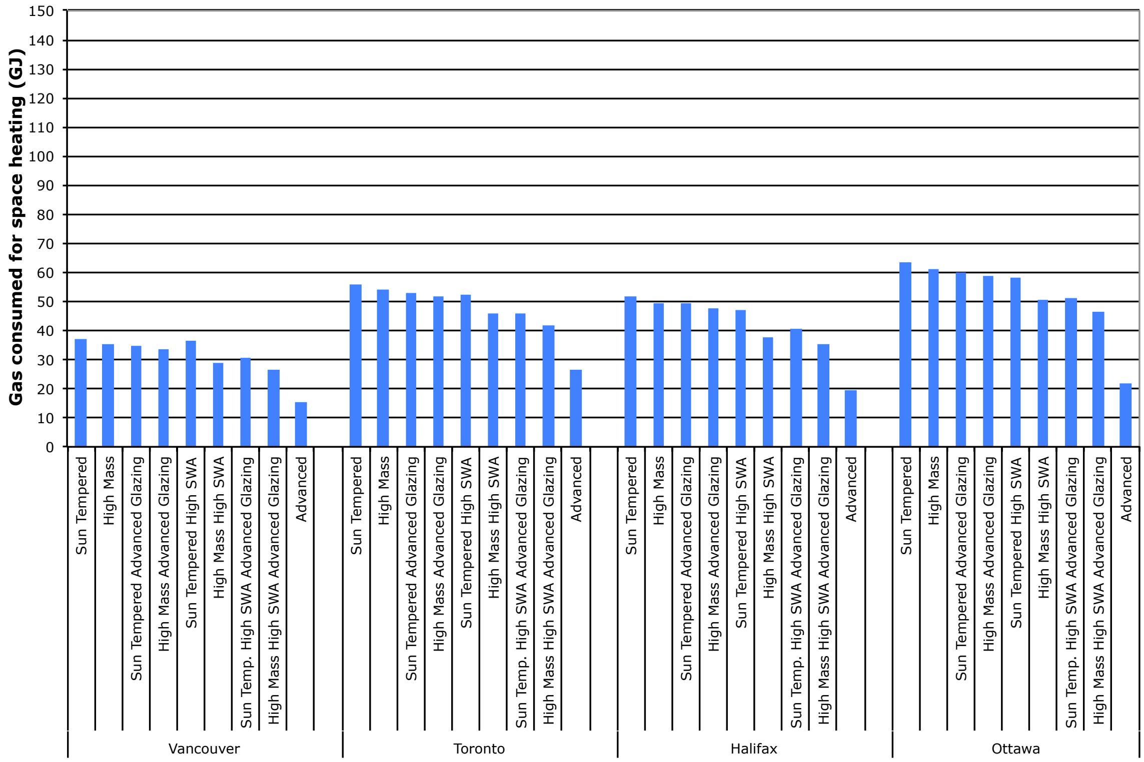

Figure 21: Furnace Gas Consumption Results: Warmer Locations

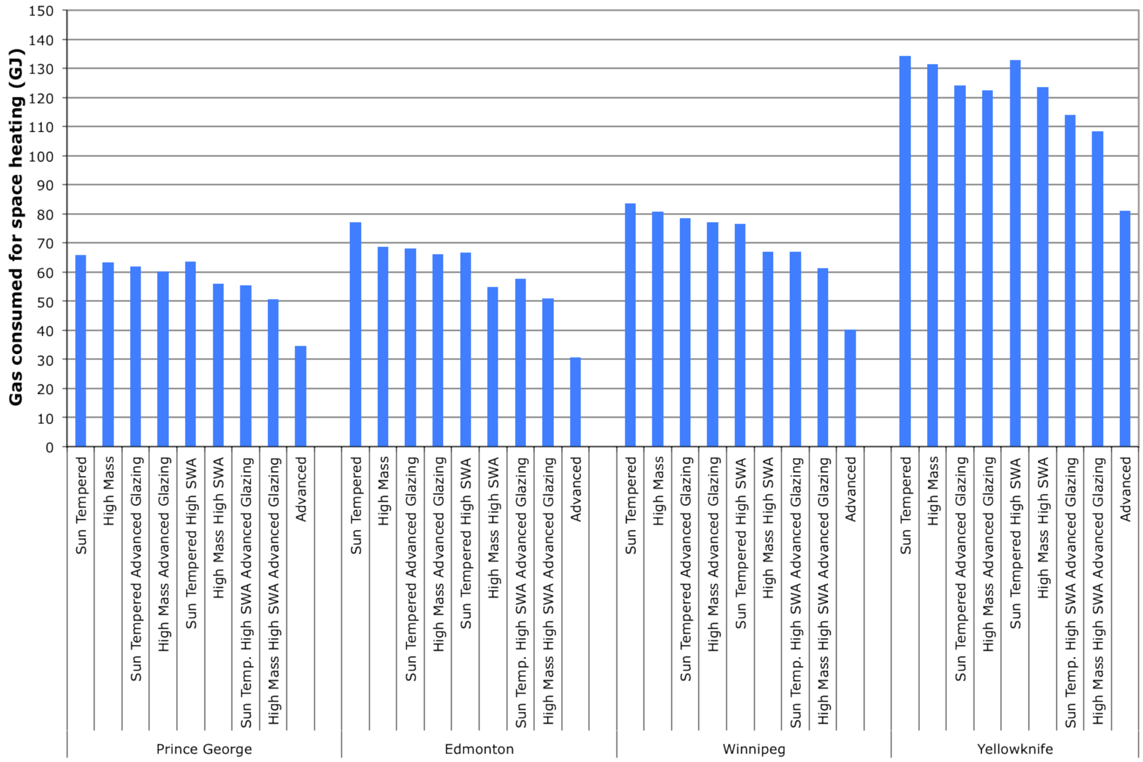

Figure 22: Furnace Gas Consumption: Cooler Locations

In all cases the highest space heating energy consumption is in Yellowknife, and the lowest is in Vancouver. Space heating energy consumption increases with increasing heating degree days, with the exception of Toronto which has lower heating degree days than Halifax yet exhibits higher heating energy consumption. This overall trend suggests that heating degree days influence energy consumption more than solar radiation for passive solar houses.

The results for solar heating fractions are shown below in Figures 23 and 24.

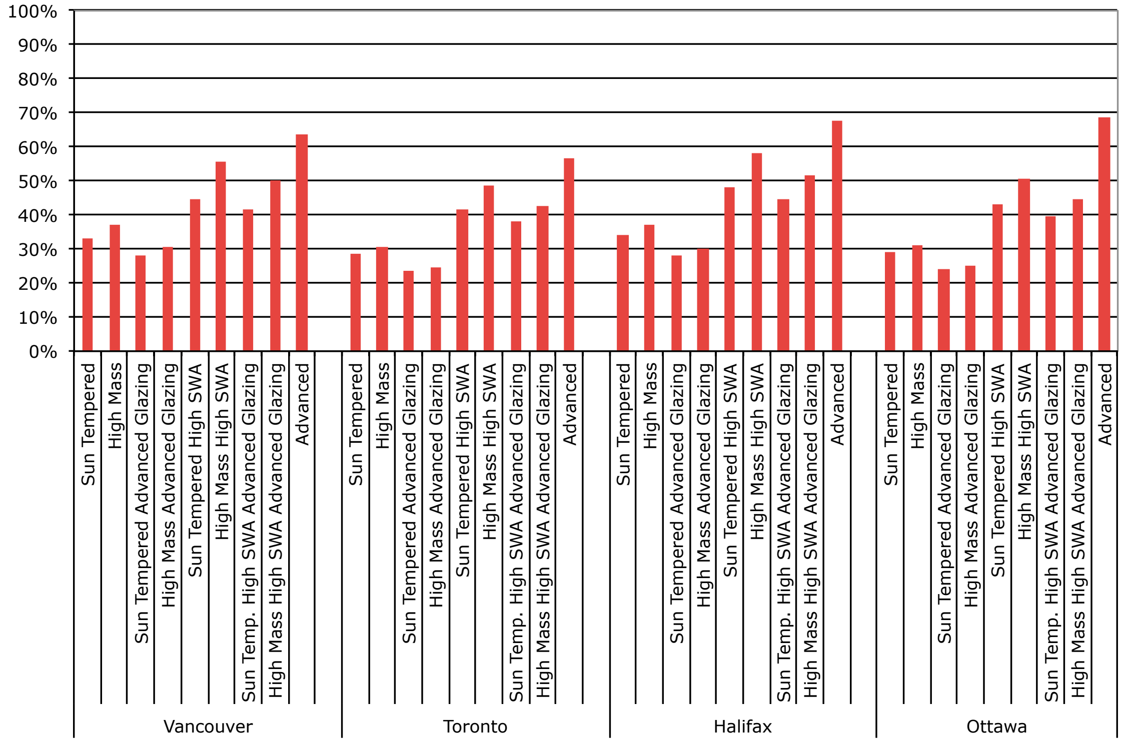

Figure 23: Solar Heating Fractions: Warmer Locations

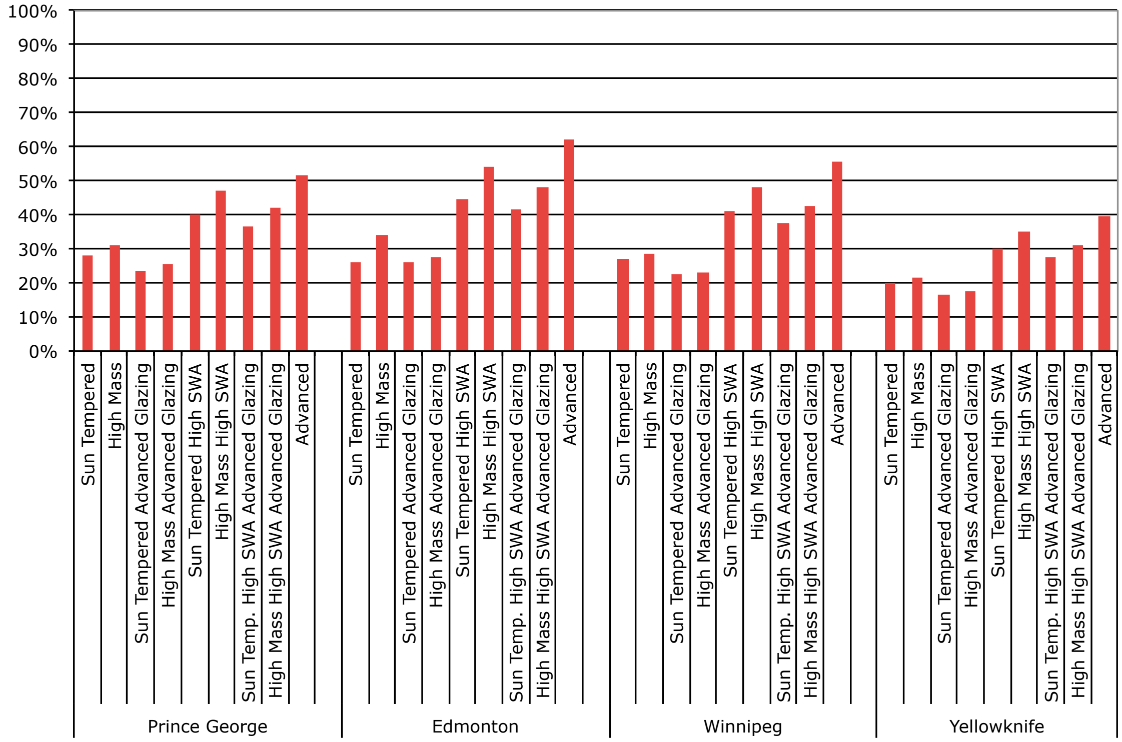

Figure 24: Solar Heating Fractions: Cooler Locations

The solar heating fraction is typically highest in Halifax, with three exceptions where it is higher in Vancouver. For all locations the high mass, high SWA scenario achieves the highest solar heating fraction of the CCHT design scenarios. The solar factions achieved for the improved scenarios are considerably higher in all locations. In all cases the addition of the advanced glazing lead to a lower SHF. This is likely explained by the lower SHGC. In all cases advanced glazing reduced energy consumption. The Advanced house scenario achieves the highest solar fraction in Ottawa. For all scenarios the SHF is lowest in Yellowknife.

A parameter study was conducted on the results to determine the incremental energy savings achieved by changes to each of the three input parameters studied. Because all combinations of the input parameters variables were simulated, for each location there are three pairs of scenarios which only differ by one input parameter. For each of these pairs, the incremental energy savings associated with each given parameter was quantified as a percent reduction relative to the scenario where the given parameter is not present. For example, the savings for thermal mass was calculated as follows for the first scenario pair:

$$\% \text{ Savings } (1) = (E_{SunTempered} - E_{HighMass}) / E_{SunTempered} \qquad \textbf{(5-1)}$$

The average reduction in energy consumption due to added thermal mass ranged from 1.4% (in Yellowknife, sun tempered) to 20.2% (in Vancouver), with an average of 8%. The energy savings from thermal mass was largest for the cases with the double glazing, and for higher south window areas. Energy savings from increasing window area ranged from 1.1% (Yellowknife sun tempered) to 25.7% (Halifax, high mass advanced glazing), with an average of 14%. Energy savings from changing to advanced glazing was more modest, ranging from 2.6% (Halifax, high mass) to 15.5% (Vancouver, high SWA), with an average of 8%.

5.4.2 Overheating Assessment

Although assessment of thermal comfort and overheating is not a focus of this research, overheating potential was considered to ensure the validity of the results. According to CMHC (1998) occupants will find conditions comfortable if the temperature does not exceed 4˚C above the thermostat set point for 4% of the time during sunny periods. Applying this rule to the actual CCHT thermostat set point, of 22˚C, 26˚C was used as a benchmark for overheating analysis, a value also used in other passive solar studies (eg. CMHC 1998, O'Brien et al. 2011). The advanced house does not exceed 26˚C in any zones during occupied periods from the beginning of October to the end of May (which is approximately the heating season), despite the south high glazing to floor area ratio. The temperature profile for the warmest zone (South 2a) for the Advanced house is shown below in Figure 25.

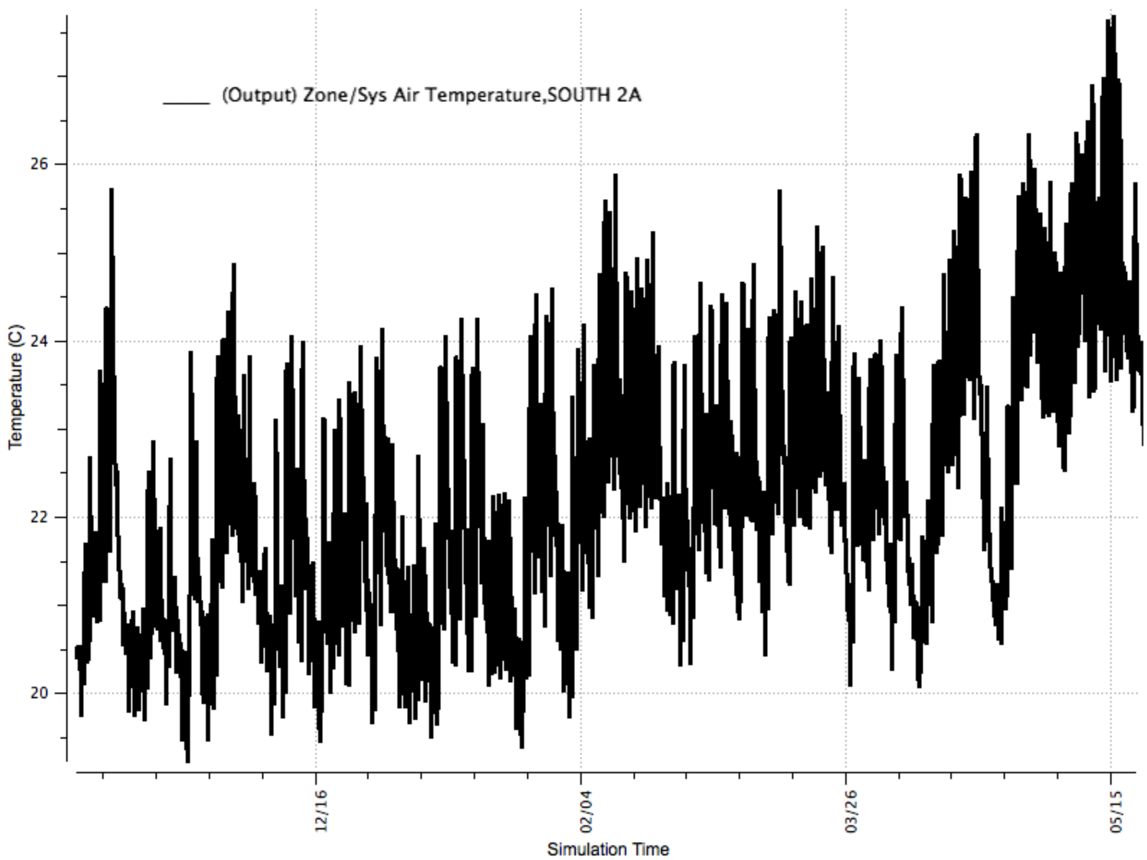

Figure 25: Advanced House Temperature Profile (Zone S2a)

The worst case scenario for overheating is the Sun Tempered High SWA case, the temperature profile for the south 2a, is shown below in Figure 26. The temperature exceeds 30˚C routinely during sunny periods throughout most of the heating season, with a maximum temperature of 33.6˚C during mid March. Although these temperatures are very high, they appear quite feasible given that temperature peaks of up to 27.2˚C have been recorded in the same zone of CCHT house during mid February (Manning et al. 2008) and in the High SWA case the south window area of this zone has more than doubled.

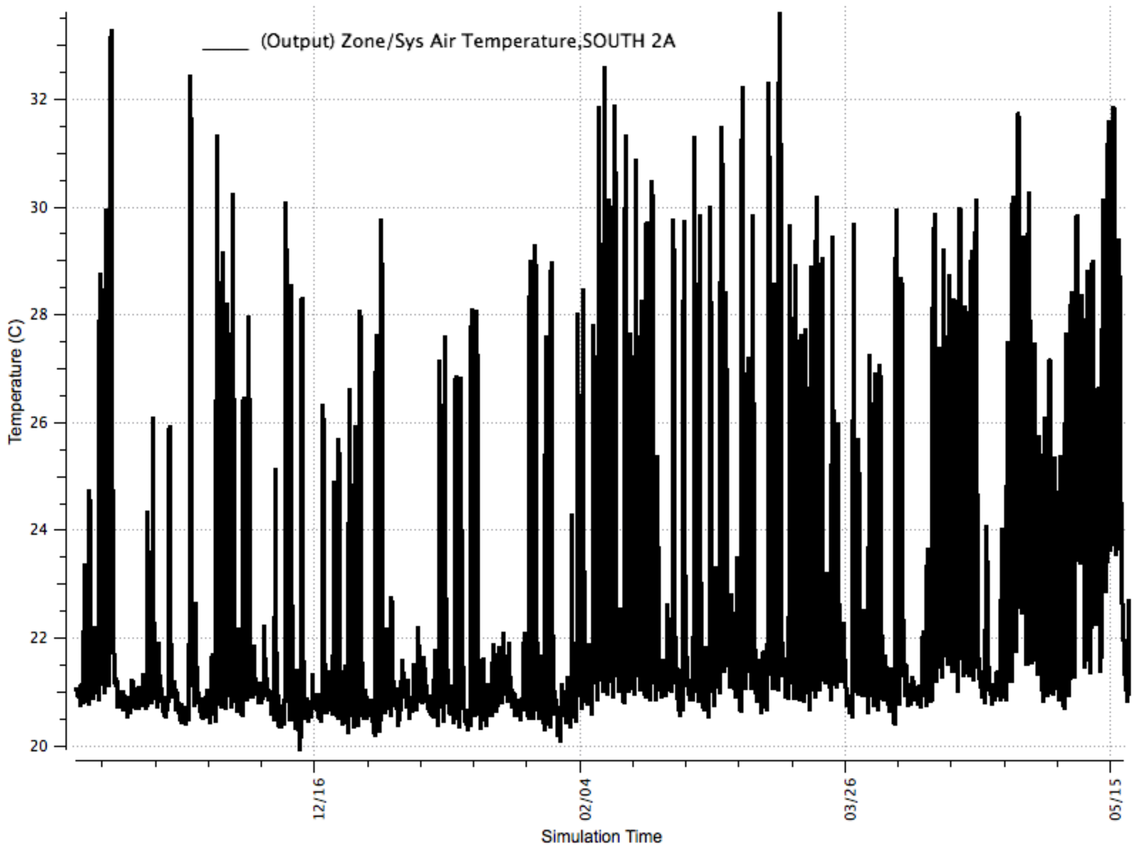

Figure 26: Sun Tempered High SWA Temperature Profile (Zone S2a)

Despite the extreme temperatures predicted for this scenario, overheating (above 26˚C) occurs rarely for any zone while it is occupied. The south zones in the CCHT house are areas of lower occupancy, including a bathroom, entryway (modelled as unoccupied), two bedrooms and the living room. The bedrooms are only occupied during the night and early morning, and the living room is only occupied during the late evening. Table 13, below, summarizes the maximum time the temperature exceeds 26˚C in any zone, during an occupied period.

Table 13 – Frequency of Overheating for Sun Tempered High SWA Scenario

Winter	0 %
April	0.2 %
May	1.0 %
October	0.6 %
November	0.1 %

The Sun Tempered High SWA Advanced Glazing scenario, is the second worst scenario for overheating, however the peaks are considerably lower due to the lower SHGC of the advanced windows. As shown below in Figure 27, temperatures in the South 2a zone reach a maximum of 32˚C during mid-march and a majority of temperature peaks being between 26˚ and 29˚C.

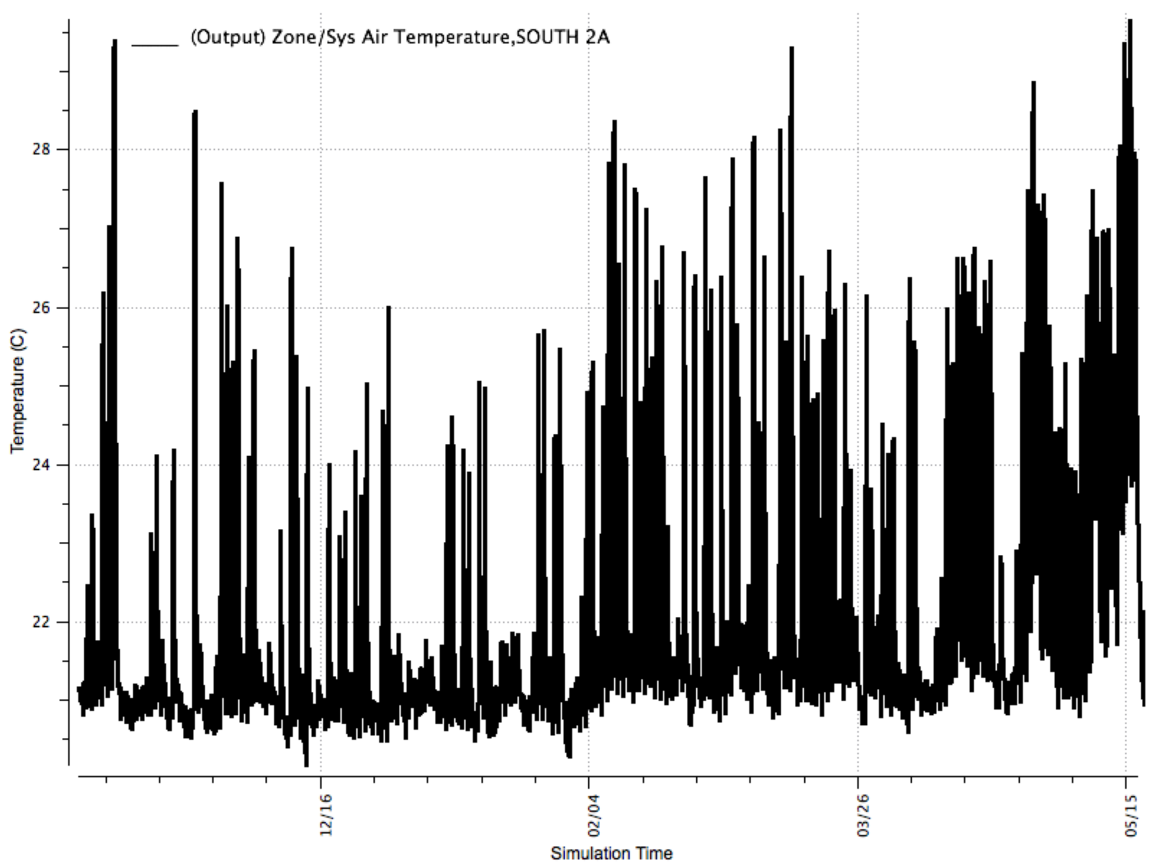

Figure 27: Sun Tempered High SWA Advanced Glazing Temperature Profile (Zone S2a)

Even though both of these scenarios, would likely meet comfort requirements for almost all hours occupied for the assumed occupancy pattern, there are other implications of allowing such extreme temperatures. For example, such designs would likely not be compatible with house plants as most plants are harmed by temperatures above 32˚C (CMHC 1998). With different occupancy patterns more moderate temperatures could be maintained, however more venting of excess solar gains would reduce the energy savings of these scenarios. From this temperature analysis it can be concluded that the results from the scenarios with high SWA and no added thermal mass would are not valid for occupancy usage patterns where south zones are occupied during the day, as additional venting or other measures would be required which would reduce the solar fraction of these scenarios.

A very large reduction in temperature fluctuations is observed with the addition of thermal mass, as shown in Figure 28 below. The addition of thermal mass to the worst case, Sun Tempered High SWA scenario reduces the temperature peaks to below 26˚C for the entire heating season, with the exception of the late spring.

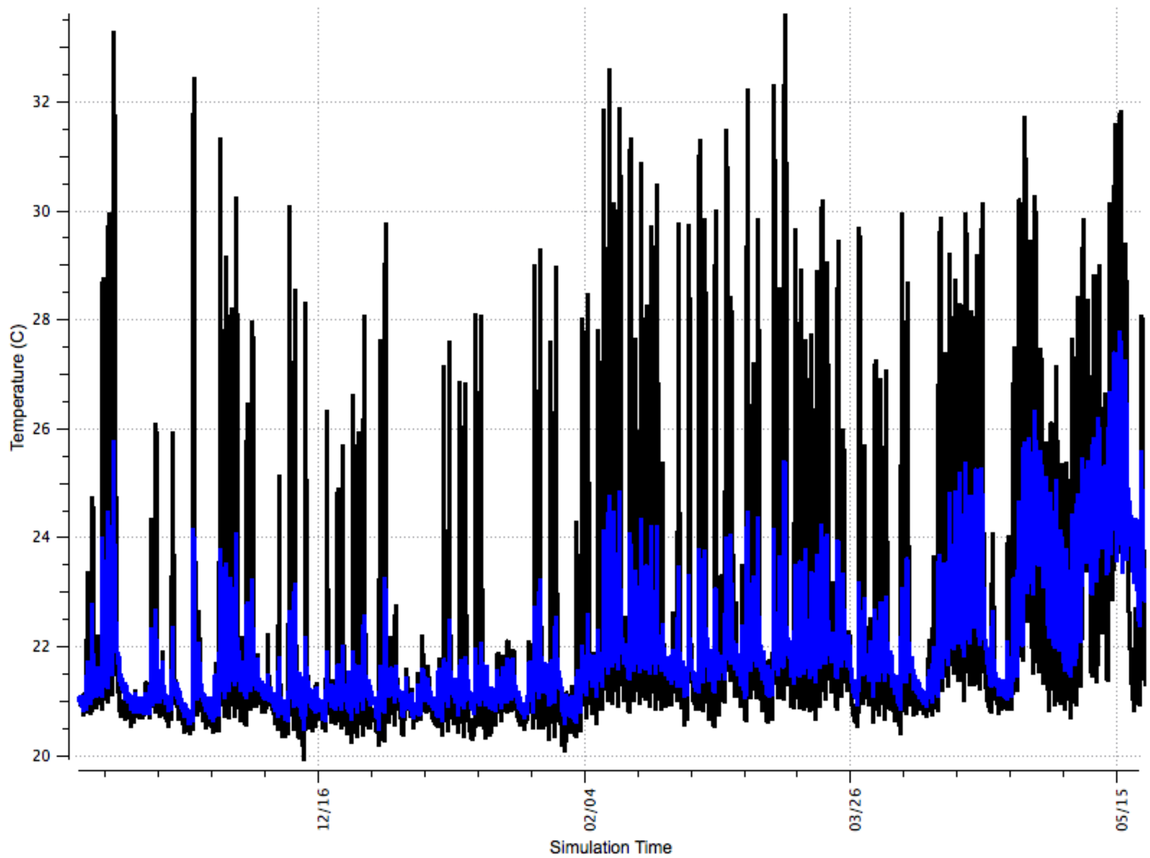

Figure 28: Temperature Profile for High SWA with (blue) and without (black) Thermal Mass (Zone S2a)

5.4 Discussion

The results indicate that even with very basic passive solar design measures, such as the CCHT house as-is, solar gains contribute a considerable fraction of a typical house's heating requirements in cold climates such as Canada (20 to 34%), and with more aggressive passive solar design applied to a typical house (i.e. High Mass High SWA Advanced Glazing) this fraction can be considerably high (35 to 52%). For an Advanced passive solar house predicted solar fractions ranged from 40 to 69%. These results suggest the potential energy savings for passive solar design is considerably higher than previous estimates, such as the 30 to 50% from CMHC 1998. This highlights the importance of solar access for buildings in heating dominated climates. For all typical house scenarios in all of the climate locations considered, south facing windows were found to be energy positive, demonstrated in the results by the reduction in heating energy consumption that occurs when window area is increased.

The results for solar heating fractions in this study are remarkably close to results from Balcomb (1983), which conducted a computer analysis of monitored data from 48 passive solar houses across the US and found an average solar heating fraction of 37% (Balcomb 1983), whereas the average SHF for all of the scenarios considered in this study is 38%. Generally it would be expected that considerably lower SHFs would be achieved in Canada than the US, however the similarity of the US study can likely be explained by the lower insulation levels, and less advanced windows used during the 1980s, and earlier when the houses studied were built.

