Whole-Building Energy Analysis and Lessons Learned for a Near Net-Zero Energy Solar House

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ABSTRACT

Whole-Building Energy Analysis and Lessons Learned for a
Near Net-Zero Energy Solar House

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This thesis presents a comprehensive, whole-system energy analysis of ÉcoTerra using measured data. ÉcoTerra is a low-energy, near net-zero energy, solar house. It was constructed as part of the Canada Mortgage and Housing Corporation's EQuilibrium™ Sustainable Housing Demonstration Initiative, and incorporates a building-integrated photovoltaic/thermal roof coupled with a ventilated concrete slab. The roof collects thermal energy and generates electrical energy simultaneously. The thermal energy is collection is achieved by passing air under the surface of the roof and ducting this air into the house. This thermal energy is used to preheat domestic hot water, actively heat the ventilated concrete slab, and for drying clothes. The energy stored in the slab is released passively into the space. The overall energy use and end-use breakdown of the house are analyzed and discussed. The house's control system is documented, as are the changes that were made to the controls since construction. The main contributions of this work include a comprehensive energy analysis of the house and the identification of important conclusions and lessons learned. Recommendations are also made as to how ÉcoTerra, and future low-energy homes, could reach net-zero energy consumption. Large amounts of high quality data have been collected since the construction of the house, and significant effort was made, as part of this work, to structure and organize the data into usable forms for future research.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

A	Electrical current (Amp)
W	Electrical power (Watt)
kW	Electrical power (Killowatt)
kWh	Electrical energy (Killowatt-hour)
V	Electrical voltage (Volt)
cfm	Volumetric flow rate (cubic foot per minute)
gpm	Volumetric flow rate (gallon per minute)
L/s	Volumetric flow rate (litre/second)
kg	Mass (Killogram)
$\dot{m}$	Mass flow rate (kg/s)
Cp	Specific heat (Joule/kg·K)
ε	Heat exchanger effectiveness
h_{conv}	Convection heat transfer coefficient ($W/m^2 \cdot K$)
Pa	Pressure (Pascal)
R	Thermal resistance ($ft^2 \cdot F$/Btuh)
RSI	Thermal resistance ($m^2 \cdot °C/W$)
U	Overall heat transfer coefficient ($W/m^2 \cdot °C$)

Acronyms

BIPV/T	Building-integrated photovoltaic / thermal
CMHC	Canada Mortgage and Housing Corporation
COP	Coefficient of performance

CSA	Canadian Standards Association
DHW	Domestic hot water
EGH	EnerGuide for Houses
HDD	Heating degree-days
HRV	Heat recovery ventilator
HVAC	Heating ventilation and Air Conditioning
IEA	International Energy Agency
NRCan	Natural Resources Canada
NREL	National Renewable Energy Laboratory
NSERC	Natural Science and Engineering Research Council
PV	Photovoltaic
PV/T	Photovoltaic / thermal
SBRN	Solar Buildings Research Network
SQL	Structured query language
VCS	Ventilated concrete slab

1 INTRODUCTION

Energy use is a significant contributing factor to climate change and each individual bears some responsibility for overall energy use (Alley et al., 2007). In Canada, residential buildings, their systems and occupants account for approximately 17% of overall energy consumed (Statistics Canada, 2008).

Most of this energy comes from fossil fuels, which are responsible for significant carbon dioxide emissions. The International Energy Agency (IEA) reported that oil production from traditional, known reserves of crude oil has already peaked, and total overall fossil fuel production is expected to peak within the next 25 years (IEA, 2010). The sun, however, is one of the most abundant sources of energy available and it will continue to be available for billions of years (Goldsmith and Owen, 2001). Up to 1,200 W/m^2 of power from the sun is available on the Earth's surface each day. This energy is well suited to reducing energy use in buildings by means of passive and active solar technologies. High performance buildings, such as net-zero energy homes, solar technologies and energy efficiency techniques, present significant opportunities to reduce overall energy use.

This thesis presents a whole-building energy analysis off a near net-zero, passive solar house – ÉcoTerra; makes recommendations on how ÉcoTerra and future net-zero houses can be improved; and documents the lessons learned during the design, construction and operation of the house.

1.1 ÉcoTerra House

ÉcoTerra (shown in Figure 1.1) is a two-story, two-bedroom, single family, detached home located in Eastman, Québec, Canada (45.3° N, -72.3° W) with a basement and single car garage. It has a heated floor area of 211.1 m^2 and a heated volume of 609.1 m^3. The garage accounts for an additional 26.6 m^2 and 76.9 m^3. ÉcoTerra was constructed by Alouette Homes with research support from the Canadian Solar Buildings Research network (SBRN) and funding from Natural Resources Canada (NRCan), Canada Mortgage and Housing Corporation (CMHC), HydroQuébec, Régulvar and others. A front view of ÉcoTerra can be seen in Figure 1.1 (Chen et al., 2010a). The home's building-integrated photovoltaic/thermal system is seen in the highlighted area of Figure 1.1 and described in detail later.

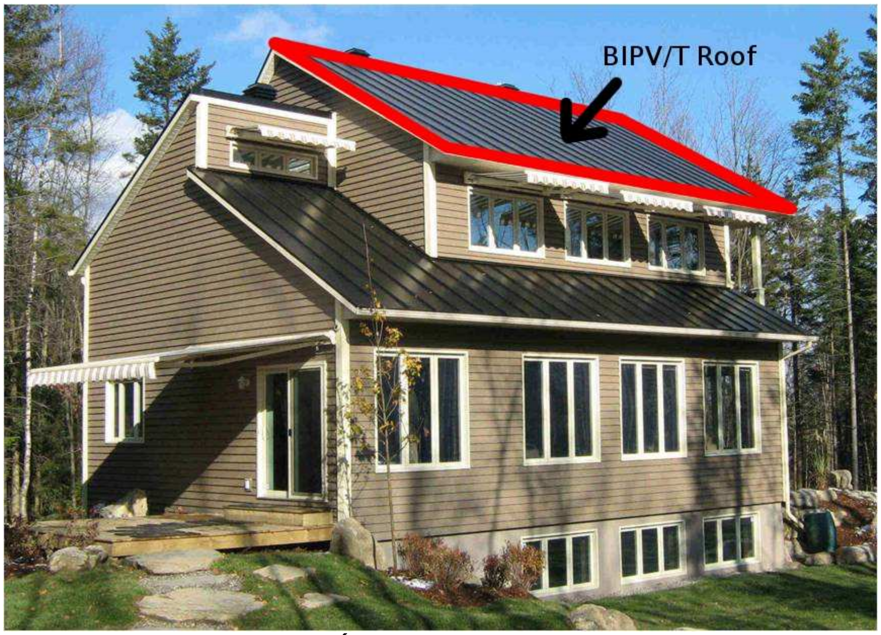

Figure 1.1: Front view of ÉcoTerra with BIPV/T roof (from southwest)

ÉcoTerra's building envelope was designed according to passive solar principles. It has a south-facing width-to-depth ratio of 1.38, an overall window-to-wall-area ratio of 15.2% (42% for the south facade) and a south-facade-to-floor ratio of 9.1% (excluding the garage). The windows are argon-filled and triple-glazed with a low-e coating.

Significant thermal mass is integrated into the basement and main level. The basement slab is approximately 100 mm thick over the ventilated concrete slab and 75 mm thick in the rest of the basement. A 250 mm thick concrete dividing wall divides the basement in two and extends 900 mm upwards into the main floor living space. The main level has a 150 mm thick concrete slab in the south zone. These concrete slabs and walls serve as thermal mass, helping to dampen room air-temperature swings by storing direct solar gains.

The exterior walls are insulated using a layered system of BASF Walltite, Neopor and Enertite insulation, for a total of approximately RSI 6.4 (R 36.3). The roof is insulated to approximately RSI 9.2 (R 52.2) for the vaulted ceiling portions and RSI 10.9 (R 61.8) for the flat portion. The insulation under the basement slab is approximately RSI 1.3 (R 7.4). The basement walls are insulated to approximately RSI 2.5 (R 14.2) for the above-grade portions and RSI 5.7 (R 32.3) below-grade. After construction, the air-tightness of the house was assessed by a third party, using a blower-door depressurization test, and was measured to be 0.85 air changes per hour at 50 Pascal.

ÉcoTerra was prefabricated in the Alouette Homes factory in 2007. The house was assembled on-site, on a pre-poured concrete foundation, from six modules, within four to six hours. The roof itself was one module; the main and second floors had two modules each, and the basement mechanical systems module was the sixth. Prefabrication allowed for strict control of the construction environment and better precision for the construction and instrumentation of the BIPV/T roof.

1.2 EQuilibrium Competition

ÉcoTerra was constructed as part of CMHC's EQuilibrium™ competition. From the CMHC website (CMHC, 2010):

> *"EQuilibrium™ is a national Sustainable Housing Demonstration initiative, led by CMHC, that brings the private and public sectors together to develop homes that combine resource- and energy-efficient technologies with renewable energy technologies in order to reduce their environmental impact. Project teams have been selected to build EQuilibrium™ demonstration projects across Canada."*

The EQuilibrium™ competition was announced in May of 2006. Approximately 80 teams submitted applications and 15 were selected to receive funding, technical support and public exposure for their projects (CMHC, 2009).

The main goals of the EQuilibrium™ program are best stated by CMHC in this excerpt from their website (CMHC, 2010):

> The goals of the EQuilibrium™ housing initiative are to:
>
> 1. Develop a clear vision and approach to develop and promote low-environmental impact healthy housing across Canada.
>
> 2. Build the capacity of Canada's home builders, developers, architects and engineers to design and build EQuilibrium™ homes and communities across the country;
>
> 3. Educate consumers on the benefits of owning an EQuilibrium™ home and achieve market acceptance of EQuilibrium™ houses and sustainable communities; and
>
> 4. Enhance Canada's domestic and international leadership and business opportunities in sustainable housing design, construction services and technologies.

Applicants to the competition were evaluated based on a set of requirements that were designed around the five core principles guiding the program: occupant health, energy efficiency, resource conservation, low environmental impact and affordability.

Some of the more specific requirements include using the EGH and EGH* rating systems and modelling the home using HOT2000 and RETScreen.

1.3 Design Process

An integrated design team is an important part of designing a high-performance building (Keeler and Burke, 2009). Many parties were involved in the funding, design, support and construction of ÉcoTerra. The goals of the design team were to design a home that reached or approached net-zero energy while still being economically feasible. With ÉcoTerra, team members aimed to demonstrate that such homes are viable in Canada and sought to use integration to help reduce costs, as building components can be combined to fulfill multiple purposes. Integration can also lead to reductions in the materials and labour required for construction (Chen et al., 2010a).

One of the most important first steps in the design of ÉcoTerra was the design charrette. A charrette is an intense brainstorming and design meeting that brings together all of the parties involved in the project so that they can create the basic design. Three main groups were present at the charrette for ÉcoTerra: the engineering team, the architectural team and the builder team. The engineering team, from Concordia University in Montreal, Canada., was headed by Dr. Andreas Athienitis and included several of his graduate students. They provided engineering, research, design and support. The architect for the project was Masa Noguchi, and the builder was Alouette Homes. The Alouette Homes group was made up of Bradley Berneche and his technicians and tradespeople.

Other stakeholders that were involved with the design process include HydroQuébec (monitoring), a distributor of ground-source heat pumps, a photovoltaics expert (Yves

Poissant of NRCan) and a representative from the municipality. Nicole Laberge (project manager), Jean Ardouin (construction manager) and representatives from CMHC were also involved.

The design process itself had specific goals and methods. The team applied an integrated and systematic design approach to which all parties contributed. The supply and demand sides were examined simultaneously to minimize the requirements of the demand and maximize the output of the supply – all while consciously reducing costs as much as possible. See Figure 1.2 for an overview of the high-level design process used for ÉcoTerra (Doiron et al., 2011).

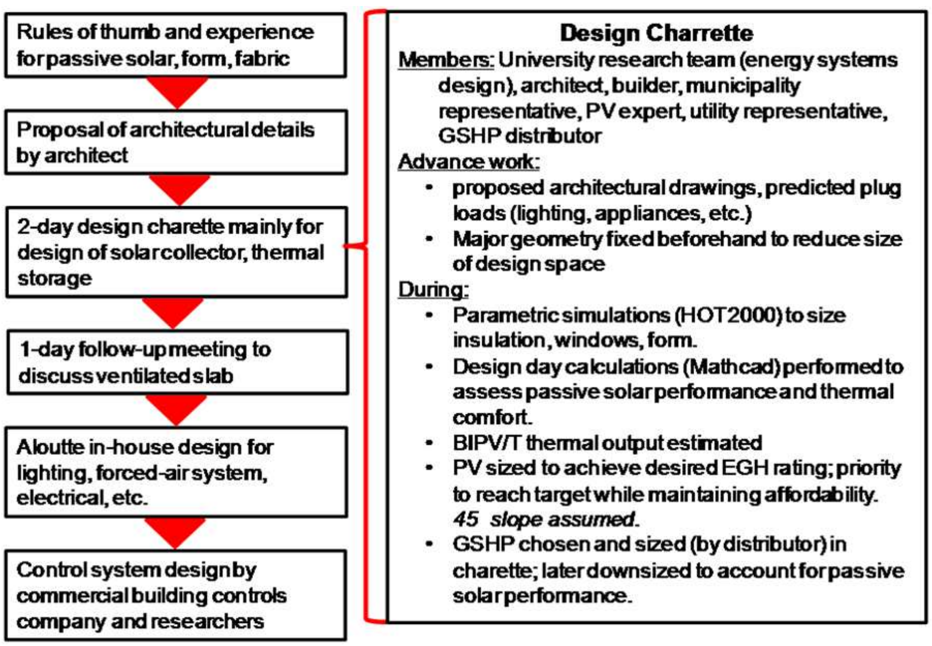

Figure 1.2: High-level design process for ÉcoTerra
Image Source: (Doiron et al., 2011)

The building envelope was an important part of the energy efficiency. It was designed to have low air leakage, high insulating value and optimized windows. Energy efficient appliances and equipment were selected to reduce energy consumption. The home was oriented south to achieve optimal solar radiation, and features such as thermal mass and shading were employed to mitigate temperature swings.

The supply side was examined concurrently and designed to fit the needs of the house. Electricity and heated air are provided during sunny periods by the building-integrated photovoltaic/thermal system that makes up ÉcoTerra's roof. The primary heating system was chosen to be a ground-source heat pump.

1.4 Net-Zero Energy

One of the ÉcoTerra project's goals was to achieve near net-zero energy consumption. The concept of net-zero energy can be defined in various ways, but for this project, it was defined by the EQuilibrium™ Program's requirements as a building that produces, on-site, as much energy as it consumes over the course of a year. ÉcoTerra, therefore, is equipped with a bidirectional electrical meter that measures energy going out as well as energy coming in. The sum of the energy used at the end of the year is compared to the sum of energy exported, to judge how close the house is to net-zero.

A net-zero building essentially uses the electrical grid as a battery. When the building produces more energy than is required, it “stores” the energy on the grid. This energy is later “retrieved” during those times when the house does not produce enough energy for its needs. This has implications for utility companies who manage the grid and is an area that is being investigated by various parties.

1.5 ÉcoTerra's Systems

Traditional solar collectors provide only one type of energy: electricity (photovoltaic panels) or thermal energy (solar thermal panels). These systems are typically stand-alone systems or add-ons to a building. ÉcoTerra's building-integrated photovoltaic / thermal (BIPV/T) system is designed to increase the overall solar energy collected (by collecting both electrical and thermal energy) and to be integrated into the building itself, forming the outer layer of the metal roof (on the top, south side) (Chen et al., 2009).

Figure 1.3 shows a system schematic of ÉcoTerra (Chen et al., 2010a). A more detailed schematic of the system, created by the author of this thesis and including the location of key sensors, can be found in Appendix A - System Schematic.

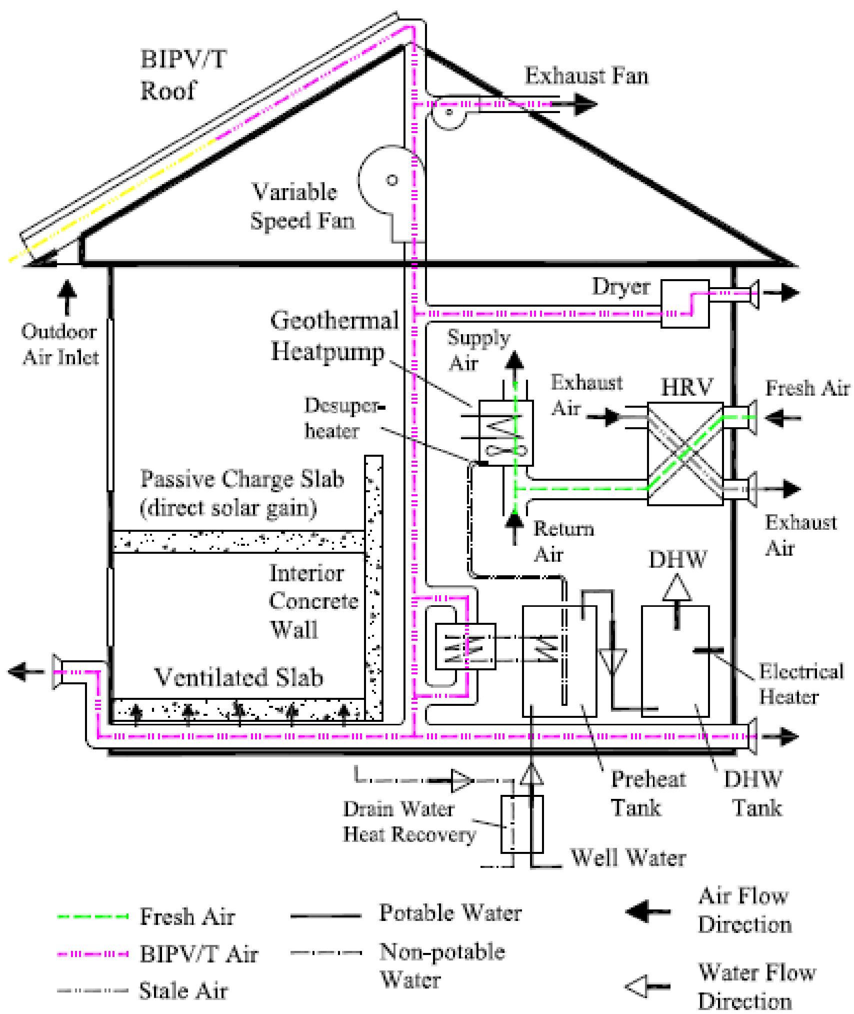

Figure 1.3: System schematic of ÉcoTerra
Image Source: (Chen et al., 2010a)

While the heat recovery component of the BIPV/T roof is operating, air is drawn through openings along the roof soffit and through channels on the underside of the roof surface by a variable speed fan. This air is heated by the sun as it travels under the metal roof layer and is drawn through an insulated manifold and duct into the house's mechanical room to be used before being exhausted outside. The outer surface of the roof is covered by amorphous silicon photovoltaic (PV) panels, which convert the incident solar radiation into electricity. Since the PV panels are about 6% efficient at converting the energy into electricity, much of the remainder can be recovered by the air passing below their surface. A cross-section of the BIPV/T roof is seen in Figure 1.4 (Chen et al., 2010a).

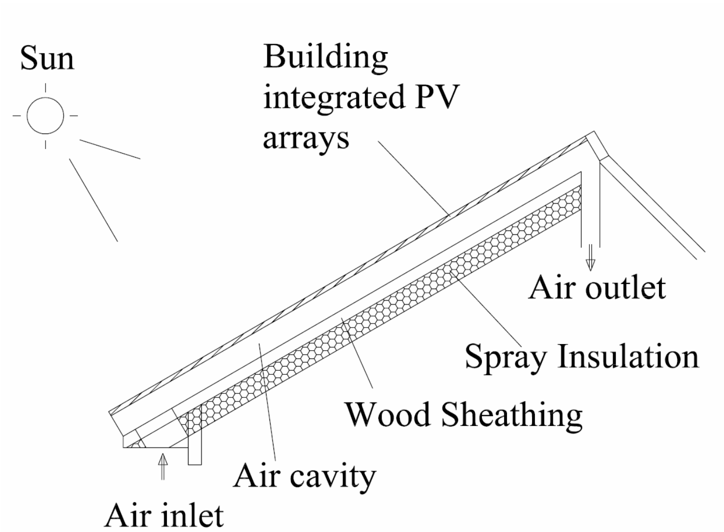

Figure 1.4: Cross-section of BIPV/T roof system
Image Source: (Chen et al., 2010a)

The integrated nature of this system means that the surface on which the PV is installed serves a dual purpose – it is an energy collector (for PV and heat) and it is also the roof's outer layer. In most systems, a separate roof is built and the PV system is installed later. The integrated approach used here can lower costs and allows for easier collection of thermal energy all while maintaining the aesthetics of the roof.

The electrical energy can be used either on-site or sold to the electrical grid, while the thermal energy must be used on-site, either immediately or stored for later use. The heated air can be used to preheat the domestic hot water using an air-to-water heat exchanger, dry clothes, heat the ventilated concrete slab (VCS) or any combination of these applications.

There are several sub-systems integrated into the BIPV/T system. The 21 photovoltaic panels are Uni-Solar PVL-136 amorphous silicon and are located on the roof. Each panel has a rated capacity of 136 W for a total capacity of 2.8 kW. The electricity they produce is used on-site if there is appropriate demand, or exported to the electrical grid otherwise. The direct current produced by the panels is converted to alternating current by the Fronius IG 3000 inverter. Table 1.1 lists some important specifications of the photovoltaic panels and the inverter, and Figure 1.5 shows a schematic of the photovoltaic electrical system. More detailed specifications can be found in Appendix I - Equipment Information.

Table 1.1: Summary of photovoltaic system specifications

Photovoltaic Panels	**Uni-Solar PVL-136**
Maximum Power	136 W (± 5%)
Voltage at Max Power	33.0 V
Current at Max Power	4.13 A
Cell Type	Triple junction amorphous silicon
Temperature Coefficient	-0.21%/°C
Roof/PV Surface Area	55 m^2
Inverter	**Fronius IG 3000**
Recommended PV Power	2,500 - 3,300 Wp
Operating DC Input Range	150 - 1450 V
Nominal AC Output	240 V
Max Output Power	2,700 W
Maximum Efficiency	95.20%

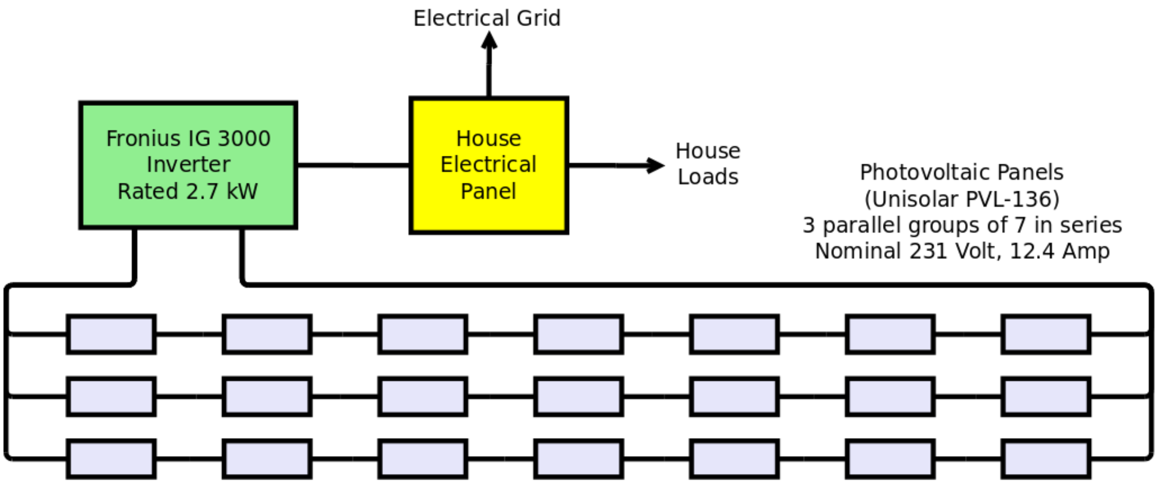

Figure 1.5: Schematic of photovoltaic electrical system

The dryer sub-system provides roof-heated air to a standard residential clothes dryer. A schematic of this system is shown in Figure 1.6. When the dryer is operating and there is warm air available from the roof, a booster fan is turned on and the dampers divert air from the roof to the intake of the dryer. When there is no solar-heated air available, the dampers switch to allow air to be drawn into the dryer from the basement.

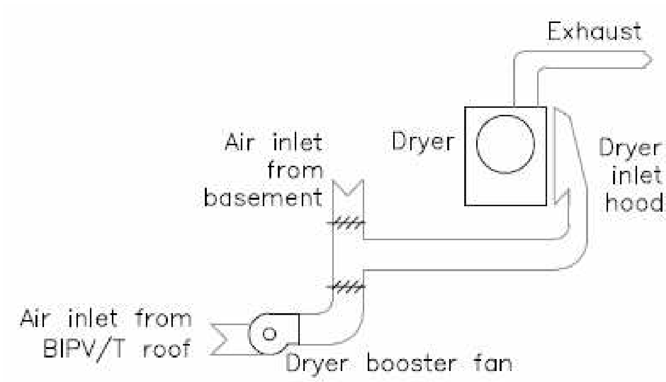

Figure 1.6: Schematic of solar-assisted clothes dryer sub-system

The domestic hot water sub-system consists of a preheat tank, which is used for storage and collection, and the primary hot water tank. Both tanks are standard 60 gal residential hot water tanks. They are connected as shown in Figure 1.7.

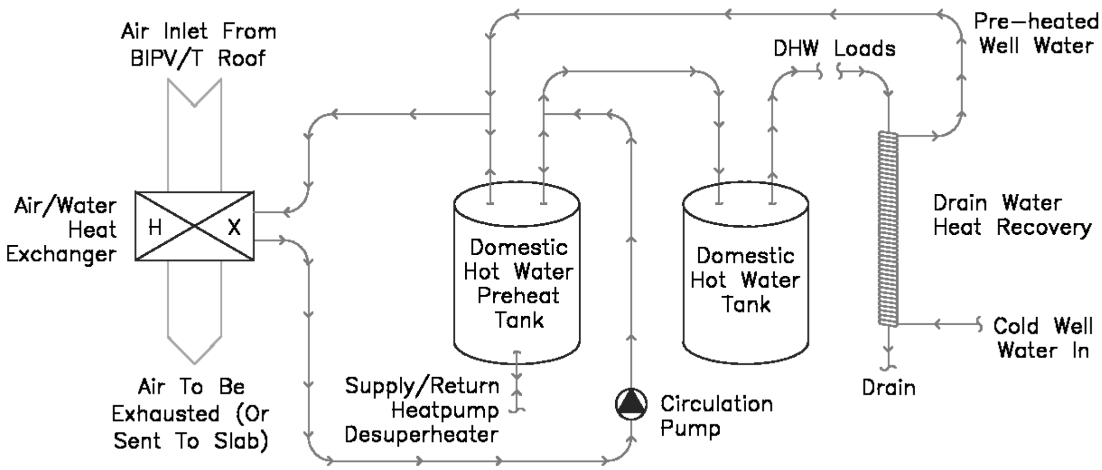

Figure 1.7: Schematic of domestic hot water sub-system

Air heated by the roof passes through the air-to-water heat exchanger. A small pump circulates water through this heat exchanger which extracts heat from the air and stores it in the preheat tank. The preheat tank is also heated by the heat pump desuperheater. Water entering the system from the well is preheated by the drainwater heat recovery system. When the occupants use hot water, it is drawn from the primary hot water tank, which has a standard electric heating coil to ensure a water temperature of 55 °C. The primary tank draws water from the preheat tank instead of the well, reducing the overall energy use of the hot water system.

The VCS sub-system is a structural element of the house (the basement floor), but it also has corrugated metal decking embedded at its bottom which forms air channels. Heated air from the BIPV/T roof is passed through these channels, thereby actively heating the slab. The energy stored actively in the significant thermal mass of the floor is then discharged passively into the space, offsetting the heating energy consumption when passive solar gains are unavailable. Figure 1.8 shows a cross-section of the ventilated concrete slab (Chen et al., 2010b).

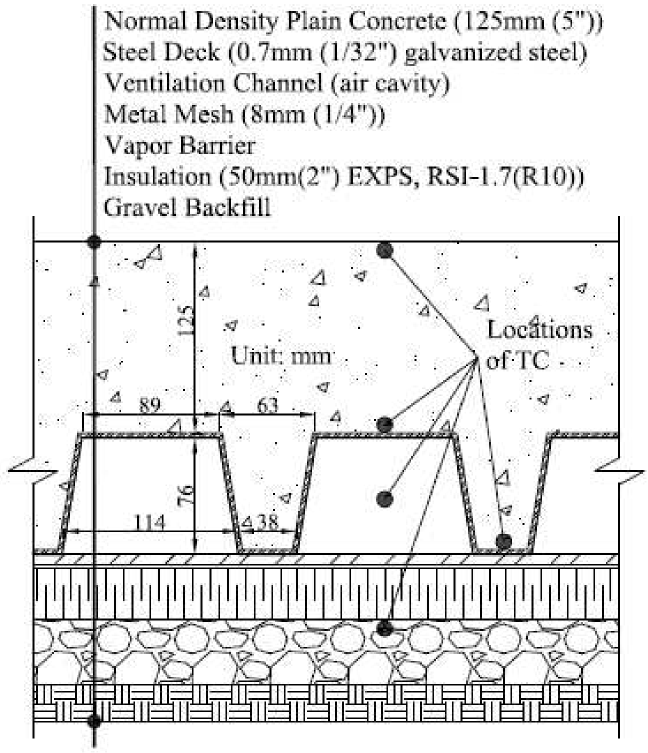

Figure 1.8: Cross-section of ventilated concrete slab sub-system
Image Source: (Chen et al., 2010b)

1.6 Objectives

This thesis provides a comprehensive, whole-system energy analysis of ÉcoTerra, focused on measured data from the house. The overall energy use and end-use breakdown are analyzed and discussed. The house's control system is documented, as are the changes that have been made to the controls since construction. A review of the literature related to similar projects and analyses is performed. Also included is a section on lessons learned throughout the energy analysis process and the design, construction and operation of the house. Recommendations are made as to how ÉcoTerra, and future low-energy homes, can be improved. Large amounts of high quality data have been collected since the construction of the house, and significant work has been done as part of this thesis to structure and organize the data into usable forms, in support of this thesis as well as the work of future researchers.

The main objective of the thesis is to provide an overall, integrated picture of the house's energy performance and to discuss the lessons that can be learned from ÉcoTerra.

The following is a summary of the contents of each chapter:

- Chapter 1 – Introduction: Introduces ÉcoTerra and provides background on the project and the objectives of this thesis.
- Chapter 2 – Literature Review: Reviews the relevant literature concerning net-zero buildings, monitoring and energy analysis.
- Chapter 3 – Control System: Discusses the rationale behind the control system and the significant changes made since construction.
- Chapter 4 – Measured Data: Presents the data collected, corrections made to it, the monitoring process and sources of error.
- Chapter 5 – Energy Analysis: Discusses the overall energy consumption and end-use breakdown, as well as the performance of various parts of the house.
- Chapter 6 – Reaching Net-Zero: Provides a series of recommendations for ÉcoTerra and future net-zero homes in order to reach net-zero energy.
- Chapter 7 – Conclusions: Summarizes the results of the work of this thesis.
- Appendices: Provide supporting documentation and schematics as well as the code for the scripts used in this thesis' calculations.

2 LITERATURE REVIEW

This chapter will review the literature regarding the design, monitoring and analysis of net-zero energy and low-energy houses. The various definitions for net-zero are examined, as are the types of monitoring and analysis generally performed. Other building-integrated photovoltaic thermal systems will also be examined.

2.1 Passive Solar Design

Passive solar design is the practice of designing a building to work with the sun's natural cycles to maintain comfortable indoor conditions with minimal active components such as fans. The concept of passive solar design is not new – Greek and Chinese cultures are known to have oriented their buildings to face the sun (Butti and Perlin, 1980), and many traditional types of architecture "collect and store the sun's heat for use at night" (Henderson et al., 2009).

Some important factors to achieve a good passive design are a good understanding of solar paths, proper orientation of the building, envelope design, thermal storage and internal layout. These concepts result in lower energy use for passive solar buildings, as fewer resources are required to forcibly maintain interior conditions.

The basic design goal for a passive solar building is to maximize solar gain and utilization while at the same time not overheating during the warm months (Chiras, 2002). The envelope design is crucial for this. The first step is to minimize the heating load of the building. This is done by highly insulating the walls and paying careful attention to air-sealing of walls, windows, doors, headers, etc. Next, careful selection of window size, location and glazing properties is required, so as to achieve the best balance between the amount of energy admitted through them as solar gain and the energy lost through them (Chiras, 2002). The location of windows will be affected by the orientation of the building itself. Passive solar buildings in the northern hemisphere usually have a larger concentration of windows on the south-facing façades than on the north-facing façades (Chiras, 2002).

A home designed to maximize solar gain can, during times of peak solar radiation, overheat significantly. There are various strategies to mitigate this, including overhangs and shades (internal or external). Thermal mass can also be used to dampen temperature fluctuations and distribute solar gains more evenly throughout the day (Henderson et al., 2009). Energy can also be redistributed using fans or used for other purposes, such as domestic hot water (Chen et al., 2010).

The geographic location of a passive solar project has a large impact on the basic design of the building. Regions that are heating-dominated will tend to produce designs that focus on collecting as much solar energy as possible and, likely, on the storage of that energy. Cooling-dominated regions will focus much more on strategies for mitigating overheating (Chiras, 2002).

2.2 Defining Net-Zero

The concept of low-energy buildings is important due to the significant portion of energy that is currently used to power buildings. Achieving net-zero reduces the use of that energy significantly. The general definition of a net-zero building is one that, over the course of a given year, consumes as much energy as it produces from renewable energy sources (Sartori et al., 2010). This definition, however, is not universal, and various exceptions, qualifications and interpretations exist that depend on many factors. Some definitions allow energy created off-site to offset the on-site usage. Others define energy use in terms of primary energy (the energy at the source such as the power plant) and others in terms of secondary energy (the energy as it is used on-site, without taking into account transmission losses) (Sartori et al., 2010).

Various classification systems and definitions have been developed around the world. Significant work has been done by the National Renewable Energy Laboratory (NREL) in the United States to systematize the application of the term “net-zero” (Crawley et al., 2009). The NREL system classifies the definition into net-zero A, B, C or D. The A and B definitions include on-site generation only. The A option includes generation on the building itself or within its footprint. The B option allows generation on-site and directly connected to the building's systems. The C option allows energy to be collected or stored off-site, but brought on-site before use (an example of this would be to burn wood pellets as a source of energy). The D option allows the use of renewable energy credits to offset on-site generation by funding off-site generation.

Another idea that has gained widespread support is that the definition of net-zero must include certain other basic requirements. NREL supports this conclusion when they say that defining and reaching net-zero is not just a supply problem – “Tackle demand first, then supply” (Crawley et al., 2009). An example is the idea that a building should not qualify as net-zero if it is a typical, inefficient, poorly insulated building, with a proportionally large PV array to make up for its deficiencies. This means that net-zero buildings are not *just* net-zero energy, they are also high-performance, energy efficient buildings. Indoor air quality is also a factor. High-performance buildings should be “better” buildings, buildings as they “should” be, and the health of the occupants is therefore also important. Health, however, is not dependent on indoor air quality alone.

High-performance buildings tend to offer better lighting conditions with lots of natural light, better ventilation, and more natural temperature and humidity ranges (Yudelson, 2009).

This leads to a broad requirement for net-zero buildings. They must meet the definition for energy use, but they must also be high-performance buildings. Characteristics of high-performance buildings will often include elements of passive solar design, which are discussed in Section 2.1 - Passive Solar Design.

Other work is being done by the International Energy Agency's Solar heating and Cooling (IEA-SHC) Task 40 “Net Zero Energy Solar Buildings”. Subtask A, specifically, focuses on “Definitions and Implications” with the goal to “establish an internationally agreed understanding on NZEBs [net-zero energy buildings] based on a common methodology” (IEA-SHC Task 40, 2010).

2.3 Building Energy Classification Systems

An important classification, especially for ÉcoTerra, is the EnerGuide for Homes (EGH) rating system (NRCan, 2010a). This system was developed by NRCan and rates homes on a scale from 0 to 100. A home rated 0 would have a poor building envelope (minimal insulation and high air leakage) and high energy use. The average Canadian home built to codes and standards would receive an EGH rating of between 65-72, while a highly energy efficiency home would rate 80 to 90. A home rated 100 is a net-zero home that produces as much energy as it consumes in a given year (NRCan, 2010a).

The EGH rating must be calculated using software called HOT2000, also developed by NRCan (NRCan, 2010b). HOT2000 models the house and compares it to a reference building with similar characteristics, but with standard occupancy, internal loads and occupant-based loads such as lighting and appliances. The EGH formula is given in Equations 2.1, 2.2 and 2.3 (Candanedo et al., 2007).

$$EGH = 100 - 20 \cdot \left(\frac{Estimated\ Annual\ Energy\ Consumption}{Reference\ Annual\ Energy\ Consumption} \right) \tag{2.1}$$

$$Estimated\ Annual\ Energy\ Consumption = Modeled\ by\ HOT2000 \tag{2.2}$$

$$Reference\ Annual\ Energy\ Consumption = Sum\ of\ Reference\ Benchmarks \tag{2.3}$$

Various other classification systems and baselines exist, but none were directly applied to ÉcoTerra. One such standard is the R2000 program, which is equivalent to EGH 80. This program sets standards to encourage homes to be built with high energy efficiency, good indoor air quality and high quality building envelope (CMHC, 2005). The Model National Energy Code of Canada was created by the National Research Council (NRC) and provides a broad standard for buildings' energy efficiency (NRC, 2010).

2.4 Monitoring and Analysis of Low-energy Homes

The monitoring of advanced houses is not a recent development. The Saskatchewan conservation house (Besant et al., 1979) was studied in the late 1970s and the Novel Kirk Farm was studied in the late 1980's (Poehlman et al., 1988).

The monitoring schemes for low-energy houses vary widely from a few temperatures that are measured hourly (Smith, 2001) to many dozens monitored by the minute (Chen, 2009) and (Dhople et al., 2010). The literature reviewed for this chapter generally did not go into detail about the monitoring setup, other than to describe the typical values that are monitored. Only a few authors, such as Summerfield et al. (2007) and Norton and

Christensen (2008), discuss monitoring systems in detail. The work by Dhople et al. (2010) includes highly detailed descriptions of the wiring and electrical setup of the monitoring system for their Solar Decathlon house.

Commonly monitored values include air temperatures in various rooms; outdoor conditions such as temperature, humidity, insolation, and wind speed; energy consumption of various equipment, ranging from appliances to HVAC equipment; PV electrical generation; and temperatures and flow rates of various air and water streams in the houses. Sources such as Norton et al. (2005) and Norton and Christensen (2008) give large tables of monitored values, including many of those listed above. The values chosen are not typically justified. It is assumed that the researchers, builders or owners of the buildings in question decided what to monitor based on their own goals. When the goal was to achieve net-zero energy status, then significant monitoring was done on energy consuming devices, as in Norton & Christensen (2008). Other examples include Smith (2001) and Summerfield et al. (2007) which focus more on the thermal performance of the building, so these monitoring systems measured more air temperatures and humidities.

A mix of monitoring durations is also demonstrated. Some short-term monitoring was performed on specific systems, such as the consumption of appliances and heat pump performance (Norton et al., 2005). Long-term monitoring was also carried out in the same article and in others, such as Steinbock et al. (2007), where monitoring was performed for two years and is still ongoing. Although it does not mention its monitoring setup, Voss et al. (1996) provides trends and an analysis of three years of performance data.

Most articles focused on single buildings, but Summerfield et al. (2007) monitored 19 buildings in a group of low-energy houses, and Thomsen et al. (2005) provided case studies for a group of 15 demonstration projects. Another article, by Zydeveld (1998), reported overall statistics from approximately 4,000 homes which, although not net-zero, were designed using passive solar principles. Several other articles provide information on over-all energy consumption and performance of general solar homes, such as Turrent (1981). Additionally, while various case studies do not mention monitoring, they provide general information on the performance of specific low-energy houses such as the CMHC Healthy House (Leung, 1996), the Procos House (O'Brien, 2003), the Minto ecoHome (CMHC, 2008), and the Waterloo Green Home (Vamberger, 1994).

The data resulting form the previously mentioned monitoring allows for a wide range of analysis to be performed. However, each individual article or study typically focused on a specific, narrow analysis of one system or a high-level analysis of overall energy use. Many of the sources gave overall energy use or energy density for comparison to some benchmarks, but only the work of Norton & Christensen (2008) included an energy end-use breakdown for the building.

Most sources focused on the performance of specific systems, such as the photovoltaic, heating or domestic hot water systems, and none of them tried to interrelate the performance of the various systems or building components.

There is significant international interest in the monitoring and analysis of low-energy houses. The previously-mentioned IEA Task 40 is cataloguing and documenting net-zero and near net-zero houses as part of an effort to learn from the many projects that have already been completed around the world. ÉcoTerra is part of the database of case studies that has been created by the Task 40 Subtask D. A case study sheet completed earlier in ÉcoTerra's history can be found in Appendix G - IEA Case Study. ÉcoTerra is also being used as part of Subtask B to help in the creation of a design tool.

2.5 PV/T Systems

ÉcoTerra's building-integrated photovoltaic thermal system has several innovative features, but the idea of combining electricity and heat production is found in various buildings and even commercially available products.

Another EQuilibrium™ house (Alstonvale) uses a system similar to ÉcoTerra's (Candanedo et al., 2007). Alstonvale's system is also building-integrated, but has several features that go beyond those of ÉcoTerra. First is the fact that the heated air is used as a source of energy for an air-source heat pump. This type of system offers good potential for high coefficients of performance since the heated air will be much warmer than the outside air. The second unique feature is the clear glazing portion of the roof, which helps boost the air temperature over the last section of the BIPV/T roof (Candanedo et al., 2007).

Several commercial products are also available that use PV/T principles. One such product is a type of glass roofing tile manufactured by SolTech Energy (SolTech, 2010). These tiles work in a way that is similar to the glazing section at Alstonvale. The sun's energy is trapped below them by a heat absorber and used to heat air for use in the house. The SolTech system is flexible and so can be coupled with various systems such as air-source heat pumps or hydronic systems. The SolTech tiles are not themselves photovoltaic panels, but could easily be integrated with products such as SRS Energy's

Solé Power Tile™, which resembles the SolTech tile in appearance but is coated with an amorphous photovoltaic panel (SRS Energy, 2010).

International attention has been paid to the subject of PV/thermal systems, including the work of the International Energy Agency's Solar Heating and Cooling (IEA-SHC) Task 35 “PV Thermal Solar Systems” (Hansen and Sørensen, 2006). A significant contribution of this task was a comprehensive catalogue of commercially available PV/T systems. The catalogue includes many manufacturers, their products and links to their websites (Zondag, 2007).

ÉcoTerra's PV/thermal system is different from the other systems mentioned here in that it is not simply PV/thermal, but building-integrated PV/thermal. The difference being that conventional PV/thermal technologies are typically add-ons or stand-alone systems which are then connected to the building. ÉcoTerra (and also Alstonvale) use a building-integrated approach which means the PV/thermal system is not simply attached to the building envelope, but is an integrated part of it. The integrated approach can lower costs and allows for easy collection of thermal energy, while maintaining the aesthetics of the building.

2.6 Design and Construction

Some of the projects found during this review used interdisciplinary teams during their design and construction. All of the EQuilibrium™ projects, for example, were required to do so as part of the program. Various other projects used interdisciplinary teams by choice, such as Dhople et al. (2010), but many other sources did not discuss the design process itself, just the results.

The construction processes also varied. Some houses used modular or prefabricated technologies like ÉcoTerra such as the works by Norton et al. (2005), Dhople et al. (2010) and Smith (2001). While all projects were built to the codes and standards of their region, some chose to follow more stringent standards, such as the work by Wall (2006) whose subject house was built to the Passivehause standard (Passivehaus Institut, 2010).

Some projects were built by home manufacturing companies, such as in the Minto home (CMHC, 2008), but others used local labourers, such as in the work of Norton & Christensen (2008) and Barley et al. (2004), which described the owners' direct involvement in the construction.

Most of the projects made heavy use of modelling, simulation and/or optimization software. A wide variety of building simulation software was used for these purposes, including TRNSYS, BEOpt and DOE2 (Norton and Christensen, 2008).

2.7 Conclusions

A significant amount of work has been done over the last 50 years in terms of designing, constructing and learning from low-energy houses. Many of the projects reviewed as part of this chapter had certain common approaches. They all used passive solar design to some extent. Some were concerned with cooling and others with heating, but the concepts of solar orientation, glazing and thermal mass were a common theme. The building envelope was also important to all of the cited projects. Significant work went into modelling and optimizing the windows, insulation levels and thermal mass.

Each project also adapted its design and construction methods to the local climate (sometimes micro-climate (Krüger and Givoni, 2008)), codes, standards and work force. These efforts demonstrate that low-energy homes are most successful if they are integrated into their site. Another common finding was the importance of occupant factors (Thomsen et al., 2005).

Some differences were also apparent. Each project had its own goals so their analysis and reporting were different. Almost all cited projects monitored some temperatures and humidities, but only one did a comprehensive energy end-use analysis or analyzed the building as a system (Norton and Christensen, 2008).

The reviewed literature does not provide a widely used or agreed upon definition for net-zero. ÉcoTerra uses the definition required by the EQuilibrium™ program.

Several of the works reviewed mentioned integrated design and construction, but only (Norton and Christensen, 2008) made an effort to follow through with this approach into the monitoring and analysis phase. This review, therefore, shows that there is great potential for low-energy buildings with many success stories to be found. Further advancement, however, will require looking at these homes in a holistic way by treating them as systems, from their design phase through to their operation. This thesis will build on the integrated design process that was used for ÉcoTerra and will analyze the house as a system in order to learn from individual systems as well as their interactions.

3 CONTROL SYSTEM

ÉcoTerra's supervisory control system was installed by Régulvar, which is a large controls company based in Québec, Canada. The control system was designed during the charettes and subsequent discussions between Régulvar and Concordia University.

3.1 Design Rationale

ÉcoTerra's control system was designed to provide the basic supervisory control necessary to allow for the collection and storage of solar thermal energy as well as maintenance of thermal comfort in the house. The system could potentially have been significantly more complex, but the goal was to achieve a functional system above all else. Some advanced features were purposefully not included, such as predictive control based on weather forecasts.

The basic rationale behind the control system is to bring warm air into the basement mechanical systems if it was warm enough to provide adequate energy. Certain key factors were taken into account to achieve these ends. They include: the passive solar design of the house, the occupant behaviour and the potential of the BIPV/T system. The passive design of the house includes features such as high thermal mass. This means that the house will respond slowly to increases in outdoor temperature or solar radiation. This required the careful selection of setpoints and thermostat deadbands to prevent overheating and maintain comfort. The setpoints involved in the BIPV/T system were chosen based on engineering experience to maintain suitable differences in temperature across the heat exchanger, slab and preheat tank. The system also had to be easy for the owner to understand and use, so a touch-sensitive LCD screen was installed, with an appropriate user interface, to give the owners real-time feedback on key systems. The heating system mode, the status of various fans and local weather data are provided via this system.

3.2 Existing Controls

A condensed version of this control sequence is included here. A copy of the full sequence can be found in Appendix D - Detailed Control Sequences. A detailed system schematic is shown in Figure 3.1. A schematic for the control system at ÉcoTerra is shown in Figure 3.2

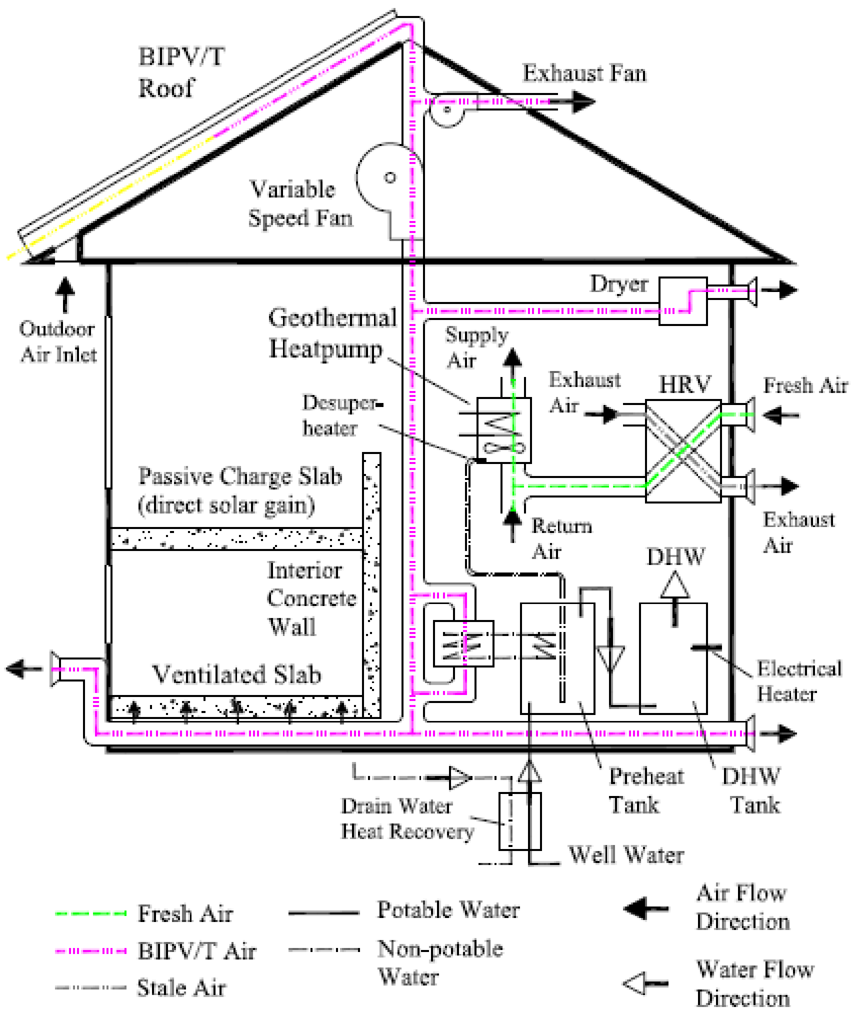

Figure 3.1: System schematic of ÉcoTerra
Image Source: (Chen et al., 2010)

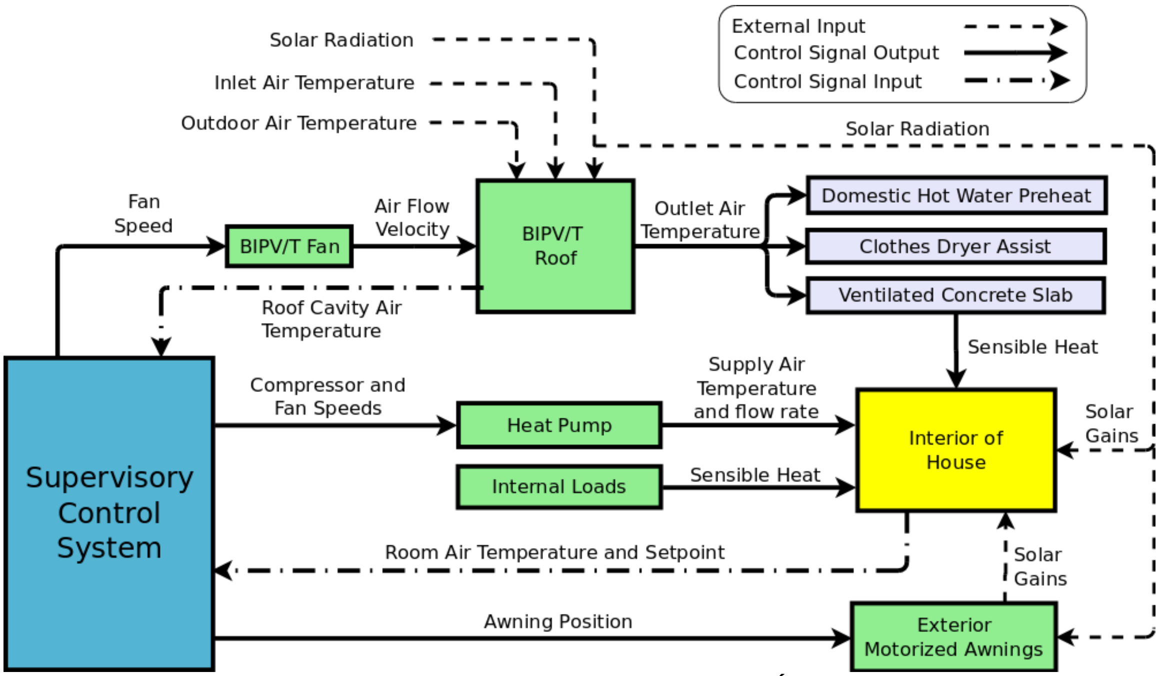

Figure 3.2: Control system schematic for ÉcoTerra

3.2.1 BIPV/T System

The driving force behind the BIPV/T system is the fan, which draws the air through the roof. While the BIPV/T fan is running, multiple damper configurations are possible. Each configuration diverts air from the roof for one or more purposes. The fan is turned on by the control system when all of the following conditions are true:

- There is a demand from the slab, the dryer or the domestic hot water system.
- The low limit flag for the roof cavity air temperature must not be set. This low limit flag prevents air that is too cold from being drawn into the house.
- There is sufficient solar radiation (determined by the inverter's output amperage).

The temperature setpoint for the roof air cavity is maintained by continuously modulating the speed of the fan between 40% and 80% of the maximum based on the output of a PI controller. The maximum is limited to 80% to reduce noise from the fan.

The roof air cavity temperature setpoint is defined as the maximum of the following values:

- The temperature of the domestic hot water heat recovery reservoir plus 10 °C. This value is considered only if the system is in DHW mode.
- The average slab temperature plus 10 °C. This value is considered only if the system is in slab charging mode.
- 30 °C if there is demand for the dryer.

Domestic Hot Water Preheating

If there is demand from the DHW heat recovery reservoir, then the dampers divert air through the air-to-water heat exchanger. There is considered to be demand when the temperature of the heat recovery reservoir drops below the reservoir setpoint of 35 °C.

A low-limit flag for the temperature of the roof air cavity disables DHW mode. This is to ensure that a useful difference in temperature exists between the incoming air and the DHW reservoir.

The pump, which circulates water between the heat exchanger and the heat recovery reservoir, runs while the system is in DHW mode and is off otherwise.

Slab Charging

The slab in the basement can be heated or cooled actively. This large thermal mass helps to stabilize the temperature of the house and stores energy from the sun when possible. While running, the BIPV/T fan maintains a specific slab setpoint, which is determined based on outdoor air temperature. When the outdoor air temperature rises past

10 °C, the slab setpoint will be 15 °C to allow for slab cooling. When the outdoor air temperature falls below 8 °C, the slab setpoint will be 29 °C to allow for slab heating.

The dampers are controlled to divert air coming from the roof depending on the demand. If there is demand for slab charging, the dampers allow air from the roof to pass through the slab first before being exhausted outdoors.

There is considered to be demand for slab heating if the average slab temperature drops below the slab setpoint. A low-limit flag for the temperature of the roof cavity air will disable slab heating mode. This is to ensure that a useful difference in temperature exists between the incoming air and the slab.

There is considered to be demand for slab cooling when the roof cavity air temperature drops 4 °C below the average temperature of the slab, and the maximum outdoor air temperature during the previous day was higher than 25 °C.

3.2.2 Awnings

The awnings are controlled based on the output of a proportional-integral controller, which monitors the temperature in the south bedroom on the second floor. The awnings open and close to maintain a comfortable temperature in that room. They are prevented from operating when there is strong wind and during the winter months.

3.2.3 Heat Pump

The house will be permitted to enter heating mode only after the outdoor air temperature has dropped below 12 °C. When heating is allowed, the first stage of heating is turned on once the reference room temperature in the house drops 1 °C below the heating setpoint and remains on until the reference air temperature rises 0.5 °C above the setpoint. If, after 15 minutes, the setpoint has not been reached or the temperature has dropped 1.5 °C below the setpoint, the second stage of heating is turned on. The second stage of heating remains on until the reference room temperature has risen 0.5 °C above the setpoint. If, after 30 minutes, the heating setpoint has still not been reached, the auxiliary heating (2 electric coils in parallel) may be permitted to operate if certain emergency conditions are triggered. Such conditions include a difference of more than 4 °C between the setpoint and reference temperatures. Several other operating modes include: “Comfort Override”, which allows cooling; and “Disabled” and “Vacation” modes, which use reduced setpoints.

A single reference temperature is used to control the heat pump – the main level dining room air temperature. There are several other sensors on other floors, but due to the house's open design, the system is essentially a single zone. The main level was judged to be a representative area.

The single-zone control provides simpler control sequences, but has disadvantages. With a single representative sensor controlling the system, it is possible that the upper or lower floors will be under or over heated/cooled. The south bedroom on the top floor acts as a separate zone in that it has a dedicated damper that branches from the main supply duct. This damper is modulated based on a PI controller which senses the air-temperature in the south bedroom zone. This damper was installed to help mitigate the potential overheating in this direct-gain area that lacks significant thermal mass. The basement and main levels have significant thermal mass, so their temperature swings are dampened.

3.3 History of Changes

The original controls installed at ÉcoTerra were the product of a loose coordination between several parties. The beginnings of the sequence of operation were discussed at the design charettes, and further details were filled in through various informal exchanges via email, phone, etc. Small changes were made by various people at various times as the project progressed. The complexity of the programming increased and the clarity and legibility of the code decreased. Documents on specific aspects of the project were created along the way, but no single document was created that described the entire state of the control system, the sequence of operations, or the various changes made throughout the control system's history.

The control system worked adequately under simple, unoccupied conditions, however, in August of 2009, when the new owners began spending significant time in the house, issues were discovered that had not been obvious before. The cooling system was not operating as expected, so the house was overheating. More overheating occurred later in the fall due to higher than desired heating setpoints. Upon investigating these issues, it became obvious that the lack of documentation for the control system was a problem. When a fix was attempted, some unintended consequences resulted in over-cooling. The eventual temporary solution provided adequate comfort, but without full control of setpoints and schedules.

At this point, both Régulvar and Concordia were reluctant to make significant changes to the controls code without understanding it fully. So, the author of this thesis analyzed the existing controls programming and documented each sequence of operation for each piece of equipment as it was being controlled at that time. During this process, each piece of equipment and damper was identified using a common naming scheme, and a schematic was created to show the location of each item (see Appendix A - System Schematic). Previous versions of system schematics were out of date or were missing significant components. This schematic was also used to identify the location and owners of key sensors and monitoring devices.

Régulvar, Alouette Homes, the owners and the team from Concordia University then examined the new controls documentation and contributed comments. When the complete picture of the control system emerged, two conclusions became apparent. First, several changes needed to be made to how the system was controlled, above and beyond the issues with heating or cooling. Second, the level of effort required to modify the control system's code in its existing state was greater than that required to replace it.

The Concordia University team (the author of this thesis, fellow students and Dr. Athienitis) used these comments to propose a revision to the existing (Version 1.0) controls to be referred to as Version 2.0. The revisions were incorporated into the v1.0 document by the author of this thesis, and the new Version 2.0 was distributed and reviewed once again.

This revised control system was installed by Régulvar at ÉcoTerra as of December 10, 2009, by Régulvar. Only data after this point is considered valid for the purposes of some analyses. The heating and cooling system performance data, specifically, is not considered useful before this date. However, unoccupied heating and cooling data is available prior to the owners' move-in date . Some data is not affected by occupancy. The photovoltaic generation data, for example, is valid throughout the period for which data exists. Most analyses performed as part of this thesis concentrate on data from after December 10, 2009, unless stated otherwise.

Small changes continued to be made to the controls and continue as of the writing of this thesis. These changes were documented and incorporated into an updated version of the controls documentation (Version 2.1). A condensed version of this control sequence is included later in this section, and a copy of the full, detailed sequence of operations, as written by the author of this thesis, can be found in Appendix D - Detailed Control Sequences. Most of the existing control sequence was kept intact, however, some significant changes were also made. As part of the new controls installation, it was decided that changes to the controls code would be made by Régulvar only, so that they would always be aware of the history of the code. The author of this thesis was the technical contact for the changes described here and documented them in the control sequence. The author also answered questions and coordinated with Régulvar and Alouette Homes.

One major change was the removal of proportional-integral (PI) control for the thermostat setpoint control. The heat pump is now controlled with a simple stepped on/off approach using specified dead-bands. It was felt that with the house having such significant thermal mass, and being a unique building in terms of its controls, that a simple approach was better than trying to properly tune a PI controller. Also, the original PI controller was designed to maintain a constant room air temperature, as is typical for most buildings. This is not applicable for a passive solar building, so a simpler algorithm was selected. The algorithm simply calls for heat when the reference room air temperature drops 1.0 °C below the setpoint and heats until the air is 0.5 °C above the setpoint. The deadbands were chosen to minimize overshoot, so there is a lower deadband above the setpoint than there is below (and vice-versa for cooling setpoints).

The heat recovery ventilator (HRV) was previously controlled based only on the interior relative humidity. It would run until the indoor humidity dropped to a setpoint. This assumes, however, that the outdoor humidity is always less than the indoor humidity. This is not true during the summer. It was observed that during the summer of 2008, the HRV ran almost continuously in high speed mode. This is because the indoor relative humidity was being increased by the HRV and so never dropped below the setpoint.

The Version 2.0 controls allow the HRV to run in low-speed mode at all times except when one of two conditions occur. First, the high-speed mode can be activated when the bathroom or kitchen overrides are activated. Second, the high-speed mode can be activated automatically if the relative humidity in the house rises above a specified setpoint. If this happens, the outdoor conditions are verified and, if appropriate (indoor specific humidity is greater than the outdoor specific humidity), high-speed mode will engage to reduce the indoor humidity. The high-speed mode will continue until the indoor relative humidity is below 45% or until the outdoor specific humidity becomes higher than the indoor specific humidity. As of the writing of this thesis, the owners complained that the HRV ran too much. This may result in adjustments to the humidity setpoints or simply allowing manual control of these setpoints via the home's touch-screen interface.

The heat pump previously operated only when there was a call for heating. In the Version 2.0 controls, it also runs in low-speed, recirculation mode when there is no heating or cooling demand. This is intended to reduce stratification in the house's indoor air temperatures. However, the fan is estimated to use almost 1,800 kWh per year and the destratification effect of running the fan has not yet been quantified. This is significant for a low energy house, therefore a better way to control the recirculation mode should be researched.

The upper limit of the BIPV/T fan speed was reduced from its full 100% to 80%. Also, its startup sequence was changed to ramp up slowly instead of starting immediately at its target speed. These items are intended to reduce noise from the fan and duct system.

A sequence was added to the Version 2.0 controls to allow the slab to be cooled by night air. This mode has yet to be activated because the conditions required have simply not occurred. This warrants further study, since pre-cooling the thermal mass of the building at night could reduce overheating the following day. This type of pre-cooling would be useful primarily in the shoulder seasons.

A series of heating and cooling modes were introduced in the Version 2.0 controls. The Eco mode provides heating, but no cooling. The Comfort Override mode switches between heating and cooling automatically. The Vacation mode uses reduced setpoints and does not allow cooling.

A time-of-year lockout was added to the motorized awnings to provide a simpler method to reduce the chance of snow damaging them. There is also little need for them in the winter, when maximizing solar radiation is desired. During an unseasonably warm summer period, it was observed that the awnings operated at night. This was due to the lack of constraint to operate only during the day. The awnings were changed to verify solar radiation via the inverter current before being allowed to operate. A manual mode was also added to allow the occupants the option to manually override the awnings' position.

Changes were made to the control of the auxiliary electric heater inside the heat pump. This heater is intended as an emergency backup, but it was observed to be operating at various times during the winter. This was discovered to be due to the control sequence that defined one of the emergency cases as whenever the room air temperature was four degrees below the setpoint. This was intended to mean that the compressors were malfunctioning or that a window was left open, however, it also occurred regularly in the mornings. The overnight setpoint was 18 °C and the morning setpoint was 22.5 °C, so each morning the auxiliary heater would interpret the change in setpoint as an emergency. To correct this, the four degrees is temporarily changed to six degrees each morning and reverts to four degrees two hours after the heating system first operates.

A problem with condensation was observed in the winter of 2009/2010, when ice and water was discovered in the attic. This is likely due to problems with damper control, which allows warm air rising from the house to reach the attic via the BIPV/T duct system. This issue is being corrected as of the writing of this thesis.

The BIPV/T system is able to provide warm air to the dryer to offset its energy consumption. However, for practical reasons encountered during construction, the duct branch that feeds the dryer was placed before the BIPV/T fan instead of after as the design specified. A booster fan draws air from the main BIPV/T duct system into the dryer, but this fan is much smaller than the BIPV/T fan so there was some concern that there would be flow backwards through this fan if the BIPV/T fan operated at the same time. Before this was tested, the control sequence prevented the two fans from operating at the same time. Tests were performed on site in August of 2010 and no backwards flow was observed, so the control sequence was adjusted to allow the two fans to run simultaneously. Significantly more warm air was delivered to the dryer with both fans running. In fact, almost no warm air was able to be drawn from the roof by the dryer booster fan alone.

4 MEASURED DATA

This section describes the available, measured data, how it was gathered, the problems encountered and the corrections made. Sources of error are also discussed. As discussed in Section 2 - Literature Review, few buildings have field data as comprehensive as ÉcoTerra. Various other projects have focused on one or more specific systems, but very few give an overall picture of the energy performance of the house as a system. Large scale monitoring allows effects to be observed which may not be visible if a narrow monitoring scheme was used.

4.1 Monitoring System

The monitoring system was created to meet the needs of the three parties involved in its design – The Solar Buildings Research Network (SBRN) based at Concordia University, HydroQuébec and CMHC. The BIPV/T system and room air temperatures are monitored by SBRN in order to judge the energy performance of the BIPV/T system and the thermal comfort of the house. The heatpump and other mechanical systems are monitored by HydroQuébec to judge their performance, and spot measurements are taken by CMHC. The PV system is also monitored by SBRN to track its performance.

A large amount of data is being collected at ÉcoTerra on an ongoing basis. Over 150 sensors monitor temperatures, energy consumption and outdoor conditions (Chen, 2009). SBRN has a large number of temperature, pressure and solar radiation sensors. These values are recorded as three-minute averages by several Agilent data acquisition systems. SBRN is also responsible for collecting the data recorded by the Fronius data logger attached to the PV system. This data is recorded every 15 minutes as 15-minute averages.

The SBRN and Fronius data is logged by a laptop computer. HydroQuébec monitors power, current and temperature values for major equipment. Their data is sampled every 20 seconds and recorded as two-minute averages (Chen, 2009). CMHC collects some data as well, but it is typically spot measurements or short-term logging on specific equipment. A list of some important measured values and their uses is shown in Table 4.1 and a system schematic is shown in Figure 4.1.

Table 4.1: Summary of important measured values

Value Measured:	Used for Calculation of:
Roof Inlet/Outlet Air Temperatures	Energy Collected
Fan/Pump Amperage	Air/Water Flow Rate
Preheat Tank Inlet/Outlet Water Temperatures	Energy Stored
Slab Inlet/Outlet Air Temperatures	Energy Stored
Air/Water Heat Exchanger Inlet/Outlet Water and Air Temperatures	Heat Transfered
Inverter AC/DC Input and Output	Energy Generated
Heat Pump Compressor/Fan/Pump	Energy Consumption
Ground Loop Inlet/Outlet Brine Temperatures	Heat Pump Performance
Supply/Return Air Temperatures	Energy Delivered to Space
Solar Radiation	Energy Input to System
Room Air Temperatures	Thermal Comfort

All of the above-mentioned data, except for the CMHC data, is collected and stored in a common, central database. This database is accessed via SQL queries entered into a web-based interface. The database performs linear interpolation on the data before it is output due to the different sampling intervals of the data sources. All data used in this thesis is from this database and is therefore interpolated to one-minute intervals. This interpolation preserves the original data, however, and some calculations performed later in this thesis take into account whether a given data point is genuine or interpolated.

The result of this data collection and interpolation is a large data set. Since the new controls were installed, 525,600 minutes worth of data has been collected. For each minute, there is data for over 150 sensors. This means approximately 78.8 million data points are available for analysis. The scale of the available data required a programmatic approach. Excel was not an option due to the large amount of data – it became slow and unusable. MATLAB was an acceptable candidate, but the open source programming language Python (Python Software Foundation, 2010) was selected for its open nature, strong community support, flexibility, and mature scientific and data analysis libraries. All scripts written for this thesis were written in Python version 2.6 and are included in Appendix B - Python Scripts.