CMHC's 20 house designs evaluated for Vancouver, Winnipeg and Ottawa; were simulated to have solar heating fractions ranging from 13% (Winnipeg) to 67% (Vancouver), with an average of 34% (CMHC 1998). Their results are typically lower than the findings in this research, which predicts an average SHF for Vancouver, Winnipeg, and Ottawa of 40%. CMHC's maximum predicted SHF for Vancouver is higher than predicted by this research (67% cf. 63%). The work by CMHC was carried out using DOE-2, therefore it is likely that some of the discrepancy is due to refinements made to EnergyPlus and DOE-2, one of such being the introduction of sub-hourly timesteps. SHFs of 0.34 to 0.53 were observed in Canada by (Barakat 1984) for simple one-zone test units, with only south facing glazing in Ottawa. A more recent example, the Alstonvale Net Zero Energy House (NZEH), near Montreal (Canada), had a predicted passive SHF of approximately 60% (Candanedo and Athienitis 2009). The high solar heating fraction can also be attributed to the high level of thermal performance. The Alstonvale NZEH has much higher thermal resistance values than the CCHT Twin houses, with R values of 5.6, 12, 4.6 m^2K/W in the walls, roof and floor, respectively (Candanedo et al. 2012).

The results from this study support the south facing window areas suggested by CMHC (1998) for sun tempered (low mass) designs. However for high mass designs the results indicate the higher SWA values recommended by Charron and Athienitis (2006) may be desirable, due to the very high solar fraction that can be achieved, and the understanding that with a south facing glazing to floor area ratio of 15.4% thermal comfort can still be maintained during occupied hours for high mass designs. Similarly, for the Advanced house thermal comfort is maintained even though the SWA to floor area ratio is 20%. This suggests that with careful design larger window areas may be feasible. For advanced glazing, SHGCs tend to decrease with decreasing U values, due to increased number of glazing lites, and coating selection. With lower SHGCs it is expected that larger glazing areas can be exploited, however, the results of this research support the notion that careful analysis is required for each climate and floor plan. However, it should be noted that this conclusion would not be valid for floor plans and usage patterns where south zones are frequently be occupied during sunny periods.

The results from this research depend on many input parameters that are uncertain or vary for different site conditions and house designs. These results are only valid for sites which are un-shaded during the heating season. Heating energy savings for the designs considered would be close to the total energy savings, however for house designs without movable shading, cooling load would increase with increasing window area. The implications that climate change presents to these results is uncertain, however it is expected that general warming trends would cause the results of this study to over predict energy consumption. Changes to floor plans and usage patterns would affect the results of this study considerably, as the energy savings associated with larger temperature swings during unoccupied periods would be reduced if these zones were more rigorously controlled (eg. if occupied). It is expected that the uncertainty and error in the results will increase as scenarios depart further from the calibrated reference case.

5.4.1 Implications for Simulation

The results of the final multi-zone were compared to previous results to gain insight into the implications of the various levels of simulation detailed employed in the three major versions of the model. Table 14, summarizes the main differences between each version of the simulation model.

Table 14 - Comparison of Simulation Models

Model	Description	Major Assumptions / Details added
Version 1	Simple single zone model (Zirnhelt and Richman 2011)	Simple window model used (U and SHGC)
Version 2	Detailed single zone model	Detailed window model, Enhanced Infiltration model, detailed thermal bridging calculations
Version 3	Detailed multi-zone model	Venting excess solar gain, Window reveals added, revised thermal bridging, detailed revised internal heat gain including garage, 30 timesteps / hours

Figure 29, below, presents the predicted space heating gas consumption for all three versions of the model. The results presented in Zirnhelt and Richman (2011) did not cover all of the scenarios covered in the subsequent work.

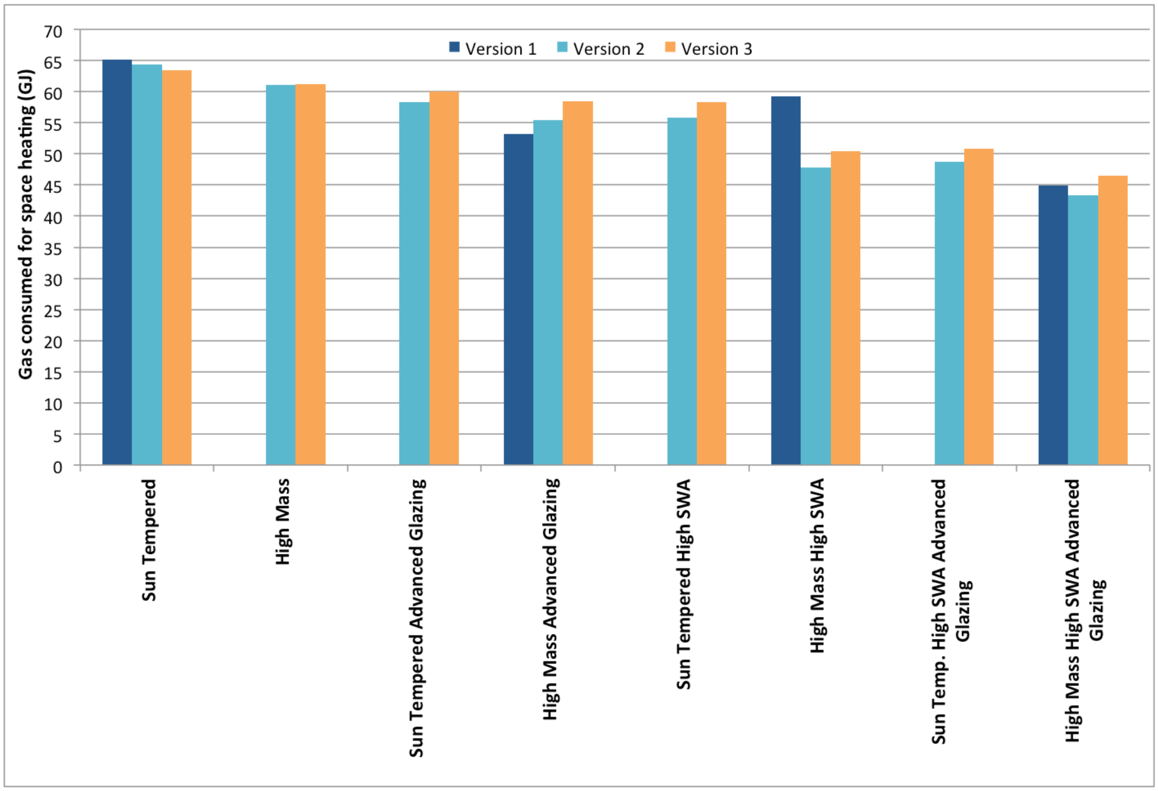

Figure 29: Model Results Comparison: Furnace Gas Consumption

The predicted energy consumption values for the three version of the model were fairly consistent, with typical variations being on the order of 5%. The relatively small difference was not expected, as errors in a simulation model could multiply with extrapolation. It is expected that the use of calibration was a factor in the relatively small difference between the results. This suggests simpler models may be appropriate for predicting annual energy consumption of a passive solar house, when less resources are available for model development. A larger discrepancy was found between results from the three model versions for SHF, as shown below in Figure 30.

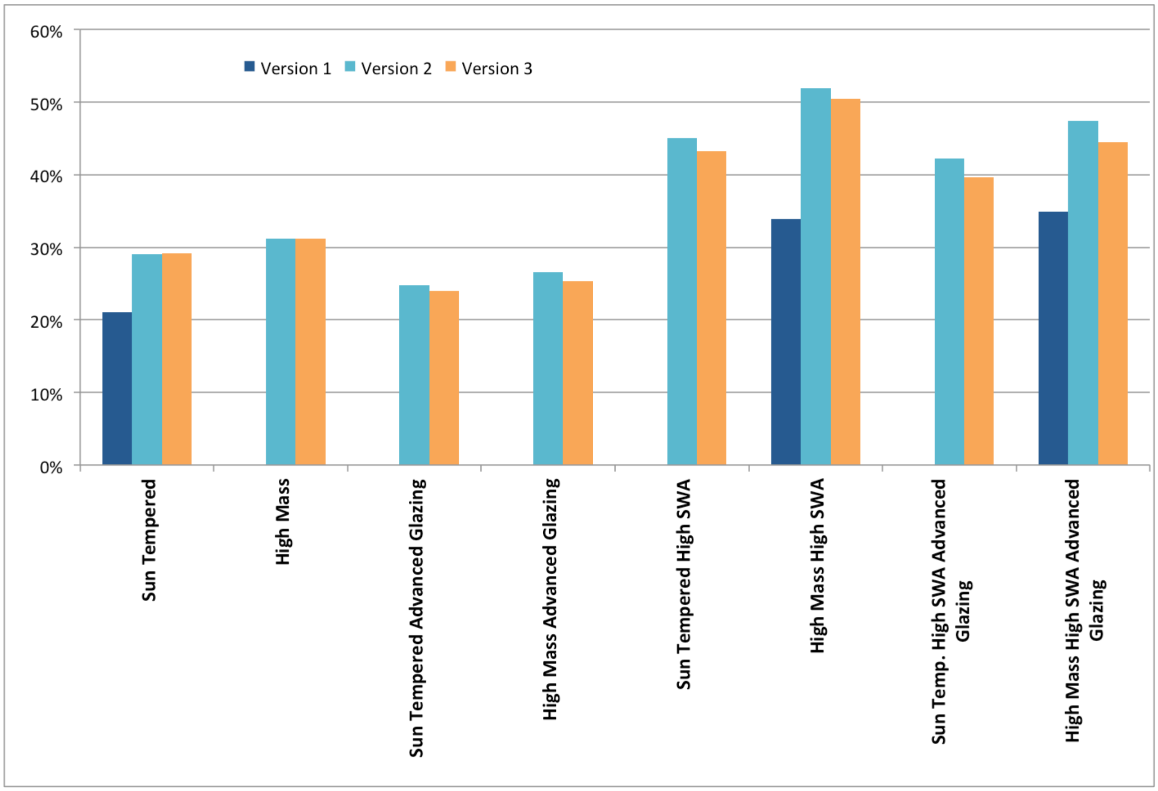

Figure 30: Model Results Comparison: Solar Heating Fractions

The difference between the first and final version of the model ranged from 22% to 33%, highlighting the importance of careful attention to relevant simulation sub-models when predicting the energy savings. It is expected that the main cause of the discrepancy between version 1 and the other versions is the use of the simplified window model. As described in the calibration chapter, the window model had a large influence on results, and other errors existed in version 1 that were compensating for the window model error.

The difference between the predicted SHF from the second version and the final version was much smaller. This is likely explained by the fact that the multi-zone model has a high degree of mixing due to the constant air circulation through the furnace fan, such that the fully mixed assumption may not have been very significant. The final model generally predicted smaller SHFs, this can likely be explained by the venting that was added to the final version. The discrepancy increases with increasing window area.

6. Further Research

The results of this research lay the foundations for further related research. Further simulation work is required to fully understand the relative contribution of the design parameters involved in the advanced passive solar house, such as geometry, elimination of north facing windows, further increased south window area, and increased insulation levels. Further investigation into the added cooling load would is required for house designs that do not employ movable shading.

To further investigate the potential for energy savings and greenhouse gas emission reductions on a broader scale, the results of this research could be combined with building stock modelling. The results from the heating energy calculations could be directly used in cost studies, which could include lifecycle cost analysis of passive solar measures in Canada. Further research on the incremental cost of passive solar measures such as adding thermal mass and increased window area is warranted by the promising results from this research. Given the typically low incremental cost of passive solar design and the high predicted energy savings, passive solar may prove to be highly economical. In addition to lifecycle cost, lifecycle analysis including evaluation of operational and embodied GHG emissions should be carried out.

7. Conclusion

Estimates of the potential energy savings from passive solar houses in a range of Canadian climates were produced, based on a calibrated EnergyPlus model of the CCHT Reference House, a representative sample of new Canadian single-family dwellings. The results indicate that solar gains contribute a considerable fraction of a typical house's heating requirements in Canadian climates, (20% to 34%), and with more aggressive passive solar design applied to a typical house this fraction can be considerably high (35% to 52%). For an advanced passive solar house predicted solar fractions ranged from 40% to 69%. These results are typically higher than previous estimates, and show that passive solar large potential energy savings even in the far North. The highest energy savings are achieved in the coldest climates, where space heating energy consumption is the highest. The highest solar heating fractions occur in areas where solar radiation is high relative to envelope losses. Based on the simulation results, very large solar fractions (up to 69%) can be achieved if the architecture is optimized for passive solar collection and has high envelope thermal resistance values. In all locations for the design scenarios considered, south facing windows were found to be energy positive over the heating season.

The results from this study could be used to support policies that encourage passive solar design, and policies such as the Right to Light law in the UK, which protects the solar exposure of existing buildings (Waltham Forest Council 2011); and the City of Campbell River's official community plan, which requires the consideration of passive solar design for new developments (City of Campbell River 2012).

References

Anderson, K. and Bows, A., 2011. Beyond 'dangerous' climate change: emission scenarios for a new world. *Philosophical transactions of the Royal Society A,* 369. 20 – 44.

Armstrong, M., Ruest, K., Swinton, M., 2011. Assessing the impact of cold climate on basement temperatures. National Research Council Canada.

ASHRAE, 2002. ASHRAE Guideline 14-2002, Measurement of Energy and Demand Savings. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta.

ASHRAE 2008. HVAC Systems and Equipment. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta.

ASHRAE 2009. Fundamentals. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta.

Athienitis, A., 1997. Investigation of thermal performance of a passive solar building with floor radiant heating. *Solar Energy 61(5).*

Athienitis, A., 2007. Design of a solar home with BIPV-thermal system and heat pump. 2nd Canadian Solar Buildings Conference Calgary, June 10 – 14, 2007.

Augenbroe, G., 2002. Trends in building simulation. *Building and Environment 37*, 891 – 902.

Balcomb, J.D., 1983. Evaluating the performance of passive solar heated buildings. Proc. 6th Technical Conference of the ASME Solar Division, Orlando, FL, April 19-21, 1983. Retrieved November 8, 2012 from http://www.osti.gov/energycitations/purl.cover.jsp?purl=/6441698-Dclj0q/

Balcomb, J.D. (ed), 1992. Passive Solar Buildings. MIT Press, Cambridge, MA.

Balcomb, J.D. and Jones, R. 1983. (eds). Passive Solar Design Handbook Volume 3. New York, NY: American Solar Energy Society.

Balcomb, J.D. and Jones, G., 1985. Natural air motion in passive solar buildings. Solar Buildings: Realties for Today, Trends for Tomorrow. Washington, D.C. March 18-20th 1985.

Barakat, S.A., 1982. Passive solar design heating studies at the division of building research. Building Research Note 188. Division of Building Research, National Research Council of Canada. Retrieved August 2011 from http://nparc.cisti-icist.nrc-cnrc.gc.ca/npsi/ctrl?action=rtdoc&an=5210181&article=18&lang=en

Barakat, S.A., 1984. NRCC Passive solar design test facility: performance of direct-gain units. Building Research Note 215. Division of Building Research, National Research Council of Canada. Retrieved August 2011 from http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/brn/brn215/brn215.pdf

Burch, J., Wortman, D., Judkoff, R., Hunn, B., 1985. Solar energy research institute (SERI) validation test house site handbook. SERI research report.

BRANZ (Building Research Association of New Zealand) 2004. R-values and cavities. Retrieved October 2012 from http://www.branz.co.nz/cms_show_download.php?id=6d94af4d279466880e748b2d382c7998e6fde45b

Candanedo, J. and Athienitis, A., 2009. A systematic approach for energy design of advanced solar houses. IEEE Electrical Power & Energy Conference.

CCHT (Canadian Centre for Housing Technology), 2010. Twin Research Houses.

Retrieved July 2011 from http://www.ccht-cctr.gc.ca/eng/twin_houses.html

Chan, H., Riffat, S., Zhu, J., 2010. Review of passive solar heating and cooling technologies. *Renewable and Sustainable Energy Reviews 14.*

Charron, R., and Athienitis, A., 2006. Design and optimization of net zero energy solar homes. ASHRAE Transactions 112 (2), 285–295.

Chiras, D. 2002. The Solar House: Passive Solar Heating and Cooling. White River Junction, Vermont: Chelsea Green Publishing.

CMHC (Canada Mortgage and Housing Corporation), 1998. Tap the Sun: Passive solar design techniques and home designs. CMHC, Canada (out of print).

Crawley, D., et al., 2004. EnergyPlus: New, capable, and linked. *Journal of Architecture and Planning Research 21(4),* 292 - 302.

Crawley, D., Hand, J., Michael, K., Griffith, B., 2008. Contrasting the capabilities of building energy performance simulation programs. *Building and Environment 43,* 661-673.

DOE-2, n.d., Table 2.3 solar absorptance for various exterior surfaces. Loads 2.11. Retrieved October 24th 2012 from http://simulationresearch.lbl.gov/dirpubs/BASIC/lds2.pdf

EnergyPlus, 2012. Auxiliary EnergyPlus Programs.

EnergyPlus, 2012. EnergyPlus Engineering Reference.

EnergyPlus, 2012. EnergyPlus Input Output Reference.

EMR (Energy, Mines and Resources Canada), 1984. Super energy efficient housing and solar orientation: A research report. Ottawa: Energy, Mines and Resources Canada.

Gu, L., 2007. Airflow network modeling in EnergyPlus. 10th International Building Performance Simulation Association Conference and Exhibition on September 3-6, 2007 in Beijing, China.

Gusdorf, J., Swinton, M.C., Entchev, E., Simpson, C., Castellan, B., 2002. The impact of ECM furnace motors on natural gas use and overall energy use during the heating season of CCHT research facility. Gas Technology Institute's First Natural Gas Technologies Conference and Exhibition, Orlando, Florida, Sept. 29-Oct. 2, 2002, pp. 1-15

Gusdorf, J., Armstrong, M., Szadkowski, F., Sager, J., 2011. Summer shading performance of awnings at the Canadian Centre for Housing Technology. CCHT Report B-6041.1

Hachem, C., Athienitis, A., Fazio, P., 2011a. Parametric investigation of geometrical form effects on solar potential of housing units. *Solar Energy 85 (9),* 1864 – 1867.

Hachem, C., Athienitis, A., Fazio, P., 2011b. Investigation of the solar potential of housing units in different neighborhood designs. *Energy and Buildings 43,* 2262-2273.

Haggard, K., Bainbridge, D., Aljilani, R., 2009. Passive solar architecture pocket reference. International Solar Energy Society, Freiburg.

Hastings, R., 1995. Myths in passive solar design. *Solar Energy 55* (6).

Henninger, R. and Witte, M., 2007. EnergyPlus testing with building thermal envelope and fabric load tests from ANSI/ASHRAE standard 140-2007. Ernest Orlando Lawrence Berkeley National Laboratory. Retrieved August 2011 from http://apps1.eere.energy.gov/buildings/energyplus/pdfs/energyplus_ashrae_140_envelope.pdf

Hockerton Housing Project, 2011, Southwell, UK. Retrieved April 10, 2011 from http://www.hockertonhousingproject.org.uk

IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: Synthesis Report. Retrieved September 2011 from www.ipcc.ch.

Jones, R., 1992. Analytical Results for Specific Systems. In Balcomb, J. (ed), 1992. Passive solar design Buildings. MIT Press, Cambridge, MA.

Johnson, T., 1981. Solar Architecture: The direct gain approach. McGraw Hill: New York.

Johnson, T., 1992. Materials and Components, In Balcomb, J. (ed), 1992. Passive solar design Buildings. MIT Press, Cambridge, MA.

Judkoff, R., Wortman, D., Burch, J., 1983. Measured versus predicted performance of the SERI test house: a validation study. SERI/TP-254-1953. National Heat Transfer Conference Seattle, WA, 1983.

Kalamees, T., et al., 2008. The distribution of the air leakage places and thermal bridges in Finnish detached houses and apartment buildings. Proceedings of the 8th symposium on building physics in the Nordic countries NSB2008, Copenhagen, Denmark.

Keller, J., and Khuen, C., 2011. A new web-based detailed weather data system providing global support for precision energy modeling, analyses and tracking. 11th International Conference on Enhanced Building Operations, New York, Oct. 18-20, 2011.

Kisilewicz, T., 2007. Computer Simulation in Solar Architecture Design. *Architectural engineering and design management 3*, 106–123.

Langdon, W. 1980. Movable insulation: a guide to reducing heating and cooling losses through the windows in your home. Emmaus, PA: Rodale Press.

Laouadi, A., 2010. Guidelines for effective residential solar shading devices. IRC-RR-300. National Research Council of Canada.

LBNL, n.d., Software Tools. Available at http://windows.lbl.gov/software/

Littlefair, J., 1998. Passive solar urban design: ensuring the penetration of solar energy into the city. *Renewable and Sustainable Energy Reviews 2,* 303-326.

Littlewood, J. and Geens A., 2004. The computer modelling methodology for the dynamic thermal simulation of a two-storey earth sheltered house. *Int. J. of Computer Applications in Technology, Vol. 20, Nos. 1-3.*

Lutz, J., Dunham-Whitehead, C., Lekov, A., McMahon, J., 2004. Modeling energy consumption of residential furnaces and boilers in U.S. homes. Lawrence Berkeley National Lab. Research Report # LBNL-53924.

Manning, M. et al., 2007. The effects of thermostat set-back and set- up on seasonal energy consumption, surface temperatures and recovery times at the CCHT Twin

House Facility. *ASHRAE Transactions 113,* (1), 1-12.

Manning, M. et al., 2008. Summer and winter field monitoring of high and low solar heat gain glazing at the Canadian twin house facility. National Research Council of Canada.

Mithraratne, K. and Vale, B., 2006. Simulation of High Thermal Mass Passive Solar Buildings. *Architectural Science Review 49*, 17-29.

Reddy, T., 2006. Literature review on calibration of building energy simulation programs: uses, problems, procedures, uncertainty and tools. ASHRAE Transactions 112, 226.

Regan, J. and Acklam, D., 1979. Solar reflectivity of common building materials and its influence of the roof heat gain of typical Southwestern U.S.A residences. *Energy and Buildings 2,* 237-248.

Reynolds, M., 1990. Earthship Volume 1. Taos, New Mexico: Solar Survival Press.

Swinton, M., Moussa, H., Marchand, R., 2001. Commissioning twin houses for assessing the performance of energy conserving technologies. Performance of Exterior Envelopes of Whole Buildings VIII: Integration of Building Envelopes, Dec. 2-7, 2001, Clearwater Beach, Florida, pp. 1-10.

Swinton, M. et al., 2004. Adapting and assessing energy conversion technologies for integration in houses. Proceedings of the Joint NSC-NRC Workshop on Construction Technologies, Taipei, Taiwan, April 26-27, 2004, pp. 187-194

Thevenard, D., and Haddad, K., 2006. Ground reflectivity in the context of building energy simulation. *Energy and Buildings 38* (972 – 980).

NRCan, 2008. Hot2000 Software. Retrieved November 25th 2012 from *http://oee.nrcan.gc.ca/residential/new-homes/r-2000/standard/5577*

NRCan, 2011. Comprehensive Energy Use Database Tables. Retrieved November 2012 from http://www.oee.nrcan.gc.ca/corporate/statistics/neud/dpa/trends_res_ca.cfm?attr=0

NRCan, 2012. R-2000 Homes: Continuing a proud tradition. Retrieved November 25, 2012 http://www.nrcan.gc.ca/media-room/news-release/2012/21a/3784

Numerical Logics, 1999. Canadian Weather for Energy Calculations, Users Manual and CD-ROM. Environment Canada, Downsview, Ontario.

O'Brien, W., Kesik, T., Athienitis, A., 2008. The use of solar design days in a passive solar design house conceptual design tool. 3rd Canadian Solar Buildings Conference Fredericton, N.B., Aug. 20-22, 2008.

O'Brien, W., Kesik, T., Athienitis, A., 2011. Thermal zoning and interzonal airflow in the design and simulation of solar houses: a sensitivity analysis. *Journal of Building Performance Simulation,* 1-18.

Purdy, J., and Beausoleil-Morrison, I., 2001. The significant factors in modeling residential buildings. Seventh International IBPSA Conference Rio de Janeiro, Brazil: August 13-15, 2001.

Phillips, B., 1998. Impact of blower performance on residential forced-air heating system performance. ASHRAE Transactions, V. 104, Pt.1, Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Quirouette, R., 1980. Insulated Window Shutters. Building Practice Note. Division of Building Research, National Research Council of Canada. Available at http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/bpn/17_e.pdf

Villi, G., Peretti, C., Graci, S., De Carli, M., 2012. Building leakage analysis and infiltration modelling for an Italian multi-family building, *Journal of Building Performance Simulation 6 (2).*

Walker, I., and Wilson, D., 1998. Field validation of equations for stack and wind driven air infiltration calculations. *International Journal of HVAC&R Research 4*(2).

Zirnhelt, H., and Richman, R., 2011. Residential passive solar design for Canadian cities: assessing the potential. Proceedings of ISES Solar World Congress 2011 rapid transition to a renewable energy world, 28 Aug–2 Sept 2011, Kassel, Germany. Kassel University, Kassel, pp. 678–687

EnergyPlus Index

Appendix A: Measured and Simulated Daily Furnace Gas Consumption

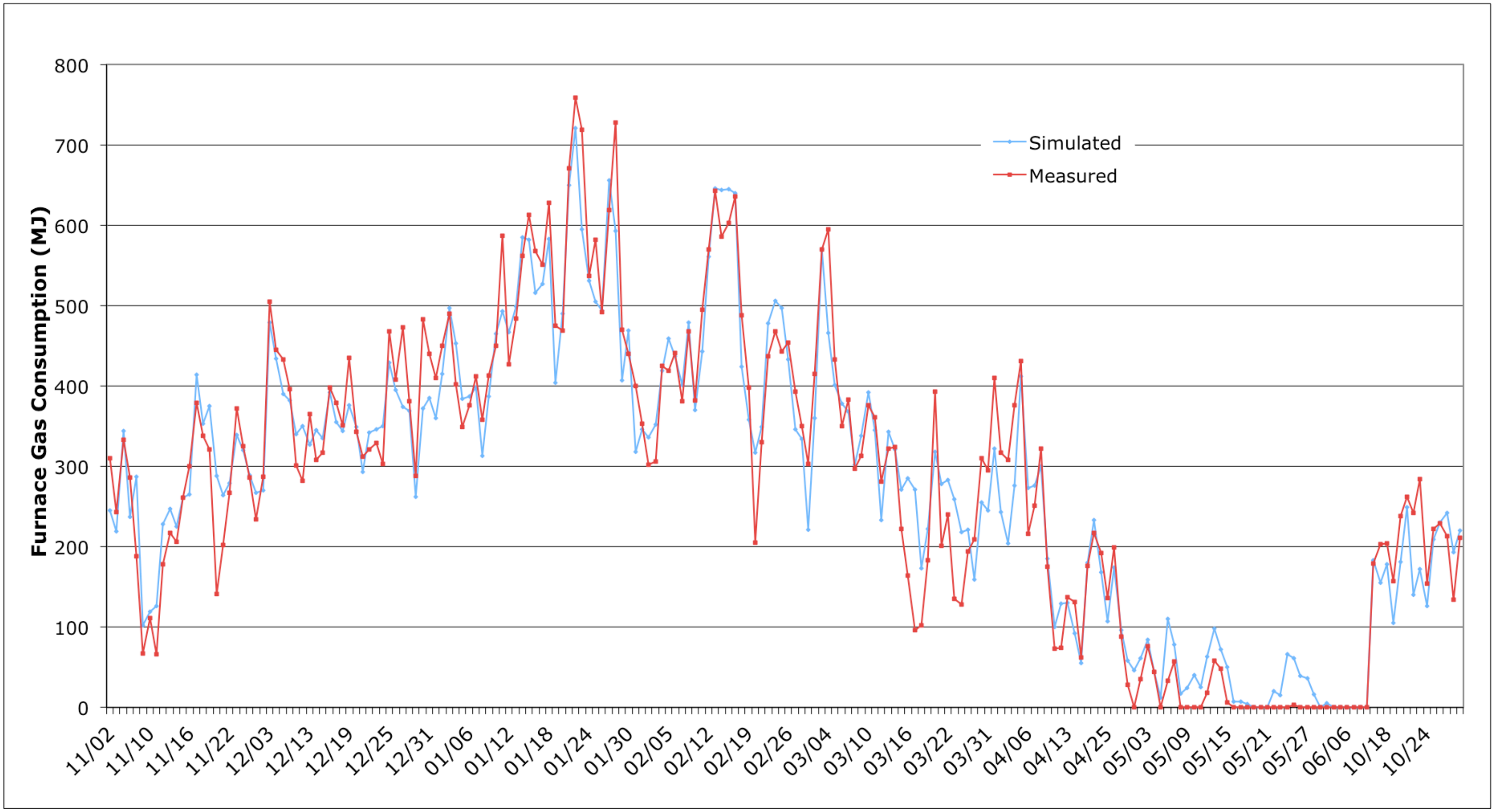

Figure 31: Final calibrated multi-zone model (version 3)

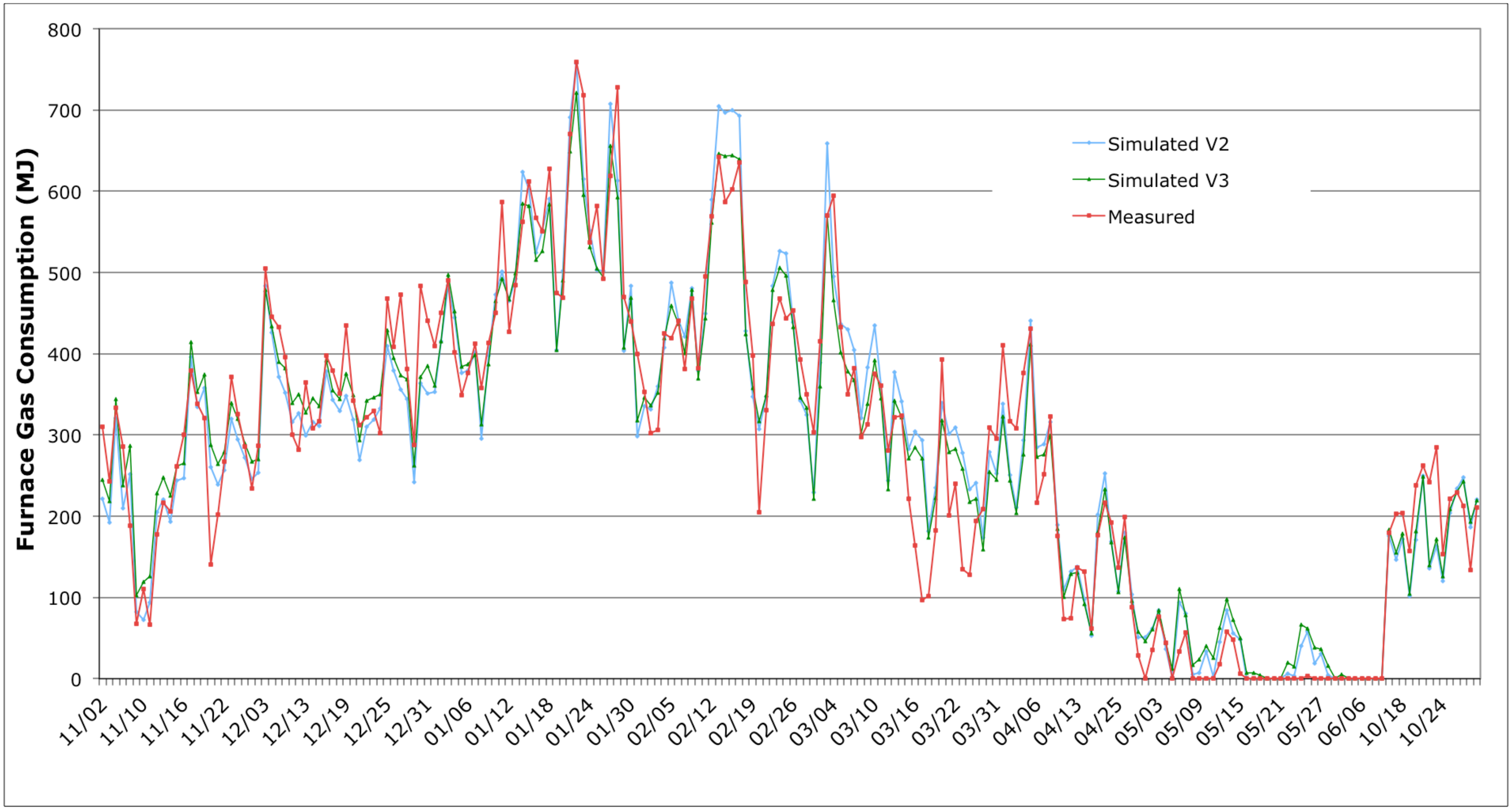

Figure 32: Comparison of model version 2 and 3

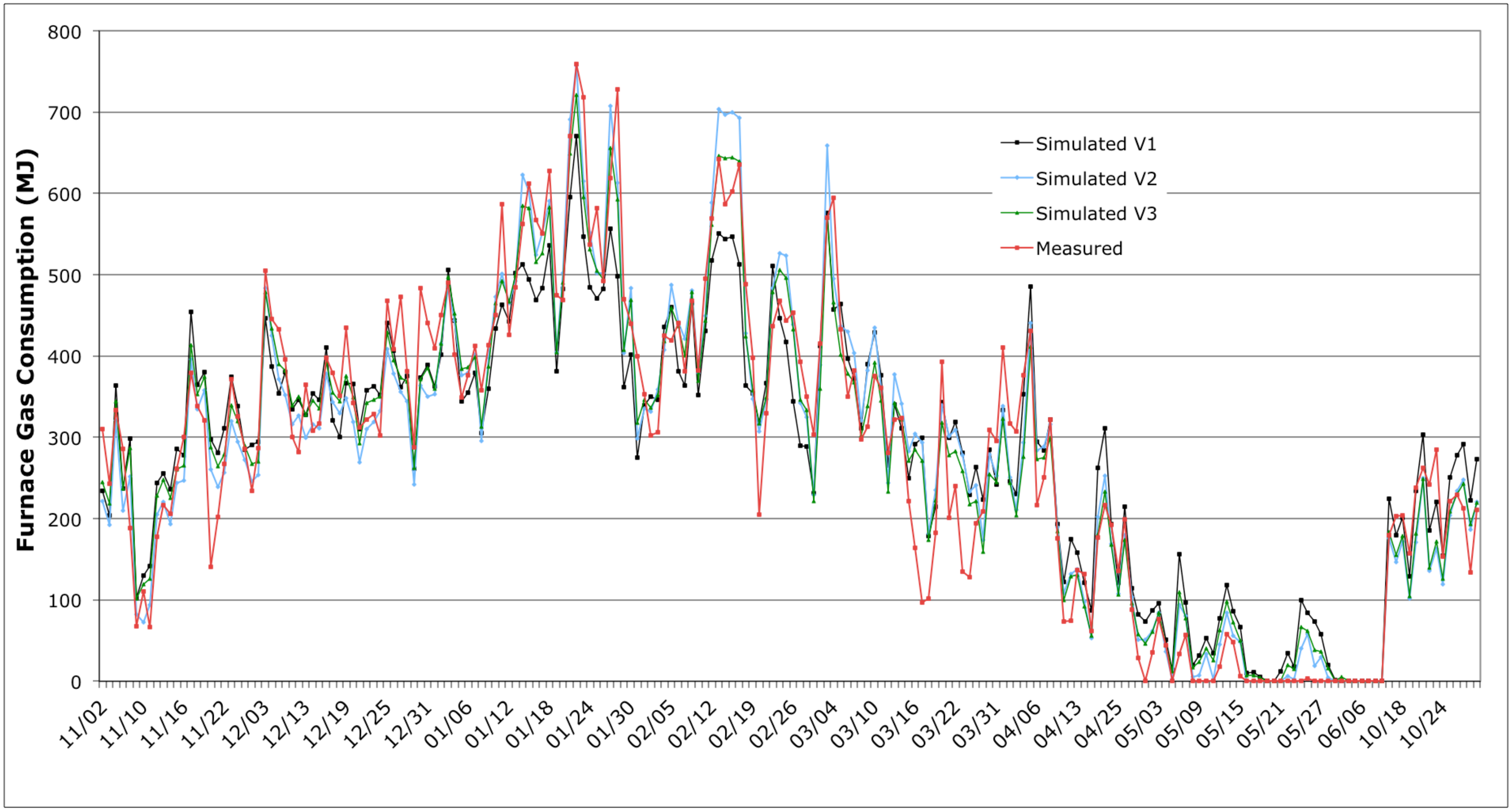

Figure 33: Comparison of model versions 1, 2, and 3

Appendix B: CCHT Reference Model Input Data File (idf)

```
!- CCHT REFERENCE HOUSE
!- CREATED BY HAYES ZIRNHELT
!- MAY 2011
!- Updated Dec 2011 - Mar 2012, Oct 2012 – Dec 2012


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

  Version,7.2;

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

  SimulationControl,
    No,                      !- Do Zone Sizing Calculation
    No,                      !- Do System Sizing Calculation
    No,                      !- Do Plant Sizing Calculation
    No,                      !- Run Simulation for Sizing Periods
    Yes;                     !- Run Simulation for Weather File Run Periods

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

  Building,
    CCHT REFERENCE HOUSE,    !- Name
    0,                       !- North Axis {deg}
    Suburbs,                 !- Terrain
    0.001,                   !- Loads Convergence Tolerance Value
    0.005,                   !- Temperature Convergence Tolerance Value {deltaC}
    FullInteriorAndExteriorwithreflections,  !- Solar Distribution
    100,                     !- Maximum Number of Warmup Days
    6;                       !- Minimum Number of Warmup Days was 6

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

  ShadowCalculation,
    10,                      !- Calculation Frequency ! was 10
    15000;                   !- Maximum Figures in Shadow Overlap Calculations

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

  SurfaceConvectionAlgorithm:Inside,AdaptiveConvectionAlgorithm;

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

  SurfaceConvectionAlgorithm:Outside,AdaptiveConvectionAlgorithm;

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

  HeatBalanceAlgorithm,ConductionTransferFunction,200;

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

ZoneAirHeatBalanceAlgorithm, ThirdOrderBackwardDifference; !- Choices are ThirdOrderBackwardDifference
(default), AnalyticalSolution, EulerMethod

!-   ===========  ALL OBJECTS IN CLASS: ZONECAPACITANCEMULTIPLIER:RESEARCHSPECIAL
===========
```

```
    ZoneCapacitanceMultiplier:ResearchSpecial,
  1,                  !- Temperature Capacity Multiplier
  1,                  !- Humidity Capacity Multiplier
  1,                  !- Carbon Dioxide Capacity Multiplier
  1.0;                !- Generic Contaminant Capacity Multiplier

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

 Timestep,30;      !- per hour 10 = 60/10 = 6mins 60/20 = 3

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

 ConvergenceLimits,
  0,              !- Minimum System Timestep {minutes} (was 0) 1 is minimum
  30,             !- Maximum HVAC Iterations
  2,                  !- Minimum Plant Iterations - default = 2
  8;              !- Maximum Plant Iterations - default = 8

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

 RunPeriod,
  EPW 2002-2003 Annual Sim,!- Name
  11,                 !- Begin Month
  1,                  !- Begin Day of Month
  10,                 !- End Month - was Oct
  31,                 !- End Day of Month - was 31
  UseWeatherFile,         !- Day of Week for Start Day
  No,                 !- Use Weather File Holidays and Special Days
  No,                 !- Use Weather File Daylight Saving Period
  Yes,                !- Apply Weekend Holiday Rule
  Yes,                !- Use Weather File Rain Indicators
  Yes,                !- Use Weather File Snow Indicators
  1;                  !- Number of Times Runperiod to be Repeated

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

 RunPeriodControl:DaylightSavingTime,
  1st Sunday in April,     !- Start Date
  Last Sunday in October;  !- End Date

!-  =========== ALL OBJECTS IN CLASS:SITE:GROUNDTEMPERATURE:BUILDINGSURFACE  ========


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

SurfaceProperty:OtherSideCoefficients,
 surfPropOthSdCoefBasementAvgWall,    !- Name
 0.0,                        !- Combined Convective Radiative Film Coefficient
 1.0,                        !- Constant Temperature
 1.0,                        !- Constant Temperature Coefficient
 0.0,                        !- External Dry-Bulb Temperature Coefficient
 0.0,                        !- Ground Temperature Coefficient
 0.0,                        !- Wind Speed Coefficient
 0.0,                        !- Zone Air Temperature Coefficient
 scheduleOSCBasementWallSurfaceTemp,  !- Constant Temperature Schedule Name
 No,                          !- Sinusoidal Variation of Constant Temperature Coefficient
 24;                         !- Period of Sinusoidal Variation

Schedule:Compact,
 scheduleOSCBasementWallSurfaceTemp,  !- Name
 Temperature,                 !- ScheduleType
 Through:   1/31,             !- Field
```

```
          For:AllDays,                    !- Field
  Until:24:00,                 !- Field
  3.450,                       !- Field
  Through:   2/28,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  2.510,                       !- Field
  Through:   3/31,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  5.947,                       !- Field
  Through:   4/30,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  9.446,                       !- Field
  Through:   5/31,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  13.14,                       !- Field
  Through:   6/30,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  16.05,                       !- Field
  Through:   7/31,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  17.67,                       !- Field
  Through:  8/31,              !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  18.45,                       !- Field
  Through:  9/30,              !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  16.81,                       !- Field
  Through:  10/31,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  13.21,                       !- Field
  Through:   11/30,            !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  9.376,                       !- Field
  Through:   12/31,            !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  6.260;                       !- Field


SurfaceProperty:OtherSideCoefficients,
  surfPropOthSdCoefBasementAvgFloor,   !- Name
  0.0,                         !- Combined Convective Radiative Film Coefficient
  1.0,                         !- Constant Temperature
  1.0,                         !- Constant Temperature Coefficient
  0.0,                         !- External Dry-Bulb Temperature Coefficient
  0.0,                         !- Ground Temperature Coefficient
  0.0,                         !- Wind Speed Coefficient
  0.0,                         !- Zone Air Temperature Coefficient
  scheduleOSCBasementFloorTemp,        !- Constant Temperature Schedule Name
  No,                          !- Sinusoidal Variation of Constant Temperature Coefficient
  24;                          !- Period of Sinusoidal Variation
```

```
    Schedule:Compact,
  scheduleOSCBasementFloorTemp,        !- Name
  Temperature,                         !- ScheduleType
  Through:   1/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  16.22,                               !- Field
  Through:   2/28,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  16.85,                               !- Field
  Through:   3/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  18.36,                               !- Field
  Through:   4/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.99,                               !- Field
  Through:  5/31,                      !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.11,                               !- Field
  Through:   6/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.25,                               !- Field
  Through:   7/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  16.60,                               !- Field
  Through:  8/31,                      !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.71,                               !- Field
  Through:  9/30,                      !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.58,                               !- Field
  Through:  10/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.49,                               !- Field
  Through:   11/30,                    !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  16.25,                               !- Field
  Through:   12/31,                    !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  15.98;                               !- Field


SurfaceProperty:OtherSideCoefficients,
  surfPropOthSdCoefSlabAverage,        !- Name
  0.0,                                 !- Combined Convective Radiative Film Coefficient
  1.0,                                 !- Constant Temperature
  1.0,                                 !- Constant Temperature Coefficient
  0.0,                                 !- External Dry-Bulb Temperature Coefficient
  0.0,                                 !- Ground Temperature Coefficient
  0.0,                                 !- Wind Speed Coefficient
  0.0,                                 !- Zone Air Temperature Coefficient
```

```
      scheduleOSCSlabAverageSurfaceTemp,   !- Constant Temperature Schedule Name
  No,                          !- Sinusoidal Variation of Constant Temperature Coefficient
  24;                          !- Period of Sinusoidal Variation

Schedule:Compact,
  scheduleOSCSlabAverageSurfaceTemp,   !- Name
  Temperature,                 !- ScheduleType
  Through:   1/31,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  9.301,                       !- Field
  Through:   2/28,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  8.191,                       !- Field
  Through:   3/31,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  9.784,                       !- Field
  Through:   4/30,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  12.662,                      !- Field
  Through:   5/31,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  16.853,                      !- Field
  Through:   6/30,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  20.910,                      !- Field
  Through:   7/31,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  23.716,                      !- Field
  Through:   8/31,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  25.332,                      !- Field
  Through:   9/30,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  24.301,                      !- Field
  Through:  10/31,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  20.893,                      !- Field
  Through:  11/30,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  17.047,                      !- Field
  Through:  12/31,             !- Field
  For:AllDays,                 !- Field
  Until:24:00,                 !- Field
  13.155;                      !- Field

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

  Site:GroundReflectance,0.26,0.26,0.26,0.26,0.26,0.26,0.26,0.26,0.26,0.26,0.26,0.3; ! was 0.26

!-   ===========  ALL OBJECTS IN CLASS: SITE:GROUNDREFLECTANCE:SNOWMODIFIER ===========
```

```
      Site:GroundReflectance:SnowModifier,
  2.5,                  !- Ground Reflected Solar Modifier  ! 2.5*0.26 = 0.65
  2.5;                  !- Daylighting Ground Reflected Solar Modifier

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

 ScheduleTypeLimits,
  Fraction,             !- Name
  0,                    !- Lower Limit Value
  1,                    !- Upper Limit Value
  Continuous,           !- Numeric Type
  Dimensionless;        !- Unit Type

 ScheduleTypeLimits,
  Temperature,          !- Name
  -60,                  !- Lower Limit Value
  200,                  !- Upper Limit Value
  Continuous,           !- Numeric Type
  Dimensionless;        !- Unit Type

 ScheduleTypeLimits,
  Control Type,         !- Name
  0,                    !- Lower Limit Value
  4,                    !- Upper Limit Value
  Discrete,             !- Numeric Type
  Dimensionless;        !- Unit Type

 ScheduleTypeLimits,
  On/Off,               !- Name
  0,                    !- Lower Limit Value
  1,                    !- Upper Limit Value
  Discrete,             !- Numeric Type
  Dimensionless;        !- Unit Type

 ScheduleTypeLimits,
  Any Number,           !- Name
  ,                     !- Lower Limit Value
  ,                     !- Upper Limit Value
  Continuous,           !- Numeric Type
  ;                     !- Unit Type

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

 Schedule:Compact,
  Zone1Control,         !- Name
  Control Type,         !- Schedule Type Limits Name
  Through: 12/31,       !- Field 1
  For: Alldays,         !- Field 2
  Until: 24:00,1;       !- Field 3

 Schedule:Compact,
  Zone1HeatingAvail,    !- Name
  Fraction,             !- Schedule Type Limits Name
  Through: 12/31,       !- Field 1
  For: Alldays,         !- Field 2
  Until: 24:00,1;       !- Field 3

 Schedule:Compact,
  Furnace Fan Operating Mode Schedule,  !- Name
  Fraction,             !- Schedule Type Limits Name
  Through: 12/31,       !- Field 1
  For: Alldays,         !- Field 2
```

```
      Until: 24:00,1;          !- Field 3  %%% 1 indicates continuous, 0 indicates cycles on and off with coil

Schedule:Compact,
  Zone1HeatingSetPoint,    !- Name
  Temperature,           !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,21;       !- Field 3

Schedule:Compact,
  HRV_Schedule,          !- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,1;        !- Field 3

Schedule:Compact,
  Inf_schedule,          !- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For:Alldays,           !- Field 2
  Until: 24:00,1;        !- Field 3

Schedule:Compact,
  Extra Occupancy Schedule,      !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,1;        !- Field 3

Schedule:Compact,
  Extra Humans Activity Schedule,  !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,80;       !- Field 23

Schedule:Compact,
  S2a Occupancy Schedule,      !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until:06:45,1,
  Until:21:00,0,
  Until: 24:00,1;        !- Field 3

Schedule:Compact,
  S2a Occupant Activity Schedule,  !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,66;       !- Field 23

Schedule:Compact,
  S2c Occupancy Schedule,  !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until:06:45,1,
  Until:23:00,0,
  Until:24:00,1;
```

```
      Schedule:Compact,
  S2c Occupant Activity Schedule,   !- Name %% Master Bedroom
  Any Number,              !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until:24:00,100;

Schedule:Compact,
  N1 Occupancy Schedule,  !- Name
  Any Number,              !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until:07:00,0,
  Until:08:00,1,
  Until:12:00,0,
  Until:12:30,1,
  Until:24:00,0;

Schedule:Compact,
  N1 Occupant Activity Schedule,   !- Name %% Master Bedroom
  Any Number,              !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until:24:00,166;

Schedule:Compact,
  S1a Occupancy Schedule,  !- Name
  Any Number,              !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until:19:00,0,
  Until:21:00,1,
  Until:24:00,0;

Schedule:Compact,
  S1a Occupant Activity Schedule,   !- Name %% Living Room
  Any Number,              !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until:24:00,166;

Schedule:Compact,
  2nd Floor Light Schedule,!- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 6:45,0,           !- Field 3
  Until: 7:45,1,           !- Field 5
  Until: 18:00,0,          !- Field 7
  Until: 23:00,1,          !- Field 9
  Until: 24:00,0;          !- Field 11

Schedule:Compact,
  Main Floor Light Schedule,  !- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 7:00,0,           !- Field 3
  Until: 8:00,1,           !- Field 5
  Until: 12:00,0,          !- Field 7
  Until: 12:15,1,          !- Field 9
  Until: 17:00,0,          !- Field 11
```

```
          Until: 19:30,1,          !- Field 13
  Until: 24:00,0;          !- Field 15

Schedule:Compact,
  Kitchen Appliance Schedule,  !- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 7:30,0,           !- Field 3
  Until: 7:40.2,1,         !- Field 5
  Until: 12:00,0,          !- Field 7
  Until: 12:10.2,1,        !- Field 9
  Until: 17:30,0,          !- Field 11
  Until: 17:40.2,1,        !- Field 13
  Until: 24:00,0;          !- Field 15

Schedule:Compact,
  Kitchen Fan Schedule,    !- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 7:30,0,           !- Field 3
  Until: 7:40.2,1,         !- Field 5
  Until: 12:00,0,          !- Field 7
  Until: 12:15,1,          !- Field 9
  Until: 17:30,0,          !- Field 11
  Until: 17:33.6,1,        !- Field 13
  Until: 24:00,0;          !- Field 15

Schedule:Compact,
  Kitchen Stove Schedule,  !- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 7:30,0.005,           !- Field 3
  Until: 7:50,1,           !- Field 5
  Until: 12:00,0.005,          !- Field 7
  Until: 12:15,1,          !- Field 9
  Until: 17:30,0.005,          !- Field 11
  Until: 18:00,1,          !- Field 13
  Until: 24:00,0.005;          !- Field 15

Schedule:Compact,
  Dining Rm Appliance Schedule,  !- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 18:00,0,          !- Field 3
  Until: 20:00,1,          !- Field 5
  Until: 24:00,0;          !- Field 7

Schedule:Compact,
  Dryer Schedule,          !- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 19:00,0,          !- Field 3
  Until: 19:25.2,1,        !- Field 5
  Until: 24:00,0;          !- Field 7

Schedule:Compact,
  Washing Machine Schedule,!- Name
```

```
        Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 17:15,0,        !- Field 3
  Until: 18:05,1,        !- Field 5
  Until: 24:00,0;        !- Field 7

 Schedule:Compact,
  Dishwasher Schedule,!- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 19:05,0,        !- Field 3
  Until: 20:05,1,        !- Field 5
  Until: 24:00,0;        !- Field 7

 Schedule:Compact,
  Always On Schedule,    !- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,1;        !- Field 3
```