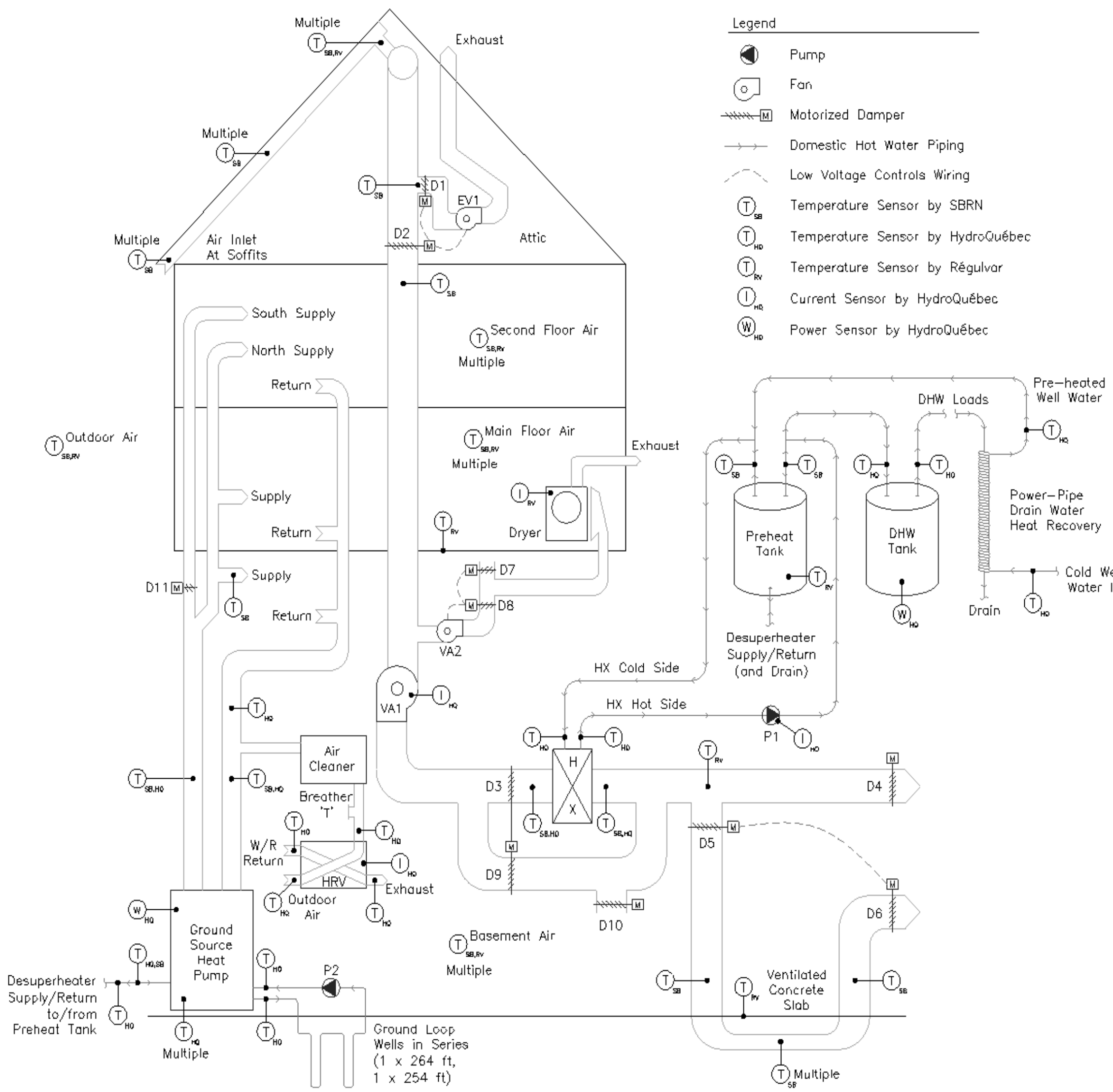

Figure 4.1: Detailed system schematic for ÉcoTerra

4.2 Data Quality

As with any field setup, data quality can be a challenge. The data acquisition systems are powered by the home itself and require a working Internet connection to function. On several occasions, power outages or network problems caused losses of data. Uninterruptible power supplies are attached to all monitoring equipment, but some power outages were longer than the batteries were able to last. Very few gaps are present in the data for the period over which the majority of the analyses in this thesis are performed. Approximately 0.23%, 8.78% and 0.23% of the data is missing from the HydroQuébec, SBRN and inverter data, respectively, between December 10, 2009 and December 9, 2010. The SBRN data has a significantly higher percentage due to several outages caused by various hardware and software failures.

These gaps are corrected for as much as possible. If the gaps were small and part of a continuous data stream (as opposed to discrete events), it was filled in using linear interpolation. This creates obvious disjoints in a few cases, but those data fields are not required for significant analysis during those periods. Data such as the outdoor air temperature and solar radiation are monitored by several sources, so when gaps exist in one source, data from the other is used instead. The alternate data sources have a lower sampling rate, resulting in a loss of resolution, but this is preferable to a complete lack of data in these areas.

Other data fields, such as the heat pump power consumption, are composed of discrete events. The gaps in this type of data were filled in using zeros. Most gaps occurred when no equipment was running, so this introduces little error. Also, gaps in this type of data, which is primarily from HydroQuébec and the inverter, account for very little of the total missing data.

As mentioned in the introduction, the house was purchased in August of 2009. At this time, several issues were discovered with the control system, and new programming was installed on December 10, 2009. This date represents the beginning of “usable” data. Some analysis, such as PV generation, can be performed for previous periods, but any occupant-related data, or data relating to the heating system, uses data only from after December 10, 2009.

Another significant issue is related to the fact that there are three different data collection devices (laptop, inverter data logger and HydroQuébec's data logging computer). Each of these systems has an independently set clock. This led to some data being slightly ahead or slightly behind other data. This needed to be corrected before an accurate analysis could be performed.

The differences in clocks does not create issues when calculations are performed using data from a single source as all data from a given source is assumed to be synchronized with itself. However, when using SBRN data as a reference for HydroQuébec data, or vice-versa, the synchronization of time-stamps introduces error. Some calculations were improved by as much as 13.7% after synchronization corrections were applied.

The challenge was that HydroQuébec data was not always offset by the same amount. Some periods of data were shifted forward by approximately 22 minutes, while other periods were shifted back by as much as 45 minutes. This problem was resolved by creating a script that individually synchronized each 24-hour period of data. This could have resulted in discontinuities between days of data. Fortunately, the only data that needed to be synchronized is made-up of discrete events in the middle of the day (daylight hours) with zeros in between. One example is the operation of the BIPV/T fan, which occurs only during sunny days.

The synchronization of time-stamps was achieved by finding a common point of data from each source and calculating the difference in time between them. One data source was then shifted to be aligned with the other. For the purposes of this thesis, the SBRN data is assumed to be the “correct” time, as all SBRN data uses a time-stamp synchronized via Internet time server.

The pressure drop across the roof manifold and the operation of the BIPV/T fan were the two data columns used to synchronize SBRN and HydroQuébec data. These two values are directly linked by cause and effect because the pressure drop varies very little other than when the fan is in operation. If the two data sources were perfectly synchronized, one would expect the pressure drop to change immediately or within only a few minutes of the fan being powered on. The actual data shows, however, that the pressure can spike sometimes as much as 22 minutes *before* the fan is powered on.

A programmatic approach was required in order to synchronize the large amount of data. The pressure drop and fan power were ideal for this application as they exhibit very specific, predictable and pronounced patterns that were easily identifiable by the created program. Figure 4.2 shows an example of the offset between data sources and the points that were identified in order to synchronize them.

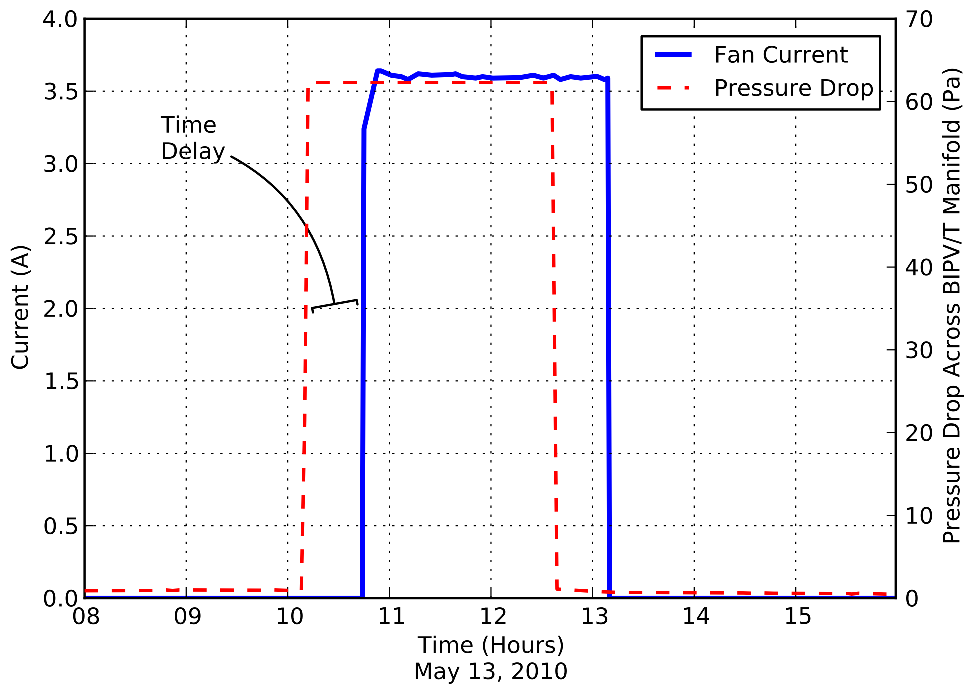

Figure 4.2: Sample of time synchronization correction

Another data quality issue was discovered in late June of 2010. The raw HydroQuébec data is sampled every 20 seconds and recorded as two-minute averages, but when data was retrieved from the database, it appeared to have been recorded at varying intervals from 2 to 6 minutes. This was discovered to be an unintended consequence of a filter added to the database to drop erroneous data. As much as 62% of valid HydroQuébec data was dropped upon import to the database and the gaps were filled using linear interpolation. This resulted in a significant loss of resolution in the data. This issue was corrected, however, and all available data was used in the calculations performed for this thesis.

4.3 Sources of Error

Several significant sources of error are discussed in this section. They include the correlations used for the BIPV/T fan flow rate, the heat pump air-flow rates, the measurements themselves, data time-stamp synchronization and the measurement of incoming solar radiation.

4.3.1 Air Flow Rates

An important variable is the volumetric air flow rate through the BIPV/T system. This flow rate allows the mass flow rate to be determined, which is needed throughout the analysis. The flow rate through the BIPV/T fan is not monitored directly, though; instead, the amperage to the fan is monitored. A correlation was developed using data gathered by previous students to relate measured fan amperage to volumetric flow rate. The students' experiment involved setting the fan to various speeds, then measuring the flow rate and amperage for each speed. A series of data points was created this way. The author of this thesis then plotted and fit a curve to this data for the purposes of this thesis. The equation for this curve is used throughout the thesis as a way to estimate volumetric flow in the BIPV/T system.

Several correlations are needed, because the system can operate in several modes. Each mode directs the air along a different path through the duct system resulting in different pressure losses. The modes are described in general in Section 3 - Control System and in more detail in Appendix D - Detailed Control Sequences. The correlations are listed below as Equations 4.1, 4.2 and 4.3.

$$\textit{DHW Mode:} \quad \dot{Q} = 97.131 \cdot I^{1.337} \tag{4.1}$$

$$\textit{Slab Mode:} \quad \dot{Q} = 96.195 \cdot I^{1.0979} \tag{4.2}$$

$$\textit{Slab and DHW:} \quad \dot{Q} = 101.11 \cdot I^{1.0849} \tag{4.3}$$

Where $\dot{Q}$ is the volumetric flow rate of air through the system in cubic feet per minute and I is the BIPV/T fan current in amps. The R^2 values for each are 0.995, 0.997 and 0.998, respectively. See Appendix C - Correlations for details regarding these correlations.

Several issues with the air flow-rate correlations reduce their accuracy. One is that all of the measurements were taken shortly after starting the fan. This means that the air coming from the roof did not have time to reach it's normal temperature. The ducts at the bottom of the system would be cool and the air at the top, hot. This affects the density of the air and, therefore, the flow rate, especially since there are significant vertical distances present in the duct system (leading to a stack effect). The wind and interior temperature/pressure will also affect the system pressure, and therefore flow rate. Also, the temperature of the air varies naturally with the wind speed and strength of the sun, so the density of the air will change with these factors as well. Another source of error is the flow measurements themselves – the calibration and usage techniques of the balometer will affect the accuracy of the correlations. Some thermal mass is present in the metal ductwork, which would delay the heating of the air and therefor its density. None of the above-mentioned factors are taken into account in the flow rate correlations and the only factor that is quantified is the accuracy of the measurement equipment. The balometer has an accuracy of ± 3% of the reading plus ± 7 cfm.

Various incidental changes in the house will also affect the accuracy of the correlation as the measurements were taken under controlled conditions. The house is now occupied, so at any given moment there may be changes in pressure, temperature, etc., relating to occupant activities such as showers, cooking, and opening windows and doors.

The system operating mode also introduces error since the ten dampers can be in several positions. The four primary operating modes were tested and individual correlations developed for each, but determining which mode is being used can be problematic. The amperage of the DHW preheat tank circulation pump is used to determine system operating mode. The timestamps on the data relating to the circulation pump is often shifted forward or backward in time, making it difficult to choose an appropriate system operating mode. This time synchronization issue was corrected for as much as possible as is discussed later in this section. Software has recently been installed at ÉcoTerra that will allow direct recording of changes in system operating mode.

The heat pump air flow rate is also estimated. The factory defaults are 590 L/s (1,250 cfm), but it is unknown how closely these values match the actual flow rates. The static pressure in the heat pump duct system has not been measured. Some calculations involve using the heat pump volumetric flow rate to calculate the air mass flow rate. Uncertainty in the volumetric flow rate introduces significant error into any calculations that use it. Fortunately, the air balance is only one part of the heat pump analysis and the water-side balance can be used as a comparison. All necessary variables are monitored directly on the water-side, including the flow rate of the ground loop.

4.3.2 Synchronization and Pattern Matching

Three sources of data are used for the analysis in this report: SBRN data, HydroQuébec data and inverter data. The timestamps on the various data sources do not match. This means that some events appear to happen out of sequence. An effort was made to find the offset between the sources and then shift the data to synchronize them. This correction is described in Section 4.2 - Data Quality. While significant improvement resulted from this correction (some calculations improved by 13.7%), some error results from using the correction as well, so even the re-synchronized data is not perfect.

Pattern matching algorithms were used to filter the garage heater from the other data. The only way to verify this algorithm is by visual inspection. This was done for the period of February 10 to March 9, 2010 and the estimated error was ±2.2%.

4.3.3 Interpolation

All data used in this thesis comes from the central database in which all data for the project is collected. The various data sources use different sampling rates, so the database interpolates its outputs to one-minute intervals in order to provide a common output. This interpolation leads to error in some cases.

An example of error caused by interpolation is seen in Figure 4.3. It is required, during the analysis, to view a filtered version of the net house power consumption data with other known loads removed. If the interpolated domestic hot water energy use is simply subtracted from the net, overall power data, some interpolated data points are left over leading to an over-estimation of energy consumption. This effect is mitigated in this thesis by using only genuine, non-interpolated data when necessary and then re-interpolating to the common one-minute interval.

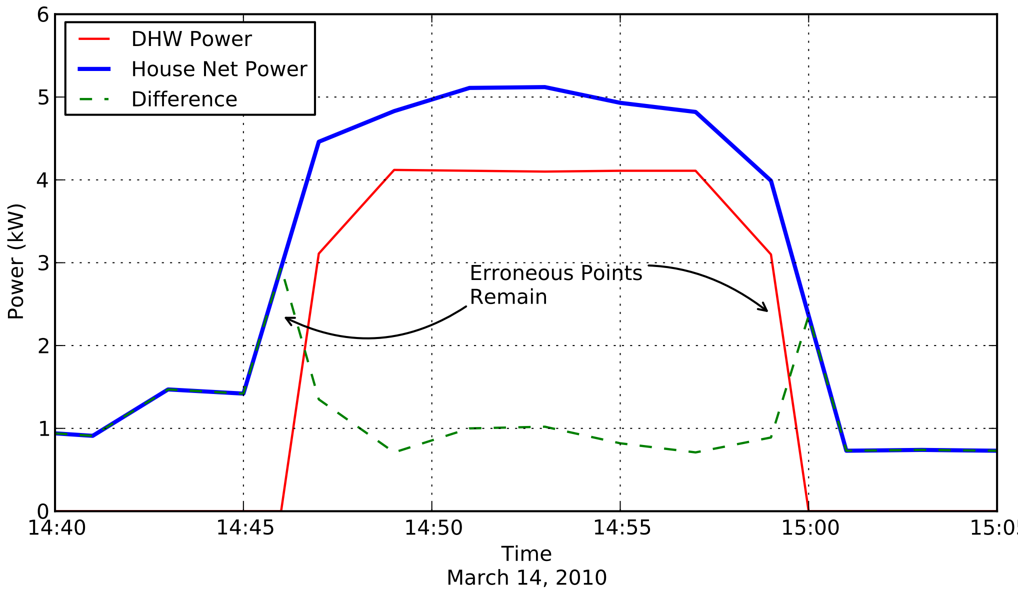

Figure 4.3: Error due to interpolation of DHW data

4.3.4 Measurement and Error Propagation

The temperatures used to determine energy stored are measured at single points in the ducts. This will introduce error since the air stream may or may not be uniform. The thermocouples themselves also have an error of approximately ±0.5 °C.

The measurement of solar radiation also has some error due to the sensor used. The manner in which the radiation value is used also introduces some error. The data measured is a point measurement of the intensity of solar radiation (W/m2). This value is then extrapolated, assuming that the entire roof receives exactly the same radiation at exactly the same time. This, however, is not always the case. Sometimes the sensor will be shaded while the roof is not and vice-versa. The various sensors and measurement devices used each have an associated error. Table 4.2 summarizes some of these accuracies.

Table 4.2: Measurement devices and their accuracies

Value	Accuracy
Type T Thermocouples	±0.5 °C
Pyranometers	± 5.0% of reading
Pressure sensors	± 0.5% of reading
Amp Meters	±0.05% of reading + 0.06
Voltage meters	± 0.1% of reading + 0.0002
Balometer (volumetric flow meter)	± 3.0% of the reading plus ± 7

The overall absolute error was analyzed as described in (Andraos, 1996). The paper describes a generalized approach to error propagation and provides an equation that represents the overall absolute error of a calculation. This equation is seen in Equation 4.4, where Δf is the overall, absolute error associated with the function f, n is the number of variables in the equation and x_i is a given variable in the function.

$$\Delta f = \pm\sqrt{\sum_{i=1}^{n}\left(\frac{\partial f}{\partial x_i}\right)^2 \cdot \left(\Delta x_i\right)^2} \quad (4.4)$$

Error propagation was applied to several of the primary calculations in this thesis and the absolute error can be found along side the results in their respective chapters.

4.4 Potential Improvements

Various lessons can be learned from the issues encountered during the data monitoring and subsequent analysis. Several issues resulted, such as the lack of synchronization between the clocks for the different data sources, the mis-match between those monitoring specific data and those who require the data, and less-than-ideal uptime for the SBRN data monitoring system.

A standard laptop was used as the data collection device for the SBRN system. The laptop had previously been used as a user's laptop and so had significant software which was unrelated to data monitoring. If a laptop is used in the future, it is recommended that it be wiped clean of all inessential software to minimize any interference during the monitoring period.

It is also recommended that, during the planning stages of future monitoring systems, focused, unified and detailed plans be made regarding the types of data that will be monitored and the goals behind the monitoring. The plans should be a collaborative effort between all parties interested in the data. This will allow for the efficient use of resources and simplify data collection, analysis and maintenance of the monitoring system. A key objective of this plan should be to reduce the number of monitoring systems (preferably, there would be only one system) and/or synchronize all systems to a common clock. This common clock should be synchronized using an Internet time server. All systems should also use a common sampling frequency if at all feasible. This will negate the need for interpolation of data to a common frequency during analysis.

Aside from the planning and design of the system, certain types of data should be more closely monitored. The following are areas that could improve future monitoring of net-zero or low-energy houses:

- *All* major equipment such as the auxiliary electric heaters, preheat tank elements, air cleaners and additional heaters (such as the garage heater) should be monitored so that their energy consumption is does not have to be calculated or estimated.
- Kitchen-related circuit breakers should be monitored. Monitoring the small number of breakers that serve the kitchen is trivial and would provide valuable information about appliance use. A more detailed, but expensive, option would be to monitor each major appliance individually.

- Any flows that can feasibly be monitored should be. The DHW, desuperheater, drain water, BIPV/T system, heat pump, etc. should have their air or water flows monitored directly. Using correlations or other estimates reduces accuracy.
- Analyses such as Fourier analysis or end-use deaggregation could benefit from a greater sampling rate than two minute averages for power data. This should be examined to see if it is useful or necessary for the given case.

5 ENERGY ANALYSIS

This section describes the methods, process and results of a detailed, whole-building energy analysis performed on the monitored data from ÉcoTerra house. An energy end-use breakdown is presented; the heat pump, BIPV/T and domestic hot water system performances are analyzed; and the results are compared to the modelled values. Figure 5.1 shows a schematic of the energy flows at ÉcoTerra.

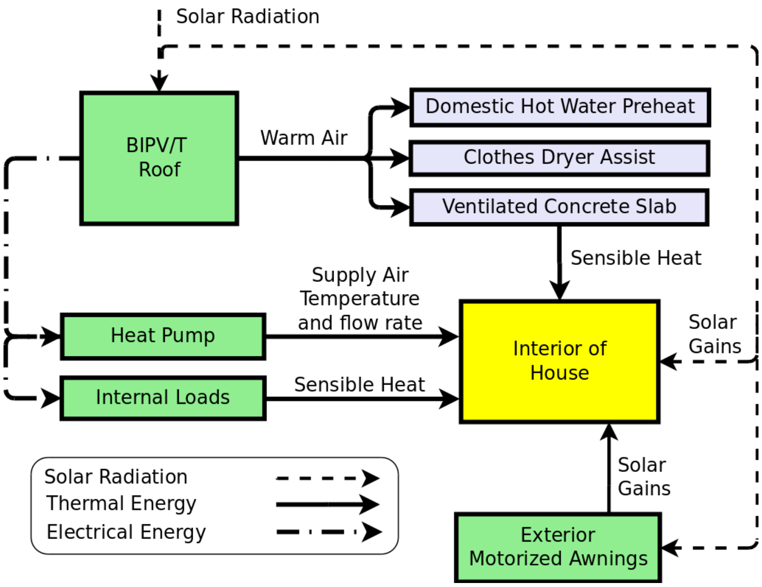

Figure 5.1: System energy flow schematic

5.1 Annual Energy Consumption

ÉcoTerra has been monitored since its construction. Over 150 sensors are installed throughout the house monitoring temperatures, energy consumption, solar radiation, etc. The data is collected automatically and stored in a central database from which it is queried for the various, ongoing analyses being performed on the house. The data set includes both occupied and unoccupied periods. For the purposes of this thesis, only the occupied data was examined. Section 4 - Measured Data provides more detail about the collection and preparation of the required data.

As of the writing of this thesis, there are twelve full months of valid data available for analysis of the occupied house: from December 10, 2009 through December 9, 2010, inclusive. Values before December 10, 2009 exist, but a new control system was installed on this date, so data before that is not considered for energy consumption analysis. Figure 5.2 shows a comparison between ÉcoTerra's annual energy consumption and that of typical single-family detached homes in Canada (NRCan, 2008a) (NRCan, 2008b).

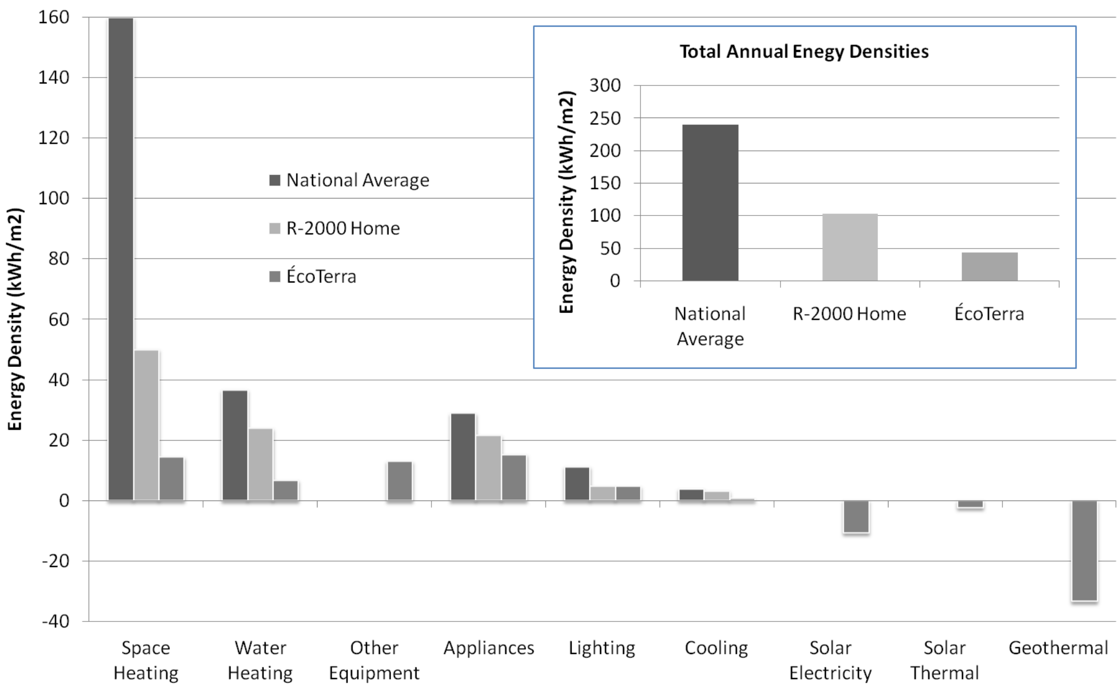

Figure 5.2: Comparison of ÉcoTerra with typical Canadian homes

Although ÉcoTerra did not reach net-zero energy consumption, it consumes only 26.8% of the energy of a typical Canadian home and had an energy density of only 18.1% of the national average. Significant differences exist between each category of energy use as seen in Figure 5.2. The largest difference is that of the space heating consumption. ÉcoTerra uses only 8.9% of the heating energy per unit area of a typical Canadian home. This is primarily due to the significant effort put into the passive solar design of the house, but is also due to the contribution of the ground source heat pump and thermal energy collected by the roof. The domestic hot water energy use at ÉcoTerra is also much lower. The heat pump desuperheater, the drain-water heat recovery and the solar thermal collection all contribute to this. The least differences exist in the lighting and appliance use. This is because similar lighting technology is used to an R-2000 home and many appliances today are already EnergyStar rated or better.

Figure 5.3 shows the monthly energy use pattern at ÉcoTerra. The house shows the typical seasonal pattern for a Canadian home, with highest energy use in the winter due to heating loads. The energy use from April through August is relatively constant. This energy is the house's base load (mostly non-seasonal loads such as hot water and appliance use).

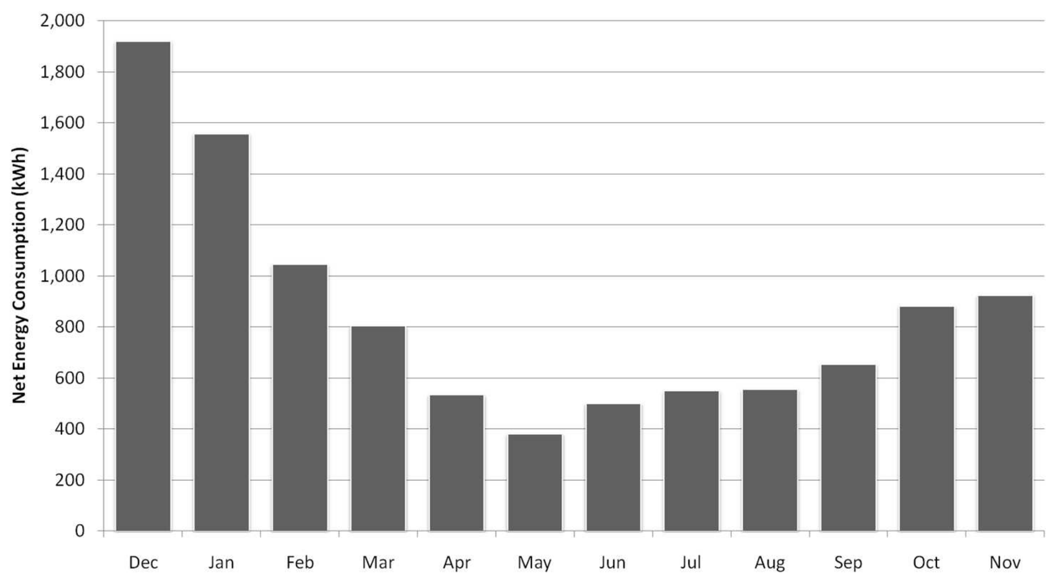

Figure 5.3: Overall annual energy use by month

The following sections examine a more detailed breakdown of energy use to better understand the house and to help determine potential improvements.

5.2 Energy End-use Breakdown

Understanding the energy consumption patterns of a building requires identifying how the energy is used. This section describes the end-use analysis performed on ÉcoTerra, how each end-use was identified, and the information that can be gained from this breakdown.

5.2.1 Load Identification

Although significant data is available, not all loads are monitored directly, leaving some values to be calculated or extracted from other data. Any analysis in this thesis relating to energy consumption uses HydroQuébec data along with calculations and on-site measurements. Relevant loads and specifications are summarized in Table 5.1.

Table 5.1: Monitored and calculated loads and specifications

Value	Equipment Specifications	Monitored or Calculated	Source
Heat Pump (fan, compressor, brine pump)	GeoSmart GT038, 38MBH (11.1 kW)	Monitored	HydroQuébec
Heat Pump While in Recirculation Mode		Calculated	Author
Heat Recovery Ventilator	Lifebreath 155ECM, 70 L/s	Monitored	HydroQuébec
Air Cleaner	Lifebreath TFP3000HEPA, 70 L/s	Calculated	Author
DHW Tank	Giant 172ETE-3F5M, 240 L	Monitored	HydroQuébec
DHW Preheat Tank	Giant 172ETE-3F5M, 240 L	Calculated	Author
BIPV/T Fan	Fantech FKD-12, 365 L/s	Monitored	HydroQuébec
DHW Heat Exchanger Pump	Taco 006-BT4, 12 W	Monitored	HydroQuébec
PV Generation	21 x Uni-Solar PVL-136, 2.8 kW peak	Monitored	Inverter
PV Exported	-	Calculated	Author
PV Consumed in House	-	Calculated	Author
Net Metered Power	-	Monitored	HydroQuébec
Lighting, Appliances, Plug Load	-	Calculated	Author
Equipment (Controls, Monitoring, Alarm, Etc)	-	Calculated	Author
Heat Pump Auxiliary Electric Heat	9.6 kW	Calculated	Author
Supplementary Garage Heater	5.0 kW	Calculated	Author

While many of the large loads are monitored, calculations had to be performed to estimate the consumption of certain equipment. The heat pump, for example, is monitored only while the compressor is running. Changes were made to the control system, however, which allowed the heat pump to run in fan-only mode as well. This consumption is not monitored. The heat recovery ventilator (HRV) is monitored, but the air cleaner is not. The air-cleaner is, however, interlocked with the HRV so its runtime is known. An on-site measurement of the air-cleaner's power consumption was then used to judge its consumption. The domestic hot water preheat tank has an electric coil that is used to heat the tank once a month in order to kill bacteria. This coil is not monitored, but an estimate of its use was made using the known volume of the tank and the temperature setpoint. The net metered power and total photovoltaic generation are monitored, so from these the gross consumption, consumed photovoltaic and exported photovoltaic energy can be calculated. The lighting, appliances, plug loads, auxiliary heater or garage heater are not monitored.

Some of the monitored data is recorded as electrical current in amps. Energy consumption is the desired purpose, so these values are converted to watts assuming a constant 115 Volts and 0.85 power factor (Laughton and Warne, 2003).

The net metered power includes all energy consumption and production in the house, so it serves as the starting point to get a complete picture of the end-use breakdown. In this data, positive values are kilowatts of power use and negative values are kilowatts of power export. The data sampling rate of the photovoltaic production is significantly lower (every 15 minutes) than the data sampling rate of the net power use (every two minutes).

This introduces some error when analyzing gross energy consumption of the house, which is most often what is required.

Custom scripts were written to perform the load identification calculations because of the large amount of data involved. The scripts were written in the Python programming language and are included in Appendix B - Python Scripts. The load identification algorithm involves the following steps, each of which is described in detail later:

1. Importation and cleaning of data and filling of gaps/invalid values
2. Synchronization of data timestamps.
3. Subtracting known loads from net metered power.
4. Adding photovoltaic production to net metered power to get gross power.
5. Searching for and removing manually-located auxiliary heater peaks.
6. Searching for and removing garage heater peaks, located programmatically.

The first step involves loading the required data into the script and checking for missing timestamps. If there are any gaps in the data, these gaps are filled with either linearly-interpolated values from the surrounding data or from alternate data sources. The outdoor air temperature, for example, is recorded by both SBRN and the inverter, so if SBRN data is missing, the inverter data (with longer sampling rate) is used to fill in the gaps.

The second step is the synchronization of data as discussed previously. Most of the data used for the energy end-use analysis is from a single source (HydroQuébec), but the photovoltaic production data is also an important component and this data is out-of-sync. The photovoltaic data is synchronized in the same manner. This process is described in Section 4.2 - Data Quality.

The next step is to filter the known, monitored loads from the net metered data. This is done by simply subtracting them from the net metered data. The photovoltaic generation is considered negative, so it is added to the net data. This is not as simple as it seems, however. The data used for this analysis is interpolated to a common interval of one minute. When various monitored loads are interpolated individually and then subtracted from each other, the interpolation introduces error. Therefore, only genuine, non-interpolated data is used during this filtering process. Once this is finished, the data is re-interpolated to one-minute intervals for the remaining analysis.

What remains is a set of data that includes the lighting, appliances, plug loads, auxiliary heater and garage heater. The two heaters need to be filtered next, but these are a challenge since they are not monitored. Fortunately, the garage heater has a distinctive energy use pattern, so a pattern-matching algorithm was created to identify and filter this load. The script identifies the start and end points for each garage heater event, based on the sudden change in power use of a specific size, and then saves all data points between them. The data within the garage heater event are reduced in value by the rated power of the garage heater (5 kW).

The auxiliary electric heater in the heat pump has a load pattern that is easily identifiable visually, but proved to be difficult to identify programmatically. There were only five to ten peaks resulting from the auxiliary heater, so these peaks were identified manually (visually) and the script was programmed to filter and save the specified data ranges. All data in these ranges is reduced in value by the rated power consumption of the auxiliary heater (9.6 kW). Figure 5.4 shows the result of the garage and auxiliary heater energy consumption filtering.

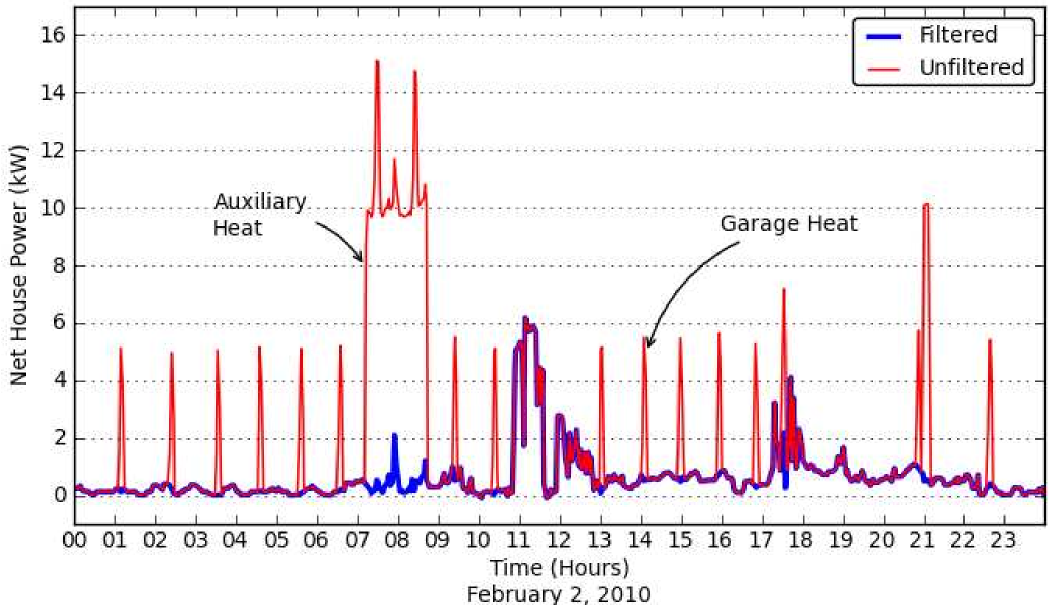

Figure 5.4: Sample of peak identification for garage and auxiliary heaters

Gaps exist in the data due to downtime of the monitoring system, so a correction is needed to account for this missing data. It is assumed that the average baseload consumption continues for those times when there is no information about the energy consumption of the house. This "gap correction" is calculated by finding the average of the estimated lighting and plug load power data and then adding the known or estimated baseload equipment such as the air cleaner, the alarm system, and the heat pump fan in recirculation mode.

The house's monitoring system consumes approximately 1,864 kWh annually. This consumption was removed from the load analysis and the heat pump energy consumption was adjusted accordingly. This adjustment is necessary to account for the extra energy that it would have had to deliver had the monitoring system not been present. In the summer, the heat pump energy consumption was reduced by an equivalent amount, as the heat pump would consume less energy without the extra heat. This value was calculated assuming that the entire energy consumed by the monitoring system was delivered directly to the house and by using the COP of the heat pump, at each data point, as calculated later in this thesis.

Another correction that was applied to the energy consumption data involves a 500 Watt load that, as of the writing of this thesis, has not been identified. The "mystery" load began operating in mid-summer and has been running continuously, regardless of any other building systems, since then. This load is not attributable to any of the monitored energy consumptions. This load was removed from the energy analysis because it is not part of the typical energy use pattern of the house. No new equipment was added and no changes were made to how existing equipment is controlled. Once identified, this load will be turned off and should not be present in future energy consumption data.

The power data remaining after these corrections, and the filtering of known loads, is made up of only the lighting, appliance and plug loads. An example of broken-down data is shown in Figure 5.5.

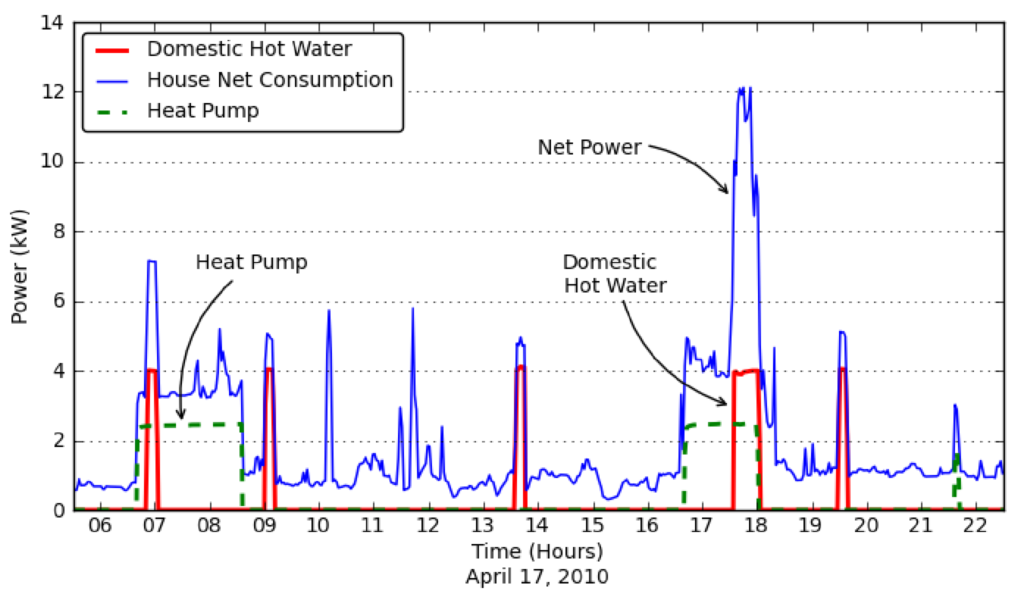

Figure 5.5: Sample of power data broken down into end-uses

5.2.2 Fourier Analysis

The garage heater accounts for significant energy use and no pattern matching algorithm could be perfect. Fourier analysis was investigated as an alternate method to locate the garage heater events and other loads. Fourier transformations translate functions based in the time domain to functions in the frequency domain. This allows easier observation of periodic, cyclical patterns in data (Stein and Shakarchi, 2003). The method used for this thesis is the fast Fourier transform function built into the the Python programming language's NumPy numerical mathematics library. It is an implementation of a discrete Fourier transform algorithm based on the work of (Cooley et al., 1969).

A comparison of two periods of net power data and their Fourier transforms are seen in Figures 5.6 and 5.7. A strong steady state frequency component can be seen in both periods. This indicates a strong baseload contribution to the energy profile – that is a constant, always-on component. The day of December 17, 2009 was examined in Figure 5.6 as a short duration case. The Fourier transform of this day shows a weak response at 37 cycles per day. This corresponds to the number of garage heater peaks observed in the original data.

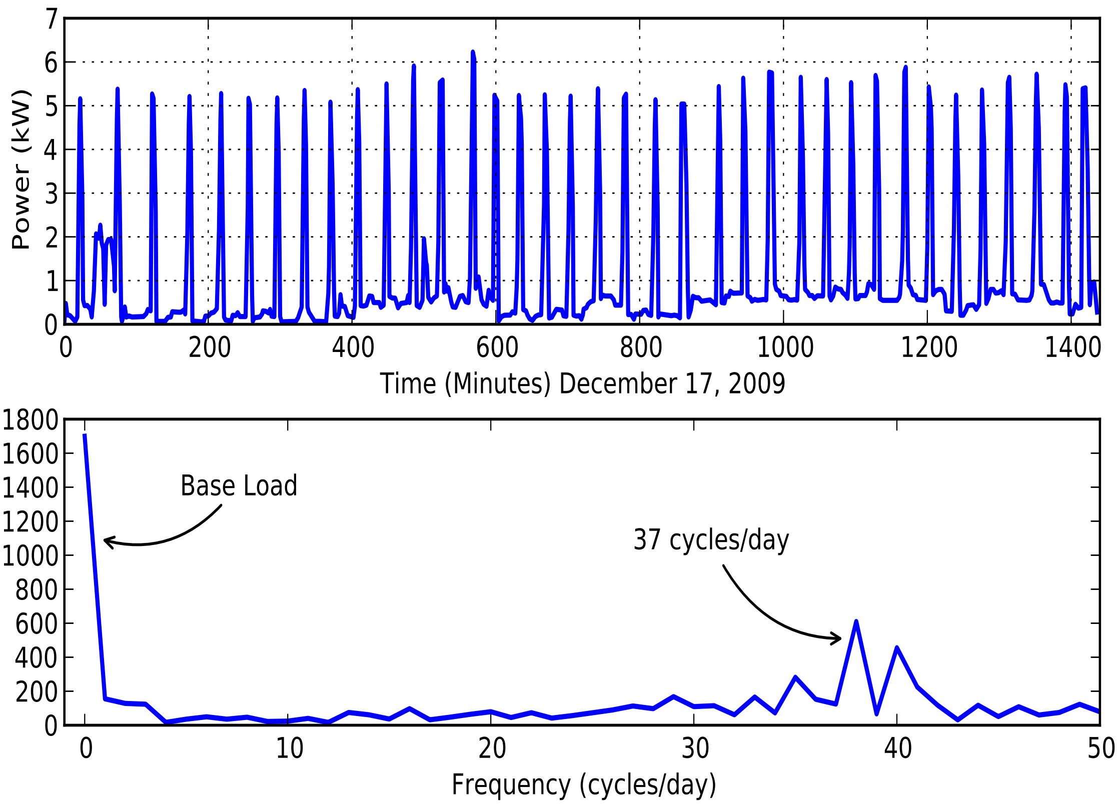

Figure 5.6: Fourier analysis of net power data – short term

When a slightly longer period is examined, such as the five day period of January 1 to 5, 2009, in Figure 5.7, the only strong response is a single cycle per day. This one cycle is not related to the garage heater, but simply to the normal pattern of daily energy use (greater during the day than at night). Longer periods of data show a similar one cycle per day, but as the period becomes longer, the patterns more closely resemble those of the solar radiation cycle – one cycle per day during daylight hours.

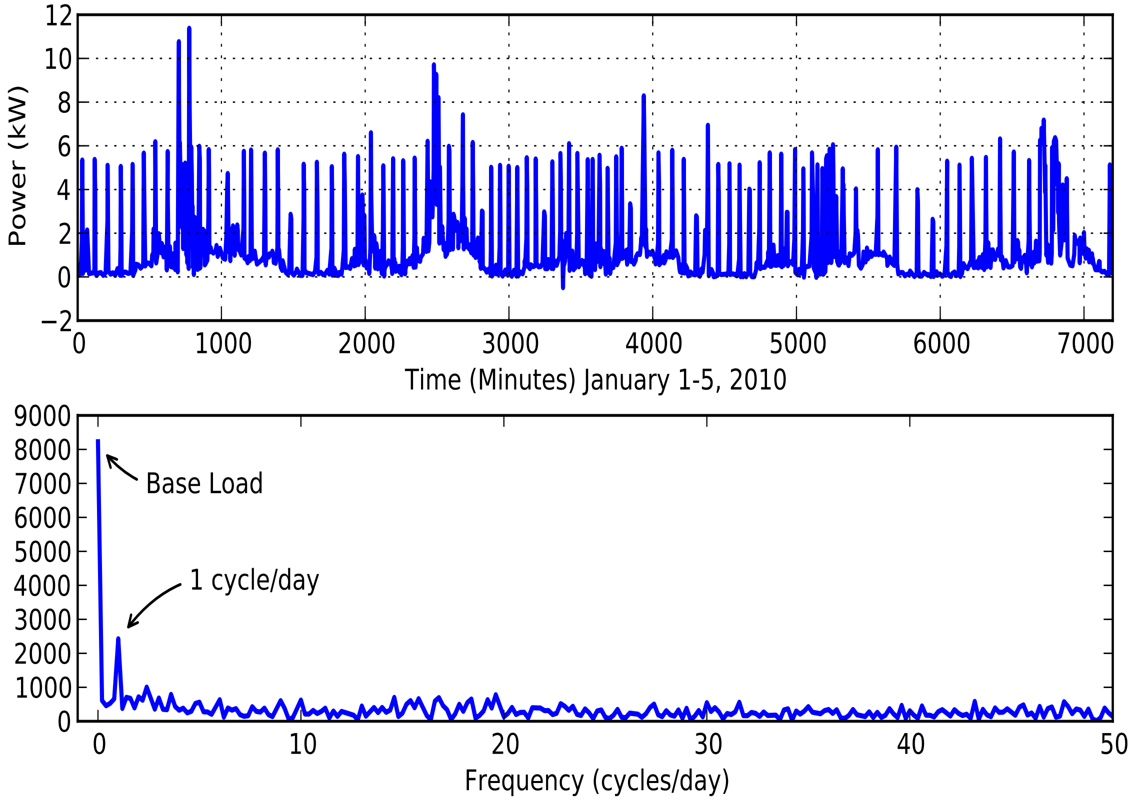

Figure 5.7: Fourier analysis of net power data – long term

The garage heater appears to be very regular upon visual inspection, but the Fourier analysis shows that it is in fact more complicated than it appears. It is likely that other factors affect the cycles per day such as outdoor temperature, solar radiation and occupant use patterns in the garage where the heater is located. The conclusion is that the pattern matching algorithm (discussed in Section 5.2.1 - Load Identification), which matches the shape of the peaks, is the better solution for filtering the garage heater.

A Fourier analysis of the domestic hot water loads was performed as well. Even on a relatively short timescale, Figure 5.8 shows that there was little pattern to the energy consumption. This is likely due to the sporadic use of hot water by the occupants and the interaction of the hot water tank with the preheat tank and BIPV/T system.

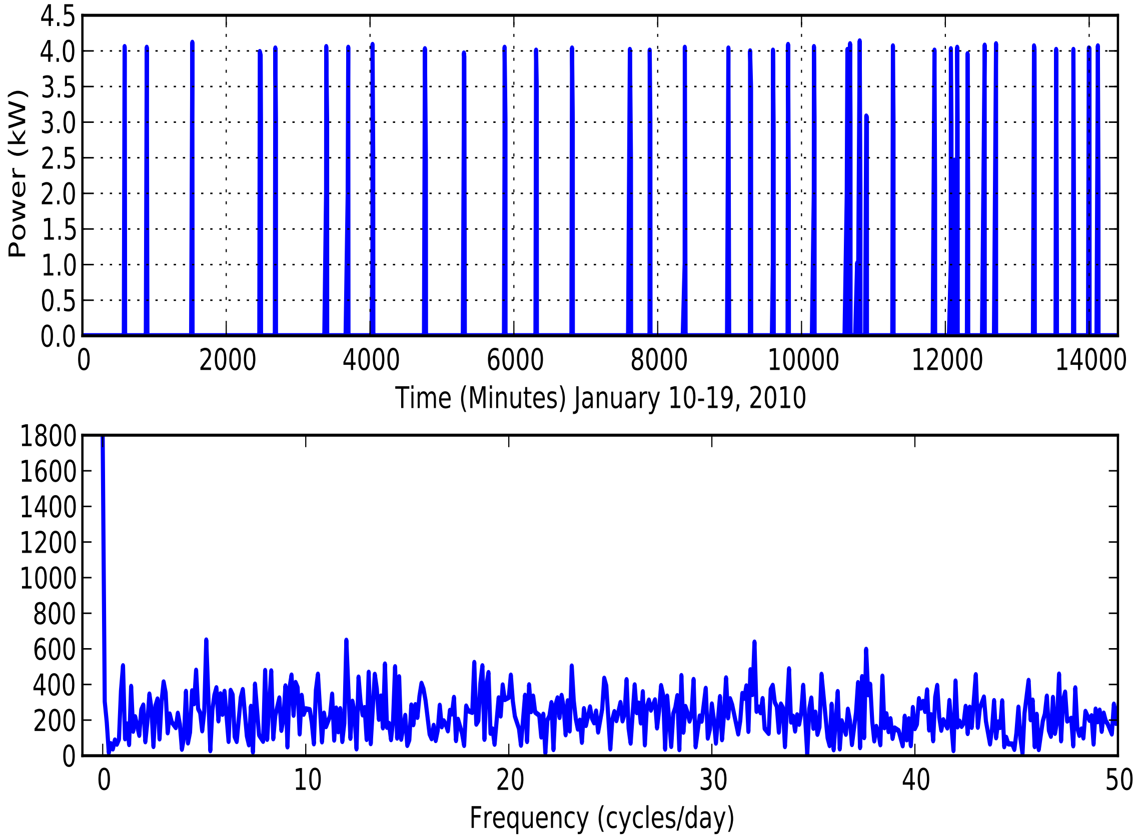

Figure 5.8: Fourier analysis of domestic hot water data

Some other work has been done to “disaggregate” loads from total consumption using pattern matching (Farinaccio and Zmeureanu, 1999). This work, however, requires training of a pattern matching algorithm using load patterns recorded on-site using the actual equipment. This was not done for ÉcoTerra, since the main item requiring filtering has a varied consumption profile between 2 kW and 5 kW at varying cycles, durations, etc. The data used in the mentioned paper is also recorded at very short intervals (16 seconds) whereas HydroQuébec data is composed of two-minute averages. Also, no more detail is required for this thesis than to say that the remaining loads are occupant-based – lighting, appliances and plug loads.

5.2.3 *End-use Breakdown*

The end-use analysis in this thesis uses data from the period of December 10, 2009 to December 9, 2010. Figure 5.9 shows a pie chart form of the energy end-use breakdown for the total twelve month period. Figure 5.10 shows a further breakdown by month. A more detailed table can be found in Appendix E - Detailed Energy End-use Results.

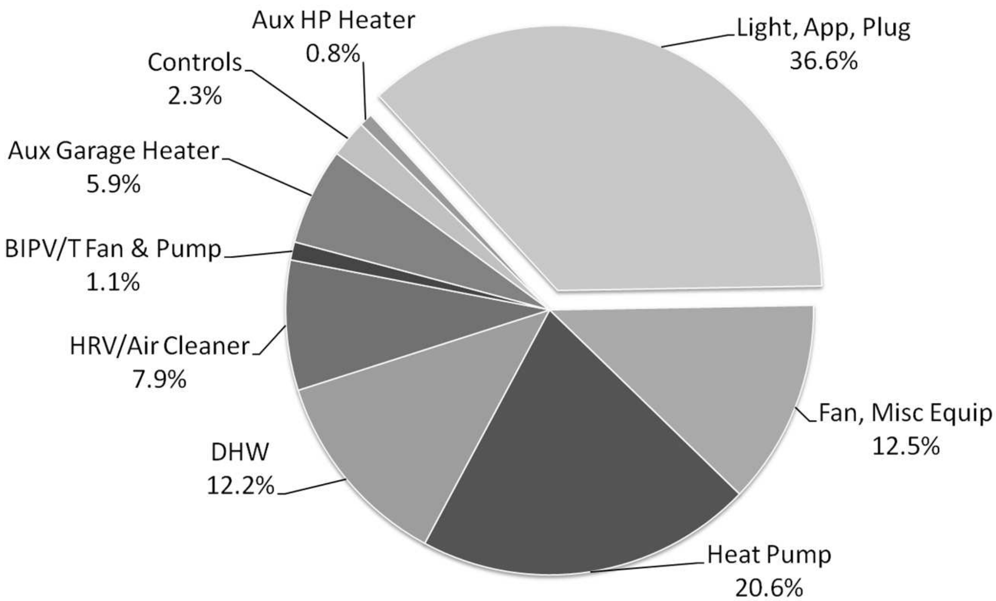

Figure 5.9: ÉcoTerra's annual energy end-use breakdown

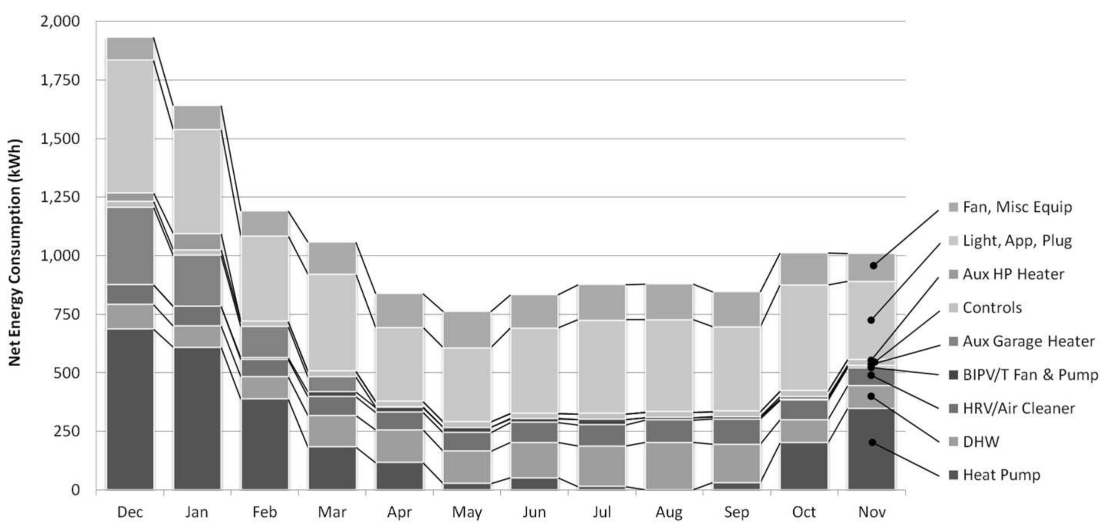

Figure 5.10: ÉcoTerra's Annual energy end-use breakdown by month

For the purposes of this thesis, gross consumption is defined as the sum of the measured net consumption and the PV production. This definition is chosen because it is the definition used in the concept of net-zero energy. Some of the generated electricity is not used, but exported. It is assumed, however, that this exported electricity is of the same value as the electricity used on-site and so “counts” toward reaching net-zero energy.

These figures show a total, gross annual energy consumption of 12,888 kWh and a net consumption of 10,318 kWh. This includes 4,715 kWh of lighting, appliances and plug load; 2,658 kWh for the heat pump; 1,578 kWh for domestic hot water; 1,022 kWh for the HRV/air cleaner; 763 kWh for the garage heater; 104 kWh for the auxiliary electric heater in the heat pump; 142 kWh for the BIPV/T fan and pump; and 1,611 kWh for equipment use, mostly the heat pump fan while in recirculation mode. The PV system offset 2,570 kWh of this consumption. These results are summarized in Table 5.2.

Table 5.2: Summary of annual energy end-use breakdown

End-use	Existing (Kwh)	Neglecting Air Cleaner and Garage Heater (kWh)
Lighitng, Appliances, Plug Loads	4,715	4,715
Heat Pump Recirculation Mode, Misc Equipment	1,611	1,611
Heat Pump	2,658	2,658
Domestic Hot Water	1,578	1,578
HRV/Air Cleaner	1,022	593
BIPV/T Fan and Pump	142	142
Garage Heater (added by owners)	763	0
Controls	294	294
Auxiliary Electric Heater in Heat Pump	104	104
Gross Annual Consumption	12,888	11,696
PV Production	2,570	2,570
Net Annual Consumption	10,318	9,125

The garage heater is a significant and unexpected load (5.9% of the annual energy use). No heat was provided for the garage in the original design. The garage is now used as a workshop, however, so the owners installed an electric fan-coil unit to provide supplementary heat. The significant energy consumption of the heater was noticed during ongoing analysis of the energy use in the house. The owners were informed of this high use and have since reduced the heater's setpoint. It is expected that this garage heater will consume considerably less energy during future winters.

The equipment use is also high. This is due mostly to the heat pump fan in recirculation mode. The heat pump fan consumption is monitored separately while the heat pump is operating in heating or cooling mode, but while in recirculation mode, an estimate was made by examining the baseload power data. The fan was programmed to operate continuously (24/7) in order to reduce stratification in the house. The effectiveness of this strategy is examined briefly in Section 6.7 - Further Reducing Energy Consumption. It is expected that this energy consumption can be reduced since there is almost surely a more optimal control scheme that would balance the energy use of the fan with the reduction in stratification it allows.

The BIPV/T fan and pump consumed relatively little energy. The winter of the year analyzed was cloudy, so there were fewer opportunities for the BIPV/T system to function. Also, the pump did not operate significantly for several months due to a mis-positioned valve in the domestic hot water heat recovery system.

The largest component of the home's energy use is the lighting, appliances and plug loads. This load is entirely occupant-based, so it depends on the habits, lifestyle and day-to-day schedules of the home's owners. The home is equipped with commercially available, but high-efficiency, residential appliances.

The end-use breakdown of a typical Canadian single-family detached home is seen in Figure 5.11 (NRCan, 2008a). The distribution of energy use is significantly different than that seen in Figure 5.9. The heating energy is significantly higher here due to lack of passive solar design. The appliance loads in the typical house are a relatively small proportion of the total load as opposed to ÉcoTerra in which they are the largest.

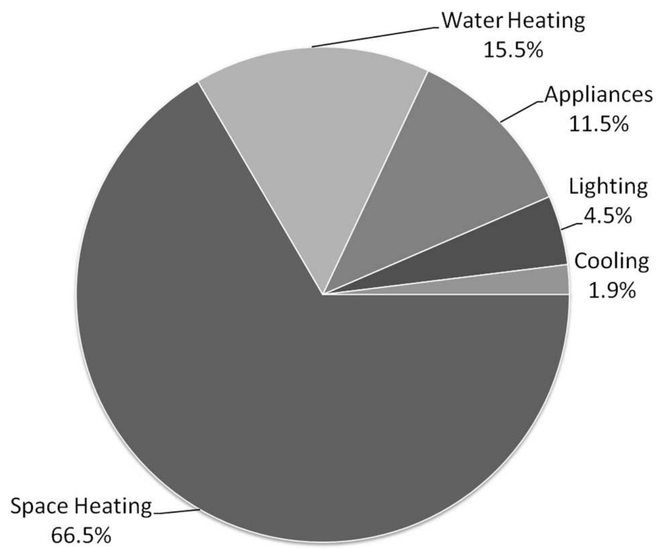

Figure 5.11: Typical annual energy end-use breakdown

5.3 Heat Pump Performance

The primary heating system at ÉcoTerra is a ground-source heat pump, and its performance was examined over the six-month period of December 10, 2009 to June 9, 2010, as well as in more detail over several shorter periods. The periods were chosen in an effort to determine how the house performed under various outdoor conditions.

The heat pump is a GeoSmart Energy GT038, two-stage, 38MBH (11.1 kW) model with ECM fan, complete with integrated domestic hot water heating via desuperheater and two-stage auxiliary electric heating coil (9.6 kW). The fan can operate at three speeds: recirculation mode (355 L/s), low speed (495 L/s) and high speed (590 L/s). The heatpump has ARI-rated COP of 4.2 at full load, maximum flow rate. The cooling performance is rated at an EER of 19.8 for full load, full maximum rate.

5.3.1 Heating Degree Days

The effects of outdoor air temperature can be accounted for by normalize the energy consumption against the outdoor air temperature data. To do this, the heating degree days were calculated for each period. This required the determination of the balance temperatures for the building – that is, the outdoor temperature above which no heating is required and below which no cooling is required.

The balance temperature was derived using the daily heating load and the daily average outdoor air temperatures. The heating load was calculated by examining the energy consumed by the heat pump at each moment and normalizing this using the calculated COP for the given time-step. The COP was calculated using the same method described in Section 5.3.2 - Coefficient of Performance. The graph of the results can be seen in Figure 5.12.

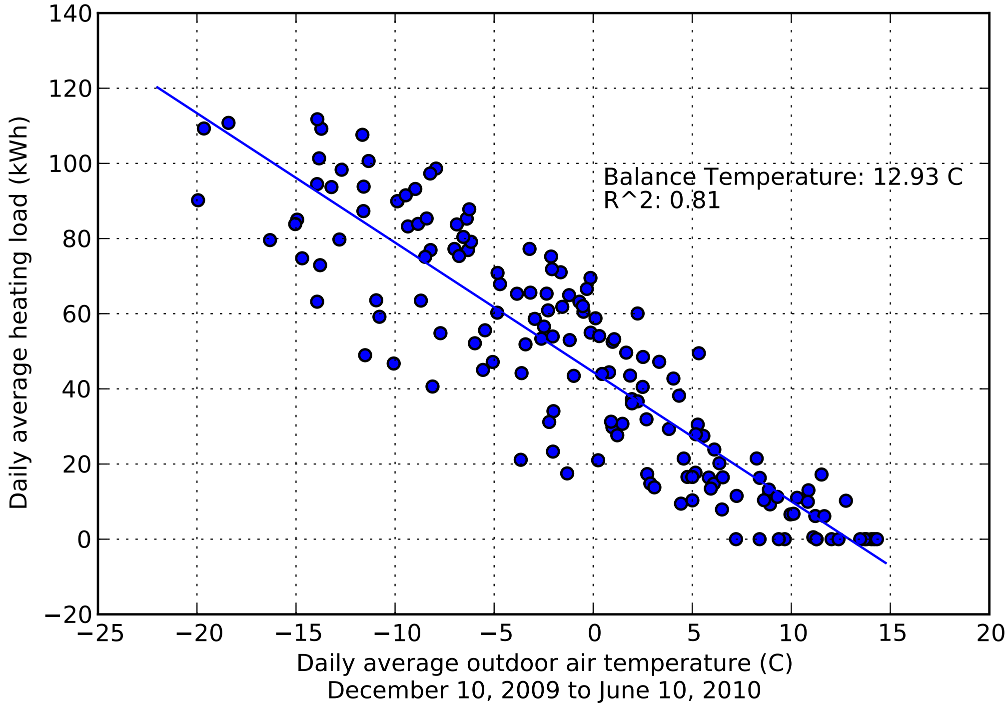

Figure 5.12: Daily heating load vs. daily average outdoor temperature

The heating balance temperature is estimated to be 12.93 °C. After normalizing for heating degree days, and using this base temperature, the overall energy use per heating degree day (HDD) is 0.94 kWh/HDD for the period of December 10, 2009 to June 9, 2010 (using HDD with a base of 12.93 °C). The value is slightly better at 0.68 kWh / HDD if the more common base 18 is used for finding the HDD.

The heating and cooling portion of the heat pump consumption is not differentiated in the recorded data. This makes it difficult to calculate the cooling balance temperature. Based on observations of the supply air temperature data, however, there does not appear to have been any cooling in the house for the period up to June 9.

5.3.2 Coefficient of Performance

The primary metric that will be used to judge heat pump performance is the coefficient of performance (COP). The COP is the ratio between the energy provided by the heat pump and the energy it consumes (Equation 5.1). COP is also equal to the sum of the energy extracted from the environment and the energy consumed by the heat pump, divided by the energy consumed by the heat pump (Equation 5.2) (ASHRAE, 2005).

$$COP = \frac{Energy\ Deliverd\ to\ Space}{Energy\ to\ Power\ Heatpump} \tag{5.1}$$

$$COP = \frac{Envirronmental\ Energy + Energy\ to\ Power\ Heatpump}{Energy\ to\ Power\ Heatpump} \tag{5.2}$$

Typically, this formula does not include auxiliary devices such as fans and pumps, however, for the case of ÉcoTerra, the pump and fan are lumped together in the heat pump data due to the monitoring setup, so they are taken into account as part of the COP. This means the COP given here will be slightly lower than it might otherwise be. The

COP was calculated using both equations 5.1 and 5.2 and then compared. For the first method, the energy delivered to the space was calculated using the typical energy formula - Equation 5.3 (Incropera and DeWitt, 2002).

$$Q = \dot{m} \cdot Cp \cdot \Delta T \cdot t$$
$$Energy = Mass\ Flow\ Rate \cdot Specific\ Heat \cdot Difference\ in\ Temperature \cdot Time \qquad (5.3)$$

The difference in temperature used was the measured difference across the supply and return ducts of the heat pump, and the mass flow rate was calculated using an approximate air flow of the heat pump. The density of the air was calculated at each interval using the average temperatures for that moment. The airflow of the heat pump is assumed to be as per its dip-switch settings (factory defaults). This neglects any difference due to pressure loss in the duct system. The heat pump has low, medium and high air flow rates of 354 L/s (750 cfm), 519 L/s (1,100 cfm) and 614 L/s (1,250 cfm) respectively. The flow rate of the heat pump is not monitored directly, but is inferred from its power consumption. A rough correlation was created to allow an estimate of flow rate at a given power consumption. The energy to power the heat pump is measured and includes the compressor, brine pump and fan.

The heat recovery ventilator (HRV) injects air into the return stream of the heat pump ducting. This injected air is preheated, but not always to room temperature, so the return air temperature is slightly lower than it would be otherwise. The slight increase in load resulting from this air would be present either directly, due to the HRV, or indirectly due to infiltration, so it is considered part of the house's heating load.

For the second method, Equation 5.3 is used again, this time on the water side, with the temperatures being the measured difference between the supply and return of the ground loop. The mass flow rate is calculated from the measured volumetric flow rate. The ground loop fluid is 25% methanol by weight, 75% water. This is converted to percent by volume using the densities of water and methanol at each step (calculated using the average loop temperature at each step).

The previously described analysis was performed for the period of December 10, 2009 to July 9, 2010. Four other seven-day periods were also examined: a cold sunny period (February 1 to 7, 2010); a cold overcast period (January 3 to 9, 2010); a cool sunny period (March 5 to 11, 2010); and a warm sunny period (April 20 to 26, 2010). A summary of the results is shown in Table 5.3.

Table 5.3: Heat pump performance summary

	December 10 to June 9	**January 3 to 9 (Cold, Overcast)**	**February 1 to 7 (Cold, Sunny)**	**March 5 to 11 (Cool, Sunny)**	**April 20 to 26 (Warm, Sunny)**
Energy Consumed by HP (kWh)	2,010.73	175.66	126.18	33.23	19.03
Energy Provided by HP (kWh)	7,459.81	634.13	476.96	129.60	74.79
COP of HP (ground side)	3.71	3.61	3.78	3.90	3.93
COP of HP (air side)	3.85	3.84	4.19	3.73	3.67
HDD in Period (Base 12.93 °C)	2,150.04	157.88	169.49	88.68	16.95
HDD in Period (Base 18 °C)	2,951.36	193.37	204.98	124.17	52.44
Average Ground Temp (°C)	4.43	3.94	4.09	4.93	5.93
Average Outdoor Air Temp (°C)	1.88	-9.62	-11.28	0.26	10.51
kWh / Day Input	11.11	25.09	18.03	4.75	2.72
kWh / HDD (Base 12.93 °C)	0.94	1.11	0.74	0.37	1.12
kWh / HDD (Base 18 °C)	0.68	0.91	0.62	0.27	0.36

The general pattern in the above table shows better performance with increased solar radiation. This is to be expected for a house designed to take advantage of solar radiation. The COP calculated for the air- and ground-side energy balances differ slightly. This is due to the relatively large error in the air flow rate estimate of the heat pump fan.