! below schedules determine fraction of total infiltration for each effective zone, based on weighted average with 70% leakage along window / door frame edges, and 30% proportional to wall area

```
 Schedule:Compact,
  Infiltration Coeff N1,    !- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,0.33;        !- Field 3

 Schedule:Compact,
  Infiltration Coeff S1a,    !- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,0.11;        !- Field 3

 Schedule:Compact,
  Infiltration Coeff S1b,    !- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,0.06;        !- Field 3

 Schedule:Compact,
  Infiltration Coeff N2,    !- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,0.17;        !- Field 3

 Schedule:Compact,
  Infiltration Coeff S2a,    !- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,0.13;        !- Field 3

 Schedule:Compact,
```

```
    Infiltration Coeff S2b,      !- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,0.06;         !- Field 3

 Schedule:Compact,
  Infiltration Coeff S2c,     !- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,0.07;         !- Field 3

 Schedule:Compact,
  Infiltration Coeff Bsmt,     !- Name
  Fraction,              !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: Alldays,          !- Field 2
  Until: 24:00,0.06;         !- Field 3

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

 People,
  Master Bedroom humans,             !- Name
  South 2c,                !- Zone or ZoneList Name
  S2c Occupancy Schedule,      !- Number of People Schedule Name
  People,                !- Number of People Calculation Method
  1,                     !- Number of People
  ,                      !- People per Zone Floor Area {person/m2}
  ,                      !- Zone Floor Area per Person {m2/person}
  0.90,                    !- Fraction Radiant         #### was 0.3 rad  - current values are for calibration
  0.10,                    !- Sensible Heat Fraction  ### was 0.4 sensible
  S2c Occupant Activity Schedule;  !- Activity Level Schedule Name

 People,
  Bedroom 2 humans,            !- Name
  South 2a,                !- Zone or ZoneList Name
  S2a Occupancy Schedule,      !- Number of People Schedule Name
  People,                !- Number of People Calculation Method
  1,                     !- Number of People
  ,                      !- People per Zone Floor Area {person/m2}
  ,                      !- Zone Floor Area per Person {m2/person}
  0.90,                    !- Fraction Radiant
  0.1,                     !- Sensible Heat Fraction
  S2a Occupant Activity Schedule;  !- Activity Level Schedule Name

 People,
  Family room humans,            !- Name
  North 1,                 !- Zone or ZoneList Name
  N1 Occupancy Schedule,      !- Number of People Schedule Name
  People,                !- Number of People Calculation Method
  1,                     !- Number of People
  ,                      !- People per Zone Floor Area {person/m2}
  ,                      !- Zone Floor Area per Person {m2/person}
  0.9,                   !- Fraction Radiant
  0.1,                     !- Sensible Heat Fraction
  N1 Occupant Activity Schedule;  !- Activity Level Schedule Name

 People,
  Living room humans,            !- Name
  South 1a,                !- Zone or ZoneList Name
```

```
      S1a Occupancy Schedule,      !- Number of People Schedule Name
    People,                 !- Number of People Calculation Method
    1,                      !- Number of People
    ,                       !- People per Zone Floor Area {person/m2}
    ,                       !- Zone Floor Area per Person {m2/person}
    0.9,                    !- Fraction Radiant
    0.1,                    !- Sensible Heat Fraction
    S1a Occupant Activity Schedule;  !- Activity Level Schedule Name

! based on measured values
  People,
    Extra humans,           !- Name
    North 1,                !- Zone or ZoneList Name
    Extra Occupancy Schedule,      !- Number of People Schedule Name
    People,                 !- Number of People Calculation Method
    1,                      !- Number of People
    ,                       !- People per Zone Floor Area {person/m2}
    ,                       !- Zone Floor Area per Person {m2/person}
    0.9,                    !- Fraction Radiant
    0.1,                    !- Sensible Heat Fraction
    Extra Humans Activity Schedule;  !- Activity Level Schedule Name

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

  Lights,
    Level 2 Lights,        !- Name
    Second Floor Zones,                !- Zone or ZoneList Name
    2nd Floor Light Schedule,!- Schedule Name
    Watts/Area,          !- Design Level Calculation Method
    ,                  !- Lighting Level {W}
    3.07237,                      !- Watts per Zone Floor Area {W/m2}
    ,                    !- Watts per Person {W/person}
    0,                   !- Return Air Fraction
    0.8,                 !- Fraction Radiant  %% was 0.95
    0.1,                 !- Fraction Visible  %% was 0.05
    1,                   !- Fraction Replaceable
    Lighting,              !- End-Use Subcategory
    No;                   !- Return Air Fraction Calculated from Plenum Temperature

  Lights,
    Main floor lights,       !- Name
    Main Floor Zones,                !- Zone or ZoneList Name
    Main Floor Light Schedule,  !- Schedule Name
    Watts/Area,          !- Design Level Calculation Method
    ,                  !- Lighting Level {W}
    1.93713,                      !- Watts per Zone Floor Area {W/m2}
    ,                    !- Watts per Person {W/person}
    0,                   !- Return Air Fraction
    0.8,                 !- Fraction Radiant
    0.1,                 !- Fraction Visible
    1,                   !- Fraction Replaceable
    Lighting,            !- End-Use Subcategory
    No;                   !- Return Air Fraction Calculated from Plenum Temperature

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

  ElectricEquipment,
    KitchenAppliances,       !- Name
    North 1,                !- Zone or ZoneList Name
    Kitchen Appliance Schedule,  !- Schedule Name
    EquipmentLevel,          !- Design Level Calculation Method
    450,                  !- Design Level {W}
```

```
          ,                    !- Watts per Zone Floor Area {W/m2}
  ,                    !- Watts per Person {W/person}
  0,                   !- Fraction Latent
  0.3,                 !- Fraction Radiant
  0,                   !- Fraction Lost
  Appliances;          !- End-Use Subcategory

ElectricEquipment,
  KitchenFan,          !- Name
  North 1,             !- Zone or ZoneList Name
  Kitchen Fan Schedule,    !- Schedule Name
  EquipmentLevel,      !- Design Level Calculation Method
  80,                  !- Design Level {W}
  ,                    !- Watts per Zone Floor Area {W/m2}
  ,                    !- Watts per Person {W/person}
  0,                   !- Fraction Latent
  0.1,                 !- Fraction Radiant
  0,                   !- Fraction Lost
  Fan;                 !- End-Use Subcategory

ElectricEquipment,
  KitchenStove,        !- Name
  North 1,             !- Zone or ZoneList Name
  Kitchen Stove Schedule,  !- Schedule Name
  EquipmentLevel,      !- Design Level Calculation Method
  1364,                !- Design Level {W}
  ,                    !- Watts per Zone Floor Area {W/m2}
  ,                    !- Watts per Person {W/person}
  0,                   !- Fraction Latent
  0.5,                 !- Fraction Radiant
  0,                   !- Fraction Lost
  Appliances;          !- End-Use Subcategory

ElectricEquipment,
  DiningRoomAppliances,    !- Name
  North 1,             !- Zone or ZoneList Name
  Dining Rm Appliance Schedule,  !- Schedule Name
  EquipmentLevel,      !- Design Level Calculation Method
  225,                 !- Design Level {W}
  ,                    !- Watts per Zone Floor Area {W/m2}
  ,                    !- Watts per Person {W/person}
  0,                   !- Fraction Latent
  0.3,                 !- Fraction Radiant
  0,                   !- Fraction Lost
  Appliances;          !- End-Use Subcategory

ElectricEquipment,
  Dryer,               !- Name
  North 2,             !- Zone or ZoneList Name
  Dryer Schedule,      !- Schedule Name
  EquipmentLevel,      !- Design Level Calculation Method
  2192,                !- Design Level {W}
  ,                    !- Watts per Zone Floor Area {W/m2}
  ,                    !- Watts per Person {W/person}
  0,                   !- Fraction Latent
  0.1,                 !- Fraction Radiant
  0.7,                 !- Fraction Lost
  Appliances;          !- End-Use Subcategory

ElectricEquipment,
  Washing Machine,     !- Name
  North 2,             !- Zone or ZoneList Name
```

```
    Washing Machine Schedule,!- Schedule Name
    EquipmentLevel,         !- Design Level Calculation Method
    223,                    !- Design Level {W}
    ,                       !- Watts per Zone Floor Area {W/m2}
    ,                       !- Watts per Person {W/person}
    0,                      !- Fraction Latent
    0,                      !- Fraction Radiant
    0,                      !- Fraction Lost
    Appliances;             !- End-Use Subcategory

  ElectricEquipment,
    Dishwasher,             !- Name
    North 1,                !- Zone or ZoneList Name
    Dishwasher Schedule,!- Schedule Name
    EquipmentLevel,         !- Design Level Calculation Method
    429,                    !- Design Level {W}
    ,                       !- Watts per Zone Floor Area {W/m2}
    ,                       !- Watts per Person {W/person}
    0,                      !- Fraction Latent
    0,                      !- Fraction Radiant
    0.1,                    !- Fraction Lost
    Appliances;             !- End-Use Subcategory

  ElectricEquipment,
    Fridge,                 !- Name
    North 1,                !- Zone or ZoneList Name
    Always On Schedule,     !- Schedule Name
    EquipmentLevel,         !- Design Level Calculation Method
    46,                     !- Design Level {W} ! value for winter
    ,                       !- Watts per Zone Floor Area {W/m2}
    ,                       !- Watts per Person {W/person}
    0,                      !- Fraction Latent
    0.1,                    !- Fraction Radiant
    0,                      !- Fraction Lost
    Appliances;             !- End-Use Subcategory

  ElectricEquipment,
    ControlRoom,            !- Name
    Garage_zone,            !- Zone or ZoneList Name
    Always On Schedule,     !- Schedule Name
    EquipmentLevel,         !- Design Level Calculation Method
    723,                    !- Design Level {W} ! value for winter
    ,                       !- Watts per Zone Floor Area {W/m2}
    ,                       !- Watts per Person {W/person}
    0,                      !- Fraction Latent
    0.1,                    !- Fraction Radiant
    0,                      !- Fraction Lost
    Appliances;             !- End-Use Subcategory

! Misc Basement Gain includes 7W of elect used by HW tank, 10W from HRV exhaust fan / electronics
  ElectricEquipment,
    MiscBasementGain,       !- Name
    Basement_Zone,          !- Zone or ZoneList Name
    Always On Schedule,     !- Schedule Name
    EquipmentLevel,         !- Design Level Calculation Method
    17,                     !- Design Level {W} ! value for winter
    ,                       !- Watts per Zone Floor Area {W/m2}
    ,                       !- Watts per Person {W/person}
    0,                      !- Fraction Latent
    0,                      !- Fraction Radiant
    0,                      !- Fraction Lost
    Appliances;             !- End-Use Subcategory
```

```
! HRV Gain assumed to be in airstream, HRV supply fan gain added to furnace fan


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

  HotWaterEquipment,
    Zone1DHW,               !- Name
    All Living Space Zones,  !- Zone or ZoneList Name
    Always On Schedule,      !- Schedule Name
    EquipmentLevel,          !- Design Level Calculation Method
    31.3,                    !- Design Level {W} 250/8
    ,                        !- Watts per Zone Floor Area {W/m2}
    ,                        !- Watts per Person {W/Person}
    0.2,                     !- Fraction Latent
    0.1,                     !- Fraction Radiant
    0.6,                     !- Fraction Lost
    Zone1 DHW;               !- End-Use Subcategory

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

  Material,
    Concrete 75,             !- Name
    Rough,                   !- Roughness
    0.075,                   !- Thickness {m}
    1.3,                     !- Conductivity {W/m-K}
    2240,                    !- Density {kg/m3}
    900,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    0.6,                     !- Solar Absorptance
    0.6;                     !- Visible Absorptance

  Material,
    Concrete 100,            !- Name
    Rough,                   !- Roughness
    0.1,                     !- Thickness {m}
    1.3,                     !- Conductivity {W/m-K}
    2240,                    !- Density {kg/m3}
    900,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    0.6,                     !- Solar Absorptance
    0.6;                     !- Visible Absorptance

  Material,
    Concrete 200,            !- Name
    Rough,                   !- Roughness
    0.2,                     !- Thickness {m}
    1.3,                     !- Conductivity {W/m-K}
    2240,                    !- Density {kg/m3}
    900,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    0.6,                     !- Solar Absorptance
    0.6;                     !- Visible Absorptance

! solar absorption of tile based on Reagan & Acklam 1979 "medium" category
  Material,
    Tile,                    !- Name
    Rough,                   !- Roughness
    0.0127,                  !- Thickness {m}
    1.3,                     !- Conductivity {W/m-K}
    2240,                    !- Density {kg/m3}
    900,                     !- Specific Heat {J/kg-K}
```

```
          0.9,                    !- Thermal Absorptance
    0.55,                !- Solar Absorptance
    0.6;                 !- Visible Absorptance

  Material,
    Carpet,                 !- Name
    Rough,              !- Roughness ## from EPLUS data set "ASHRAE 2005 HOF Materials"
    0.019,              !- Thickness {m} ## Ashrae
    0.0452,                 !- Conductivity {W/m-K} ## backcalculated from ASHRAE R=0.42
    110,                !- Density {kg/m3}
    1380,                 !- Specific Heat {J/kg-K} ## from EPLUS data set "ASHRAE 2005 HOF Materials"
    0.9,                !- Thermal Absorptance
    0.55,                 !- Solar Absorptance ## light coloured carpet - from ISES Passive Solar Architecture Pocket
Reference
    0.6;                !- Visible Absorptance

  Material,
    XPS,                  !- Name
    Rough,                  !- Roughness
    0.1,                !- Thickness {m}
    0.034,                !- Conductivity {W/m-K}
    35,                 !- Density {kg/m3}
    1400,                 !- Specific Heat {J/kg-K}
    0.9,                !- Thermal Absorptance
    0.6,                !- Solar Absorptance
    0.6;                !- Visible Absorptance

  Material,
    Brick,                !- Name
    Rough,                  !- Roughness
    0.1,                !- Thickness {m}
    0.72,                !- Conductivity {W/m-K}
    1920,                !- Density {kg/m3}
    800,                !- Specific Heat {J/kg-K}
    0.9,                !- Thermal Absorptance
    0.55,                !- Solar Absorptance
    0.6;                !- Visible Absorptance

! Gypsum solar absorptance updated (was 0.2) now 0.35

  Material,
    Gypsum,                 !- Name
    Rough,                 !- Roughness
    0.0127,                !- Thickness {m}
    0.16,                !- Conductivity {W/m-K}
    640,                !- Density {kg/m3}
    1150,                !- Specific Heat {J/kg-K}
    0.9,                !- Thermal Absorptance
    0.35,                !- Solar Absorptance
    0.6;                !- Visible Absorptance

  Material,
    OSB,                  !- Name
    Rough,                 !- Roughness
    0.016,                !- Thickness {m}
    0.091,                !- Conductivity {W/m-K}
    650,                !- Density {kg/m3}
    1880,                !- Specific Heat {J/kg-K}
    0.9,                !- Thermal Absorptance
    0.4,                !- Solar Absorptance
    0.6;                !- Visible Absorptance
```

```
        Material,
 Insulation AG,          !- Name
 Rough,                  !- Roughness
 0.14,                   !- Thickness {m}
 0.0536,                 !- Conductivity {W/m-K}
 101,                    !- Density {kg/m3} (was 14)
 1081,                   !- Specific Heat {J/kg-K} (was 840)
 0.9,                    !- Thermal Absorptance
 ,                       !- Solar Absorptance
 ;                       !- Visible Absorptance

Material,
 Insulation AGw,         !- Name
 Rough,                  !- Roughness
 0.14,                   !- Thickness {m}
 0.0592,                 !- Conductivity {W/m-K}
 70,                     !- Density {kg/m3}
 1081,                   !- Specific Heat {J/kg-K}
 0.9,                    !- Thermal Absorptance
 ,                       !- Solar Absorptance
 ;                       !- Visible Absorptance

Material,
 Insulation BG,          !- Name
 Rough,                  !- Roughness
 0.089,                  !- Thickness {m}
 0.0510,                 !- Conductivity {W/m-K}
 55,                     !- Density {kg/m3}
 955,                    !- Specific Heat {J/kg-K}
 0.9,                    !- Thermal Absorptance
 ,                       !- Solar Absorptance
 ;                       !- Visible Absorptance

Material,
 CeilingInsulation,      !- Name
 Rough,                  !- Roughness
 0.3658,                 !- Thickness {m}
 0.0438,                 !- Conductivity {W/m-K}
 55,                     !- Density {kg/m3}   ! assumption
 955,                    !- Specific Heat {J/kg-K}
 0.9,                    !- Thermal Absorptance
 ,                       !- Solar Absorptance
 ;                       !- Visible Absorptance

Material,
 GarageCeilingInsulation, !- Name
 Rough,                  !- Roughness
 0.292,                  !- Thickness {m}
 0.0448,                 !- Conductivity {W/m-K}
 55,                     !- Density {kg/m3}
 955,                    !- Specific Heat {J/kg-K}
 0.9,                    !- Thermal Absorptance
 ,                       !- Solar Absorptance
 ;                       !- Visible Absorptance

Material,
 Shingles_Asphalt,       !- Name
 Rough,                  !- Roughness
 0.003,                  !- Thickness {m}
 0.038,                  !- Conductivity {W/m-K}
 920,                    !- Density {kg/m3}
 1510,                   !- Specific Heat {J/kg-K}
```

```
        0.9,                    !- Thermal Absorptance
    0.8,                    !- Solar Absorptance
    0.9;                    !- Visible Absorptance

  Material,
    wood,                   !- Name
    Rough,                  !- Roughness
    0.090,                  !- Thickness {m}
    0.1,                    !- Conductivity {W/m-K}
    395,                    !- Density {kg/m3}
    1880,                   !- Specific Heat {J/kg-K}
    0.9,                    !- Thermal Absorptance
    0.4,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! area weighted properties based on 15% wood framing & air
  Material,
    hollow_frame_wall_mat,                  !- Name
    Rough,                  !- Roughness
    0.14,                   !- Thickness {m}
    5,                      !- Conductivity {W/m-K}
    60,                     !- Density {kg/m3}
    1140,                   !- Specific Heat {J/kg-K}
    0.9,                    !- Thermal Absorptance
    0.4,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance



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

  Material:NoMass,
    door_material_insulated, !- Name
    MediumSmooth,           !- Roughness
    2.1,                    !- Thermal Resistance {m2-K/W}
    0.8,                    !- Thermal Absorptance
    0.4,                    !- Solar Absorptance
    0.4;                    !- Visible Absorptance

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

  Material:AirGap,
    AirSpace20,             !- Name (horizontal)
    0.15;                   !- Thermal Resistance {m2-K/W}

! drained air cavity assumed to have R value = 1/2 of sealed cavity - BRANZ standard, sealed cavity value = 0.18
(ASHRAE)
  Material:AirGap,
    VentedGap,              !- Name (horizontal)
    0.09;                   !- Thermal Resistance {m2-K/W}

  Material:AirGap,
    AirSpace90horiz,        !- Name
    0.16;                   !- Thermal Resistance {m2-K/W}

  Material:AirGap,
    AirSpace90vertical,     !- Name
    0.15;                   !- Thermal Resistance {m2-K/W}

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

  WindowMaterial:Glazing,
```

```
      layer1,               !- Name
  SpectralAverage,        !- Optical Data Type
  ,                    !- Window Glass Spectral Data Set Name
  0.003,                  !- Thickness {m}
  0.837,                  !- Solar Transmittance at Normal Incidence
  0.075,                  !- Front Side Solar Reflectance at Normal Incidence
  0.075,                  !- Back Side Solar Reflectance at Normal Incidence
  0.899,                  !- Visible Transmittance at Normal Incidence
  0.083,                  !- Front Side Visible Reflectance at Normal Incidence
  0.083,                  !- Back Side Visible Reflectance at Normal Incidence
  0,                   !- Infrared Transmittance at Normal Incidence
  0.84,                  !- Front Side Infrared Hemispherical Emissivity
  0.84,                  !- Back Side Infrared Hemispherical Emissivity
  1,                   !- Conductivity {W/m-K}
  ,                    !- Dirt Correction Factor for Solar and Visible Transmittance
  No;                    !- Solar Diffusing

 WindowMaterial:Glazing,
  layer2,               !- Name
  SpectralAverage,        !- Optical Data Type
  ,                    !- Window Glass Spectral Data Set Name
  0.003023,               !- Thickness {m}
  0.692,                  !- Solar Transmittance at Normal Incidence
  0.122,                  !- Front Side Solar Reflectance at Normal Incidence
  0.112,                  !- Back Side Solar Reflectance at Normal Incidence
  0.824,                  !- Visible Transmittance at Normal Incidence
  0.115,                  !- Front Side Visible Reflectance at Normal Incidence
  0.110,                  !- Back Side Visible Reflectance at Normal Incidence
  0,                   !- Infrared Transmittance at Normal Incidence
  0.156,                  !- Front Side Infrared Hemispherical Emissivity
  0.840,                  !- Back Side Infrared Hemispherical Emissivity
  1,                   !- Conductivity {W/m-K}
  ,                    !- Dirt Correction Factor for Solar and Visible Transmittance
  No;                    !- Solar Diffusing

! no glass material is using for hallway openings
 WindowMaterial:Glazing,
  no glass,               !- Name
  SpectralAverage,        !- Optical Data Type
  ,                    !- Window Glass Spectral Data Set Name
  0.001,               !- Thickness {m}
  0.9,                 !- Solar Transmittance at Normal Incidence
  0.1,                 !- Front Side Solar Reflectance at Normal Incidence
  0.1,                 !- Back Side Solar Reflectance at Normal Incidence
  0.9,                 !- Visible Transmittance at Normal Incidence
  0.1,                 !- Front Side Visible Reflectance at Normal Incidence
  0.1,                 !- Back Side Visible Reflectance at Normal Incidence
  0.9,                    !- Infrared Transmittance at Normal Incidence
  0.1,                 !- Front Side Infrared Hemispherical Emissivity
  0.1,                 !- Back Side Infrared Hemispherical Emissivity
  100,                    !- Conductivity {W/m-K}
  ,                    !- Dirt Correction Factor for Solar and Visible Transmittance
  No;                    !- Solar Diffusing

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

 WindowMaterial:GasMixture,
  gap1,                 !- Name
  0.0125,                 !- Thickness {m}
  2,                   !- Number of Gases in Mixture
  Argon,                  !- Gas 1 Type
  0.95,                 !- Gas 1 Fraction
```

```
        Air,                 !- Gas 2 Type
  0.05;                !- Gas 2 Fraction

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

 WindowProperty:FrameAndDivider,
  CCHT Ref Frames No Div,        !- Name
  0.08,                  !- Frame Width {m}
  0.01,                  !- Frame Outside Projection {m}
  0.05,                  !- Frame Inside Projection {m}
  1.89,                  !- Frame Conductance {W/m2-K}
  1.07,                  !- Ratio of Frame-Edge Glass Conductance to Center-Of-Glass Conductance
  0.15,                  !- Frame Solar Absorptance
  0.2,                   !- Frame Visible Absorptance
  0.9,                   !- Frame Thermal Hemispherical Emissivity
  ,                      !- Divider Type
  ,                      !- Divider Width {m}
  ,                      !- Number of Horizontal Dividers
  ,                      !- Number of Vertical Dividers
  ,                      !- Divider Outside Projection {m}
  ,                      !- Divider Inside Projection {m}
  ,                      !- Divider Conductance {W/m2-K}
  ,                      !- Ratio of Divider-Edge Glass Conductance to Center-Of-Glass Conductance
  ,                      !- Divider Solar Absorptance
  ,                      !- Divider Visible Absorptance
  ,                      !- Divider Thermal Hemispherical Emissivity
  0.55,                  !- Outside Reveal Solar Absorbtance
  0.06,                  !- Inside Sill Depth
  0.35,                  !- Inside Sill Solar Absorptance
  0.06,                  !- Inside Reveal Depth
  0.35;                  !- Inside Reveal Solar Absorptance

 WindowProperty:FrameAndDivider,
  CCHT Ref Frames 1 Div,        !- Name
  0.08,                  !- Frame Width {m}
  0.01,                  !- Frame Outside Projection {m}
  0.05,                  !- Frame Inside Projection {m}
  1.89,                  !- Frame Conductance {W/m2-K}
  1.07,                  !- Ratio of Frame-Edge Glass Conductance to Center-Of-Glass Conductance
  0.15,                  !- Frame Solar Absorptance
  0.2,                   !- Frame Visible Absorptance
  0.9,                   !- Frame Thermal Hemispherical Emissivity
  DividedLite,                   !- Divider Type
  0.12,                  !- Divider Width {m}
  0,                     !- Number of Horizontal Dividers
  1,                     !- Number of Vertical Dividers
  0.01,                  !- Divider Outside Projection {m}
  0.05,                  !- Divider Inside Projection {m}
  1.89,                  !- Divider Conductance {W/m2-K}
  1.07,                  !- Ratio of Divider-Edge Glass Conductance to Center-Of-Glass Conductance
  0.15,                  !- Divider Solar Absorptance
  0.2,                   !- Divider Visible Absorptance
  0.9,                   !- Divider Thermal Hemispherical Emissivity
  0.55,                  !- Outside Reveal Solar Absorbtance
  0.06,                  !- Inside Sill Depth
  0.35,                  !- Inside Sill Solar Absorptance
  0.06,                  !- Inside Reveal Depth
  0.35;                  !- Inside Reveal Solar Absorptance

 WindowProperty:FrameAndDivider,
  CCHT Ref Frames 2 Div,        !- Name
  0.08,                  !- Frame Width {m}
```

```
      0.01,                  !- Frame Outside Projection {m}
  0.05,               !- Frame Inside Projection {m}
  1.89,               !- Frame Conductance {W/m2-K}
  1.07,               !- Ratio of Frame-Edge Glass Conductance to Center-Of-Glass Conductance
  0.15,               !- Frame Solar Absorptance
  0.2,                !- Frame Visible Absorptance
  0.9,                !- Frame Thermal Hemispherical Emissivity
  DividedLite,              !- Divider Type
  0.12,                 !- Divider Width {m}
  0,                  !- Number of Horizontal Dividers
  2,                  !- Number of Vertical Dividers
  0.01,                 !- Divider Outside Projection {m}
  0.05,                 !- Divider Inside Projection {m}
  1.89,                 !- Divider Conductance {W/m2-K}
  1.07,                 !- Ratio of Divider-Edge Glass Conductance to Center-Of-Glass Conductance
  0.15,                 !- Divider Solar Absorptance
  0.2,                 !- Divider Visible Absorptance
  0.9,                 !- Divider Thermal Hemispherical Emissivity
  0.55,                 !- Outside Reveal Solar Absorbtance
  0.06,                 !- Inside Sill Depth
  0.35,                 !- Inside Sill Solar Absorptance
  0.06,                 !- Inside Reveal Depth
  0.35;                 !- Inside Reveal Solar Absorptance

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

 Construction,
  Brick_Wall,           !- Name
  Brick,              !- Outside Layer
  VentedGap,
  OSB,                !- Layer 2
  Insulation AG,        !- Layer 3
  Gypsum;              !- Layer 4

 Construction,
  Brick_Wall_w,          !- Name
  Brick,              !- Outside Layer
  VentedGap,
  OSB,                !- Layer 2
  Insulation AGw,        !- Layer 3
  Gypsum;              !- Layer 4

 Construction,
  basement_floor,        !- Name
  concrete 75;          !- Outside Layer

 Construction,
  garage_floor,        !- Name
  concrete 100;          !- Outside Layer

 Construction,
  ceiling_insulated,      !- Name
  CeilingInsulation,      !- Outside Layer
  Gypsum;              !- Layer 2

 Construction,
  ceiling_insulated_reverse,  !- Name
  Gypsum,              !- Outside Layer
  CeilingInsulation;      !- Layer 2

 Construction,
  Roof_uninsulated,       !- Name
```

```
      Shingles_Asphalt,       !- Outside Layer
  OSB;                  !- Layer 2

 Construction,
  Brick_Wall_Uninsulated,  !- Name
  Brick,                !- Outside Layer
  VentedGap,
  OSB,                  !- Layer 2
  AirSpace90vertical,
  Gypsum;                  !- Layer 4

 Construction,
  below_grade,            !- Name
  Concrete 200,           !- Outside Layer
  ventedgap,            !- Layer 2
  Insulation BG,          !- Layer 3
  Gypsum;               !- Layer 4

 Construction,
  garage_ceiling,         !- Name
  GarageCeilingInsulation,  !- Outside Layer
  Gypsum;

 Construction,
  garage_ceiling_reverse,      !- Name
  Gypsum,                  !- Outside Layer
  GarageCeilingInsulation;

 Construction,
  garage_ceiling_carpet,         !- Name
  Carpet,                      !- Outside Layer
  GarageCeilingInsulation,
  OSB,
  Gypsum;

 Construction,
  garage_ceiling_carpet_rev,
  Gypsum,
  GarageCeilingInsulation,
  OSB,
  Carpet;

 Construction,
  interior_garage_wall,    !- Name
  Gypsum,               !- Outside Layer
  Insulation AG,          !- Layer 2
  Gypsum;               !- Layer 3

! second floor
 Construction,
  interior_floor_carpet,         !- Name
  Gypsum,               !- Outside Layer
  AirSpace90horiz,        !- Layer 2
  OSB,
  Carpet;                 !- Layer 3

 Construction,
  interior_floor_carpet_rev,      !- Name
  Carpet,               !- Outside Layer
  OSB,
  AirSpace90horiz,        !- Layer 2
  Gypsum;               !- Layer 3
```

```
  Construction,
    interior_floor_tile,     !- Name
    Gypsum,                  !- Outside Layer
    AirSpace90horiz,         !- Layer 2
    OSB,                     !- Layer 3
    Tile;                    !- Layer 4

  Construction,
    interior_floor_tile_rev, !- Name
    Tile,                    !- Outside Layer
    OSB,                     !- Layer 2
    AirSpace90horiz,         !- Layer 3
    Gypsum;                  !- Layer 4

! main floor is different than second floor
  Construction,
    main_floor_carpet,       !- Name
    OSB,                     !- Outside Layer
    Carpet;                  !- Layer 2

  Construction,
    main_floor_carpet_rev,      !- Name
    Carpet,                  !- Outside Layer
    OSB;

  Construction,
    main_floor_tile,     !- Name
    OSB,
    Tile;

  Construction,
    main_floor_tile_rev, !- Name
    Tile,                    !- Outside Layer
    OSB;                     !- Layer 4

  Construction,
    interior wall,           !- Name
    Gypsum,                  !- Outside Layer
    hollow_frame_wall_mat,      !- Layer 2
    Gypsum;                  !- Layer 3

  Construction,
   woodwork,
   wood;

  Construction,
    door_insulated,          !- Name
    door_material_insulated; !- Outside Layer

  Construction,
    CCHT REF WINDOWS HSHG,   !- Name
    layer1,                  !- Outside Layer
    gap1,                    !- Layer 2
    layer2;                  !- Layer 3


! openings modelled as glass door (used for hallways etc)
  Construction,
    opening,
    no glass;
```

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

GlobalGeometryRules,
  LowerLeftCorner,        !- Starting Vertex Position
  Counterclockwise,       !- Vertex Entry Direction
  Relative,               !- Coordinate System
  Relative,               !- Daylighting Reference Point Coordinate System
  Relative;               !- Rectangular Surface Coordinate System

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

Zone,
  South 1a,               !- Name
  0,                      !- Direction of Relative North {deg}
  0,                      !- X Origin {m}
  0,                      !- Y Origin {m}
  0,                      !- Z Origin {m}
  1,                      !- Type
  1,                      !- Multiplier
  ,                       !- Ceiling Height {m}
  79,                     !- Volume {m3} was 570
  autocalculate,          !- Floor Area {m2}
  ,                       !- Zone Inside Convection Algorithm
  ,                       !- Zone Outside Convection Algorithm
  Yes;                    !- Part of Total Floor Area

Zone,
  South 1b,               !- Name
  0,                      !- Direction of Relative North {deg}
  0,                      !- X Origin {m}
  0,                      !- Y Origin {m}
  0,                      !- Z Origin {m}
  1,                      !- Type
  1,                      !- Multiplier
  ,                       !- Ceiling Height {m}
  37,                     !- Volume {m3} was 570
  autocalculate,          !- Floor Area {m2}
  ,                       !- Zone Inside Convection Algorithm
  ,                       !- Zone Outside Convection Algorithm
  Yes;                    !- Part of Total Floor Area

Zone,
  North 1,                !- Name
  0,                      !- Direction of Relative North {deg}
  0,                      !- X Origin {m}
  0,                      !- Y Origin {m}
  0,                      !- Z Origin {m}
  1,                      !- Type
  1,                      !- Multiplier
  ,                       !- Ceiling Height {m}
  152,                    !- Volume {m3} was 570
  autocalculate,          !- Floor Area {m2}
  ,                       !- Zone Inside Convection Algorithm
  ,                       !- Zone Outside Convection Algorithm
  Yes;                    !- Part of Total Floor Area

Zone,
  South 2a,               !- Name
  0,                      !- Direction of Relative North {deg}
  0,                      !- X Origin {m}
  0,                      !- Y Origin {m}
  0,                      !- Z Origin {m}
```

```
      1,                    !- Type
  1,                    !- Multiplier
  ,                     !- Ceiling Height {m}
  61,                   !- Volume {m3} was 570
  autocalculate,          !- Floor Area {m2}
  ,                     !- Zone Inside Convection Algorithm
  ,                     !- Zone Outside Convection Algorithm
  Yes;                    !- Part of Total Floor Area

Zone,
  South 2b,               !- Name
  0,                    !- Direction of Relative North {deg}
  0,                    !- X Origin {m}
  0,                    !- Y Origin {m}
  0,                    !- Z Origin {m}
  1,                    !- Type
  1,                    !- Multiplier
  ,                     !- Ceiling Height {m}
  55,                   !- Volume {m3} was 570
  autocalculate,          !- Floor Area {m2}
  ,                     !- Zone Inside Convection Algorithm
  ,                     !- Zone Outside Convection Algorithm
  Yes;                    !- Part of Total Floor Area

Zone,
  South 2c,               !- Name
  0,                    !- Direction of Relative North {deg}
  0,                    !- X Origin {m}
  0,                    !- Y Origin {m}
  0,                    !- Z Origin {m}
  1,                    !- Type
  1,                    !- Multiplier
  ,                     !- Ceiling Height {m}
  34,                   !- Volume {m3} was 570
  autocalculate,          !- Floor Area {m2}
  ,                     !- Zone Inside Convection Algorithm
  ,                     !- Zone Outside Convection Algorithm
  Yes;                    !- Part of Total Floor Area

Zone,
  North 2,               !- Name
  0,                    !- Direction of Relative North {deg}
  0,                    !- X Origin {m}
  0,                    !- Y Origin {m}
  0,                    !- Z Origin {m}
  1,                    !- Type
  1,                    !- Multiplier
  ,                     !- Ceiling Height {m}
  125,                   !- Volume {m3} was 570
  autocalculate,          !- Floor Area {m2}
  ,                     !- Zone Inside Convection Algorithm
  ,                     !- Zone Outside Convection Algorithm
  Yes;                    !- Part of Total Floor Area

Zone,
  Basement_Zone,          !- Name
  0,                    !- Direction of Relative North {deg}
  0,                    !- X Origin {m}
  0,                    !- Y Origin {m}
  0,                    !- Z Origin {m}
  1,                    !- Type
  1,                    !- Multiplier
```

```
          2.35,                  !- Ceiling Height {m} was 2.6
    ,                   !- Volume {m3}
    autocalculate,          !- Floor Area {m2}
    ,                   !- Zone Inside Convection Algorithm
    ,                   !- Zone Outside Convection Algorithm
    No;                    !- Part of Total Floor Area

  Zone,
    Attic_Zone,            !- Name
    0,                  !- Direction of Relative North {deg}
    0,                  !- X Origin {m}
    0,                  !- Y Origin {m}
    0,                  !- Z Origin {m}
    1,                  !- Type
    1,                  !- Multiplier
    ,                   !- Ceiling Height {m}
    ,                   !- Volume {m3}
    autocalculate,          !- Floor Area {m2}
    ,                   !- Zone Inside Convection Algorithm
    ,                   !- Zone Outside Convection Algorithm
    no;                    !- Part of Total Floor Area

  Zone,
    Garage_Zone,            !- Name
    0,                  !- Direction of Relative North {deg}
    0,                  !- X Origin {m}
    0,                  !- Y Origin {m}
    0,                  !- Z Origin {m}
    1,                  !- Type
    1,                  !- Multiplier
    ,                 !- Ceiling Height {m} was 2.77
    ,                   !- Volume {m3}
    autocalculate,          !- Floor Area {m2}
    ,                   !- Zone Inside Convection Algorithm
    ,                   !- Zone Outside Convection Algorithm
    No;                    !- Part of Total Floor Area

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

  Zonelist,
    All Living Space Zones,  !- Name
    South 1a,
    South 1b,
    North 1,
    South 2a,
    South 2b,
    South 2c,
    North 2,
    Basement_Zone;

  Zonelist,
    Main Floor Zones,  !- Name
    South 1a,
    South 1b,
    North 1;

  Zonelist,
    Second Floor Zones,  !- Name
    South 2a,
    South 2b,
    South 2c,
    North 2;
```

```
  Zonelist,
    All Unoccupied Zones,    !- Name
    Attic_Zone,              !- Zone 1 Name
    Garage_Zone;             !- Zone 2 Name

!-   ===========  ALL OBJECTS IN CLASS: BUILDINGSURFACE:DETAILED ===========
!- SOUTH WALLS

  BuildingSurface:Detailed,
    south wall 1_a,          !- Name
    Wall,                    !- Surface Type
    Brick_Wall_w,            !- Construction Name
    South 1a,                !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.5,                     !- View Factor to Ground
    4,                       !- Number of Vertices
    0,0,0.36,  !- X,Y,Z ==> Vertex 1 {m}
    4.38,0,0.36,  !- X,Y,Z ==> Vertex 2 {m}
    4.38,0,3.38,  !- X,Y,Z ==> Vertex 3 {m}
    0,0,3.38;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
    south wall 2_a,          !- Name
    Wall,                    !- Surface Type
    Brick_Wall_w,            !- Construction Name
    south 2a,                !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.5,                     !- View Factor to Ground
    4,                       !- Number of Vertices
    0,0,3.38,  !- X,Y,Z ==> Vertex 1 {m}
    4.38,0,3.38,  !- X,Y,Z ==> Vertex 2 {m}
    4.38,0,6.6,  !- X,Y,Z ==> Vertex 3 {m}
    0,0,6.6;  !- X,Y,Z ==> Vertex 4 {m}

  BuildingSurface:Detailed,
    south wall attic_a,          !- Name
    Wall,                    !- Surface Type
    Brick_Wall_Uninsulated,  !- Construction Name
    attic_zone,              !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.5,                     !- View Factor to Ground
    3,                       !- Number of Vertices
    0,0,6.6,  !- X,Y,Z ==> Vertex 1 {m}
    4.38,0,6.6,  !- X,Y,Z ==> Vertex 2 {m}
    2.19,0,8.425;  !- X,Y,Z ==> Vertex 3 {m}

  BuildingSurface:Detailed,
    south bsmt wall 1,       !- Name
    Wall,                    !- Surface Type
    below_grade,             !- Construction Name
    Basement_Zone,           !- Zone Name
    Outdoors,                !- Outside Boundary Condition
```

```
          ,                    !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,                     !- Number of Vertices
  0,0,0,  !- X,Y,Z ==> Vertex 1 {m}
  4.38,0,0,  !- X,Y,Z ==> Vertex 2 {m}
  4.38,0,0.36,  !- X,Y,Z ==> Vertex 3 {m}
  0,0,0.36;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  south bg wall 1,       !- Name
  Wall,                  !- Surface Type
  below_grade,           !- Construction Name
  Basement_Zone,         !- Zone Name
  OtherSideCoefficients,  !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,                    !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,                     !- Number of Vertices
  0,0,-2.24,  !- X,Y,Z ==> Vertex 1 {m}
  4.38,0,-2.24,  !- X,Y,Z ==> Vertex 2 {m}
  4.38,0,0,  !- X,Y,Z ==> Vertex 3 {m}
  0,0,0;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  south wall 1_b,        !- Name
  Wall,                  !- Surface Type
  Brick_Wall_w,          !- Construction Name
  South 1b,              !- Zone Name
  Outdoors,              !- Outside Boundary Condition
  ,                      !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  0.5,                   !- View Factor to Ground
  4,                     !- Number of Vertices
  4.38,1.23,0.36,  !- X,Y,Z ==> Vertex 1 {m}
  6.6,1.23,0.36,  !- X,Y,Z ==> Vertex 2 {m}
  6.6,1.23,3.38,  !- X,Y,Z ==> Vertex 3 {m}
  4.38,1.23,3.38;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  south bsmt wall 2a,    !- Name
  Wall,                  !- Surface Type
  below_grade,           !- Construction Name
  Basement_Zone,         !- Zone Name
  Outdoors,              !- Outside Boundary Condition
  ,                      !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,                     !- Number of Vertices
  4.38,1.23,0,  !- X,Y,Z ==> Vertex 1 {m}
  6.6,1.23,0,  !- X,Y,Z ==> Vertex 2 {m}
  6.6,1.23,0.36,  !- X,Y,Z ==> Vertex 3 {m}
  4.38,1.23,0.36;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  south bg wall 2a,      !- Name
  Wall,                  !- Surface Type
  below_grade,           !- Construction Name
```

```
          Basement_Zone,          !- Zone Name
  OtherSideCoefficients,  !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,                     !- Outside Boundary Condition Object
  NoSun,                  !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                      !- Number of Vertices
  4.38,1.23,-2.24,  !- X,Y,Z ==> Vertex 1 {m}
  6.6,1.23,-2.24,  !- X,Y,Z ==> Vertex 2 {m}
  6.6,1.23,0,  !- X,Y,Z ==> Vertex 3 {m}
  4.38,1.23,0;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  south bg wall 2b,       !- Name
  Wall,                   !- Surface Type
  below_grade,            !- Construction Name
  Basement_Zone,          !- Zone Name
  OtherSideCoefficients,  !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,                     !- Outside Boundary Condition Object
  NoSun,                  !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                      !- Number of Vertices
  6.6,6.8,-2.24,  !- X,Y,Z ==> Vertex 1 {m}
  12,6.8,-2.24,  !- X,Y,Z ==> Vertex 2 {m}
  12,6.8,0.36,  !- X,Y,Z ==> Vertex 3 {m}
  6.6,6.8,0.36;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  garage south,           !- Name
  Wall,                   !- Surface Type
  Brick_Wall_Uninsulated,  !- Construction Name
  Garage_Zone,            !- Zone Name
  Outdoors,               !- Outside Boundary Condition
  ,                       !- Outside Boundary Condition Object
  SunExposed,             !- Sun Exposure
  WindExposed,            !- Wind Exposure
  0.5,                    !- View Factor to Ground
  4,                      !- Number of Vertices
  6.6,1.23,0.36,  !- X,Y,Z ==> Vertex 1 {m}
  12,1.23,0.36,  !- X,Y,Z ==> Vertex 2 {m}
  12,1.23,3.38,  !- X,Y,Z ==> Vertex 3 {m}
  6.6,1.23,3.38;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  south wall 2_b,         !- Name
  Wall,                   !- Surface Type
  Brick_Wall_w,           !- Construction Name
  South 2b,               !- Zone Name
  Outdoors,               !- Outside Boundary Condition
  ,                       !- Outside Boundary Condition Object
  SunExposed,             !- Sun Exposure
  WindExposed,            !- Wind Exposure
  0.5,                    !- View Factor to Ground
  4,                      !- Number of Vertices
  4.38,1.23,3.38,  !- X,Y,Z ==> Vertex 1 {m}
  6.6,1.23,3.38,  !- X,Y,Z ==> Vertex 2 {m}
  6.6,1.23,6.6,  !- X,Y,Z ==> Vertex 3 {m}
  4.38,1.23,6.6;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  south wall 2_c,         !- Name
```

```
        Wall,                   !- Surface Type
    Brick_Wall_w,           !- Construction Name
    South 2c,               !- Zone Name
    Outdoors,               !- Outside Boundary Condition
    ,                       !- Outside Boundary Condition Object
    SunExposed,             !- Sun Exposure
    WindExposed,            !- Wind Exposure
    0.5,                    !- View Factor to Ground
    4,                      !- Number of Vertices
    6.6,1.23,3.38,  !- X,Y,Z ==> Vertex 1 {m}
    9.24,1.23,3.38,  !- X,Y,Z ==> Vertex 2 {m}
    9.24,1.23,6.6,  !- X,Y,Z ==> Vertex 3 {m}
    6.6,1.23,6.6;  !- X,Y,Z ==> Vertex 4 {m}

  BuildingSurface:Detailed,
    south wall attic_b,          !- Name
    Wall,                   !- Surface Type
    Brick_Wall_Uninsulated,  !- Construction Name
    Attic_Zone,             !- Zone Name
    Outdoors,               !- Outside Boundary Condition
    ,                       !- Outside Boundary Condition Object
    SunExposed,             !- Sun Exposure
    WindExposed,            !- Wind Exposure
    0.5,                    !- View Factor to Ground
    3,                      !- Number of Vertices
    6.36,1.23,6.6,  !- X,Y,Z ==> Vertex 1 {m}
    9.24,1.23,6.6,  !- X,Y,Z ==> Vertex 2 {m}
    7.8,1.23,7.8;  !- X,Y,Z ==> Vertex 3 {m}

  BuildingSurface:Detailed,
    south wall attic_c,          !- Name
    Wall,                   !- Surface Type
    Brick_Wall_uninsulated,             !- Construction Name
    attic_zone,                 !- Zone Name
    Outdoors,               !- Outside Boundary Condition
    ,                       !- Outside Boundary Condition Object
    SunExposed,             !- Sun Exposure
    WindExposed,            !- Wind Exposure
    0.5,                    !- View Factor to Ground
    4,                      !- Number of Vertices
    9.24,1.23,3.38,
    12,1.23,3.38,
    12,1.23,4.71667,
    9.24,1.23,4.71667;

!- SOUTH ROOFS


!- EAST WALLS

  BuildingSurface:Detailed,
    east wall 1_a,           !- Name
    Wall,                   !- Surface Type
    Brick_Wall_uninsulated,  !- Construction Name
    Garage_Zone,            !- Zone Name
    Outdoors,               !- Outside Boundary Condition
    ,                       !- Outside Boundary Condition Object
    SunExposed,             !- Sun Exposure
    WindExposed,            !- Wind Exposure
    0.5,                    !- View Factor to Ground
    4,                      !- Number of Vertices
    12,1.23,0.36,  !- X,Y,Z ==> Vertex 1 {m}
```

```
          12,6.8,0.36,  !- X,Y,Z ==> Vertex 2 {m}
 12,6.8,3.38,  !- X,Y,Z ==> Vertex 3 {m}
 12,1.23,3.38;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
 east wall 1_b,           !- Name
 Wall,                    !- Surface Type
 Brick_Wall_w,            !- Construction Name
 North 1,                 !- Zone Name
 Outdoors,                !- Outside Boundary Condition
 ,                        !- Outside Boundary Condition Object
 SunExposed,              !- Sun Exposure
 WindExposed,             !- Wind Exposure
 0.5,                     !- View Factor to Ground
 4,                       !- Number of Vertices
 12,6.8,0.36,  !- X,Y,Z ==> Vertex 1 {m}
 12,11.89,0.36,  !- X,Y,Z ==> Vertex 2 {m}
 12,11.89,3.38,  !- X,Y,Z ==> Vertex 3 {m}
 12,6.8,3.38;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
 east wall attic_a,           !- Name
 Wall,                    !- Surface Type
 Brick_Wall_uninsulated,            !- Construction Name
 attic_zone,              !- Zone Name
 Outdoors,                !- Outside Boundary Condition
 ,                        !- Outside Boundary Condition Object
 SunExposed,              !- Sun Exposure
 WindExposed,             !- Wind Exposure
 0.5,                     !- View Factor to Ground
 4,                       !- Number of Vertices
 12,1.23,3.38,
 12,3.49,3.38,
 12,3.49,6.6,
 12,1.23,4.71667;

BuildingSurface:Detailed,
 east wall 2_a,           !- Name
 Wall,                    !- Surface Type
 Brick_Wall,              !- Construction Name
 south 2c,                !- Zone Name
 Outdoors,                !- Outside Boundary Condition
 ,                        !- Outside Boundary Condition Object
 SunExposed,              !- Sun Exposure
 WindExposed,             !- Wind Exposure
 0.5,                     !- View Factor to Ground
 4,                       !- Number of Vertices
 12,3.49,3.38,
 12, 6.8, 3.38,
 12, 6.8, 6.6,
 12,3.49,6.6;

BuildingSurface:Detailed,
 east wall 2_b,           !- Name
 Wall,                    !- Surface Type
 Brick_Wall,              !- Construction Name
 North 2,                 !- Zone Name
 Outdoors,                !- Outside Boundary Condition
 ,                        !- Outside Boundary Condition Object
 SunExposed,              !- Sun Exposure
 WindExposed,             !- Wind Exposure
 0.5,                     !- View Factor to Ground
```

```
      4,                    !- Number of Vertices
  12,6.8,3.38,
  12, 9.105, 3.38,
  12, 9.105, 6.6,
  12,6.8,6.6;

BuildingSurface:Detailed,
  east wall attic_b,          !- Name
  Wall,                 !- Surface Type
  Brick_Wall_Uninsulated,           !- Construction Name
  attic_zone,                !- Zone Name
  Outdoors,              !- Outside Boundary Condition
  ,                   !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  0.5,                  !- View Factor to Ground
  4,                   !- Number of Vertices
  12, 9.105, 3.38,
  12, 11.89, 3.38,
  12, 11.89, 3.815,
  12, 9.105, 6.6;

BuildingSurface:Detailed,
  east wall 2_c,           !- Name
  Wall,                 !- Surface Type
  Brick_Wall,            !- Construction Name
  North 2,               !- Zone Name
  Outdoors,              !- Outside Boundary Condition
  ,                   !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  0.5,                  !- View Factor to Ground
  3,                   !- Number of Vertices
  9.24,11.89,3.815,  !- X,Y,Z ==> Vertex 1 {m}
  9.24,11.89,6.6,  !- X,Y,Z ==> Vertex 2 {m}
  9.24,9.105,6.6;  !- X,Y,Z ==> Vertex 3 {m}

BuildingSurface:Detailed,
  east wall 2_d,           !- Name
  Wall,                 !- Surface Type
  Brick_Wall,            !- Construction Name
  South 2b,               !- Zone Name
  Outdoors,              !- Outside Boundary Condition
  ,                   !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  0.5,                  !- View Factor to Ground
  3,                   !- Number of Vertices
  9.24,1.23,4.716667,  !- X,Y,Z ==> Vertex 1 {m}
  9.24,3.49,6.6,  !- X,Y,Z ==> Vertex 2 {m}
  9.24,1.23,6.6;  !- X,Y,Z ==> Vertex 3 {m}

BuildingSurface:Detailed,
  east wall 2_e,           !- Name
  Wall,                 !- Surface Type
  Brick_Wall,            !- Construction Name
  South 1a,               !- Zone Name
  Outdoors,              !- Outside Boundary Condition
  ,                   !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  0.5,                  !- View Factor to Ground
```

```
        4,                       !- Number of Vertices
  4.38,0,0.36,  !- X,Y,Z ==> Vertex 1 {m}
  4.38,1.23,0.36,  !- X,Y,Z ==> Vertex 2 {m}
  4.38,1.23,3.38,  !- X,Y,Z ==> Vertex 3 {m}
  4.38,0,3.38;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  east wall 2_f,            !- Name
  Wall,                     !- Surface Type
  Brick_Wall,               !- Construction Name
  South 2a,                 !- Zone Name
  Outdoors,                 !- Outside Boundary Condition
  ,                         !- Outside Boundary Condition Object
  SunExposed,               !- Sun Exposure
  WindExposed,              !- Wind Exposure
  0.5,                      !- View Factor to Ground
  4,                        !- Number of Vertices
  4.38,0,3.38,  !- X,Y,Z ==> Vertex 1 {m}
  4.38,1.23,3.38,  !- X,Y,Z ==> Vertex 2 {m}
  4.38,1.23,6.6,  !- X,Y,Z ==> Vertex 3 {m}
  4.38,0,6.6;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  east bg wall 1a,          !- Name
  Wall,                     !- Surface Type
  below_grade,              !- Construction Name
  Basement_Zone,            !- Zone Name
  OtherSideCoefficients,  !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,                     !- Outside Boundary Condition Object
  NoSun,                    !- Sun Exposure
  NoWind,                   !- Wind Exposure
  autocalculate,            !- View Factor to Ground
  4,                        !- Number of Vertices
  6.6,1.23,-2.24,  !- X,Y,Z ==> Vertex 1 {m}
  6.6,6.8,-2.24,  !- X,Y,Z ==> Vertex 2 {m}
  6.6,6.8,0.36,  !- X,Y,Z ==> Vertex 3 {m}
  6.6,1.23,0.36;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  east bsmt wall 1b,        !- Name
  Wall,                     !- Surface Type
  below_grade,              !- Construction Name
  Basement_Zone,            !- Zone Name
  Outdoors,                 !- Outside Boundary Condition
  ,                         !- Outside Boundary Condition Object
  SunExposed,               !- Sun Exposure
  WindExposed,              !- Wind Exposure
  autocalculate,            !- View Factor to Ground
  4,                        !- Number of Vertices
  12,6.8,0,  !- X,Y,Z ==> Vertex 1 {m}
  12,11.89,0,  !- X,Y,Z ==> Vertex 2 {m}
  12,11.89,0.36,  !- X,Y,Z ==> Vertex 3 {m}
  12,6.8,0.36;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  east bg wall 1b,          !- Name
  Wall,                     !- Surface Type
  below_grade,              !- Construction Name
  Basement_Zone,            !- Zone Name
  OtherSideCoefficients,  !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,                     !- Outside Boundary Condition Object
  NoSun,                    !- Sun Exposure
```

```
      NoWind,                 !- Wind Exposure
   autocalculate,          !- View Factor to Ground
   4,                      !- Number of Vertices
   12,6.8,-2.24,  !- X,Y,Z ==> Vertex 1 {m}
   12,11.89,-2.24,  !- X,Y,Z ==> Vertex 2 {m}
   12,11.89,0,  !- X,Y,Z ==> Vertex 3 {m}
   12,6.8,0;  !- X,Y,Z ==> Vertex 4 {m}

  BuildingSurface:Detailed,
   east bsmt wall 4,       !- Name
   Wall,                   !- Surface Type
   below_grade,            !- Construction Name
   Basement_Zone,          !- Zone Name
   Outdoors,               !- Outside Boundary Condition
   ,                       !- Outside Boundary Condition Object
   SunExposed,             !- Sun Exposure
   WindExposed,            !- Wind Exposure
   autocalculate,          !- View Factor to Ground
   4,                      !- Number of Vertices
   4.38,0,0,  !- X,Y,Z ==> Vertex 1 {m}
   4.38,1.23,0,  !- X,Y,Z ==> Vertex 2 {m}
   4.38,1.23,0.36,  !- X,Y,Z ==> Vertex 3 {m}
   4.38,0,0.36;  !- X,Y,Z ==> Vertex 4 {m}

  BuildingSurface:Detailed,
   east bg wall 4,         !- Name
   Wall,                   !- Surface Type
   below_grade,            !- Construction Name
   Basement_Zone,          !- Zone Name
   OtherSideCoefficients,  !- Outside Boundary Condition
   surfPropOthSdCoefBasementAvgWall,                       !- Outside Boundary Condition Object
   NoSun,                  !- Sun Exposure
   NoWind,                 !- Wind Exposure
   autocalculate,          !- View Factor to Ground
   4,                      !- Number of Vertices
   4.38,0,-2.24,  !- X,Y,Z ==> Vertex 1 {m}
   4.38,1.23,-2.24,  !- X,Y,Z ==> Vertex 2 {m}
   4.38,1.23,0,  !- X,Y,Z ==> Vertex 3 {m}
   4.38,0,0;  !- X,Y,Z ==> Vertex 4 {m}

!-North Walls

  BuildingSurface:Detailed,
   north wall 1,           !- Name
   Wall,                   !- Surface Type
   Brick_Wall_w,           !- Construction Name
   North 1,                !- Zone Name
   Outdoors,               !- Outside Boundary Condition
   ,                       !- Outside Boundary Condition Object
   SunExposed,             !- Sun Exposure
   WindExposed,            !- Wind Exposure
   0.5,                    !- View Factor to Ground
   4,                      !- Number of Vertices
   12,11.89,0.36,
   0,11.89,0.36,
   0,11.89,3.38,
   12,11.89,3.38;

  BuildingSurface:Detailed,
   north wall attic_a,           !- Name
   Wall,                   !- Surface Type
   Brick_Wall_uninsulated,           !- Construction Name
```

```
      attic_zone,             !- Zone Name
  Outdoors,               !- Outside Boundary Condition
  ,                       !- Outside Boundary Condition Object
  SunExposed,             !- Sun Exposure
  WindExposed,            !- Wind Exposure
  0.5,                    !- View Factor to Ground
  4,                      !- Number of Vertices
  12,11.89,3.38,
  9.24,11.89,3.38,
  9.24,11.89,3.815,
  12,11.89,3.815;

 BuildingSurface:Detailed,
  north wall 2,           !- Name
  Wall,                   !- Surface Type
  Brick_Wall_w,           !- Construction Name
  North 2,                !- Zone Name
  Outdoors,               !- Outside Boundary Condition
  ,                       !- Outside Boundary Condition Object
  SunExposed,             !- Sun Exposure
  WindExposed,            !- Wind Exposure
  0.5,                    !- View Factor to Ground
  4,                      !- Number of Vertices
  9.24,11.89,3.38,
  0,11.89,3.38,
  0,11.89,6.6,
  9.24,11.89,6.6;

 BuildingSurface:Detailed,
  north bsmt wall 1a,     !- Name
  Wall,                   !- Surface Type
  below_grade,            !- Construction Name
  Basement_Zone,          !- Zone Name
  Outdoors,               !- Outside Boundary Condition
  ,                       !- Outside Boundary Condition Object
  SunExposed,             !- Sun Exposure
  WindExposed,            !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                      !- Number of Vertices
  12,11.89,0,  !- X,Y,Z ==> Vertex 1 {m}
  0,11.89,0,  !- X,Y,Z ==> Vertex 2 {m}
  0,11.89,0.36,  !- X,Y,Z ==> Vertex 3 {m}
  12,11.89,0.36;  !- X,Y,Z ==> Vertex 4 {m}

 BuildingSurface:Detailed,
  north bg wall 1a,       !- Name
  Wall,                   !- Surface Type
  below_grade,            !- Construction Name
  Basement_Zone,          !- Zone Name
  OtherSideCoefficients,  !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,                   !- Outside Boundary Condition Object
  NoSun,                  !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                      !- Number of Vertices
  12,11.89,-2.24,  !- X,Y,Z ==> Vertex 1 {m}
  0,11.89,-2.24,  !- X,Y,Z ==> Vertex 2 {m}
  0,11.89,0,  !- X,Y,Z ==> Vertex 3 {m}
  12,11.89,0;  !- X,Y,Z ==> Vertex 4 {m}

!- North Roofs
```

```
!- West Wall

  BuildingSurface:Detailed,
    west wall 1_a,            !- Name
    Wall,                    !- Surface Type
    Brick_Wall,              !- Construction Name
    North 1,                 !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.5,                     !- View Factor to Ground
    4,                       !- Number of Vertices
    0,11.89,0.36,  !- X,Y,Z ==> Vertex 1 {m}
    0,6.8,0.36,  !- X,Y,Z ==> Vertex 2 {m}
    0,6.8,3.38,  !- X,Y,Z ==> Vertex 3 {m}
    0,11.89,3.38;  !- X,Y,Z ==> Vertex 4 {m}

  BuildingSurface:Detailed,
    west wall 1_b,            !- Name
    Wall,                    !- Surface Type
    Brick_Wall,              !- Construction Name
    South 1a,                !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.5,                     !- View Factor to Ground
    4,                       !- Number of Vertices
    0, 6.8, 0.36,
    0, 0, 0.36,
    0, 0, 3.38,
    0, 6.8, 3.38;

  BuildingSurface:Detailed,
    west wall 2_a,            !- Name
    Wall,                    !- Surface Type
    Brick_Wall,              !- Construction Name
    North 2,                 !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.5,                     !- View Factor to Ground
    4,                       !- Number of Vertices
    0,11.89,3.38,  !- X,Y,Z ==> Vertex 1 {m}
    0,6.8,3.38,  !- X,Y,Z ==> Vertex 2 {m}
    0,6.8,6.6,  !- X,Y,Z ==> Vertex 3 {m}
    0,11.89,6.6;  !- X,Y,Z ==> Vertex 4 {m}

  BuildingSurface:Detailed,
    west wall 2_b,            !- Name
    Wall,                    !- Surface Type
    Brick_Wall,              !- Construction Name
    south 2a,                !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.5,                     !- View Factor to Ground
```

```
      4,                 !- Number of Vertices
  0, 6.8, 3.38,
  0, 0, 3.38,
  0, 0, 6.6,
  0, 6.8, 6.6;

 BuildingSurface:Detailed,
  west bsmt wall 1,       !- Name
  Wall,                   !- Surface Type
  below_grade,            !- Construction Name
  Basement_Zone,          !- Zone Name
  Outdoors,               !- Outside Boundary Condition
  ,                       !- Outside Boundary Condition Object
  SunExposed,             !- Sun Exposure
  WindExposed,            !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                      !- Number of Vertices
  0,11.89,0,  !- X,Y,Z ==> Vertex 1 {m}
  0,0,0,  !- X,Y,Z ==> Vertex 2 {m}
  0,0,0.36,  !- X,Y,Z ==> Vertex 3 {m}
  0,11.89,0.36;  !- X,Y,Z ==> Vertex 4 {m}

 BuildingSurface:Detailed,
  west bg wall 1,         !- Name
  Wall,                   !- Surface Type
  below_grade,            !- Construction Name
  Basement_Zone,          !- Zone Name
  OtherSideCoefficients,  !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,                    !- Outside Boundary Condition Object
  NoSun,                  !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                      !- Number of Vertices
  0,11.89,-2.24,  !- X,Y,Z ==> Vertex 1 {m}
  0,0,-2.24,  !- X,Y,Z ==> Vertex 2 {m}
  0,0,0,  !- X,Y,Z ==> Vertex 3 {m}
  0,11.89,0;  !- X,Y,Z ==> Vertex 4 {m}

!- West Roofs



!- BASEMENT FLOOR

 BuildingSurface:Detailed,
  basement floor 1,       !- Name
  Floor,                  !- Surface Type
  basement_floor,         !- Construction Name
  basement_zone,          !- Zone Name
  OtherSideCoefficients,  !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgFloor,                   !- Outside Boundary Condition Object
  NoSun,                  !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                      !- Number of Vertices
  6.6,11.89,-2.24,  !- X,Y,Z ==> Vertex 1 {m}
  12,11.89,-2.24,  !- X,Y,Z ==> Vertex 2 {m}
  12,6.8,-2.24,  !- X,Y,Z ==> Vertex 3 {m}
  6.6,6.8,-2.24;  !- X,Y,Z ==> Vertex 4 {m}

 BuildingSurface:Detailed,
  basement floor 2,       !- Name
```

```
    Floor,                   !- Surface Type
  basement_floor,          !- Construction Name
  Basement_Zone,           !- Zone Name
  OtherSideCoefficients,  !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgFloor,                     !- Outside Boundary Condition Object
  NoSun,                   !- Sun Exposure
  NoWind,                  !- Wind Exposure
  autocalculate,           !- View Factor to Ground
  6,                       !- Number of Vertices
  0,11.89,-2.24,  !- X,Y,Z ==> Vertex 1 {m}
  6.6,11.89,-2.24,  !- X,Y,Z ==> Vertex 2 {m}
  6.6,1.23,-2.24,  !- X,Y,Z ==> Vertex 3 {m}
  4.38,1.23,-2.24,  !- X,Y,Z ==> Vertex 4 {m}
  4.38,0,-2.24,  !- X,Y,Z ==> Vertex 5 {m}
  0,0,-2.24;  !- X,Y,Z ==> Vertex 6 {m}


!  ======== INTERZONE PARTIONS & FLOORS  =======

! Partitions level 1

 BuildingSurface:Detailed,
  South 1a partition 1,    !- Name
  Wall,                    !- Surface Type
  interior wall,    !- Construction Name
  South 1a,             !- Zone Name
  Surface,                 !- Outside Boundary Condition
  North 1 partition 1a,    !- Outside Boundary Condition Object
  NoSun,                   !- Sun Exposure
  NoWind,                  !- Wind Exposure
  autocalculate,           !- View Factor to Ground
  4,                       !- Number of Vertices
  0,6.8,0.36,
  4.38,6.8,0.36,
  4.38,6.8,3.38,
  0,6.8,3.38;

 BuildingSurface:Detailed,
  North 1 partition 1a,    !- Name
  Wall,                    !- Surface Type
  interior wall,    !- Construction Name
  North 1,             !- Zone Name
  Surface,                 !- Outside Boundary Condition
  South 1a partition 1a,    !- Outside Boundary Condition Object
  NoSun,                   !- Sun Exposure
  NoWind,                  !- Wind Exposure
  autocalculate,           !- View Factor to Ground
  4,                       !- Number of Vertices
  0,6.8,3.38,
  4.38,6.8,3.38,
  4.38,6.8,0.36,
  0,6.8,0.36;

 BuildingSurface:Detailed,
  South 1b - North 1,    !- Name
  Wall,                    !- Surface Type
  interior wall,    !- Construction Name
  South 1b,             !- Zone Name
  Surface,                 !- Outside Boundary Condition
  North 1 - South 1b,    !- Outside Boundary Condition Object
  NoSun,                   !- Sun Exposure
  NoWind,                  !- Wind Exposure
```

```
      autocalculate,          !- View Factor to Ground
    4,                   !- Number of Vertices
    4.38,6.8,0.36,
    6.6,6.8,0.36,
    6.6,6.8,3.38,
    4.38,6.8,3.38;

  BuildingSurface:Detailed,
    North 1 - South 1b,    !- Name
    Wall,                  !- Surface Type
    interior wall,    !- Construction Name
    North 1,             !- Zone Name
    Surface,               !- Outside Boundary Condition
    South 1b - North 1,    !- Outside Boundary Condition Object
    NoSun,                 !- Sun Exposure
    NoWind,                 !- Wind Exposure
    autocalculate,          !- View Factor to Ground
    4,                   !- Number of Vertices
    4.38,6.8,3.38,
    6.6,6.8,3.38,
    6.6,6.8,0.36,
    4.38,6.8,0.36;

  BuildingSurface:Detailed,
    South 1a partition 2,    !- Name
    Wall,                  !- Surface Type
    interior wall,    !- Construction Name
    South 1a,            !- Zone Name
    Surface,               !- Outside Boundary Condition
    South 1b partition 2,    !- Outside Boundary Condition Object
    NoSun,                 !- Sun Exposure
    NoWind,                 !- Wind Exposure
    autocalculate,          !- View Factor to Ground
    4,                   !- Number of Vertices
    4.38,6.8,0.36,
    4.38,1.23,0.36,
    4.38,1.23,3.38,
    4.38,6.8,3.38;

  BuildingSurface:Detailed,
    South 1b partition 2,    !- Name
    Wall,                  !- Surface Type
    interior wall,    !- Construction Name
    South 1b,            !- Zone Name
    Surface,               !- Outside Boundary Condition
    South 1a partition 2,    !- Outside Boundary Condition Object
    NoSun,                 !- Sun Exposure
    NoWind,                 !- Wind Exposure
    autocalculate,          !- View Factor to Ground
    4,                   !- Number of Vertices
    4.38,6.8,3.38,
    4.38,1.23,3.38,
    4.38,1.23,0.36,
    4.38,6.8,0.36;

!- Garage

  BuildingSurface:Detailed,
    East garage int wall,    !- Name
    Wall,                  !- Surface Type
    interior_garage_wall,    !- Construction Name
    Garage_Zone,           !- Zone Name
```

```
    Surface,                !- Outside Boundary Condition
  West garage int wall,    !- Outside Boundary Condition Object
  NoSun,                   !- Sun Exposure
  NoWind,                  !- Wind Exposure
  autocalculate,           !- View Factor to Ground
  4,                       !- Number of Vertices
  6.6,1.23,0.36,  !- X,Y,Z ==> Vertex 1 {m}
  6.6,6.8,0.36,  !- X,Y,Z ==> Vertex 2 {m}
  6.6,6.8,3.38,  !- X,Y,Z ==> Vertex 3 {m}
  6.6,1.23,3.38;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  West garage int wall,    !- Name
  Wall,                    !- Surface Type
  interior_garage_wall,    !- Construction Name
  South 1b,                !- Zone Name
  Surface,                 !- Outside Boundary Condition
  East garage int wall,    !- Outside Boundary Condition Object
  NoSun,                   !- Sun Exposure
  NoWind,                  !- Wind Exposure
  autocalculate,           !- View Factor to Ground
  4,                       !- Number of Vertices
  6.6,6.8,0.36,  !- X,Y,Z ==> Vertex 1 {m}
  6.6,1.23,0.36,  !- X,Y,Z ==> Vertex 2 {m}
  6.6,1.23,3.38,  !- X,Y,Z ==> Vertex 3 {m}
  6.6,6.8,3.38;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  South garage int wall,   !- Name
  Wall,                    !- Surface Type
  interior_garage_wall,    !- Construction Name
  Garage_Zone,             !- Zone Name
  Surface,                 !- Outside Boundary Condition
  North garage int wall,   !- Outside Boundary Condition Object
  NoSun,                   !- Sun Exposure
  NoWind,                  !- Wind Exposure
  autocalculate,           !- View Factor to Ground
  4,                       !- Number of Vertices
  6.6,6.8,0.36,  !- X,Y,Z ==> Vertex 1 {m}
  12,6.8,0.36,  !- X,Y,Z ==> Vertex 2 {m}
  12,6.8,3.38,  !- X,Y,Z ==> Vertex 3 {m}
  6.6,6.8,3.38;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  North garage int wall,   !- Name
  Wall,                    !- Surface Type
  interior_garage_wall,    !- Construction Name
  North 1,                 !- Zone Name
  Surface,                 !- Outside Boundary Condition
  South garage int wall,   !- Outside Boundary Condition Object
  NoSun,                   !- Sun Exposure
  NoWind,                  !- Wind Exposure
  autocalculate,           !- View Factor to Ground
  4,                       !- Number of Vertices
  12,6.8,0.36,  !- X,Y,Z ==> Vertex 1 {m}
  6.6,6.8,0.36,  !- X,Y,Z ==> Vertex 2 {m}
  6.6,6.8,3.38,  !- X,Y,Z ==> Vertex 3 {m}
  12,6.8,3.38;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  Garage floor,            !- Name
  Floor,                   !- Surface Type
```

```
          garage_floor,         !- Construction Name
  Garage_Zone,           !- Zone Name
  OtherSideCoefficients,              !- Outside Boundary Condition
  surfPropOthSdCoefSlabAverage,                       !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                    !- Number of Vertices
  6.6,6.8,0.36,  !- X,Y,Z ==> Vertex 1 {m}
  12,6.8,0.36,  !- X,Y,Z ==> Vertex 2 {m}
  12,1.23,0.36,  !- X,Y,Z ==> Vertex 3 {m}
  6.6,1.23,0.36;  !- X,Y,Z ==> Vertex 4 {m}