5.3.3 *Stratification and Auxiliary Heat*

Uneven distribution of supply air, or solar gains can result in some areas of a house having higher or lower temperatures than others. This can result in occupant discomfort and can also impact energy consumption. This is especially true in systems with a small number of zones, such as ÉcoTerra. If one area is significantly colder than another, it may cause the heating system to activate even though the overall temperature in the house may already be comfortable. Figure 5.13 shows a schematic of the heating zone layout at ÉcoTerra, which is essentially a single-zone system. There is a small pseudo-zone for the upstairs, south bedroom which is controlled via a damper on a branch of the main heating duct.

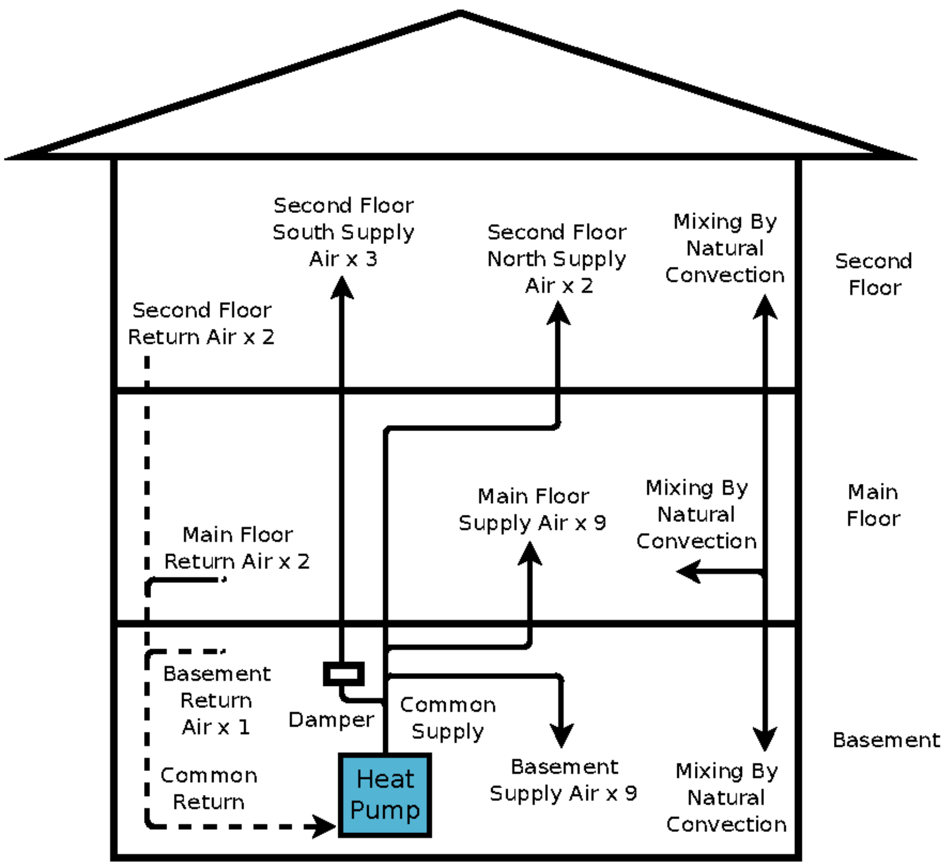

Figure 5.13: Heating zone schematic

Figure 5.14 shows a trend of room air and supply air temperatures. The air temperatures from the different zones in the house approach each other overnight due to the mixing effect of the heat pump fan.

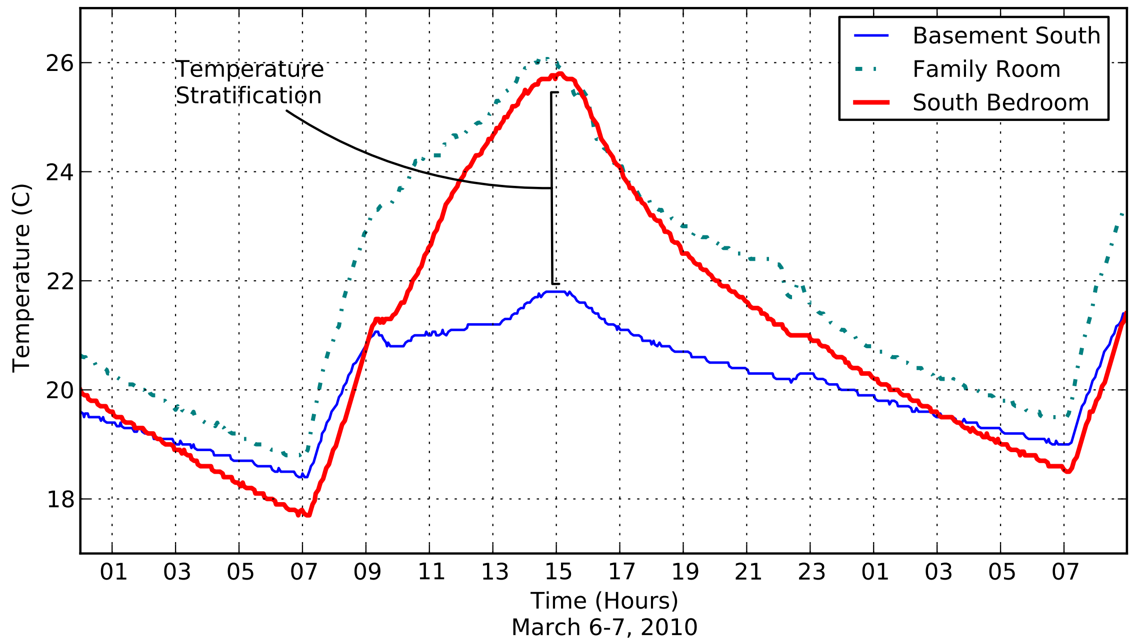

Figure 5.14: Temperature stratification between floors

Simulations were performed in Doiron et al., (2011) to determine if similar destratification could be achieved with less fan energy consumption. An estimated savings of 722 kWh was reported. A balance can be achieved, but more work is necessary to balance energy consumption vs. comfort (Doiron et al., 2011). Table 5.4 shows the stratification between floors for six representative days in 2010 – three sunny and three cloudy. The fan runs in recirculation mode (approximately 355 L/s) whenever there is no demand for heating or cooling and at higher speeds (up to 590 L/s) while in heating/cooling mode. There is slightly more stratification observed during the sunny days, as is expected for a solar house. The differences in air temperature between floors ranges from 0.9 °C to 2.1 °C.

Table 5.4: Air temperature stratification between floors for representative days

	Winter		Shoulder		Summer	
Sunny	February 6, 2010 (20:16)		March 26, 2010 (16:43)		August 19, 2010 (3:16)	
	Top Floor	22.6	Top Floor	21.1	Top Floor	24.3
	Main Level	22.8	Main Level	21.5	Main Level	24.3
	Basement	20.5	Basement	19.9	Basement	22.3
	Max Difference	2.1	Max Difference	1.2	Max Difference	2.0
Cloudy	January 23, 2010 (18:45)		March 23, 2010 (18:27)		August 25, 2010 (18:13)	
	Top Floor	22.7	Top Floor	20.9	Top Floor	24.4
	Main Level	23.3	Main Level	21.8	Main Level	24.5
	Basement	20.7	Basement	20.1	Basement	22.6
	Max Difference	2.0	Max Difference	0.9	Max Difference	1.8

The supply air temperature sometimes rose past 35 °C. This would not occur normally, so is the result of the auxiliary electric heater in the heat pump. The control sequence allows the auxiliary heater to come on if the outdoor air temperature is low enough and if there is a temperature difference greater than 4 °C between the current reference temperature and the setpoint. These conditions occurred on several days during the cold sunny period, specifically in the mornings when the setpoint changes from its night setback value of 18 °C to its daytime setpoint of 22.5 °C. The energy use associated with these occurrences is approximately 104 kWh. This consumption is unnecessary, therefore, it is recommended that the control sequence be adjusted to reduce the auxiliary heating use by increasing the allowable difference between setpoint and current temperature. Increasing this value from the existing 4 °C to 6 °C should eliminate most of the auxiliary heating use.

5.3.4 Impact on Room Temperatures

The following Figures (5.15, 5.16 and 5.17) show some indoor temperature trends for different times of the year. Figure 5.15 shows some overheating due to unseasonably high temperatures on a moderately sunny day. A three hour delay can be seen between the peak outdoor temperature and the peak indoor temperature. This is due to the significant thermal mass in the house. Figure 5.16 shows that in the shoulder seasons, it is sometimes unnecessary to heat the house for most of a sunny day – only a small amount of heat was required on March 7th.

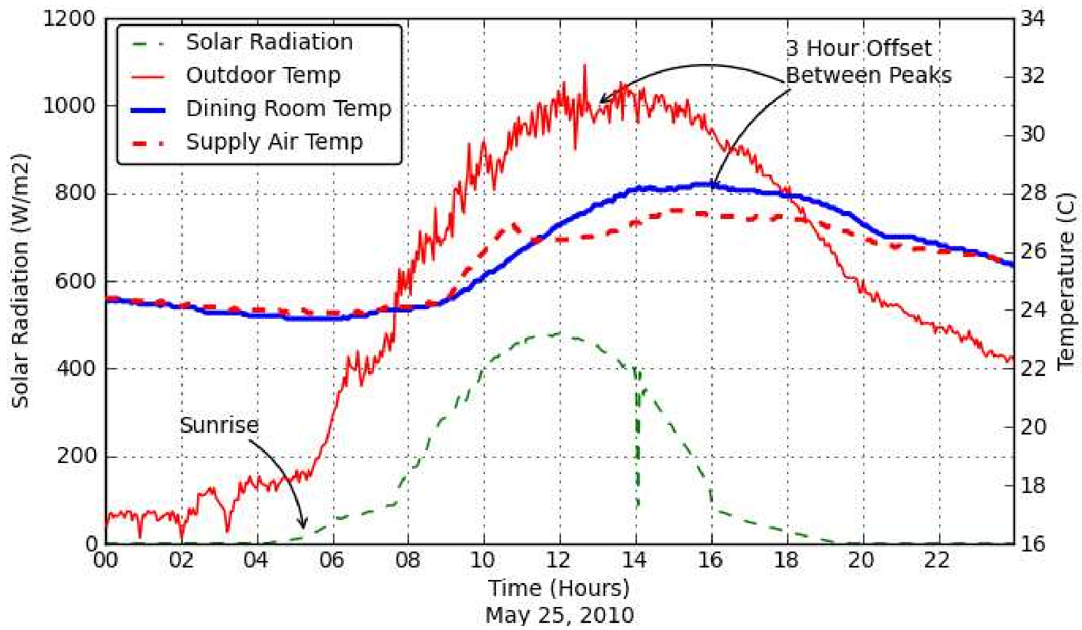

Figure 5.15: Solar radiation and indoor temperature – May 25, 2010

Even though overheating occurred occasionally, only about 124 kWh of cooling was used for the year. This is a combination of the personal preferences of the occupants and the appropriate use of blinds, windows and the motorized awnings.

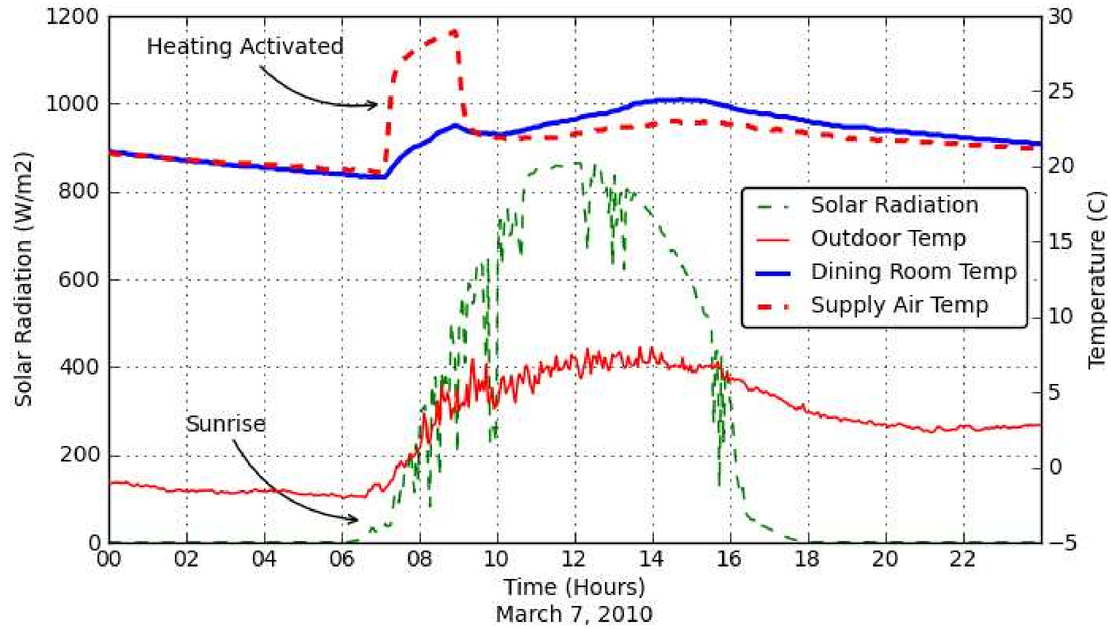

Figure 5.16: Solar radiation and indoor temperature – March 7, 2010

Even on a cold day, the heating load is reduced, as shown in Figure 5.17. For instance, on December 18, no heating was required during most of the day.

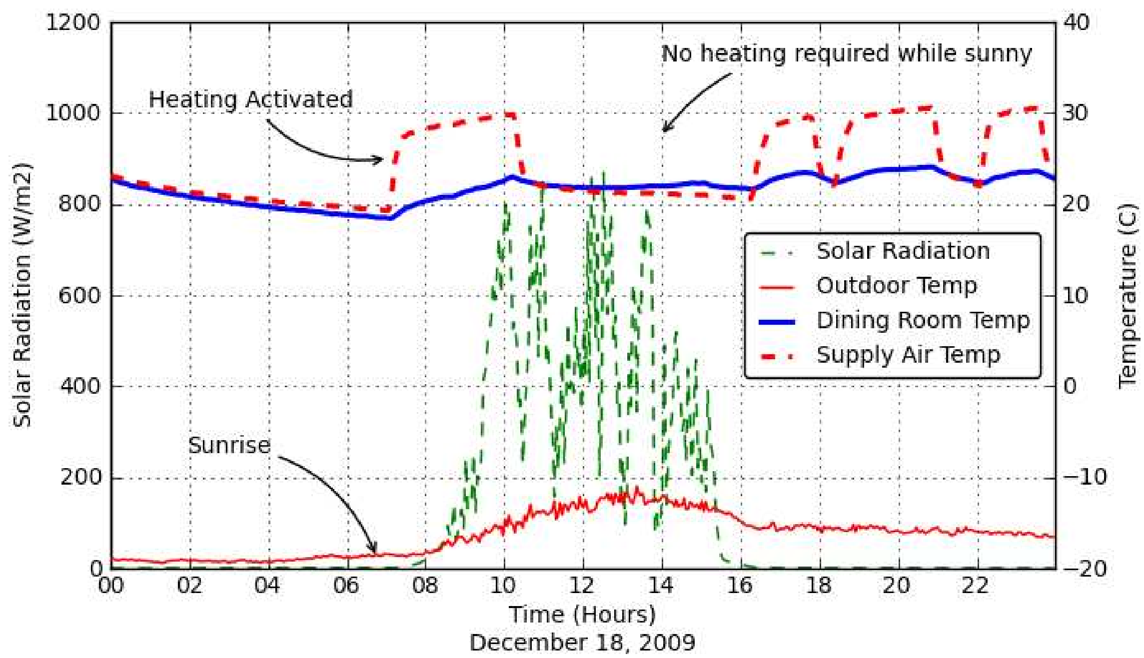

Figure 5.17: Solar radiation and indoor temperature – December 15, 2009

5.4 BIPV/T Performance

The overall performance of the BIPV/T system was examined for the period of December 10, 2009 to December 9, 2010 and a detailed analysis was performed for other shorter periods. This section will examine the inlet, outlet, slab, DHW temperatures, and the energy stored and consumed. The thermal and electrical efficiencies of the BIPV/T system, the coefficient of performance and the sources of error will also be investigated. Figure 5.18 shows a cross-section of the BIPV/T roof system.

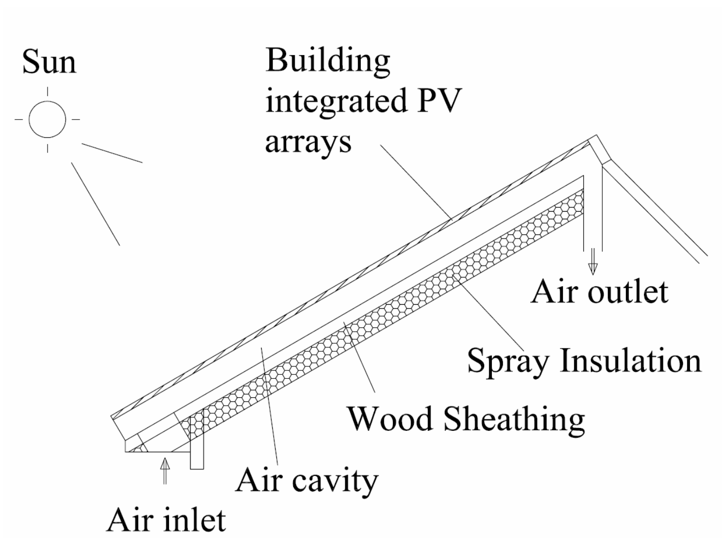

Figure 5.18: Cross-section of BIPV/T roof system
Image Source: (Chen et al., 2010)

5.4.1 BIPV/T Temperature Trends

Figure 5.19 shows that there is a difference between the temperature of the air as it exits the manifold in the roof and the temperature of the air that reaches the heat recovery devices. For the period examined, this difference averaged 3.2 °C, but was as much as 10.3 °C. This difference may be the result of several factors. First, the ducts between the roof and the basement are negatively pressurized while the fan is operating. This means that some air may leak from the house into the ducts and be drawn down into the basement. This air will, under some circumstances, be cooler than the air from the roof so would cool the air stream. The ducts themselves are also a source of heat loss. The metal ducts are surrounded by the house, so they will tend toward room temperature. Some heat is then lost to the ducts as the hot air travels down the cooler ducts to the basement. The metal of the ducts may also act as thermal mass, introducing a lag between when the air flow begins and when the air reaching the basement achieves a significant temperature.

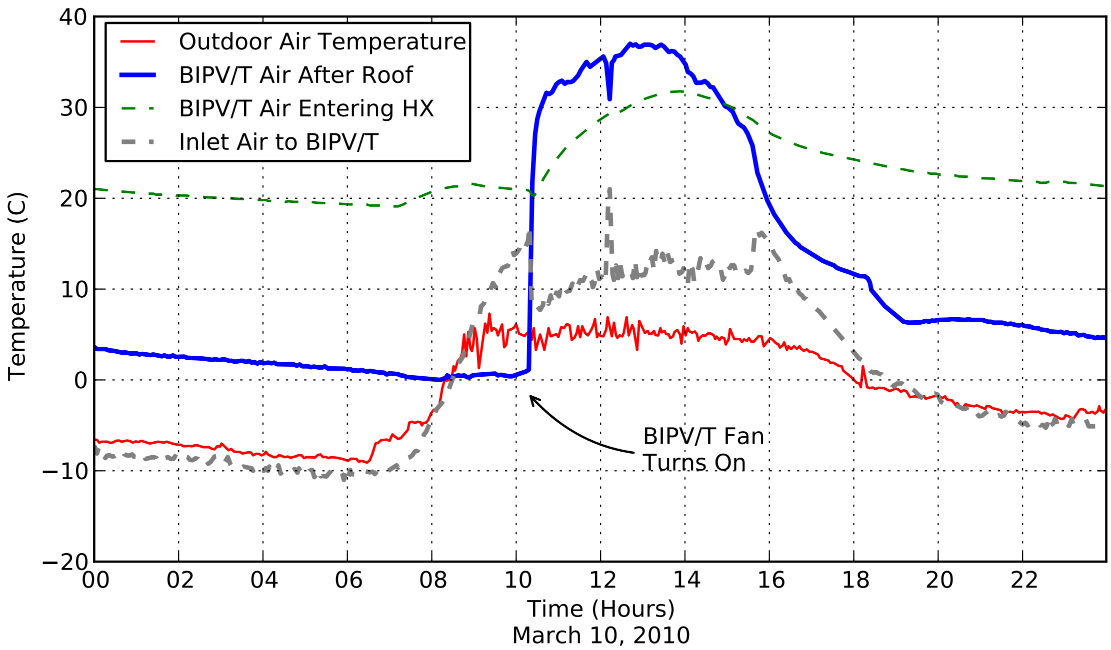

Figure 5.19: Sample air temperatures for BIPV/T system

Another interesting effect can be observed from the same graph (Figure 5.19). The inlet air temperature is higher than the ambient outdoor air temperature. During the period examined, the inlet air averaged 4.4 °C higher than the ambient air temperature, but had peaks of as much as 14.2 °C higher in rare cases. This difference results from heating of the building facade by the sun. The layer of air in contact with the facade is heated and rises naturally. This heated air, rather than ambient outdoor air, enters the BIPV/T system at the soffits.

The energy potentially available from the BIPV/T system was calculated for the day shown in Figure 5.19 (March 10, 2010), using a mathematical model developed in MATHCAD by Chen et. al. (Chen et al., 2010). The model shows that 31.1 kWh would be available during the times when the outlet air temperature is above 15 °C. The amount of energy actually collected for this day was 30.2 kWh. Not all of this collected energy was stored, however. Only 10.8 kWh (36.7%) was stored in the slab and no energy was stored in the domestic hot water preheat tank. The remaining energy was either exhausted or not used due to the temperatures in the preheat tank and slab.

Table 5.5 summarizes the range of temperatures for the examined period. The recorded temperature differences are only from the period of time during which the BIPV/T fan was running. This means these ranges could be different at other times, but those values are not important for the performance of the system. Note, however, that some negative values exist. This indicates that there is sometimes a gain of heat between the roof and basement. Figure 5.20 shows this effect for March 4, 2010. This is possibly due to thermal lag and the mass of the duct-work, or it could be that warm air is being drawn from the house.

Table 5.5: Summary of temperature differences

Temperature Difference	Maximum (°C)	Minimum (°C)	Mean (°C)
Across roof	27.6	-	18.30
Between inlet and ambient	14.20	-2.80	4.40
Between roof manifold and basement	10.30	-16.60	3.20

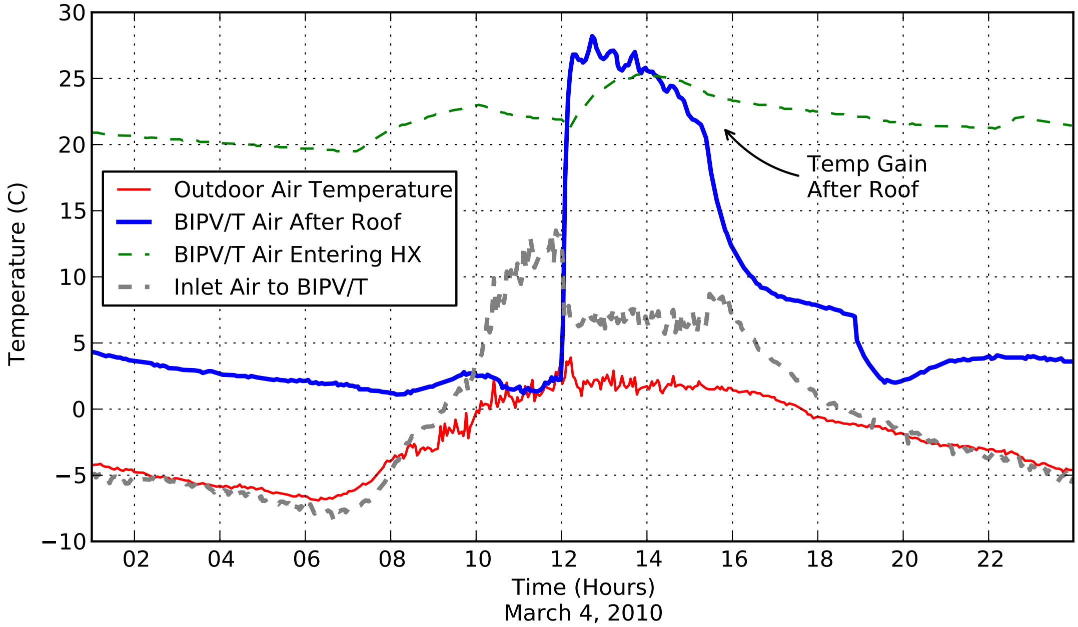

Figure 5.20: Gain in temperature between roof and basement

The slab and domestic hot water preheat tank are charged using the roof so their temperatures vary with the operation of the BIPV/T system. Figure 5.21 shows the temperature variations on March 11, one of only three days in March when the preheat tank was charged using the BIPV/T system.

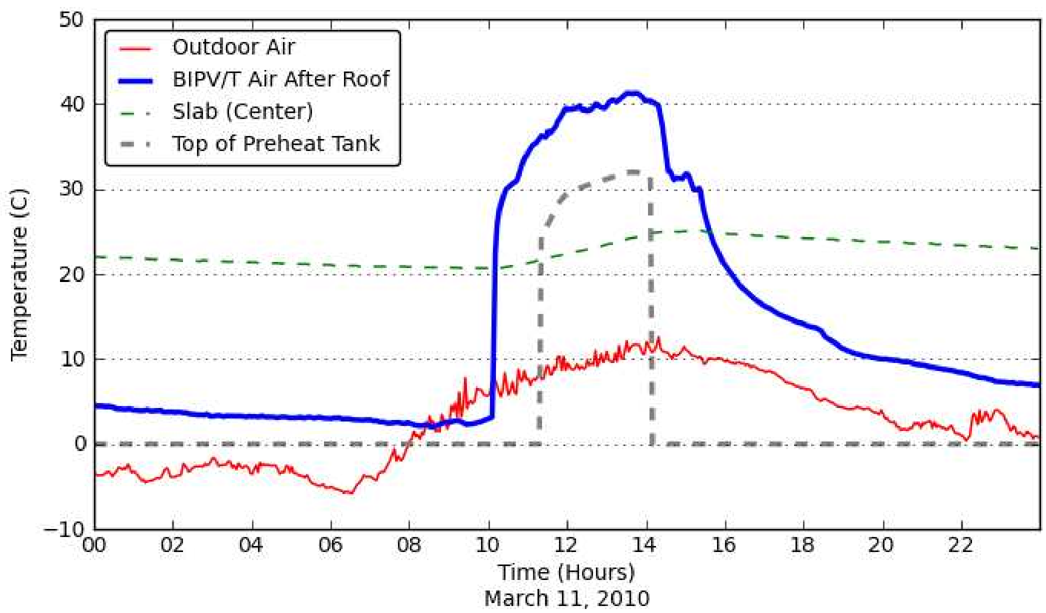

Figure 5.21: Slab and preheat tank temperatures

The sensors used for the tank temperatures in Figure 5.21 belong to HydroQuébec and they record data only while the BIPV/T system is operating. This is why it appears that the preheat tank temperature jumps from zero when the system starts. The preheat tank has various other sensors, but they were malfunctioning up until they were repaired on April 17, 2010. After this date, continuous temperature trends are available. Figure 5.22 shows temperature trends in the preheat tank for four days (June 4 to 7, 2010). The tank was being charged on the first and last days, while the middle two days have no charging. These middle days demonstrate the gradual standby losses to the surroundings. For the middle days, neither the desuperheater nor the BIPV/T system operated, so these sensors show the temperatures at the top and bottom of the preheat tank.

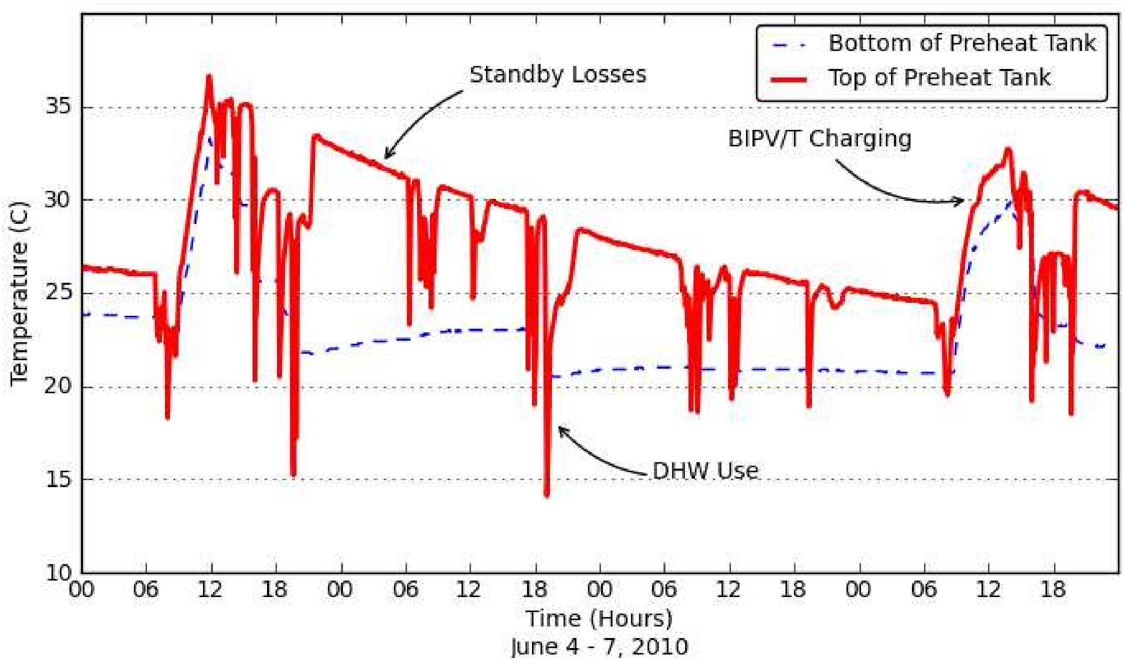

Figure 5.22: Temperatures at top and bottom of preheat tank

5.4.2 Energy Collected and Generated

The energy collection and storage performance is examined in this section. Energy is stored in the ventilated concrete slab (VCS) when air, heated by the roof, passes through it. The domestic hot water preheat tank also stores energy from warm roof air, but receives energy from the heat pump's desuperheater as well. The photovoltaic surface of the BIPV/T roof generates electricity, some of it being used and the rest being exported to the grid.

The energy collected by the BIPV/T system includes two types: thermal and electrical. The electrical energy produced by the PV system is monitored directly and the thermal energy was calculated using Equation 5.1. Significant electricity was generated by the photovoltaic system during the period of December 10, 2009 and December 9, 2010, and 16% of it was exported to the grid. Significant energy was also stored in the slab. The domestic hot water system did not function up until April 17, 2010 due to a valve that was mistakenly left closed.

Table 5.6 shows a summary of the energy stored, collected, generated and exported by ÉcoTerra for the period of December 10, 2009 to December 9, 2010.

Table 5.6: Summary of storage, collection, generation and export

Component	kWh	Source
Storage in Preheat Tank (by BIPV/T)	245.0 ± 7.1	Calculated
Storage in Preheat Tank (by HP)	601.7 ± 10.4	Calculated
Storage in VCS	329.8 ± 11.1	Calculated
PV Generation	2,570	Measured
PV Electricity Exported	410.5	Calculated
PV Electricity Consumed	2,159.5	Calculated

Energy Stored in Slab

The energy stored in the slab was calculated using Equation 5.3. The difference in temperature used was the difference between the inlet and outlet air temperatures of the slab itself, which are measured. The airflow was estimated using the previously mentioned amperage-flow rate correlations (Equations 4.1, 4.2 and 4.3). For each data point, the state of the BIPV/T fan was examined. If it was on, the flow-rate was calculated using the given amperage. This flow was then used, along with the inlet and outlet temperatures for that moment, to calculate the amount of energy transferred for that time-step. The energy calculated for all time-steps is them added together to give the total energy stored for the period.

The issue with time synchronization is critical for this calculation. The temperature data used is recorded by SBRN, while the fan amperage is recorded by HydroQuébec. Without the time correction described in Section 4.2- Data Quality, the differences in temperature selected for the energy calculation would not be those that existed while the fan was actually operating. The correction improves the results by up to 13.7%.

Not all of the energy removed from the air is transferred to the slab. A correction must be made to account for the losses to the ground beneath the slab. Recall from Figure 1.8 that part of the air channel is exposed to the insulation below the slab. The ground temperature just below the insulation and the air temperature in the channels are measured at nine locations each. These values are used to calculate average ground and airflow temperatures for use in calculating the energy lost to the ground. The formula used is found in Equation 5.3 (Hutcheon and Handegord, 1995).

$$Energy = U \cdot Area \cdot \Delta Temp \cdot time \qquad (5.4)$$

The area over which the heat transfer occurs is calculated using the dimensions of the channels. The U value (overall heat transfer coefficient) is calculated using the known insulation value of below the slab (RSI 1.3) and a correlation for the convection heat transfer coefficient seen in Equation 5.5 (Chen, 2009). The coefficient has typical values of between approximately 8.6 and 13.0 W/m^2·K.

$$h_{conv} = 3.94 + Velocity_{air} + 5.45 \qquad (5.5)$$

The air velocity was calculated using the known cross-sectional area of the channels and the previously mentioned flow-rate correlations. Radiation heat transfer is neglected because the difference in surface temperatures within the slab channels is low. This loss correction is calculated at each time-step and subtracted from the value calculated for the energy stored in the slab at that step.

Energy Stored in Preheat Tank

The calculation of the energy stored in the preheat tank involved several challenges. Several sources of energy may be charging the tank, potentially simultaneously. Fortunately, during the examined period, the heat pump and BIPV/T fan never ran at the same time. This is not surprising as there is often enough solar radiation and thermal mass to maintain the air temperature into the evening. On colder days when the heat pump might run during the day, there was little sun and so little energy to be collected by the BIPV/T system. This provides a way to examine the effect of the BIPV/T system and the desuperheater individually.

The temperatures in the tank and of the desuperheater flow are monitored by HydroQuébec, but only while the heat pump is on. SBRN monitors these values as well, but the SBRN thermocouples were malfunctioning until April 17, 2010. Until this date, very little energy was collected by the BIPV/T system. This may be a result of an incorrectly positioned valve, which was corrected at the same time as the thermocouples were repaired.

The portion of energy contributed by the BIPV/T system is calculated by using the differences in temperature across the air-to-water heat exchanger, the flow-rate correlations and Equation 5.3. The contribution from the desuperheater was calculated as well. The flow rate through the desuperheater system is not monitored, however, the heat pump manufacturer's documentation gives the flow rate to be 0.025 L/s (0.4 gpm) per rated tonne of heat pump capacity. The heat pump has a rated capacity of 11.1 kW (38 MBH), which gives an estimated desuperheater flow of 0.0799 L/s (1.27 gpm). This value was confirmed with HydroQuébec which did extensive testing on the heat pump. HydroQuébec also stated that the pump that circulates water through the desuperheater runs whenever the heat pump is in heating mode. Equation 5.3 is then used to calculate the energy transfered by the desuperheater. The temperature in and out is monitored directly, and mass flow rate is calculated using the density of water and the estimated volumetric flow.

PV Generation

The energy generated by the PV system is monitored directly, so this is calculated by totalling values in the appropriate data column. The amount of PV generation that is exported is the sum of the negative portions of the net metered power data. The difference between these two quantities is the amount of PV electricity consumed by the house.

5.4.3 Thermal and Electrical Efficiencies

Efficiency is defined as the ratio between the energy output and the energy input. In the case of thermal efficiency, the energy input (the potential energy available) is the recorded incident solar radiation (W/m^2), for those times when the BIPV/T fan was operating, multiplied by the roof area. The whole roof area is used, except for a small part of the soffit which overhangs the openings to the BIPV/T channels. The output for the thermal efficiency is the amount of energy transferred to the air as it travels through the roof, as calculated using Equation 5.3 (between the air inlet and the roof outlet). The efficiency is also calculated between the air inlet and the point after duct manifold, which takes into account losses between the roof outlets and the manifold.

The energy output, in the case of electrical efficiency, is the generated electricity, as measured. For PV efficiency, only the area of the panels is used, since the surrounding roof does not contribute to electricity production. Table 5.7 shows a summary of the overall efficiencies calculated for the period of December 10, 2009 to December 9, 2010.

Table 5.7: Summary of electrical and thermal efficiencies

	Value	Source
Thermal energy collected across roof (inlet to manifold)	1,173 kWh	Calculated
Thermal energy collected across roof (inlet to outlet)	1,545 kWh	Calculated
Potential thermal energy available	13,846 kWh	Calculated
Thermal efficiency (inlet to manifold)	8.77%	Calculated
Thermal efficiency (inlet to outlet)	11.20%	Calculated
Electrical energy generated	2,570 kWh	Measured
Electrical efficiency (December 2009 to December 2010)	5.15%	Calculated
Electrical efficiency (March 20010)	5.29%	Calculated
Electrical Efficiency (March 26, 2010)	5.34%	Calculated

The difference observed between the two thermal efficiencies is approximately 20%. This difference may be due to losses in energy between the outlets of the BIPV/T roof air channels and the measurement point, which is after manifold. The manifold collects the air from each outlet and ducts it into the house. The ductwork has significant surface area, but is insulated, so the losses may result from air leakage through a damper located at the manifold. This damper opens only when the emergency exhaust fan operates (in cases when the roof temperature exceeds 70 °C). This damper may be leaking cold air from the outside, which would reduce the amount of energy that reaches the house's main duct leading into the basement. Some of this difference may not be due to losses, however, but an overestimate of temperature at the outlets. The thermocouples in the outlet air stream are very close to the interior surface of the roof, so they may be reading slightly higher temperatures than the actual air stream.

The rated efficiency of the PV modules used at ÉcoTerra is 6.29%. This means the panels are operating at 81.9% of their rated capacity. This is consistent with previous studies of similar PV systems (King and Kratochvil, 2002). The efficiency is calculated using the measured solar radiation in the plane of the PV panels. This value is measured at a single point, but it is assumed that the rest of the roof surface has equal and even solar radiation. The surface area of the PV panels is known, so the potential energy is calculated by multiplying the solar radiation in the plane of the PV panels by the area of the panels. This is then compared with the actual PV production to calculate electrical generation efficiency.

The method used introduces some error, as it is possible that the roof was at times covered in snow while the solar radiation sensor was not. This would cause a lower efficiency to be measured. However, the opposite is possible as well – the sensor may have had ice or snow on it, while the roof was already bare. It is also possible that at times the sensor was shaded while the roof was not, and vice versa.

The inverter efficiency was also examined. Figure 5.23 shows the alternating and direct current power generation for a sunny day. The efficiency for the day was calculated to be 96.3%. The long range efficiency was also calculated for the same period of analysis as the energy consumption data. This efficiency was calculated to be 95.4%.

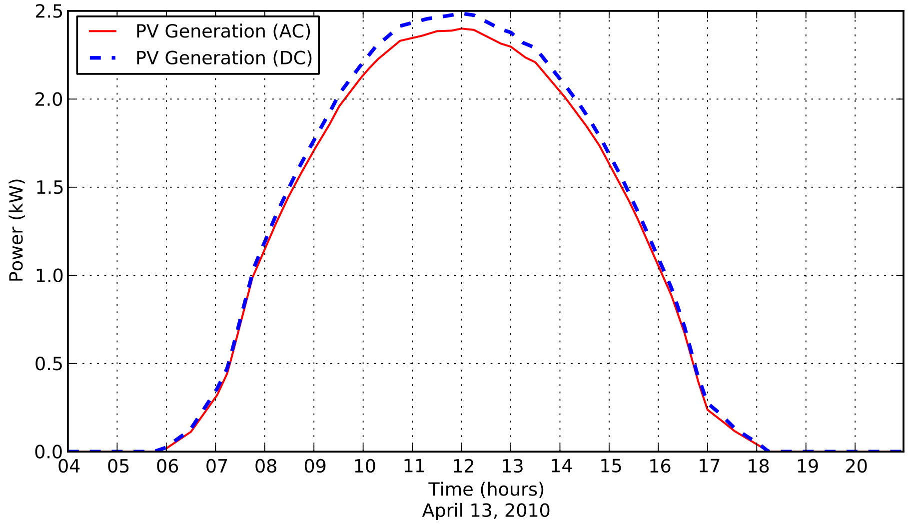

Figure 5.23: AC and DC power generation – April 13, 2010

5.4.4 Air-water Heat Exchanger

The air to water heat exchanger heats water from the domestic hot water preheat tank using air heated by the BIPV/T roof. A schematic of the heat exchanger is found in Figure 5.24.

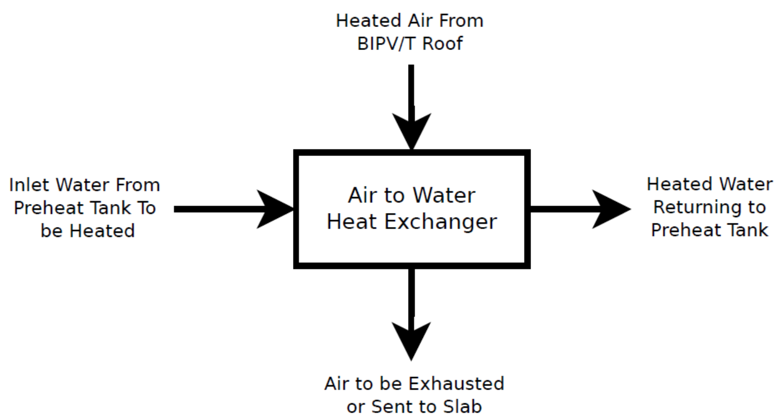

Figure 5.24: Air-water heat exchanger schematic

The efficiency of the air-to-water heat exchanger was examined. Effectiveness ε is defined as the ratio between the actual heat transfered and the maximum potential heat transfer. The formula used to judge its performance is Equation 5.4, where $(\dot{m}C_p)_{min}$ is the minimum mass and specific heat product of the two fluids (Bartlett, 1996).

$$\varepsilon = \frac{q}{q_{max}} = \frac{(\dot{m}C_p)_{hot}(T_{in} - T_{out})_{hot}}{(\dot{m}C_p)_{min}(T_{in,\,hot} - T_{in,\,cold})} \tag{5.6}$$

The effectiveness of the heat exchanger was examined for May 21, 2010 and the results can be seen in Figure 5.25. The effectiveness was found to ramp up quickly at the beginning and stabilize at approximately 68%. Similar patterns and ranges were observed throughout the month of May, 2010. This is within the range of expected values for a cross-flow heat exchanger (55-85%) (Gladstone and Bevirt, 1996), however, it might be lower than possible for ÉcoTerra for several reasons. One is the fact that the air flow rate is chosen based on the temperature at the roof and not based on providing good heat transfer at the heat exchanger. Also, there is a less-than-ideal transition between the main duct and the heat-exchanger. It is suggested that so-called “eccentric” transitions, such as those entering and leaving the heat exchanger, be angled at a maximum of 30° for even flow (SMACNA, 1990). In this case, the transition is over 50° (as observed on site). Also, there are 'T' duct intersections on each side of the heat exchanger which would interfere with the even flow of air. These issues would not be easy to correct, however, since the mechanical room at ÉcoTerra is small, and may not provide the room to create an alternate duct arrangement.

Figure 5.25 also shows the rate of heat transfer calculated for May 21, 2010, which ranges from between 1.2 and 1.4 kW. The heat transfer rate is negatively affected by the same conditions relating to the duct transition, as mentioned previously.

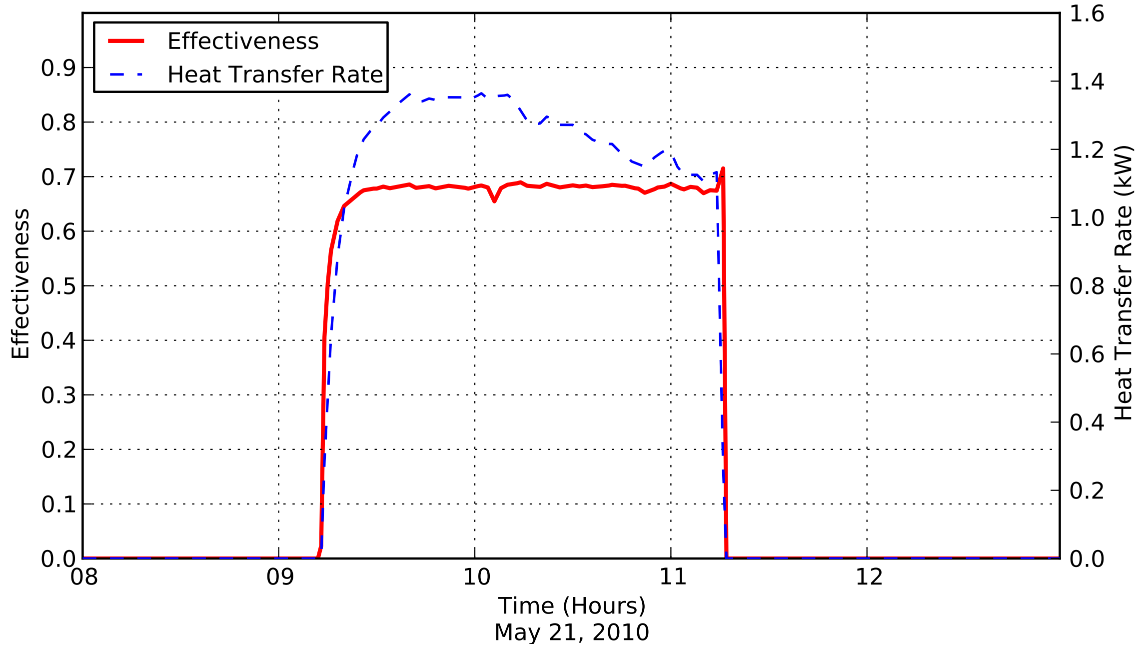

Figure 5.25: Air-water heat exchanger effectiveness and heat transfer rate

In some cases, latent heat must also be considered, however, in the case of ÉcoTerra, this is not necessary. The air entering the heat exchanger is brought into the roof at outdoor conditions and then heated, lowering its relative humidity. Heat is extracted in various ways throughout the BIPV/T system, but the heat recovery is never perfect, so the air leaving the house will always be warmer than the air entering. This means that the exiting relative humidity will always be lower than that of the entering air, eliminating the possibility of condensation.

Steady-state conditions are assumed, but this may not be accurate in all cases, as the heat exchanger's copper coils will have some capacity to store heat and so some thermal lag will be present. However, because these formulae are evaluated over long periods of time, at one minute intervals and using measured data, any transient effects should already be accounted for.

5.4.5 Energy Used vs. Energy Collected

While significant energy was stored, energy was also consumed in order to accomplish this. Table 5.8 summarizes the ratio between the amount of energy collected by the BIPV/T system and the energy consumed by it.

Table 5.8: Summary of energy used vs. energy collected

	Value	Source
Energy used by BIPV/T fan	117.1 kWh	Measured
Energy used by preheat tank pump	25.2 kWh	Measured
Total thermal energy collected	574.7 kWh	Calculated
Total energy used	142.3 kWh	Measured
Energy used vs. collected	4.04	Calculated

The overall average performance ratio is 4.04. Figure 5.26 shows a plot of performance and fan amperage versus time for March 10, 2010. The amperage is mostly constant, meaning the fan was supplying almost constant flow rate, but the performance varies. This variation is due to changing solar radiation, and outdoor air, slab and preheat tank temperatures. The figure shows that the COP can be much higher than the average (up to 7.5 on the day shown). This shows potential for improving performance with optimization of the controls.

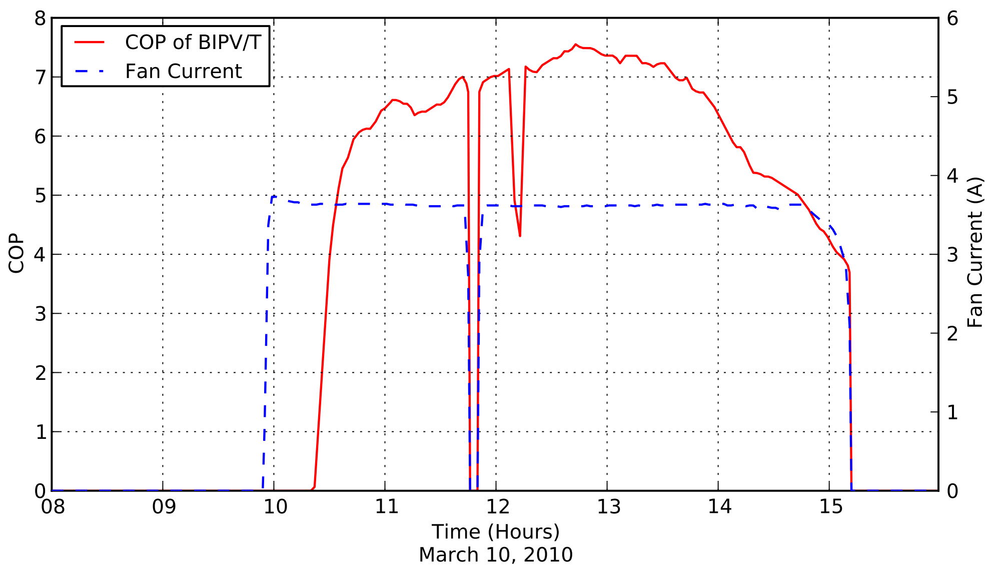

Figure 5.26: Performance vs. fan current – March 10, 2010

5.5 Clothes Dryer Performance

The author of this thesis assisted in a study of the performance of the solar-assisted clothes dryer. Measurements were taken of the inlet and outlet temperatures and relative humidity. Two wet towels were dried using the dryer to judge its performance. The mass of the towels was measured at various stages, including before being wet, while wet and after having been dried. The data collected during the experiment can be shown in Figure 5.27.

The dryer was tested in solar-only mode, but could easily function with the sun providing a boost to the existing electric heating coil. The dryer was found to remove approximately 0.8 kg/hour of water from the clothes. Actual performance will vary with the type of clothing being dried, the amount of clothes being dried at once and environmental conditions such as the temperature and humidity in the house.

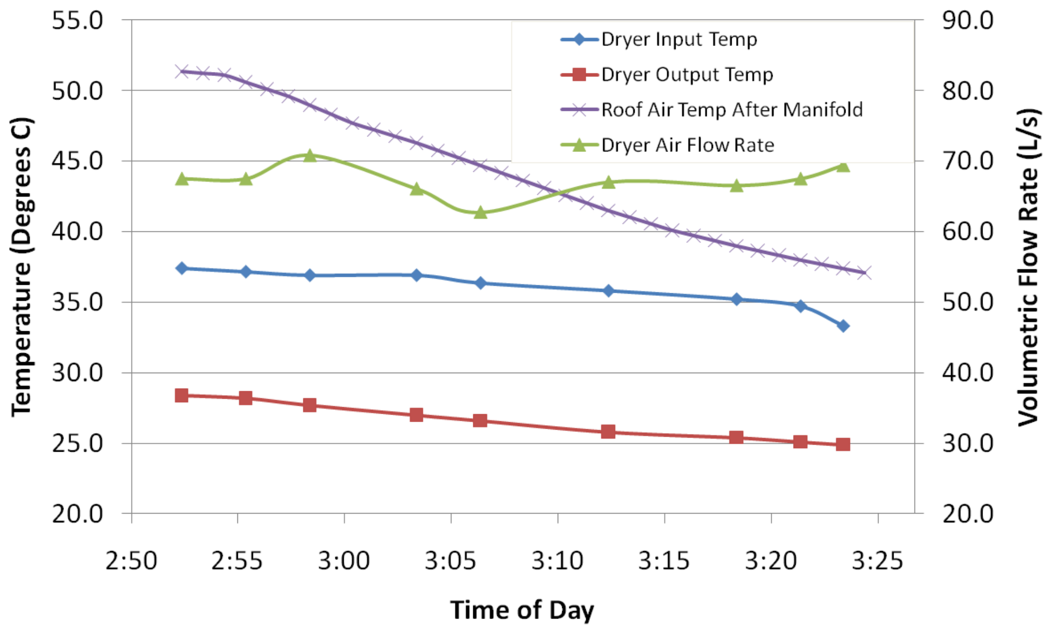

Figure 5.27: Performance test data for solar-assisted clothes dryer

The Canadian Standards Association (CAN/CSA-C 361-92) defines energy factor as the mass of clothing that can be dried per unit of energy input. The minimum acceptable energy factor is stated to be 1.36 kg/kWh (CSA, 1992). The CSA also defines a standard load of laundry as 3.15 kg of mixed clothing (dry). The amount of water content in the clothes before drying is defined as 70% of the mass of the dry clothes, and the water content after drying is 2.5-5% of the mass of the dry clothes. This equates to 2.2 kg of water per load before drying and 0.12 kg after.

The energy consumption of the dryer operating in conventional mode was compared to the energy consumed by the solar-air mode. The standard CSA load and moisture conditions were applied to a theoretical load of laundry dried using BIPV/T-heated air only and being dried at the rate measured during the experiment (0.8 kg/hour).

The energy consumption of the solar-only option is the sum of the energy consumption of the BIPV/T fan, the dryer booster fan (approximately 140 Watts) and the internal dryer fan, run for the time it takes to remove the amount of water defined by the CSA. The energy consumption of the conventional mode was estimated using the energy factor for a similar dryer model found on the Office of Energy Efficiency website (1.4 kg/kWh). The dryer has an internal fan which draws approximately 70.8 L/s (150 cfm) and a 5.4 kW electric heating element.

The conventional mode would consume 2.5 kWh per standard load and the solar-only mode would consume 1.36 kWh to dry the same load by the same amount, resulting in a savings of 38.3%. The actual savings would vary slightly because the rate of water removal was calculated using a few towels only, while the rated energy factor was calculated using a mix of towels and other clothing types.

The time taken to dry the loads was also compared. The amount of time to dry a standard load is not given, but typically this would be less than one hour. The solar-only mode would take significantly longer, at approximately 2.5 hours. Some home owners may not be willing to wait this long to dry a load of laundry, so a combination of the conventional mode and the solar mode may provide a good balance between time and energy efficiency.

The drying time could be shortened if the air flow rate through the dryer were increased, however, the flow rate is limited by the dryer booster fan and the internal dryer fan. This indicates the need for further research and perhaps collaboration with dryer manufacturers. Decreased drying time and increased performance could result from the use of specialized dryers developed to incorporate larger flow rates and variable-speed fans. The temperature of the air entering the dryer could also be increased if the BIPV/T fan flow rate were decreased. This could also have positive or negative effect on the other systems relying on the BIPV/T fan.

5.6 Modelled vs. Actual Consumption

The previous sections showed a detailed breakdown of the whole-house energy consumption, collection and production at ÉcoTerra. To put these values in context, they were compared with expected values. Several models were created by the designers during the design phase, to predict the overall performance of the house and each of its systems. These models were revisited, now that significant monitored data is available, to examine how closely they matched actual performance. A summary of the results of this comparison are found in Table 5.9.

Table 5.9: Summary of modelled vs. actual whole-house energy consumption

Value	Modelled Value (kWh)	Actual Value (kWh)	Difference (%)	Difference Without Owner Additions (%)
Heat Pump (Including Fan)				
Heating	2,366	2,534	7.1%	7.1%
Cooling	0	124	-	-
Subtotal	*2,366*	*2,658*	12.3%	12.3%
Domestic Hot Water				
Subtotal	*3,276*	*1,578*	*-51.8%*	-51.8%
HRV / Air Cleaner				
HRV	635	593	-6.6%	-6.6%
Air Cleaner	0	429	100.0%	-
Subtotal	*635*	*1,022*	*61.0%*	-6.6%
Appliances/Lighting/Plug Load				
Subtotal	*3,993*	*4,715*	*18.1%*	18.1%
Other Loads				
Garage Heater	0	763	-	-
Auxiliary Elec Heater in HP	0	104	-	-
BIPV/T Fan/Pump	0	142	-	-
Controls	0	294	-	-
Heat Pump Recirc and Misc	0	1,612	-	-
Subtotal	*0*	*2,915*	-	-
Gross Consumption				
Total	*10,270*	*12,888*	*25.5%*	13.9%
PV Generation				
Total	*-3,465*	*-2,570*	*-25.8%*	-25.8%
Net Consumption				
Total	*6,805*	*10,318*	*51.6%*	34.1%

The house energy consumption model was created in NRCan's HOT2000 software (NRCan, 2010) and the PV generation was modelled with NRCan's RETScreen software (NRCan, 2005). Many of the issues addressed here are discussed in more detail in other sections of this thesis. Overall energy consumption is over 50% higher than the modelled values. This must be seen in context, however, as the actual performance of the house is still only 12.5% of the national average. Also, there are many reasons that the actual performance did not match the modelled performance.

On the demand side, the house consumed more energy than was expected in several areas. The heat pump energy consumption (for heating and cooling) was 12% higher than the modelled value. This is due to several factors. One is that there was no cooling modelled, so any cooling occurring at ÉcoTerra is beyond the modelled value. The setpoints used during design were 21 °C for the main floor and 19 °C for the basement. The occupants of the house kept the setpoints at 22.5 °C for the entire house during the day and 18 °C for the entire house during the night. Another factor is that the models were not able to account for the effect of the desuperheater on the heat pump performance. Also, a slightly larger capacity heat pump was installed in the house than was used during modelling.

Domestic hot water loads are significantly lower than those modelled. This is due to the fact that HOT2000 is not capable of modelling ÉcoTerra's drain-water heat recovery system, nor the BIPV/T thermal energy collection system. Neither can it model the energy supplied by the heat pump's desuperheater. All of these sources provided significant energy to the hot water system and therefore offset the domestic hot water loads.

The heat recovery ventilator used slightly less energy than modelled, but the air cleaner was added after the fact and therefore was not included in the modelled values.

The occupant-based loads, such as lighting and plug loads, were approximately 18% higher. This value is difficult to estimate because it depends completely on the habits and daily routines of the occupants. Additional lighting was installed by the occupants, and events such as holidays (during which the house was decorated with significant Christmas lights) were not considered during modelling.

Various other loads were not considered during the modelling phase. These include the energy consumption of the control system itself, and the BIPV/T fan and pump. The original design did not provide heating in the garage, but the owners now use the garage as a workshop, so they installed an electric fan-coil unit as supplementary heat. This load is significant and was not included in the modelling. The heat pump also has an auxiliary heating element intended for emergency use. However, its control sequence allowed it to come on more than necessary. Another change was that the heat pump fan was allowed to run continuously, but at low speed, when there was no heating or cooling demand. This is in order to reduce stratification in the house by mixing the air. This recirculation energy consumption was not modelled.

The electricity generated by the house's photovoltaic system was lower than expected, due to the higher than expected snow accumulation. The roof angle contributes to this greatly. At 30° slope, the snow seems to shed less easily. A better angle would be 40° or greater (Athienitis, 2007), but this was not practical due to restrictions of the prefabrication process.

5.7 Demand Reduction

Energy consumption savings is important, but demand reduction is also worth examining. Demand, in this case, is defined from the point of view of the electrical utility as the total power consumption of the house at a given moment. ÉcoTerra, as with other net-zero houses, is connected to the electrical grid and so draws electricity from the grid whenever the photovoltaic panels do not meet its needs. Due to the fact that ÉcoTerra produces power, it sometimes offsets its drain on the grid by either reducing its draw or actually contributing to the grid's available power generation.

Two types of demand were investigated: instantaneous and billed demand. ÉcoTerra produces power during sunny periods, so its demand is always less than that of a typical house (by the amount of power being generated at a given moment). This can be seen clearly in Figure 5.28, where there is an obvious decrease in energy consumption over the sunny part of the day.

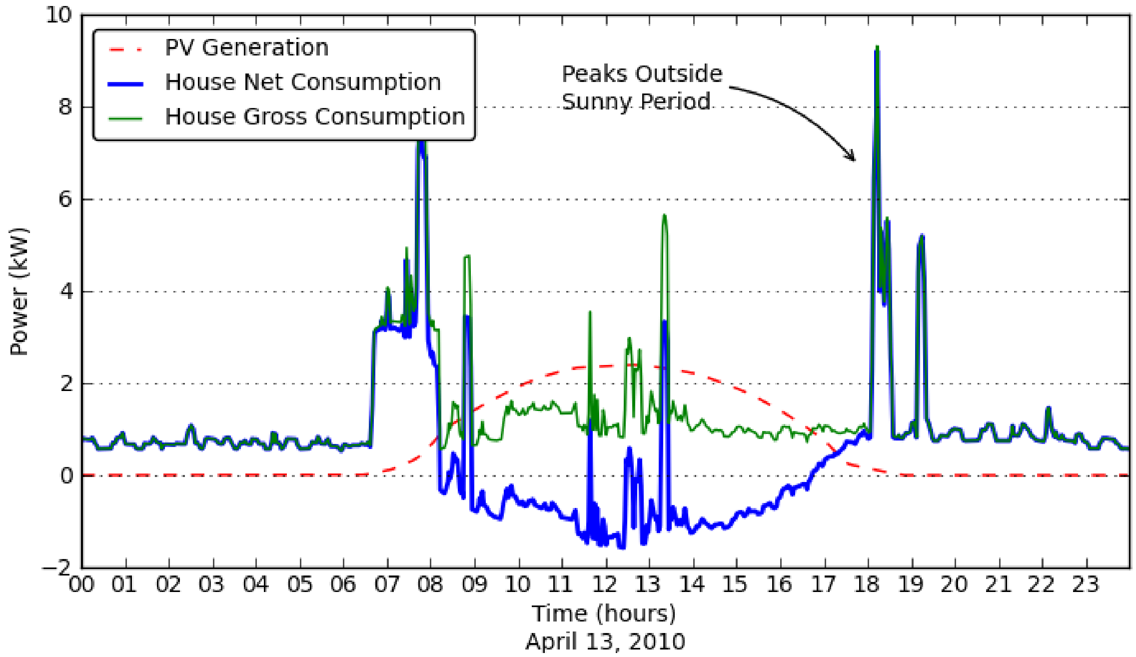

Figure 5.28: Demand reduction due to PV generation – April 13, 2010

Additional days were examined: a sunny cold day in December, and a sunny warm day in August. The graphs of these days are found in Figures 5.29 and 5.30. Similar patterns are observed in these cases, with the winter generation being significantly lower.

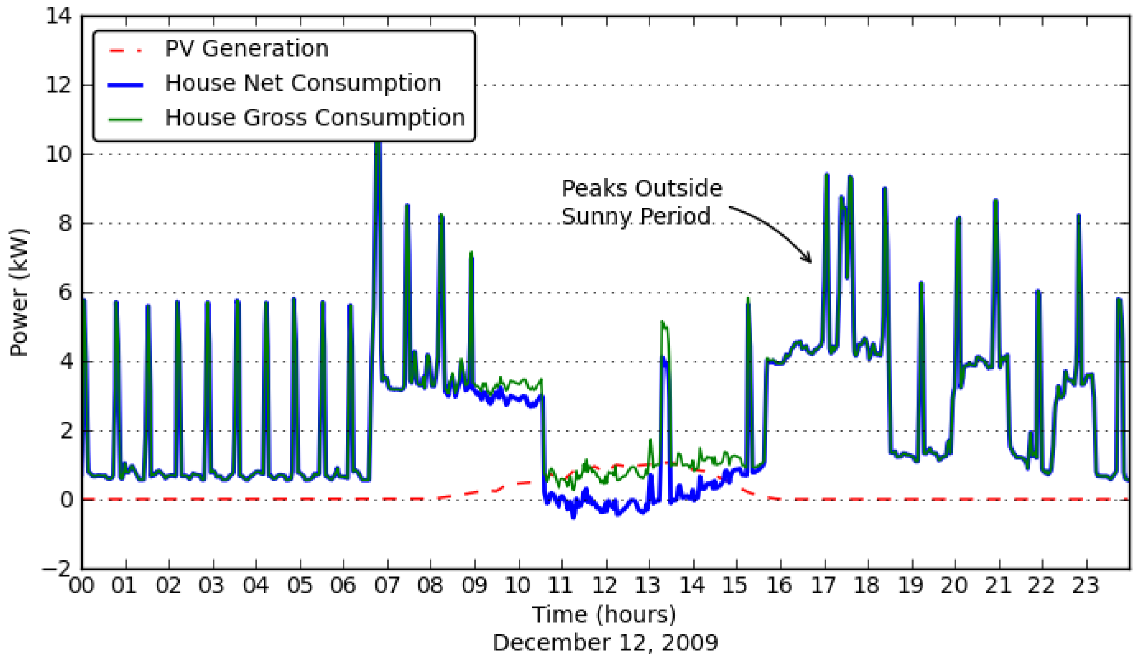

Figure 5.29: Demand reduction due to PV generation – December 12, 2009

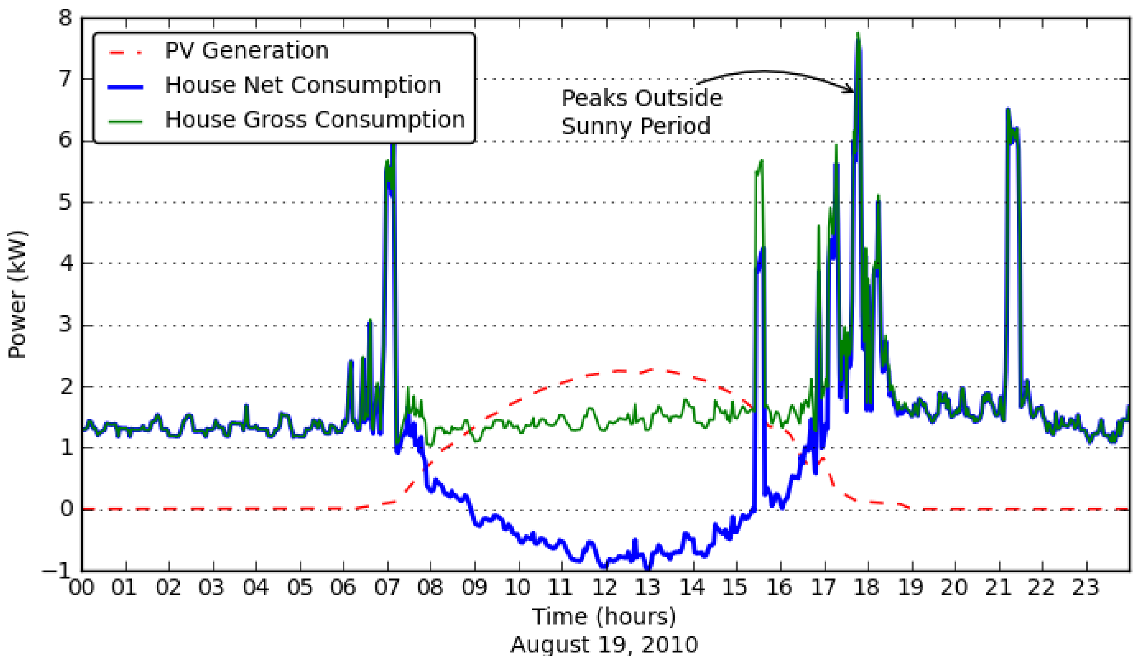

Figure 5.30: Demand reduction due to PV generation – August 19, 2010

The picture is not as clear, however, when it comes to billed demand, which is defined as the maximum demand that was sustained for 15 minutes or more over the period of one billing cycle. This is what customers see on their bill if they are billed at a rate code that includes demand. The details of billed demand can differ between utilities and many residential rate codes do not consider demand, but for the purposes of this thesis it is assumed that the building is billed for demand.

When billed demand is examined, very little difference can be seen between those times with or without a photovoltaic installation. The total annual savings in billed demand is estimated to be only 2.2 kW (less than $30 assuming a typical rate code). The reason for this can be seen in Figures 5.28, 5.29 and 5.30, which show that although the instantaneous demand is reduced by the photovoltaic generation, the peaks in demand do not usually occur during the sunny times of the day. Instead, they occur in the morning or evening. This corresponds to the morning routine before work and the evening preparation of meals. The heat pump also runs more during the times of day when there are reduced solar gains. The winter case, Figure 5.29, shows significant heat pump usage and many smaller spikes due to the auxiliary electric garage heater.

A mode detailed view of a shoulder season say is see in Figure 5.31. The smaller peaks are due to domestic hot water use; the large peak in the morning is the heat pump and the tallest peak occurs in the evening due to appliance use. There is a significant reduction in the instantaneous demand of the house during the day shown, which was sunny. The bottom graph in Figure 5.31 shows the solar radiation, outdoor temperature, indoor temperature and temperature setpoint.

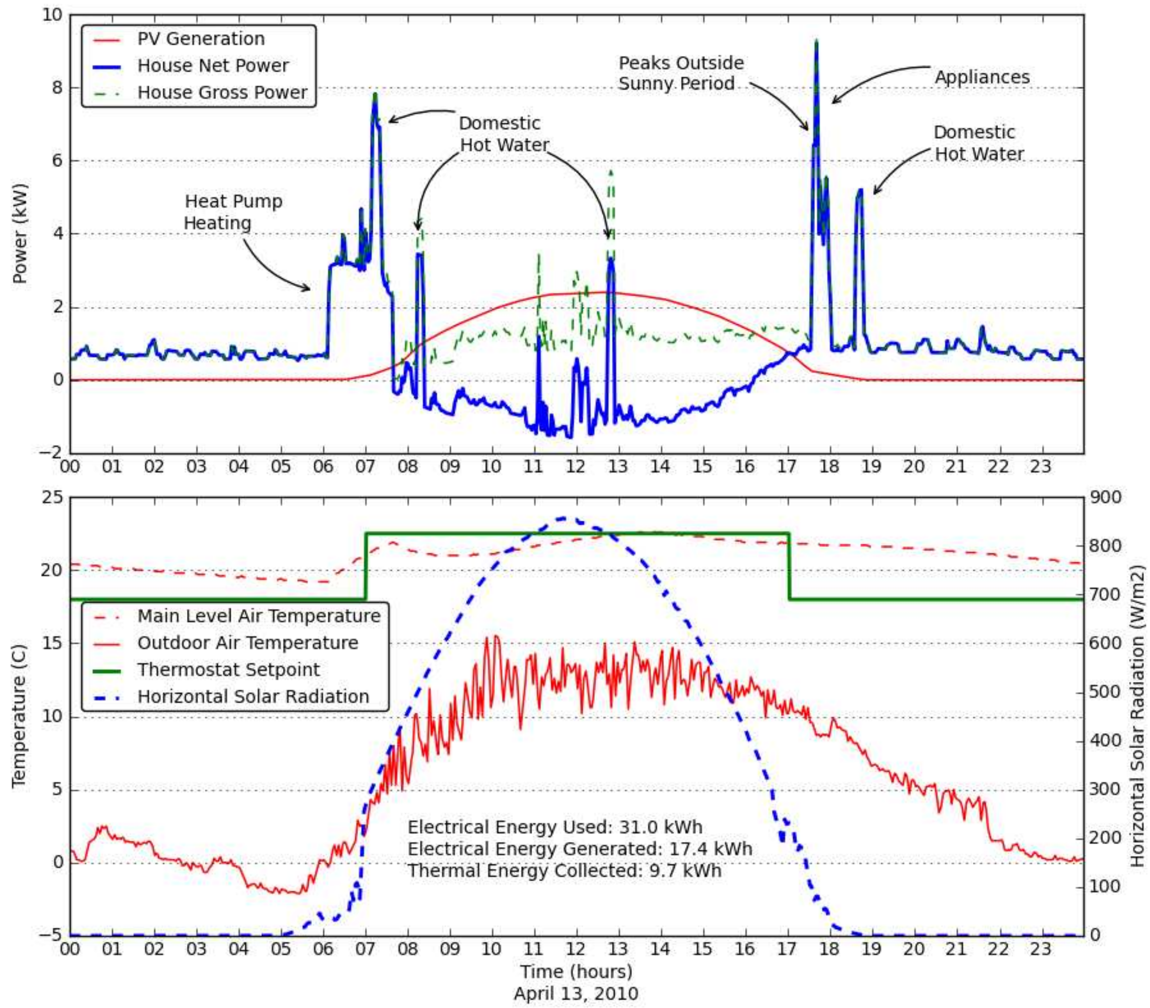

Figure 5.31: Demand reduction due to PV generation – April 13, 2010

The following figures show the differences between demand curves for different times of year. The three graphs down the left-hand column of Figure 5.32 are from sunny days and the three on the right-hand column are for cloudy days. The top, middle and bottom rows are for winter, shoulder season, and summer days, respectively. There is little difference between cloudy days – they all have minimal energy production, so their demand curves are unaffected. The sunny days all show a noticeable effect in that their energy consumption is reduced during the day due to PV generation. The negative consumption indicates exportation of electricity to the grid. The sunny days all show a similar pattern to that shown in Figure 5.31 (daily demand peaks occur outside of electricity-generating hours).

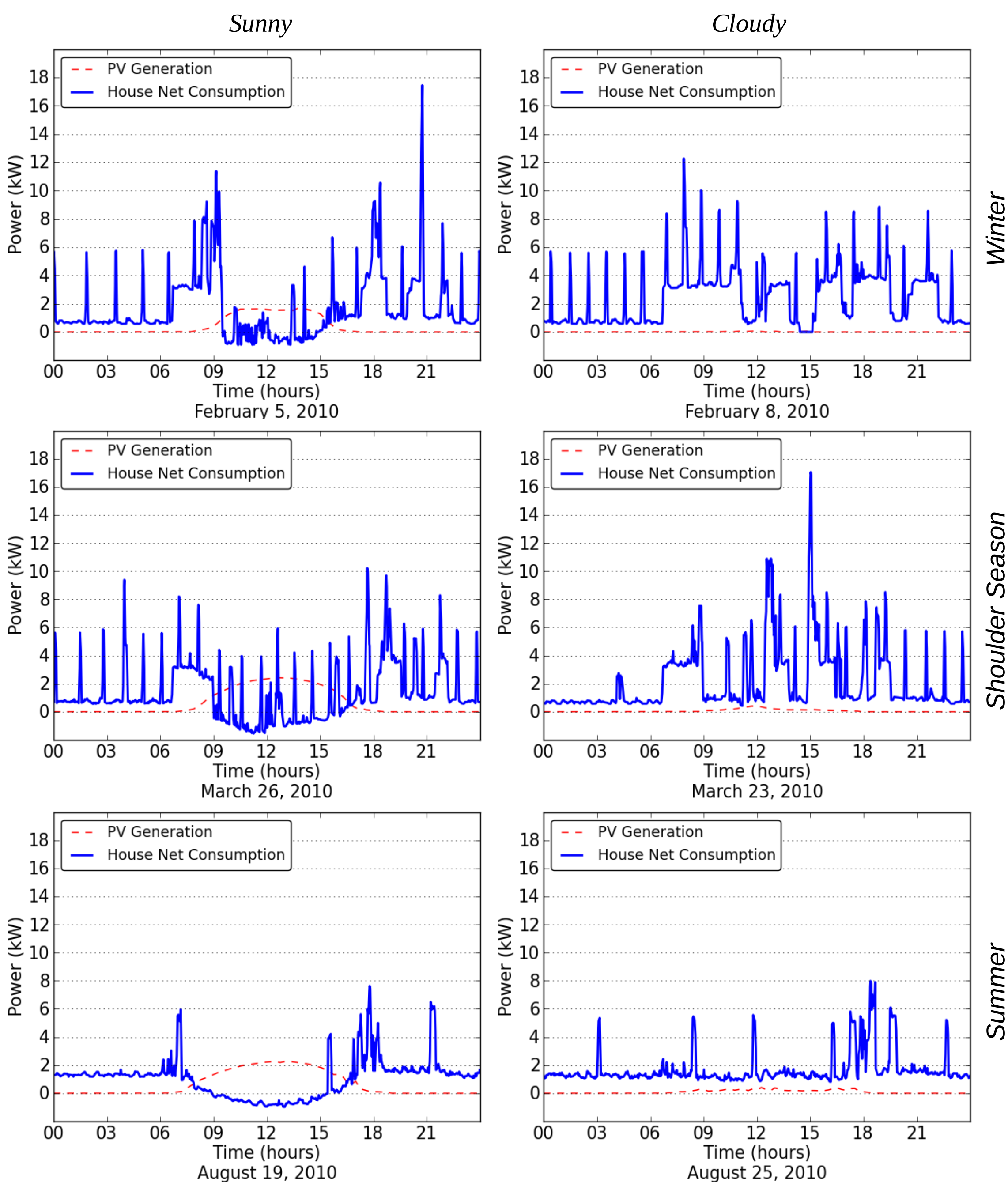

Figure 5.32: Production and consumption for representative days in 2010

6 STUDY OF WAYS TO REACH NET-ZERO

This section will examine the changes that could be made to ÉcoTerra or to similar, projects that would improve their performance and ultimately reach net-zero energy. A range of potential improvements will be examined from those that are easy to implement in any house to those that are feasible only for future houses. The following table (Table 6.1) is summary of the measures that will be examined in this chapter:

Table 6.1: Summary of potential energy-saving measures

Measure	Ease of Implementation	
	Existing Building (ÉcoTerra)	Future Net-zero Houses
Heat pump fan controls (reduced runtime)	Easy	Easy
HRV controls (reduced runtime)	Easy	Easy
Remove air cleaner	Easy	Easy
Improved air-tightness	Difficult	Easy
Improved windows	Not Practical	Easy
Duct redesign (reduced pressure losses)	Not Practical	Easy
Improved energy use feedback	Easy	Easy
Roof slope	Not Applicable	Easy
Improved shade control	Easy	Easy
Alternative garage heat	Medium Difficulty	Easy
Glazing section for roof	Not Applicable	Easy
Additional PV	Difficult	Easy
More efficient PV	Difficult	Easy
Reduced BIPV/T losses	Difficult	Easy

6.1 General Controls Improvements

Various improvements are possible for the control system. Many of them have already been implemented and are described in Section 3 - Control System. Some items, however, remain unimplemented as of the writing of this thesis.

The heat pump fan currently runs continuously, even when there is no heating or cooling demand. This is intended to reduce stratification of air temperatures between the three levels of the largely open concept house. At this point, no experimental results are available to determine the level of stratification that would exist without the recirculation, or what balance could be achieved between fan power and reduced stratification.

The HRV currently runs continuously at low speed unless the washroom or kitchen overrides temporarily put it into high speed mode. The runtime could potentially be reduced because ventilation is required only during occupied periods. A system that links ventilation rate to occupancy would provide a more efficient use of the HRV. Also, the use of an energy recovery ventilator (ERV), which recovers humidity as well as heat, could be investigated for future net-zero homes.

6.2 Lessons from Commercial Buildings

Prefabricated homes have a reputation for high quality due to their controlled manufacturing conditions. This is true of ÉcoTerra as well. Something that is clear from various previous studies is that high performance, low-energy buildings must also be high quality buildings (Torcellini et al., 2006). Furthermore, it is becoming clear that the attention to detail is critical to low-energy and net-zero energy houses. As with other high performance buildings, industry best-practices and building codes for houses are advancing continuously. One source of inspiration for potential improvements is the commercial building industry.

The manner in which duct systems are designed and constructed is a good example. For commercial buildings, an engineer or HVAC expert typically designs the duct system, selects the fans, and oversees its construction. In the residential sector, an engineer is usually unnecessary, however, with the HVAC systems in high-performance houses, small deviations from the design can have a significant impact on the performance of the system. This can be seen in the high static pressure loss in the ductwork at ÉcoTerra.

There are approximately a dozen 90 degree bends and ten dampers in 27 m (87 ft) of duct. Figure 6.1 shows the estimated worst case pressure loss diagram for the duct system from the entrance of the roof to the exit after the ventilated slab. The overall static pressure varies depending on the given damper configuration. The estimated worst case static pressure losses in the system were found to be approximately 331.6 Pa (1.33 in. Water). These values were calculated according to ASHRAE (2005).

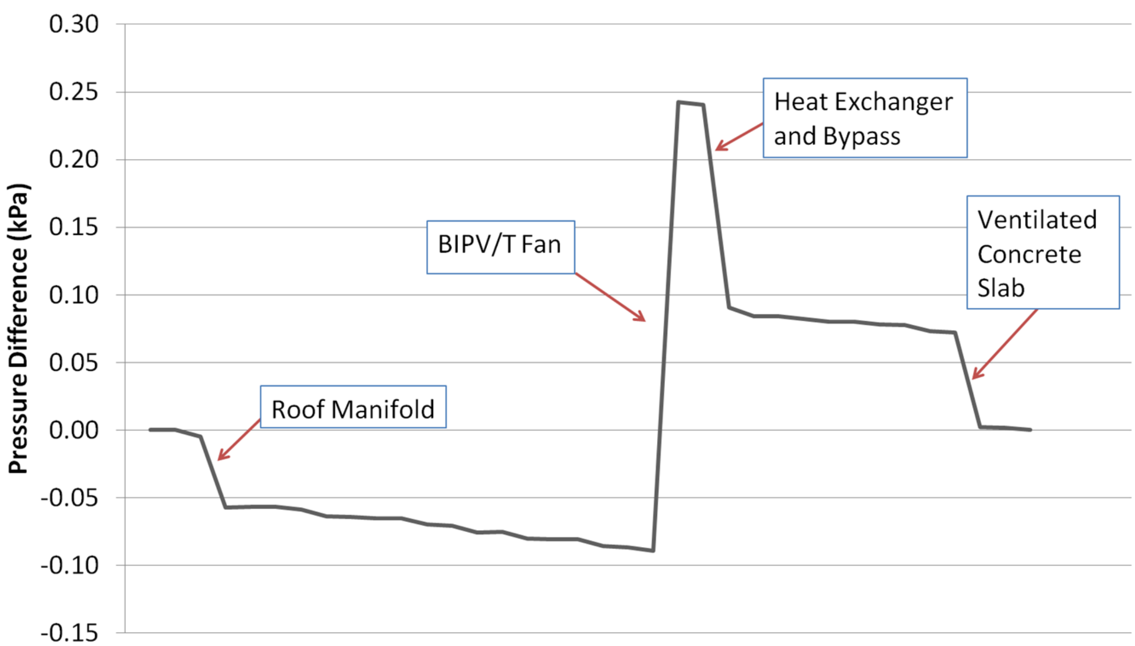

Figure 6.1: Pressure losses in the duct system for the estimated worst-case

It is estimated that if features such as standard duct transitions and turning vanes had been included, the pressure losses would have been reduced to approximately 287.8 Pa (1.16 in. Water). If a complete redesign was performed on the duct system and the amount of ductwork was reduced in key areas, the pressure losses would be further reduced to approximately 278.7 Pa (1.12 in. Water). Overall, this would result in a reduction of 52.9 Pa (0.21 in Water). This would reduce fan energy consumption and fan noise, and could possibly have led to the selection of a different fan during the design process. Reduced ductwork could also reduce materials and time required, and therefore cost. However, such improvements are best implemented early in the design process, thus reinforcing the concept of integrated design, in which an engineer or technician is involved from the beginning of design through to the completion of construction and commissioning.

Other practices that can further improve the residential sector include full air sealing of all ducts and duct joints, and vibration isolation for equipment like fans and pumps. The BIPV/T fan, for example, is screwed directly to the basement floor joist, which causes its vibration to be transmitted to the living space under some conditions.

A full, commercial building style commissioning would also be beneficial. This would include testing, adjusting and balancing of the HVAC system, and BIPV/T air and water systems as well as verifying the installed controls code. This option is, however, expensive and those industry experts experienced with commissioning are not familiar with the residential sector. Additional work is required in this area to provide the benefits of a full commissioning at a cost that is competitive in the housing industry.

6.3 Design and Construction

Various lessons can be learned from the design and construction process used for ÉcoTerra. First, is the fact that the prefabrication process provides significant advantages. These include a tightly controlled manufacturing environment which makes it easier to achieve an airtight and uniform building envelope. The prefabricated nature of the home also allowed less site work and quicker assembly once on-site. The potentially complicated assembly of the BIPV/T roof system was simplified due to the controlled environment in the factory. This allowed good insulation coverage, an airtight building envelope, and precise air balancing of the roof portion of the BIPV/T system.

The design process, discussed briefly in Section 1.3, was also an advantage to ÉcoTerra. This integrated design process used an interdisciplinary approach, which took advantage of the skills and experience of the various parties involved. The interdisciplinary approach is recommended for future net-zero homes and high performance buildings in general.

Nonetheless, some aspects of the design and construction process could be improved for future projects. One aspect of the design process that could be improved is the design of the duct system. Various people worked on the duct system throughout the project, and a significant amount of experience was present on the team. However, there was not enough continuity between the initial designs and the final construction. As the design evolves, a single point of contact is recommended for the major house components, such as the HVAC systems. When changes are made to the design, as is inevitable, someone must be responsible for examining the consequences of the change. If the change introduces additional pressure drop or cost, for example, then the whole team must be aware of this and proceed based on this knowledge. With ÉcoTerra, various changes were made along the way – such as introducing additional dampers, turns and transitions – and once the final ductwork was installed, significantly more pressure drop was seen in the system than was expected. This may have happened regardless of the process, but it should have been understood earlier so that if it turned out to be a major problem, it could be corrected before the operation of the finished product.

Minor details such as the addition of the air cleaner are another example of issues which should be understood at the time they occur rather than months later when the energy bills arrive. The air-cleaner was added simply because it was donated. It was not, however, part of the original design because the specified HRV has a built-in filter. The air-cleaner uses approximately 429 kWh annually, which is not significant for a typical house, but can be, for a house like ÉcoTerra whose equipment loads are already low.

The garage heater provides another lesson. The original design did not allow for heat in the garage, but the owners now use it as a workshop. Future designs should take this into account by, for example, creating a separate heating zone so that the garage temperature can be controlled independently.

6.4 Occupant Comfort and Behaviour

It is apparent, from working with the owners of ÉcoTerra, that for occupants, comfort is a priority. This is understandable and is an important factor to be considered during the design of such a house. Even if this issue is considered carefully by the designers, the occupants ultimately have a significant impact on their own comfort. The placement of floor rugs, the operation of windows and blinds, and the changing of setpoints all affect the comfort of the occupants, yet cannot be predicted easily.

The addition of the garage heater is another issue that may have been predicted had the home been being built for a specific owner. However, ÉcoTerra was not built with particular occupants in mind. When the new owners began using the garage as a workshop, they found it too cold and installed the heater. Another addition that was made consists of approximately 24 luminaires. Although daylighting was part of the original design, the owners felt that certain areas were dark and so added fixtures. The house was designed by minimizing non-south facing windows, as recommended for passive solar design. However, this may have resulted in a lack of daylight in the north side of the house.

The owners mentioned that they found the air in the house to be dry during the previous winter. This may be related to the control of the heat recovery ventilator. By reducing its operating time during unoccupied periods, the air may be less dry and the energy consumption of the HRV will also be reduced. The use of an energy recovery ventilator (ERV), in which latent energy is also recovered, would help with this.

Occupants can act to improve their own comfort, but must be educated and provided with the appropriate information about their home. For example, occupants should be encouraged to open windows and control blinds at appropriate times. This is an area that could be improved using a well-designed digital interface. There is an LCD touch-screen in the house, but its potential is not fully realized. This interface already provides some feedback, such as current weather, and identifying when the conditions are right for the solar-assisted dryer. However, additional variables could be used to make recommendations to the owners such as current energy consumption, when to operate the blinds, and when to open the windows.

6.5 System Complexity

Advanced buildings such as ÉcoTerra are complex systems and this can lead to problems. An example of this is the loose wire in the control panel. The wire connecting the dryer current sensor to the home's control system was loose, meaning that the current was read by the control system as being very high. The control system interpreted this to mean that the dryer was on, so the dryer booster fan was therefore activated. Due to concerns with backwards flow through the dryer fan, the BIPV/T fan was not allowed to run at the same time as the dryer booster fan. This loose wire, therefore, resulted in the dryer booster fan running continuously and the BIPV/T fan being locked out during several sunny weeks. It is not immediately obvious that the behaviour of the dryer is connected with the behaviour of the BIPV/T fan.

A similar situation involved a mispositioned valve for the hot water preheat tank. This valve was normally open, allowing water to circulate between the air-to-water heat exchanger and the preheat tank. During maintenance on the heat exchanger, the valve was closed, and mistakenly left that way. Due to the large number of valves and many feet of pipe, it was not until several visits later that the mispositioned valve was noticed.

Such situations become more common as the complexity of a system increases. Other factors contribute as well, such as the arrival or departure of team members. Even with good documentation and communication between incoming and outgoing team members, complex systems can be difficult to fully grasp.

This points to the importance of minimizing complexity wherever possible. The basic ideas behind passive solar, for example, have low complexity, so this type of design should be the first priority. Even the idea behind the BIPV/T system is relatively simple – bring solar-heated air into the building to heat something else. The challenge is to make the most use out of this energy with the least complex system. Integration is one way to achieve this. Using one building component to fill several roles can be a good way to reduce complexity.

6.6 Roof Slope

The roof at ÉcoTerra is sloped at approximately 30°. An optimal configuration, for ÉcoTerra's location, would include a steeper slope of approximately 45°. This slope was not practical due to issues involved in constructing the roof as a prefabricated module. It was also important to keep the length of the roof the same as the length of the PV panels, which were off-the-shelf products, so could not be lengthened or shortened. If the roof had not been the same length, then an obvious and unattractive line would have been visible across the roof where the panels stopped.

RETScreen was used to estimate the additional available solar energy if the roof was sloped at this optimal angle. The difference in slope alone would increase electrical performance by only 1.4%. However, if the potential increase in roof area is also considered, assuming a constant footprint, then approximately 23.1% more electrical energy would be collected annually. The RETScreen printout can be found in Appendix F - RETScreen Model.

The thermal energy increase was estimated in Doiron et al. (2011). The change in roof angle causes the roof to be better oriented for the winter, when the solar altitude is low and when thermal energy demands are greater. The roof was modelled for both the current 30° slope and the 45° configurations, and the thermal output was compared to the space heating and DHW loads on a monthly basis. The thermal energy was only considered useful if the outlet air temperature exceeded 20 °C because the air temperature must exceed the basement slab temperature to enable heat transfer. The model used is described by Chen et al. (Chen et al., 2010a). The results indicate that the useful thermal output of the BIPV/T roof nearly doubles during the heating season, while it remains relatively unchanged in the summer. For example, increasing the slope of the roof increases the fraction of loads met by its thermal output for March and November by 60% and 90%, respectively. As well as increasing the slope, the addition of a solar-assisted heat pump should be considered, as was done for the Alstonvale House (Pogharian, 2008), as it would significantly decrease the outlet temperature threshold above which the energy is useful.

The most significant effect, however, of having a suboptimal slope is the increased snow coverage in the winter. A roof angle of 40° or more, with the same roof construction and surface, has been shown to shed snow effectively (Athienitis, 2007). As of the writing of this thesis, CMHC is negotiating an arrangement with the owners that would have them photograph the roof of the house each day during the winter. This would provide a visual record of what proportion of the roof is covered by snow for a typical season and, therefore, what impact snow is having on energy collection/production.

6.7 Further Reducing Energy Consumption

Many lessons have been learned throughout the design and construction process, so the potential to further reduce ÉcoTerra's net energy consumption was considered as part of Doiron et al. (2011). The easiest and least expensive changes were examined first, followed by changes to the building envelope and then changes related to generation.

Additional savings (429.2 kWh/year) can be achieved by removing the air cleaner, which can be considered redundant to the air filter built into the heat recovery ventilator (HRV). The HRV could also be run less frequently during unoccupied periods. A conservative reduction of 10% (59.3 kWh) is assumed for this option.

The owners have been made aware of the energy consumption of the garage heater, so it is expected that during future winters, its energy consumption will be reduced. The auxiliary heater in the heat pump itself is also expected to operate less due to adjustments in the control sequence that prevents it from being activated unless there is need for emergency heating. See Section 3 - Control System for details.

The charging of the domestic hot water preheat tank is also expected to be more effective in coming years, as a misconfiguration of the system's valves was discovered and corrected. The BIPV/T fan was also unable to run for several weeks during the summer due to a loose wire in the control panel, so more energy should be stored in the slab in the future.

As discussed in Section 5.2.3, the discretionary loads are the single largest part of the home's energy consumption. If the occupants are provided with comprehensive and useful feedback on their energy use, it is reasonable to assume that the discretionary loads, such as lighting and appliances, could be reduced by approximately 10% (Chetty et al., 2008). The appliance loads would also be slightly less due to a change in the control sequence for the solar-assisted dryer, which should make it more effective. It would be particularly useful if the electrical loads of the house were further disaggregated (e.g., lighting by room, each major kitchen appliance). This would allow the homeowners to make direct connections between their actions and the associated electricity cost.

These improvements were analyzed, as part of Doiron et al. (2011), using a model of ÉcoTerra created in EnergyPlus (US Department of Energy, 2009), which was chosen for its relative ease of use, extensive features and interoperability with a variety of other tools. The geometry for the model was derived from the architectural drawings and manually input using SketchUp/OpenStudio (US Department of Energy, 2009). The house was modelled as four conditioned zones, in an attempt to properly characterize any discomfort resulting from stratification. In addition, a zone was assigned to each of the roof spaces and to the garage. A survey of energy-consuming household objects was performed to determine appropriate internal gains. Appliance, lighting and air distribution loads were assumed to be seasonally-invariant. The infiltration rate was input based on the value measured for the house using a blower door test.

An operational improvement examined using this model was to change the controls of the heat pump distribution fan. The fan is currently operated in a low-speed, recirculation mode whenever there is no heating or cooling requirement. Simulations were run to determine the potential benefit from reducing the fan run time (when heating and cooling are unneeded) to operate only when the mean air temperature difference between zones exceeds 2 °C. This resulted in annual savings of 722 kWh.

The addition of intelligent shade control – either manual or automated – was also considered. For the cooling season, shades were assumed to be closed during periods when the zone air temperature exceeds 20 °C during the period from May 1 to September 30. This is predicted to reduce cooling loads, resulting in 226 kWh of electricity savings. However, the owners were observed to use less than 124 kWh of cooling for the year, so this savings is likely overestimated. This may be due to underestimating the manual use of blinds and windows. Proper shade control also improves thermal comfort by mitigating overheating and direct beam solar radiation on occupants. However, it must be balanced with the occupants' desire for views to the outside, therefore, closed shades are most suitable for unoccupied periods.

If all of these improvements were implemented, the annual energy consumption of ÉcoTerra could be as low as 7,716 kWh (a 25% reduction). The potential energy end-use breakdown is seen in Figure 6.2. This reduction would bring the house down to just under 10% of the energy density of the average Canadian home. Any further reduction would depend primarily on modifying occupant-related loads or on the addition of generating capacity. This could be in the form of additional photovoltaic panels, more efficient panels to replace the existing models, or other renewable energy sources such as wind.

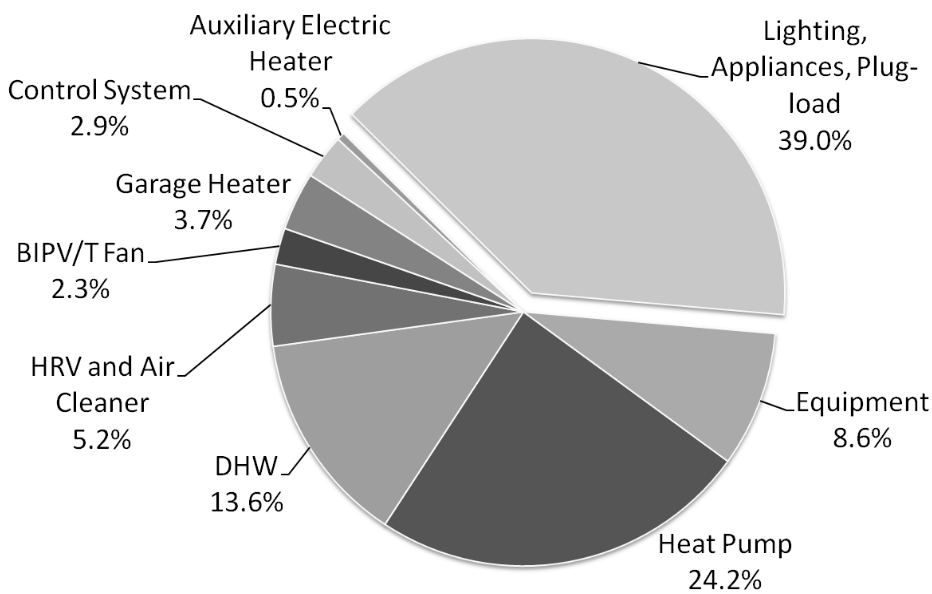

Figure 6.2: Predicted annual energy end-use breakdown

This predicted end-use breakdown is similar to the actual breakdown seen in Section 5.2.3 - End-use Breakdown. The lighting, appliance and plug loads make up a slightly greater percentage of the total. This further emphasizes the importance of occupant behaviour.

6.8 Building Envelope Improvements

Potential improvements to the building envelope were also examined. The house is already more air-tight than a typical Canadian home (0.85 ACH at 50 Pa), but lower leakage rates are possible. Another EQuilibrium™ house, Riverdale, achieved 0.5 ACH at 50 Pa (CMHC, 2009a). Calculations were performed to estimate how much energy would be saved if ÉcoTerra had achieved the same air-tightness.

Air changes per hour defines how often the volume of air in the house is exchanged with the outdoors. The standardized measurement uses a blower-door tester and a pressure differential of 50 Pa. This can be approximately converted to air changes under natural outdoor conditions by dividing by 20 (Sherman, 1987). This value was used to calculate the volumetric flow rate of air leaking from the house (and therefore being replaced with outdoor air). The indoor and outdoor temperatures are monitored, so this data was substituted into Equation 5.3 to calculate the resulting load. The average COP of the heat pump was used to calculate the energy consumption required to satisfy this load. This procedure was repeated for the proposed case of 0.5 ACH and the two were compared. It is estimated that 129.7 kWh would be saved annually if ÉcoTerra's air leakage was reduce to the same level as that of Riverdale.

A similar analysis was performed, using Equation 5.4, to estimate what energy savings may be possible if windows with higher insulating value were used. The existing windows have an insulating value of RSI 0.85 (R 4.8), but the windows at Riverdale have insulating values of RSI 1.2 (R 6.8) (CMHC, 2009b). If the windows at ÉcoTerra had similar insulating values, approximately 301.7 kWh would be saved annually. The increase in insulating value may come with a disadvantage, however, since it can also mean reduced solar heat gain.

6.9 Other Uses for BIPV/T Energy

Another way to reduce the home's energy consumption would be to increase the house's solar fraction by making greater use of the energy available from the BIPV/T roof. One way to do this would be to use the solar-heated air to heat the garage in place of the existing electric fan-coil unit installed by the owners.

The energy available from the system in its current form was estimated assuming that the garage was maintained at a constant 15 °C and using the air exiting the BIPV/T system as a source of energy. Equation 5.3 was used to estimate that the additional energy available would be 137.1 kWh for the year analyzed – 18% of the energy consumed by the garage heater. This is energy that is not used by the other components in the system and so would otherwise be wasted.

This estimate is low, however, since the control system is designed to allow the BIPV/T fan to operate only when the temperature in the roof is higher than that of the DHW preheat tank or slab. Both of these temperatures are typically much higher than would be required to heat the garage to a minimal level. An effort was made to account for this effect by using a mathematical model, developed by Chen et al. (Chen et al., 2010b), in MATHCAD. More detail regarding the model is found later, in Section 6.10. Using the model, energy was collected only while the outlet temperature of the BIPV/T roof was between 15 °C and 20 °C. These conditions represent times when the BIPV/T system would not normally operate because these temperatures will always be lower than the preheat tank of slab temperatures. The model predicted that an estimated 156.6 kWh would be available to heat the garage with these conditions. This can be added to the energy previous calculated because it is additional collection from times other than normal operation. This gives a total of 293.7 kWh – 38.5% of the consumption of the garage heater.

Using the BIPV/T air to heat the garage has the potential to reduce energy consumption, but it also has disadvantages, at least at ÉcoTerra. Drawing air through the duct system to the garage would mean drawing cool air through the center of the house. The ducts are insulated, but there would be some impact on the heating loads of the house. This would be a retrofit, so the walls would need to be opened and new wiring, ductwork and controls would also be necessary. Also, this scenario would involve the air from the BIPV/T system mixing with the air inside the garage. The air from the roof was not originally intended to be used inside occupied spaces, so it may have some odour. Despite these potential downsides, it has promise and so should at least be considered for future net-zero houses.

It was been shown that there is often heated air available that is not directly useful at the given moment due to its low temperature. This air could still be used, however, as a source of energy for an air-source heat pump. This solar-assisted, air-source heat pump concept was incorporated into the Alstonvale house and shows promise. It has the potential to reach high efficiencies, but requires good control and careful design of the thermal storage system (Candanedo et al., 2007).

6.10 BIVP/T Energy Collection

The effectiveness and rate of heat transfer of the heat exchanger could be improved if the flow rate through it were varied. The existing controls attempt to maintain a specific temperature exiting the BIPV/T roof cavity. This temperature is chosen based on the temperature of the preheat tank and slab only. This temperature setpoint should be chosen based on several variables, including the temperatures of the slab, preheat tank, room air, outdoor air, and potentially the weather forecast. More research is required in this area.

The amount of solar energy stored in the preheat tank is negatively affected by its interactions with the desuperheater. On November 3, 2010, significant solar radiation was available, but no energy was stored in the preheat tank, as the desuperheater had already heated the tank above its setpoint. This effect can be seen in Figure 6.3 and should be considered in future designs.

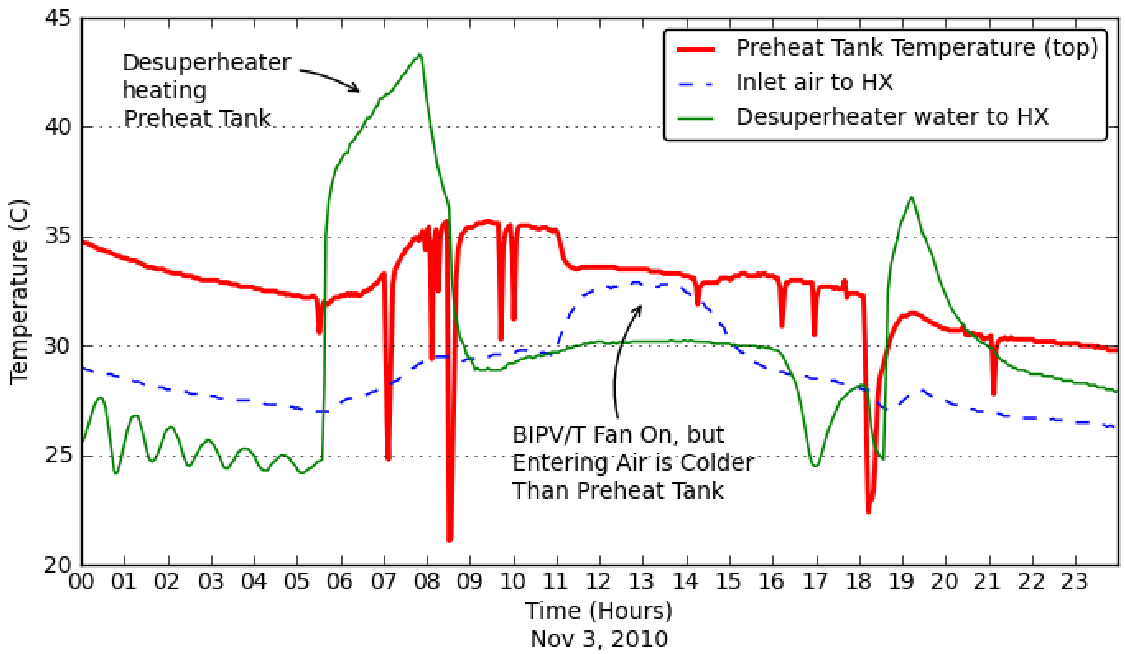

Figure 6.3: Preheat tank charging and temperature trends

It is suspected that this would occur primarily during the winter, when there is heavy use of the heat pump and, therefore, of the desuperheater as well. It is estimated that the BIPV/T system operated for approximately 19 hours in 2010, during which the preheat tank was unable to accept the heat available to it due to its already high temperature. This is only 5.5% of the BIPV/T runtime, but it does not account for the times when the BIPV/T system would not have operated at all due to lack of demand from any component.

An effort was made to quantify this effect by calculating the number of hours during the year that the roof cavity air temperature was above 25 °C and yet the preheat tank was not being charged. The value of 25 °C was chosen simply because the tank will never be at or above this unless heated by an outside source. If temperatures such as this are available from the roof, then there is potential to store energy in the preheat tank. Losses between the roof and the basement were also accounted for. It was estimated that there were 517 hours during the year when the roof air was above 25 °C, but the preheat tank was not charged. This indicates that the desuperheater has a strong effect on the temperature of the preheat tank and that significant solar energy may have been lost.

Possible solutions include greater thermal storage or controlling the desuperheater to prioritize energy collected from the BIPV/T roof. A control-based solution may require a predictive element, as the desuperheater would need to be disabled based on future availability of solar energy. More research is required in this area.

The slab storage component could also be improved. On April 20-21, 2010, the heat pump ran during the mornings, but the slab was not charged, even though significant heat was available. This heat was not used due to the control sequence, which does not allow slab charging when the outdoor temperature is above 10 °C. This is generally acceptable, but in the shoulder seasons, the following nights and preceding mornings are cold enough to require heat, as can be seen from Figure 6.4. If additional solar energy had been stored, the heating energy requirement may have been reduced. It is not necessarily a simple matter to adjust the setpoints, however, as allowing slab charging when the outdoor temperature is higher risks causing overheating. More research is required in this area to balance the charging with the risk of overheating. Predictive control based on weather forecasts may be useful in this case.

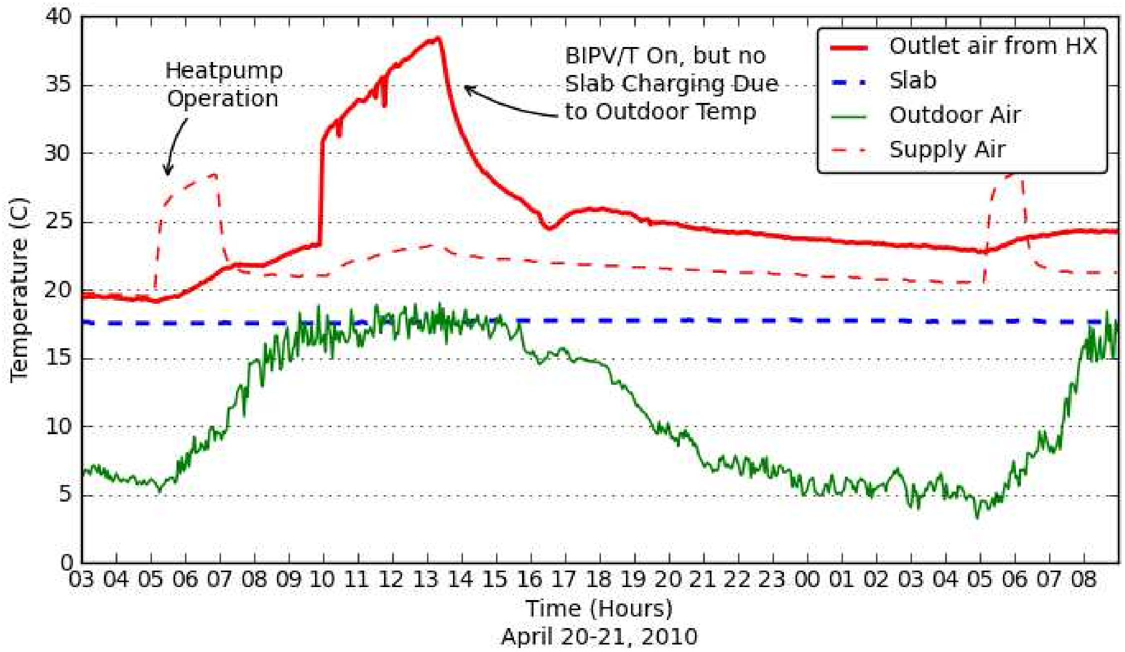

Figure 6.4: Slab charging and temperature trends

The energy stored in the slab as calculated in this thesis is potentially overestimated because an error in the programming of the control system, which allowed the slab to be heated during the summer. Just under 100 kWh of energy was stored in the slab during the summer. This energy was not needed and may have contributed to some overheating.

It was estimated in Section 5.4.3 that 1,545 kWh was collected at the roof. If this is compared to the total amount of energy stored of 575 kWh (from Section 5.4.2 – Energy Collected and Generated), there is clearly potential to improve the system, and to increase the fraction of solar energy collected. This difference is the result of losses in the duct system, as well as the imperfect heat transfer at the air-to-water heat exchanger and in the slab. If the remaining 970 kWh of energy collected at ÉcoTerra was used or stored, it would, for example, reduce the domestic hot water consumption by 61% or eliminate the need for auxiliary electric heat in the garage.

Future projects could increase energy collection by adopting a design similar to that of the Alstonvale house (another EQuilibrium™ project). Alstonvale used a similar BIPV/T roof concept, but incorporates a clear glazing section near the top of the roof, before the air outlets. It is estimated that this glazing section can increase the difference in temperature achieved by 30% (Candanedo et al., 2007). This increase in temperature, combined with an increase in roof slope, as discussed in Section 6.6 – Roof Slope, would allow an overall increase in energy collection of approximately 60%. This is equivalent to an additional 896 kWh of thermal energy collected at the roof. This comes at the expense of some electrical energy, however, because adding the clear glazing section reduces the area available for PV by about 25%. This loss is approximately equivalent to the gain achieved due to a steeper roof angle.

Another way to improve the BIPV/T performance is to reduce the losses observed between the roof and the basement. These losses were discussed briefly in Section 5.4.3 – Thermal and Electrical Efficiencies where it was seen that there may be as much as 20% loss between the roof and manifold alone. There is also an observed loss between the manifold and the basement, as discussed in Section 5.4.1 – BIPV/T Temperature Trends. These losses likely result from a combination of effects such as the thermal mass of the ducts, imperfectly sealed or insulated ducts, and leaking dampers. Simply reducing the amount of ductwork, as described in Section 6.2 – Lessons from Commercial Buildings, would have a positive effect on this issue. More research is needed in this area and special attention should be paid to this topic in future projects.

Maximizing the use of available solar energy is important if future low-energy houses are to reach net-zero energy consumption. The maximum energy that could be collected from ÉcoTerra's BIPV/T roof was examined in order to give perspective to the house's actual performance. A mathematical model, developed by Chen (Chen et al., 2010b), in MATHCAD, was used. The model requires inputs of monitored data from ÉcoTerra (solar radiation, wind speed, outdoor temperature and attic temperature) and outputs the outlet temperature of the BIPV/T roof. Equation 5.3 was applied using the difference between the inlet and outlet temperatures, and constant air velocity (0.85 m/s) and properties. The model was applied for the twelve months of available data. The model shows that had ÉcoTerra's BIPV/T system run whenever the outlet temperature was at least 20 °C, it could have collected approximately 3,259 kWh. Compare this with the energy actually collected of 1,545 kWh, and it is clear that there is significant potential for improvement.

6.11 Achieving Net-Zero

If all of the various potential improvements mentioned in this chapter were applied to a new house, with similar geometry and energy usage patterns, its energy consumption could be as low as 3,543 kWh per year. This assumes a new roof angle of 45° (less snow, more area), higher efficiency PV (from 6% to 12%), the discussed building envelope improvements, as well as the improvements mentioned in Section 6.7. It also assumes some garage heating with the BIPV/T roof, a clear glazing section, increased collection at the roof and reduced losses between the roof and basement. This level of energy consumption would be a 65.7% reduction over ÉcoTerra's existing case and only 9.2% of the national average, but still not net-zero. If, however, additional PV panels were added to the lower roof section, net-zero energy could be achieved. A summary of the measures from this chapter is found in Table 6.2.

Table 6.2: Summary of energy-saving measures to reach net-zero

Value	Existing Value (kWh)	Potential Value (kWh)	Difference (%)	Method of Reduction
Heat Pump (Including Fan)				
Heating	2,534	1,912	-24.6%	Fewer air changes, better windows, more BIPV/T slab charging,
Cooling	124	0	-100.0%	Better blind controls
Subtotal	*2,658*	*1,912*	-28.1%	
Domestic Hot Water				
Subtotal	*1,578*	845	*-46.5%*	More BIPV/T preheat charging
HRV / Air Cleaner				
HRV	593	534	-10.0%	Better control
Air Cleaner	429	0	-100.0%	Eliminate air cleaner
Subtotal	*1,022*	*534*	*-47.8%*	
Appliances/Lighting/Plug Load				
Subtotal	*4,715*	4,008	*-15.0%*	Provide more and better occupant feedback
Other Loads				
Garage Heater	763	88	*-88.5%*	Better control, BIPV/T heat
Auxiliary Elec Heater in HP	104	52	-50.0%	Better control
BIPV/T Fan/Pump	142	237	67.0%	Increased BIPV/T usage
Controls	294	294	-	-
Heat Pump Recirc and Misc	1,611	889	-44.8%	Reduced heatpump circulation mode runtime
Subtotal	*2,914*	*1,560*	-46.5%	
Gross Consumption				
Total	*12,887*	*8,858*	*-31.3%*	
PV Generation				
Upper, BIPV/T section	*-2,570*	-5,315	*106.8%*	Double efficiency, less snow (greater angle), greater roof area, but glazing section.
Lower Roof, Just PV	-	-3,807	-	New PV on lower roof, no BIPV/T so uncooled, 12%
Subtotal	-2,570	-9,122		
Net Consumption				
Total	*10,317*	*-264*	*-102.6%*	Slightly net positive

Once energy consumption is this low, factors such as occupant behaviour, and the energy efficiency of appliances and electronics become the next biggest challenges. Other measures such as varying wall insulation, trying different window coatings, and optimizing controls are areas worthy of further research, but additional on-site generation is required, unless significant progress is made in these areas. There is additional space area on the lower roof at ÉcoTerra that could be covered in PV panels. This area, however, would not allow the panels to be cooled as easily as on the upper roof, as is currently done by the BIPV/T system. This would reduce their energy output slightly and also their life expectancy.

7 CONCLUSIONS

This thesis provided a comprehensive, whole-system energy analysis of ÉcoTerra. The overall energy use and end-use breakdown were analyzed and discussed. Also addressed were lessons learned throughout the energy analysis process and also throughout the design, construction and operation of the house. The large amounts of high quality data available were structured and organized into usable forms for the work of this thesis and for the work of future researchers.

7.1 Energy Performance

The twelve months of available occupied data was analyzed. The house consumed 12,888 kWh in the analyzed year and produced 2,570 kWh, for a net annual energy consumption of 10,318 kWh. This means the house's energy density is only 18.1% of the national average for single-family detached homes. The garage heater and air-cleaner were not part of the original design. If they are subtracted from these values, the gross consumption becomes 11,696 kWh and the net consumption becomes 9,126 kWh (16.6% of the national average energy density).

Significant work was done to split the overall energy use into end-uses. This enables a better understanding the overall energy use in the house and leads to some conclusions. First, the occupant-related loads are very important. Once the heating and hot water loads are reduced to the level typical for a low-energy house, the lighting, appliances and plug loads represent the single largest energy use. Also, typically small loads, such as the heat recovery ventilator become more important as other loads shrink.

A Fourier analysis was performed on the power data, but it was found that the loads were not regular enough for this approach to be useful over the periods of time for which such analyses are desired (monthly or annually).

The performance of the BIPV/T and heat pump systems were examined. The heat pump was found to have an overall COP of 3.77 for the year and the BIPV/T system collected 575 kWh of energy for every kWh of energy spent. The BIPV/T system had several problems, however, including a loose wire in the control panel and a mispositioned valve. These issues were corrected so that future performance is expected to be better, especially if the control sequence is optimized.

The photovoltaic panels collected significant energy, though not as much as predicted. This is due mainly to snow collection on the roof and, potentially, some shading. These issues cannot easily be corrected, but should be considered carefully for the design of future low-energy houses. The photovoltaic panels operated at an efficiency of 5.15% compared to their rated efficiency of 6.29%. Some reduction is expected for amorphous photovoltaic panels. This calculated efficiency includes some error due to the dependency on a single point measurement for solar radiation.

The performance of the solar-assisted clothes dryer was examined and found to provide significant savings over a typical dryer. However, the length of time to dry a load of laundry is increased. The drying time could be reduced if dryers were equipped with variable-speed fans, so further research, and collaboration with industry, is needed.

The house's performance was compared to the expected values obtained from the original models created for the EQuilibrium™ program. The overall performance was significantly lower than what was modelled, but a wide range of factors account for this.

These include the lack of accounting for the BIPV/T system in the original models and the later addition of several control sequences and pieces of equipment. The higher than expected snow accumulation and occupant-based loads also help to explain this.

Some simple improvements were examined and if they are all implemented, the annual energy consumption of ÉcoTerra would be as low as 7,716 kWh.

Significant BIPV/T energy was collected (1,575 kWh), but significant energy was lost due to losses or due to there being no use for the energy at the given moment. The domestic hot water tank was often fully charged by the desuperheater and the slab control sequence was sometimes not able to run due to the outdoor air temperature. The overall solar fraction could be improved if more energy were used for things like heating the garage or drying clothes.

The issue of electrical demand was examined and it was found that although there is a positive impact on instantaneous demand, there is little benefit in terms of billed demand. The pattern of consumption and production was examined for six representatives days in a year. It was found that although the demand is reduced due to generation, the peaks occur outside of electricity-generating times (in the mornings and evenings).

7.2 Reaching Net-Zero

A variety of measure were examined in an effort to find ways of reaching net-zero energy consumption. Various improvements were made to the control system throughout the writing of this thesis and more are recommended. These include optimizing the speed of the BIPV/T fan and reducing the run-time of the heat pump fan in recirculation mode. Changes already made include reducing the number of times that the auxiliary heat pump heater operated and allowing the dryer booster fan to run concurrently with the BIPV/T fan.

Several lessons were learned from the commercial building industry, such as applying best-practices in duct design, duct sealing, vibration isolation, duct transitions, and the coordination of changes on-site

Occupant comfort was confirmed to be an important issue. Most occupants of a home will not compromise their comfort for the sake of energy consumption. Overall, the owners of ÉcoTerra report a comfortable first year in the house.

Even with the relatively simple principles applied, the complexity of houses like ÉcoTerra can lead to problems. This should be taken into account when planning and designing future low-energy buildings.

The roof slope could be improved for future low-energy homes. The slope of ÉcoTerra's roof is 30°, but the optimal slope for its location would be 45°. This made relatively little difference in terms of optimal solar angle, but had significant impact on overall generation, as it made snow accumulation worse. A steeper slope would also have allowed more photovoltaic panels to be placed on the roof.

The potential energy performance of the house was examined and the energy consumption could be reduced by approximately 25% with some relatively simple measures. These savings result from changes to the control system, some occupant feedback, and taking into account some corrections made such as the mispositioned valve and the loose wire. Some improvements were considered for the building envelope as well. These include windows with increased insulating value and increasing the air-tightness of the house.

The original design of the house did not provide heat to the garage, but the owners now use it as a workshop. The potential exists to use heat from the BIPV/T roof to heat the garage, instead of using the supplementary electric heater installed by the owners. Several scenarios were examined, and it is estimated that up to a third of the garage heater energy could be offset by the BIPV/T system. However, this would require additional ductwork and wiring, and changing the controls of the BIPV/T system.

Several factors reduced the effectiveness of the BIPV/T system. The heat pump desuperheater provided significant energy to the preheat tank, but this sometimes prevented solar energy from being stored. The outdoor air temperatures also prevented the slab from being charged as much as it could be. These issues require further study, however, because the possible solutions could negatively impact other systems. Roof systems similar to that used at the Alstonvale net-zero house, as well as decreasing heat losses in the BIPV/T ductwork, offer other opportunities to improve future designs.

If all of the proposed changes and improvements were implemented in a new house, with similar geometry and energy use patterns, the energy consumption of that house could be as low as 3,543 kWh per year. This assumes a new roof angle (less snow, more area), higher efficiency PV (from 6% to 12%), the discussed building envelope improvements, as well as the improvements mentioned in Section 7.1. It also assumes some garage heating with the BIPV/T roof, a clear glazing section, increased collection at the roof and reduced losses between the roof and basement. If additional PV panels were added to the remaining, unused, lower roof, the net energy consumption would be further reduced. In fact, the house would be slightly net-positive at -264 kWh annual consumption.

7.3 Future Work

With such large quantities of data available, and more being recorded every day, many avenues for further study are available, including the following:

- Consider not only energy stored, but how useful that energy is and any efficiencies associated with actually using the stored energy (losses during storage, retrieval, etc). Some energy is lost to the ground, to the air, etc. Time-of-use issues are also worth examining. Energy is not always needed, so it may be better to store energy closer to the time of use to minimize storage losses. Even if this meant lower collection efficiency, it would increase the amount of solar energy being used and therefore reduce overall energy use by the house.
- The control of the BIPV/T fan has not yet been optimized. The fan controls should account for the efficiency of the heat transfer at the roof, as well as the effectiveness of the heat exchanger.
- If transfer functions were developed that would predict outlet temperature of the roof given the current outdoor conditions, the fan power could be predicted and the potential energy stored could be estimated. Then a COP could be predicted and the highest value could be chosen. This would allow control of the fan speed to provide the best balance of fan power, efficiency and thermal energy collection.
- Predictive control could be examined to improve the prioritization of energy storage or to improve heating and cooling of the slab.
- The control of the ventilated slab has yet to be optimized. Various factors should be considered to provide the best efficiency while not allowing the slab to get too cold or too hot (for comfort reasons).

- A significant amount of lighting, appliance and plug load energy is consumed at ÉcoTerra. The energy signatures of specific appliances could be investigated in an effort to achieve more detail in the appliance energy end-use breakdown.

7.4 Limitations and Scope

This thesis focuses on a near-net-zero energy house in a cold climate (Montreal, Canada). Many aspects of passive solar design can be adapted to other climates, but the priorities may be different, therefore, not all findings are directly applicable in all climates. Some aspects of non-residential buildings are related, but this work focuses on residential buildings.

The energy collected and generated was examined, but the manner in which this energy was used was outside the scope of this thesis. A number of important issues should be considered, such as the efficiency of transferring energy from one location to another and losses during storage.

Each low-energy house may use different technologies or even different implementations of the BIPV/T system, but this thesis shows the potential for this type of system. The specific performance of other systems will not necessarily be the same as those at ÉcoTerra, but should be similar.

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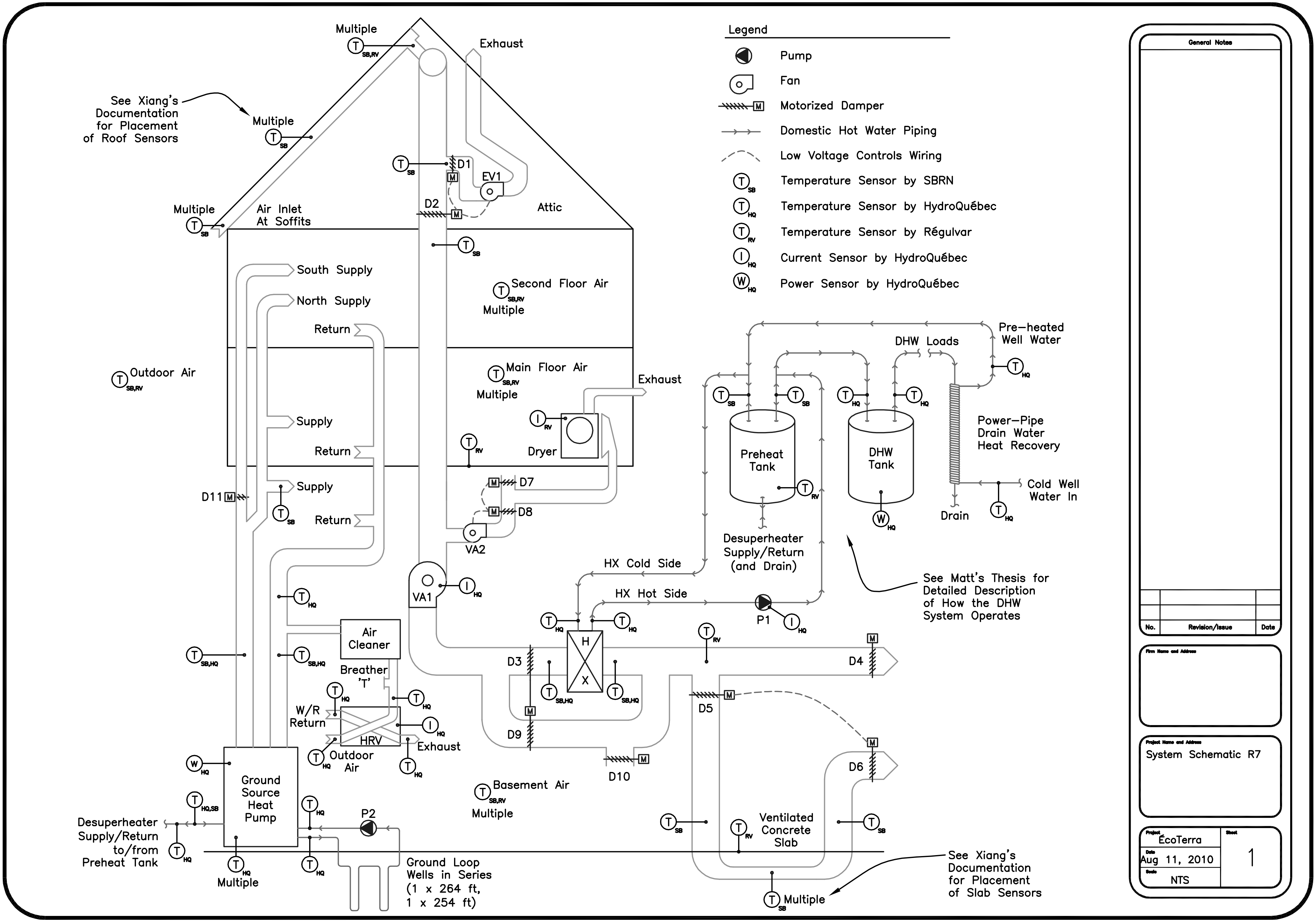
Appendix A - System Schematic



Legend
Pump
Fan
Motorized Damper
Domestic Hot Water Piping
Low Voltage Controls Wiring
Temperature Sensor by SBRN
Temperature Sensor by HydroQuébec
Temperature Sensor by Régulvar
Current Sensor by HydroQuébec
Power Sensor by HydroQuébec
See Xiang's Documentation for Placement of Roof Sensors
Multiple
Exhaust
D1
EV1
D2
Attic
Air Inlet At Soffits
South Supply
North Supply
Return
Second Floor Air
Outdoor Air
Main Floor Air
Exhaust
Supply
Return
Dryer
Supply
D11
D7
D8
VA2
VA1
HX Cold Side
HX Hot Side
P1
Air Cleaner
Breather 'T'
W/R Return
HRV
Exhaust
Outdoor Air
D3
D9
D10
D4
D5
D6
Basement Air
Ground Source Heat Pump
P2
Desuperheater Supply/Return to/from Preheat Tank
Ground Loop Wells in Series (1 x 264 ft, 1 x 254 ft)
Ventilated Concrete Slab
See Xiang's Documentation for Placement of Slab Sensors
Pre-heated Well Water
DHW Loads
Preheat Tank
DHW Tank
Power-Pipe Drain Water Heat Recovery
Cold Well Water In
Drain
Desuperheater Supply/Return (and Drain)
See Matt's Thesis for Detailed Description of How the DHW System Operates
General Notes
No.
Revision/Issue
Date
Firm Name and Address
Project Name and Address
System Schematic R7
Project
ÉcoTerra
Sheet
1
Date
Aug 11, 2010
Scale
NTS