!- Second Level Floors

 BuildingSurface:Detailed,
  SE Attic Floor,  !- Name
  Floor,                !- Surface Type
  garage_ceiling_reverse,         !- Construction Name
  attic_zone,                !- Zone Name
  Surface,               !- Outside Boundary Condition
  Garage ceiling 2,         !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                    !- Number of Vertices
  9.24, 3.49, 3.38,
  12,3.49,3.38,
  12,1.23,3.38,
  9.24, 1.23, 3.38;

 BuildingSurface:Detailed,
  Garage ceiling 2,         !- Name
  Ceiling,               !- Surface Type
  garage_ceiling,         !- Construction Name
  Garage_Zone,           !- Zone Name
  Surface,               !- Outside Boundary Condition
  SE Attic Floor,  !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                    !- Number of Vertices
  9.24, 1.23, 3.38,  !- X,Y,Z ==> Vertex 1 {m}
  12,1.23,3.38,  !- X,Y,Z ==> Vertex 2 {m}
  12,3.49,3.38,  !- X,Y,Z ==> Vertex 3 {m}
  9.24, 3.49, 3.38;  !- X,Y,Z ==> Vertex 4 {m}

 BuildingSurface:Detailed,
  Garage ceiling 1b2,         !- Name
  Ceiling,               !- Surface Type
  garage_ceiling_carpet,         !- Construction Name
  Garage_Zone,           !- Zone Name
  Surface,               !- Outside Boundary Condition
  South 2b Floor 2,  !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                    !- Number of Vertices
  6.6,1.23,3.38,
  9.24,1.23,3.38,
  9.24,6.8,3.38,
  6.6,6.8,3.38;
```

```
BuildingSurface:Detailed,
  South 2b Floor 2,         !- Name
  Floor,                    !- Surface Type
  garage_ceiling_carpet_rev,        !- Construction Name
  South 2b,                 !- Zone Name
  Surface,                  !- Outside Boundary Condition
  Garage Ceiling 1b2,  !- Outside Boundary Condition Object
  NoSun,                    !- Sun Exposure
  NoWind,                   !- Wind Exposure
  autocalculate,            !- View Factor to Ground
  4,                        !- Number of Vertices
  6.6,6.8,3.38,
  9.24,6.8,3.38,
  9.24,1.23,3.38,
  6.6,1.23,3.38;

BuildingSurface:Detailed,
  South 1b ceiling 1,       !- Name
  Ceiling,                  !- Surface Type
  interior_floor_tile_rev,        !- Construction Name
  South 1b,                 !- Zone Name
  Surface,                  !- Outside Boundary Condition
  South 2b Floor 1,  !- Outside Boundary Condition Object
  NoSun,                    !- Sun Exposure
  NoWind,                   !- Wind Exposure
  autocalculate,            !- View Factor to Ground
  4,                        !- Number of Vertices
  4.38,1.23,3.38,
  6.6,1.23,3.38,
  6.6,6.8,3.38,
  4.38,6.8,3.38;

BuildingSurface:Detailed,
  South 2b Floor 1,         !- Name
  Floor,                    !- Surface Type
  interior_floor_tile,        !- Construction Name
  South 2b,                 !- Zone Name
  Surface,                  !- Outside Boundary Condition
  Garage Ceiling 1b2,  !- Outside Boundary Condition Object
  NoSun,                    !- Sun Exposure
  NoWind,                   !- Wind Exposure
  autocalculate,            !- View Factor to Ground
  4,                        !- Number of Vertices
  4.38,6.8,3.38,
  6.6,6.8,3.38,
  6.6,1.23,3.38,
  4.38,1.23,3.38;

BuildingSurface:Detailed,
  Garage ceiling 1c,        !- Name
  Ceiling,                  !- Surface Type
  garage_ceiling_carpet,        !- Construction Name
  Garage_Zone,              !- Zone Name
  Surface,                  !- Outside Boundary Condition
  South 2c Floor 1,  !- Outside Boundary Condition Object
  NoSun,                    !- Sun Exposure
  NoWind,                   !- Wind Exposure
  autocalculate,            !- View Factor to Ground
  4,
  9.24,3.49,3.38,
  12,3.49,3.38,
```

```
          12,6.8,3.38,
 9.24,6.8,3.38;

BuildingSurface:Detailed,
 South 2c Floor 1,         !- Name
 Floor,                !- Surface Type
 garage_ceiling_carpet_rev,         !- Construction Name
 South 2c,            !- Zone Name
 Surface,              !- Outside Boundary Condition
 Garage ceiling 1c,  !- Outside Boundary Condition Object
 NoSun,                !- Sun Exposure
 NoWind,                !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,
 9.24,6.8,3.38,
 12,6.8,3.38,
 12,3.49,3.38,
 9.24,3.49,3.38;

BuildingSurface:Detailed,
 South 2c Floor 2,         !- Name
 Floor,                !- Surface Type
 interior_floor_carpet,         !- Construction Name
 South 2c,            !- Zone Name
 Surface,              !- Outside Boundary Condition
 North 1c2,  !- Outside Boundary Condition Object
 NoSun,                !- Sun Exposure
 NoWind,                !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,
 9.24,9.105,3.38,
 12,9.105,3.38,
 12,6.8,3.38,
 9.24,6.8,3.38;

BuildingSurface:Detailed,
 North 1c2,         !- Name
 Ceiling,                !- Surface Type
 interior_floor_carpet_rev,         !- Construction Name
 North 1,            !- Zone Name
 Surface,              !- Outside Boundary Condition
 South 2c Floor 2,  !- Outside Boundary Condition Object
 NoSun,                !- Sun Exposure
 NoWind,                !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,
 9.24,6.8,3.38,
 12,6.8,3.38,
 12,9.105,3.38,
 9.24,9.105,3.38;

BuildingSurface:Detailed,
 North 2 Floor 1,        !- Name
 Floor,                !- Surface Type
 interior_floor_carpet,   !- Construction Name
 North 2,              !- Zone Name
 Surface,              !- Outside Boundary Condition
 North 1c1,              !- Outside Boundary Condition Object
 NoSun,                !- Sun Exposure
 NoWind,                !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,
```

```
      0,11.79,3.38,
 9.24,11.79,3.38,
 9.24,6.8,3.38,
 0,6.8,3.38;

BuildingSurface:Detailed,
 North 1c1,        !- Name
 Ceiling,                 !- Surface Type
 interior_floor_carpet_rev,   !- Construction Name
 North 1,               !- Zone Name
 Surface,               !- Outside Boundary Condition
 North 2 Floor 1,             !- Outside Boundary Condition Object
 NoSun,                 !- Sun Exposure
 NoWind,                 !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,
 0,6.8,3.38,
 9.24,6.8,3.38,
 9.24,11.79,3.38,
 0,11.79,3.38;

BuildingSurface:Detailed,
 South 2a Floor,         !- Name
 Floor,               !- Surface Type
 interior_floor_carpet,         !- Construction Name
 South 2a,            !- Zone Name
 Surface,               !- Outside Boundary Condition
 South 1a ceiling,  !- Outside Boundary Condition Object
 NoSun,                 !- Sun Exposure
 NoWind,                 !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,
 0,6.8,3.38,
 4.38,6.8,3.38,
 4.38,0,3.38,
 0,0,3.38;

BuildingSurface:Detailed,
 South 1a ceiling,         !- Name
 Ceiling,               !- Surface Type
 interior_floor_carpet_rev,         !- Construction Name
 South 1a,            !- Zone Name
 Surface,               !- Outside Boundary Condition
 South 2a Floor,  !- Outside Boundary Condition Object
 NoSun,                 !- Sun Exposure
 NoWind,                 !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,
 0,0,3.38,
 4.38,0,3.38,
 4.38,6.8,3.38,
 0,6.8,3.38;

BuildingSurface:Detailed,
 NE attic floor,           !- Name
 Floor,                 !- Surface Type
 ceiling_insulated,         !- Construction Name
 attic_zone,                !- Zone Name
 Surface,               !- Outside Boundary Condition
 North 1c3,      !- Outside Boundary Condition Object
 NoSun,                 !- Sun Exposure
 NoWind,                 !- Wind Exposure
```

```
          autocalculate,          !- View Factor to Ground
    4,                    !- Number of Vertices
    9.24,11.89,3.38,
    12,11.89,3.38,
    12,9.105,3.38,
    9.24,9.105,3.38;

  BuildingSurface:Detailed,
    North 1c3,            !- Name
    Ceiling,                 !- Surface Type
    ceiling_insulated_reverse,         !- Construction Name
    North 1,                 !- Zone Name
    Surface,                !- Outside Boundary Condition
    NE attic floor,      !- Outside Boundary Condition Object
    NoSun,                  !- Sun Exposure
    NoWind,                  !- Wind Exposure
    autocalculate,          !- View Factor to Ground
    4,                    !- Number of Vertices
    9.24,9.105,3.38,
    12,9.105,3.38,
    12,11.89,3.38,
    9.24,11.89,3.38;

!- Second Level Partitions

  BuildingSurface:Detailed,
    South 2a - North 2,    !- Name
    Wall,                   !- Surface Type
    interior wall,    !- Construction Name
    South 2a,            !- Zone Name
    Surface,                !- Outside Boundary Condition
    North 2 - South 2a,    !- Outside Boundary Condition Object
    NoSun,                  !- Sun Exposure
    NoWind,                  !- Wind Exposure
    autocalculate,          !- View Factor to Ground
    4,                    !- Number of Vertices
    0,6.8,3.38,
    4.38,6.8,3.38,
    4.38,6.8,6.6,
    0,6.8,6.6;

  BuildingSurface:Detailed,
    North 2 - South 2a,    !- Name
    Wall,                   !- Surface Type
    interior wall,    !- Construction Name
    North 2,            !- Zone Name
    Surface,                !- Outside Boundary Condition
    South 2a - North 2,    !- Outside Boundary Condition Object
    NoSun,                  !- Sun Exposure
    NoWind,                  !- Wind Exposure
    autocalculate,          !- View Factor to Ground
    4,                    !- Number of Vertices
    0,6.8,6.6,
    4.38,6.8,6.6,
    4.38,6.8,3.38,
    0,6.8,3.38;

  BuildingSurface:Detailed,
    South 2a - South 2b,    !- Name
    Wall,                   !- Surface Type
    interior wall,    !- Construction Name
    South 2a,            !- Zone Name
```

```
      Surface,                !- Outside Boundary Condition
 South 2b - South 2a,    !- Outside Boundary Condition Object
 NoSun,                  !- Sun Exposure
 NoWind,                 !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,                      !- Number of Vertices
 4.38,6.8,3.38,
 4.38,1.23,3.38,
 4.38,1.23,6.6,
 4.38,6.8,6.6;

BuildingSurface:Detailed,
 South 2b - South 2a,    !- Name
 Wall,                   !- Surface Type
 interior wall,    !- Construction Name
 South 2b,               !- Zone Name
 Surface,                !- Outside Boundary Condition
 South 2a - South 2b,    !- Outside Boundary Condition Object
 NoSun,                  !- Sun Exposure
 NoWind,                 !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,                      !- Number of Vertices
 4.38,6.8,6.6,
 4.38,1.23,6.6,
 4.38,1.23,3.38,
 4.38,6.8,3.38;

BuildingSurface:Detailed,
 South 2b - North 2,    !- Name
 Wall,                   !- Surface Type
 interior wall,    !- Construction Name
 South 2b,               !- Zone Name
 Surface,                !- Outside Boundary Condition
 North 2 - South 2b,    !- Outside Boundary Condition Object
 NoSun,                  !- Sun Exposure
 NoWind,                 !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,                      !- Number of Vertices
 4.38,6.8,3.38,
 9.24,6.8,3.38,
 9.24,6.8,6.6,
 4.38,6.8,6.6;

BuildingSurface:Detailed,
 North 2 - South 2b,    !- Name
 Wall,                   !- Surface Type
 interior wall,    !- Construction Name
 North 2,               !- Zone Name
 Surface,                !- Outside Boundary Condition
 South 2b - North 2,    !- Outside Boundary Condition Object
 NoSun,                  !- Sun Exposure
 NoWind,                 !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,                      !- Number of Vertices
 4.38,6.8,6.6,
 9.24,6.8,6.6,
 9.24,6.8,3.38,
 4.38,6.8,3.38;

BuildingSurface:Detailed,
 South 2c - North 2,    !- Name
 Wall,                   !- Surface Type
```

```
          interior wall,    !- Construction Name
  South 2c,           !- Zone Name
  Surface,               !- Outside Boundary Condition
  North 2 - South 2c,    !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                  !- Number of Vertices
  9.24,6.8,3.38,
  9.24,9.105,3.38,
  9.24,9.105,6.6,
  9.24,6.8,6.6;

 BuildingSurface:Detailed,
  North 2 - South 2c,    !- Name
  Wall,                 !- Surface Type
  interior wall,    !- Construction Name
  North 2,           !- Zone Name
  Surface,               !- Outside Boundary Condition
  South 2c - North 2,    !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                  !- Number of Vertices
  9.24,6.8,6.6,
  9.24,9.105,6.6,
  9.24,9.105,3.38,
  9.24,6.8,3.38;

 BuildingSurface:Detailed,
  South 2b - South 2c,    !- Name
  Wall,                 !- Surface Type
  interior wall,    !- Construction Name
  South 2b,           !- Zone Name
  Surface,               !- Outside Boundary Condition
  South 2c - South 2b,    !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                  !- Number of Vertices
  9.24,6.8,3.38,
  9.24,3.49,3.38,
  9.24,3.49,6.6,
  9.24,6.8,6.6;

 BuildingSurface:Detailed,
  South 2c - South 2b,    !- Name
  Wall,                 !- Surface Type
  interior wall,    !- Construction Name
  South 2c,           !- Zone Name
  Surface,               !- Outside Boundary Condition
  South 2b - South 2c,    !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                 !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                  !- Number of Vertices
  9.24,6.8,6.6,
  9.24,3.49,6.6,
  9.24,3.49,3.38,
  9.24,6.8,3.38;

!- partitions between attic & level 2
```

```
!- SE lower attic
  BuildingSurface:Detailed,
    S2b_SE attic wall,    !- Name
    Wall,                 !- Surface Type
    interior_garage_wall,                    !- Construction Name
    South 2b,             !- Zone Name
    Surface,              !- Outside Boundary Condition
    SE Attic wall 1,    !- Outside Boundary Condition Object
    NoSun,                !- Sun Exposure
    NoWind,               !- Wind Exposure
    autocalculate,        !- View Factor to Ground
    4,                    !- Number of Vertices
    9.24,1.23,4.71667,
    9.24,3.49,6.6,
    9.24,3.49,3.38,
    9.24,1.23,3.38;

  BuildingSurface:Detailed,
    SE attic wall 1,    !- Name
    Wall,                 !- Surface Type
    interior_garage_wall,                    !- Construction Name
    attic_zone,           !- Zone Name
    Surface,              !- Outside Boundary Condition
    S2b_SE attic wall,    !- Outside Boundary Condition Object
    NoSun,                !- Sun Exposure
    NoWind,               !- Wind Exposure
    autocalculate,        !- View Factor to Ground
    4,                    !- Number of Vertices
    9.24,1.23,3.38,
    9.24,3.49,3.38,
    9.24,3.49,6.6,
    9.24,1.23,4.71667;

  BuildingSurface:Detailed,
    S2c_SE attic wall,    !- Name
    Wall,                 !- Surface Type
    interior_garage_wall,                    !- Construction Name
    South 2c,             !- Zone Name
    Surface,              !- Outside Boundary Condition
    SE Attic wall 2,    !- Outside Boundary Condition Object
    NoSun,                !- Sun Exposure
    NoWind,               !- Wind Exposure
    autocalculate,        !- View Factor to Ground
    4,                    !- Number of Vertices
    12,3.49,3.38,
    9.24,3.49,3.38,
    9.24,3.49,6.6,
    12,3.49,6.6;

  BuildingSurface:Detailed,
    SE Attic wall 2,    !- Name
    Wall,                 !- Surface Type
    interior_garage_wall,                    !- Construction Name
    attic_zone,           !- Zone Name
    Surface,              !- Outside Boundary Condition
    S2c_SE attic wall,    !- Outside Boundary Condition Object
    NoSun,                !- Sun Exposure
    NoWind,               !- Wind Exposure
    autocalculate,        !- View Factor to Ground
    4,                    !- Number of Vertices
    12,3.49,6.6,
```

```
        9.24,3.49,6.6,
  9.24,3.49,3.38,
  12,3.49,3.38;

!- NE lower attic

 BuildingSurface:Detailed,
  N2_NE attic wall 1,    !- Name
  Wall,                !- Surface Type
  interior_garage_wall,                  !- Construction Name
  North 2,             !- Zone Name
  Surface,              !- Outside Boundary Condition
  NE Attic wall 1,    !- Outside Boundary Condition Object
  NoSun,                !- Sun Exposure
  NoWind,                !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,                  !- Number of Vertices
  9.24, 9.105, 6.6,
  9.24, 11.89, 3.815,
  9.24, 11.89, 3.38,
  9.24, 9.105, 3.38;

 BuildingSurface:Detailed,
  NE Attic wall 1,    !- Name
  Wall,                !- Surface Type
  interior_garage_wall,                  !- Construction Name
  attic_zone,             !- Zone Name
  Surface,              !- Outside Boundary Condition
  N2_NE attic wall 1,    !- Outside Boundary Condition Object
  NoSun,                !- Sun Exposure
  NoWind,                !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,                  !- Number of Vertices
  9.24, 9.105, 3.38,
  9.24, 11.89, 3.38,
  9.24, 11.89, 3.815,
  9.24, 9.105, 6.6;


 BuildingSurface:Detailed,
  N2_NE attic wall 2,    !- Name
  Wall,                !- Surface Type
  interior_garage_wall,                  !- Construction Name
  North 2,             !- Zone Name
  Surface,              !- Outside Boundary Condition
  NE Attic wall 2,    !- Outside Boundary Condition Object
  NoSun,                !- Sun Exposure
  NoWind,                !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,
  9.24,9.105,3.38,
  12,9.105,3.38,
  12,9.105,6.6,
  9.24,9.105,6.6;

 BuildingSurface:Detailed,
  NE Attic wall 2,    !- Name
  Wall,                !- Surface Type
  interior_garage_wall,                  !- Construction Name
  attic_zone,             !- Zone Name
  Surface,              !- Outside Boundary Condition
  N2_NE attic wall 2,    !- Outside Boundary Condition Object
```

```
      NoSun,                !- Sun Exposure
  NoWind,               !- Wind Exposure
  autocalculate,        !- View Factor to Ground
  4,
  9.24,9.105,6.6,
  12,9.105,6.6,
  12,9.105,3.38,
  9.24,9.105,3.38;

!- Main Floors

 BuildingSurface:Detailed,
  South 1a floor,          !- Name
  Floor,                 !- Surface Type
  main_floor_carpet,       !- Name
  South 1a,              !- Zone Name
  Surface,               !- Outside Boundary Condition
  basement ceiling s1a,     !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,                  !- Number of Vertices
  0,6.8,0.36,
  4.38,6.8,0.36,
  4.38,0,0.36,
  0,0,0.36;

 BuildingSurface:Detailed,
  basement ceiling s1a,     !- Name
  Ceiling,               !- Surface Type
  main_floor_carpet_rev,     !- Construction Name
  Basement_Zone,          !- Zone Name
  Surface,               !- Outside Boundary Condition
  South 1a floor,          !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,                  !- Number of Vertices
  0,0,0.36,
  4.38,0,0.36,
  4.38,6.8,0.36,
  0,6.8,0.36;

 BuildingSurface:Detailed,
  South 1b floor,          !- Name
  Floor,                 !- Surface Type
  main_floor_tile,        !- Construction Name
  South 1b,              !- Zone Name
  Surface,               !- Outside Boundary Condition
  basement ceiling s1b,     !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,                  !- Number of Vertices
  4.38,6.8,0.36,
  6.6,6.8,0.36,
  6.6,1.23,0.36,
  4.38,1.23,0.36;

 BuildingSurface:Detailed,
  basement ceiling s1b,     !- Name
  Ceiling,               !- Surface Type
```

```
      main_floor_tile_rev,      !- Construction Name
 Basement_Zone,          !- Zone Name
 Surface,                !- Outside Boundary Condition
 South 1b floor,           !- Outside Boundary Condition Object
 NoSun,                  !- Sun Exposure
 NoWind,                 !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,                      !- Number of Vertices
 4.38,1.23,0.36,
 6.6,1.23,0.36,
 6.6,6.8,0.36,
 4.38,6.8,0.36;

BuildingSurface:Detailed,
 North 1 floor 1,           !- Name
 Floor,                  !- Surface Type
 main_floor_carpet,         !- Construction Name
 North 1,                !- Zone Name
 Surface,                !- Outside Boundary Condition
 basement ceiling n1f1,      !- Outside Boundary Condition Object
 NoSun,                  !- Sun Exposure
 NoWind,                 !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,                      !- Number of Vertices
 0,11.89,0.36,
 4.38,11.89,0.36,
 4.38,6.8,0.36,
 0,6.8,0.36;

BuildingSurface:Detailed,
 basement ceiling n1f1,      !- Name
 Ceiling,                !- Surface Type
 main_floor_carpet_rev,      !- Construction Name
 Basement_Zone,          !- Zone Name
 Surface,                !- Outside Boundary Condition
 North 1 floor 1,           !- Outside Boundary Condition Object
 NoSun,                  !- Sun Exposure
 NoWind,                 !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,                      !- Number of Vertices
 0,6.8,0.36,
 4.38,6.8,0.36,
 4.38,11.89,0.36,
 0,11.89,0.36;

BuildingSurface:Detailed,
 North 1 floor 2,           !- Name
 Floor,                  !- Surface Type
 main_floor_tile,         !- Construction Name
 North 1,                !- Zone Name
 Surface,                !- Outside Boundary Condition
 basement ceiling n1f2,      !- Outside Boundary Condition Object
 NoSun,                  !- Sun Exposure
 NoWind,                 !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,                      !- Number of Vertices
 4.38,11.89,0.36,
 12, 11.89,0.36,
 12,6.8,0.36,
 4.38,6.8,0.36;

BuildingSurface:Detailed,
```

```
        basement ceiling n1f2,      !- Name
    Ceiling,                 !- Surface Type
    main_floor_tile_rev,     !- Construction Name
    Basement_Zone,           !- Zone Name
    Surface,                 !- Outside Boundary Condition
    North 1 floor 2,         !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    autocalculate,           !- View Factor to Ground
    4,                       !- Number of Vertices
    4.38,6.8,0.36,
    12,6.8,0.36,
    12, 11.89,0.36,
    4.38,11.89,0.36;


!- Attic Floor - Upstairs ceiling

  BuildingSurface:Detailed,
    South 2a Ceiling,        !- Name
    Ceiling,                 !- Surface Type
    ceiling_insulated,       !- Construction Name
    South 2a,                !- Zone Name
    Surface,                 !- Outside Boundary Condition
    attic floor S2a,         !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    autocalculate,           !- View Factor to Ground
    4,
    0,0,6.6,
    4.38,0,6.6,
    4.38,6.8,6.6,
    0,6.8,6.6;

  BuildingSurface:Detailed,
    attic floor S2a,         !- Name
    Floor,                   !- Surface Type
    ceiling_insulated_reverse,  !- Construction Name
    Attic_Zone,              !- Zone Name
    Surface,                 !- Outside Boundary Condition
    South 2a Ceiling,        !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    autocalculate,           !- View Factor to Ground
    4,
    0,6.8,6.6,
    4.38,6.8,6.6,
    4.38,0,6.6,
    0,0,6.6;

  BuildingSurface:Detailed,
    South 2b Ceiling,        !- Name
    Ceiling,                 !- Surface Type
    ceiling_insulated,       !- Construction Name
    South 2b,                !- Zone Name
    Surface,                 !- Outside Boundary Condition
    attic floor S2b,         !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    autocalculate,           !- View Factor to Ground
    4,
    4.38,1.23,6.6,
```

```
        9.24,1.23,6.6,
  9.24,6.8,6.6,
  4.38,6.8,6.6;

BuildingSurface:Detailed,
  attic floor S2b,           !- Name
  Floor,                 !- Surface Type
  ceiling_insulated_reverse,  !- Construction Name
  Attic_Zone,            !- Zone Name
  Surface,               !- Outside Boundary Condition
  South 2b Ceiling,       !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,
  4.38,6.8,6.6,
  9.24,6.8,6.6,
  9.24,1.23,6.6,
  4.38,1.23,6.6;

BuildingSurface:Detailed,
  South 2c Ceiling,       !- Name
  Ceiling,               !- Surface Type
  ceiling_insulated,      !- Construction Name
  South 2c,              !- Zone Name
  Surface,               !- Outside Boundary Condition
  attic floor S2c,           !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,
  9.24,3.49,6.6,
  12,3.49,6.6,
  12,9.105,6.6,
  9.24,9.105,6.6;

BuildingSurface:Detailed,
  attic floor S2c,           !- Name
  Floor,                 !- Surface Type
  ceiling_insulated_reverse,  !- Construction Name
  Attic_Zone,            !- Zone Name
  Surface,               !- Outside Boundary Condition
  South 2c Ceiling,       !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,
  9.24,9.105,6.6,
  12,9.105,6.6,
  12,3.49,6.6,
  9.24,3.49,6.6;

BuildingSurface:Detailed,
  North 2 Ceiling,       !- Name
  Ceiling,               !- Surface Type
  ceiling_insulated,      !- Construction Name
  North 2,               !- Zone Name
  Surface,               !- Outside Boundary Condition
  attic floor N2,           !- Outside Boundary Condition Object
  NoSun,                 !- Sun Exposure
  NoWind,                !- Wind Exposure
  autocalculate,         !- View Factor to Ground
```

```
        4,
    0,6.8,6.6,
    9.24,6.8,6.6,
    9.24,11.89,6.6,
    0,11.89,6.6;

  BuildingSurface:Detailed,
    attic floor N2,           !- Name
    Floor,                    !- Surface Type
    ceiling_insulated_reverse,  !- Construction Name
    Attic_Zone,               !- Zone Name
    Surface,                  !- Outside Boundary Condition
    North 2 Ceiling,          !- Outside Boundary Condition Object
    NoSun,                    !- Sun Exposure
    NoWind,                   !- Wind Exposure
    autocalculate,            !- View Factor to Ground
    4,
    0,11.89,6.6,
    9.24,11.89,6.6,
    9.24,6.8,6.6,
    0,6.8,6.6;

!- SOUTH ROOFS

 BuildingSurface:Detailed,
    south roof 1a,            !- Name
    Roof,                     !- Surface Type
    Roof_uninsulated,         !- Construction Name
    Attic_Zone,               !- Zone Name
    Outdoors,                 !- Outside Boundary Condition
    ,                         !- Outside Boundary Condition Object
    SunExposed,               !- Sun Exposure
    WindExposed,              !- Wind Exposure
    autocalculate,            !- View Factor to Ground
    3,                        !- Number of Vertices
    4.38,1.23,6.6,  !- X,Y,Z ==> Vertex 1 {m}
    4.62,6.67,10.45,  !- peak
    2.19,3.627,8.425;

 BuildingSurface:Detailed,
    south roof 1b,            !- Name
    Roof,                     !- Surface Type
    Roof_uninsulated,         !- Construction Name
    Attic_Zone,               !- Zone Name
    Outdoors,                 !- Outside Boundary Condition
    ,                         !- Outside Boundary Condition Object
    SunExposed,               !- Sun Exposure
    WindExposed,              !- Wind Exposure
    autocalculate,            !- View Factor to Ground
    3,                        !- Number of Vertices
    4.38,1.23,6.6,  !- X,Y,Z ==> Vertex 1 {m}
    6.36,1.23,6.6,  !- X,Y,Z ==> Vertex 2 {m}
    4.62,6.67,10.45;  !- peak

 BuildingSurface:Detailed,
    south roof 1c,            !- Name
    Roof,                     !- Surface Type
    Roof_uninsulated,         !- Construction Name
    Attic_Zone,               !- Zone Name
    Outdoors,                 !- Outside Boundary Condition
    ,                         !- Outside Boundary Condition Object
    SunExposed,               !- Sun Exposure
```

```
          WindExposed,            !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  3,                      !- Number of Vertices
  6.36,1.23,6.6,  !- X,Y,Z ==> Vertex 2 {m}
  7.8,3.49,7.8,  !- X,Y,Z ==> Vertex 3 {m}
  4.62,6.67,10.45;  !- peak

 BuildingSurface:Detailed,
  south roof 3,           !- Name
  Roof,                   !- Surface Type
  Roof_uninsulated,       !- Construction Name
  Attic_Zone,             !- Zone Name
  Outdoors,               !- Outside Boundary Condition
  ,                       !- Outside Boundary Condition Object
  SunExposed,             !- Sun Exposure
  WindExposed,            !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                      !- Number of Vertices
  9.24,1.23,4.716667,  !- X,Y,Z ==> Vertex 1 {m}
  12,1.23,4.716667,  !- X,Y,Z ==> Vertex 2 {m}
  12,3.49,6.6,  !- X,Y,Z ==> Vertex 3 {m}
  9.24,3.49,6.6;  !- X,Y,Z ==> Vertex 4 {m}

 BuildingSurface:Detailed,
  south roof 2,           !- Name
  Roof,                   !- Surface Type
  Roof_uninsulated,       !- Construction Name
  Attic_Zone,             !- Zone Name
  Outdoors,               !- Outside Boundary Condition
  ,                       !- Outside Boundary Condition Object
  SunExposed,             !- Sun Exposure
  WindExposed,            !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                      !- Number of Vertices
  12,3.49,6.6,  !- X,Y,Z ==> Vertex 1 {m}
  9.46,6.4,9.34,  !- X,Y,Z ==> Vertex 2 {m}
  6.414,6.4,9.34,  !- X,Y,Z ==> Vertex 3 {m}
  9.24,3.49,6.6;  !- X,Y,Z ==> Vertex 4 {m}


!- NORTH ROOFS

 BuildingSurface:Detailed,
  North roof 1,           !- Name
  Roof,                   !- Surface Type
  Roof_uninsulated,       !- Construction Name
  Attic_Zone,             !- Zone Name
  Outdoors,               !- Outside Boundary Condition
  ,                       !- Outside Boundary Condition Object
  SunExposed,             !- Sun Exposure
  WindExposed,            !- Wind Exposure
  autocalculate,          !- View Factor to Ground
  4,                      !- Number of Vertices
  12,11.89,3.815,
  9.24,11.89,3.815,
  9.24,9.105,6.6,
  12,9.105,6.6;

 BuildingSurface:Detailed,
  North roof 2,           !- Name
  Roof,                   !- Surface Type
  Roof_uninsulated,       !- Construction Name
```