Appendix B - Python Scripts

```
# -*- coding: ASCII -*-
"""
Performs analysis of EcoTerra energy data and returns energy consumption
generation, storage and performance results

Written as part of a MASc Thesis by Matt Doiron (Dec 2010)

#================================================================================
# Query required for this file:
#================================================================================

SELECT

data_date_time, pressurer_drop_across_manifold, ventilated_slab_outlet_air,
ventilated_slab_inlet_air, bipvt_inlet_air_t7, bipvt_inlet_air_t8,
outlet_air_t28, outlet_air_t25, outlet_air_t24, outlet_air_t34,
outlet_air_t10, outlet_air_t11, outlet_air_t19, outlet_air_t31,
outlet_air_t22, outlet_air_t30, cavity_air_t2, bipvt_exhaust,
bipvt_air_after_manifold, desuperheater, hx_air_in, hx_air_out,
hx_water_to_reservoir, reservoir_water_to_hx, T_SUC, T_DISC, T_LIQUI, TR_OUT,
BT_IN, BT_OUT, TE_PT, TS_PT, TA_RET, TR_TOIL, TE_HRV, TS_HRV, TAE_AW, TAS_AW,
TOE_AW, TOS_AW, TE_HP, TS_HP, TOE_DR, TOS_DR, TE_DHW, TS_DHW, P_S, P_D, C_HRV,
C_F1, C_P1, B_FR, W_HOUSE, W_HP, W_DHW, hq_genuine, supply_air_temperature,
outdoor_temperature, horizontal_global_solar_irradiance,
pv_roof_global_solar_irradiance, south_facade_global_solar_irradiance,
irradiance, ac_power, anemometre, a1_soil_under_insulation,
a2_soil_under_insulation, a3_soil_under_insulation, b1_soil_under_insulation,
b2_soil_under_insulation, b3_soil_under_insulation, c1_soil_under_insulation,
c2_soil_under_insulation, c3_soil_under_insulation, a1_air_flow, a2_air_flow,
a3_air_flow, b1_air_flow, b2_air_flow, b3_air_flow, c1_air_flow, c2_air_flow,
c3_air_flow, b2_top, a3_middle, b2_middle, c1_middle, a2_bottom,
south_bedroom, gflr_slab_center_top, family_room, kitchen_top, north_bedroom,
dinning_room, bsmt_north_room, bsmt_s_center_ceiling, bflr_hall_wall,
bsmt_south_room, temperature_ext

WHERE

data_date_time BETWEEN '2009-12-10 00:00:00' AND '2010-06-09 23:59:59'
ORDER BY
data_date_time

#================================================================================
# General Notes
#================================================================================

- Slab enery storage calcs do not check for "dryer-only" conditions. This case
    never happend in 2010, but might in the future!
- Months with missing data from ALL sources (produces gaps in data)
    - Jan 25, 13:51 to 14:33
    - Apr 27, 22:13 to Apr 28 01:45
    - Apr 28, 05:48 to 09:45
    - May 18, 15:51 to 19:00
- All future occurances of garage heat should be filtered out automatically.
- Future occurances of auxiliary heat pump heat will NOT be filtered out. They
    must be idenditifed visually and added to the list of aux heater events.
```

```
    This is found in the filterPower module.
- Air temps at inlet and outlet of slab are interpolated to fill in gaps. This
    is not a problem for this data since the fan is never on during any
    of these gaps. This is important to know for the future though.
- The filterpower module uses an unsynched OAT to check for garage heater! Not
    a large error since OAT doesn't change really quickly, but need to remember.
- gross consumption difference is relatively small (always less than 1%), but
    why does it happen? It's related to the calculation of the lighting and
    appliance loads. More is filtered out than required. Not a big deal since
    this number is not used directly. The lighting and appliance loads used
    are calculated using their definition - they are the remaining consumption
    after other loads are taken into account. The calculated appliance loads
    (from filterPower module) are used only to help find the garage and aux
    heater events.
- The script will explode if there are NaN values at the start or end points!
- Due to the definition of net-zero, this analysis uses a diff definition of
    net and gross. Net is usually gross - used, but here it is gross -
    generated. Also, gross is usually total consumed, but here it is net plus
    generated.
- Sync doesn't work if there is no change in the delta pressure. This could
    happen if the fan runs for the entire specified time period (pressure is
    then constant). Probably nothing that can be done with this. There is no
    info about how much out of sync things are in these cases.
- For conductance and NTU calcs see old version of analysis8 from Nov 11, 2010
- Date format required yyyy-mm-dd h:mm:ss.0

"""

def main():
    print '=== Analysis in progress ==='

    #==========================================================================
    # Import globally-used modules
    #==========================================================================

    import datetime as dt
    startTime = dt.datetime.now()
    import numpy as np
    import getData8 as gd
    import filterPower8 as fp
    import scikits.timeseries as ts
    import sympy as sp

    # Reload my custom modules to be sure any changes are taken into account
    reload(gd)
    reload(fp)

    #==========================================================================
    # Global settings
    #==========================================================================

    # Specify the period over which the analysis will be performed
    startDate = ts.Date('T', '2010-9-1 00:00:00')
    endDate = ts.Date('T', '2010-9-30 23:59:59')

    # Specify the file from which the data will be read
    fileName = 'data/Final/ET Sep, 2010.tsv'

    # Determine whether or not to perform the synchronization corrections
    syncFlag = True

    # Sets if hourly/daily/weekly/monthly values are to be exported to csv files
```

```
    exportBreakdownFlag = False

    # Set to true if you want to save the calculation results to a file
    saveCalcResultsFlag = True

    # Set to true if you want to plot graphs as defined in the makePlots file
    makePlotsFlag = False

    # Set to true to save the synchronized, cleaned data
    saveSynchedDataFlag = False

    # Stop after saving the synchronized data to file
    noCalcsFlag = False

    #==========================================================================
    # Get Data required for calculations
    #==========================================================================

    # Call getData module to read and process data from the specified file
    myData, myDataSync, nanStats = gd.getData(fileName, syncFlag, startDate, endDate)
    if nanStats == False:
        print 'Missing data file: ' + fileName
        return

    #==========================================================================
    # Save synchronized data to a file for use outside the script
    #==========================================================================

    if saveSynchedDataFlag == True and syncFlag == True:
        testResultsFile = open('Results/Saved Synched Data '+startDate.strftime("%Y-%m-%d
%H-%M")+ ' to ' + endDate.strftime("%Y-%m-%d %H-%M") + '.csv', 'w')
         headers = 'data_date_time, C_F1, C_P1, TOS_AW, TOE_AW, ac_power, W_HP, W_DHW,
TAS_AW, TAE_AW\n'
        testResultsFile.write(headers)
        arrayToWrite = np.column_stack([ myData.dates, myDataSync['C_F1'],
                                         myDataSync['C_P1'], myDataSync['TOS_AW'],
                                         myDataSync['TOE_AW'], myDataSync['ac_power'],
                                         myDataSync['W_HP'], myDataSync['W_DHW'],
                                         myDataSync['TAS_AW'], myDataSync['TAE_AW'] ])
        np.savetxt(testResultsFile, arrayToWrite, fmt='%f', delimiter=',')
        testResultsFile.close()

    #==========================================================================
    # Exit the program if the noCalcsFlag is set to True
    #==========================================================================

    if noCalcsFlag == True:
        print '=== noCalcs flag is True, skipping calculations ==='
        return

    #==========================================================================
    # Define some variables and constants
    #==========================================================================

    dataLength = len(myData)   # number of data points
    t = 1.0 / 60.0             # time between data point in hours (1/60 = 1 min)
    qDHW = 0.0                 # energy stored in DHW tank (kWh)
    qDHW2 = 0.0                # energy stored in DHW tank (kWh)
    qDHW3 = 0.0                # energy stored in DHW tank (kWh)
    qSlab = 0.0                # energy stored in slab (kWh)
    qSlabLoss = 0.0            # energy lost from slab to ground
    qBIPVT = 0.0               # energy collected by BIPVT system
    qHPWater = 0.0             # energy from water loop
```

```
qHPAir = 0.0                # energy from air system
qDSH = 0.0                  # energy from desuperheater
garageAirFanEnergy = 0.0    # energy BIPV/T fan would use to supply garage heat
garageAirFanEnergy2 = 0.0    # energy BIPV/T fan would use to supply garage heat
garageAirEnergy = 0.0       # energy available from BIPV/T for garage heating
garageAirEnergy2 = 0.0      # energy available from BIPV/T for garage heating
gpm_to_m3s = 0.0000630902   # convert USgpm to m3/sec
hpFan = 0.200               # estimated load of heat pump fan in recirc mode (kW)
controls = 0.0336           # estimated load of controls (kW)
alarmPower = 0.0072         # alarm sys consumption (kW)
monitoring = 0.21283        # estimated load of monitoring (kW)
airCleaner = 0.049          # measured air cleaner consumption (kW)
pf = 0.85                   # power factor
lineVoltage = 115.0         # voltage of grid
cfm_to_m3s = 0.0004719474   # Conversion from cfm to m3/s
dshFlow = 0.4 * 38.0 / 12.0 * gpm_to_m3s # 0.4 gpm per ton capacity of hp
rIns = 1.32275              # RSI of insulation under slab (m2K/W) R7.5
chanArea = 0.007714         # m2 for each channel
numChans = 19.0             # number of channels in VCS
percentWaterWeight = 0.75   # percent of water by weight
percentMethWeight = 0.25    # percent of methanol by weight
cpAir = 1.005               # Constant for Cp of air
effHXList = np.zeros(dataLength)
garageAirList = np.zeros(dataLength)
garageAirList2 = np.zeros(dataLength)
qSlabLossList = np.zeros(dataLength)
stratification = np.zeros(dataLength)
copBIPVTList = np.zeros(dataLength)
hpCopWaterList = np.zeros(dataLength)
hpCopAirList = np.zeros(dataLength)
qHPWaterList = np.zeros(dataLength)
qHPAirList = np.zeros(dataLength)
qDSHList = np.zeros(dataLength)
cfmList = np.zeros(dataLength)
qSlabList = np.zeros(dataLength)
hxRateList = np.zeros(dataLength)
errorListSlab = np.zeros(dataLength)
errorListDHW = np.zeros(dataLength)
errorListDSH = np.zeros(dataLength)
lostSolar = np.zeros(dataLength)
lostSolar2 = np.zeros(dataLength)
qInfExistingList = np.zeros(dataLength)
qInfProposedList = np.zeros(dataLength)
qWindowsExistingList = np.zeros(dataLength)
qWindowsProposedList = np.zeros(dataLength)

#============================================================================
# Define Misc Correlations
#============================================================================

# Correlation for air/water HX water flow through P1 (m3/s)
p1Flow = lambda cfm: 0.0075 * cfm * gpm_to_m3s

# Correlation for density of air (kg/m3)
rhoAir = lambda temp: 0.000009 * pow(temp, 2.0) - 0.0044 * temp + 1.291

# Correlation for density of water (kg/m3)
rhoWater = lambda temp: -0.0041 * pow(temp, 2.0) - 0.0432 * temp + 1000.6

# Correlation for density of methanol (kg/m3)
rhoMeth = lambda temp: -0.8914 * temp + 808.83

# Correlation for Cp of water (kJ/kgC)
```

```
    cpWater = lambda temp: -0.0000003 * pow(temp, 3) + 0.00005 * pow(temp, 2) - 0.0024 *
temp + 4.2133

    # Correlation for Cp of methanol (kJ/kgC)
    cpMeth = lambda temp: 0.0034 * temp + 1.3704

    # Correlation for convection heat transfer coefficient in VCS (W/m2K)
    hVCS = lambda vel: 3.94 * vel + 5.45

    # Correlation for heat pump air flow rate (inputs kW, outputs cfm)
    hpCFM = lambda kW: -247.837 * pow(kW, 2) + 1354.826 * kW - 533.059

    # Accepts the amps as input and returns cfm for the specified operating mode
    def getCFM(amps, mode):
        '''Returns the cfm of the BIPV/T system for a given amps and mode'''

        # Correlations for DHW-only, slab-only and combo modes. These are from
        # Xiang's work. I curve-fitted his numbers to a power function.
        if mode == 'DHW':
            return 97.131 * pow(amps, 1.3375)
        elif mode == 'Slab':
            return 96.195 * pow(amps, 1.0979)
        elif mode == 'Both':
            return 101.11 * pow(amps, 1.0849)

    # Function to determine if the slab is in heating mode
    def slabDemand(index):
        slabInlet = myData['ventilated_slab_inlet_air'][i]
        hxOutlet = myData['hx_air_out'][i]
        if np.abs(hxOutlet - slabInlet) <= 3.0:
            return True
        else:
            return False

    #============================================================================
    # Prepare for error propagation calculations
    #============================================================================

    # Define the vars as sympy symbols for formulas that will do error propagation
    cfm_sp = sp.Symbol('cfm_sp')
    flow_sp = sp.Symbol('flow_sp')
    convert_sp = sp.Symbol('convert_sp')
    rho_sp = sp.Symbol('rho_sp')
    Cp_sp = sp.Symbol('Cp_sp')
    dT_sp = sp.Symbol('dT_sp')
    t_sp = sp.Symbol('t_sp')

    # Simple error propagation for summation or subtraction (quadrature addition)
    eSum = lambda x: np.sqrt(np.sum([var**2 for var in x]))

    # Generalized error propagation solution for any number of variables. Returns
    # absolute error.
    def eProp(func, variables):
        eFunc = sp.sqrt( sum([sp.diff(func,x)**2 * dx**2 for x, dx, val in variables]) )
        err = eFunc.subs([(x,val) for x,dx,val in variables])
        return err

    #============================================================================
    # Begin Calculations
    #============================================================================

    print '   Calculating energy stored...'
```

```
    # Calculate energy stored in slab and DHW for each row (if applicable)
    for i, row in enumerate(myDataSync):

        #============================================================================
        # Examine BIPV/T Performance
        #============================================================================

        # Reset values for this loop
        qS, qD, qD2, qD3, qdsh = 0.0, 0.0, 0.0, 0.0, 0.0

        # Use only those value where the fan is on to examine BIPV/T performance
        if row['C_F1'] > 0.0:

            # Determine operating mode based on state of pump P1
            if row['C_P1'] > 0.0:
                # Find cfm of fan in this mode
                cfm = getCFM(row['C_F1'], 'Both')
                cfmList[i] = cfm

                # Find energy stored in DHW preheat tank (using SBRN air data)
                avgTemp = (myData['hx_air_in'][i] + myData['hx_air_out'][i]) / 2.0
                m = cfm * cfm_to_m3s * rhoAir(avgTemp) # (kg/s)
                deltaTdhw = myData['hx_air_in'][i] - myData['hx_air_out'][i]
                qD = m * cpAir * deltaTdhw * t
                qDHW += qD

                # Find energy stored in DHW preheat tank (using HQ water data)
                avgTemp2 = (row['TOS_AW'] + row['TOE_AW']) / 2.0
                m2 = p1Flow(cfm) * rhoWater(avgTemp2)   # (kg/s)
                deltaTdhw2 = row['TOS_AW'] - row['TOE_AW']
                qD2 = m2 * cpWater(avgTemp2) * deltaTdhw2 * t
                qDHW2 += qD2
                if qD2 >= 0.0:
                    hxRateList[i] = qD2 / t
                else:
                    effHXList[i] = 0.0

                # Find energy stored in DHW preheat tank (using SBRN water data)
                avgTemp3 = ( (myData['hx_water_to_reservoir'][i] +
                              myData['reservoir_water_to_hx'][i]) / 2.0 )
                m3 = p1Flow(cfm) * rhoWater(avgTemp3)  #(kg/s)
                deltaTdhw3 = (myData['hx_water_to_reservoir'][i] -
                              myData['reservoir_water_to_hx'][i])
                if -50.0 < deltaTdhw3 < 50.0:
                    qD3 = m3 * cpWater(avgTemp3) * deltaTdhw3 * t
                    qDHW3 += qD3

                # Find absolute error of calc to store energy in the preheat tank
                # Store the variables in an array with their uncertainties
                variablesDHW = [(flow_sp, 0.0, p1Flow(cfm)),
                             (rho_sp, 0.002 * rhoWater(avgTemp2), rhoWater(avgTemp2)),
                             (Cp_sp, 0.019 * cpWater(avgTemp2), cpWater(avgTemp2)),
                             (dT_sp, eSum([0.5, 0.5]), deltaTdhw2),
                             (t_sp, 0.05, t)]
                # Define the equation on which to perform error propagation
                Q_sp_dhw = flow_sp * rho_sp * Cp_sp * dT_sp * t_sp
                # Pass the function, its variables and their uncertanties to the
                # error propagation solver and store the resulting absolute error
                errorListDHW[i] = eProp(Q_sp_dhw, variablesDHW)

                # Check if there is demand for slab heating (only care about times
                # when there is actually demand for heating) (could be DHW only)
                if slabDemand(i) == True:
```

```
                    # Find energy stored in slab (kWh)
                    avgTempSlab = ( (myData['ventilated_slab_inlet_air'][i] +
                                     myData['ventilated_slab_outlet_air'][i]) / 2.0 )
                    deltaTslab = ( myData['ventilated_slab_inlet_air'][i] -
                                   myData['ventilated_slab_outlet_air'][i] )
                    mSlab = cfm * cfm_to_m3s * rhoAir(avgTempSlab)
                    qS = mSlab * cpAir * deltaTslab * t
                    qSlab += qS
                    qSlabList[i] = qS

                    # Find absolute error of calc to store energy in slab
                    # Store the variables in an array with their uncertainties
                    variablesSlab = [(cfm_sp, 0.2 * cfm, cfm),
                                 (convert_sp, 0.0, cfm_to_m3s),
                                                  (rho_sp,  0.001  *  rhoAir(avgTempSlab),
rhoAir(avgTempSlab)),
                                 (Cp_sp, 0.0, cpAir),
                                 (dT_sp, eSum([0.5, 0.5]), deltaTslab),
                                 (t_sp, 0.05, t)]
                    # Define the equation on which to perform error propagation
                    Q_sp_slab = cfm_sp * convert_sp * rho_sp * Cp_sp * dT_sp * t_sp
                    # Pass the function, its variables and their uncertanties to the
                    # error propagation solver and store the resulting absolute error
                    errorListSlab[i] = eProp(Q_sp_slab, variablesSlab)

                    # Check temperature of air left-over for use in the garage
                    garageInletTemp = myData['ventilated_slab_outlet_air'][i] - 1.0
                else:
                    # Check temperature of air left-over for use in the garage
                    garageInletTemp = myData['hx_air_out'][i] - 5.0 # 5 for losses

                # Check temperature of air left-over for use in the garage
                if garageInletTemp > 15.0 and myData['outdoor_temperature'][i] < 15.0:
                    m = cfm * cfm_to_m3s * rhoAir(garageInletTemp) # (kg/s)
                    deltaTgar = garageInletTemp - 15.0
                    qAarAir = m * cpAir * deltaTgar * t
                    garageAirEnergy += qAarAir
                    garageAirList[i] = qAarAir
                    garageAirFanEnergy += row['C_F1'] * lineVoltage * pf

                # Calculate effectiveness of the air-water heat exchanger
                avgTempAir = (row['TAE_AW'] + row['TAS_AW']) / 2.0
                avgTempWater = (row['TOE_AW'] + row['TOS_AW']) / 2.0
                mAir = cfm * cfm_to_m3s * rhoAir(avgTempAir) # (kg/s)
                mWater = p1Flow(cfm) * rhoWater(avgTempWater) # (kg/s)
                mCpMin = np.min([mAir * cpAir, mWater * cpWater(avgTempWater)])
                       effHX  =  (mWater  *  cpWater(avgTempWater)  *  (row['TOE_AW']  -
row['TOS_AW'])) / (mCpMin * (row['TOE_AW'] - row['TAE_AW']))
                if effHX <= 1.0 and effHX >= 0.0:
                    effHXList[i] = effHX
                else:
                    effHXList[i] = 0.0

            # Pump is not on, so only slab mode. Guaranteed slab mode, so no need
            # to check for demand unless dryer was on, but for this data that
            # never happens
            else:
                # Find cfm of fan in this mode
                cfm = getCFM(row['C_F1'], 'Slab')
                cfmList[i] = cfm

                # Find energy stored in slab (kWh)
                avgTempSlab = ( (myData['ventilated_slab_inlet_air'][i] +
```

```
                            myData['ventilated_slab_outlet_air'][i]) / 2.0 )
                deltaTslab = ( myData['ventilated_slab_inlet_air'][i] -
                           myData['ventilated_slab_outlet_air'][i] )
                mSlab = cfm * cfm_to_m3s * rhoAir(avgTempSlab)
                qS = mSlab * cpAir * deltaTslab * t
                qSlab += qS
                qSlabList[i] = qS

                # Find absolute error of calc to store energy in slab
                # Store the variables in an array with their uncertainties
                variablesSlab = [(cfm_sp, 0.2 * cfm, cfm),
                             (convert_sp, 0.0, cfm_to_m3s),
                             (rho_sp, 0.001 * rhoAir(avgTempSlab), rhoAir(avgTempSlab)),
                             (Cp_sp, 0.0, cpAir),
                             (dT_sp, eSum([0.5, 0.5]), deltaTslab),
                             (t_sp, 0.05, t)]
                # Define the equation on which to perform error propagation
                Q_sp_slab = cfm_sp * convert_sp * rho_sp * Cp_sp * dT_sp * t_sp
                # Pass the function, its variables and their uncertanties to the
                # error propagation solver and store the resulting absolute error
                errorListSlab[i] = eProp(Q_sp_slab, variablesSlab)

                # Check temperature of air left-over for use in the garage
                garageInletTemp = myData['ventilated_slab_outlet_air'][i]
                if garageInletTemp > 15.0 and myData['outdoor_temperature'][i] < 15.0:
                    m = cfm * cfm_to_m3s * rhoAir(garageInletTemp) # (kg/s)
                    deltaTgar = garageInletTemp - 15.0
                    qAarAir = m * cpAir * deltaTgar * t
                    garageAirEnergy += qAarAir
                    garageAirList[i] = qAarAir
                    garageAirFanEnergy += row['C_F1'] * lineVoltage * pf

            # Calculate COP of the BIPV/T system for this row
            energyStoredRow = qD2 + qS
               energyConsumedRow = (row['C_F1'] + row['C_P1']) * lineVoltage * pf * t /
1000.0
            if energyConsumedRow > 0.0 and energyStoredRow > 0.0:
                copRow = energyStoredRow/energyConsumedRow
                copBIPVTList[i] = copRow
            else:
                copBIPVTList[i] = 0.0

            # Calculate energy lost from air to ground as it goes through VCS
            avgAirTemp = ( (myData['a1_air_flow'][i] +
                myData['a2_air_flow'][i] + myData['a3_air_flow'][i] +
                myData['b1_air_flow'][i] + myData['b2_air_flow'][i] +
                myData['b3_air_flow'][i] + myData['c1_air_flow'][i] +
                myData['c2_air_flow'][i] + myData['c3_air_flow'][i] ) / 9.0 )
            avgGrndTemp = ( (myData['a1_soil_under_insulation'][i] +
                                                 myData['a2_soil_under_insulation'][i]   +
myData['a3_soil_under_insulation'][i] +
                                                 myData['b1_soil_under_insulation'][i]   +
myData['b2_soil_under_insulation'][i] +
                                                 myData['b3_soil_under_insulation'][i]   +
myData['c1_soil_under_insulation'][i] +
                                                 myData['c2_soil_under_insulation'][i]   +
myData['c3_soil_under_insulation'][i]) / 9.0 )
            avgDeltaT = avgAirTemp - avgGrndTemp
            airVel = cfm * cfm_to_m3s / numChans / chanArea
            uVal = 1.0 / (1/rIns + hVCS(airVel))
            areaOfLoss = 19.0 * 0.114 * 10.3378  # m2 19 channels
            airLoss = uVal * areaOfLoss * avgDeltaT * t / 1000.0
            qSlabLoss += airLoss
```

```
            qSlabLossList[i] = qSlabLoss
            qSlab -= airLoss

            # Find energy transfered to the air in the roof cavity (kWh)
            avgInlet = ( myData['bipvt_inlet_air_t7'][i] +
                         myData['bipvt_inlet_air_t8'][i] ) / 2.0
            #avgOutlet = myData['bipvt_air_after_manifold'][i]
            avgOutlet = (myData['outlet_air_t28'][i] + myData['outlet_air_t25'][i] +
                    myData['outlet_air_t24'][i] + myData['outlet_air_t34'][i] +
                    myData['outlet_air_t10'][i] + myData['outlet_air_t11'][i] +
                    myData['outlet_air_t19'][i] + myData['outlet_air_t31'][i] +
                    myData['outlet_air_t22'][i] + myData['outlet_air_t30'][i] ) / 10.0
            m = cfm * cfm_to_m3s * rhoAir(avgOutlet)
            deltaT = avgOutlet - avgInlet
            qRowBIPVT =  m * cpAir * deltaT * t
            qBIPVT += qRowBIPVT

        #============================================================================
        # Estimate lost and potential performance
        #============================================================================

        # Check for times when the system is running, but pht is unable to
        # accept the energy (lost solar energy)
         if row['C_F1'] > 0.0 and row['C_P1'] <= 0.0 and myData['reservoir_water_to_hx']
[i] > myData['hx_air_in'][i]:
            lostSolar[i] = myData['hx_air_in'][i]

        # Check for times when the roof has reasonable energy but the system
        # is not running (lost solar energy)
        if row['C_P1'] <= 0.0 and (myData['cavity_air_t2'][i] - 10.0) >= 25.0:
            lostSolar2[i] = myData['bipvt_air_after_manifold'][i]

        # Check for energy that could be used for the roof, but isn't already
        # taken into account during system operation. Use cfm from last
        # operation of BIPV/T
        garageInletTemp2 = myData['cavity_air_t2'][i] - 10.0 # 10 for losses
          if row['C_F1'] <= 0.0 and row['C_P1'] <= 0.0 and garageInletTemp2 > 15.0 and
myData['outdoor_temperature'][i] < 15.0:
            m = 200.0 * cfm_to_m3s * rhoAir(garageInletTemp2) # (kg/s)
            deltaTgar2 = garageInletTemp2 - 15.0
            qAarAir2 = m * cpAir * deltaTgar2 * t
            garageAirEnergy2 += qAarAir2
            garageAirList2[i] = qAarAir2
            garageAirFanEnergy2 += 3.5 * lineVoltage * pf

        #============================================================================
        # Examine heat pump performance for each row in myData
        #============================================================================

        if myData['W_HP'][i] > 0.0:
            # Average temp of ground loop
            avgTemp = np.mean([myData['BT_IN'][i], myData['BT_OUT'][i]])

            # Calculate percent methanol by volume for current conditions
            volWater = percentWaterWeight / rhoWater(avgTemp)
            volMeth = percentMethWeight / rhoMeth(avgTemp)
            percentMeth = volMeth / (volWater + volMeth)
            percentWater = 1.0 - percentMeth
                      rhoMix  =  (percentMeth    *  rhoMeth(avgTemp))  +  (percentWater  *
rhoWater(avgTemp))

            # Find energy removed from ground loop water (kWh)
            mWater = myData['B_FR'][i] * gpm_to_m3s * rhoMix
```

```
            deltaTWater = myData['BT_IN'][i] - myData['BT_OUT'][i]
                    Cp_water_meth = (percentMeth * cpMeth(avgTemp)) + (percentWater *
cpWater(avgTemp))
            qWater = mWater * Cp_water_meth * deltaTWater * t
            qHPWater += qWater
            qHPWaterList[i] = qWater

            # Find energy added to air by heat pump (kWh)
            avgTemp = np.mean([myData['TS_HP'][i], myData['TE_HP'][i]])
            mAir = hpCFM(myData['W_HP'][i]) * cfm_to_m3s * rhoAir(avgTemp)
            deltaTAir = myData['TS_HP'][i] - myData['TE_HP'][i]
            qAir = mAir * cpAir * deltaTAir * t
            qHPAir += qAir
            qHPAirList[i] = qAir

            # Calculate COP of heatpump for this row (using water and air balances)
            heatPumpEnergyRow = myData['W_HP'][i] * t
            hpCopWaterList[i] = (qWater + heatPumpEnergyRow) / heatPumpEnergyRow
            hpCopAirList[i] = qAir / heatPumpEnergyRow

            # If BIPV/T fan and pump are OFF calculate desuperheater contribution
            if myData['C_P1'][i] == 0.0 and myData['C_F1'][i] == 0.0:
                # Calculate energy contributed by DSH.
                deltaDSH = myData['TE_PT'][i] - myData['TS_PT'][i]
                avgTempDSH = (myData['TE_PT'][i] + myData['TS_PT'][i]) / 2.0
                 qdsh = dshFlow * rhoWater(avgTempDSH) * cpWater(avgTempDSH) * deltaDSH *
t
                qDSH += qdsh
                qDSHList[i] = qdsh

                # Find absolute error of calc to find energy contributed by dsh
                # Store the variables in an array with their uncertainties
                variablesDSH = [(flow_sp, 0.1 * dshFlow, dshFlow),
                                                 (rho_sp, 0.002 * rhoWater(avgTempDSH),
rhoWater(avgTempDSH)),
                             (Cp_sp, 0.019 * cpWater(avgTempDSH), cpWater(avgTempDSH)),
                             (dT_sp, eSum([0.5, 0.5]), deltaDSH),
                             (t_sp, 0.05, t)]
                # Define the equation on which to perform error propagation
                Q_sp_DSH = flow_sp * rho_sp * Cp_sp * dT_sp * t_sp
                # Pass the function, its variables and their uncertanties to the
                # error propagation solver and store the resulting absolute error
                errorListDSH[i] = eProp(Q_sp_DSH, variablesDSH)

        # Calculate the difference in temperatures between basement and 2nd floor
        stratification[i] = myData['bflr_hall_wall'][i] - myData['bsmt_south_room'][i]

        #===========================================================================
        # Savings due to changed air infiltration
        #===========================================================================
        # Measured air infiltration was 0.85 @ 50 Pa
        # Riverdale's is 0.5 at 50 Pa so reduce it to this
        # from Sherman 1987, simply divide by 20 to get actual ACH (estimated)
        houseVol = 609.1 # m3
        achExisting = 0.85 / 20.0 # ACHnat
        achProposed = 0.5 / 20.0 # ACHnat
        infiltExisting = achExisting * houseVol / 3600.0  # m3/s
        infiltProposed = achProposed * houseVol / 3600.0  # m3/s
        deltaTinf = myData['dinning_room'][i] - myData['outdoor_temperature'][i]
        infTempAvg = (myData['dinning_room'][i] + myData['outdoor_temperature'][i])/2.0

        # Energy required to heat this air
        qInfExisting = infiltExisting * rhoAir(infTempAvg) * cpAir * deltaTinf * t
```

```
    qInfProposed = infiltProposed * rhoAir(infTempAvg) * cpAir * deltaTinf * t
    if deltaTinf > 0.0:
        qInfExistingList[i] = qInfExisting
        qInfProposedList[i] = qInfProposed

    #============================================================================
    # Savings due to changed window R values
    #============================================================================

    rExisting = 0.85 # RSI of windows (m2K/W) R4.8
    rProposed = 1.2 # RSI of windows (m2K/W) R7.3
    areaWindows = 33.4 # m2
    deltaTwindows = myData['dinning_room'][i] - myData['outdoor_temperature'][i]
    rFilmIn = 1 / 8.3
    rFilmOut = 1 / 34.0
    uTotalExisting = 1 / (rExisting + rFilmIn + rFilmOut)
    uTotalProposed = 1 / (rProposed + rFilmIn + rFilmOut)

    # Energy required to heat space due to windows
    qWindowExisting = uTotalExisting * areaWindows * deltaTwindows * t / 1000.0
    qWindowProposed = uTotalProposed * areaWindows * deltaTwindows * t / 1000.0
    if deltaTwindows > 0.0:
        qWindowsExistingList[i] = qWindowExisting
        qWindowsProposedList[i] = qWindowProposed

#============================================================================
# Demand analysis
#============================================================================

print '   Finding peak demand...'

# find peak and instantaneous demand without solar contribution
maxSustainedDemandPV = 0.0
houseNet = myData['W_HOUSE']
for i in range(len(houseNet)-14):
    n = houseNet[i]
    n1 = houseNet[i+1]
    n2 = houseNet[i+2]
    n3 = houseNet[i+3]
    n4 = houseNet[i+4]
    n5 = houseNet[i+5]
    n6 = houseNet[i+6]
    n7 = houseNet[i+7]
    n8 = houseNet[i+8]
    n9 = houseNet[i+9]
    n10 = houseNet[i+10]
    n11 = houseNet[i+11]
    n12 = houseNet[i+12]
    n13 = houseNet[i+13]
    n14 = houseNet[i+14]

    if ( n1 > n and n2 > n and n3 > n and n4 > n and n5 > n and n6 > n and
         n7 > n  and n8 > n and n9 > n and n10 > n and n11 > n and n12 > n and
         n13 > n and n14 > n and n > maxSustainedDemandPV ):
        maxSustainedDemandPV = n
maxInstantDemandPV = np.max(houseNet)

# find peak and instantaneous demand WITH solar contribution
maxSustainedDemandNoPV = 0.0
houseGross = myData['W_HOUSE'] + myDataSync['ac_power'] / 1000.0
for i in range(len(houseGross)-14):
    n = houseGross[i]
    n1 = houseGross[i+1]
```

```
        n2 = houseGross[i+2]
        n3 = houseGross[i+3]
        n4 = houseGross[i+4]
        n5 = houseGross[i+5]
        n6 = houseGross[i+6]
        n7 = houseGross[i+7]
        n8 = houseGross[i+8]
        n9 = houseGross[i+9]
        n10 = houseGross[i+10]
        n11 = houseGross[i+11]
        n12 = houseGross[i+12]
        n13 = houseGross[i+13]
        n14 = houseGross[i+14]

        if ( n1 > n and n2 > n and n3 > n and n4 > n and n5 > n and n6 > n and
             n7 > n  and n8 > n and n9 > n and n10 > n and n11 > n and n12 > n and
             n13 > n and n14 > n and n > maxSustainedDemandNoPV ):
            maxSustainedDemandNoPV = n
    maxInstantDemandNoPV = np.max(houseGross)

    # savings for period
    saveDem15 = maxSustainedDemandNoPV - maxSustainedDemandPV
    saveDemInst = maxInstantDemandNoPV - maxInstantDemandPV

    #============================================================================
    # Other energy analysis
    #============================================================================

    print '   Performing other energy usage calculations...'

    # Find energy used by pump P1 (kWh)
    energyP1 = np.sum(myData['C_P1']) * lineVoltage * pf * t / 1000.0

    # Find energy used by fan F1 (kWh)
    energyF1 = np.sum(myData['C_F1']) * lineVoltage * pf * t / 1000.0

    # Retrieve the filtered power data
    filtered, garHeaterPower, auxHeaterPower = fp.filterPower(myData,
                                    myDataSync['ac_power'], startDate, endDate)

    # Garage and aux heater energy consumption
    auxHeaterEnergy = np.sum(auxHeaterPower) * t
    garHeaterEnergy = np.sum(garHeaterPower) * t

    # Thermal efficiency for the period during operation
    roofArea = 10.42353 * 5.156251 # roof area over air channels (m2)
    irradiance = myData['pv_roof_global_solar_irradiance'].data
    fanAmpsSync = myDataSync['C_F1']
    irradianceFanOn = irradiance[fanAmpsSync > 0.0]
    solarThermalPotential = np.sum(irradianceFanOn) * roofArea * 0.96 * t / 1000.0
    if solarThermalPotential > 0.0:
        effThermal = qBIPVT/solarThermalPotential
    else:
        effThermal = 0.0

    # PV generation for the period (kWh)
    pvEnergy = np.sum(myData['ac_power']) * t / 1000.0

    # Calculate exported pv electricity (kWh)
    pvExportPower = np.zeros(dataLength)
    for i, var in enumerate(myData['W_HOUSE']):
        if var < 0.0:
            pvExportPower[i] = abs(myData['W_HOUSE'][i])
```

```
pvExport = np.sum(pvExportPower) * t

# Electrical efficiency for the period
pvArea = 5.486 * 0.394 * 21.0      # pv panel area (m2)
solarPVPotential = np.sum(irradiance) * pvArea * 0.96 * t / 1000.0
effElec = pvEnergy / solarPVPotential
effElecRated = (136.0 * 21.0) / pvArea / 1000.0

# Find the average inlet and outlet temps
avgInlet = (myData['bipvt_inlet_air_t7'] + myData['bipvt_inlet_air_t8']) / 2.0
#avgOutlet = myData['bipvt_air_after_manifold']
avgOutlet = (myData['outlet_air_t28'] + myData['outlet_air_t25'] +
            myData['outlet_air_t24'] + myData['outlet_air_t34'] +
            myData['outlet_air_t10'] + myData['outlet_air_t11'] +
            myData['outlet_air_t19'] + myData['outlet_air_t31'] +
            myData['outlet_air_t22'] + myData['outlet_air_t30'] ) / 10.0

# Correct synced fan by a few minutes more to be sure the initial cold blast
# of air that happens when the fan turns on is ignored
offsetFan = np.roll(fanAmpsSync, 5)

# Find maximum temperature rise across roof
diff = avgOutlet - avgInlet
deltaFanOn = diff[offsetFan > 0.0]
if len(deltaFanOn) > 0.0:
    maxDtRoof = np.max(deltaFanOn)
    meanDtRoof = np.mean(deltaFanOn)
    minDtRoof = np.min(deltaFanOn)
else:
    maxDtRoof, meanDtRoof, minDtRoof = 0.0, 0.0, 0.0

# Find maximum difference between inlet and ambient air temps
diffAmb = avgInlet - myData['outdoor_temperature']
deltaFanOnAmb = diffAmb[offsetFan > 0.0]
if len(deltaFanOnAmb) > 0.0:
    maxDTAmb = np.max(deltaFanOnAmb)
    meanDTAmb = np.mean(deltaFanOnAmb)
    minDTAmb = np.min(deltaFanOnAmb)
else:
    maxDTAmb, meanDTAmb, minDTAmb = 0.0, 0.0, 0.0

# Find maximum difference between air at manifold and air reaching basement
diffInt = avgOutlet - myData['hx_air_in']
deltaFanOnInt = diffInt[offsetFan > 0.0]
if len(deltaFanOnInt) > 0.0:
    maxDTbsmnt = np.max(deltaFanOnInt)
    meanDTbsmnt = np.mean(deltaFanOnInt)
    minDTbsmnt = np.min(deltaFanOnInt)
else:
    maxDTbsmnt, meanDTbsmnt, minDTbsmnt = 0.0, 0.0, 0.0

# Total kWh of negative usage (bad, should be low). Results from errors in
# sync of data and estimates of baseloads.
negLoad = np.sum(filtered[filtered < 0.0]) * t
negLoadPercent = (negLoad / (np.sum(filtered) * t)) * 100.0

# Calculate other energy consumptions
hrvPower = np.zeros(dataLength)
for i, var in enumerate(myData['C_HRV']):
    if var > 0.0:
        hrvPower[i] = (myData['C_HRV'][i] * lineVoltage * pf) / 1000.0 + airCleaner
hrvEnergy = np.sum(hrvPower) * t
```

```
    # Calculate equipment power / energy
    equipmentPower = np.zeros(dataLength)
    for i, var in enumerate(myData['W_HP']):
        if var <= 0.0:
            equipmentPower[i] = hpFan + alarmPower
    equipEnergy = np.sum(equipmentPower) * t

    monitoringEnergy = dataLength * monitoring * t
    dhwEnergy = np.sum(myData['W_DHW']) * t
    controlsEnergy = dataLength * controls * t
                      avgRad      =      np.mean(myData['pv_roof_global_solar_irradiance']
[myData['pv_roof_global_solar_irradiance']>0.0])
    avgOAT = np.mean(myData['outdoor_temperature'])

    # Ground loop temps
    grndTemps = myData['BT_IN'][myData['W_HP'] > 0]
    if len(grndTemps) > 0:
        groundLoopAvg = np.mean(grndTemps)
        groundLoopMin = np.min(grndTemps)
        groundLoopMax = np.max(grndTemps)
    else:
        groundLoopAvg = 0.0
        groundLoopMin = 0.0
        groundLoopMax = 0.0

    # Adjusted heat pump energy
    hpAdjusted = np.zeros(dataLength)
    for i, var in enumerate(myData['W_HP']):
        if var > 0.0:
            if myData['outdoor_temperature'][i] >= 15.0:
                hpAdjusted[i] = var - monitoring/hpCopWaterList[i]
            else:
                hpAdjusted[i] = var + monitoring/hpCopWaterList[i]
    hpEnergy = np.sum(hpAdjusted) * t

    # Portion of heatpump energy due to monitoring
    hpFromMonitoring = (np.sum(hpAdjusted) - np.sum(myData['W_HP'])) * t

    # Check for zero value of heat pump
    if hpEnergy > 0.0:
        qDSHPercent = qDSH / hpEnergy
        copHPWater = (qHPWater + hpEnergy) / hpEnergy
        copHPAir = qHPAir / hpEnergy
    else:
        qDSHPercent = 0.0
        copHPWater = 0.0
        copHPAir = 0.0

    # There are gaps in the data so the filtered data does not include some parts
    avgLightAppl = np.mean(filtered)
    avgHRV = np.mean(myData['C_HRV'][myData['C_HRV'] > 0.0]) * lineVoltage * pf / 1000.0
    gapEnergy = ( len(myData['W_HOUSE'][myData['W_HOUSE'] == 0.0]) * (airCleaner +
                  hpFan + controls + alarmPower + avgHRV + avgLightAppl) * t )

    # Actual net and gross consumptions (adjusting for and removing monitoring)
       energyNet  =  (np.sum(myData['W_HOUSE'])  *  t)  +  gapEnergy  -  monitoringEnergy  +
hpFromMonitoring
    energyGrossActual = energyNet + pvEnergy

    # Lighting and appliance loads are simply what's left-over after other loads
    # are removed.
    lightAppl= ( energyGrossActual - hrvEnergy - equipEnergy - hpEnergy -
                 dhwEnergy - auxHeaterEnergy - garHeaterEnergy - energyF1 -
```

```
                energyP1 - gapEnergy - controlsEnergy )

    # Net pv production (portion used)
    pvEnergyNet = pvEnergy - pvExport

    # Calculated gross consumption
    calcLightAppl = np.sum(filtered) * t
    energyGrossCalc = ( hrvEnergy + equipEnergy + calcLightAppl + hpEnergy +
                        dhwEnergy + auxHeaterEnergy + garHeaterEnergy +
                        energyF1 + energyP1 + gapEnergy + controlsEnergy )

    diffPercent = ((energyGrossCalc / energyGrossActual) - 1.0) * 100.0
    if energyF1 + energyP1 > 0.0:
        bipvtCOP = (qSlab + qDHW2) / (energyF1 + energyP1)
    else:
        bipvtCOP = 0.0

    # sum lost solar
    lostSolarTime = len(lostSolar[lostSolar > 0.0]) * t
    lostSolarTime2 = len(lostSolar2[lostSolar2 > 0.0]) * t

    # Calculate savings for window and infiltration calcs
    if copHPWater > 0.0:
        # find total energy required for infiltration loads
        qInfExisting = np.sum(qInfExistingList) / copHPWater
        qInfProposed = np.sum(qInfProposedList) / copHPWater
        qInfSavings = qInfExisting - qInfProposed
        # find total energy required for window loads
        qWindowExisting = np.sum(qWindowsExistingList) / copHPWater
        qWindowProposed = np.sum(qWindowsProposedList) / copHPWater
        qWindowsSavings = qWindowExisting - qWindowProposed
    else:
        qWindowExisting, qWindowProposed, qWindowsSavings = 0.0, 0.0, 0.0
        qInfExisting, qInfProposed, qInfSavings = 0.0, 0.0, 0.0

    #============================================================================
    # Perform error propagation analysis
    #============================================================================

    # Find absolute error from sum of all other slab error calculations
    errorSlab = eSum(errorListSlab)
    errorDHW = eSum(errorListDHW)
    errorDSH = eSum(errorListDSH)

    print '=== Analysis complete ==='

    #============================================================================
    #  Collect and print the results
    #============================================================================

    results = '-------------------------------------------------'
    results += '\n EcoTerra Energy Analysis for the period of:'
     results  +=  '\n  '  +  startDate.strftime("%Y-%m-%d  %H:%M:%S")+  '  to  '  +
endDate.strftime("%Y-%m-%d %H:%M:%S")
    results += '\n-------------------------------------------------'
    results += '\n       syncFlag: ' + np.str(syncFlag)
    results += '\n-------------------------------------------------'
    results += '\n BIPV/T Performance:'
    results += '\n-------------------------------------------------'
    results += '\nThrml Energy Collected at Roof: {0:>7.2f} kWh'.format(qBIPVT)
        results   +=   '\n                 Thermal   Energy   Available:   {0:>7.2f}
kWh'.format(solarThermalPotential)
    results += '\n           Thermal Efficiency: {0:>7.2f} %'.format(effThermal * 100.0)
```

```
    results += '\n                  PV Generation: {0:>7.2f} kWh'.format(pvEnergy)
    results += '\n      Solar Electric Available: {0:>7.2f} kWh'.format(solarPVPotential)
    results += '\n         Electrical Eff (Calc): {0:>7.2f} %'.format(effElec * 100.0)
     results += '\n         Electrical Eff (Rated): {0:>7.2f} %'.format(effElecRated *
100.0)
    results += '\n          Max dT (across roof): {0:>7.2f} C'.format(maxDtRoof)
    results += '\n         Mean dT (across roof): {0:>7.2f} C'.format(meanDtRoof)
    results += '\n          Min dT (across roof): {0:>7.2f} C'.format(minDtRoof)
    results += '\n          Max dT (inlet & amb): {0:>7.2f} C'.format(maxDTAmb)
    results += '\n         Mean dT (inlet & amb): {0:>7.2f} C'.format(meanDTAmb)
    results += '\n          Min dT (inlet & amb): {0:>7.2f} C'.format(minDTAmb)
    results += '\n         Max dT (roof & bsmnt): {0:>7.2f} C'.format(maxDTbsmnt)
    results += '\n        Mean dT (roof & bsmnt): {0:>7.2f} C'.format(meanDTbsmnt)
    results += '\n         Min dT (roof & bsmnt): {0:>7.2f} C'.format(minDTbsmnt)
    results += '\n      Energy Collected / Spent: {0:>7.2f}'.format(bipvtCOP)
    results += '\n-----------------------------------------------'
    results += '\n Heat Pump Performance:'
    results += '\n-----------------------------------------------'
    results += '\n             COP (water side): {0:>7.2f}'.format(copHPWater)
    results += '\n               COP (air side): {0:>7.2f}'.format(copHPAir)
    results += '\n        Ground Loop Temp (avg): {0:>7.2f} C'.format(groundLoopAvg)
    results += '\n        Ground Loop Temp (min): {0:>7.2f} C'.format(groundLoopMin)
    results += '\n        Ground Loop Temp (max): {0:>7.2f} C'.format(groundLoopMax)
    results += '\n           Avg Solar Radiation: {0:>7.2f} W/m2'.format(avgRad)
    results += '\n              Avg Outdoor Temp: {0:>7.2f} C'.format(avgOAT)
    results += '\n-----------------------------------------------'
    results += '\n Energy Collected:'
    results += '\n-----------------------------------------------'
      results += '\n                 DHW (HQ Water Data): {0:>7.2f} +/- {1:>3.2f}
kWh'.format(qDHW2,errorDHW)
    results += '\n           DHW (SBRN Air Data): {0:>7.2f} kWh'.format(qDHW)
    results += '\n         DHW (SBRN Water Data): {0:>7.2f} kWh'.format(qDHW3)
      results += '\n                         Stored in Slab: {0:>7.2f} +/- {1:>3.2f}
kWh'.format(qSlab,errorSlab)
    results += '\n             Losses to Ground: {0:>7.2f} kWh'.format(qSlabLoss)
    results += '\n                PV Generation: {0:>7.2f} kWh'.format(pvEnergy)
    results += '\n                    PV Export: {0:>7.2f} kWh'.format(pvExport)
      results += '\n                Desuperheater Contrib: {0:>7.2f} +/- {1:>3.2f}
kWh'.format(qDSH,errorDSH)
     results += '\n           Desuperheater % of HP: {0:>7.2f} %'.format(qDSHPercent *
100.0)
    results += '\n     Avail for garage (sys on): {0:>7.2f} kWh'.format(garageAirEnergy)
    results += '\n    Avail for garage (sys off): {0:>7.2f} kWh'.format(garageAirEnergy2)
    results += '\n-----------------------------------------------'
    results += '\n Energy Results:'
    results += '\n-----------------------------------------------'
    results += '\n         Lighting / Appliances: {0:>7.2f} kWh'.format(lightAppl)
    results += '\n                    Heat Pump: {0:>7.2f} kWh'.format(hpEnergy)
    results += '\n            HP from Monitoring: {0:>7.2f} kWh'.format(hpFromMonitoring)
    results += '\n                          DHW: {0:>7.2f} kWh'.format(dhwEnergy)
    results += '\n             BIPV / T Fan (F1): {0:>7.2f} kWh'.format(energyF1)
    results += '\n              DHW HX Pump (P1): {0:>7.2f} kWh'.format(energyP1)
    results += '\n             HRV / Air Cleaner: {0:>7.2f} kWh'.format(hrvEnergy)
    results += '\n                  Aux HP Heat: {0:>7.2f} kWh'.format(auxHeaterEnergy)
    results += '\n                  Garage Heat: {0:>7.2f} kWh'.format(garHeaterEnergy)
    results += '\n                    Equipment: {0:>7.2f} kWh'.format(equipEnergy)
    results += '\n                     Controls: {0:>7.2f} kWh'.format(controlsEnergy)
    results += '\n                   Monitoring: {0:>7.2f} kWh'.format(monitoringEnergy)
    results += '\n                      PV Used: {0:>7.2f} kWh'.format(pvEnergyNet)
    results += '\n                 PV Generated: {0:>7.2f} kWh'.format(pvEnergy)
    results += '\n           Data Gap Correction: {0:>7.2f} kWh'.format(gapEnergy)
    results += '\n         Net Consumption (NZB): {0:>7.2f} kWh'.format(energyNet)
```

```
        results += '\n            Gross Consumption (NZB): {0:>7.2f} kWh'.format(energyGrossActual)
        results += '\n            Demand w/PV (15 Min): {0:>7.2f} kW'.format(maxSustainedDemandPV)
        results += '\n            Demand w/PV (Instant): {0:>7.2f} kW'.format(maxInstantDemandPV)
        results += '\n            Demand w/o PV (15 Min): {0:>7.2f} kW'.format(maxSustainedDemandNoPV)
        results += '\n            Demand w/o PV (Instant): {0:>7.2f} kW'.format(maxInstantDemandNoPV)
    results += '\n      Demand Savings (Instant): {0:>7.2f} kW'.format(saveDemInst)
    results += '\n       Demand Savings (15 min): {0:>7.2f} kW'.format(saveDem15)
    results += '\n  Lost solar DHW time (sys on): {0:>7.2f} hours'.format(lostSolarTime)
    results += '\n     Lost solar time (sys off): {0:>7.2f} hours'.format(lostSolarTime2)
    results += '\n Infilt. savings (0.85 to 0.5): {0:>7.2f} kWh'.format(qInfSavings)
    results += '\n Windows savings (0.85 to 1.2): {0:>7.2f} kWh'.format(qWindowsSavings)
    results += '\n-------------------------------------------------'
    results += '\n Internal Checks:'
    results += '\n-------------------------------------------------'
    results += '\n               Gross Cons Diff: {0:>7.2f} %'.format(diffPercent)
    results += '\n     Negative Generation (bad): {0:>7.2f} %'.format(negLoadPercent)
    results += '\n                        NaN HQ: {0:>7.2f} %'.format(nanStats[0])
    results += '\n                      NaN SBRN: {0:>7.2f} %'.format(nanStats[1])
    results += '\n                       NaN Inv: {0:>7.2f} %'.format(nanStats[2])
    results += '\n-------------------------------------------------'
    print results

    #============================================================================
    # Plot some graphs
    #============================================================================

    if makePlotsFlag == True:
        # import the plotting module (stores all the plot code)
        import makePlots as mp
        reload(mp)

        # calle the makePlot method to make all the plots
             mp.makePlots(myData, myDataSync, garHeaterPower, auxHeaterPower, filtered, effHXList, hxRateList, copBIPVTList)

    #============================================================================
    # Save results to a file
    #============================================================================

    if saveCalcResultsFlag == True:
            resultsName = 'Results - '+startDate.strftime("%Y-%m-%d %H-%M")+ ' to ' + endDate.strftime("%Y-%m-%d %H-%M") + '.txt'
        resultsFile = open('Results/'+resultsName, 'w')
        resultsFile.write(results)
        resultsFile.close()

    #============================================================================
    # Exporting end-use values to files
    #============================================================================

    if exportBreakdownFlag == True:
        import exportData8 as ed
        reload(ed)
        interpError = (lightAppl - np.sum(filtered)/60.0) / (dataLength * t)
        filteredAdjusted = filtered + interpError
        gapError = gapEnergy / (len(filtered) * t)
        equipPowerAdjusted = equipmentPower + gapError
        dataEndUse = np.column_stack([filteredAdjusted * t,
```

```
                                    hpAdjusted * t,
                                    myData.data['W_DHW'] * t,
                                    myData.data['C_F1'] * lineVoltage * pf * t / 1000.0,
                                    myData.data['C_P1'] * lineVoltage * pf * t / 1000.0,
                                    hrvPower * t,
                                    equipPowerAdjusted * t,
                                    myDataSync['ac_power'] * t / 1000.0,
                                    pvExportPower * t,
                                    garHeaterPower * t,
                                    auxHeaterPower * t,
                                    np.zeros(dataLength) + controls * t,
                                    np.zeros(dataLength) + monitoring * t])
        ed.exportData(dataEndUse, myData.dates)

    #==========================================================================
    # All done! Return to end script
    #==========================================================================
    endTime = dt.datetime.now()
    runTime = endTime - startTime
    print 'Script runtime: {0:>7.2f} minutes'.format(runTime.seconds/60.0)
    return

# Don't touch this. It is responsible for executing the program if run from
# the command line
if __name__ == "__main__":
  main()
```

```
# -*- coding: ASCII -*-
"""
Function used to get data from the data file and to clean it (of NaNs)
The function will also sync certain columns if requested using syncFlag

Written as part of a MASc Thesis by Matt Doiron (Dec 2010)
"""

def getData(fileName, syncFlag, startDate, endDate):
    ''' Imports data from the specified data file and syncs it '''

    # Import libraries
    import numpy as np
    import scikits.timeseries as ts
    import os.path

    # Functions to perform on each input
    lamDate = lambda str: ts.Date('T', str)

    # Import data from data file into a timeseries object
    print '-> Reading data file...'
    if os.path.isfile(fileName):
        dataAll = ts.tsfromtxt(fileName, delimiter='\t', freq='T', dtype=None,
                               datecols=(0), dateconverter=lamDate, names=True)
        datesUnfilled = len(dataAll)
    else:
        return False, False, False

    # Construct a list of default values for any missing rows
    fillVal = [np.nan for i in range(len(dataAll[0]))]

    # Fill any missing rows with nan's
    print '   Filling in missing dates...'
    dataAll = dataAll.fill_missing_dates().filled(fill_value=fillVal)
    datesFilled = len(dataAll)
    print '   Dates from data file filled: '+ np.str(datesFilled-datesUnfilled)

    # Select only the date between the start and end date
    print '   Selecting only specified period...'
         data  =  ts.adjust_endpoints(dataAll,  start_date=startDate,  end_date=endDate,
copy=True)

    # If synchronization is requested, do it
    syncPointsFan = []
    syncPointsPress = []
    if syncFlag == True:
        print '   Synchronizing data...'
        # Locate the points where the pressure difference across the manifold
        # spikes. This indicates when the fan turns on. Save these points
        # in a list.
        temp = -1000
        deltaP = data['pressurer_drop_across_manifold']
        for i in range(len(deltaP)-3):
            n = deltaP[i]
            n1 = deltaP[i+1]
            n2 = deltaP[i+2]
            n3 = deltaP[i+3]
            if n < 7.0 and n1 < 7.0 and n2 - n1 > 2.0 and n3 - n2 > 2.0:
                if i - temp > 800:
                    syncPointsPress.append(i)
                    temp = i

        # Locate the points where the fan power jumps from nan to a positive
```

```
    # number. This indicates when the fan turns on. Save these points
    # in a list.
    temp = -1000
    fanAmps = data['C_F1']
    for i in range(len(fanAmps)-2):
        n = fanAmps[i]
        n1 = fanAmps[i+1]
        n2 = fanAmps[i+2]
        if n1 > 0.0 and np.isnan(n) and n2 > 1.0 and i - temp > 500:
            syncPointsFan.append(i)
            temp = i

    # Check to be sure there are any events to sync, otherwise return
    if len(syncPointsFan) > 0 and len(syncPointsPress) > 0:

        # The number of syncs to be done will be the max of the fan or pressure
        # events
        syncLength = max(len(syncPointsPress), len(syncPointsFan))

        # Find the shortest list. It will get extra items and be used
        # to detect the end of the available sync points.
        if len(syncPointsPress) > len(syncPointsFan):
            shortSync = syncPointsFan
            longSync = syncPointsPress
        else:
            shortSync = syncPointsPress
            longSync = syncPointsFan

        # The difference between the fan start time and the pressure spike
        # is the number of minutes by whiche the data is out of sync. Save
        # these points in a list.
        syncOffset = []
        for i in range(syncLength):
            if i < len(shortSync):
                difference = syncPointsFan[i] - syncPointsPress[i] - 1
                if difference > 120 or difference < -120:
                    shortSync.insert(i, longSync[i])
                    syncOffset.append(syncOffset[i-1])
                else:
                    syncOffset.append(difference)
            else:
                for j in range(syncLength-len(shortSync)-1):
                    syncOffset.append(syncOffset[i-1])

        # Extract the parts of the imported data that need to be resynched
        dataPart = np.column_stack([data.data['C_F1'], data.data['C_P1'],
                                data.data['TOS_AW'], data.data['TOE_AW'],
                                data.data['ac_power'], data.data['W_HP'],
                                data.data['W_DHW'], data.data['TAS_AW'],
                                data.data['TAE_AW']])

        # For each offset, shift the fan and pump data by that amount
        # using the corresponding index

        # Add the first part to the reconstructed list (the part before
        # the first out-of-sync event. Assume it's out of sync by the same
        # amount as the first sync point.
        dateOfSync = data.dates[longSync[0]]#
        startSliceDate = ts.Date(freq='T', year=dateOfSync.year,
                                 month=dateOfSync.month, day=dateOfSync.day,
                                 hour=0, minute=0, second=0)
        if startSliceDate > startDate:
            startSlice = data.date_to_index(startSliceDate)
```

```
            mySlice = dataPart[ 0 : startSlice ]
            synched = np.roll(mySlice, -syncOffset[0], axis=0)

            # Correct ac_power - it will be compared in the opposite direction
            synched[:, 4] = np.roll(synched[:, 4], 2*syncOffset[0], axis=0)

            # Save the results for later
            synchedData = synched
        else:
            synchedData = []

        # Loop through all the events and re-synch them based on their
        # offset, then add the newly-synched portion onto the
        # reconstructed list.
        for i in range(len(syncOffset)-1):
#                print "sync event index: " + np.str(i)
            date = data.dates[longSync[i]]#
            dateNext = data.dates[longSync[i+1]]#
            startSliceDate = ts.Date(freq='T', year=date.year, month=date.month,
                                     day=date.day, hour=0, minute=0, second=0)
            endSliceDate = ts.Date(freq='T', year=dateNext.year,
                                   month=dateNext.month, day=dateNext.day,
                                   hour=0, minute=0, second=0)
            startSlice = data.date_to_index(startSliceDate)
            endSlice = data.date_to_index(endSliceDate)
            mySlice = dataPart[ startSlice : endSlice ]
            if len(mySlice) != 0:
                synched = np.roll(mySlice, -syncOffset[i], axis=0)

                # Correct ac_power - it will be compared in the opposite direction
                synched[:, 4] = np.roll(synched[:, 4], 2*syncOffset[i], axis=0)

                # Stack the results
                if len(synchedData) > 0:
                    synchedData = np.vstack([synchedData, synched])
                else:
                    synchedData = synched

        # The last event is not part of loop, so do it here. Assume its offset
        # by the same amount as the last event.
        date = data.dates[longSync[-1]]#
        endSliceDate = ts.Date(freq='T', year=date.year, month=date.month,
                               day=date.day, hour=0, minute=0, second=0)
        endSlice = data.date_to_index(endSliceDate)
        mySlice = dataPart[ endSlice : , ]
        synched = np.roll(mySlice, -syncOffset[-1], axis=0)

        # Correct ac_power - it will be compared in the opposite direction
        synched[:, 4] = np.roll(synched[:, 4],
                                2*syncOffset[len(syncOffset)-1], axis=0)

        # Stack the results
        if len(synchedData) is 0:
            synchedData = synched
        else:
            synchedData = np.vstack([synchedData, synched])

        # Make the synched data into a tabular array (like genfromtxt gives)
        namesList = ['C_F1', 'C_P1', 'TOS_AW', 'TOE_AW', 'ac_power', 'W_HP',
                     'W_DHW', 'TAS_AW', 'TAE_AW']
        dataSync = np.rec.fromarrays( synchedData.transpose(),
                                      names = namesList )
```

```
            # Strip NaN values (replace them with zeroes)
            for field in namesList:
                dataSync[field][np.isnan(dataSync[field])] = 0.0
        else:
            dataSync = data.data
    else:
        dataSync = data.data

    try:
        assert(len(data) == len(dataSync))
    except AssertionError:
        print "Something went wrong with the synchronization process."
        print "the synchronized data is too short!"

    # Record some data quality stats
    print '   Recording data quality statistics...'
    tot = len(data) + 0.0
    nanHQ = len(data.data['W_HOUSE'][np.isnan(data.data['W_HOUSE'])]) / tot * 100.0
                              nanSBRN        =       len(data.data['outdoor_temperature']
[np.isnan(data.data['outdoor_temperature'])]) / tot * 100.0
    nanInv = len(data.data['ac_power'][np.isnan(data.data['ac_power'])]) / tot * 100.0
    nanStats = [nanHQ, nanSBRN, nanInv]

    # For those fields which are not made up of discreet events, use
    # linear interpolation to fill in NaN values. This introduces some error,
    # but it's better than leaving them empty (even more error).
    fieldList = ['ventilated_slab_outlet_air','ventilated_slab_inlet_air',
                 'bipvt_inlet_air_t7', 'bipvt_inlet_air_t8', 'bipvt_exhaust',
                 'bipvt_air_after_manifold', 'desuperheater', 'hx_air_in',
                 'hx_air_out', 'hx_water_to_reservoir',
                 'reservoir_water_to_hx', 'TA_RET', 'TR_TOIL', 'TE_HRV',
                 'TS_HRV', 'TOE_DR', 'TOS_DR', 'TE_DHW',
                 'TS_DHW', 'C_HRV', 'supply_air_temperature',
                 'outdoor_temperature', 'anemometre', 'a1_soil_under_insulation',
                 'a2_soil_under_insulation', 'a3_soil_under_insulation',
                 'b1_soil_under_insulation', 'b2_soil_under_insulation',
                 'b3_soil_under_insulation', 'c1_soil_under_insulation',
                 'c2_soil_under_insulation', 'c3_soil_under_insulation',
                 'a1_air_flow', 'a2_air_flow', 'a3_air_flow', 'b1_air_flow',
                 'b2_air_flow', 'b3_air_flow', 'c1_air_flow', 'c2_air_flow',
                 'c3_air_flow', 'b2_top', 'a3_middle', 'b2_middle', 'c1_middle',
                 'a2_bottom', 'south_bedroom', 'cavity_air_t2',
                 'gflr_slab_center_top', 'family_room', 'kitchen_top',
                 'north_bedroom', 'dinning_room', 'bsmt_north_room',
                 'bsmt_s_center_ceiling', 'bflr_hall_wall', 'bsmt_south_room',
                 'outlet_air_t28', 'outlet_air_t25', 'outlet_air_t24',
                 'outlet_air_t34', 'outlet_air_t10', 'outlet_air_t11',
                 'outlet_air_t19', 'outlet_air_t31', 'outlet_air_t22',
                 'outlet_air_t30']

    print '   Filling missing data from other data sources...'
    # Filled/corrected temperature (fill missing SBRN data with inveter data)
    for i, row in enumerate(data['outdoor_temperature']):
        if np.isnan(row):
            data['outdoor_temperature'][i] = data['temperature_ext'][i]

    # Filled/corrected temperature (fill missing SBRN data with inveter data)
    for i, row in enumerate(data['pv_roof_global_solar_irradiance']):
        if np.isnan(row):
            data['pv_roof_global_solar_irradiance'][i] = data['irradiance'][i]

    # Cycle through each field
    print '   Interpolating to fill missing data...'
```

```
    for field in fieldList:
        print field
        # find the gaps in the specified field
        toLinear = np.where(np.isnan(data.data[field]) == True)[0]
#        toLinear = toLin

        # Interpolate only if there are gaps to fill in
        if len(toLinear) > 0:

            # set the initial start point
            startPoint = toLinear[0] - 1

            # cycle through all rows that had NaN data
            for i in range(len(toLinear)-1):

                # if there is more than 1 min diff, it's a new gap
                if toLinear[i+1] - toLinear[i] > 1 or i == len(toLinear)-2:

                    # Choose the end point
                    if i == len(toLinear)-2:
                        if np.isnan(data.data[field][-1]):
                            endPoint = toLinear[i] - 1
                        else:
                            endPoint = toLinear[-1]# + 1
                    else:
                        endPoint = toLinear[i] + 1

                    print data[field][startPoint]
                    print data[field][endPoint]

                    # Find the equation of a line to use here for linear interpolation
                    slope = ( (data[field][startPoint] - data[field][endPoint]) /
                          (startPoint - endPoint) )
                    yint = data[field][startPoint] - slope * startPoint
                    fillVal = lambda x: slope * x + yint

                    # Replace values by linear interpolation
                    for j in range(startPoint, endPoint+1):
                        #print 'fillVal: ' + np.str(fillVal(j))
                        if np.isnan(fillVal(j)) == True:
                            data[field][j] = data[field][startPoint]
                        else:
                            data[field][j] = fillVal(j)

                    # Reset the start point for the next interval
                    startPoint = toLinear[i+1] - 1

    # Strip NaN values in non continuous data fields (replace them with zeros)
    print '    Filling remaining missing data with zeros...'
    fieldList2 = ['pressurer_drop_across_manifold', 'T_SUC', 'T_DISC',
                  'T_LIQUI', 'TR_OUT', 'BT_IN', 'BT_OUT', 'TE_PT', 'TS_PT',
                  'TAE_AW', 'TAS_AW', 'TOE_AW', 'TOS_AW', 'TE_HP', 'TS_HP',
                  'P_S', 'P_D', 'C_F1', 'C_P1', 'B_FR', 'W_HOUSE', 'W_HP',
                  'W_DHW', 'hq_genuine', 'horizontal_global_solar_irradiance',
                  'pv_roof_global_solar_irradiance',
                  'south_facade_global_solar_irradiance', 'irradiance',
                  'ac_power']
    for field in fieldList2:
        data.data[field][np.isnan(data.data[field])] = 0

    # Return the results
    print '-> Returning data for calculations...'
    return data, dataSync, nanStats
```

Appendix B – Python Scripts

```
# -*- coding: ASCII -*-
"""
Filters out known loads then locates the garage heater and auxiliary heater
events. These events are then also filtered out. Returns filtered power,
garage heater power and aux heater power all in 2 minute intervals (genuine
HQ data only)

Written as part of a MASc Thesis by Matt Doiron (Dec 2010)
"""

def filterPower(myData, pvSynched, startDate, endDate):
    '''Locates garage and aux heater events. Filters them and know loads'''

    print '-> Getting filtered power data...'

     # Import libraries
    import numpy as np
    import scikits.timeseries as ts

    # Important variables
    pf = 0.85              # assumed constant power factor
    lineVoltage = 115.0    # assumed constant line voltage (V)
    controls = 0.0336      # estimated load of controls (kW)
    monitoring = 0.21283   # estimated load of monitoring (kW)
    hpFan = 0.200          # estimated load of heat pump fan in recirc mode (kW)
    airCleaner = 0.049     # measured air cleaner consumption (kW)
#     invPower = 0.007      # inverter draw during operation (kW)
    alarmPower = 0.0072    # alarm sys consumption (kW)

    # Create temporary variables the same length as myData for filling later
    filtered_temp = np.zeros(len(myData))
    garHeaterPower_temp = np.zeros(len(myData))
    auxHeaterPower_temp = np.zeros(len(myData))

    # Grab genuine data only
    print '   Grabbing genuine data only (2 min intervals)...'
    genuineMask = np.where(myData['hq_genuine'].data==1)[0]
    pvSynched = pvSynched[myData['hq_genuine'].data==1]
    myData = myData[myData['hq_genuine'].data==1]

    #===============================================================================
    # Filter known values out of the net power
    #===============================================================================

    print '   Filtering known loads from power data...'
    # Mark zeros with high values to make them easy to find later
    myData['W_HOUSE'][myData['W_HOUSE'] == 0.0] = 1000.0

    # Filter other loads leaving only base load, aux heat and garage heater
    filtered = ( myData['W_HOUSE'] +
                 pvSynched / 1000.0 -
                 myData['W_HP'] -
                 myData['W_DHW'] -
                 myData['C_HRV'] * lineVoltage * pf / 1000.0 -
                 myData['C_F1'] * lineVoltage * pf / 1000.0 -
                 myData['C_P1'] * lineVoltage * pf / 1000.0 )

    # Filter estimated baseloads
    filtered = filtered - controls - monitoring - alarmPower

    #Filter the air cleaner for times when the HRV is on
    filtered[myData['C_HRV'] > 0.0] -= airCleaner
```

```
    # Filter the recirculation mode of the heat pump fan (only while HP is off)
    filtered[myData['W_HP'] == 0.0] -= hpFan

    # Filter the inverter power draw (only while inverter is generating)
    #filtered[pvSynched > 0.0] -= invPower

    # Set the previously marked points to zero and unmark myData
    filtered[filtered > 800.0] = 0.0
    myData['W_HOUSE'][myData['W_HOUSE'] == 1000.0] = 0.0

    # Any negative numbers now are due to error introduced because of the
    # different sampling frequencies of the inverter vs HQ
    #filtered[filtered < 0.0] = 0.0

    #===============================================================================
    # Auxiliary electric heat on heatpump
    #===============================================================================

    print '   Filtering auxuliary heating events...'
    # Locations of auxiliary heater events after Dec 10, 2010 (add as many
    # more as might be required)
    auxHeaterLocs = [ ('2009-12-16 07:12:00', '2009-12-16 08:12:00'),
                      ('2009-12-19 16:24:00', '2009-12-19 16:50:00'),
                      ('2009-12-22 16:06:00', '2009-12-22 16:24:00'),
                      ('2009-12-29 07:30:00', '2009-12-29 08:26:00'),
                      ('2010-01-09 07:11:00', '2010-01-09 08:33:00'),
                      ('2010-01-12 18:55:00', '2010-01-12 19:09:00'),
                      ('2010-01-14 07:11:00', '2010-01-14 08:27:00'),
                      ('2010-01-23 07:09:00', '2010-01-23 08:21:00'),
                      ('2010-01-29 06:11:00', '2010-01-29 06:19:00'),
                      ('2010-02-01 07:25:00', '2010-02-01 08:35:00'),
                      ('2010-02-02 07:11:00', '2010-02-02 08:45:00'),
                      ('2010-02-02 20:49:00', '2010-02-02 21:11:00'),
                      ('2010-02-04 07:11:00', '2010-02-04 08:39:00'),
                      ('2010-02-05 20:37:00', '2010-02-05 20:51:00'),
                      ('2010-02-06 19:41:00', '2010-02-06 19:55:00') ]
        auxHeaterLocs  =  [(ts.Date('T',  loc1),  ts.Date('T',  loc2))  for  loc1,  loc2  in
auxHeaterLocs]

    # Find aux heater start and end points for the inputed period of time
    auxEndPeaks = []
    auxStartPeaks = []
    for item in auxHeaterLocs:
        if item[0] >= startDate and item[1] <= endDate:
            startLoc = myData.date_to_index(item[0])
            endLoc = myData.date_to_index(item[1])
            startVal = filtered[startLoc]
            endVal = filtered[endLoc]
            auxStartPeaks.append((startVal, startLoc))
            auxEndPeaks.append((endVal, endLoc))

    # Cycle through the aux heater peaks and subtract 9.6 (coil kW)
    auxHeaterPower = np.zeros(len(filtered))
    if len(auxEndPeaks) > 0:
        for i, tup in enumerate(auxEndPeaks):
            # Find the equation of a line to use here for linear interpolation
            slope = ( (auxEndPeaks[i][0] - auxStartPeaks[i][0]) /
                  (auxEndPeaks[i][1] - auxStartPeaks[i][1]) )
            yint = auxEndPeaks[i][0] - slope * auxEndPeaks[i][1]
            baseLoad = lambda x: slope * x + yint

            # Cycle through each data point between the peak start and peak end
            peakWidth = auxEndPeaks[i][1] - auxStartPeaks[i][1]
```

```
            for j in range(1, peakWidth):
                if filtered[tup[1]-j] - 9.6 >= 0:
                    filtered[tup[1]-j] -= 9.6
                    auxHeaterPower[tup[1]-j] = 9.6
                else:
                    auxPower = filtered[tup[1]-j] - baseLoad(tup[1]-j)
                    filtered[tup[1]-j] = baseLoad(tup[1]-j)
                    auxHeaterPower[tup[1]-j] = auxPower

    #================================================================================
    # Electric Garage Heater
    #================================================================================

    print '   Filtering garage heater events...'
    # Locate garage heater peaks
    temp = -1000
    garEndPeaks = []
    garStartPeaks = []
    for i in range(len(filtered)-6):
        n = filtered[i]
        n1 = filtered[i+1]
        n2 = filtered[i+2]
        n3 = filtered[i+3]
        n4 = filtered[i+4]
        n5 = filtered[i+5]
        n6 = filtered[i+6]
        # Filter out any peaks during warm weather or that start with a dip
        if myData['outdoor_temperature'][i] > 5.0 or n > n1: #12.83
            continue
        # 7 points with no appliances
         if 3.0 < n2 and 3.0 < n3 and 3.0 < n4 and n < 1.5 and n6 < 1.5 and n1 - n > 0.25
and n5 - n6 > 0.25:
            if i - temp >= 14:
                garStartPeaks.append((n, i))
                garEndPeaks.append((n6, i+6))
                temp = i
        # 6 points with no appliances
         elif 3.0 < n2 and 3.75 < n3 and n < 1.5 and n5 < 2.1 and n1 - n > 0.25 and n4 -
n5 > 0.25:
            if i - temp >= 14:
                garStartPeaks.append((n, i))
                garEndPeaks.append((n5, i+5))
                temp = i
        # 5 points with no appliances, point on front of peak
         elif 3.0 < n1 and 3.0 < n2 and n < 1.5 and n4 < 1.5 and n1 - n > 1.0 and n3 - n4
> 0.25:
            if i - temp >= 14:
                garStartPeaks.append((n, i))
                garEndPeaks.append((n4, i+4))
                temp = i
        # 5 points with no appliances, point on back of peak
        elif 3.0 < n2 and 3.0 < n3 and n < 1.5 and n4 < 1.5 and n1 - n > 0.25 and n3 - n4
> 0.25:
            if i - temp >= 14:
                garStartPeaks.append((n, i))
                garEndPeaks.append((n4, i+4))
                temp = i
        # 4 points with no appliances, point on front of peak
        elif 4.5 < n1 and n < 1.0 and n3 < 1.0 and n1 - n > 1.0:
            if i - temp >= 14:
                garStartPeaks.append((n, i))
                garEndPeaks.append((n3, i+3))
                temp = i
```

```
        # 7 points with appliances
        if 4.5 < n3 and 4.5 < n4 and 4.5 < n5 and n < 2.5 and n6 < 4.5 and n1 - n > 0.35
and n2 - n1 > 1.0 and n4 - n5 > 1.5 and n5 - n6 > 0.15:
            if i - temp >= 14:
                garStartPeaks.append((n, i))
                garEndPeaks.append((n6, i+6))
                temp = i
        # 6 points with appliances
        elif 5.0 < n2 and 5.0 < n3 and n < 4.5 and n5 < 4.5 and n1 - n > 0.25 and n4 - n5
> 1.25:
            if i - temp >= 14:
                garStartPeaks.append((n, i))
                garEndPeaks.append((n5, i+5))
                temp = i
        # 5 points with appliances, point on front of peak
        elif 4.5 < n2 and 4.25 < n3 and n < 3.5 and n4 < 6.75 and n1 - n > 0.25 and n3 -
n4 > 1.25:
            if i - temp >= 14:
                garStartPeaks.append((n, i))
                garEndPeaks.append((n4, i+4))
                temp = i
        # 5 points with appliances, point on back of peak
        elif 4.5 < n1 and 4.5 < n2 and n < 3.25 and n4 < 3.0 and n1 - n > 3.25 and n3 -
n4 > 1.25:
            if i - temp >= 14:
                garStartPeaks.append((n, i))
                garEndPeaks.append((n4, i+4))
                temp = i

    # Cycle through the gar heater peaks and subtract the gar heater consumption
    garHeaterPower = np.zeros(len(filtered))
    if len(garEndPeaks) > 0:
        for i, tup in enumerate(garEndPeaks):
            # Find the equation of a line to use here for linear interpolation
            slope = ( (garEndPeaks[i][0] - garStartPeaks[i][0]) /
                  (garEndPeaks[i][1] - garStartPeaks[i][1]) )
            yint = garEndPeaks[i][0] - slope * garEndPeaks[i][1]
            baseLoad = lambda x: slope * x + yint

            # Cycle through each data point between the peak start and peak end
            peakWidth = garEndPeaks[i][1] - garStartPeaks[i][1]
            for j in range(1, peakWidth):
                if filtered[tup[1]-j] - 5.0 >= 0:
                    filtered[tup[1]-j] -= 5.0
                    garHeaterPower[tup[1]-j] = 5.0
                else:
                    garPower = filtered[tup[1]-j] - baseLoad(tup[1]-j)
                    filtered[tup[1]-j] = baseLoad(tup[1]-j)
                    garHeaterPower[tup[1]-j] = garPower

    # Reinterpolate to 1 minute intervals before returning values
    print '   Reinterpolating to 1 minute intervals...'

    #==========================================================================
    #     Reinterpolate for filtered power data
    #==========================================================================

    # If the first value in the list is not genuine, there will be no data
    # available to interpolate it, therfore fill them with the first genuine
    # values. This introduces a small amount of error, but is unavoidable.
    if genuineMask[0] != 0:
        for j in range(genuineMask[0]):
            filtered_temp[j] = filtered[j]
```

```
    # Cycle through each point in the genuine mask (from original data)
    for i in range(len(filtered)-1):
        val1 = filtered[i]
        val2 = filtered[i+1]
        span = genuineMask[i+1] - genuineMask[i]

        # Find equation of a line for linear interpolation
        slope = (val2 - val1) / np.float(span)
        yint = val2 - slope * np.float(span)
        fillVal = lambda x: np.float(slope * x + yint)

        # Put the new values into the temp list
        for m in range(span):
            filtered_temp[genuineMask[i]+m] = fillVal(m)

    # If the last value in the list is not genuine, there will be no data
    # available to interpolate it, therfore fill them with the last genuine
    # values. This introduces a small amount of error, but is unavoidable.
    if genuineMask[-1] != len(filtered_temp)-1:
        for k in range(len(filtered_temp) - genuineMask[-1]):
            filtered_temp[genuineMask[-1]+k] = filtered[-1]

    #============================================================================
    #     Reinterpolate for garHeaterPower data
    #============================================================================

    # If the first value in the list is not genuine, there will be no data
    # available to interpolate it, therfore fill them with the first genuine
    # values. This introduces a small amount of error, but is unavoidable.
    if genuineMask[0] != 0:
        for j in range(genuineMask[0]):
            garHeaterPower_temp[j] = garHeaterPower[j]

    # Cycle through each point in the genuine mask (from original data)
    for i in range(len(garHeaterPower)-1):
        val1 = garHeaterPower[i]
        val2 = garHeaterPower[i+1]
        span = genuineMask[i+1] - genuineMask[i]

        # Find equation of a line for linear interpolation
        slope = (val2 - val1) / np.float(span)
        yint = val2 - slope * np.float(span)
        fillVal = lambda x: np.float(slope * x + yint)

        # Put the new values into the temp list
        for m in range(span):
            garHeaterPower_temp[genuineMask[i]+m] = fillVal(m)

    # If the last value in the list is not genuine, there will be no data
    # available to interpolate it, therfore fill them with the last genuine
    # values. This introduces a small amount of error, but is unavoidable.
    if genuineMask[-1] != len(garHeaterPower_temp)-1:
        for k in range(len(garHeaterPower_temp) - genuineMask[-1]):
            garHeaterPower_temp[genuineMask[-1]+k] = garHeaterPower[-1]

    #============================================================================
    #     Reinterpolate for auxHeaterPower data
    #============================================================================

    # If the first value in the list is not genuine, there will be no data
    # available to interpolate it, therfore fill them with the first genuine
    # values. This introduces a small amount of error, but is unavoidable.
```

```
if genuineMask[0] != 0:
    for j in range(genuineMask[0]):
        auxHeaterPower_temp[j] = auxHeaterPower[j]

# Cycle through each point in the genuine mask (from original data)
for i in range(len(auxHeaterPower)-1):
    val1 = auxHeaterPower[i]
    val2 = auxHeaterPower[i+1]
    span = genuineMask[i+1] - genuineMask[i]

    # Find equation of a line for linear interpolation
    slope = (val2 - val1) / np.float(span)
    yint = val2 - slope * np.float(span)
    fillVal = lambda x: np.float(slope * x + yint)

    # Put the new values into the temp list
    for m in range(span):
        auxHeaterPower_temp[genuineMask[i]+m] = fillVal(m)

# If the last value in the list is not genuine, there will be no data
# available to interpolate it, therfore fill them with the last genuine
# values. This introduces a small amount of error, but is unavoidable.
if genuineMask[-1] != len(auxHeaterPower_temp)-1:
    for k in range(len(auxHeaterPower_temp) - genuineMask[-1]):
        auxHeaterPower_temp[genuineMask[-1]+k] = auxHeaterPower[-1]

#============================================================================
#     # Return results
#============================================================================

print '-> Returning filtered power data...'
return filtered_temp, garHeaterPower_temp, auxHeaterPower_temp
```

Appendix B – Python Scripts

```
# -*- coding: ASCII -*-
"""

Find daily average outdoor temps and het pump consumptions, then find
balance point for use with heating degree days.

Query required for this file:
SELECT
data_date_time, W_HP, outdoor_temperature, temperature_ext, BT_IN, BT_OUT,
B_FR, pv_roof_global_solar_irradiance, irradiance

WEHRE
data_date_time BETWEEN '2009-12-10 00:00:00' AND '2010-06-09 23:59:00'
ORDER BY
data_date_time

"""

# Import libraries
import numpy as np
import datetime as dt
from scipy import stats
import matplotlib.pyplot as plt
import matplotlib as mpl
import matplotlib.font_manager as font_manager

# Process the timestamp into a datetime object
lam = lambda S: dt.datetime.strptime(S, "%Y-%m-%d %H:%M:%S.%f")
convertDict = {0:lam}

# Get data from the file
fileName = 'data/HDD dec 10 to jun 9.tsv'
#fileName = 'data/ET apr 20 to apr 26.tsv'
myData = np.genfromtxt(fileName,
                       delimiter = "\t",
                       names = True,
                       dtype = None,
                       converters = convertDict)

# Strip NaN values (replace them with zeroes)
fieldList = ['W_HP', 'BT_IN', 'BT_OUT', 'B_FR']
for field in fieldList:
    myData[field][np.isnan(myData[field])] = 0

# Correlation for density of water (kg/m3)
rhoWater = lambda temp: -0.0041 * pow(temp, 2.0) - 0.0432 * temp + 1000.6

# Correlation for density of methanol (kg/m3)
rhoMeth = lambda temp: -0.8914 * temp + 808.83

# Correlation for Cp of water (kJ/kgC)
cpWater = lambda temp: -0.0000003 * pow(temp, 3) + 0.00005 * pow(temp, 2) - 0.0024 * temp
+ 4.2133

# Correlation for Cp of methanol (kJ/kgC)
cpMeth = lambda temp: 0.0034 * temp + 1.3704

# Reset the sums to be sure they are zero
sumLoadDaily = 0.0
sumOATDaily = 0.0
sumRadDaily = 0.0
sumLoadDailyAdj = 0.0
qHP = 0.0
```

```
dailyHeatingLoad = []
dailyHeatingOAT = []
dailyHeatingRad = []
dailyHeatingLoadAdj = []
heatingLoad = []
heatingOAT = []
hddList = []
percentWaterWeight = 0.75        # percent of water by weight
percentMethWeight = 0.25        # percent of methanol by weight
gpm_to_m3s = 0.0000630902    # convert USgpm to m3/sec
qHPList = []
hpCopList = []
qDT = []

# Filled/corrected temperature (fill missing SBRN data with inveter data)
for i, row in enumerate(myData['outdoor_temperature']):
    if np.isnan(row):
        myData['outdoor_temperature'][i] = myData['temperature_ext'][i]

# Filled/corrected irradiance (fill missing SBRN data with inveter data)
for i, row in enumerate(myData['pv_roof_global_solar_irradiance']):
    if np.isnan(row):
        myData['pv_roof_global_solar_irradiance'][i] = myData['irradiance'][i]

# Loop through the data
for i, row in enumerate(myData):

    # Modulus of i used to denote a day (1440 minutes)
    modDay = i % 1440.0

    # reset for this row
    qW = 0.0
    heatPumpEnergyRow = 0.0

    if row['W_HP'] > 0.0:
        # Average temp of ground loop
        avgTemp = (row['BT_IN'] + row['BT_OUT']) / 2.0

        # Calculate percent methanol by volume for current conditions
        volWater = percentWaterWeight / rhoWater(avgTemp)
        volMeth = percentMethWeight / rhoMeth(avgTemp)
        percentMeth = volMeth / (volWater + volMeth)
        percentWater = 1.0 - percentMeth
        rhoMix = (percentMeth  * rhoMeth(avgTemp)) + (percentWater * rhoWater(avgTemp))

        # Find energy removed from ground loop water (kWh)
        m = row['B_FR'] * gpm_to_m3s * rhoMix
        deltaT = row['BT_IN'] - row['BT_OUT']
        if deltaT > 0:
            Cp_water_meth = (percentMeth * cpMeth(avgTemp)) + (percentWater *
cpWater(avgTemp))
            qW = m * Cp_water_meth * deltaT / 60.0
            qHPList.append(qW)
            qDT.append(deltaT)
            heatPumpEnergyRow = row['W_HP'] / 60.0

    # Add this row to the previous row
    if not np.isnan(row['outdoor_temperature']):
        sumOATDaily += row['outdoor_temperature']
        sumLoadDaily += (qW + heatPumpEnergyRow)
        sumRadDaily += row['pv_roof_global_solar_irradiance']

    # If a day has passed (modDay) then add the results to the list and reset
```

```
    if modDay == 0 and i > 0.0 or i == len(myData)-1:

        # Average daily outdoor air temperature and irradiance
        sumOATDaily /= 1440.0
        sumRadDaily /= 1440.0

        #if sumOATDaily < 15.0:
        if sumOATDaily <= 15.0: # and sumLoadDaily > 0:
            dailyHeatingLoad.append(sumLoadDaily)
            dailyHeatingOAT.append(sumOATDaily)
            dailyHeatingRad.append(sumRadDaily)

        # Reset
        sumLoadDaily = 0.0
        sumOATDaily = 0.0
        sumRadDaily = 0.0
        sumLoadDailyAdj = 0.0

# Find the equation of a line that fits these points
slope,   intercept,   r_value,   p_value,   std_err   =   stats.linregress(dailyHeatingOAT,
dailyHeatingLoad)
yVal = lambda x: slope * x + intercept
xVal = lambda y: (y - intercept) / slope

# The balance temp 12.93
balanceTemp = xVal(0)

# Heating degre days for this period
hdd = balanceTemp - np.array(dailyHeatingOAT)
hdd18 = 18.0 - np.array(dailyHeatingOAT)

# Total heating degree days for this period
totalHDD = sum(hdd)
totalHDD18 = sum(hdd18)

# kWh energy input per HDD
kWh_per_HDD_in = sum(myData['W_HP']) / 60.0 / totalHDD

# kWh load per HDD
kWh_per_HDD = sum(dailyHeatingLoad) / totalHDD

# COP overall
hpCOP = sum(dailyHeatingLoad) / (sum(myData['W_HP']) / 60.0)

# CUSUM
predictedLoad = kWh_per_HDD * hdd
diff = dailyHeatingLoad - predictedLoad
cusum = np.cumsum(diff)

# Create an adjusted CUSUM normalized to daily solar radiation
cusumAdj = np.cumsum(diff) / dailyHeatingRad

# Print results
print '\n-----------------------------------------------'
print ' EcoTerra HDD Analysis for the period of:'
print '  Dec 10, 2009 to Jun 9, 2010'
print '-----------------------------------------------'
print '       Balance Temperature: {0:>7.2f} C'.format(balanceTemp)
print '                       R^2: {0:>7.2f}'.format(r_value**2)
print '           HDDs for period: {0:>7.2f}'.format(totalHDD)
print ' HDDs for period (Base 18): {0:>7.2f}'.format(totalHDD18)
print '            kWh/HDDs Input: {0:>7.2f} kWh/HDD'.format(kWh_per_HDD_in)
print '             kWh/HDDs Load: {0:>7.2f} kWh/HDD'.format(kWh_per_HDD)
```

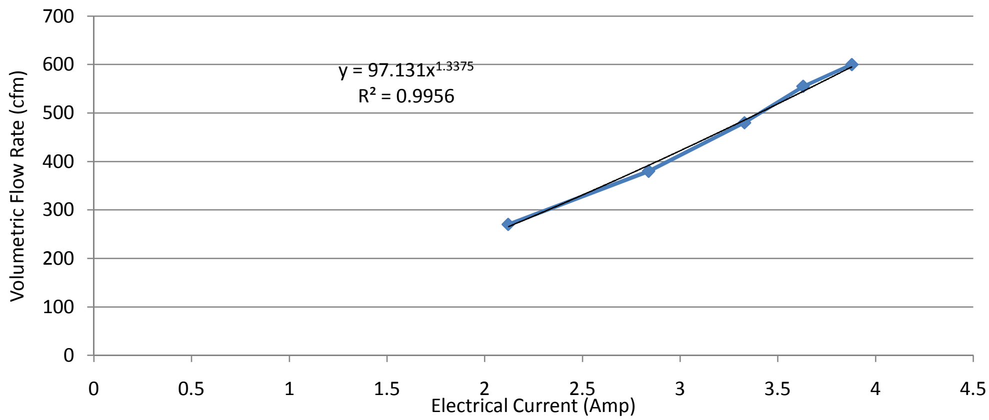
```
print '                       COP: {0:>7.2f} '.format(hpCOP)
print '-----------------------------------------------'

# ---------------------------------------------------------------------------
# Plot a graph of the heating load values, and balance point
# ---------------------------------------------------------------------------

# Plot the results
fig1 = plt.figure(num=1, figsize=(6,4.29))
fig1.subplots_adjust(left=0.1, bottom=0.13, right=0.98, top=0.96)
mpl.rcParams['font.size'] = 10.0
ax1 = fig1.add_subplot(111)
plt.scatter(dailyHeatingOAT, dailyHeatingLoad)
xRange = np.arange(-22.0, 15.0, (37.0)/len(dailyHeatingOAT))
plt.plot(xRange, yVal(xRange))
plt.grid(True)
plt.text(0.5, 93.0, 'Balance Temperature: {0:>2.2f} C'.format(xVal(0)))
plt.text(0.5, 88.0, 'R^2: {0:>2.2f}'.format(r_value**2))
plt.ylabel('Daily average heating load (kWh)')
plt.xlabel('Daily average outdoor air temperature (C)\nDecember 10, 2009 to June 9,
2010')
plt.draw()
#plt.savefig('figs/tbal.eps', dpi=200)

# ---------------------------------------------------------------------------
# Plot a CUSUM analysis
# ---------------------------------------------------------------------------

datesRaw = [dt.datetime(2008, 12, 10, 0, 0, 0) + dt.timedelta(days=i) for i in
range(len(dailyHeatingLoad))]
dates = mpl.dates.date2num(datesRaw)
fig2 = plt.figure(num=2, figsize=(6,4.29))
fig2.subplots_adjust(left=0.1, bottom=0.13, right=0.91, top=0.96)
mpl.rcParams['font.size'] = 10.0
ax2 = fig2.add_subplot(111)
line1 = ax2.plot_date(dates, cusum, linestyle='-', label='CUSUM', color='blue',
marker='', linewidth=2.0)
line2 = ax2.plot_date(dates, cusumAdj, linestyle='--', label='CUSUM', color='green',
marker='', linewidth=1.5)
ax2.set_ylabel('Cumulative Difference in Heating Load (kWh)')
ax2.grid(True)
ax2.set_xlabel('Time (Months)\nDecember 10, 2009 to June 10, 2010')
ax2a = ax2.twinx()
line3 = ax2a.plot_date(dates, dailyHeatingRad, linestyle='-', label='Insolation',
color='red', marker='', linewidth=0.9)
ax2a.set_ylabel('Average Daily Solar Radiation (W/m2)')
plt.figlegend((line1, line2, line3),
              ('CUSUM', 'Norm CUSUM', 'Avg Daily Insolation'),
              (.11,.89), prop=font_manager.FontProperties(size=10), ncol=3)

# Set formatters for dates
dateFmt = mpl.dates.DateFormatter('%b')
monthsLoc = mpl.dates.MonthLocator()
ax2.xaxis.set_major_formatter(dateFmt)
ax2.xaxis.set_major_locator(monthsLoc)

# Show the resulting graph
plt.draw()
#plt.savefig('figs/cusum.eps', dpi=200)

plt.show()
```

Appendix C - Correlations

Correlations Between Flow Rate and Current for BIPV/T Fan

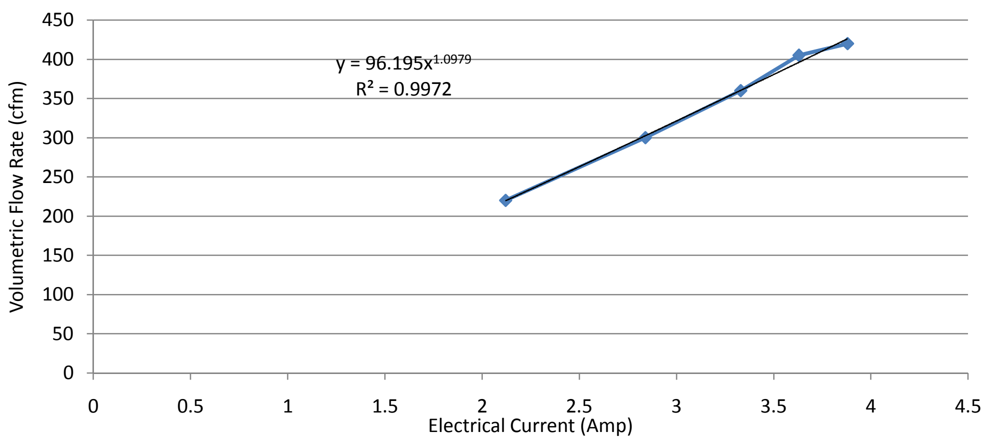
DHW Mode

amp	cfm
2.12	270
2.84	380
3.33	480
3.63	555
3.88	600



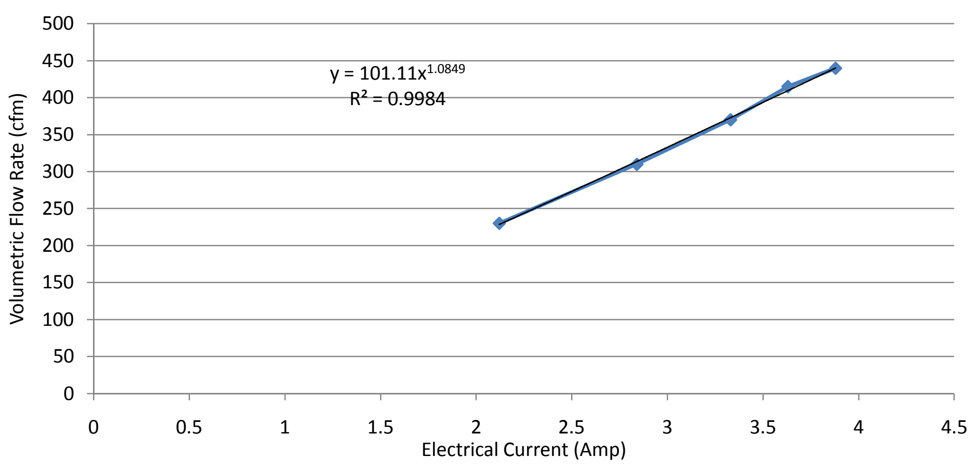
Slab Mode

amp	cfm
2.12	220
2.84	300
3.33	360
3.63	405
3.88	420



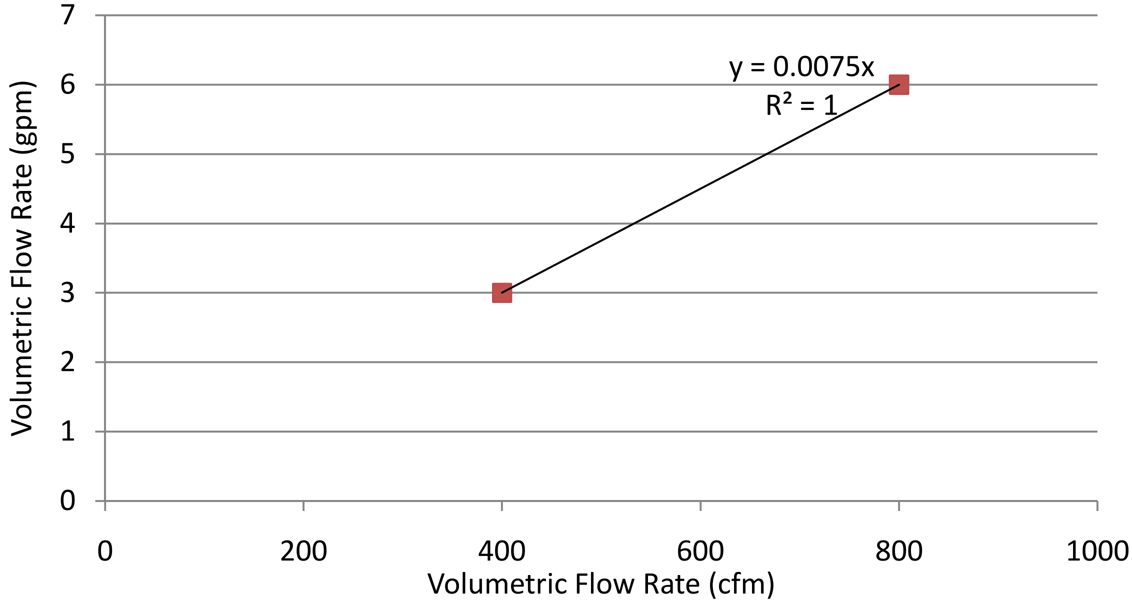
Combo DHW and Slab Mode

amp	cfm
2.12	230
2.84	310
3.33	370
3.63	415
3.88	440



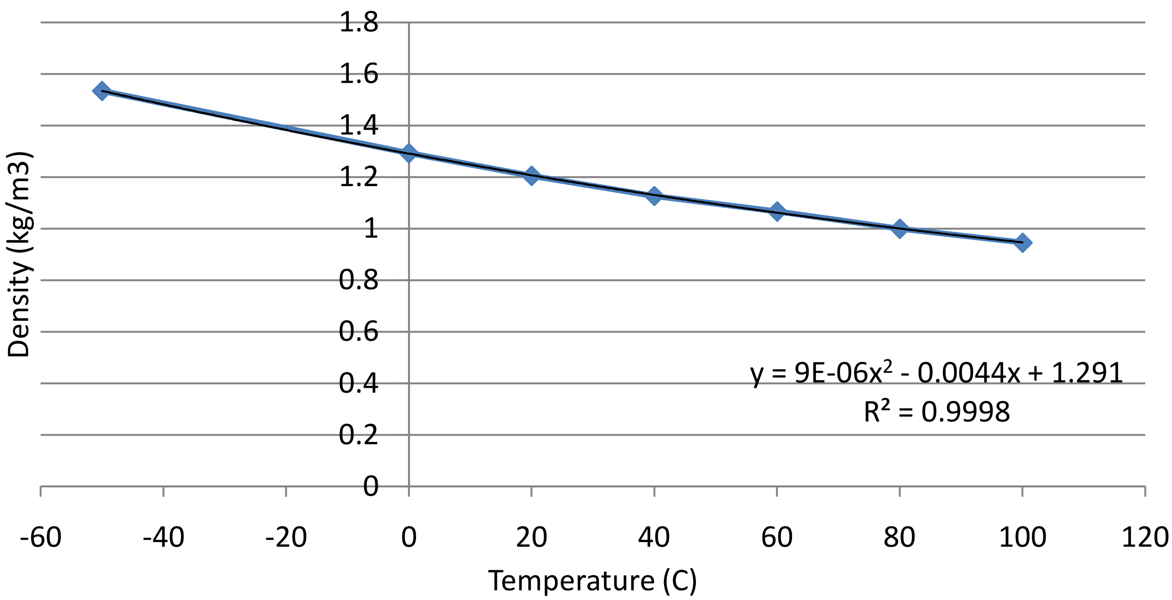
Correlation between flow rates for Pump P1 and BIPV/T Fan

cfm	gpm
400	3
800	6



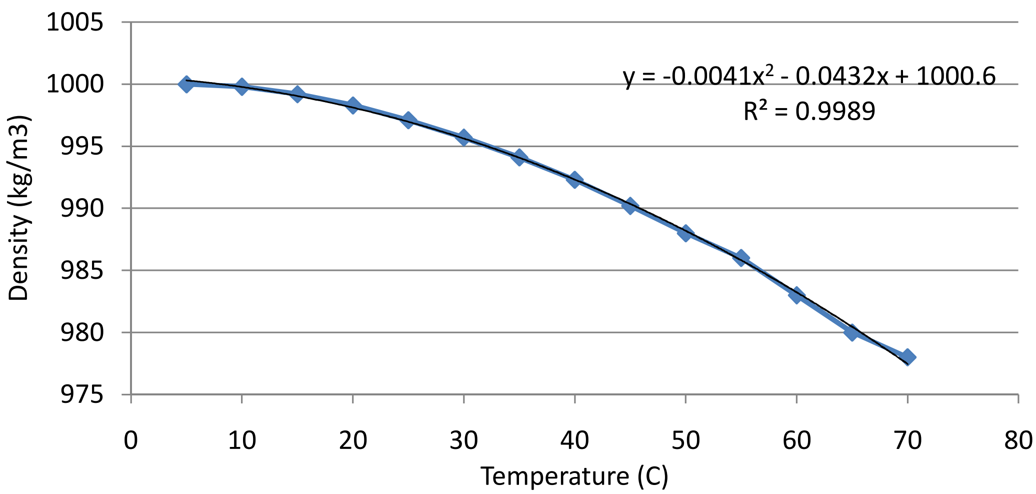
Properties of Air at Various Conditions

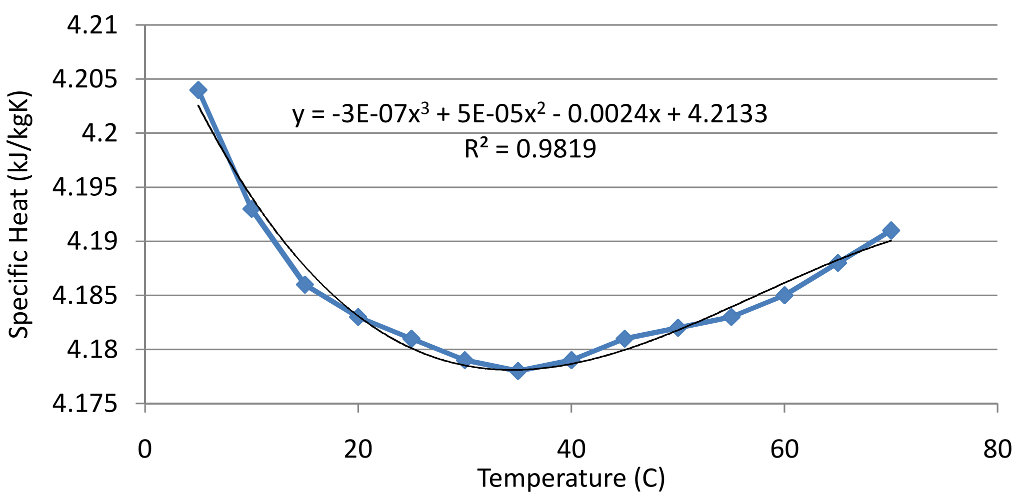
Temperature	Density	Specific heat
C	kg/m3	kJ/kgk
-50	1.534	1.005
0	1.293	1.005
20	1.205	1.005
40	1.127	1.005
60	1.067	1.009
80	1	1.009
100	0.946	1.009



Properties of Water at Various Conditions

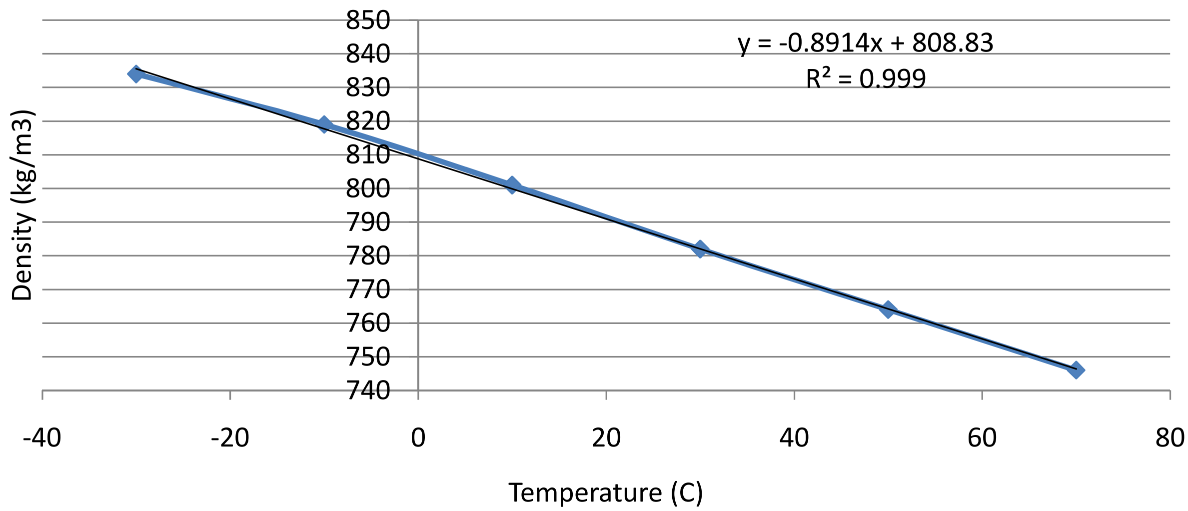
Temperature C	Density kg/m3	Specific heat kJ/kgk
0.01	999.8	4.21
5	1000	4.204
10	999.8	4.193
15	999.2	4.186
20	998.3	4.183
25	997.1	4.181
30	995.7	4.179
35	994.1	4.178
40	992.3	4.179
45	990.2	4.181
50	988	4.182
55	986	4.183
60	983	4.185
65	980	4.188
70	978	4.191

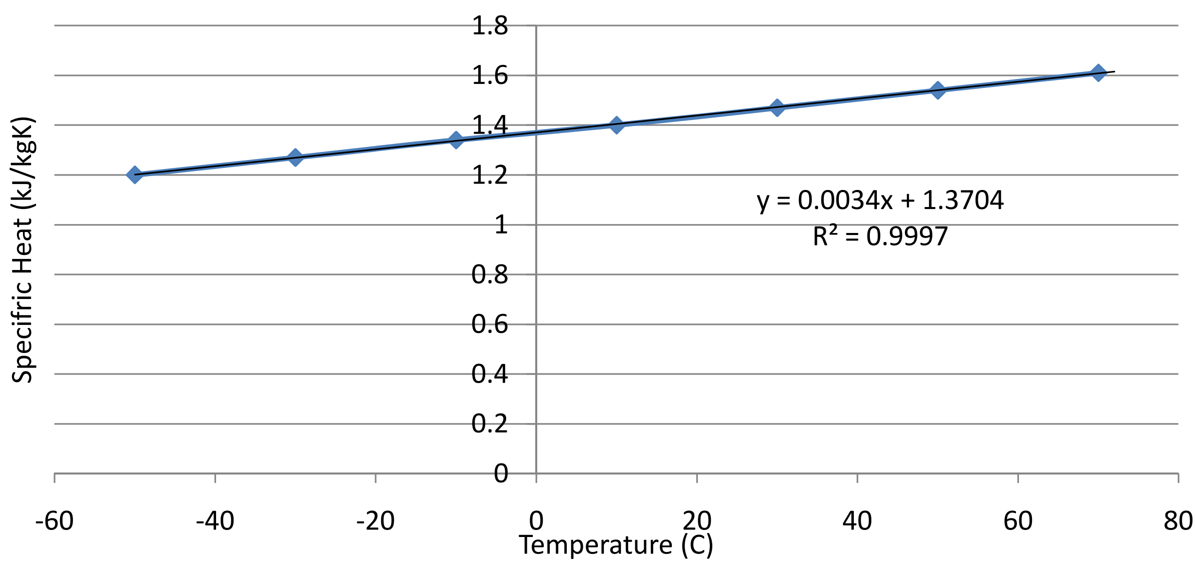




Properties of Methanol at Various Conditions

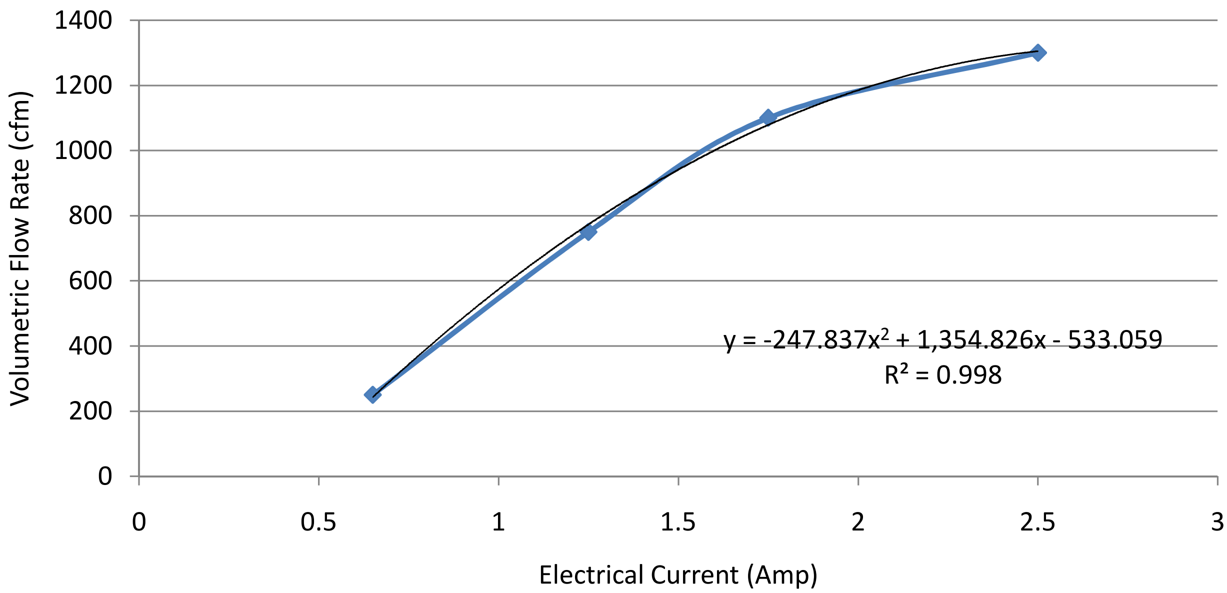
Temperature	Density	Specific Heat
C	kg/m3	kJ/kgk
-50	844	1.2
-30	834	1.27
-10	819	1.34
10	801	1.4
30	782	1.47
50	764	1.54
70	746	1.61
90	724	1.79
110	704	1.92
130	685	1.92
150	653	1.92





Correlations Between Flow Rate and Current for Heat Pump Fan

Amp	CFM
0.65	250
1.25	750
1.75	1100
2.5	1300



Appendix D - Detailed Control Sequences

D DETAILED CONTROL SEQUENCES

The following control sequences are a detailed description of how the systems of ÉcoTerra House are controlled. Each piece of equipment which is linked to the control system is documented here with details of how and when it operates. The interaction between equipment is also described. A detailed schematic of the system is found at the end of the document. There is also a table of equipment which includes tags and descriptions for each item.

D.1 BIPV/T System

The BIPV/T fan VA1, which draws air from the roof into the BIPV/T system, shall be energized only when *all* of the following conditions are true:

- There is a demand from one or more of the the slab, domestic hot water or dryer systems. Whether there is demand or not is defined by the demand flags for each system as described later in this document.
- The low limit flag for the roof cavity air temperature is not set. This low limit flag is set when the temperature of the air in the roof cavity falls below 18 °C and remains set until the temperature rises back above 20 °C.
- There is sufficient solar radiation. There is considered to be sufficient insolation when neither the amperage low limit flag nor the temperature low limit flag is set. The amperage low limit flag is set when the current passing through the inverter drops below 2.0 amps and the flag remains set until the current rises back over 3.0 amps. The temperature low limit flag is set when the outdoor air temperature

drops below -10 °C and remains set until the outdoor air temperature rises past -8 °C.

The freeze-protection damper D10 is interlocked with the fan VA1 so that while VA1 is energized, D10 is closed and while VA1 is de-energized, D10 is open.

The temperature setpoint for the roof air cavity is maintained by continuously modulating the speed of the fan VA1 between 40% and 80% of maximum based on the output of a PI controller. The maximum is limited to 80% to reduce noise from the fan. The roof air cavity temperature setpoint is defined as the maximum of the following values:

- The temperature of the domestic hot water preheat tank plus 10 °C. This value is considered only if there is demand for DHW preheat charging.
- The average slab temperature plus 10 °C. This value is considered only if there is demand for slab charging.
- If the dryer is operating, the setpoint will be 30 °C.

When starting, the fan VA1 shall start slowly in order to give the dampers enough time to fully open or close. This is to prevent high pressure and whistling in the duct system which can occur if the fan operates before the designated dampers are opened.

While the BIPV/T fan VA1 is energized, there are multiple damper configurations which are possible. Each configuration diverts solar-heated air from the roof for one or more purposes. Appropriate delay should be introduced between the opening/closing of dampers and the starting/stopping of the fan to ensure there are no undesirable spikes in duct air pressure. These modes are *not* mutually exclusive so the system may be performing one or more of the following tasks simultaneously. None of these functions shall be performed unless the BIPV/T fan VA1 is energized (see previous section for details on when the BIPV/T fan is permitted to run).

D.1.1 Domestic Hot Water Preheating

If there is demand from the DHW preheat tank, then damper D3 shall open, diverting air from the bypass duct to the heat exchanger. Damper D3 is interlocked mechanically with damper D9 so that as D3 opens, D9 closes.

There is considered to be demand when the temperature of the preheat tank drops below its setpoint of 35 °C, and demand ceases once the preheat tank temperature has risen 2 °C above the setpoint.

There is a low limit flag for the temperature of the roof air cavity that shall disable preheat tank charging. When the roof cavity air falls below a temperature that is 5 °C over the current preheat tank temperature, preheat tank charging shall be disabled. Preheat tank charging shall be re-enabled once the roof cavity air temperate rises to 10 °C over the current preheat tank temperature. This is to ensure that there is a useful difference in temperature between the incoming air and the DHW preheat tank.

The pump P1, which circulates water between the heat exchanger (HX1) and the preheat tank, shall be energized while the system is charging the preheat tank and de-energized otherwise.

D.1.2 Slab Charging

The ventilated concrete slab in the basement can be actively charged to raise or lower its temperature. This large thermal mass helps to stabilize the temperature of the house and stores energy from the sun when possible. While operating, the BIPV/T fan (VA1) runs to maintain a specific slab setpoint which is determined based on outdoor air temperature. When the outdoor air temperature rises past 10 °C, the slab setpoint will be 15°C to allow for slab cooling. When the outdoor air temperature falls below 8 °C, the slab setpoint will be 29 °C to allow for slab heating.

The dampers D4, D5, and D6 are controlled to divert air coming from the roof depending on the demand. If there is demand for slab charging, dampers D5 and D6 shall open, allowing air from the roof to pass through the slab before being exhausted outdoors. Dampers D5 and D6 operate on a shared control signal so are either both open or both closed. Damper D4 shall remain closed during this mode because, when open, it allows air to be exhausted to the outdoors without passing through the slab.

If the fan VA1 is energized, but there is no demand for slab charging, damper D4 shall remain open and both dampers D5 and D6 shall remain closed. While the fan VA1 is de-energized, dampers D4, D5 and D6 shall remain closed.

Heating:

There is considered to be demand for slab heating if the average slab temperature drops below the slab setpoint. There is no longer demand once the average slab temperature rises more than 2 °C above the slab setpoint.

There is a low limit temperature for the roof cavity air that shall disable slab heating. When the difference between the roof cavity air temperature and the average slab temperature falls below 5 °C, slab charging shall be disabled. Slab charging shall be re-enabled once the roof cavity air rises to 10 °C over the current average slab temperature. This is to ensure that there is a useful difference in temperature between the incoming air and the slab.

Cooling:

There is considered to be demand for slab cooling if the average slab temperature rises above the slab setpoint. There is no longer demand once the average slab temperature drops more than 2 °C below the slab setpoint.

There is a high limit temperature for the roof cavity air that shall disable slab cooling. When the roof cavity air temperature rises over the average slab temperature, slab cooling shall be disabled. Slab cooling shall be re-enabled once the roof cavity air drops to 4 °C below the current average slab temperature. This is to ensure that there is a useful difference in temperature between the incoming air and the slab. Also, in order to allow cooling, the maximum outdoor air temperature during the previous day must have been higher than 25 °C.

D.1.3 Clothes Dryer Assist

If there is demand for heat from the dryer then the booster fan VA2 shall be energized, damper D8 shall open, admitting air from the roof, and damper D7 shall close, preventing air from entering the dryer from the basement. Damper D7 and D8 are interlocked via shared control signal so that when D7 is open D8 is closed and vice-versa.

There is considered to be demand from the dryer when the dryer operation flag is set. The flag is set once the current flowing to the dryer rises past 3.0 amp and remains set until the current drops back below 1.0 amp.

D.2 Domestic Hot Water System

The domestic hot water system is always enabled. The primary tank cycles its heating elements based on its own internal controls to maintain its setpoint of 55 °C.

The domestic hot water preheat tank does not normally maintain any specific temperature, but is energized automatically by the control system once every 30 days to kill bacteria in the tank. When the 30 day mark is reached, the preheat tank coil shall be energized until the temperature of the tank rises above 58 °C, after which the timer is reset for the next 30 day count.

D.3 Roof Cavity Exhaust Fan

The fan EV1 is meant to ensure that the roof-integrated photovoltaic panels are not exposed to high temperatures for long periods of time. EV1 shall be energized only when the roof cavity air temperature rises above 70 °C and the fan VA1 is not already energized. Once energized, the fan EV1 shall remain energized until the roof cavity air temperature drops below 68 °C or until VA1 is energized. The damper D1 shall remain open while EV1 is energized and closed otherwise. The damper D2 is interlocked with D1 so that while D1 is open, D2 is closed and vice versa.

D.4 Ground Source Heat Pump

The ground source heat pump provides both heating and cooling for the house. There are three thermostat zones, but a single supply duct. The second floor is split into north and south zones by the motorized damper D11.

Each compressor shall be prevented from cycling more than once every 10 minutes in order to reduce wear on the heat pump.

D.4.1 Temperature Setpoints

There are three thermostats in the house – one for each floor (basement, main and second). The main level thermostat is used as the reference temperature to determine how much heating or cooling is required at a given time. The control system will enable the first and/or second stages of the heatpump in order to maintain the given setpoints. The specific setpoints will be determined by the current schedule.

The setpoints and scheduling are adjustable by the home's occupants via the HMI touch screen, but the initial values are broken down into sets of four daily periods with setpoints as follows:

Table D.1: Setpoint Schedule Summary

	Start Time	Heating Setpoint (°C)	Cooling Setpoint (°C)
Weekdays			
Morning	07:00 AM	20	23
Daytime	10:00 AM	18	25
Evening	5:00 PM	20	23
Night	11:00 PM	18	24
Weekends			
Morning	07:00 AM	20	23
Daytime	10:00 AM	20	23
Evening	5:00 PM	20	23
Night	11:00 PM	18	24
Vacation			
Morning	07:00 AM	16	26
Daytime	10:00 AM	16	26
Evening	5:00 PM	16	26
Night	11:00 PM	16	26

D.4.2 Heat Pump Operating Modes

The heatpump system operates in one of several modes. Each one uses different setpoints or schedules. The modes are described in more detail in this section and include Eco Mode as well as several override modes. Eco Mode is the default operating mode with the others being selectable via the HMI touch screen.

The heat pump shall run in low-speed, fan mode whenever there is no demand for heating or cooling. This will provide better mixing of the air in the house which will reduce stratification and provide better distribution of outdoor air.

Eco Mode

This is the default operating mode and the house will remain in this mode unless an override is enabled. The house will be permitted to enter heating mode only after the outdoor air temperature has dropped below 12 °C. When heating is allowed, the first stage of heating shall be energized once the reference room temperature in the house drops 1 °C below the heating setpoint and shall remain energized until the reference air temperature rises 0.5 °C above the setpoint. If, after 15 minutes, the setpoint has not been reached or the temperature has dropped 1.5 °C below the setpoint, the second stage of heating shall be energized. The second stage of heating shall remain energized until the reference room temperature has risen 0.5 °C above the setpoint. If, after 30 minutes, the heating setpoint has still not been reached, the auxiliary heating (2 electric coils in parallel) may be permitted to operate if any of the following conditions are true:

- The outdoor air temperature low limit flag is set. This flag is set when the outdoor air temperature drops below -15 °C and remains set until the outdoor air temperature rises past -10 °C.
- The room temperature flag is set. This flag is set if the lowest room temperature sensor of the basement, main floor and second floor drops below the low limit setpoint of 16 °C and remains set until the lowest of these sensors rises back above 18 °C.
- The reference room temperature is 4 °C below the setpoint and the heating system has been operating for at least 2 hours. If the heating system has been activated

within the last 2 hours, the reference room temperature must be 6 °C below the setpoint to allow the auxiliary electric heat to activate.

If any of the preceding conditions are true, the first stage of auxiliary heating shall be energized and shall remain energized until the reference room temperature reaches 0.5 °C above the heating setpoint. If the first stage of auxiliary heating remains energized for more than 30 minutes, and the setpoint has still not been reached, then the second stage of auxiliary heating shall be energized and shall remain energized until the reference room temperature rises 1 °C past the setpoint.

Damper D11, for the south bedroom zone, shall be modulated between 80% and 100% open, based on a PI controller which reads room temperature from the second floor zone. The damper shall be 80% open when the PI controller outputs 100%, fully open when it outputs 0% and modulate accordingly between these values.

Comfort Override Mode

This mode automatically switches the heat pump between heating and cooling modes based on outdoor air and zone temperatures. The house will be permitted to enter heating mode only after the outdoor air temperature has dropped below 12 °C and will only be permitted to enter cooling mode once the outdoor air temperature has risen past 25 °C. The reversing valve on the heat pump shall change from its heating position to its cooling position based on these same temperatures.

When heating is allowed, this mode will operate identically to Eco mode. When cooling is allowed, the first stage of cooling shall be energized once the reference room temperature in the house rises 1.5 °C above the cooling setpoint and shall remain energized until the reference room temperature drops 0.5 °C below the setpoint. If, after 15 minutes, the setpoint has not been reached, or if the room temperature has risen 2 °C above the setpoint, the second stage of cooling shall be energized. The second stage shall remain energized until reference room temperature drops 0.5 °C below the setpoint.

Damper D11, for the south bedroom zone, shall be modulated between 20% and 100% open, based on a PI controller which reads room temperature from the second floor zone. The damper shall be fully opened when the PI controller outputs 40%, 20% open when it outputs 20% and modulate accordingly between these values.

Vacation and Disabled Modes

The vacation override operates identically to Eco mode except that the vacation schedule and setpoints are used instead of the regular weekday or weekend schedules.

Disabled mode operates identically to Eco mode except except that no heating will be permitted unless the lowest room temperature sensor of the basement, main floor and second floor drops below 5 °C.

D.5 Motorized Awnings

The motorized awnings can be controlled manually or automatically. Automatic mode is the default and is designed to reduce solar radiation entering the house during peak times. When the awnings are enabled, they modulate open and closed according to a PI controller which reads the room air temperature of the second floor south bedroom zone. The awnings are disabled and closed fully when any of the following are true:

- It is winter. The awnings will be permitted to operate only between May and October inclusive.
- No communication exists with RUBI (the weather reporting software).
- The local wind speed (as read by RUBI) reaches 30 km/hr. The overhangs shall remain locked out until the wind speed drops back below 25 km/hr.
- The building is in Vacation or Disabled mode.
- The amperage low limit flag is set. This is the same flag used by the BIPV/T fan VA1 (see Section D.1 - BIPV/T System).

While in manual override mode, the user may enter a percentage value for the amount that the awnings will be opened. The awnings will revert to automatic mode if any of the lockout conditions are triggered or after 6 hours.

D.6 HRV and Air Cleaner

The heat recovery ventilator (HRV) and air cleaner are controlled via a common control signal. Both devices will run at low speed at all times except when triggered to run at high speed. The devices will run at high speed only when either the washroom override signal or the indoor relative humidity flag is set.

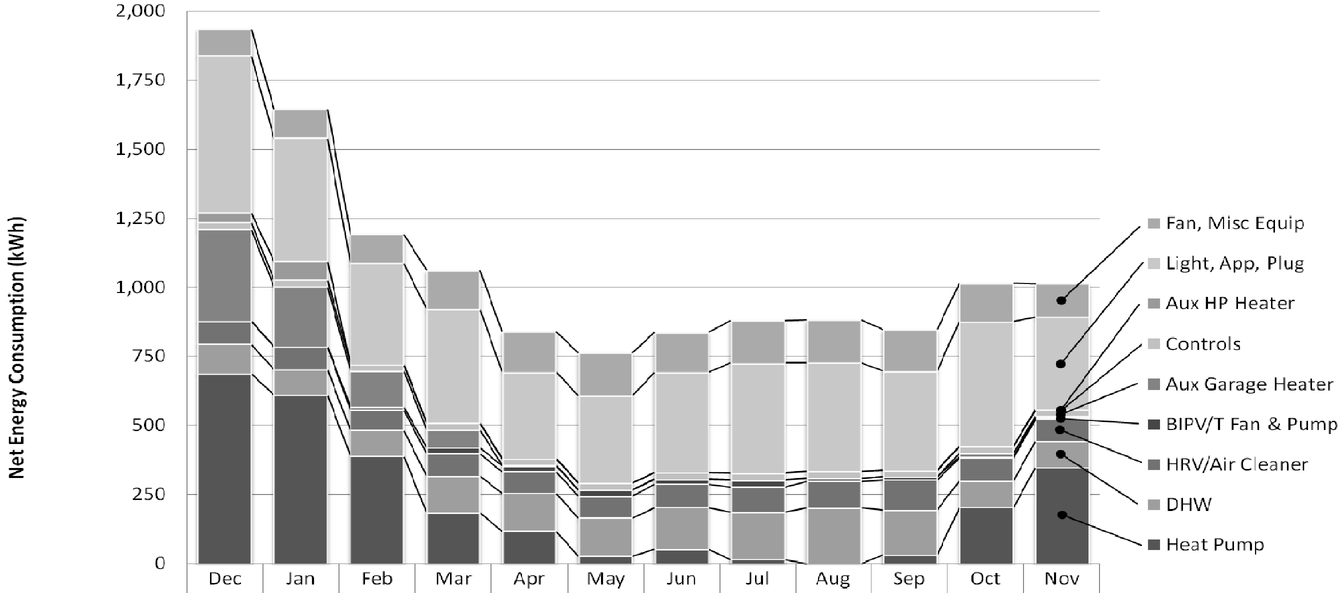
The washroom override signal is hard-wired to the HRV and is not connected to the building's control system. The indoor relative humidity flag is set as long as the indoor specific humidity is greater than the outdoor specific humidity and the indoor relative humidity is above 50%. This flag remains set until the indoor relative humidity falls below 40% or until the indoor specific humidity is no longer greater than the outdoor specific humidity.

Table D.2: ÉcoTerra Equipment List

Tag	Description	Notes
VA1	Ventilation fan for BIPV/T roof system	Primary fan used to bring air through BIPV/T roof and into the house. Located in basement.
EV1	Exhaust fan in attic	Used only if temperature of roof exceeds high limit temperature.
VA2	Dryer booster fan	Fan used to draw air from BIPV/T system into dryer.
P1	DHW heat exchanger circulation pump	Circulates water between preheat tank and heat exchanger coil.
P2	Ground loop circulation pump	Circulates water/methanol through ground loop for ground-source heat pump.
P3	Sump Pump	Pumps excess water from basement sump pit.
HRV	Heat recovery ventilator	Provides outdoor air to air cleaner which feeds into the return air ductwork of the heating system.
ACL	Air cleaner	Filters air from HRV and supplies the return air ductwork of the heating system. Shares control signal with HRV.
HP	Geothermal HP (Water-Air)	c/w dual speed ECM fan and desuperheater for DHW.
D1	Damper 1 for roof ventilator	Controls air flow to EV1.
D2	Damper 2 for roof ventilator	Controls air flow into the duct system from the roof. Interlocked with D1 via controls code. Shares control signal with roof ventilator EV1.
D3	Damper 1 for bypass of heat exchanger	Interlocked with D9 by physical linkage so will always be in opposite position to D9.
D4	Damper to control exhaust to outdoors	When open, air is directly exhausted instead of first going through slab.
D5	Damper 1 to control air flow through slab	When open, air passes through floor slab before being exhausted.
D6	Damper 2 to control air flow through slab	When open, air passes through floor slab before being exhausted. Interlocked to D5 via shared control signal.
D7	Damper 1 for clothes dryer	When open, dryer takes air form basement.
D8	Damper 2 for clothes dryer	When open, dryer takes air from roof with assistance of VA2. Interlocked to D7 via shared control signal.
D9	Damper 2 for bypass of	Interlocked with D3 by physical linkage so will always be in

	heat exchanger	opposite position to D3.
D10	Freeze protection damper	Shares output signal with main fan to close when fan is on.
D11	Zone damper for upper floor south	Modulates to control HVAC airflow to upper floor south bedroom.
PHT	Domestic hot water preheat tank	Fed by heat pump desuperheater, drain water heat recovery and heat exchanger in BIPV/T air duct.
DHW	Domestic hot water tank	Heats domestic hot water for the house – fed by PHT.
HX1	Coil heat exchanger	Recovers heat from roof air for storage in DHW preheat tank.

Appendix E - Detailed Energy End-use Results



	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Fan, Misc Equip	97.27	104.48	106.08	139.79	146.17	155.42	144.78	153.53	154.86	151.34	137.15	119.78
Light, App, Plug	567.52	443.73	365.70	412.60	313.46	314.97	361.86	398.73	392.28	358.00	451.81	334.16
Aux HP Heater	35.61	68.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Controls	25.00	25.00	22.58	25.00	24.19	25.00	24.19	25.00	25.00	24.19	25.00	24.19
Aux Garage Heater	331.98	216.90	132.34	62.99	2.36	0.00	0.00	0.00	0.00	0.00	11.68	4.52
BIPV/T Fan & Pump	0.00	0.00	8.47	22.09	19.96	22.02	16.52	22.68	10.96	9.72	4.47	5.47
HRV/Air Cleaner	83.81	83.08	73.74	80.65	77.19	79.85	84.65	92.20	96.59	108.53	83.61	78.39
DHW	105.37	92.17	93.79	133.72	138.49	137.29	151.18	171.34	200.69	162.52	96.15	95.51
Heat Pump	686.93	609.04	388.55	182.72	116.50	26.98	51.28	14.56	0.00	31.09	202.07	348.38

Annual End-use Breakdown (kWh)

	House Net	PV Generated	Heat Pump	DHW	HRV/Air Cleaner	BIPV/T Fan & Pump	Aux Garage Heater	Controls	Aux HP Heater	Light, App, Plug	Fan, Misc Equip	Monitoring
Dec 10 to Jan 9	1921.28	12.21	686.93	105.37	83.81	0.00	331.98	25.00	35.61	567.52	97.27	158.35
Jan 10 to Feb 9	1558.14	84.68	609.04	92.17	83.08	0.00	216.90	25.00	68.42	443.73	104.48	158.35
Feb 10 to Mar 9	1046.22	145.03	388.55	93.79	73.74	8.47	132.34	22.58	0.00	365.70	106.08	143.02
Mar 10 to Apr 9	806.19	253.37	182.72	133.72	80.65	22.09	62.99	25.00	0.00	412.60	139.79	158.35
Apr 10 to May 9	535.27	303.05	116.50	138.49	77.19	19.96	2.36	24.19	0.00	313.46	146.17	153.24
May 10 to Jun 9	382.03	379.50	26.98	137.29	79.85	22.02	0.00	25.00	0.00	314.97	155.42	158.35
Jun 10 to Jul 9	500.59	333.87	51.28	151.18	84.65	16.52	0.00	24.19	0.00	361.86	144.78	153.24
Jul 10 to Aug 9	550.54	327.50	14.56	171.34	92.20	22.68	0.00	25.00	0.00	398.73	153.53	158.35
Aug 10 to Sep 9	555.97	324.41	0.00	200.69	96.59	10.96	0.00	25.00	0.00	392.28	154.86	158.35
Sep 10 to Oct 9	654.62	190.77	31.09	162.52	108.53	9.72	0.00	24.19	0.00	358.00	151.34	153.24
Oct 10 to Nov 9	881.33	130.61	202.07	96.15	83.61	4.47	11.68	25.00	0.00	451.81	137.15	158.35
Nov 10 to Dec 9	925.38	85.02	348.38	95.51	78.39	5.47	4.52	24.19	0.00	334.16	119.78	153.24
Subtotals	**10,318**	**2,570**	**2,658**	**1,578**	**1,022**	**142**	**763**	**294**	**104**	**4,715**	**1,611**	**1,864**
Gross	**12,888**											

Energy Collected and Generated (kWh)

	DHW Preheat	Desuperheater	% of HP	Slab	PV Generation	PV Export	BIPV/T Fan	DHW Pump	Total DHW	Demand Savings
Dec 10 to Jan 9	0	142.3	20.7%	0	12.21	0.44	0	0	0	0
Jan 10 to Feb 9	0	148.19	24.3%	0	84.68	9.56	0	0	0	0
Feb 10 to Mar 9	0	70.5	18.1%	37.01	145.03	23.67	8.47	0	37.01	0
Mar 10 to Apr 9	30.86	46.64	25.5%	102.91	253.37	44.53	20.74	1.35	133.77	0.03
Apr 10 to May 9	23.4	33.39	28.7%	33.59	303.05	75.94	17.98	1.98	56.99	0.08
May 10 to Jun 9	53.1	7.91	29.3%	27.6	379.50	102.14	18.91	3.11	80.7	0.06
Jun 10 to Jul 9	48.25	10.67	20.8%	32.36	333.87	68.64	14	2.52	80.61	0.41
Jul 10 to Aug 9	60.83	1.37	9.4%	64.07	327.50	32.41	18.78	3.9	124.9	0.11
Aug 10 to Sep 9	5.11	0	0.0%	0.28	324.41	36.3	0.99	9.97	5.39	1.51
Sep 10 to Oct 9	20.4	10.33	33.2%	-0.05	190.77	11.47	7.71	2.01	20.35	0
Oct 10 to Nov 9	2.87	46.91	23.2%	11.45	130.61	4.87	4.15	0.32	14.32	0
Nov 10 to Dec 9	0.14	83.45	0.239537287	20.54	85.02	0.54	5.41	0.04	20.68	0
Subtotals	**245.0**	**601.7**	**22.6%**	**329.8**	**2570.0**	**410.5**	**117.1**	**25.2**	**574.7**	**2.2**

Lost Solar Hours (sys on)	Lost Solar Hours (sys off)	Potential Garage (sys on)	Potential Garage (sys off)	PV potential	Thermal Potential	Thermal Collected	Window Savings	Infiltration Savings	DHW error	Slab Error	DSH Error
0	0	0	0	849.32	0	0	54.78	23.78	0	0	5.38
0	0	0	1	2087.14	0	0	51.05	22.16	0	0	6.9
3.37	0.18	22.85	4.54	3037.52	1002.43	124	36.65	15.75	0	3.1	2.4
5.25	22.22	46.03	32.31	4770.15	2447.78	306.54	26.59	11.32	2.72	6.38	2.16
4.67	58.03	43.04	50.47	5622.83	2122.1	236.38	20.59	8.72	1.92	3.42	1.94
0.1	129.35	11.41	29.34	7283.04	2444.42	249.05	12.22	5.13	3.21	3.55	0.99
0	131.33	0	1.24	6301.4	1713.55	168.54	0	0	3.26	3.85	1.16
0	130.8	0	0.02	6080.14	2217.78	217.86	0	0	3.58	5.15	0.26
0	14.53	0	0.24	6068.47	90.7	11.1	0	0	1.38	0.24	0
0.52	18.6	6.63	10.49	3498.25	887.78	101.87	16.33	6.85	1.91	0.15	1.13
5.2	11.83	19.08	22.55	2431.3	452.15	56.94	28.69	12.2	0.62	1.72	2.15
4.32	7.15	19.02	16.5	1890.85	467.43	73.13	36.87	15.83	0.16	2.24	2.89
23.43	**524.02**	**168.06**	**168.7**	**49920.41**	**13846.12**	**1545.41**	**283.77**	**121.74**	**7.1**	**11.1**	**10.4**
									2.91%	**3.38%**	**1.72%**

Appendix F - RETScreen Model

RETScreen Energy Model - Power project ☐ Show alternative units

Proposed case power system [redacted]

Technology: Photovoltaic

Analysis type: ◘ Method 1 / ◘ Method 2

Resource assessment

Solar tracking mode		Fixed
Slope	°	30.2
Azimuth	°	0.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	1.61	2.81	1.0	0.207
February	2.63	4.07	1.0	0.269
March	3.91	5.06	1.0	0.367
April	4.46	4.83	1.0	0.336
May	5.27	5.24	1.0	0.374
June	5.49	5.26	1.0	0.362
July	5.51	5.37	1.0	0.381
August	4.67	4.85	1.0	0.345
September	3.56	4.11	1.0	0.284
October	2.30	3.05	1.0	0.220
November	1.41	2.15	1.0	0.151
December	1.28	2.29	1.0	0.168
Annual	**3.51**	**4.09**	**1.00**	**3.465**

Annual solar radiation - horizontal	MWh/m²	1.28
Annual solar radiation - tilted	MWh/m²	1.49

Photovoltaic

Type		a-Si	
Power capacity	kW	2.86	*See product database*
Manufacturer		Uni-Solar	
Model		a-Si - PVL-136W	21 unit(s)
Efficiency	%	6.3%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.11%	
Solar collector area	m²	45	
Miscellaneous losses	%	10.0%	

Inverter

Efficiency	%	95.0%
Capacity	kW	2.7
Miscellaneous losses	%	5.0%

Summary

Capacity factor	%	13.8%
Electricity exported to grid	MWh	3.465

Appendix G - IEA Case Study

IEA SHC Task 40 – ECBCS Annex 52
Towards Net Zero Energy Solar Buildings

Research structure

General Information

- Project overview
- General project information
- General data and values
- Contact information
- Pictures, drawings, images

NZEB passive and efficiency methods

efficiency measures

- Advanced thermal insulation
- Efficient solar shading
  - Moveable shading elements
  - Fixed shading elements
- Advanced day lighting measures
- Advanced active energy storage
  - Thermal storage
  - Electricity storage
- Advanced controls
  - Integrated monitoring
  - Energy / load management
  - Others
- Efficient appliances
  - Efficient household appliances
  - Efficient office equipment
- Efficient lighting
- Efficient HVAC equipment
- Occupant information system
- Water conservation measures
- Hot water heat recovery
- Ventilation heat recovery
- Natural or hybrid ventilation
- Cross ventilation
- Passive cooling
- Architectural measures

passive solar measures

- Increased passive solar gains
- Advanced passive thermal storage
  - Heavy weight construction
  - Phase change materials
- Architectural measures
- Arrangements beyond the building

NZEB supply methods

energy supply

- Fuel sources
  - Natural gas
  - Liquid gas
  - Oil
  - Biomass
  - Bio fuels
- Electricity sources
  - Electricity mix from the grid
  - "Green" electricity from the grid
  - Off-site electricity sources
- Heat / cold sources
  - Local heat / cold renewable
  - Local heat / cold non or partly renewable
  - Local solar heat / cold
  - Local CHP renewable
  - Local CHP non or partly renewable
  - District heat / cold renewable
  - District heat / cold non or partly renewable
  - District solar heat / cold
  - District CHP renewable
  - District CHP non or partly renewable
  - Active solar cooling
- Natural sources
  - Solar radiation
  - Geothermal energy
  - Ground water
  - Surface water
  - Outside air
  - Wind

grid interaction

- Gas grid
- Electricity grid
  - Electricity input to the grid
- District heating / cooling grid
  - Heat input into the grid
- Energy missmatch
- Other balance / storage methods
  - Certificate or emission trading
  - Embodied energy
  - Others and innovations
- Special primary energy factors
  - Gas
  - Electricity
  - Heat / Cold
  - Bio fuels / -mass
  - Embodied energy

Tools and software

- Design process
  - Simulation
  - Design
  - Spread sheet calculation
  - Combination of tools and software
- Monitoring
  - Measured data
  - Data acquisition system
  - Energy control / management
  - Possibility of engagement
  - Load management
  - Occupant information
  - Preparation of measured data

Data

- Weather data
- Detailed energy + monitoring data
- Embodied energy
- Quality aspects
- Comfort aspects

The intention is that always the way behind the measure and energy source is described. So the energy collection about tanks, the energy change about the technology, the energy storage and if necessary the distribution and the handing over. Please mark the used sources or strategies with "X" in the according field and describe them in the text fields at the middle of the current page. See even the example at the right side of sheet "3 - supply methods".

For questions or comments please contact:
Eike Musall, M.Sc.arch., PhD student and scientific employee of
University Wuppertal, Department of Architecture,
Building Physics and Technical Services, Univ. Prof. Dr.-Ing. Karsten Voss
D - 42285 Wuppertal, Haspelerstr. 27
Email: emusall@uni-wuppertal.de, www.btga.uni-wuppertal.de, tel. +49 (0) 202 439 4292, fax +49 (0)202 439 4296

Please send the document back as an excel file and a pdf file to the following addresses:
emusall@uni-wuppertal.de and garde@univ-reunion.fr

Brief instructions

	White field for entering texts - suitably to the heading or with notes to the used / marked passive or efficiency methods or supply options. Sometimes proposals are given on the right side
	Field for entering information or values or mark with "X" when these strategy, technology or method is used. Then please describe these strategies in the text fields at the middle of the current page
choose	Click in the field to be able to select from a drop down menu
kWh/m²y	Field with an unit. You don´t have to type anything
0.00	Field for entering data. Please change the written numbers. This field is not shown in the printed sheet but it is used in a chart and for background information
0.00	Automatically generated calculation result
	Please click at the fields with red triangles and check the comments behind before writing information, data or values. Sometimes examples for the inout are given.
images	Placing of pictures is mandatory for the site plan at the respective place, only. Nevertheless, it is important that the respective drawings (floor plan, cross section, elevation) are inserted and the main relevant pictures or graphics are shown

Please notice that only those fields are selectable on which you should or have to put down information or in which you can take a choice

Comments and critics to this spreadsheet and its methology

IEA SHC Task 40 – ECBCS Annex 52
Towards Net Zero Energy Solar Buildings

EcoTerra

Eastman, Quebec, Canada

Typology:	**Single residential building**	NZEB-label:	**Equilibrium building**
Climate type:	**snow** **Dfd**	Status:	**new**

Total primary energy consumption
-5,785.00 kWh/y

Total primary energy delivered to the grids
2,505.00 kWh/y
Sources choose choose

Energy balance
-3,280.00 kWh/y

Sort of available data
monitoring / measured data

Quantity and quality of available data
high

Used balance criterion
Site energy

Main stimulation of the project
Demonstration or test building

Main actor of the project
Home building company

Projects impact on the architecture scene
high

Importance of architecture for NZEB status
high

Architectural background
Demonstration project
Research / test project

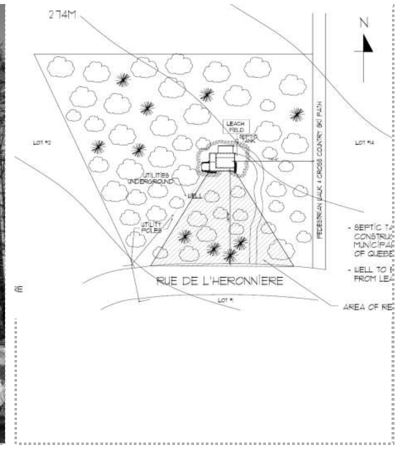
Site context / setting	rural
Status of the project	entire building
Weekly utilisation period	Sun - Sat
Daily utilisation period	0:00 - 24:00
Number of occupants	0 pc
Number of stories	2 pc
Number of buildings	1 pc
Conditioned net floor area	230 m²
Conditioned net volume	671 m³
Total envelope area	354 m²
Envelope to volume ratio	0.53
Start / completion date	Ap. 07 Se. 07
Building costs	965 €/m²
Building construction	medium

Location information

Longitude	west	72.3 °
Latitude	north	45.3 °
Altitude		274 m

Web links http://www.maisonalouette.com/e

South View of EcoTerra House

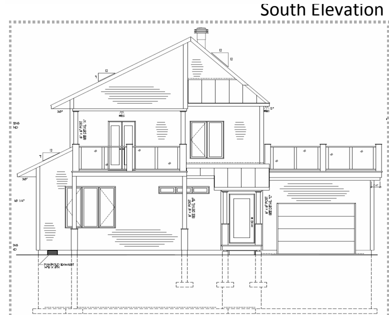


caption

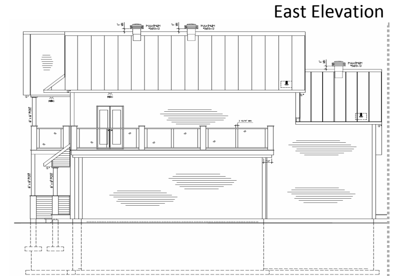
Project description

"The ÉcoTerra is a detached house built by Alouette Homes – a prefabricated home manufacturer - in a wooded area in the Mont Orford area, Eastman,Quebec. The floor area is about 140 m2 plus a 90 m2 heated basement floor and a non-heated garage. The lowest monthly average dry bulb temperature is 10.9°C in January and the highest is 18.3°C in July. The heating design temperature is –28°C (Sherbrooke city). The house aims at fulfilling the objectives of the EQuilibrium Initiative: to provide a healthy and comfortable living space for its occupants, while reaching the goal of annual net-zero energy consumption through environmentally sound strategies. The ÉcoTerra has been developed through the efforts of a team led by Alouette Homes, a major prefabricated home manufacturer in Quebec. The energy system of the house and its integrated control strategy have been designed by a Concordia University team. Major attention was given to optimizing the window area on the south facing façade and the solar roof design." - Dr. Athienitis, EcoTerra Feature Sheet

South Elevation



East Elevation



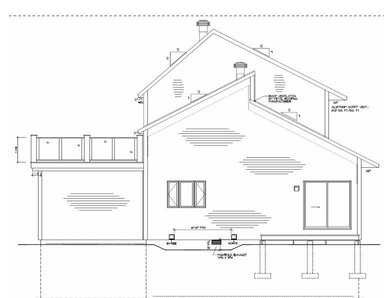
North Elevation

Team

Client	Alouette Homes
Architect	Alouette Homes
Main engineers	Concordia University
Contact	Dr. Athienitis, Concordia University

Lessons learned

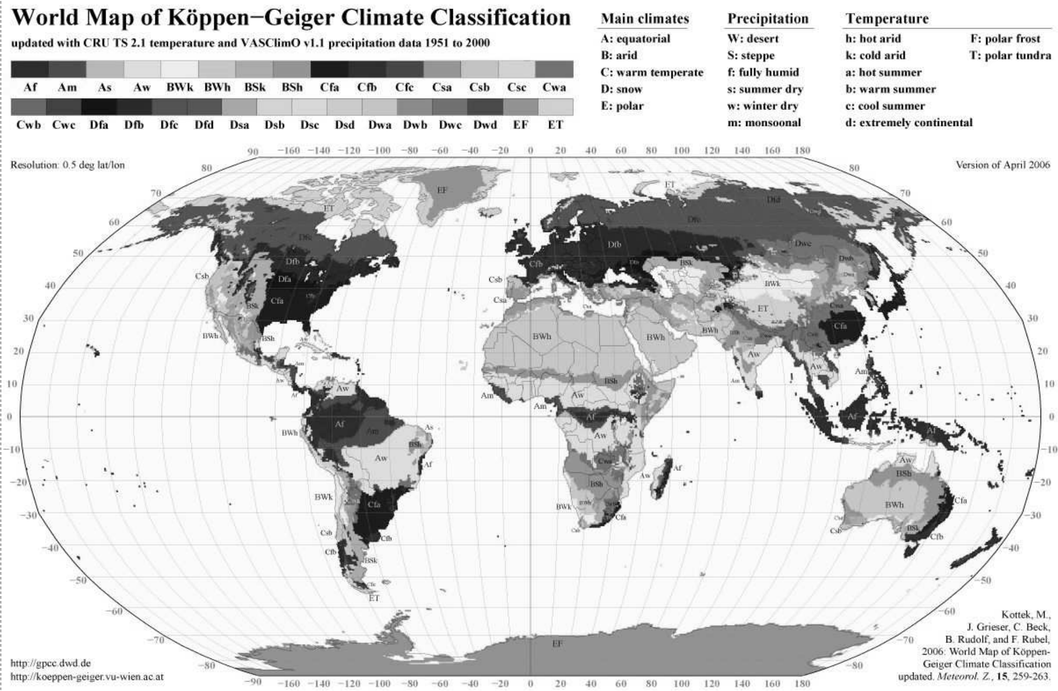
- The roof slope is an important factor in the design of the house. The slope of the roof at EcoTerra is approximatley 30 degrees, which is not optimal. 45 degree would be better and would increase energy production in the winter as there would be less snow collection.