```
      Attic_Zone,            !- Zone Name
  Outdoors,                !- Outside Boundary Condition
  ,                   !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  3,                  !- Number of Vertices
  9.24,11.89,6.6,
  0,11.89,6.6,
  4.62,7.27,10.45;

 BuildingSurface:Detailed,
  North roof 3,         !- Name
  Roof,                !- Surface Type
  Roof_uninsulated,       !- Construction Name
  Attic_Zone,            !- Zone Name
  Outdoors,                !- Outside Boundary Condition
  ,                   !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,                  !- Number of Vertices
  12,9.105,6.6,
  9.24,9.105,6.6,
  6.414,6.4,9.34,
  9.46,6.4,9.34;

! East Roofs

 BuildingSurface:Detailed,
  East Roof 1,           !- Name
  Roof,                !- Surface Type
  Roof_uninsulated,       !- Construction Name
  Attic_Zone,            !- Zone Name
  Outdoors,                !- Outside Boundary Condition
  ,                   !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  3,                  !- Number of Vertices
  12,3.49,6.6,  !- X,Y,Z ==> Vertex 1 {m}
  12,9.105,6.6,  !- X,Y,Z ==> Vertex 2 {m}
  9.46,6.4,9.34;  !- X,Y,Z ==> Vertex 3 {m}

 BuildingSurface:Detailed,
  East Roof 2,           !- Name
  Roof,                !- Surface Type
  Roof_uninsulated,       !- Construction Name
  Attic_Zone,            !- Zone Name
  Outdoors,                !- Outside Boundary Condition
  ,                   !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  autocalculate,         !- View Factor to Ground
  4,                  !- Number of Vertices
  4.38,0,6.6,  !- X,Y,Z ==> Vertex 1 {m}
  4.38,1.23,6.6,  !- X,Y,Z ==> Vertex 2 {m}
  2.19,3.627,8.425,  !- # 3 of SR1a
  2.19,0,8.425;  !- # 3 of SWa_a

 BuildingSurface:Detailed,
  East Roof 3a,           !- Name
```

```
     Roof,                !- Surface Type
 Roof_uninsulated,       !- Construction Name
 Attic_Zone,             !- Zone Name
 Outdoors,               !- Outside Boundary Condition
 ,                       !- Outside Boundary Condition Object
 SunExposed,             !- Sun Exposure
 WindExposed,            !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 4,                      !- Number of Vertices
 9.24,1.23,6.6,
 9.24,3.49,6.6,
 7.8,3.49,7.8,           !- = SR1c #2
 7.8,1.23,7.8;

BuildingSurface:Detailed,
 East Roof 3b,           !- Name
 Roof,                   !- Surface Type
 Roof_uninsulated,       !- Construction Name
 Attic_Zone,             !- Zone Name
 Outdoors,               !- Outside Boundary Condition
 ,                       !- Outside Boundary Condition Object
 SunExposed,             !- Sun Exposure
 WindExposed,            !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 3,                      !- Number of Vertices
 9.24,3.49,6.6,
 6.414,6.4,9.34,
 4.62,6.67,10.45;


BuildingSurface:Detailed,
 East Roof 3c,           !- Name
 Roof,                   !- Surface Type
 Roof_uninsulated,       !- Construction Name
 Attic_Zone,             !- Zone Name
 Outdoors,               !- Outside Boundary Condition
 ,                       !- Outside Boundary Condition Object
 SunExposed,             !- Sun Exposure
 WindExposed,            !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 3,                      !- Number of Vertices
 9.24,3.49,6.6,
 4.62,6.67,10.45,
 7.8,3.49,7.8;

BuildingSurface:Detailed,
 East Roof 4,            !- Name
 Roof,                   !- Surface Type
 Roof_uninsulated,       !- Construction Name
 Attic_Zone,             !- Zone Name
 Outdoors,               !- Outside Boundary Condition
 ,                       !- Outside Boundary Condition Object
 SunExposed,             !- Sun Exposure
 WindExposed,            !- Wind Exposure
 autocalculate,          !- View Factor to Ground
 3,                      !- Number of Vertices
 6.414,6.4,9.34,
 4.62,7.27,10.45,
 4.62,6.67,10.45;

BuildingSurface:Detailed,
 East Roof 5a,           !- Name
```

```
        Roof,                    !- Surface Type
    Roof_uninsulated,       !- Construction Name
    Attic_Zone,             !- Zone Name
    Outdoors,               !- Outside Boundary Condition
    ,                       !- Outside Boundary Condition Object
    SunExposed,             !- Sun Exposure
    WindExposed,            !- Wind Exposure
    autocalculate,          !- View Factor to Ground
    3,                      !- Number of Vertices
    9.24,9.105,6.6,  !- X,Y,Z ==> Vertex 1 {m}
    9.24,11.89,6.6,  !- X,Y,Z ==> Vertex 2 {m}
    4.62,7.27,10.45;

  BuildingSurface:Detailed,
    East Roof 5b,           !- Name
    Roof,                   !- Surface Type
    Roof_uninsulated,       !- Construction Name
    Attic_Zone,             !- Zone Name
    Outdoors,               !- Outside Boundary Condition
    ,                       !- Outside Boundary Condition Object
    SunExposed,             !- Sun Exposure
    WindExposed,            !- Wind Exposure
    autocalculate,          !- View Factor to Ground
    3,                      !- Number of Vertices
    9.24,9.105,6.6,  !- X,Y,Z ==> Vertex 1 {m}
    4.62,7.27,10.45,
    6.414,6.4,9.34;

! West Roof 1

  BuildingSurface:Detailed,
    West Roof 1a,           !- Name
    Roof,                   !- Surface Type
    Roof_uninsulated,       !- Construction Name
    Attic_Zone,             !- Zone Name
    Outdoors,               !- Outside Boundary Condition
    ,                       !- Outside Boundary Condition Object
    SunExposed,             !- Sun Exposure
    WindExposed,            !- Wind Exposure
    autocalculate,          !- View Factor to Ground
    4,                      !- Number of Vertices
    0,11.89,6.6,
    2.19,3.627,8.425,
    4.62,6.67,10.45,
    4.62,7.27,10.45;

  BuildingSurface:Detailed,
    West Roof 1b,           !- Name
    Roof,                   !- Surface Type
    Roof_uninsulated,       !- Construction Name
    Attic_Zone,             !- Zone Name
    Outdoors,               !- Outside Boundary Condition
    ,                       !- Outside Boundary Condition Object
    SunExposed,             !- Sun Exposure
    WindExposed,            !- Wind Exposure
    autocalculate,          !- View Factor to Ground
    3,                      !- Number of Vertices
    0,11.89,6.6,
    0,0,6.6,
    2.19,3.627,8.425;

  BuildingSurface:Detailed,
```

```
      West Roof 2,            !- Name
   Roof,                   !- Surface Type
   Roof_uninsulated,       !- Construction Name
   Attic_Zone,             !- Zone Name
   Outdoors,               !- Outside Boundary Condition
   ,                       !- Outside Boundary Condition Object
   SunExposed,             !- Sun Exposure
   WindExposed,            !- Wind Exposure
   autocalculate,          !- View Factor to Ground
   3,                      !- Number of Vertices
   0,0,6.6,
   2.19,0,8.425,
   2.19,3.627,8.425;

  BuildingSurface:Detailed,
   West Roof 3,            !- Name
   Roof,                   !- Surface Type
   Roof_uninsulated,       !- Construction Name
   Attic_Zone,             !- Zone Name
   Outdoors,               !- Outside Boundary Condition
   ,                       !- Outside Boundary Condition Object
   SunExposed,             !- Sun Exposure
   WindExposed,            !- Wind Exposure
   autocalculate,          !- View Factor to Ground
   3,                      !- Number of Vertices
   6.36,1.23,6.6,
   7.8,1.23,7.8,
   7.8,3.49,7.8;


!-   ==========  ALL OBJECTS IN CLASS: INTERNAL MASS  ===========
! internal mass separated includes studs 15% framing by air weighted properties calc

! N1 includes surface area of counter, island, cabinets
  InternalMass,
   North 1 partitions,     !- Name
   interior wall,          !- Construction Name
   North 1,                !- Zone Name
   21;                     !- Surface Area {m2}

  InternalMass,
   South 1a partitions,    !- Name
   interior wall,          !- Construction Name
   South 1a,               !- Zone Name
   12.2;                   !- Surface Area {m2}

  InternalMass,
   South 1b partitions,    !- Name
   interior wall,          !- Construction Name
   South 1b,               !- Zone Name
   12.2;                   !- Surface Area {m2}

  InternalMass,
   North 2 partitions,     !- Name
   interior wall,          !- Construction Name
   North 2,                !- Zone Name
   53.8;                   !- Surface Area {m2}

  InternalMass,
   South 2a partitions,    !- Name
   interior wall,          !- Construction Name
```

```
      South 2a,              !- Zone Name
  55.4;              !- Surface Area {m2}

 InternalMass,
  South 2b partitions,       !- Name
  interior wall,        !- Construction Name
  South 2b,             !- Zone Name
  39;               !- Surface Area {m2}

 InternalMass,
  South 2c partitions,       !- Name
  interior wall,        !- Construction Name
  South 2c,             !- Zone Name
  13.6;              !- Surface Area {m2}

 InternalMass,
  garage partitions,       !- Name
  interior wall,        !- Construction Name
  Garage_zone,             !- Zone Name
  50;               !- Surface Area {m2} = 3.38*3.6*4

 InternalMass,
  garage woodwork,       !- Name
  woodwork,        !- Construction Name
  Garage_zone,             !- Zone Name
  3;               !- Surface Area {m2}


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

! South shading

 Shading:Building:Detailed,
  Garage Fin Shade,       !- Name
  ,                    !- Transmittance Schedule Name
  4,                   !- Number of Vertices
  6.67,1.23,0,  !- X,Y,Z ==> Vertex 1 {m}
  6.67,0,0,  !- X,Y,Z ==> Vertex 2 {m}
  6.67,0,3.03,  !- X,Y,Z ==> Vertex 3 {m}
  6.67,1.23,3.03;  !- X,Y,Z ==> Vertex 4 {m}

 Shading:Building:Detailed,
  Garage Roof Shade,       !- Name
  ,                    !- Transmittance Schedule Name
  4,                   !- Number of Vertices
  4.38,-0.3,3.03,
  12.3,-0.3,3.03,
  12.3,1.23,4.71667,
  4.38,1.23,4.71667;

 Shading:Building:Detailed,
  Shade above door and garage,       !- Name
  ,                    !- Transmittance Schedule Name
  4,                   !- Number of Vertices
  4.38,0,3.03,
  12.3,0,3.03,
  12.3,1.23,3.03,
  4.38,1.23,3.03;

 Shading:Building:Detailed,
  SW attic a overhang 1,       !- Name
  ,                    !- Transmittance Schedule Name
```

```
    4,                       !- Number of Vertices
  -0.3,-0.3,6.35,
  2.19,-0.3,8.425,
  2.19,0,8.425,
  -0.3,0,6.35;

 Shading:Building:Detailed,
  SW attic a overhang 2,        !- Name
  ,                    !- Transmittance Schedule Name
  4,                   !- Number of Vertices
  2.19,-0.3,8.425,
  4.68,-0.3,6.35,
  4.68,0,6.35,
  2.19,0,8.425;

 Shading:Building:Detailed,
  SW2b overhang,       !- Name
  ,                    !- Transmittance Schedule Name
  4,                   !- Number of Vertices
  4.38,0.93,6.35,
  6.6,0.93,6.35,
  6.6,1.23,6.35,
  4.38,1.23,6.35;

 Shading:Building:Detailed,
  SW attic b overhang 1,        !- Name
  ,                    !- Transmittance Schedule Name
  4,                   !- Number of Vertices
  6.06,0.93,6.35,
  7.8,0.93,7.8,
  7.8,1.23,7.8,
  6.06,1.23,6.35;

 Shading:Building:Detailed,
  SW attic b overhang 2,        !- Name
  ,                    !- Transmittance Schedule Name
  4,                   !- Number of Vertices
  7.8,0.93,7.8,
  9.54,0.93,6.35,
  9.54,1.23,6.35,
  7.8,1.23,7.8;

! East Shading

 Shading:Building:Detailed,
  East overhang 1,       !- Name
  ,                    !- Transmittance Schedule Name
  4,                   !- Number of Vertices
  12.3,1.23,4.71667,
  12.3,3.49,6.6,
  12,3.49,6.6,
  12,1.23,4.71667;

 Shading:Building:Detailed,
  East overhang 2,       !- Name
  ,                    !- Transmittance Schedule Name
  4,                   !- Number of Vertices
  12.3,3.49,6.35,
  12.3,9.105,6.35,
  12,9.105,6.35,
  12,3.49,6.35;
```

```
        Shading:Building:Detailed,
    East overhang 3,       !- Name
    ,                      !- Transmittance Schedule Name
    4,                     !- Number of Vertices
    12.3,9.105,6.35,
    12.3,11.89,3.565,
    12,11.89,3.815,
    12,9.105,6.6;

  Shading:Building:Detailed,
    East attic 2c overhang,        !- Name
    ,                      !- Transmittance Schedule Name
    4,                     !- Number of Vertices
    9.54,9.105,6.35,
    9.54,11.89,6.35,
    9.24,11.89,6.6,
    9.24,9.105,6.6;

  Shading:Building:Detailed,
    East R3 overhang,       !- Name
    ,                      !- Transmittance Schedule Name
    4,                     !- Number of Vertices
    9.54,1.23,6.35,
    9.54,3.49,6.35,
    9.24,3.49,6.6,
    9.24,1.23,6.6;

  Shading:Building:Detailed,
    East R2 overhang,       !- Name
    ,                      !- Transmittance Schedule Name
    4,                     !- Number of Vertices
    4.68,0,6.35,
    4.68,1.23,6.35,
    4.38,1.23,6.6,
    4.38,0,6.6;

! North Overhangs

  Shading:Building:Detailed,
    North overhang 1,       !- Name
    ,                      !- Transmittance Schedule Name
    4,                     !- Number of Vertices
    12.3,12.19,3.515,
    9.54,12.19,3.515,
    9.54,11.89,3.515,
    12.3,11.89,3.515;

  Shading:Building:Detailed,
    North overhang 2,       !- Name
    ,                      !- Transmittance Schedule Name
    4,                     !- Number of Vertices
    9.54,12.19,6.35,
    -0.3,12.19,6.35,
    -0.3,11.89,6.35,
    9.54,11.89,6.35;

!- West
  Shading:Building:Detailed,
    West overhang 1,       !- Name
    ,                      !- Transmittance Schedule Name
    4,                     !- Number of Vertices
    -0.3,12.19,6.35,
```

```
            -0.3,0,6.35,
    0,0,6.35,
    0,12.19,6.35;

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

! garage fin based on brick values from Passive solar architecture pocket ref
ShadingProperty:Reflectance,
  Garage Fin Shade, !- Name of Surface:Shading Object
  0.45, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
  , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
  0, !- Fraction of Shading Surface That Is Glazed
  ; !- Name of Glazing Construction

ShadingProperty:Reflectance,
  Garage Roof Shade, !- Name of Surface:Shading Object
  0.2, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
  , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
  0, !- Fraction of Shading Surface That Is Glazed
  ; !- Name of Glazing Construction

! value used below is for non gloss or off white paint
ShadingProperty:Reflectance,
   Shade above door and garage,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    SW attic a overhang 1,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    SW attic a overhang 2,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    SW2b overhang,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    SW attic b overhang 1,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    SW attic b overhang 2,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    East overhang 1,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
```

```
          0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    East overhang 2,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    East overhang 3,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    East attic 2c overhang,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    East R3 overhang,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    East R2 overhang,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    North overhang 1,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    North overhang 2,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction
ShadingProperty:Reflectance,
    West overhang 1,
   0.65, !- Diffuse Solar Reflectance of Unglazed Part of Shading Surface
   , !- Diffuse Visible Reflectance of Unglazed Part of Shading Surface
   0, !- Fraction of Shading Surface That Is Glazed
   ; !- Name of Glazing Construction

!-   ======   ALL OBJECTS IN CLASS: FENESTRATIONSURFACE:DETAILED  =======
!- SOUTH WINDOWS

  FenestrationSurface:Detailed,
    south XX7,              !- Name
    Window,                 !- Surface Type
    CCHT Ref Windows HSHG,   !- Construction Name
    south wall 1_a,          !- Building Surface Name
    ,                       !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                       !- Shading Control Name
```

```
      CCHT Ref Frames 2 Div,        !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  0.88,0.125,1.32,  !- X,Y,Z ==> Vertex 1 {m}
  3.145,0.125,1.32,  !- X,Y,Z ==> Vertex 2 {m}
  3.145,0.125,2.985,  !- X,Y,Z ==> Vertex 3 {m}
  0.88,0.125,2.985;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  south XX6,               !- Name
  Window,                  !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  south wall 2_a,          !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
  autocalculate,           !- View Factor to Ground
  ,                        !- Shading Control Name
  CCHT Ref Frames 2 Div,        !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  0.88,0.125,4.505,  !- X,Y,Z ==> Vertex 1 {m}
  3.145,0.125,4.505,  !- X,Y,Z ==> Vertex 2 {m}
  3.145,0.125,5.97,  !- X,Y,Z ==> Vertex 3 {m}
  0.88,0.125,5.97;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  south WW4,               !- Name
  Window,                  !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  south wall 2_c,          !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
  autocalculate,           !- View Factor to Ground
  ,                        !- Shading Control Name
  CCHT Ref Frames 2 Div,        !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  6.78,1.355,4.92,  !- X,Y,Z ==> Vertex 1 {m}
  8.845,1.355,4.92,  !- X,Y,Z ==> Vertex 2 {m}
  8.845,1.355,5.93,  !- X,Y,Z ==> Vertex 3 {m}
  6.78,1.355,5.93;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  south L3,                !- Name
  Window,                  !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  south wall 2_b,          !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
  autocalculate,           !- View Factor to Ground
  ,                        !- Shading Control Name
  CCHT Ref Frames 1 Div,        !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  4.58,1.355,5.105,  !- X,Y,Z ==> Vertex 1 {m}
  6.045,1.355,5.105,  !- X,Y,Z ==> Vertex 2 {m}
  6.045,1.355,5.97,  !- X,Y,Z ==> Vertex 3 {m}
  4.58,1.355,5.97;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  front door,              !- Name
  Door,                    !- Surface Type
  door_insulated,          !- Construction Name
  south wall 1_b,          !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
```

```
            autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
  ,                    !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  4.38,1.23,0.94,  !- X,Y,Z ==> Vertex 1 {m}
  5.0436,1.23,0.94,  !- X,Y,Z ==> Vertex 2 {m}
  5.0436,1.23,2.475,  !- X,Y,Z ==> Vertex 3 {m}
  4.38,1.23,2.475;  !- X,Y,Z ==> Vertex 4 {m}

 FenestrationSurface:Detailed,
  front door window 1,     !- Name
  Window,               !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  south wall 1_b,          !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
  CCHT Ref Frames No Div,        !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  5.2236,1.355,1.157,  !- X,Y,Z ==> Vertex 1 {m}
  5.495,1.355,1.157,  !- X,Y,Z ==> Vertex 2 {m}
  5.495,1.355,2.495,  !- X,Y,Z ==> Vertex 3 {m}
  5.2236,1.355,2.495;  !- X,Y,Z ==> Vertex 4 {m}

 FenestrationSurface:Detailed,
  front door window 2,     !- Name
  Window,               !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  south wall 1_b,          !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
  CCHT Ref Frames No Div,        !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  4.38,1.355,2.655,  !- X,Y,Z ==> Vertex 1 {m}
  5.515,1.355,2.655,  !- X,Y,Z ==> Vertex 2 {m}
  5.515,1.355,2.88,  !- X,Y,Z ==> Vertex 3 {m}
  4.38,1.355,2.88;  !- X,Y,Z ==> Vertex 4 {m}

 FenestrationSurface:Detailed,
  garage door,            !- Name
  Door,                 !- Surface Type
  door_insulated,         !- Construction Name
  garage south,          !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
  ,                    !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  6.9,1.23,0.36,  !- X,Y,Z ==> Vertex 1 {m}
  11.8,1.23,0.36,  !- X,Y,Z ==> Vertex 2 {m}
  11.8,1.23,2.49,  !- X,Y,Z ==> Vertex 3 {m}
  6.9,1.23,2.49;  !- X,Y,Z ==> Vertex 4 {m}

!- WEST WINDOWS

 FenestrationSurface:Detailed,
  West JJ4,              !- Name
```

```
      Window,              !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  West Wall 2_b,           !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
  autocalculate,           !- View Factor to Ground
  ,                        !- Shading Control Name
  CCHT Ref Frames No Div,       !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  0.125,6.045,3.62,  !- X,Y,Z ==> Vertex 1 {m}
  0.125,4.88,3.62,  !- X,Y,Z ==> Vertex 2 {m}
  0.125,4.88,4.685,  !- X,Y,Z ==> Vertex 3 {m}
  0.125,6.045,4.685;  !- X,Y,Z ==> Vertex 4 {m}

!- EAST WINDOWS

 FenestrationSurface:Detailed,
  East E7A,                !- Name
  Window,                  !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  East Wall 1_b,           !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
  autocalculate,           !- View Factor to Ground
  ,                        !- Shading Control Name
  CCHT Ref Frames No Div,       !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  11.875,7.614,1.517,  !- X,Y,Z ==> Vertex 1 {m}
  11.875,8.079,1.517,  !- X,Y,Z ==> Vertex 2 {m}
  11.875,8.079,3.182,  !- X,Y,Z ==> Vertex 3 {m}
  11.875,7.614,3.182;  !- X,Y,Z ==> Vertex 4 {m}

 FenestrationSurface:Detailed,
  East E7B,                !- Name
  Window,                  !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  East Wall 1_b,           !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
  autocalculate,           !- View Factor to Ground
  ,                        !- Shading Control Name
  CCHT Ref Frames No Div,       !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  11.875,10.51,1.517,  !- X,Y,Z ==> Vertex 1 {m}
  11.875,10.985,1.517,  !- X,Y,Z ==> Vertex 2 {m}
  11.875,10.985,3.182,  !- X,Y,Z ==> Vertex 3 {m}
  11.875,10.51,3.182;  !- X,Y,Z ==> Vertex 4 {m}

!- NORTH WINDOWS

 FenestrationSurface:Detailed,
  North H7a,               !- Name
  Window,                  !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  North Wall 1,            !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
  autocalculate,           !- View Factor to Ground
  ,                        !- Shading Control Name
  CCHT Ref Frames 1 Div,       !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  11.272,11.765,1.38,  !- X,Y,Z ==> Vertex 1 {m}
```

```
          10.407,11.765,1.38,  !- X,Y,Z ==> Vertex 2 {m}
  10.407,11.765,3.045,  !- X,Y,Z ==> Vertex 3 {m}
  11.272,11.765,3.045;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  North H7b,              !- Name
  Window,                 !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  North Wall 1,           !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
  CCHT Ref Frames 1 Div,        !- Frame and Divider Name
  1,                    !- Multiplier
  4,                    !- Number of Vertices
  8.37,11.765,1.38,  !- X,Y,Z ==> Vertex 1 {m}
  7.585,11.765,1.38,  !- X,Y,Z ==> Vertex 2 {m}
  7.585,11.765,3.045,  !- X,Y,Z ==> Vertex 3 {m}
  8.37,11.765,3.045;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  North A1a,              !- Name
  Window,                 !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  north bsmt wall 1a,      !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
  CCHT Ref Frames No Div,        !- Frame and Divider Name
  1,                    !- Multiplier
  4,                    !- Number of Vertices
  11.38,11.765,0.095,  !- X,Y,Z ==> Vertex 1 {m}
  10.14,11.765,0.095,  !- X,Y,Z ==> Vertex 2 {m}
  10.14,11.765,0.34,  !- X,Y,Z ==> Vertex 3 {m}
  11.38,11.765,0.34;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  North A1b,              !- Name
  Window,                 !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  north bsmt wall 1a,      !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
  CCHT Ref Frames No Div,        !- Frame and Divider Name
  1,                    !- Multiplier
  4,                    !- Number of Vertices
  2.34,11.765,0.095,  !- X,Y,Z ==> Vertex 1 {m} these were shifted down by 100mm
  1.1,11.765,0.095,  !- X,Y,Z ==> Vertex 2 {m}
  1.1,11.765,0.34,  !- X,Y,Z ==> Vertex 3 {m}
  2.34,11.765,0.34;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  North C3,              !- Name
  Window,                 !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  North Wall 1,           !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
  CCHT Ref Frames 1 Div,        !- Frame and Divider Name
  1,                    !- Multiplier
```

```
      4,                    !- Number of Vertices
  6.04,11.765,0.80,  !- X,Y,Z ==> Vertex 1 {m}
  4.675,11.765,0.80,  !- X,Y,Z ==> Vertex 2 {m}
  4.675,11.765,3.06,  !- X,Y,Z ==> Vertex 3 {m}
  6.04,11.765,3.06;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  North L7,              !- Name
  Window,                !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  North Wall 1,           !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
  CCHT Ref Frames 1 Div,        !- Frame and Divider Name
  1,                    !- Multiplier
  4,                    !- Number of Vertices
  2.54,11.765,1.38,  !- X,Y,Z ==> Vertex 1 {m}
  1.075,11.765,1.38,  !- X,Y,Z ==> Vertex 2 {m}
  1.075,11.765,3.045,  !- X,Y,Z ==> Vertex 3 {m}
  2.54,11.765,3.045;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  North U4,              !- Name
  Window,                !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  North Wall 2,           !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
  CCHT Ref Frames 1 Div,        !- Frame and Divider Name
  1,                    !- Multiplier
  4,                    !- Number of Vertices
  6.74,11.765,5.2,  !- X,Y,Z ==> Vertex 1 {m}
  5.685,11.765,5.2,  !- X,Y,Z ==> Vertex 2 {m}
  5.685,11.765,5.865,  !- X,Y,Z ==> Vertex 3 {m}
  6.74,11.765,5.865;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  North E3,              !- Name
  Window,                !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  North Wall 2,           !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
  CCHT Ref Frames No Div,        !- Frame and Divider Name
  1,                    !- Multiplier
  4,                    !- Number of Vertices
  4.14,11.765,5.2,  !- X,Y,Z ==> Vertex 1 {m}
  3.675,11.765,5.2,  !- X,Y,Z ==> Vertex 2 {m}
  3.675,11.765,5.865,  !- X,Y,Z ==> Vertex 3 {m}
  4.14,11.765,5.865;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  North X4,              !- Name
  Window,                !- Surface Type
  CCHT Ref Windows HSHG,   !- Construction Name
  North Wall 2,           !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  autocalculate,          !- View Factor to Ground
  ,                    !- Shading Control Name
```

```
        CCHT Ref Frames 2 Div,        !- Frame and Divider Name
    1,                    !- Multiplier
    4,                    !- Number of Vertices
    2.54,11.765,4.4,  !- X,Y,Z ==> Vertex 1 {m}
    0.885,11.765,4.4,  !- X,Y,Z ==> Vertex 2 {m}
    0.885,11.765,5.865,  !- X,Y,Z ==> Vertex 3 {m}
    2.54,11.765,5.865;  !- X,Y,Z ==> Vertex 4 {m}

!- ******* Interior openings & doors *********

  FenestrationSurface:Detailed,
    S1a-S1b hallway,          !- Name
    GlassDoor,                !- Surface Type
    opening,        !- Construction Name
    South 1a partition 2,         !- Building Surface Name
    S1b-S1a hallway,                     !- Outside Boundary Condition Object
    autocalculate,         !- View Factor to Ground
    ,                    !- Shading Control Name
    ,                    !- Frame and Divider Name
    1,                    !- Multiplier
    4,                    !- Number of Vertices
    4.38,5,0.36,
    4.38,3.2,0.36,
    4.38,3.2,3.38,
    4.38,5,3.38;

  FenestrationSurface:Detailed,
    S1b-S1a hallway,          !- Name
    GlassDoor,                !- Surface Type
    opening,        !- Construction Name
    South 1b partition 2,         !- Building Surface Name
    S1a-S1b hallway,                     !- Outside Boundary Condition Object
    autocalculate,         !- View Factor to Ground
    ,                    !- Shading Control Name
    ,                    !- Frame and Divider Name
    1,                    !- Multiplier
    4,                    !- Number of Vertices
    4.38,5,3.38,
    4.38,3.2,3.38,
    4.38,3.2,0.36,
    4.38,5,0.36;

  FenestrationSurface:Detailed,
    S1a-N1 hallway,          !- Name
    GlassDoor,                !- Surface Type
    opening,        !- Construction Name
    South 1a partition 1,         !- Building Surface Name
    N1-S1a hallway,                     !- Outside Boundary Condition Object
    autocalculate,         !- View Factor to Ground
    ,                    !- Shading Control Name
    ,                    !- Frame and Divider Name
    1,                    !- Multiplier
    4,                    !- Number of Vertices
    2.18,6.8,0.36,
    4.38,6.8,0.36,
    4.38,6.8,3.38,
    2.18,6.8,3.38;

  FenestrationSurface:Detailed,
    N1-S1a hallway,          !- Name
    GlassDoor,                !- Surface Type
    opening,        !- Construction Name
```

```
        North 1 partition 1a,        !- Building Surface Name
  S1a-N1 hallway,                    !- Outside Boundary Condition Object
  autocalculate,         !- View Factor to Ground
  ,                      !- Shading Control Name
  ,                      !- Frame and Divider Name
  1,                     !- Multiplier
  4,                     !- Number of Vertices
  2.18,6.8,3.38,
  4.38,6.8,3.38,
  4.38,6.8,0.36,
  2.18,6.8,0.36;

FenestrationSurface:Detailed,
  S2a-N2 hallway,            !- Name
  GlassDoor,                 !- Surface Type
  opening,               !- Construction Name
  South 2a - North 2,        !- Building Surface Name
  N2-S2a hallway,                    !- Outside Boundary Condition Object
  autocalculate,         !- View Factor to Ground
  ,                      !- Shading Control Name
  ,                      !- Frame and Divider Name
  1,                     !- Multiplier
  4,                     !- Number of Vertices
  2.6,6.8,3.38,
  4.38,6.8,3.38,
  4.38,6.8,6.6,
  2.6,6.8,6.6;

FenestrationSurface:Detailed,
  N2-S2a hallway,            !- Name
  GlassDoor,                 !- Surface Type
  opening,               !- Construction Name
  North 2 - South 2a,        !- Building Surface Name
  S2a-N2 hallway,                    !- Outside Boundary Condition Object
  autocalculate,         !- View Factor to Ground
  ,                      !- Shading Control Name
  ,                      !- Frame and Divider Name
  1,                     !- Multiplier
  4,                     !- Number of Vertices
  2.6,6.8,6.6,
  4.38,6.8,6.6,
  4.38,6.8,3.38,
  2.6,6.8,3.38;