West Elevation

Information and background page
General information

For choosing the different climate classifications use this map. Please choose the main climate and the subgroups in the sheet



Input: Project description

Please make notes to following points:

1. ARCHITECTURAL DESCRIPTION OF THE BUILDING with content of the CONCEIVING
- how, why and by whom is the project conceived?
- how the idea of the building was born (public initiative, private initiative, research project, competition…)
- if some strategies to get the building accepted by the inhabitants have been considered: for example interaction of occupants or participations
- if some of the features of the building were required by the "call" for example the use of special materials or energy system as one of the requirements set by the client, or by the competition. If yes, which?
- Analysis steps
- Integral planning
- Construction tradition and construction culture
- if retrofit, please describe in detail how the retrofit is conceived (change in function, envelope maintenance, energetic improvement….)

2. HOW THE NET-ZERO AIM IS REACHED
- all over strategies, passive solar use, active solar use: what and how
- LCA methods / label applied
- Spatial identity / recognition / individual creation
- Mixture of utilisation
- Structural fabric / raw materials and building materials

3. SPECIFIC ASPECTS IN DESIGN PHASE AND YARD
- how the NZEB aim has influenced urban and architectual design
- architectural main features, building technologies ecological concepts, energy standards, low budget building, environmental design…
- special accuracy in the yard, such as: the way the parts of the envelope have been built; the building sequence; the way the yard team is organized

4. BUILDING OPERATION
- commissioning, verifications, monitoring, control systems, post occupancy evaluation
- Facility management or contracting

5. GENERAL INFORMATION / OTHER INTERESTING ASPECTS
- Local public infrastructure and mobility / ambiance and location
- Building cost, special costs because of net zero energy aim, investments, life cycle costs, external costs
- Free surfaces and building area

Input: Lessons learned

Please describe your experiences (lessons learned, highlights, results)

IEA SHC Task 40 – ECBCS Annex 52
Towards Net Zero Energy Solar Buildings

EcoTerra

Eastman, Quebec, Canada

Typology: **Single residential building** NZEB-label: **Equilibrium building**
Climate type: **snow** **Dfd** Status: **new**

1	Efficiency measures	
1.1	**Advanced thermal insulation**	X
1.2	**Efficient solar shading**	
	Moveable shading elements	X
	Fixed shading elements	X
1.3	**Advanced day lighting measures**	
1.4	**Advanced active energy storage**	
	Thermal storage	X
	Electricity storage	
1.5	**Advanced controls**	
	Integrated Monitoring	X
	Energy / load management	X
	Others	
1.6	**Efficient equipment**	
	Efficient household appliances	X
	Efficient office equipment	
1.7	**Efficient lighting**	X
1.8	**Efficient HVAC equipment**	X
1.9	**Occupant information system**	X
1.10	**Water conservation measures**	X
1.11	**Hot water heat recovery**	X
1.12	**Ventilation heat recovery**	X
1.13	**Natural or hybrid ventilation**	
1.14	**Cross natural ventilation**	
1.15	**Passive cooling**	
1.16	**Architectural measures**	X
	Others and innovations	
1.17	Building-integrated PV/Thermal Roof	X
1.18	Ventilated Concrete Slab	X
1.19		

Efficiency and passive solar measures

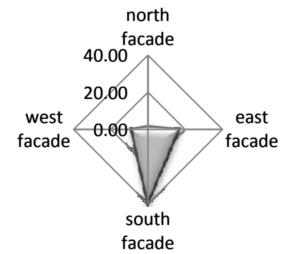
"Space planning and building form:
The house is oriented due south. The footprint is roughly a rectangle with an aspect ratio of about 1.4. The south façade of the house (and hence the roof as well) is longer to receive more direct solar radiation. A family room with large glazing area (13 m2) is located in the south portion of the ground floor. It is the main direct gain zone for passive solar heating. Open space layout and forced-air HVAC system design allow the heat gain to be

"Thermal mass:
The main direct gain zone that stores the solar gains is in the family room. The floor mass consists of 15 cm thick concrete slab covered with medium brown coloured ceramic tiles. The tiles have a solar absorptance of 0.6-0.7, which is recommended to facilitate absorption of solar gains into the mass, while also providing good daylighting performance. The 15 cm concrete mass is cast directly on the plywood subfloor supported by wood trusses. Additional mass also includes two short walls (0.3 m thick and 4 m high versus 1 m high above the ground floor) separating the family room from the other areas. The floor slab in the basement also receives significant passive solar gains that can also be stored in that location. There is a hollow core slab that is also actively charged by heated air from the BIPV/T roof. Although the charging is active, the heat release into the living space is passive.

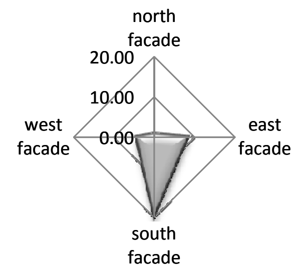
"Natural lighting:
A skylight window with an area of about 1 m2 located above the stairways brings in daylight for the kitchen and dining area. All rooms are equipped with windows except the north portion of the basement, where the mechanical room is located. Large south-facing windows and open space architectural layout help improve daylight distribution.

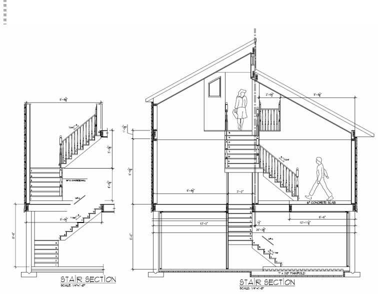
"Passive cooling:
The optimal length of the overhangs (e.g. soffit) over the south-facing windows was calculated. It blocks most of the direct solar radiation in the summer season, but allows the window to be fully exposed to direct solar radiation as much as possible in the winter season.
All the windows are operable. This enables cross ventilation for passive free cooling. "
- Dr. Athienitis, EcoTerra Features Sheet

Percentage of windows per facade area



Percentage of openable windows / facade openings per facade area - facade prorsity





Stair Section

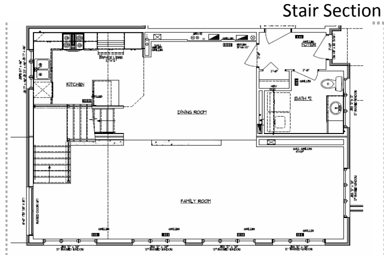
2	Passive solar measures	
2.1	**Increased passive solar gains**	X
2.2	**Advanced passive thermal storage**	
	Heavy weight construction	X
	Phase change materials	
2.3	**Architectural measures**	X
	Others and innovations	
2.4	Motorized window overhangs	X
2.5	Tripple-glazed windows	X
2.6		

3	Arrangements beyond the building	
3.1		
3.2		
3.3		
3.4		
3.5		

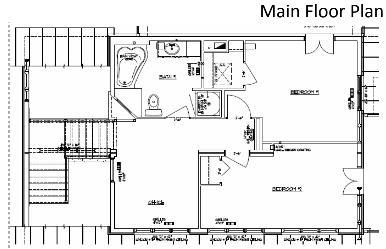
Research findings and innovations

- "The hollow-core slab stores the heat from the air heated by the BIPV/T roof during the heating season and the coolness from the night time outdoor cool air during the cooling season. Due to the large amount of concrete (~5 m3) and the concrete's high thermal capacity (~2100 kJ/m3K), the slab can store about 3 kWh of thermal energy for every degree Celsius change." - Dr. Athienitis, EcoTerra Features Sheet

- " The BIPV/T roof includes amorphous silicon photovoltaic laminates directly attached to a metal roof, with air passing under the metal to recover heat that can in turn be used for space or water heating. By building such a roof, the costs of a hybrid electric/thermal system can be significantly lowered through mass production, and quality control can be enhanced through construction under controlled factory conditions." - Dr. Athienitis, EcoTerra Features Sheet



Main Floor Plan



Upper Floor Plan

Information and background page
Passive + efficiency methods

Input: Efficiency and passive solar measures

Please make notes to the used strategies and aspects from the left side. Add information about the architectual integration of used methods.
Describe the interaction of the different used strategies and technical innovations or special ideas.

Distribution of the window surfaces per facade area

Please fill in the values for facade and window surfaces and change the red numbers in the marked fields. In this case it makes no difference whether the windows are openable or not. The graphic will provide itself

Surface north facade	49.42	m²	Surface of windows at north facade	0.65	m²	Distribution	1.32	%
Surface east facade	39.90	m²	Surface of windows at east facade	6.67	m²	Distribution	16.72	%
Surface south facade	52.64	m²	Surface of windows at south facade	20.90	m²	Distribution	39.70	%
Surface west facade	58.93	m²	Surface of windows at west facade	5.20	m²	Distribution	8.82	%
Sum facade surfaces	200.89	m²	Sum surfaces of windows	33.42	m²	Distribution	16.64	%

Percentage of openable windows / facade openings per facade area - facade prorsity

Please fill in the values for facade and openable window respectively facade opening surfaces and change the red numbers in the marked fields. The graphic will provide itself

Surface north facade	49.42	m²	Facade openings at north facade	0.33	m²	Distribution	0.66	%
Surface east facade	39.90	m²	Facade openings at east facade	3.34	m²	Distribution	8.36	%
Surface south facade	52.64	m²	Facade openings at south facade	10.45	m²	Distribution	19.85	%
Surface west facade	58.93	m²	Facade openings at west facade	2.60	m²	Distribution	4.41	%
Sum facade surfaces	200.89	m²	Sum surfaces of facade openings	16.71	m²	Distribution	8.32	%

Input: Research findings and innovations

Please describe news about innovative technologies, special research findings, advanced integration of different techniques, new concepts or innovative architectual drafts.

IEA SHC Task 40 – ECBCS Annex 52
Towards Net Zero Energy Solar Buildings

EcoTerra
Eastman, Quebec, Canada

SHC Solar Heating & Cooling Programme · Energy Conservation in Buildings and Community Systems Programme

Typology: **Single residential building** NZEB-label: **Equilibrium building**
Climate type: **snow** **Dfd** Status: **new**

	4 Energy Supply	
4.1	**Fuel sources**	
	Natural gas	
	Liquid gas	
	Oil	
	Biomass	
	Bio fuels	
4.2	**Electricity sources**	
	Electricity mix from the grid	X
	"Green" electricity from the grid	
	Off-site electricity sources	
4.3	**Heat / cold sources**	
	Local heat / cold renewable	
	Local heat / cold non or partly renewable	
	Local solar heat / cold	X
	Local CHP renewable	
	Local CHP non or partly renewable	
	District heat / cold renewable	
	District heat / cold non or partly renewable	
	District solar heat / cold	
	District CHP renewable	
	District CHP non or partly renewable	
	Active solar cooling	
4.4	**Natural sources**	
	Solar radiation	X
	Geothermal energy	X
	Ground water	
	Surface water	
	Outside air	
	Wind	
	Others and innovations	
4.5	Building-integrated PV/Thermal Roof	X
4.6	Ventilated Concrete Slab	
4.7		

	5 Grid interaction	
5.1	**Gas grid**	
5.2	**Electricity grid**	X
	Electricity input to the grid	X
5.3	**District heating / cooling grid**	
	Heat input into the grid	
5.4	**Energy missmatch**	

	6 Other balance methods	
6.1	**Certificate or emission trading**	
6.2	**Embodied energy**	
6.3	**Others and innovations**	

	7 Special primary energy factors	
	Gas	
	Electricity	
	Heat / Cold	
	Bio fuels / -mass	
	Embodied energy	

Energy supply, grid interaction and balance methods

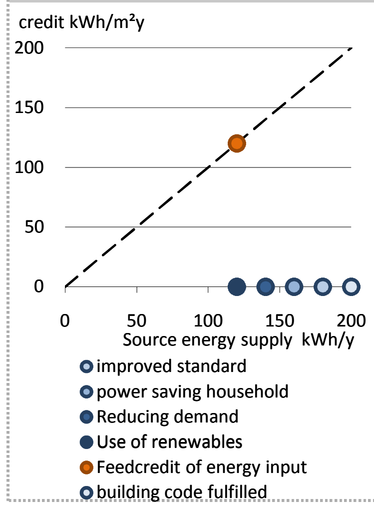
Energy supplies to the house include the building-integrated photovoltaic/thermal roof, the ground (via heat pump) and the electrical grid.

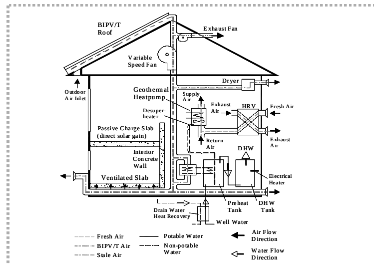
The photovoltaic panels also export electricity to the grid.

Special primary energy factors

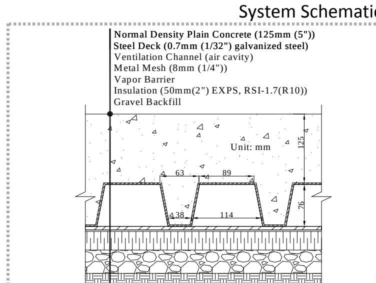
CO2 factors were taken from a publication called: "CANADIAN GHG CHALLENGE REGISTRY GUIDE TO ENTITY & FACILITY-BASED REPORTING" published by the Canadian Standards Association.

The way to the net zero energy aim

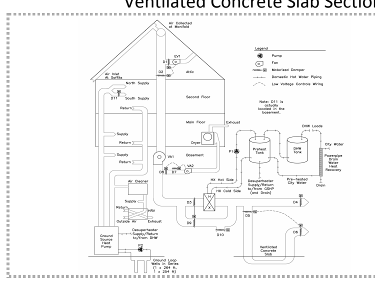




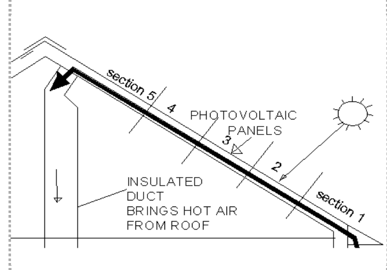
System Schematic



Ventilated Concrete Slab Section



Detailed System Schematic



BIPV/T Roof

Information and background page
Supply methods

The way to the net zero energy aim

Please fill in the different energy standards and change the red numbers in the marked fields.
The graphic will provide itself

Building with national building code fulfilled + typical user related loads	200.00	kWh/m²a
Improved buildings energy standard (passive house, etc.)	180.00	kWh/m²a
Power saving household (efficient appliances, efficient lighting,…)	160.00	kWh/m²a
Use of efficiency measures, reducing demand	140.00	kWh/m²a
Use of renewable and efficient energy supply	120.00	kWh/m²a
Feed credit for energy input into the grid (PV-power, wind power,…)	120.00	kWh/m²a

Input: Energy supply, grid interaction and balance methods

Please make here notes to the main strategies and aspects from the left side. Add information about the architectual integration and the interaction of the different used methods.
Make notes to points like energy offer, Availability of raw materials, available radiation anf how these facts influenced the project

Call for example the portion of CHP or renewables in the heating grid or the connection and location of external arrangements to the building.

Example for filling inand describe the energy supply options

In case of using photovoltaik arrays to generate renewable electricity please mark the source "solar radiation" under item 4.4 natural sources and describe in the text field "energy supply, grid interaction and balance methods" that pv-cells are used, where they are used (roof top, parking lot, off-site...) and add any other information for which you think they are important (size, adjustment, inclination, change judge etc.).
Do the same for any other supply method, sourc and equipment.

Input: Special primary energy factors

What source of information have you used for your primary energy and/or CO_2 factors? In case of using special energy sources (like rape oil, bio ethanol…) or special calculation factors for primary energy and CO_2 (public or local specialities), please describe these factors, how and why they are used and if you had your own resource for calculation (for example gemis - Global Emission Model for Integrated Systems).
Describe how you calculated the embodied energy (factors, tools, values).

IEA SHC Task 40 – ECBCS Annex 52
Towards Net Zero Energy Solar Buildings

EcoTerra
Eastman, Quebec, Canada

Typology:	**Single residential building**	NZEB-label:	**Equilibrium building**
Climate type:	**snow** **Dfd**	Status:	**new**

8 Design process

8.1 Simulation tools or software

Custom MathCAD Models	X

8.2 Design tools or software

HOT2000	X
RETScreen	X

8.3 Spreadsheet calculation

8.4 Combination of tools and software

Tools and software during the design process

Various software tools were used during the design process including HOT2000, custom MathCAD models and RETScreen.

Further pictures

Assembling the prefabricated modules

BIPV/T Roof Insulation

9 Monitoring

9.1	**Measured data**	X
9.2	**Data acquisition system**	X
9.3	**Energy control / management**	X
9.4	**Possibility of engagement**	
9.5	**Load management**	
9.6	**Occupant information system**	X
9.7	**Preparation of measured data**	X

Monitoring and energy control

Commercial control system based on the BACNet protocol was used for control. Monitoring is accomplished using Agilent data aquesition systems and a laptop computer. There is also a National Instruments data aquesition system. The tools are internet-connected and data is retrieved and stored in a database remotely.

BIPV/T Roof Construction

10 Weather data

10.1 Annual average

Temperature	4.11	° C
Wind speed	2.62	m/s
Relative humidity	82.66	%

10.2 Annual sum

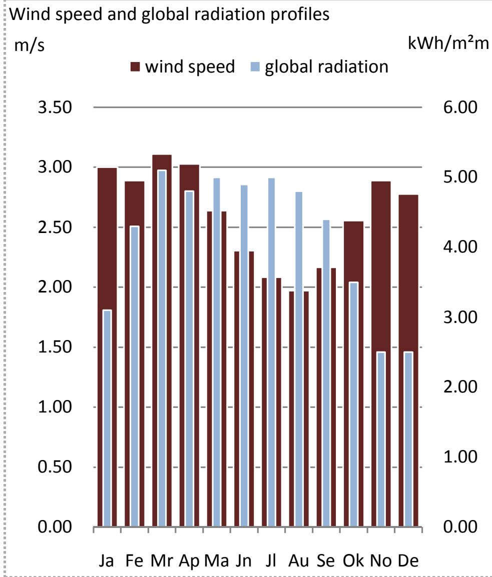
Global radiation	50	kWh/m²y
Heating degree d		Kd/a
Cooling degree d		Kd/a

10.3 Source of weather data

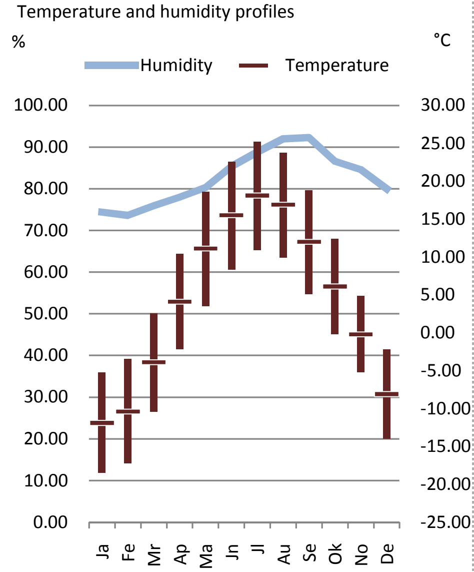
Weather data is from Environment Canada archives. Weather is for city of Sherbrooke since it is the closest weather station for which data is available.

Charts of weather data

Wind speed and global radiation profiles



Temperature and humidity profiles



Information and background page
Tools and software

Input: Tools and software during the design process

Please make notes about tools and software which you have applied to check the overall building energy balance considering the aim of a net zero energy building. Name them and describe your experiences.
Describe at which stage of the the building design process you first created an energy model and what fraction of total building design time you spend on energy modeling / using this tool.
Indicate which feature of each tool you have used and how suitable these tools were or how and why you had to combine different tools and software.

Input: Monitoring and energy control

Please make some short notes about the energy control, the energy management and the interaction of the different plants and equipment.

Weather data

Please fill in the different values for the weather data and change the red numbers in the marked fields. As a resource you could use, for example, the software meteonorm. The graphics will provide itself

Month	Ja	Fe	Mr	Ap	Ma	Jn	Jl	Au	Se	Ok	No	De	
Max. temperature	-5.70	-3.90	2.10	9.90	18.10	22.10	24.70	23.30	18.30	11.90	4.40	-2.70	°C
Min. temperature	-18.00	-16.70	-9.90	-1.70	4.00	8.80	11.40	10.40	5.60	0.30	-4.70	-13.50	°C
Average monthly temperature	-11.90	-10.40	-3.90	4.10	11.10	15.50	18.10	16.90	12.00	6.10	-0.20	-8.10	°C
Average monthly relative humidity	74.40	73.60	75.90	78.00	80.30	85.40	88.80	92.00	92.30	86.60	84.60	80.00	%
Average monthly global radiation	3.10	4.30	5.10	4.80	5.00	4.90	5.00	4.80	4.40	3.50	2.50	2.50	kWh/m²
Average monthly wind speed	3.00	2.89	3.11	3.03	2.64	2.31	2.08	1.97	2.17	2.56	2.89	2.78	m/s

Heating Degree-days (HDD12/20) - Unit: Kd/a [Kelvin.day/year]
Tindoor = 20°C average indoor temperature - no internal gains
Toutdoor = daily average outside temperature
Tlimit = 12°C
If Toutdoor < Tlimit → hdegree-day = (Tindoor – Toutdoor) [K.d], HDDharm = 1-h (Tindoor – Toutdoor) [K.d/a], h Number of days with Toutdoor < Tlimit
HDDharm……Heating degree-days harmonized
Cooling Degree-days (CDDharm,20) - Unit: Kd/a [Kelvin.day/year]
Toutdoor, av = daily average outside temperature
Tindoor = 20°C* average indoor temperature - no internal gains –-above this temperature limit a building might be cooled. The degree days are now calculated based on the daily difference.
Cdegree-day = (Toutdoor, av. – Tindoor) [K.d], If cdegree-day > 0 then: CDDharm = 1-c (Toutdoor – Tindoor) [K.d/a], cdegree-day Negative results are not considered !, CDDharm,20 Cooling degree-days harmonized
Alternative calculation method: use a source for DD data www.degreedays.net

IEA SHC Task 40 – ECBCS Annex 52
Towards Net Zero Energy Solar Buildings

EcoTerra
Eastman, Quebec, Canada

Typology:	**Single residential**	NZEB-label:	**Equilibrium building**
Climate type:	**snow** **Dfd**	Status:	**new**

11	**Consumption sectors: energy / non renewables delivered to the building**	**values for end energy**	**pe-factor**	**values for primary energy**	**CO_2-factor**	**values for CO_2-emissions**	**cost factor**	**values for energy costs**
	Heating and cooling	-1,650.20 kWh/y	1.50	-2,475.30 kWh/y	9	-15.35 kg/y	0.0474	-78.14 €/y
	Domestic hot water	-968.80 kWh/y	1.50	-1,453.20 kWh/y	9	-9.01 kg/y	0.0474	-45.88 €/y
	Equipment electricity	-196.90 kWh/y	1.50	-295.35 kWh/y	9	-1.83 kg/y	0.0474	-9.32 €/y
	Operating energy	-294.30 kWh/y	1.50	-441.45 kWh/y	9	-2.74 kg/y	0.0474	-13.94 €/y
	Auxiliary energy	-211.60 kWh/y	1.50	-317.40 kWh/y	9	-1.97 kg/y	0.0474	-10.02 €/y
	Auxiliary energy	-1,073.90 kWh/y	1.50	-1,610.85 kWh/y	9	-9.99 kg/y	0.0474	-50.85 €/y
	User related energy	-1,390.80 kWh/y	1.50	-2,086.20 kWh/y	9	-12.93 kg/y	0.0474	-65.86 €/y

12	**Generation sectors: energy delivered to grids / energy generated**	**values for end energy**	**pe-factor**	**values for primary energy**	**CO_2-factor**	**values for CO_2-emissions**	**cost factor**	**values for energy credits**
	On-site PV electricity	2,505.00 kWh/y	1.50	3,757.50 kWh/y	9	23.30 kg/y	0.0474	118.62 €/y
	choose	0.00 kWh/y	1.00	0.00 kWh/y	9	0.00 kg/y	0.0000	0.00 €/y
	choose	0.00 kWh/y	1.00	0.00 kWh/y	9	0.00 kg/y	0.0000	0.00 €/y
	choose	0.00 kWh/y	1.00	0.00 kWh/y	9	0.00 kg/y	0.0000	0.00 €/y

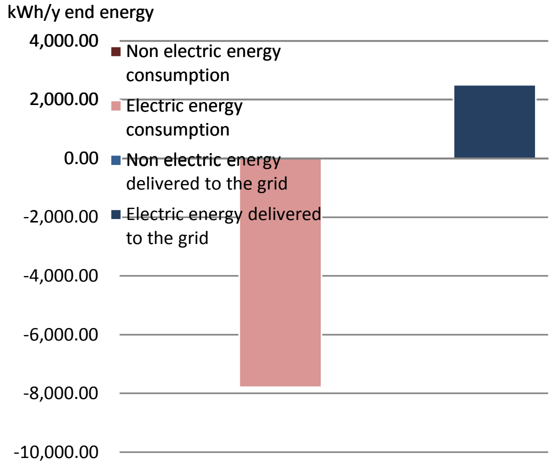
13	**Annual net zero balance**	**primary energy**	**CO_2-emissions**	**energy costs**
	Sum delivered to the building	-8,679.75 kWh/y	-53.81 kg/y	-274.01 €/y
	Sum generation/delivered to grids	3,757.50 kWh/y	23.30 kg/y	118.62 €/y
	Net zero balance	**-4,922.25** kWh/y	**-30.52** kg/y	**-155.39** €/y

14	**Embodied energy**	**primary energy**	**CO_2-emissions**	**energy costs**
	Embodied energy in the building	kWh/y	0.00 kg/y	0.00 €/y
	Net zero balance with embodied e.	**-4,922.25** kWh/y	**-30.52** kg/y	**-155.39** €/y

15	**Quality aspects / values**	
15.1	**U-values**	
	Exterior walls	6.3 W/m²K
	Roof	9.1 W/m²K
	Ground floor	1.5 W/m²K
	North windows	0.85 W/m²K
	East windows	0.85 W/m²K
	South windows	0.85 W/m²K
	West windows	0.85 W/m²K
	Averages	
	Opaque envelope	7.07 W/m²K
	Total envelope	6.4 W/m²K
	Thermal bridges	0.96 W/m²K
15.2	**S-values**	
	North facade	
	East facade	
	South facade	
	West facade	
	Roof	
	North windows	
	East windows	
	South windows	
	West windows	
	Averages	
	Opaque envelope	
	Total envelope	
15.3	**Solar heat gain coefficients / g-values**	
	North windows	0.5
	East windows	0.5
	South windows	0.5
	West windows	0.5
15.4	**Quality attributes**	
	Air leakage rate	0.85 1/h
	Air change rate (oh)	0.3 1/h
	Air change rate (uh)	0.25 1/h
	Solar shading class	
15.5	**Indoor Environment Quality**	
	Comfort class IEQ	

Charts of the annual balance (monitored values)

Annual end energy balance



Annual primary energy balance

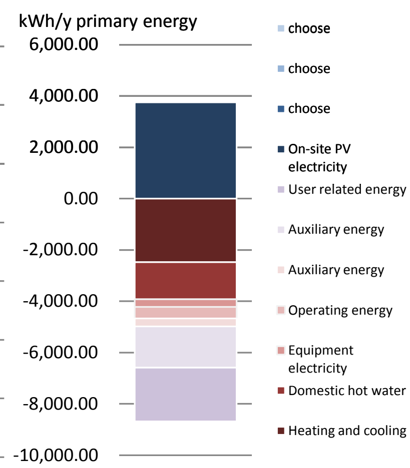
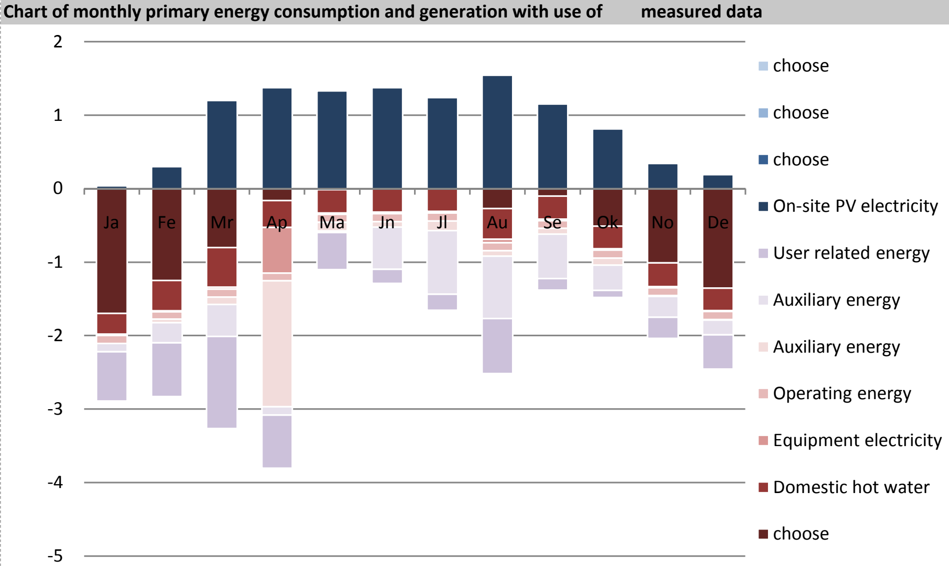


Chart of monthly primary energy consumption and generation with use of measured data



Information and background page
Data

Monitored values of the different consumption and generation sectors

Please fill in the monitored values of the different areas of energy consumption and generation in the spreadsheet. The graphics below will provide itself

Table of primary energy factors and CO_2-equivalent emissions factors of various energy carriers

Energy Type	Energy Carrier	PE (non-renewable) kWh_{prim}/kWh_{Final}	PE (total) kWh_{prim}/kWh_{Final}	CO_2 g/kWh_{end}
Fuel Source	Fuel oil	1.35	1.35	330
	Natural gas	1.36	1.36	277
	Liquid gas	1.11	1.11	263
	Bio fuels			
	Wood shavings	0.06	1.06	4
	Wood pellets	0.14	1.16	41
	Biomass			
	Log	0.09	1.09	14
	Beech log	0.07	1.07	13
	Fir log	0.1	1.1	20
Electricity	El. from hydraulic power plant	0.5	1.5	7
	El. from	2.8	2.8	16
	El. from	4.05	4.05	1340
	El. Mix UCPTE	3.14	3.31	617

Source: EN 15603:2008 Annex E and GEMIS 4.5

Energy Type	Energy Carrier	PE (non-renewable)	PE (total)	CO_2
District heating	CHP-coal condensation 79%, oil 30%	0.77		241
	CHP-coal condensation 35%, oil 65%	1.12		323
	oil 100 %	1.48		406
	Local ,oil 100%	1.47		323
Heat	Local Solar	0		0
	Solar heat (flat) central	0.16		51
Electricity	Photovoltaic (multi)	0.4		130
	Wind electricity	0.04		20

Source: IEA 28-Volumes 2, Appendix 1, Table A1.1, p 254. Primary energy (PEF) and CO2 conversion factors

End energy chart

Please fill in the different consumptions and generations and change the red numbers in the marked fields. The graphic will provide itself

Non electric energy consumption	0.00	kWh/y
Electric energy consumption	-7,790.69	kWh/y
Non electric energy delivered to the grid	0.00	kWh/y
Electric energy delivered to the grid	2,505.00	kWh/y

Monthly distribution of primary energy of the consumption and generation areas

Please change the red numbres in the marked fields. The graphics will provide itselve

Please indicate if the values below are modelled or measured data **measured data**

Consumption sectors	Ja	Fe	Mr	Ap	Ma	Jn	Jl	Au	Se	Ok	No	De	
choose	-1.70	-1.25	-0.80	-0.16	-0.01	0.00	0.00	-0.27	-0.10	-0.51	-1.01	-1.35	kWh/m²
Domestic hot water	-0.28	-0.41	-0.54	-0.36	-0.32	-0.32	-0.31	-0.42	-0.31	-0.31	-0.32	-0.30	kWh/m²
Equipment electricity	-0.01	-0.01	-0.03	-0.62	-0.02	-0.02	-0.02	-0.05	-0.02	-0.02	-0.01	-0.01	kWh/m²
Operating energy	-0.11	-0.10	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	kWh/m²
Auxiliary energy	0.00	-0.05	-0.10	-1.71	-0.12	-0.07	-0.13	-0.08	-0.08	-0.10	-0.02	-0.01	kWh/m²
Auxiliary energy	-0.11	-0.27	-0.43	-0.11	-0.02	-0.58	-0.87	-0.84	-0.61	-0.34	-0.28	-0.20	kWh/m²
User related energy	-0.67	-0.73	-1.25	-0.72	-0.50	-0.19	-0.22	-0.75	-0.15	-0.10	-0.29	-0.46	kWh/m²
Generation sectors													
On-site PV electricity	0.04	0.30	1.20	1.37	1.33	1.37	1.24	1.54	1.15	0.81	0.34	0.19	kWh/m²
choose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	kWh/m²
choose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	kWh/m²
choose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	kWh/m²
Monthly net zero balance	-2.85	-2.53	-2.06	-2.43	0.23	0.08	-0.42	-0.97	-0.23	-0.67	-1.69	-2.26	kWh/m²

Appendix H - BIPV/T Model

EcoTerra BIPV/T Roof Model (Steady State)

Citation for Model: Chen, Y., Athienitis, A.K. & Galal, K., 2010. Modeling, design and thermal performance of a BIPV/T system thermally coupled with a ventilated concrete slab in a low energy solar house: Part 1, BIPV/T system and house energy concept. Solar Energy, 84(11), pp.1892-1907.

Variables

$Dm\_L_{BIPVT} := 5.156251$ $\quad NoSection := 36$ $\quad Step_{rf} := \dfrac{\dfrac{Dm\_L_{BIPVT}}{m}}{NoSection}$

$Dm\_W_{BIPVT} := 10.42353$

$Dm\_H_{BIPVT} := 0.038$

$i_{section} := 1 .. NoSection$ $\quad \upsilon c_{p.air} := 1200$ $\quad Step_{rf} = 0.143 \dfrac{1}{m}$ ... m

$\varepsilon_{PV} := 0.9$ $\quad \varepsilon_{back} := 0.9$ $\quad F_{\varepsilon} := \dfrac{1}{\dfrac{1}{\varepsilon_{PV}} + \dfrac{1}{\varepsilon_{back}} - 1}$ $\quad F_{\varepsilon} = 0.818$

$\sigma_{SB} := 5.67 \cdot 10^{-8}$ $\quad$ Stefan_Boltzmann Constant, unit $\dfrac{W}{m^2 \cdot K^4}$

$U_{ins} := 1.5 \cdot \dfrac{W}{m^2 \cdot K}$ $\quad k_{wood} := 0.15 \cdot \dfrac{W}{m \cdot K}$ $\quad U_{wood} := \dfrac{k_{wood}}{\dfrac{3}{4} \cdot in}$ $\quad U_{wood} = 7.874 \cdot \dfrac{W}{m^2 \cdot K}$

$U_t := \left(\dfrac{1}{U_{ins}} + \dfrac{1}{U_{wood}} \right)^{-1}$ $\quad U_t = 1.26 \cdot \dfrac{W}{m^2 \cdot K}$ $\quad u_{back.attic} := 1$ ... $\dfrac{W}{m^2 \cdot K}$

PV configuration

$Coef_{temp} := 0.286$ ... $\dfrac{W}{K}$ $\quad P_{max} := 136$ ...W $\quad Area_{panel} := \dfrac{5486mm \cdot 394mm}{m^2}$

$Fn\_E_{pv.output}(T_{pv}, I_a) := \left[136 - \left[T_{pv} - (25 + 273.15)\right] \cdot Coef_{temp}\right] \cdot \dfrac{I_a}{1000}$ ... W

I_a is in W/m2; T_{pv} is in K

$\alpha_{pv} := 0.9$ $\quad Fn\_\eta_{pv}(T_{pv}) := \dfrac{P_{max} - Coef_{temp} \cdot \left[T_{pv} - (25 + 273.15)\right]}{1000 \cdot Area_{panel}}$ $\quad Fn\_\eta_{pv}(303) = 0.062$

Data Input, to verify the model with measured data

DAS :=

	1	2	3	4
1	1	0	2.4	2.9
2	0.933	0	2.333	2.867
3	0.867	0	2.267	...

... specify the input data wind, solar radiation, exterior temp, attic temp for last column

$V_{wind} := DAS^{\langle 1 \rangle}$ $I_{solar} := DAS^{\langle 2 \rangle}$ $T_{ext} := DAS^{\langle 3 \rangle} + 273.15$

$T_{attic} := DAS^{\langle 4 \rangle} + 273.15$ $Row_{DAS} := rows(DAS)$ $i := 1 .. Row_{DAS}$

$V_{wind_i} := \begin{cases} 5 & \text{if } IsNaN\left(V_{wind_i}\right) \\ V_{wind_i} & \text{otherwise} \end{cases}$ $V_{wind_i} := \begin{cases} 5 & \text{if } V_{wind_i} \le 5 \\ V_{wind_i} & \text{otherwise} \end{cases}$

$I_{solar_i} := \begin{cases} 0 & \text{if } IsNaN\left(I_{solar_i}\right) \\ I_{solar_i} & \text{otherwise} \end{cases}$ $T_{ext_i} := \begin{cases} 0 & \text{if } IsNaN\left(T_{ext_i}\right) \\ T_{ext_i} & \text{otherwise} \end{cases}$

$T_{inlet} := T_{ext} + 4.4$ $T_{attic_i} := \begin{cases} 0 & \text{if } IsNaN\left(T_{attic_i}\right) \\ T_{attic_i} & \text{otherwise} \end{cases}$

$Fn\_h_{c\_cavity}\left(V_{air}\right) := \max\left(12 \cdot V_{air} + 3, 10.2\right)$ ... $\frac{W}{m^2 \cdot K}$ ... CHTC in the air cavity

$Fn\_h_{c\_rf}(wind) := (4.2 + wind \cdot 3.5)$

$V_{air.PVT} := 0.85$ ... m/s

$$BIPVT_{upwind} :=$$

$$h_{c\_cavity} \leftarrow Fn\_h_{c\_cavity}\left(V_{air.PVT}\right)$$

$$F_{air} \leftarrow V_{air.PVT} \cdot \frac{Dm\_H_{BIPVT}}{m} \cdot \upsilon c_{p.air}$$

for $ii_{time} \in 1 .. Row_{DAS}$

$$T_{inlet} \leftarrow T_{ext_{ii_{time}}} + 4.4$$

$$T_{sky} \leftarrow T_{ext_{ii_{time}}} \cdot \left[0.8 + \frac{T_{ext_{ii_{time}}} - (273 + 10)}{250}\right]^{0.25}$$

$$h_{c\_rf} \leftarrow Fn\_h_{c\_rf}\left(V_{wind_{ii_{time}}}\right)$$

for $ii_{sc} \in 1 .. NoSection$

$$T_{top_{ii_{sc}}} \leftarrow T_{ext_{ii_{time}}}, T_{back_{ii_{sc}}} \leftarrow T_{attic_{ii_{time}}}$$

$$T_{previous} \leftarrow 300, T_{current} \leftarrow 301$$

while $\left|T_{previous} - T_{current}\right| > 0.1$

$$T_{previous} \leftarrow T_{current}$$

$$trace\left(T_{current}\right)$$

for $is \in 1 .. NoSection$

$$h_{r.top.back} \leftarrow F_{\varepsilon} \cdot \sigma_{SB} \cdot \left(T_{top_{is}} + T_{back_{is}}\right) \cdot \left[\left(T_{top_{is}}\right)^2 + \left(T_{back_{is}}\right)^2\right]$$

$$h_{r.top.sky} \leftarrow \varepsilon_{PV} \cdot \sigma_{SB} \cdot \left(T_{top_{is}} + T_{sky}\right) \cdot \left[\left(T_{top_{is}}\right)^2 + T_{sky}^{\ 2}\right]$$

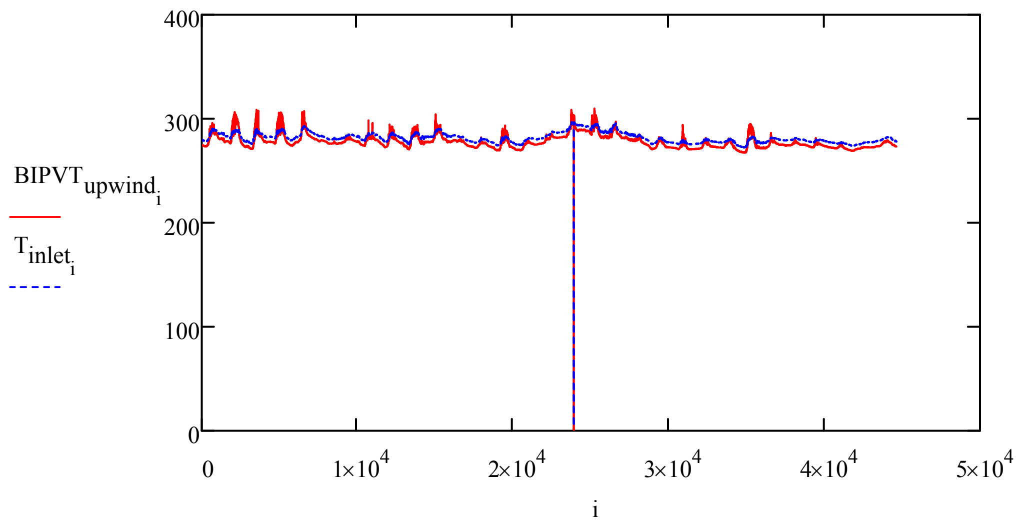
$$T_{top_{is}} \leftarrow \frac{h_{r.top.sky} \cdot T_{sky} + h_{c\_rf} \cdot T_{ext_{ii_{time}}} + \left(h_{c\_cavity} \cdot \begin{cases} T_{air_{is-1}} & \text{if is :} \\ T_{inlet} & \text{otherwis} \end{cases} \right. + h_{r.top.back} \cdot T_{back_{is}} + I_{solar_{ii_{time}}} \cdot \alpha_{pv} \cdot \left(1 - Fn\_\eta_{pv}\left(T_{top_{is}}\right)\right)}{h_{r.top.sky} + h_{c\_rf} + h_{c\_cavity} + h_{r.top.back}}$$

$$T_{back_{is}} \leftarrow \frac{\left(h_{c\_cavity} \cdot \begin{cases} T_{air_{is-1}} & \text{if } is > 1.5 \\ T_{inlet} & \text{otherwise} \end{cases}\right) + u_{back.attic} \cdot T_{attic_{ii_{time}}} +}{h_{c\_cavity} + u_{back.attic} + h_{r.top.back}}$$

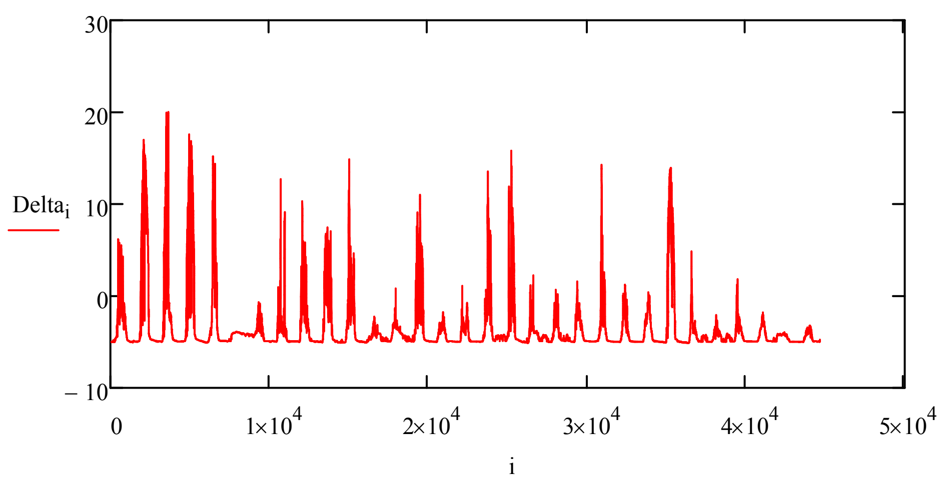
$$T_{air_{is}} \leftarrow \frac{\left(F_{air} \cdot \begin{cases} T_{air_{is-1}} & \text{if } is > 1.5 \\ T_{inlet} & \text{otherwise} \end{cases}\right) + h_{c\_cavity} \cdot Step_{rf} \cdot \left(T_{top_{is}} + T_{bac}\right.}{F_{air} + 2 \cdot h_{c\_cavity} \cdot Step_{rf}}$$

$$T_{current} \leftarrow T_{air_{NoSection}}$$

$$\left| \begin{array}{l} \left| \, T_{outlet.PVT_{ii_{time}}} \leftarrow T_{current} \right. \\ T_{outlet.PVT} \end{array} \right.$$



$$Delta := BIPVT_{upwind} - T_{inlet}$$



$$Area_{cavity} := Dm\_H_{BIPVT} \cdot Dm\_W_{BIPVT}$$

$$Q := \frac{V_{air.PVT} \cdot Area_{cavity} \cdot \upsilon c_{p.air} \cdot Delta \cdot \frac{1}{60}}{1000} \qquad Q_{all_i} := \left| \begin{array}{ll} Q_i & \text{if } Q_i > 0 \\ 0 & \text{otherwise} \end{array} \right.$$

$$Q_{limited20_i} := \begin{cases} Q_i & \text{if } \left[BIPVT_{upwind_i} > (20 + 273.15)\right] \wedge Q_i > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$Q_{limited30_i} := \begin{cases} Q_i & \text{if } \left[BIPVT_{upwind_i} > (30 + 273.15)\right] \wedge Q_i > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$Q_{limited1520_i} := \begin{cases} Q_i & \text{if } \left[(15 + 273.15) < BIPVT_{upwind_i} < (20 + 273.15)\right] \wedge Q_i > 0 \\ 0 & \text{otherwise} \end{cases}$$

Energy that could be collected assuming constant, maximum flow rate, constant air properties, and 4.4 increase in inlet temperature over ambient.

$\sum_i Q_{all_i} = 136.42 \text{ kWh}$ Assuming all energy is used (even when the outlet temperature is very low).

$\sum_i Q_{limited20_i} = 89.929 \text{ kWh}$ Assuming collection of energy only when the outlet temperature is above 20 C.

$\sum_i Q_{limited30_i} = 25.389 \text{ kWh}$ Assuming collection of energy only when the outlet temperature is above 30 C.

$\sum_i Q_{limited1520_i} = 29.67 \text{ kWh}$ Assuming collection of energy only when the outlet temperature between 15 and 20 C (low grade for use in garage).

Appendix I - Equipment Information

ARI/ISO 13256-1 Performance Ratings

English (IP) Units

Model	Capacity Modulation	Flow Rate		Ground Water Heat Pump				Ground Loop Heat Pump			
				Cooling EWT 59°F		Heating EWT 50°F		Cooling Brine Full Load 77°F Part Load 68°F		Heating Brine Full Load 32°F Part Load 41°F	
		gpm	cfm	Capacity Btuh	EER Btuh/W	Capacity Btuh	COP	Capacity Btuh	EER Btuh/W	Capacity Btuh	COP
026	Full	8	950	31,000	25.8	25,800	5.1	27,800	19.0	18,900	4.1
	Part	7	750	23,000	33.5	19,500	5.7	22,000	28.0	16,000	4.5
038	Full	9	1200	43,200	24.1	35,800	4.9	39,900	19.8	25,700	4.2
	Part	8	1000	31,000	31.2	25,600	5.3	30,800	28.0	22,500	4.8
049	Full	12	1500	54,600	22.7	48,300	4.7	51,300	18.3	37,600	4.1
	Part	11	1300	42,500	29.6	36,100	5.1	41,300	25.0	31,400	4.5
064	Full	16	1800	74,800	22.2	59,300	4.4	67,800	17.5	47,000	3.9
	Part	14	1500	55,800	29.0	42,500	4.6	51,000	24.8	36,000	4.1
072	Full	18	2000	81,800	21.6	73,400	4.5	73,900	16.5	54,400	3.6
	Part	16	1500	62,600	27.6	53,000	4.6	58,400	23.1	44,000	4.0
022	Single	8	850	25,500	32.2	20,600	5.4	22,000	22.0	14,600	4.0
030	Single	8	900	31,300	30.0	27,000	5.1	29,000	21.2	20,000	3.9
036	Single	9	1200	38,800	29.8	32,500	5.2	35,000	21.8	24,000	4.2
042	Single	11	1300	47,000	29.5	37,500	5.1	42,000	22.2	28,500	4.1
048	Single	12	1500	55,000	27.0	48,500	4.9	48,500	19.5	37,600	4.0
060	Single	15	1800	72,200	25.5	59,400	4.6	65,800	19.2	45,000	3.8
070	Single	18	2000	80,400	24.3	69,900	4.5	73,200	17.9	54,000	3.7

9/29/06

Metric (SI) Units

Model	Capacity Modulation	Flow Rate		Ground Water Heat Pump				Ground Loop Heat Pump			
				Cooling EWT 15°C		Heating EWT 10°C		Cooling Brine Full Load 25°C Part Load 20°C		Heating Brine Full Load 0°C Part Load 5°C	
		water L/S	air L/S	Capacity Watts	EER (W/W)	Capacity Watts	COP	Capacity Watts	EER (W/W)	Capacity Watts	COP
026	Full	0.5	448.4	9,086	7.6	7,562	5.1	8,148	5.6	5,539	4.1
	Part	0.4	354.0	6,741	9.8	5,715	5.7	6,448	8.2	4,689	4.5
038	Full	0.6	566.4	12,661	7.1	10,492	4.9	11,694	5.8	7,532	4.2
	Part	0.5	472.0	9,086	9.1	7,503	5.3	9,027	8.2	6,594	4.8
049	Full	0.8	708.0	16,002	6.7	14,156	4.7	15,035	5.4	11,020	4.1
	Part	0.7	613.6	12,456	8.7	10,580	5.1	12,104	7.3	9,203	4.5
064	Full	1.0	849.6	21,923	6.5	17,380	4.4	19,871	5.1	13,775	3.9
	Part	0.9	708.0	16,354	8.5	12,456	4.6	14,947	7.3	10,551	4.1
072	Full	1.1	944.0	23,974	6.3	21,512	4.5	21,659	4.8	15,944	3.6
	Part	1.0	708.0	18,347	8.1	15,533	4.6	17,116	6.8	12,896	4.0
022	Single	0.5	401.2	7,474	9.4	6,038	5.4	6,448	6.4	4,279	4.0
030	Single	0.5	424.8	9,174	8.8	7,913	5.1	8,499	6.2	5,862	3.9
036	Single	0.6	566.4	11,372	8.7	9,525	5.2	10,258	6.4	7,034	4.2
042	Single	0.7	613.6	13,775	8.6	10,991	5.1	12,309	6.5	8,353	4.1
048	Single	0.8	708.0	16,120	7.9	14,215	4.9	14,215	5.7	11,020	4.0
060	Single	0.9	849.6	21,161	7.5	17,409	4.6	19,285	5.6	13,189	3.8
070	Single	1.1	944.0	23,564	7.1	20,487	4.5	21,454	5.2	15,826	3.7

9/29/06

Cooling capacities based upon 80.6°F/27°C DB, 66.2°F/19°C WB entering air temperature
Heating capacities based upon 68°F/20°C DB, 59°F/15°C WB entering air temperature
All ratings based upon 208V operation

ARI Standard 13256-1

Physical Data (Dual Capacity)

Model	DUAL CAPACITY				
	026	038	049	064	072
Compressor (1 each)	Copeland 2-speed Scroll, UltraTech				
ICM Fan Motor & Blower					
Fan Motor Type/Speeds	ICM Variable Speed				
Fan Motor- hp [W]	1/2 [373]	1/2 [373]	1/2 [373]	1 [746]	1 [746]
Blower Wheel Size (Dia x W), in. [mm]	9 x 7 [229 x 178]	11 x 10 [279 x 254]	11 x 10 [279 x 254]	11 x 10 [279 x 254]	11 x 10 [279 x 254]
Coax and Water Piping					
Water Connections Size - Swivel - in [mm]	1" [25.4]	1" [25.4]	1" [25.4]	1" [25.4]	1" [25.4]
HWG Connection Size - Swivel - in [mm]	1" [25.4]	1" [25.4]	1" [25.4]	1" [25.4]	1" [25.4]
Coax & Piping Water Volume - gal [l]	0.7 [2.6]	1.3 [4.9]	1.6 [6.1]	1.6 [6.1]	2.3 [8.7]
Vertical					
Factory Charge R410a, oz [kg]	62 [1.76]	78 [2.21]	89 [2.52]	122 [3.46]	140 [3.97]
Air Coil Dimensions (H x W), in. [mm]	28 x 20 [711 x 542]	28 x 25 [711 x 635]	32 x 25 [813 x 635]	36 x 25 [914 x 635]	36 x 25 [914 x 635]
Air Coil Total Face Area, ft2 [m2]	3.9 [0.362]	4.9 [0.451]	5.6 [0.570]	6.3 [0.641]	6.3 [0.641]
Air Coil Tube Size, in [mm]	3/8 [9.5]	3/8 [9.5]	3/8 [9.5]	3/8 [9.5]	3/8 [9.5]
Air Coil Number of rows	3	3	3	4	4
Filter Standard - 1" [51mm] Pleated MERV7 Throwaway, in [mm]	28 x 24 [712 x 610]	36 x 30 [914 x 762]	36 x 30 [914 x 762]	36 x 30 [914 x 762]	36 x 30 [914 x 762]
Weight - Operating, lb [kg]	305 [138]	370 [168]	420 [190]	465 [211]	480 [218]
Weight - Packaged, lb [kg]	315 [143]	380 [172]	430 [195]	475 [215]	490 [222]
Horizontal					
Factory Charge R410a, oz [kg]	60 [1.70]	76 [2.15]	89 [2.52]	124 [3.52]	160 [4.54]
Air Coil Dimensions (H x W), in. [mm]	18 x 30 [457 x 762]	20 x 35 [508 x 889]	20 x 40 [508 x 1016]	20 x 45 [508 x 1143]	20 x 45 [508 x 1143]
Air Coil Total Face Area, ft2 [m2]	3.9 [0.362]	4.9 [0.451]	5.6 [0.570]	6.3 [0.641]	6.3 [0.641]
Air Coil Tube Size, in [mm]	3/8 [9.5]	3/8 [9.5]	3/8 [9.5]	3/8 [9.5]	3/8 [9.5]
Air Coil Number of rows	3	3	3	4	4
Filter Standard - 1" [51mm] Pleated MERV7 Throwaway, in [mm]	1 - 18 x 32 [457 x 813]	1 - 20 x 37 [686 x 940]	1 - 20 x 20 [508 x 508] 1 - 20 x 22 [508 x 559]	1 - 20 x 25 [508 x 635] 1 - 20 x 22 [508 x 559]	1 - 20 x 25 [508 x 635] 1 - 20 x 22 [508 x 559]
Weight - Operating, lb [kg]	307 [139]	375 [170]	425 [193]	470 [213]	485 [220]
Weight - Packaged, lb [kg]	322 [146]	390 [177]	440 [200]	485 [220]	500 [227]

10/2/06

Notes: Sizes 038, 049 available with 1HP blower motor.

Auxliary Heat Ratings

Model	KW 208V	KW 230V	Stages	BTU/HR 208V	BTU/HR 230V	Min CFM	Envision Series Compatibility 022	026 - 030	036 - 049	060 - 072
EAM(H)5	3.6	4.8	1	12,300	16,300	450	•	•		
EAM(H)8	5.7	7.6	2	19,400	25,900	550	•	•		
EAM(H)10	7.2	9.6	2	24,600	32,700	650		•		
EAL(H)10	7.2	9.6	2	24,600	32,700	1100			•	•
EAL(H)15	10.8	14.4	3	36,900	49,100	1250			•	•
EAL(H)20	14.4	19.2	4	49,200	65,500	1500				•

"H" is used in part number for horizontal units

Auxiliary Heat Electrical Data

MODEL	SUPPLY CIRC	HEATER AMPS 208 V	HEATER AMPS 240 V	MIN CIRC AMP 208 V	MIN CIRC AMP 240 V	FUSE (USA) 208 V	FUSE (USA) 240 V	FUSE (CAN) 208 V	FUSE (CAN) 240 V	CKT BRK (CAN) 208 V	CKT BRK (CAN) 240 V
SINGLE SPEED											
EAM(H)5	Single	17.3	20.0	26.7	30.0	30	30	30	30	30	30
EAM(H)8	Single	27.5	31.7	39.3	44.6	40	45	40	45	40	45
EAM(H)10	Single	34.7	40.0	48.3	55.0	50	60	50	60	50	60
EAL(H)10	Single	34.7	40.0	53.3	60.0	60	60	60	60	60	60
EAL(H)15	Single L1/L2 L3/L4	52.0 34.7 17.3	60.0 40.0 20.0	75.0 53.3 21.7	85.0 60.0 25.0	80 60 25	90 60 25	80 60 25	90 60 25	80 60 25	90 60 25
EAL(H)20	Single L1/L2 L3/L4	69.3 34.7 34.7	80.0 40.0 40.0	96.7 53.3 43.3	110.0 60.0 50.0	100 60 45	110 60 50	100 60 45	110 60 50	100 60 40	110 60 50
DUAL CAPACITY											
EAL(H)10	Single	34.7	40.0	53.3	60.0	60	60	60	60	60	60
EAL(H)15	Single L1/L2 L3/L4	52.0 34.7 17.3	60.0 40.0 20.0	75.0 53.3 21.7	85.0 60.0 25.0	80 60 25	90 60 25	80 60 25	90 60 25	80 60 25	90 60 25
EAL(H)20	Single L1/L2 L3/L4	69.3 34.7 34.7	80.0 40.0 40.0	96.7 53.3 43.3	110.0 60.0 50.0	100 60 45	110 60 50	100 60 45	110 60 50	100 60 40	110 60 50

Notes: All heaters rated single phase 60 cycle and include the unit fan load. All fuses type “D” time delay (or HACR circuit breaker in USA). Supply wire size to be determined by local codes.

Fan Performance Data
ECM2

Single Speed

MODEL	MAX ESP	AIR FLOW DIP SWITCH SETTINGS											
		1	2	3	4	5	6	7	8	9	10	11	12
022	0.50		400	500 L	**600 M**	**700**	**800 H**	**900**	1000	1100	1200		
030	0.50		400	500 L	600	**700 M**	**800**	**900 H**	**1000**	**1100**	1200		
036	0.50	650	750	850 L	1000	**1100 M**	**1200**	**1300 H**	**1400**	**1500**			
036 w/1hp*	0.75	800	1000 L	**1100 M**	**1300 H**	**1500**	**1600**	1800					
042	0.50	650	800	900 L	1050	**1150 M**	**1250**	**1350**	**1450 H**	**1550**			
042 w/1hp*	0.75	800	900 L	1000	**1200 M**	**1400 H**	**1600**	**1700**	**1850**	2000	2200	2300	2400
048	0.50	650	800	900	1050 L	1150	**1250**	**1350 M**	**1450**	**1550 H**			
048 w/1hp*	0.75	800	900	1000 L	1200	**1400 M**	**1600 H**	**1700**	**1850**	2000	2200	2300	2400
060	0.75	800	950	1100 L	1300	**1500 M**	**1750**	**1950 H**	**2100**	**2300**			
070	0.75	800	950	1100 L	1300	**1500**	**1750 M**	**1950**	**2100 H**	**2300**			

5/30/06

Factory settings are at recommended L-M-H DIP switch locations
M-H settings MUST be located within boldface CFM range
Lowest and Highest DIP switch settings are assumed to be L and H respectively

CFM is controlled within ±5% up to the maximum ESP
Max ESP includes allowance for wet coil and standard filter

Dual Capacity

MODEL	MAX ESP	AIR FLOW DIP SWITCH SETTINGS											
		1	2	3	4	5	6	7	8	9	10	11	12
026	0.50		400	500 L	600	**700 M**	**800**	**900 H**	**1000**	1100	1200		
038	0.50	650	750 L	850	1000	**1100 M**	**1200**	**1300 H**	**1400**	**1500**			
038 w/1hp*	0.75	800 L	1000	**1100 M**	**1300 H**	**1500**	**1600**	1800					
049	0.50	650	800 L	900	1050	1150	**1250**	**1350 M**	**1450**	**1550 H**			
049 w/1hp*	0.75	800 L	900	1000	1200	**1400 M**	**1600 H**	**1700**	**1850**	2000	2200	2300	2400
064	0.75	800	950 L	1100	1300	**1500 M**	**1750**	**1950 H**	**2100**	**2300**			
072	0.75	800	950	1100 L	1300	**1500**	**1750 M**	**1950**	**2100 H**	**2300**			

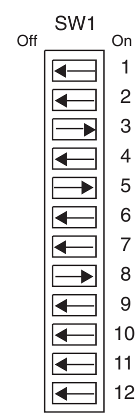
5/30/06

Factory settings are at recommended L-M-H DIP switch locations
M-H settings MUST be located within boldface CFM range
Lowest and Highest DIP switch settings are assumed to be L and H respectively

CFM is controlled within ±5% up to the maximum ESP
Max ESP includes allowance for wet coil and standard filter

A 12-position DIP switch package on the control allows the airflow levels to be set for low, medium, and high speed when using the ECM2 blower motor. Only three of the DIP switches can be in the "on" position.

- The first "on" switch (the lowest position number) determines the low speed fan setting.
- The second "on" switch determines the medium speed fan setting.
- The third "on" switch determines the high speed fan setting.



The example to the right shows SW1 on the control board configured for the following 042 airflow settings.