FenestrationSurface:Detailed,
  S2b-N2 door,            !- Name
  GlassDoor,                 !- Surface Type
  opening,               !- Construction Name
  South 2b - North 2,        !- Building Surface Name
  N2-S2b door,                    !- Outside Boundary Condition Object
  autocalculate,         !- View Factor to Ground
  ,                      !- Shading Control Name
  ,                      !- Frame and Divider Name
  1,                     !- Multiplier
  4,                     !- Number of Vertices
  6.4,6.8,3.38,
  7.21,6.8,3.38,
  7.21,6.8,5.41,
  6.4,6.8,5.41;
  ! Note: 32" door = 0.81m 6'8" = 2.03m

FenestrationSurface:Detailed,
```

```
    N2-S2b door,            !- Name
  GlassDoor,                !- Surface Type
  opening,                  !- Construction Name
  North 2 - South 2b,       !- Building Surface Name
  S2b-N2 door,              !- Outside Boundary Condition Object
  autocalculate,            !- View Factor to Ground
  ,                         !- Shading Control Name
  ,                         !- Frame and Divider Name
  1,                        !- Multiplier
  4,                        !- Number of Vertices
  6.4,6.8,5.41,
  7.21,6.8,5.41,
  7.21,6.8,3.38,
  6.4,6.8,3.38;

! connection between E & W of master bedroom
 FenestrationSurface:Detailed,
  S2b-S2c opening,          !- Name
  GlassDoor,                !- Surface Type
  opening,                  !- Construction Name
  South 2b - South 2c,      !- Building Surface Name
  S2c-S2b opening,          !- Outside Boundary Condition Object
  autocalculate,            !- View Factor to Ground
  ,                         !- Shading Control Name
  ,                         !- Frame and Divider Name
  1,                        !- Multiplier
  4,                        !- Number of Vertices
  9.24,6.75,3.38,
  9.24,3.45,3.38,
  9.24,3.45,6.6,
  9.24,6.75,6.6;

 FenestrationSurface:Detailed,
  S2c-S2b opening,          !- Name
  GlassDoor,                !- Surface Type
  opening,                  !- Construction Name
  South 2c - South 2b,      !- Building Surface Name
  S2b-S2c opening,          !- Outside Boundary Condition Object
  autocalculate,            !- View Factor to Ground
  ,                         !- Shading Control Name
  ,                         !- Frame and Divider Name
  1,                        !- Multiplier
  4,                        !- Number of Vertices
  9.24,6.75,6.6,
  9.24,3.45,6.6,
  9.24,3.45,3.38,
  9.24,6.75,3.38;

GlazedDoor:Interzone,
  S1a-S2a stairwell,        !- Name
  opening,                  !- Construction Name
  South 1a ceiling,         !- Building Surface Name
  S2a-S1a stairwell,        !- Outside Boundary Condition
  1,                        !- Multiplier
  0,  !- Starting X Coordinate - Door starting coordinate is specified relative to the Base Surface origin.
  5.8,    !- Starting Z Coordinate - How far up the wall the Door starts. (in 2-d, this would be a Y Coordinate)
  1,  !-  Length
  1;    !- Height

GlazedDoor:Interzone,
  S2a-S1a stairwell,        !- Name
  opening,                  !- Construction Name
```

```
        South 2a floor,          !- Building Surface Name
   S1a-S2a stairwell,            !- Outside Boundary Condition
   1,                   !- Multiplier
   0,  !- Starting X Coordinate - Door starting coordinate is specified relative to the Base Surface origin.
   0,   !- Starting Z Coordinate - How far up the wall the Door starts. (in 2-d, this would be a Y Coordinate)
   1,  !-  Length
   1;   !- Height

! =====  OBJECTS for custom U values for Interzone heat transfer =====

SurfaceProperty:ConvectionCoefficients,

  S1a-S1b hallway, !- Surface Name

  Inside,        !- Convection Coefficient 1 Location

  Value,           !- Convection Coefficient 1 Type
  11;

SurfaceProperty:ConvectionCoefficients,

  S1b-S1a hallway, !- Surface Name

  Inside,        !- Convection Coefficient 1 Location

  Value,           !- Convection Coefficient 1 Type
  11;

SurfaceProperty:ConvectionCoefficients,

  S1a-S2a stairwell, !- Surface Name

  Inside,        !- Convection Coefficient 1 Location

  Value,           !- Convection Coefficient 1 Type
  20;

SurfaceProperty:ConvectionCoefficients,

  S2a-S1a stairwell, !- Surface Name

  Inside,        !- Convection Coefficient 1 Location

  Value,           !- Convection Coefficient 1 Type
  20;

SurfaceProperty:ConvectionCoefficients,

  S2b-N2 door, Inside, Value, 11;

SurfaceProperty:ConvectionCoefficients,

  N2-S2b door, Inside, Value, 11;

SurfaceProperty:ConvectionCoefficients,

  S1a-N1 hallway, Inside, Value, 11;

SurfaceProperty:ConvectionCoefficients,

  N1-S1a hallway, Inside, Value, 11;
```

```
!-   ===========  ALL OBJECTS IN CLASS: ZoneInfiltration:FlowCoefficient  ===========

  ZoneInfiltration:FlowCoefficient,
    Infiltration N1,  !- Name
    North 1,                 !- Zone Name
    Infiltration Coeff N1,      !- Schedule Name
    0.02296,                !- Flow Coefficient
    0.078,                  !- Stack Coefficient - ! two stories no flue
    0.699,                  !- Pressure Exponent
    0.17,                   !- Wind Coefficient - ! basement / slab two stories no flue
    0.85;                   !- Shelter Factor

  ZoneInfiltration:FlowCoefficient,
    Infiltration S1a,  !- Name
    South 1a,                !- Zone Name
    Infiltration Coeff S1a,      !- Schedule Name
    0.02296,                !- Flow Coefficient
    0.078,                  !- Stack Coefficient
    0.699,                  !- Pressure Exponent
    0.17,                   !- Wind Coefficient
    0.85;                   !- Shelter Factor

  ZoneInfiltration:FlowCoefficient,
    Infiltration S1b,  !- Name
    South 1b,                !- Zone Name
    Infiltration Coeff S1b,      !- Schedule Name
    0.02296,                !- Flow Coefficient
    0.078,                  !- Stack Coefficient
    0.699,                  !- Pressure Exponent
    0.17,                   !- Wind Coefficient
    0.85;                   !- Shelter Factor

  ZoneInfiltration:FlowCoefficient,
    Infiltration N2,  !- Name
    North 2,                 !- Zone Name
    Infiltration Coeff N2,      !- Schedule Name
    0.02296,                !- Flow Coefficient
    0.078,                  !- Stack Coefficient
    0.699,                  !- Pressure Exponent
    0.17,                   !- Wind Coefficient
    0.85;                   !- Shelter Factor

  ZoneInfiltration:FlowCoefficient,
    Infiltration S2a,  !- Name
    South 2a,                !- Zone Name
    Infiltration Coeff S2a,      !- Schedule Name
    0.02296,                !- Flow Coefficient
    0.078,                  !- Stack Coefficient
    0.699,                  !- Pressure Exponent
    0.17,                   !- Wind Coefficient
    0.85;                   !- Shelter Factor

  ZoneInfiltration:FlowCoefficient,
    Infiltration S2b,  !- Name
    South 2b,                !- Zone Name
    Infiltration Coeff S2b,      !- Schedule Name
    0.02296,                !- Flow Coefficient
    0.078,                  !- Stack Coefficient
    0.699,                  !- Pressure Exponent
```

```
      0.17,             !- Wind Coefficient
  0.85;               !- Shelter Factor

 ZoneInfiltration:FlowCoefficient,
  Infiltration S2c,  !- Name
  South 2c,              !- Zone Name
  Infiltration Coeff S2c,     !- Schedule Name
  0.02296,             !- Flow Coefficient
  0.078,               !- Stack Coefficient
  0.699,               !- Pressure Exponent
  0.17,               !- Wind Coefficient
  0.85;               !- Shelter Factor

 ZoneInfiltration:FlowCoefficient,
  Infiltration bsmt,  !- Name
  basement_zone,             !- Zone Name
  Infiltration Coeff Bsmt,     !- Schedule Name
  0.02296,             !- Flow Coefficient
  0.078,               !- Stack Coefficient
  0.699,               !- Pressure Exponent
  0.17,               !- Wind Coefficient
  0.85;               !- Shelter Factor

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

 ZoneInfiltration:DesignFlowRate,
  attic_ach,           !- Name
  attic_zone,          !- Zone or ZoneList Name
  Inf_schedule,         !- Schedule Name
  AirChanges/Hour,       !- Design Flow Rate Calculation Method
  ,                 !- Design Flow Rate {m3/s}
  ,                 !- Flow per Zone Floor Area {m3/s-m2}
  ,                 !- Flow per Exterior Surface Area {m3/s-m2}
  0.75,               !- Air Changes per Hour {1/hr} 0.5 = 10@50, 0.75 = 15ACH@50
  0.606,                !- Constant Term Coefficient
  0.03636,                !- Temperature Term Coefficient
  0.1177,             !- Velocity Term Coefficient
  0;                !- Velocity Squared Term Coefficient

 ZoneInfiltration:DesignFlowRate,
  Garage_ach,           !- Name
  Garage_Zone,          !- Zone or ZoneList Name
  Inf_schedule,         !- Schedule Name
  AirChanges/Hour,       !- Design Flow Rate Calculation Method
  ,                 !- Design Flow Rate {m3/s}
  ,                 !- Flow per Zone Floor Area {m3/s-m2}
  ,                 !- Flow per Exterior Surface Area {m3/s-m2}
  0.15,               !- Air Changes per Hour {1/hr} =3@50 ( 0.075 1.5 ACH @50)
  0.606,                !- Constant Term Coefficient
  0.03636,                !- Temperature Term Coefficient
  0.1177,             !- Velocity Term Coefficient
  0;                !- Velocity Squared Term Coefficient

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

ZoneCrossMixing,
  S2c_S2b Mixing,
  South 2c,
  Always On Schedule,
  Flow/Zone,
  1,      !- { m3/s }
  ,      !- Flow Rate per Zone Floor Area
```

```
          ,       !- Flow Rate per Person
  ,       !- Air Changes per Hour
  South 2b, !- Source Zone Name
  0,      !- Delta T
  ;

ZoneCrossMixing,
  S1a_N1 Mixing,
  North 1,
  Always On Schedule,
  Flow/Zone,
  0.0448,     ! { m3/s } %% = circulation flow into S1a & S1b, returns are in N1
  ,         ! Flow Rate per Zone Floor Area
  ,         ! Flow Rate per Person
  ,         ! Air Changes per Hour
  South 1a,     ! Source Zone Name
  0,         ! Delta T
  ;          ! Delta Temperature Schedule Name

ZoneCrossMixing,
  S2a_N2 Mixing,
  North 2,
  Always On Schedule,
  Flow/Zone,
  0.189,      !- { m3/s }
  ,       !- Flow Rate per Zone Floor Area
  ,       !- Flow Rate per Person
  ,       !- Air Changes per Hour
  South 2a, !- Source Zone Name
  2,      !- Delta T
  ;

!-  ====  HVAC ===
!-  ===========  ALL OBJECTS IN CLASS: ZONECONTROL:THERMOSTAT ===========

 ZoneControl:Thermostat,
   Zone 1 Thermostat,      !- Name
   South 1a,                !- Zone or ZoneList Name
   Zone1Control,           !- Control Type Schedule Name
   ThermostatSetpoint:SingleHeating,  !- Control 1 Object Type
   Setpoint Zone 1;        !- Control 1 Name

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

 ThermostatSetpoint:SingleHeating,
   Setpoint Zone 1,        !- Name
   Zone1HeatingSetPoint;    !- Setpoint Temperature Schedule Name

!-  ===========  All Objects in class: SingleDuct:Uncontrolled ===========

 AirTerminal:SingleDuct:Uncontrolled,
   North1_airterminal,             !- Name
   Zone1heatingAvail,      !- Availability Schedule Name
   North_1_Inlet_Node,                !- Zone Supply Air Node Name
   0.1570;                !- Maximum Air Flow Rate {m3/s}

 AirTerminal:SingleDuct:Uncontrolled,
   South1a_airterminal,    !- Name
   Zone1heatingAvail,      !- Availability Schedule Name
   South_1a_Inlet_Node,    !- Zone Supply Air Node Name
   0.0660;                !- Maximum Air Flow Rate {m3/s}
```

```
        AirTerminal:SingleDuct:Uncontrolled,
    South1b_airterminal,     !- Name
    Zone1heatingAvail,       !- Availability Schedule Name
    South_1b_Inlet_Node,     !- Zone Supply Air Node Name
    0.0334;                  !- Maximum Air Flow Rate {m3/s}

  AirTerminal:SingleDuct:Uncontrolled,
    North2_airterminal,      !- Name
    Zone1heatingAvail,       !- Availability Schedule Name
    North_2_Inlet_Node,      !- Zone Supply Air Node Name
    0.1286;                  !- Maximum Air Flow Rate {m3/s}

  AirTerminal:SingleDuct:Uncontrolled,
    South2a_airterminal,     !- Name
    Zone1heatingAvail,       !- Availability Schedule Name
    South_2a_Inlet_Node,     !- Zone Supply Air Node Name
    0.0768;                  !- Maximum Air Flow Rate {m3/s}

  AirTerminal:SingleDuct:Uncontrolled,
    South2b_airterminal,     !- Name
    Zone1heatingAvail,       !- Availability Schedule Name
    South_2b_Inlet_Node,     !- Zone Supply Air Node Name
    0.0565;                  !- Maximum Air Flow Rate {m3/s}

  AirTerminal:SingleDuct:Uncontrolled,
    South2c_airterminal,     !- Name
    Zone1heatingAvail,       !- Availability Schedule Name
    South_2c_Inlet_Node,     !- Zone Supply Air Node Name
    0.0323;                  !- Maximum Air Flow Rate {m3/s}

  AirTerminal:SingleDuct:Uncontrolled,
    Basement_airterminal,      !- Name
    Zone1heatingAvail,       !- Availability Schedule Name
    Basement_Inlet_Node,                 !- Zone Supply Air Node Name
    0.0714;                  !- Maximum Air Flow Rate {m3/s} was 0.0933

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


  ZoneHVAC:EquipmentList,
    HVACequipment list North1,  !- Name
    Airterminal:SingleDuct:Uncontrolled,  !- Zone Equipment 1 Object Type
    North1_airterminal,             !- Zone Equipment 1 Name
    1,                       !- Zone Equipment 1 Cooling Sequence
    1;                       !- Zone Equipment 1 Heating or No-Load Sequence

  ZoneHVAC:EquipmentList,
    HVACequipment list South1a,  !- Name
    Airterminal:SingleDuct:Uncontrolled,  !- Zone Equipment 1 Object Type
    South1a_airterminal,            !- Zone Equipment 1 Name
    1,                       !- Zone Equipment 1 Cooling Sequence
    1;                       !- Zone Equipment 1 Heating or No-Load Sequence

  ZoneHVAC:EquipmentList,
    HVACequipment list South1b,  !- Name
    Airterminal:SingleDuct:Uncontrolled,  !- Zone Equipment 1 Object Type
    South1b_airterminal,            !- Zone Equipment 1 Name
    1,                       !- Zone Equipment 1 Cooling Sequence
    1;                       !- Zone Equipment 1 Heating or No-Load Sequence

  ZoneHVAC:EquipmentList,
    HVACequipment list North2,  !- Name
```

```
    Airterminal:SingleDuct:Uncontrolled,  !- Zone Equipment 1 Object Type
  North2_airterminal,            !- Zone Equipment 1 Name
  1,                   !- Zone Equipment 1 Cooling Sequence
  1;                   !- Zone Equipment 1 Heating or No-Load Sequence

 ZoneHVAC:EquipmentList,
  HVACequipment list South2a,  !- Name
  Airterminal:SingleDuct:Uncontrolled,  !- Zone Equipment 1 Object Type
  South2a_airterminal,            !- Zone Equipment 1 Name
  1,                   !- Zone Equipment 1 Cooling Sequence
  1;                   !- Zone Equipment 1 Heating or No-Load Sequence

 ZoneHVAC:EquipmentList,
  HVACequipment list South2b,  !- Name
  Airterminal:SingleDuct:Uncontrolled,  !- Zone Equipment 1 Object Type
  South2b_airterminal,            !- Zone Equipment 1 Name
  1,                   !- Zone Equipment 1 Cooling Sequence
  1;                   !- Zone Equipment 1 Heating or No-Load Sequence

 ZoneHVAC:EquipmentList,
  HVACequipment list South2c,  !- Name
  Airterminal:SingleDuct:Uncontrolled,  !- Zone Equipment 1 Object Type
  South2c_airterminal,            !- Zone Equipment 1 Name
  1,                   !- Zone Equipment 1 Cooling Sequence
  1;                   !- Zone Equipment 1 Heating or No-Load Sequence

 ZoneHVAC:EquipmentList,
  HVACequipment list basement_zone,  !- Name
  Airterminal:SingleDuct:Uncontrolled,  !- Zone Equipment 1 Object Type
  Basement_airterminal,      !- Zone Equipment 1 Name
  1,                   !- Zone Equipment 1 Cooling Sequence
  1;                   !- Zone Equipment 1 Heating or No-Load Sequence

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

 ZoneHVAC:EquipmentConnections,
  North 1,                !- Zone Name
  HVACequipment list North1,  !- Zone Conditioning Equipment List Name
  North_1_Inlet_Node,            !- Zone Air Inlet Node or NodeList Name
  ,                     !- Zone Air Exhaust Node or NodeList Name
  North_1_Air_Node,         !- Zone Air Node Name
  North_1_Outlet_Node;                 !- Zone Return Air Node Name

 ZoneHVAC:EquipmentConnections,
  South 1a,          !- Zone Name
  HVACequipment list South1a,  !- Zone Conditioning Equipment List Name
  South_1a_Inlet_Node,               !- Zone Air Inlet Node or NodeList Name
  ,                   !- Zone Air Exhaust Node or NodeList Name
  South_1a_air_node,  !- Zone Air Node Name
  South_1a_Outlet_Node;               !- Zone Return Air Node Name

 ZoneHVAC:EquipmentConnections,
  South 1b,          !- Zone Name
  HVACequipment list South1b,  !- Zone Conditioning Equipment List Name
  South_1b_Inlet_Node,               !- Zone Air Inlet Node or NodeList Name
  ,                   !- Zone Air Exhaust Node or NodeList Name
  South_1b_air_node,  !- Zone Air Node Name
  South_1b_Outlet_Node;               !- Zone Return Air Node Name

 ZoneHVAC:EquipmentConnections,
  North 2,         !- Zone Name
  HVACequipment list North2,  !- Zone Conditioning Equipment List Name
```

```
        North_2_Inlet_Node,              !- Zone Air Inlet Node or NodeList Name
  ,                  !- Zone Air Exhaust Node or NodeList Name
  North_2_air_node,  !- Zone Air Node Name
  North_2_Outlet_Node;               !- Zone Return Air Node Name

 ZoneHVAC:EquipmentConnections,
  South 2a,          !- Zone Name
  HVACequipment list South2a,  !- Zone Conditioning Equipment List Name
  South_2a_Inlet_Node,               !- Zone Air Inlet Node or NodeList Name
  ,                  !- Zone Air Exhaust Node or NodeList Name
  South_2a_air_node,  !- Zone Air Node Name
  South_2a_Outlet_Node;              !- Zone Return Air Node Name

 ZoneHVAC:EquipmentConnections,
  South 2b,          !- Zone Name
  HVACequipment list South2b,  !- Zone Conditioning Equipment List Name
  South_2b_Inlet_Node,               !- Zone Air Inlet Node or NodeList Name
  ,                  !- Zone Air Exhaust Node or NodeList Name
  South_2b_air_node,  !- Zone Air Node Name
  South_2b_Outlet_Node;              !- Zone Return Air Node Name

 ZoneHVAC:EquipmentConnections,
  South 2c,          !- Zone Name
  HVACequipment list South2c,  !- Zone Conditioning Equipment List Name
  South_2c_Inlet_Node,               !- Zone Air Inlet Node or NodeList Name
  ,                  !- Zone Air Exhaust Node or NodeList Name
  South_2c_air_node,  !- Zone Air Node Name
  South_2c_Outlet_Node;              !- Zone Return Air Node Name

 ZoneHVAC:EquipmentConnections,
  Basement_Zone,          !- Zone Name
  HVACequipment list basement_zone,  !- Zone Conditioning Equipment List Name
  Basement_Inlet_Node,               !- Zone Air Inlet Node or NodeList Name
  ,                  !- Zone Air Exhaust Node or NodeList Name
  Basement_Zone_air_node,  !- Zone Air Node Name
  Basement_Outlet_Node;              !- Zone Return Air Node Name

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

 OutdoorAir:NodeList,
  Outdoor Air Node List,             !- Node or NodeList Name 1
  OA Nodes;

Nodelist,
 OA Nodes,
 OA_Intake_Node,
 OA_Exhaust_Node;

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

 Fan:OnOff,
  Furnace Fan,       !- Name
  zone1heatingAvail,       !- Availability Schedule Name
  0.24,                    !- Fan Efficiency
  175,                   !- Pressure Rise {Pa}
  0.622,                 !- Maximum Flow Rate {m3/s}
  0.6,                   !- Motor Efficiency
  1,                   !- Motor In Airstream Fraction
  Mixed Air Node,              !- Air Inlet Node Name
  node9,                 !- Air Outlet Node Name
  ,                  !- Fan Power Ratio Function of Speed Ratio Curve Name
  ,                  !- Fan Efficiency Ratio Function of Speed Ratio Curve Name
```

```
      HVAC;              !- End-Use Subcategory

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

  Coil:Heating:Gas,
    Furnace Coil,          !- Name
    Zone1HeatingAvail,    !- Availability Schedule Name
    0.802,                 !- Gas Burner Efficiency
    19778,                 !- Nominal Capacity {W}
    node9,                 !- Air Inlet Node Name
    node10a,               !- Air Outlet Node Name
    ,                    !- Temperature Setpoint Node Name
    ,                  !- Parasitic Electric Load {W}
    ,                    !- Part Load Fraction Correlation Curve Name
    0;                    !- Parasitic Gas Load {W}

!-   ===========  ALL OBJECTS IN CLASS: AirLoopHVAC:Unitary:Furnace:HeatOnly ===========

  AirLoopHVAC:Unitary:Furnace:HeatOnly,
    A2Furnace,             !- Name
    zone1control,          !- Availability Schedule Name
    Mixed Air Node,                !- Furnace Air Inlet Node Name
    node10a,               !- Furnace Air Outlet Node Name
    Furnace Fan Operating Mode Schedule,  !- Supply Air Fan Operating Mode Schedule Name
    57,                   !- Maximum Supply Air Temperature {C}
    0.622,                 !- Supply Air Flow Rate {m3/s}
    South 1a,               !- Controlling Zone or Thermostat Location
    Fan:OnOff,             !- Supply Fan Object Type
    Furnace Fan,       !- Supply Fan Name
    BlowThrough,           !- Fan Placement
    Coil:Heating:Gas,       !- Heating Coil Object Type
    Furnace Coil;          !- Heating Coil Name

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

  AirLoopHVAC,
    AirLoopHVAC,                 !- Name
    ,    !- Controller List Name
    Availability Schedule Manager,  !- Availability Manager List Name
    0.622,                       !- Design Supply Air Flow Rate {m3/s}
    Inlet Branches,               !- Branch List Name
    ,                         !- Connector List Name
    node3a,               !- Supply Side Inlet Node Name
    node3b,               !- Demand Side Outlet Node Name
    node10b,              !- Demand Side Inlet Node Names
    node10a;              !- Supply Side Outlet Node Names

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

  AirLoopHVAC:ZoneSplitter,
    Airloop Splitter,    !- Name
    node10b,              !- Inlet Node Name
    North_1_Inlet_Node,                !- Outlet 1 Node Name
    South_1a_Inlet_Node,
    South_1b_Inlet_Node,
    North_2_Inlet_Node,
    South_2a_Inlet_Node,
    South_2b_Inlet_Node,
    South_2c_Inlet_Node,
    Basement_Inlet_Node;

!-   ===========  ALL OBJECTS IN CLASS: AirLoopHVAC:SupplyPath ==========
```

```
  AirLoopHVAC:SupplyPath,
    AirLoopHVAC Supply,      !- Name
    node10b,                 !- Supply Air Path Inlet Node Name
    AirLoopHVAC:ZoneSplitter,!- Component 1 Object Type
    AirLoop Splitter;    !- Component 1 Name

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

  AirLoopHVAC:ZoneMixer,
    Airloop Mixer,       !- Name
    node3b,                 !- Outlet Node Name
    South_2b_Outlet_Node,                 !- Inlet 1 Node Name
    South_2c_Outlet_Node,
    Basement_Outlet_Node,
    South_2a_Outlet_Node,
    North_2_Outlet_Node,
    North_1_Outlet_Node,
    South_1b_Outlet_Node,
    South_1a_Outlet_Node;


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

  AirLoopHVAC:ReturnPath,
    AirLoopHVAC Return,      !- Name
    node3b,                 !- Return Air Path Outlet Node Name
    AirLoopHVAC:ZoneMixer,   !- Component 1 Object Type
    AirLoop Mixer;       !- Component 1 Name

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

  Branch,
    Branch 1,              !- Name
    0.622,                 !- Maximum Flow Rate {m3/s} was 0.622
    ,                     !- Pressure Drop Curve Name
    AirLoopHVAC:OutdoorAirSystem,
    OA System,
    Node3a,
    Mixed Air Node,
    ,
    AirLoopHVAC:Unitary:Furnace:HeatOnly,  !- Component 1 Object Type
    A2Furnace,              !- Component 1 Name
    Mixed Air Node,                !- Component 1 Inlet Node Name
    node10a,                !- Component 1 Outlet Node Name
    ;                     !- Component 1 Branch Control Type


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

  BranchList,
    Inlet Branches,           !- Name
    Branch 1;

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

  AvailabilityManager:Scheduled,
    Availability Schedule,   !- Name
    Zone1Control;           !- Schedule Name

!-  ===========  All Objects in Class: AvailabilityManagerAssignmentList ======
```

```
      AvailabilityManagerAssignmentList,
   Availability Schedule Manager,  !- Name
   AvailabilityManager:Scheduled,  !- Availability Manager 1 Object Type
   Availability Schedule;   !- Availability Manager 1 Name

!- Heat Recovery Ventilator

!-   ==========  OutdoorAirSystem  =======

AirLoopHVAC:OutdoorAirSystem,
  OA System,     ! Name
  OA Controllers,           ! Name of an AirLoopHVAC:ControllerList object (required)
  OA Equip list, !field Outdoor Air Equipment List Name
  Availability Schedule Manager; ! name of an AvailabilityManagerAssignmentList object.

AirLoopHVAC:OutdoorAirSystem:EquipmentList,
  OA Equip list,
  HeatExchanger:AirtoAir:SensibleandLatent,
  CCHT HRV Heat Exchanger,
  OutdoorAir:Mixer,
  OA Mixer;

AirLoopHVAC:ControllerList,
  OA Controllers,
  Controller:OutdoorAir,
  OA Controller;

!-   ========= All Objects in class: Controller:OutdoorAir =====

Controller:OutdoorAir,
  OA Controller,
  node6,            !- Relief Air Outlet Node
  Node3a,           !- Return Air Node
  Mixed Air Node,    !- Mixed Air Node
  OA_Intake_Node,    !- Actuator Node / OA inlet node
  0.03,             !- Minimum Outdoor Air Flow Rate (was 0.03)
  0.03,               !- Maximum Outdoor Air Flow Rate (was 0.03)
  ;                 ! Economizer Control Type

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

OutdoorAir:Mixer,
  OA Mixer,
  Mixed Air Node,  ! Mixed Air Node Name
  node5,   ! Outdoor Air Stream Node Name
  node6,   ! Relief Air Stream Node Name
  node3a;  ! return air stream node


!-   ===========  ALL OBJECTS IN CLASS: HeatExchanger:AirtoAir:SensibleandLatent ==========

  HeatExchanger:AirtoAir:SensibleandLatent,
   CCHT HRV Heat Exchanger, !- Name
   HRV_Schedule,           !- Availability Schedule Name
   0.03,                   !- Nominal Supply Air Flow Rate {m3/s}
   0.84,                   !- Sensible Effectiveness at 100% Heating Air Flow {dimensionless}
   0,                     !- Latent Effectiveness at 100% Heating Air Flow {dimensionless}
   0.84,                   !- Sensible Effectiveness at 75% Heating Air Flow {dimensionless}
   0,                     !- Latent Effectiveness at 75% Heating Air Flow {dimensionless}
   ,                      !- Sensible Effectiveness at 100% Cooling Air Flow {dimensionless}
   ,                      !- Latent Effectiveness at 100% Cooling Air Flow {dimensionless}
   ,                      !- Sensible Effectiveness at 75% Cooling Air Flow {dimensionless}
```

```
            ,                        !- Latent Effectiveness at 75% Cooling Air Flow {dimensionless}
    OA_Intake_Node,          !- Supply Air Inlet Node Name
    node5,     !- Supply Air Outlet Node Name
    node6,  !- Exhaust Air Inlet Node Name
    OA_Exhaust_Node,    !- Exhaust Air Outlet Node Name ! was HRV_Exhaust_Air_Node
    0,                      !- Nominal Electric Power {W}
    No,                     !- Supply Air Outlet Temperature Control
    Plate,                  !- Heat Exchanger Type
    ExhaustAirRecirculation, !- Frost Control Type
    -5,                     !- Threshold Temperature {C}
    0.1,                    !- Initial Defrost Time Fraction {dimensionless}
    0.0091,                 !- Rate of Defrost Time Fraction Increase {1/K}
    Yes;                    !- Economizer Lockout


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

  Output:VariableDictionary,IDF,Name;

!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:SURFACES:LIST ===========

  Output:Surfaces:List,Details,IDF;

!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:SURFACES:DRAWING ===========

  Output:Surfaces:Drawing,DXF,Triangulate3DFace;

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

  Output:Constructions,Constructions,Materials;

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

 Output:Variable,*,Zone/Sys Air Temperature,Hourly;

Output:Variable,*,Wind Speed,hourly;
Output:Variable,*,Outdoor Dry Bulb,hourly; !- Zone Average [C]

!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:METER:METERFILEONLY ===========

  Output:Meter:MeterFileOnly,Gas:HVAC,Annual;

  Output:Meter:MeterFileOnly,Gas:HVAC,daily;

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

  Output:Diagnostics,
    DisplayAllWarnings,
    DisplayUnusedObjects;    !- Key 1

!Output:Diagnostics,DisplayZoneAirHeatBalanceOffBalance;

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

  Output:SQLite,
    Simple;                  !- Option Type
```