- Low Speed Fan: 900 CFM
- Medium Speed Fan: 1150 CFM
- High Speed Fan: 1450 CFM

GT038 Low Speed

Capacity Data (1050 CFM)

EWT °F	Flow gpm	WPD PSI	WPD FT	HEATING - EAT 70°F Airflow cfm	HC kBtuh	Power kW	HE kBtuh	LAT °F	COP	HWC kBtuh	COOLING - EAT 80/67 °F Airflow cfm	TC kBtuh	SC kBtuh	S/T Ratio	Power kW	HR kBtuh	EER	HWC kBtuh
20	4.0	0.9	2.1	Operation not recommended							Operation not recommended							
	6.0	1.7	4.0	Operation not recommended							Operation not recommended							
	8.0	2.9	6.7	900	15.6	1.38	10.9	86.0	3.32	2.5	Operation not recommended							
				1050	16.2	1.41	11.4	84.3	3.37	2.2								
30	4.0	0.9	2.0	Operation not recommended							Operation not recommended							
	6.0	1.7	3.9	900	17.3	1.36	12.6	87.8	3.72	2.4	900	28.6	18.1	0.63	0.76	31.2	37.6	0.7
				1050	18.0	1.40	13.2	85.9	3.78	2.2	1050	29.4	20.1	0.68	0.78	32.1	37.9	0.8
	8.0	2.8	6.5	900	18.4	1.39	13.6	88.9	3.87	2.5	900	29.1	18.6	0.64	0.76	31.7	38.5	0.7
				1050	19.2	1.43	14.3	86.9	3.92	2.3	1050	29.9	20.6	0.69	0.77	32.5	38.8	0.7
40	4.0	0.8	1.9	Operation not recommended							Operation not recommended							
	6.0	1.6	3.8	900	20.4	1.39	15.7	91.0	4.32	2.5	900	29.8	19.4	0.65	0.83	32.6	36.1	0.7
				1050	21.1	1.41	16.3	88.6	4.38	2.3	1050	30.7	21.5	0.70	0.84	33.5	36.4	0.8
	8.0	2.7	6.3	900	21.5	1.42	16.7	92.1	4.44	2.6	900	30.3	19.9	0.66	0.82	33.1	37.0	0.7
				1050	22.3	1.45	17.3	89.6	4.51	2.4	1050	31.2	22.0	0.71	0.83	34.0	37.4	0.8
50	4.0	0.8	1.9	900	22.5	1.41	17.7	93.1	4.67	2.6	900	30.8	20.8	0.67	0.94	34.0	32.8	1.0
				1050	23.2	1.43	18.3	90.5	4.75	2.4	1050	31.7	23.0	0.73	0.96	34.9	33.1	1.0
	6.0	1.6	3.7	900	23.3	1.41	18.5	94.0	4.83	2.7	900	31.1	20.9	0.67	0.92	34.2	34.0	0.9
				1050	24.0	1.43	19.1	91.2	4.91	2.5	1050	32.0	23.1	0.72	0.93	35.1	34.2	1.0
	8.0	2.6	6.1	900	24.4	1.45	19.4	95.1	4.94	2.8	900	31.6	21.4	0.68	0.91	34.7	34.8	0.8
				1050	25.1	1.46	20.1	92.1	5.03	2.5	1050	32.5	23.7	0.73	0.92	35.6	35.1	0.9
60	4.0	0.8	1.8	900	25.4	1.44	20.5	96.1	5.17	2.8	900	29.6	20.0	0.68	1.05	33.2	28.2	1.3
				1050	26.0	1.45	21.0	92.9	5.26	2.6	1050	30.4	22.2	0.73	1.07	34.1	28.4	1.4
	6.0	1.5	3.6	900	26.4	1.44	21.5	97.1	5.38	2.9	900	29.9	20.1	0.67	1.02	33.3	29.2	1.2
				1050	27.0	1.44	22.1	93.8	5.48	2.7	1050	30.7	22.3	0.73	1.04	34.2	29.4	1.3
	8.0	2.5	5.9	900	27.3	1.47	22.3	98.1	5.45	3.0	900	30.3	20.7	0.68	1.01	33.8	29.9	1.1
				1050	27.9	1.48	22.9	94.6	5.54	2.8	1050	31.2	22.9	0.73	1.03	34.7	30.2	1.3
70	4.0	0.8	1.8	900	28.2	1.46	23.2	99.0	5.64	3.1	900	29.2	20.3	0.69	1.19	33.3	24.5	1.8
				1050	28.7	1.46	23.7	95.3	5.75	2.9	1050	30.0	22.5	0.75	1.21	34.2	24.7	1.9
	6.0	1.5	3.5	900	29.4	1.46	24.4	100.2	5.91	3.2	900	29.5	20.4	0.69	1.16	33.4	25.4	1.7
				1050	29.9	1.46	25.0	96.4	6.03	3.0	1050	30.3	22.6	0.75	1.18	34.3	25.6	1.9
	8.0	2.5	5.7	900	30.2	1.49	25.1	101.0	5.94	3.3	900	30.0	20.9	0.70	1.15	33.9	26.1	1.6
				1050	30.7	1.49	25.6	97.1	6.05	3.1	1050	30.8	23.2	0.75	1.17	34.8	26.3	1.8
80	4.0	0.7	1.7	900	30.8	1.49	25.7	101.7	6.06	3.5	900	28.1	19.9	0.71	1.36	32.7	20.7	2.5
				1050	31.2	1.48	26.2	97.6	6.18	3.3	1050	28.9	22.0	0.76	1.38	33.6	20.9	2.7
	6.0	1.4	3.3	900	32.3	1.48	27.3	103.2	6.39	3.6	900	28.4	20.0	0.71	1.32	32.9	21.5	2.3
				1050	32.7	1.47	27.7	98.8	6.52	3.4	1050	29.2	22.1	0.76	1.35	33.7	21.7	2.5
	8.0	2.4	5.5	900	32.8	1.51	27.6	103.7	6.35	3.7	900	28.8	20.5	0.71	1.31	33.3	22.0	2.2
				1050	33.1	1.50	28.0	99.2	6.48	3.5	1050	29.6	22.7	0.77	1.33	34.2	22.2	2.4
90	4.0	0.7	1.6	900	33.4	1.52	28.3	104.4	6.47	4.0	900	26.0	18.6	0.71	1.54	31.3	16.9	3.3
				1050	33.7	1.50	28.6	99.7	6.60	3.7	1050	26.8	20.6	0.77	1.57	32.1	17.0	3.5
	6.0	1.4	3.2	900	35.2	1.50	30.0	106.2	6.86	4.1	900	26.3	18.7	0.71	1.50	31.4	17.5	3.1
				1050	35.4	1.48	30.3	101.2	7.00	3.8	1050	27.0	20.7	0.77	1.53	32.2	17.6	3.4
	8.0	2.3	5.3	900	35.3	1.53	30.1	106.3	6.75	4.2	900	26.7	19.2	0.72	1.49	31.8	17.9	2.9
				1050	35.5	1.51	30.3	101.3	6.89	3.9	1050	27.5	21.2	0.77	1.52	32.6	18.1	3.2
100	4.0	0.7	1.6	Operation not recommended							Operation not recommended							
	6.0	1.3	3.1	Operation not recommended							900	25.4	19.0	0.75	1.72	31.2	14.8	4.1
											1050	26.1	21.0	0.81	1.75	32.0	14.9	4.4
	8.0	2.2	5.1	Operation not recommended							900	25.8	19.5	0.76	1.70	31.6	15.1	3.8
											1050	26.5	21.6	0.81	1.74	32.4	15.3	4.2
110	4.0	0.7	1.5	Operation not recommended							Operation not recommended							
	6.0	1.3	3.0	Operation not recommended							900	22.7	17.9	0.79	1.95	29.4	11.6	5.1
											1050	23.4	19.8	0.85	1.99	30.2	11.7	5.6
	8.0	2.1	4.9	Operation not recommended							900	23.1	18.3	0.79	1.94	29.7	11.9	4.8
											1050	23.8	20.3	0.85	1.97	30.5	12.0	5.3
120	4.0	0.6	1.5	Operation not recommended							Operation not recommended							
	6.0	1.2	2.9	Operation not recommended							900	21.5	17.7	0.82	2.22	29.1	9.7	6.4
											1050	22.1	19.6	0.88	2.26	29.8	9.8	6.9
	8.0	2.0	4.7	Operation not recommended							900	21.9	18.1	0.83	2.20	29.4	10.0	5.9
											1050	22.5	20.1	0.89	2.24	30.1	10.0	6.6

Rev: 10/10/06

IMPORTANT NOTE: Refer to page 19 (Notes to Capacity Tables) for additional information.

GT038 High Speed

Capacity Data (1250 CFM)

EWT °F	Flow gpm	WPD		HEATING - EAT 70°F							COOLING - EAT 80/67 °F							
		PSI	FT	Airflow cfm	HC kBtuh	Power kW	HE kBtuh	LAT °F	COP	HWC kBtuh	Airflow cfm	TC kBtuh	SC kBtuh	S/T Ratio	Power kW	HR kBtuh	EER	HWC kBtuh
20	5.0	1.3	3.0	Operation not recommended							Operation not recommended							
	7.0	2.3	5.2	Operation not recommended														
	9.0	3.5	8.1	1050	22.2	1.93	15.6	89.6	3.37	2.8								
				1250	23.0	1.99	16.2	87.0	3.38	2.6								
30	5.0	1.2	2.9	Operation not recommended							Operation not recommended							
	7.0	2.2	5.1	1050	25.6	1.97	18.9	92.6	3.81	3.0	1050	37.3	22.1	0.59	1.40	42.1	26.8	1.5
				1250	26.3	2.03	19.4	89.5	3.81	2.8	1250	39.5	24.7	0.63	1.48	44.5	26.7	1.6
	9.0	3.4	7.9	1050	26.0	1.99	19.2	92.9	3.84	3.1	1050	37.6	24.4	0.65	1.35	42.2	27.8	1.4
				1250	26.9	2.05	19.9	89.9	3.84	2.8	1250	39.8	27.1	0.68	1.44	44.8	27.6	1.5
40	5.0	1.2	2.8	Operation not recommended							Operation not recommended							
	7.0	2.1	4.9	1050	29.9	2.09	22.8	96.4	4.20	3.4	1050	38.8	23.7	0.61	1.54	44.0	25.2	1.6
				1250	30.8	2.13	23.5	92.8	4.24	3.1	1250	40.9	26.4	0.65	1.62	46.4	25.2	1.7
	9.0	3.3	7.6	1050	30.5	2.11	23.3	96.9	4.24	3.5	1050	39.1	25.7	0.66	1.50	44.2	26.1	1.4
				1250	31.5	2.15	24.1	93.3	4.29	3.2	1250	41.3	28.6	0.69	1.59	46.7	26.0	1.6
50	5.0	1.2	2.7	1050	32.4	2.14	25.1	98.6	4.44	3.7	1050	39.0	24.7	0.63	1.83	45.2	21.3	1.9
				1250	33.4	2.17	26.0	94.7	4.51	3.4	1250	41.1	27.5	0.67	1.92	47.6	21.4	2.0
	7.0	2.1	4.8	1050	33.6	2.19	26.1	99.6	4.50	3.8	1050	39.8	25.0	0.63	1.72	45.7	23.1	1.8
				1250	34.6	2.22	27.1	95.7	4.58	3.5	1250	41.9	27.8	0.66	1.81	48.1	23.2	1.9
	9.0	3.2	7.4	1050	34.3	2.21	26.8	100.3	4.56	3.9	1050	40.2	26.7	0.66	1.68	46.0	23.9	1.6
				1250	35.4	2.24	27.8	96.2	4.64	3.6	1250	42.4	29.7	0.70	1.76	48.4	24.0	1.8
60	5.0	1.1	2.6	1050	35.7	2.24	28.1	101.5	4.67	4.1	1050	38.6	25.3	0.66	1.95	45.2	19.8	2.3
				1250	36.9	2.26	29.2	97.3	4.79	3.8	1250	40.5	28.1	0.70	2.03	47.4	19.9	2.4
	7.0	2.0	4.6	1050	37.3	2.31	29.5	102.9	4.74	4.2	1050	39.5	25.6	0.65	1.85	45.8	21.4	2.1
				1250	38.5	2.32	30.6	98.5	4.86	3.9	1250	41.4	28.4	0.69	1.93	48.0	21.5	2.3
	9.0	3.1	7.2	1050	38.2	2.33	30.3	103.7	4.81	4.4	1050	39.9	27.0	0.68	1.80	46.0	22.1	2.0
				1250	39.5	2.34	31.5	99.3	4.94	4.0	1250	41.9	29.9	0.71	1.89	48.3	22.2	2.2
70	5.0	1.1	2.5	1050	39.1	2.36	31.1	104.5	4.85	4.6	1050	38.6	26.2	0.68	2.14	45.8	18.1	2.8
				1250	40.5	2.36	32.4	100.0	5.02	4.3	1250	40.2	29.1	0.72	2.22	47.8	18.2	3.0
	7.0	1.9	4.5	1050	41.1	2.44	32.8	106.3	4.94	4.8	1050	39.5	26.5	0.67	2.04	46.5	19.3	2.6
				1250	42.5	2.44	34.1	101.5	5.10	4.4	1250	41.2	29.3	0.71	2.12	48.5	19.5	2.8
	9.0	3.0	6.9	1050	42.2	2.47	33.8	107.2	5.00	4.9	1050	39.9	27.5	0.69	1.99	46.8	20.0	2.4
				1250	43.6	2.46	35.2	102.3	5.19	4.5	1250	41.7	30.5	0.73	2.07	48.8	20.1	2.7
80	5.0	1.1	2.5	1050	41.6	2.46	33.2	106.7	4.96	5.2	1050	37.2	25.8	0.69	2.32	45.1	16.0	3.5
				1250	43.1	2.44	34.7	101.9	5.17	4.8	1250	38.7	28.7	0.74	2.39	46.8	16.2	3.7
	7.0	1.9	4.3	1050	44.0	2.56	35.3	108.8	5.04	5.3	1050	38.2	26.1	0.68	2.24	45.9	17.1	3.3
				1250	45.5	2.53	36.9	103.7	5.27	4.9	1250	39.8	29.0	0.73	2.31	47.6	17.2	3.6
	9.0	2.9	6.7	1050	45.3	2.59	36.4	109.9	5.12	5.5	1050	38.6	26.8	0.69	2.19	46.1	17.6	3.0
				1250	46.8	2.55	38.1	104.7	5.38	5.1	1250	40.2	29.7	0.74	2.26	47.9	17.8	3.4
90	5.0	1.0	2.4	1050	44.2	2.57	35.4	108.9	5.03	5.8	1050	35.1	25.1	0.71	2.51	43.7	14.0	4.4
				1250	45.7	2.53	37.1	103.9	5.29	5.4	1250	36.4	27.9	0.77	2.57	45.1	14.2	4.6
	7.0	1.8	4.2	1050	46.9	2.69	37.8	111.4	5.12	6.0	1050	36.2	25.4	0.70	2.44	44.5	14.9	4.1
				1250	48.6	2.64	39.6	106.0	5.40	5.5	1250	37.5	28.2	0.75	2.50	46.0	15.0	4.4
	9.0	2.8	6.5	1050	48.4	2.73	39.1	112.7	5.20	6.2	1050	36.6	25.7	0.70	2.39	44.8	15.3	3.8
				1250	50.1	2.66	41.0	107.1	5.52	5.7	1250	37.9	28.4	0.75	2.45	46.3	15.5	4.2
100	5.0	1.0	2.3	Operation not recommended							Operation not recommended							
	7.0	1.7	4.0								1050	34.9	25.2	0.72	2.72	44.1	12.8	5.0
											1250	36.0	28.0	0.78	2.76	45.4	13.0	5.5
	9.0	2.7	6.2								1050	35.2	25.1	0.71	2.67	44.3	13.2	4.7
											1250	36.4	27.8	0.76	2.71	45.6	13.4	5.2
110	5.0	1.0	2.2								Operation not recommended							
	7.0	1.7	3.9								1050	31.9	23.7	0.74	2.97	42.0	10.7	6.1
											1250	32.8	26.3	0.80	2.99	43.0	11.0	6.7
	9.0	2.6	6.0								1050	32.2	23.4	0.73	2.91	42.2	11.1	5.7
											1250	33.1	25.8	0.78	2.95	43.1	11.2	6.3
120	5.0	0.9	2.1								Operation not recommended							
	7.0	1.6	3.7								1050	30.0	23.2	0.77	3.31	41.3	9.1	7.4
											1250	30.7	25.8	0.84	3.31	42.0	9.3	8.0
	9.0	2.5	5.8								1050	30.3	22.6	0.75	3.26	41.4	9.3	6.9
											1250	30.9	24.9	0.81	3.27	42.1	9.5	7.6

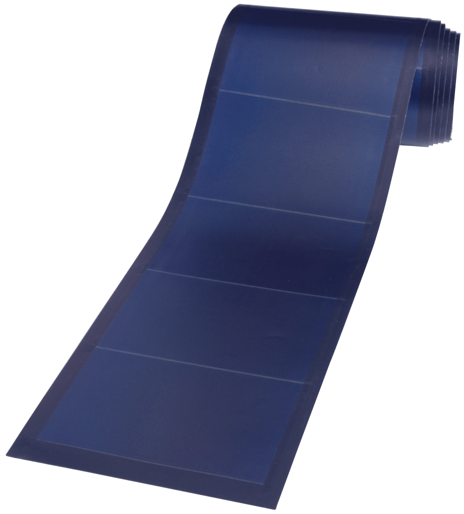
Rev: 10/10/06

IMPORTANT NOTE: Refer to page 19 (Notes to Capacity Tables) for additional information.

Solar Laminate PVL-Series

Model: PVL-136

UNI-SOLAR®



- High Temperature and Low Light Performance
- 5-Year Limited Product Warranty
- Limited Power Output Warranty:
  92% at 10 years, 84% at 20 years, 80% at 25 years (of minimum power)
- Quick-Connect Terminals and Adhesive Backing
- Bypass Diodes for Shadow Tolerance

Performance Characteristics

Rated Power (P_{max}):	136 Wp
Production P_{max} Tolerance:	± 5 %

Construction Characteristics

Dimensions:	Length: 5486 mm (216”), Width: 394 mm (15.5”), Depth: 4 mm (0.2”), 16 mm (0.6”) including potted terminal housing assembly
Weight:	7.7 kg (17.0 lbs)
Output Cables:	4 mm^2 (12 AWG) cable with weatherproof DC-rated quick-connect terminals 560 mm (22“) length
Bypass Diodes:	Connected across every solar cell
Encapsulation:	Durable ETFE high light-transmissive polymer
Adhesive:	Ethylene propylene copolymer adhesive sealant with microbial inhibitor
Cell Type:	22 triple junction amorphous silicon solar cells 356 mm x 239 mm (14” x 9.4”) connected in series

Qualifications and Safety

UL 1703 Listed by Underwriters Laboratories for electrical and fire safety (Class A Max. Slope 2/12, Class B Max. Slope 3/12, Class C Unlimited Slope fire ratings) for use in systems up to 600 VDC.

IEC 61646 and IEC 61730 certified by TÜV Rheinland for use in systems up to 1000 VDC.

Laminate Standard Configuration

Photovoltaic laminate with potted terminal housing assembly with output cables and quick-connect terminals on top.

Application Criteria*

- Installation temperature between 10 °C - 40 °C (50 °F - 100 °F)
- Maximum roof temperature 85 °C (185 °F)
- Minimum slope: 3° (1/2:12)
- Maximum slope 60° (21:12)
- Approved substrates include certain membrane and metal roofing products. See United Solar for details.

**Detailed installation requirements are specified in United Solar installation manuals.*

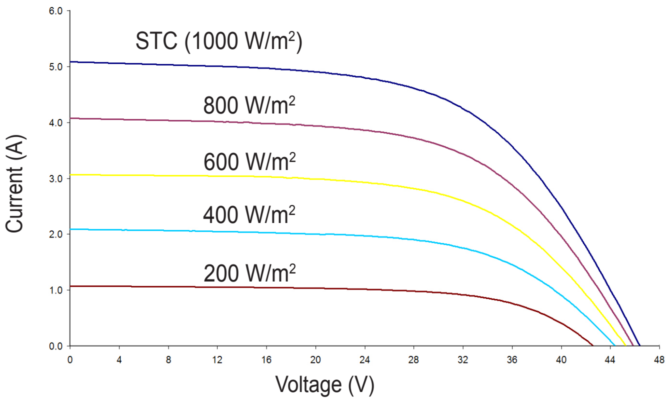
Technical Data Sheet

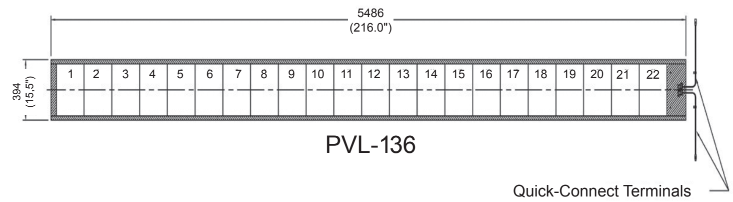
Solar Laminate PVL-Series

Model: PVL-136

UNI-SOLAR®

IV Curves at various Levels of Irradiance at Air Mass 1.5 and 25 °C Cell Temperature





All measurements in mm
Inches in parentheses
Tolerances: Length: ± 5 mm (1/4"), Width: ± 3 mm (1/8")

Electrical Specifications

STC

(Standard Test Conditions)
(1000 W/m², AM 1.5, 25 °C Cell Temperature)

Maximum Power (P_{max}): 136 W
Voltage at Pmax (V_{mp}): 33.0 V
Current at Pmax (I_{mp}): 4.13 A
Short-circuit Current (I_{sc}): 5.1 A
Open-circuit Voltage (V_{oc}): 46.2 V
Maximum Series Fuse Rating: 8 A

NOCT

(Nominal Operating Cell Temperature)
(800 W/m², AM 1.5, 1 m/sec. wind)

Maximum Power (P_{max}): 105 W
Voltage at Pmax (V_{mp}): 30.8 V
Current at Pmax (I_{mp}): 3.42 A
Short-circuit Current (I_{sc}): 4.1 A
Open-circuit Voltage (V_{oc}): 42.2 V
NOCT: 46 °C

Temperature Coefficients

(at AM 1.5, 1000 W/m² irradiance)

Temperature Coefficient (TC) of I_{sc}: 0.001/°K(0.10%/°C)
Temperature Coefficient (TC) of V_{oc}: -0.0038/°K (-0.38%/°C)
Temperature Coefficient (TC) of P_{max}: -0.0021/°K (-0.21%/°C)
Temperature Coefficient (TC) of I_{mp}: 0.001/°K (0.10%/°C)
Temperature Coefficient (TC) of V_{mp}: -0.0031/°K (-0.31%/°C)

y = yreference • [1 + TC • (T- Treference)]

Notes:

1. During the first 8-10 weeks of operation, electrical output exceeds specified ratings. Power output may be higher by 15%, operating voltage may be higher by 11% and operating current may be higher by 4%.
2. Electrical specifications are based on measurements performed at standard test conditions of 1000 W/m² irradiance, Air Mass 1.5, and cell temperature of 25 °C after stabilization.
3. Actual performance may vary up to 10% from rated power due to low temperature operation, spectral and other related effects. Maximum system open-circuit voltage not to exceed 600 VDC per UL, 1000 VDC per TÜV Rheinland.
4. Specifications subject to change without notice.

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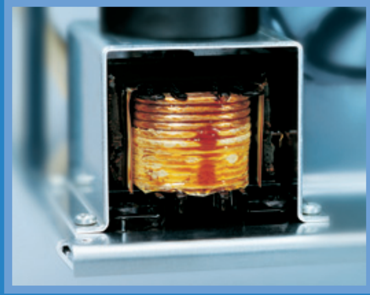
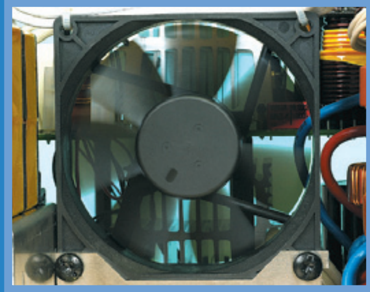
A subsidiary of Energy Conversion Devices, Inc. (Nasdaq: ENER)





FRONIUS IG

GRID-TIED INVERTERS FOR PHOTOVOLTAIC SYSTEMS

Light Weight — At 26 lbs, the FRONIUS IG inverters are the lightest grid-connected inverters making them easy and cost effective to install.

Flexible — The wide voltage range of 150-500 V allows you to use different types of modules and system configuration possibilities.

Lower Cost — Integrated UL approved DC & AC disconnects which reduce installation time and complexity - often eliminating the need for additional disconnects.

LCD Display — User-friendly and comes standard with every FRONIUS IG; tracks more than 20 critical system performance parameters.

Plug-and-Play — Expansion slots in the inverter allow you to easily upgrade the inverter with data communication options.

Reliable — Fronius has been in business for over 60 years and has more than 200,000 FRONIUS IG inverters installed worldwide.

Warranty — 10 year Premium Warranty.

Fronius

POWERING YOUR FUTURE

FRONIUS IG

FRONIUS IG 2000 / 3000 / 2500-LV - Specifications

DC Input Data	**FRONIUS IG 2000**	**FRONIUS IG 3000**	**FRONIUS IG 2500-LV**
Recommended PV power	1500 – 2500 Wp	2500 – 3300 Wp	1800 – 3000 Wp
Max. DC input voltage	500 V	500 V	500 V
Operating DC voltage range	150 – 450 V	150 – 450 V	150 – 450 V
Max. usable DC input current	13.6 A	18 A	16.9 A
AC Output Data	**FRONIUS IG 2000**	**FRONIUS IG 3000**	**FRONIUS IG 2500-LV**
Maximum output power @40° C	2000 W	2700 W	2350 W
Nominal AC output voltage	240 V		208 V
Utility AC voltage range	212 – 264 V (240 V +10% / -12%)		183 - 227 V
Maximum AC current	8.35 A	11.25 A	11.25 A
Maximum utility back feed current	0.0 A	0.0 A	0.0 A
Operating frequency range	59.3 – 60.5 Hz (60 Hz nom)		
Total Harmonic Distortion THD	< 5%		
Power Factor (cos phi)	1		
General Data	**FRONIUS IG 2000**	**FRONIUS IG 3000**	**FRONIUS IG 2500-LV**
Max. efficiency	95.2%	95.2%	94.4%
Consumption in stand-by	< 0.15 W (night)		
Consumption during operation	7 W		
Enclosure	NEMA 3R		
Size (l x w x h)	18.5 x 16.5 x 8.8 inches (470 x 418 x 223 mm)		
Weight	26 lbs. (11.8 kg)		
Ambient temperature range	-5 to 122 °F (-20 to +50 °C)		
Cooling	controlled forced ventilaton		
Integrated AC and DC disconnects	standard UL approved DC & AC disconnects		
Protections			
Ground fault protection	Internal GFDI, in accordance with UL 1741		
DC reverse polarity protection	Internal diode		
Islanding protection	Internal, in accordance with UL 1741, IEEE 1547		
Over temperature	Output power derating		
Surge protection	Internal DC & AC protection, Tested to 6 kV		
Compliance			
Safety	UL 1741		
EMI	FCC Part 15; Class A & B		
Anti-Islanding protection	UL 1741, IEEE 1547		
Ground fault detector and interrupter	Compliant with NEC Art. 690 requirements, UL 1741		
Miscellaneous			
Maximum AC over current protection	Two-pole, 15 / 20 A circuit breaker		
AC wire sizing	Use maximum AWG 6 194°F (90 °C) copper wire		
DC wire sizing	Use maximum AWG 8 194°F (90 °C) copper wire		
AC disconnect	16 A		
DC disconnect	25 A		
Warranty	10 year Premium Warranty is Standard		

Distributed by

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Solar Electronic Division
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www.fronius-usa.com

40,0006,2438 (1/07)

Fantech

JUNE 2009

FKD SERIES

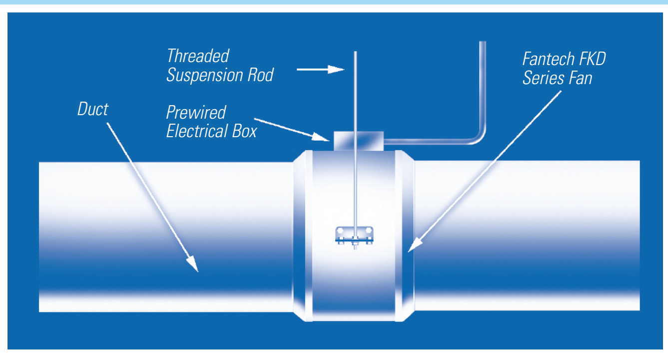
ROUND INLINE MIXED FLOW **CENTRIFUGAL FANS**

Fantech FKD direct drive, mixed flow centrifugal fans blend the high flow of axial fans with the higher pressure, non-overloading characteristics of backward curved impellers. An excellent choice for exhaust or supply applications where quieter performance and easy installation are important. Perfect for commercial and institutional structures such as offices, hospitals, beauty salons, veterinary clinics as well as residential applications such as kitchen range hood exhaust.

FKD straight-through inline design fans are available in a wide range of sizes for easy installation in duct sizes from 8" to 20". Fans can be mounted at any angle at any point along the duct work. Motors are capable of operating in airstream temperatures up to 140° F. Motor bearings are permanently sealed, self lubricating ball type.

100% Speed Controllable

All FKD fans are 100% speed controllable through voltage reduction allowing for on-demand ventilation or precision balancing of systems.



amca CERTIFIED RATINGS SOUND AND AIR PERFORMANCE AIR MOVEMENT AND CONTROL ASSOCIATION, INC.

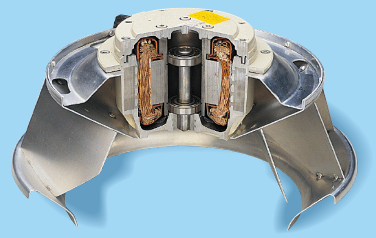
Fantech, Inc. and Fantech Limited certify that the FKD Series shown herein is licensed to bear the AMCA Seal. The ratings shown are based on tests and procedures performed in accordance with AMCA Publication 211 and AMCA Publication 311 and comply with the requirements of the AMCA Certified Ratings Program.

c UL us

THREE YEAR WARRANTY

EXTERNAL ROTOR MOTORS

All FKD Series fans utilize our unique external rotor motors. The motor's enclosed design allows the fan to operate in high moisture, lint and dust laden air. The motors are a permanent split capacitor type, with automatic reset thermal overload protection and sealed ball bearings. These features ensure long life and maintenance free operation. All motors and impellers are designed as one integral unit, allowing for excellent motor heat dissipation, even at a low RPM.



HARD WORKING. LONG LASTING. **HERE'S WHY:**

- Galvanized steel housing
- External rotor motor with built-in thermal overload protection and automatic reset
- Mixed flow impeller
- Permanently lubricated sealed ball bearings
- Excellent heat dissipation to ensure long motor life
- Suitable for airstream temperatures up to 140° F
- 100% speed controllable
- Terminal box with prewired electrical strip
- Three-year warranty

FKD 10

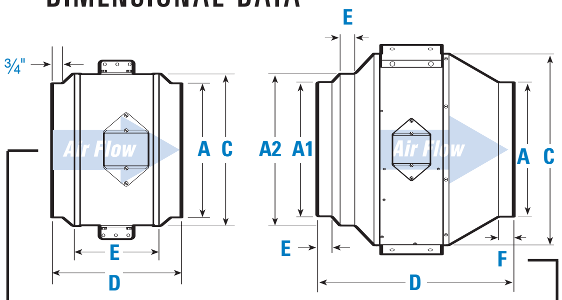
12 MODELS TO CHOOSE FROM:

- 8" to 20" duct diameters
- 836 to 6291 CFM
- 100% speed controllable
- Rated for airstream temperatures up to 140° F
- Three-year factory warranty

FKD SERIES

INLINE MIXED FLOW DUCT FANS

DIMENSIONAL DATA

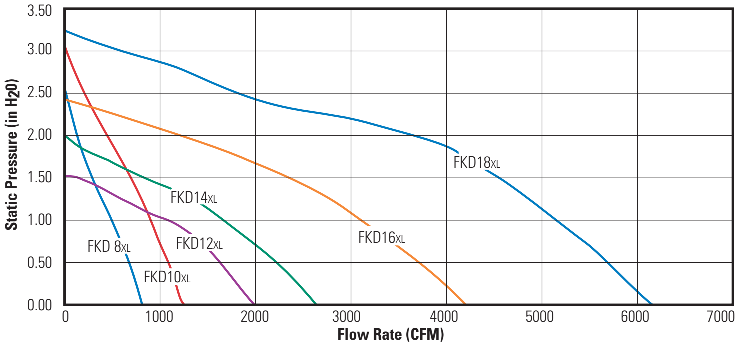


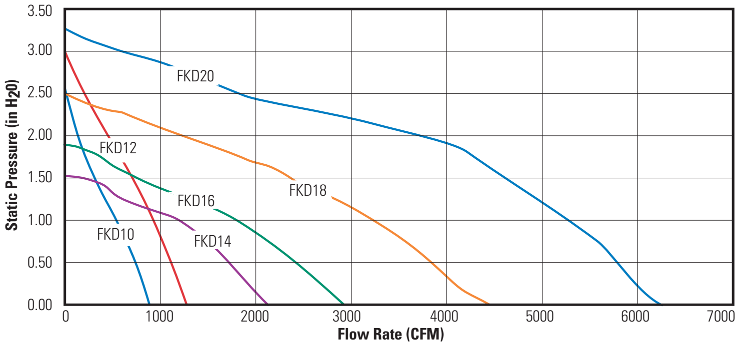
Model	A	A1	A2	C	D	E	F
FKD 8XL	8	–	–	12½	15½	7	–
FKD 10	10	–	–	12½	12½	7	–
FKD 10XL	10	–	–	14	15	8	–
FKD 12	12	–	–	14	12½	8	–
FKD 12XL	12	12	14	17⅞	18⅞	⅞	1⅝
FKD 14	14	12	14	17⅞	17¼	1	1⅝
FKD 14XL	14	14	16	19¾	20¼	1½	1½
FKD 16	16	14	16	19¾	18¾	1½	1⅝
FKD 16XL	16	16	18	22⅛	23¼	1¼	1⅝
FKD 18	18	16	18	22⅛	21¾	1¼	1⅝
FKD 18XL	18	18	20	22¼	29¼	2	1¾
FKD 20	20	18	20	22¼	27¼	2	1¾

All dimensions in inches.

Fantech, Inc. and Fantech Limited certify that the FKD Series shown herein is licensed to bear the AMCA Seal. The ratings shown are based on tests and procedures performed in accordance with AMCA Publication 211 and AMCA Publication 311 and comply with the requirements of the AMCA Certified Ratings Program.

AIR PERFORMANCE GRAPHS





PERFORMANCE DATA (For sound performance data refer to publication FKD0808.)

Fan Model	RPM	Voltage	Rated Watts	Max. Amps	Static Pressure in Inches W.G. 0″	0.125″	0.25″	0.375″	0.5″	0.75″	1.0″	1.25″	1.5″	2.0″	Max Ps. 2.50″	Duct Dia.	Sones†
FKD 8XL	2700	115	327	2.99[1]	836	799	761	720	680	595	499	393	286	—	2.59″	8″	14.1
FKD 10	2700	115	329	3.01[1]	910	873	836	795	752	653	547	432	342	—	2.60″	10″	15.3
FKD 10XL	2850	115	529	4.84[2]	1266	1226	1187	1147	1100	1006	911	810	696	460	3.08″	10″	21.0
FKD 12	2900	115	531	4.86[2]	1305	1266	1228	1189	1145	1054	948	833	712	479	3.08″	12″	23.0
FKD 12XL	1700	115	500	4.80[2]	2016	1920	1832	1746	1649	1423	1066	606	—	—	1.52″	12″	18.7
FKD 14	1700	115	495	4.76[2]	2156	2061	1965	1868	1764	1520	1193	623	—	—	1.52″	14″	18.4
FKD 14XL	1550	115	738	7.12[2]	2619	2517	2416	2303	2180	1936	1662	1294	843	—	1.94″	14″	19.0
FKD 16	1600	115	742	6.39[2]	2952	2831	2707	2580	2445	2144	1804	1306	774	—	1.90″	16″	18.5
FKD 16XL	1600	115	1421	12.40[3]	4274	4144	4014	3880	3743	3452	3137	2794	2379	1242	2.42″	16″	25.0
FKD 18	1600	115	1411	12.04[3]	4448	4992	4130	3991	3871	3583	3239	2843	2380	1231	2.51″	18″	24.0
FKD 18XL	1700	460/3	2208	3.75	6236	6115	5995	5874	5754	5500	5199	4909	4602	3703	3.24″	18″	32.0
FKD 20	1750	460/3	2218	3.73	6291	6174	6054	5933	5829	5617	5307	4987	4667	3757	3.27″	20″	33.0

Performance certified is for installation type D - Ducted inlet, Ducted outlet. Speed (RPM) shown is nominal. Performance is based on actual speed of test. Performance ratings do not include the effects of appurtenances (accessories).
† The sound ratings shown are loudness values in fan sones at 5ft. (1.5m) in hemispherical free field calculated per AMCA Standard 301. Values shown are for installation Type D: ducted inlet hemispherical fan sone levels. Ratings do not include the effect of duct end correction. All sone values shown are calculated at 0.5″ (static pressure in inches W.G.). Note: Three phase motors are wound for 230/460 volt. Motors are prewired for 460 volts but may be delivered as 230 volt or may be rewired in the field. [1] Recommended speed control rating 5A. [2] Recommended speed control rating 10A. [3] Recommended speed control rating 15A.

Fantech
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Item #: 450396
Rev Date: 110209

General details of the TD-MIXVENT range

Low profile mixed flow fans, manufactured in plastic material (up to model 200) or in **galvanized steel** sheet protected with Epoxy paint (model 250 and up), with external terminal box, removable motor-impeller assembly and adjustable single-phase motor, Class B, IP44.

Construction characteristics

	100	100x	125	150	200	200x	250	315	355	400
Polypropylene housing	•	•	•	•	•	•				
Steel housing with epoxy coating							•	•	•	•
ABS fan blades	•	•	•	•		•				
Aluminum fan blades					•		•	•	•	•
Thermal link via fuse	•	•	•							
Thermal link with automatic reset				•	•	•	•	•	•	•
Permanently lubricated ball bearings	•	•	•	•	•	•	•	•	•	•
Speed controllable 2-speed motor	•	•	•	•	•	•	•	•		

The extensive range of the TD-MIXVENT series makes it an effective solution for a wide range of residential and light commercial ventilation installations.

Performance characteristics

All models include a direct two speed motor connection, except TD-355 and 400.

Model	Nom. RPM	Volts	Max. Watts	Speed	CFM v Static Pressure (SP) Ins. WG							Max. SP	Max operating temp. (°F)	Weight (lbs)	Duct Dia. Ins.
					0"	0.125"	0.25"	0.375"	0.5"	0.75"	1.0"				
TD-100	2431	120	23	LS	97	81	51	-	-	-	-	.4	104	2	4"
	2516	120	26	HS	101	85	57	-	-	-	-	.4	104	2	4"
TD-100x	1556	120	20	LS	100	77	48	-	-	-	-	.375	104	4.4	4"
	2096	120	33	HS	135	113	90	53	-	-	-	.55	104	4.4	4"
TD-125	1633	120	24	LS	149	110	73	-	-	-	-	.35	104	4.4	5"
	2146	120	38	HS	197	168	133	86	22	-	-	.55	104	4.4	5"
TD-150	1709	120	54	LS	218	193	163	128	105	24	-	.8	140	4.4	6"
	2289	120	65	HS	293	273	250	227	206	131	35	1.15	140	4.4	6"
TD-200	2322	120	139	LS	476	422	373	317	260	40	-	1.38	140	8.8	8"
	2781	120	184	HS	538	495	458	418	367	190	10	1.625	140	8.8	8"
TD-200x	1935	120	122	LS	419	393	363	327	295	215	107	1.4	140	8.8	8"
	2467	120	169	HS	478	457	432	402	372	285	192	1.75	140	8.8	8"
TD-250	2400	115	162	LS	541	475	418	355	295	218	170	2.03	140	19.8	10"
	3200	115	241	HS	754	715	680	640	606	520	405	2.53	140	19.8	10"
TD-315	2000	115	208	LS	751	670	545	420	285	190	130	1.62	140	30.9	12.4"
	2500	115	335	HS	1050	990	932	850	770	600	420	2.95	140	30.9	12.4"
TD-355	1400	115	464	-	1829	1740	1620	1530	1450	1190	-	1.1	140	43	14"
TD-400	1400	115	756	-	2630	2490	2360	2240	2100	1750	350	1.2	140	58	16"

TD 250 & 315 are UL listed for outdoor use.

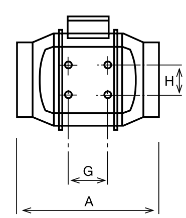
LS= Low Speed
HS = High Speed

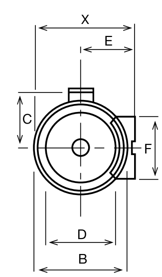
Soler & Palau USA certifies that the TD range shown herein is licensed to bear the AMCA Seal. The ratings shown are based on tests and procedures performed in accordance with AMCA Publication 211 and comply with the requirements of the AMCA Certified Ratings Program.

The TD-MIXVENT Series fans are California Title 24 compliant and meet ASHRAE 62.2 when installed with 3 way switch and remotely mounted speed control.

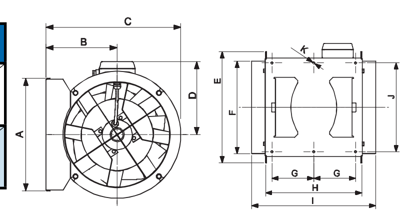
Dimensions (inches/mm)

Model	X	A	B	C	D	E	F	G	H
TD-100	5 15/16 / 151	9 1/8 / 232	5 7/16 / 138	3 3/4 / 96	3 7/8 / 98	3 1/4 / 82	3 3/4 / 95	1 7/8 / 48	2 1/16 / 52
TD-100x	7 3/8 / 188	11 15/16 / 303	6 15/16 / 176	4 1/2 / 115	3 13/16 / 97	3 15/16 / 100	3 9/16 / 90	3 1/8 / 80	2 3/8 / 60
TD-125	7 3/8 / 188	10 3/16 / 258	6 15/16 / 176	4 1/2 / 115	4 13/16 / 123	3 15/16 / 100	3 9/16 / 90	3 1/8 / 80	2 3/8 / 60
TD-150	8 3/8 / 212	11 5/8 / 295	7 7/8 / 200	5 / 127	5 13/16 / 147	4 7/16 / 112	5 1/8 / 130	3 1/8 / 80	2 3/8 / 60
TD-200	9 3/16 / 233	11 7/8 / 302	8 9/16 / 217	5 9/16 / 141	7 13/16 / 198	4 7/8 / 124	5 1/2 / 140	3 15/16 / 100	3 11/16 / 94
TD-200x	9 3/16 / 233	11 7/8 / 302	8 9/16 / 217	5 9/16 / 141	7 13/16 / 198	4 7/8 / 124	5 1/2 / 140	3 15/16 / 100	3 11/16 / 94
TD-250	11 7/16 / 291	15 3/16 / 386	10 11/16 / 272	7 9/16 / 192	9 3/4 / 248	6 1/8 / 155	6 5/8 / 168	5 11/16 / 145	5 1/2 / 140
TD-315	14 / 356	17 11/16 / 450	13 1/4 / 336	8 13/16 / 224	12 5/16 / 312	7 3/8 / 188	8 1/4 / 210	7 3/16 / 182	7 / 178





Model	A	B	C	D	E	F	G	H	I	J	K
TD-355	14 5/6 / 377	9 3/8 / 238	17 3/4 / 451	8 5/6 / 224	16 7/9 / 426	13 8/9 / 354	5 8/9 / 150	14 1/2 / 368	18 2/3 / 474	13 3/8 / 340	1/3 / 8.5
TD-400	16 / 407	9 4/5 / 249	19 3/8 / 492	10 1/2 / 267	19 1/6 / 487	15 5/7 / 399	6 2/7 / 160	16 3/4 / 425	21 5/9 / 547	14 4/7 / 370	1/3 / 8.5



Sound characteristics

Fan sound levels are measured in sones. At this time there are no sone level test standards available through HVI due to the fact that remote mounted fan noise levels are in proportion to the following: type of duct, length of duct, fan distance from the intake source and other miscellaneous factors. However, it is generally accepted that remote mounted venting is usually quieter than standard (in room) venting.

Submittal Data Information

101-028

Model 006 Cartridge Circulator

Effective: September 21, 2009 **Supersedes:** March 15, 2004

Job: ______________ Engineer: ______________ Contractor: ______________ Rep: ______________

ITEM NO.	MODEL NO.	IMP. DIA.	G.P.M.	HEAD/FT.	H.P.	ELEC. CHAR.

Features

- Standard High Capacity Output-Compact Design
- Quiet, Efficient Operation
- Direct Drive-Low Power Consumption
- Unique Replaceable Cartridge Design-Field Serviceable
- Self Lubricating
- No Mechanical Seal
- Unmatched Reliability-Maintenance Free
- Bronze or Stainless Steel Construction with Sweat, Threaded or Union Connections

Materials of Construction

Casing (Volute):	Bronze or Stainless Steel
Stator Housing:	Steel
Cartridge:	Stainless Steel
Impeller:	Non-Metallic
Shaft:	Ceramic
Bearings:	Carbon
O-Ring & Gaskets:	EPDM

Model Nomenclature

B - Bronze, 3/4" Sweat
BC - Bronze, 1/2" Sweat, Panel Mount
ST - Stainless Steel
BC-1 - Bronze, Union, Panel Mount

Variations:

Z - Zoning Circulator
VS - Variable Speed, Set Point
VR - Variable Speed, Outdoor Reset
VV - Variable Speed, Variable Voltage

Performance Data

Flow Range: 0 – 10 GPM
Head Range: 0 – 9 Feet
Minimum Fluid Temperature: 40°F (4°C)
Maximum Fluid Temperature: 220°F (104°C)
Maximum Working Pressure: 125 psi
Connection Sizes:
1/2" Swt, 3/4" Swt, 3/4" NPT or Union

c UL us LISTED

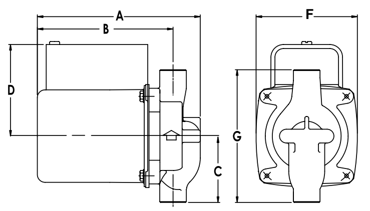
FOR INDOOR USE ONLY

Application

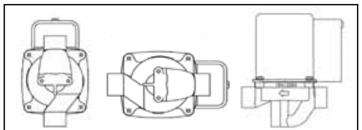
The Taco 006 is designed for circulating hot or chilled fresh water in open or closed loop applications. Typical uses include hydronic heating, domestic hot water recirculation, hydro-air heating/cooling, heat recovery units, water source heat pumps, drain down open loop Solar systems and potable water applications. The unique, replaceable cartridge contains all of the moving parts and allows for easy service instead of replacing the entire circulator. The compact, low power consumption design is ideal for high efficiency jobs.

Pump Dimensions & Weights

		A		B		C		D		F		G		Ship Wt.	
Model	Conn.	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	lbs.	Kg
006-B4	3/4"Swt	5-1/8	130	4-1/8	105	2-3/16	56	3-1/16	78	3-5/16	84	4-13/32	112	6.0	2.7
006-BC4	1/2"Swt	5-1/8	130	4-1/8	105	2-1/8	54	3-1/16	78	3-5/16	84	4-1/4	108	6.0	2.7
006-ST4	3/4"NPT	5-5/8	143	4-7/8	124	2	51	3-1/16	78	3-5/16	84	4	102	6.0	2.7
006-BC4-1	Union	5-5/32	131	4-11/32	110	2-31/32	76	3-1/16	78	3-5/16	84	5-15/16	151	6.0	2.7



Mounting Positions

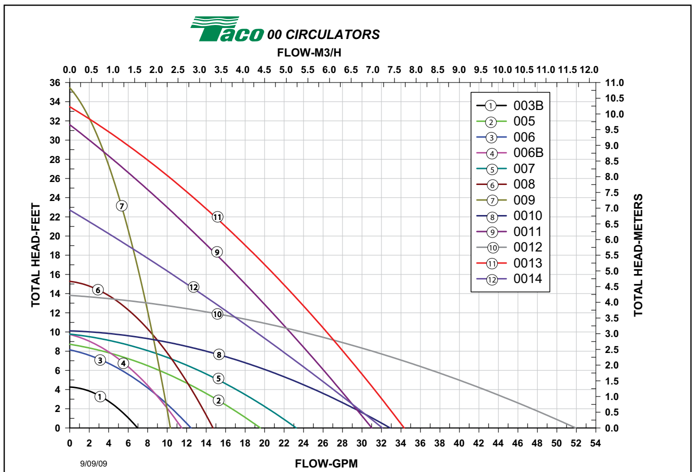


Standard Optional OK if over 20 psi

Electrical Data

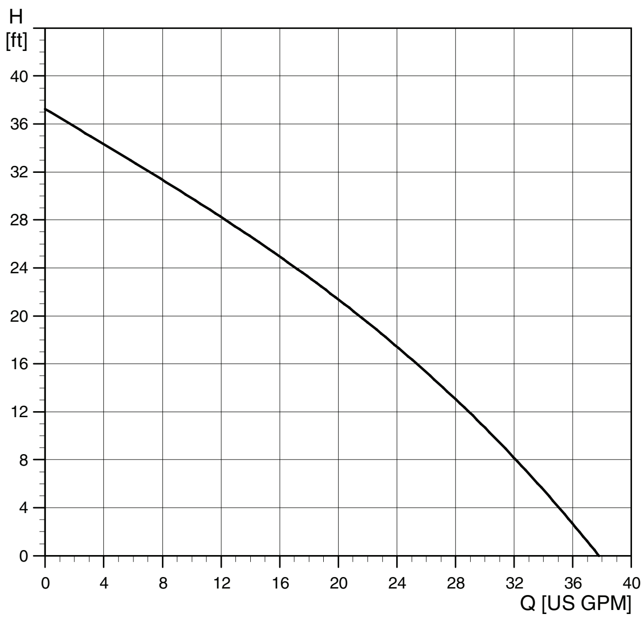
Model	Volts	Hz	Ph	Amps	RPM	HP
006 All Models	115	60	1	.52	3250	1/40
Motor Type	Permanent Split Capacitor Impedance Protected					
Motor Options	220/50/1, 220/60/1, 230/60/1, 100/110/50/60/1					

Performance Field - 60Hz



Do it Once. Do it Right.®

TACO INC., 1160 Cranston Street, Cranston, RI 02920 Telephone: (401) 942-8000 Fax: 942-2360
TACO (Canada), Ltd., 6180 Ordan Drive, Mississauga, Ontario L5T 2B3 Telephone: (905) 564-9422 Fax: (905) 564-9436
Visit our website at: www.taco-hvac.com



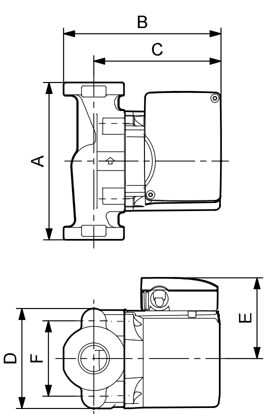
TM03 5577 0907

Flow range:	0-37 U.S. gpm
Head range:	0-37 feet
Motors:	2-pole, single-phase
Max. liquid temperature:	150 °F (65 °C)
Min. liquid temperature:	32 °F (0 °C)
Max. system pressure:	145 psi

Closed system (F) and Open system (BF)

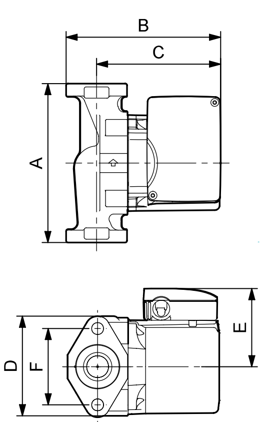
Model	Volts	Amps	Watts	Hp	Capacitor
UP 26-116F/BF	230	1.8	385	1/6	2.5µF/380 V

UP 26-116F



TM03 8758 2407

UP 26-116BF



TM03 8543 1907

Model type	Product number	A	B	C	D	E	F	Connection type and size	Shipping weight [lbs]
UP 26-116F	52722377	6 1/2	6 3/8	5 1/16	4 1/8	3 1/2	3 5/32	GF 15/26 flange (2) 1/2" dia. bolt boles	12 1/2 lbs
UP 26-116BF	52722393	6 1/2	6 3/8	5 1/16	4 1/8	3 1/2	3 5/32	GF 15/26 flange (2) 1/2" dia. bolt boles	12 1/2 lbs

LIFEBREATH®
THE ULTIMATE AIR EXCHANGER

Model 155ECM

ENGINEERING DATA

THERMALLY CONDUCTIVE, PATENTED ALUMINUM CORE
The cross-flow heat recovery core transfers heat between the two airstreams. It is easily removed for cleaning or service.

MOTORS AND BLOWERS
High effficiency electronic comutated ECM motor for maximum energy savings. Each air stream has one centrifugal blower. 5 speed fan operation driven by one double shaft motor. 120 VAC, 1.0 Amps.

FILTERS
Washable air filters in exhaust and supply air streams.

MOUNTING THE HRV
Four threaded inserts at corners of case designed to accept four reinforced polyester straps that are supplied with the unit.

DEFROST
Recirculating damper defrost system.

DEHUMIDISTAT
Adjustable Internal Dehumidistat.

CASE
Twenty gauge prepainted galvanized steel (G60) for superior corrosion resistance. Insulated to prevent exterior condensation. Drain connections 2 - 1/2" (12 mm) OD. Door balancing ports.

CONTROLS
ControlAir 15 - Standby/ON mode, 20 ON/ 40 OFF mode, 20 ON/40 Recirculation mode, Recirculation mode (each mode has 5 speeds). Control pad can be removed from HRV and remotely mounted.

Weight 71 lbs. (32.5 kg) **Shipping Weight** 73 lbs. (33.5 kg)

OPTIONAL MAIN CONTROLS

99-350 **Lifestyle Ventilation Control** 7/24 programmable ventilation, (3 wire) 20 gauge wire (min.) 100' length

99-109 **Air Sentry Air Quality Monitor** designed to accept remotely mounted Control Pad, (3 wire) 20 gauge wire (min.) 100' length

99-250 **Ventilation Dehumidistat** designed to accept remotely mounted Control Pad, (4 wire) 20 gauge wire (min.) 100' length

OPTIONAL TIMERS

99-104 **Digital Electronic Timer** - initiates high speed ventilation for 20, 40 or 60 minutes, (3 wire) 20 gauge wire (min.) 100' length

99-101 **Crank Timer** - Initiates high speed ventilation for up to 60 minutes, (2 wire) 20 gauge wire (min.) 100' length

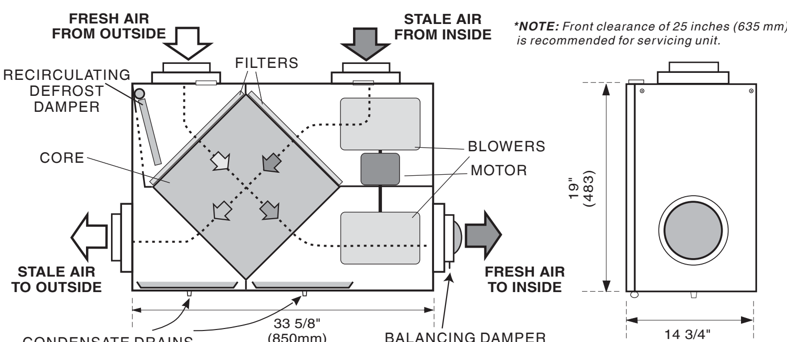
OPTIONAL ACCESSORIES

99-163 **Duct Heater w/ Electronic SCR Thermostat,** 1 Kw, 6" (150 mm)

99-164 **Duct Heater w/ Electronic SCR Thermostat**, 2 Kw, 6" (150 mm)

99-185 **Weatherhoods**, Two - 6" (150 mm) c/w 1/4" (6 mm) mesh screen

DIMENSIONS 155ECM *inches (mm)*



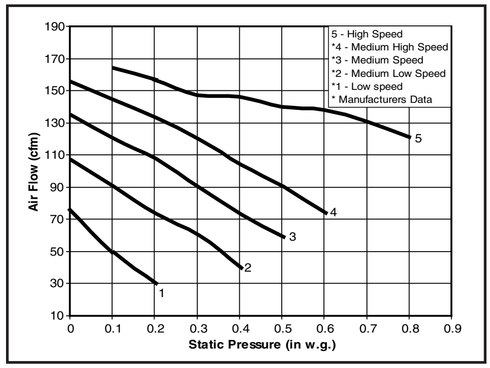
*All Duct Connections 6" (150mm)

Performance (HVI certified)

Net supply air flow in cfm (L/s) against external static pressure

E.S.P (external static pressure)		[cfm (L/s)]
@ 0.1" (25 Pa)		164 (77)
@ 0.2" (50 Pa)		157 (74)
@ 0.3" (75 Pa)		147 (69)
@ 0.4" (100 Pa)		146 (69)
@ 0.5" (125 Pa)		140 (66)
@ 0.6" (150 Pa)		138 (65)
@ 0.7" (175 Pa)		131 (62)
@ 0.8" (200 Pa)		121 (57)
Max. Temperature Recovery		79%
Sensible Effectiveness @ 66 cfm (31 L/s)	32°F (0°C)	72%
*Sensible Efficiency @ 66 cfm (31 L/s)	32°F (0°C)	66%
*Sensible Efficiency @ 66 cfm (31 L/s)	-13°F (-25°C)	67%
VAC @ 60HZ		120
WATTS / Low speed.		34
WATTS / High speed		95
Amp rating		1.4

**Sensible Efficiency – thermal **Latent Efficiency – moisture*
Note: Effectiveness - based on temp. differential between the 2 airstreams
Efficiency – takes into account all power inputs



All units conform to CSA and UL standards.

WARRANTY
Units carry a LIFETIME warranty on the heat recovery core and a 5 year replacement parts warranty.

⚠ ATTENTION

The ECM motor produces a tone that some may find objectionable. We recommend the installation of the optional 99-SILENCER6 on the 'Stale Air from Inside' and 'Fresh Air to Inside' ducts.

Date: ______________________ Contractor: ______________________

Tag: ____________ Qty: ____________ Supplier: ______________________

Project: ______________________ Quote#: ______________________

Engineer: ______________________ Submitted by: ______________________

nutech BRANDS INC.

511 McCormick Blvd.
London, Ontario N5W 4C8
T (519) 457-1904
F (519) 457-1676
Email: nutech@lifebreath.com

270 Regency Ridge, Suite 210
Dayton, Ohio 45459
T (937) 439-6676
F (937) 439-6685
Website: www.lifebreath.com

ISO 9001 REGISTERED

Motors and Blowers
2 speed, high efficiency PSC Motor - 150 cfm/75 cfm.
110 watts - 120 VAC - standard three prong plug to receptacle.
The TFP is equipped with a standard power supply on 5'5" (1.6 meters) cable.

OFF/LOW/HIGH Speed Selector Switch
Select 75 cfm (Low) or 150 cfm (High).

Airflow
150cfm @ .4" WC (High Speed)
75 cfm @ .4" WC (Low Speed)

Collectors
Model TFP3000 - Two replaceable TFP collectors
Model TFPC3000 CONSOLE - Two replaceable TFP collectors
• Easy to remove for cleaning and replacement
• Annual inspection recommended

Case
Twenty gauge prepainted galvanized steel (G60) for superior corrosion resistance

Weight
55 lbs. (24.4 Kgs)

Electrical Codes
Conforms to CSA and UL standards

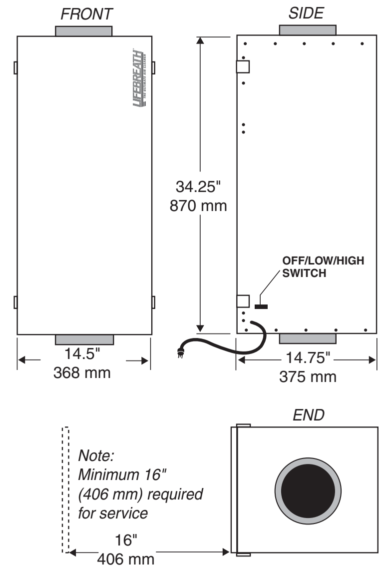
Mounting the Wholehouse TFP - very flexible
a. Mount to the furnace return
b. Mount between the HRV and the furnace
c. Hang from a joist and duct to the furnace
d. Stand alone installation

Warranty
Units carry a five year warranty on all replacement parts except the collectors/filters.

Options
65-503R - One replacement TFP Collector
65-502R - One replacement HEPA filter

Optional Installation Kit: Part # 99-TFP
Includes - two 7" Duct Connection Collars
- 12.5' of 7" Non-insulated Flex Duct
- four Nylon Duct Zip Ties

TFP3000



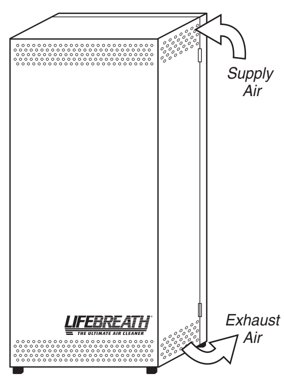
All duct connections are 7" (178 mm)

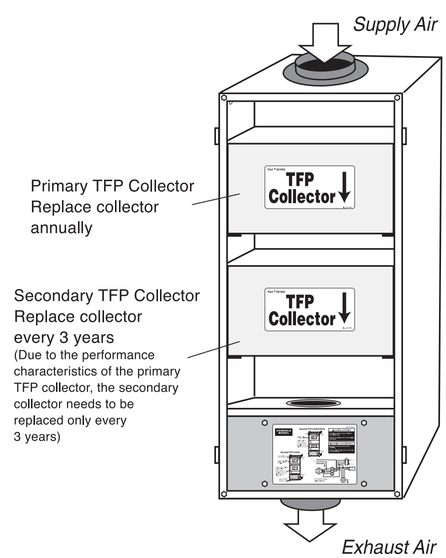
Model TFP 3000 & TFPC3000 Particle Capture Rate

Particle Size (microns)	Percentage Caught
5 or more	99%
2 - 3	97%
1	95%
0.5 - 0.9	90%

• A human hair is 100 microns wide.
• Spores and pollen are all larger than 8 microns.
• A micron is 1/1000 of a millimetre, or less than 1/2 of 1/10,000 of an inch.

Console Portable Model TFPC3000





Date: ______________________
Tag: ____________ Qty: ____________
Project: ______________________
Engineer: ______________________
Contractor: ______________________
Supplier: ______________________
Quote#: ______________________
Submitted by: ______________________

nutech BRANDS INC.
511 McCormick Blvd.
London, Ontario N5W 4C8
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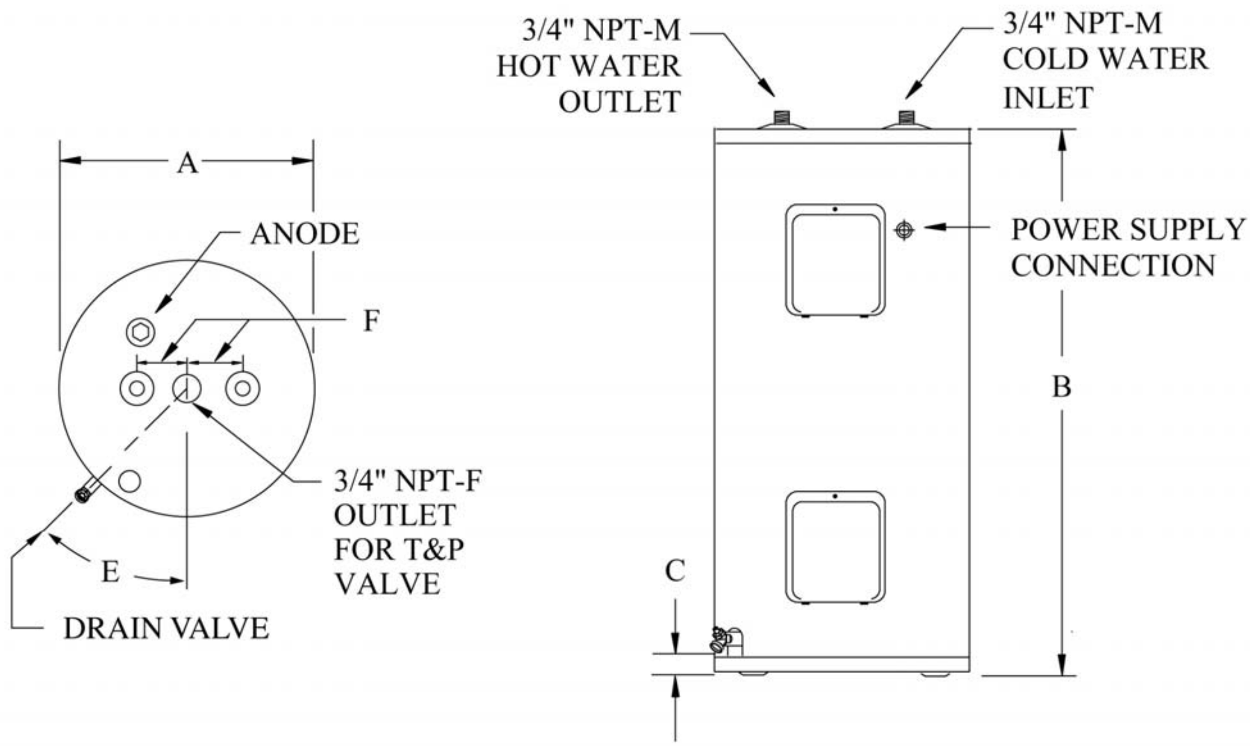
F (519) 457-1676
Email: nutech@lifebreath.com
270 Regency Ridge, Suite 210
Dayton, Ohio 45459
T (937) 439-6676
F (937) 439-6685
Website: www.lifebreath.com
ISO 9001 REGISTERED

ENGINEERING SUBMITTAL DATA SHEET

C191.1 TOP ENTRY
RESIDENTIAL ELECTRIC WATER HEATERS
MODELS 172ETE
62.5 IMPERIAL GALLONS / 284 LITRES
INSULATED WITH 2" ECO-FRIENDLY GREENFOAM®

All models meet or exceed NRCan energy efficiency requirements

Model	Storage capacity Imp. gal.	Litres	Input	Voltage	Standby loss	Diameter (A) in/cm	Height (B) in/cm	C in/cm	E	F in/cm	Plumbing connections	Est. ship. wt. lb/kg
172ETE-1F7M	62.5	284	1,500W	120V	89W	23½/60	60/152	2⅛/5	45º	4/10	¾" NPT	197/89
172ETE-2F7M	62.5	284	4,500W	208V	89W	23½/60	60/152	2⅛/5	45º	4/10	¾" NPT	197/89
172ETE-3F7M	62.5	284	4,500W	240V	89W	23½/60	60/152	2⅛/5	45º	4/10	¾" NPT	197/89



JOB TITLE: ______________________

ADDRESS: ______________________

CONTRACTOR: ______________________

ADDRESS: ______________________

ENGINEER: ______________________

DATE SUBMITTED: ______________________

PRODUCT REQUIRED: ______________________

MODEL NO.	SIZE	QUANTITY

DATE REQUIRED: ______________________

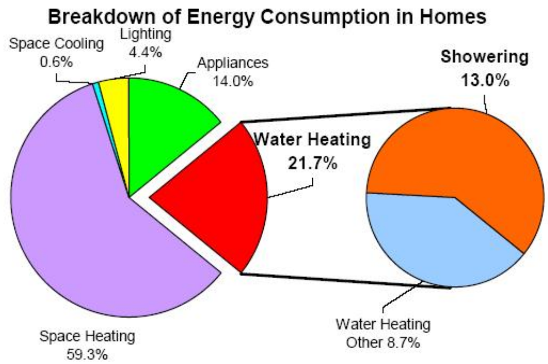
Giant Factories Inc.

40 Avenue Lesage, Montreal-East, Quebec, Canada H1B 5H3
Telephone: (514) 645-8893 Fax: (514) 640-0969 www.giantinc.com

Rev. 1: 01/07/2007

POWER-PIPE By: RenewABILITY ENERGY

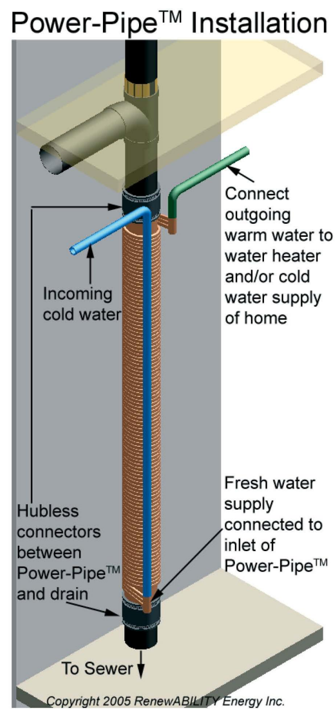
Backgrounder: For Homes



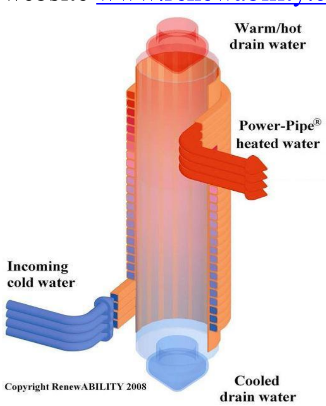
Water heating is the second most costly energy demand in homes, accounting for 20-30% of energy consumption. Furthermore, showering is typically the highest hot water load and about 90% of the energy used to heat water in a home is wasted out to the sewer.

Drain Water Heat Recovery (DWHR) units such as the Power-Pipe® recapture some or most of this valuable energy and use it to heat cold fresh water. The result is savings on your energy costs.

What does the Power-Pipe® look like?
Falling Film Heat Exchangers like the Power-Pipe have copper tube wrapped very tightly around an inner copper drainpipe. Our competitions' "First Generation" units consist of a single tube wrapped on the drainpipe resulting in high pressure loss in freshwater supply thereby causing flow problems in homes. Their "Second Generation" units have 2 or more "single" tubes wrapped at a time on the drainpipe thereby making them non-counter flow heat exchangers that result in low performance. Independent testing* has proven that the patent-pending Power-Pipe design is far superior because it has multiple coils wrapped together around the inner pipe thereby achieving the highest efficiency and very low pressure loss.

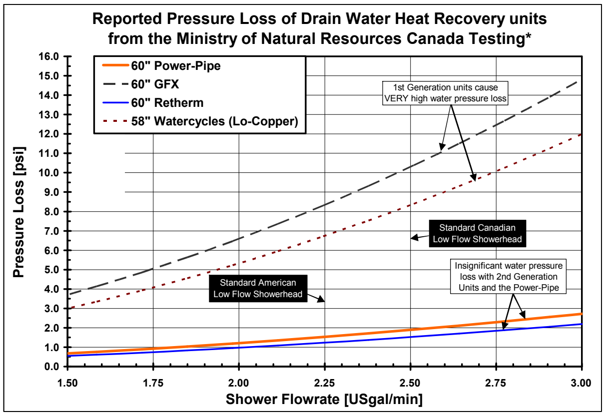


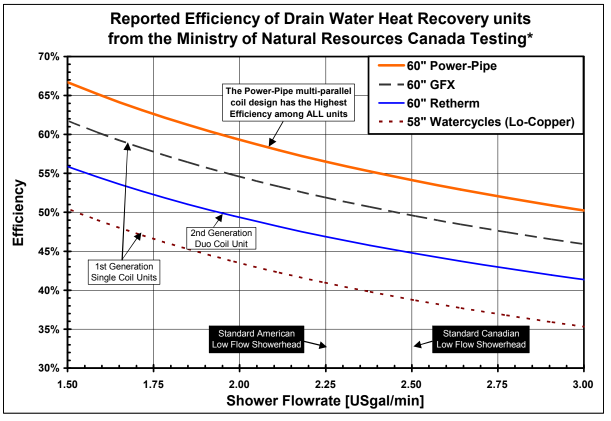
Power-Pipe® Installation is Simple:
The Power-Pipe becomes a part of your drainage stack, usually in your basement, by cutting your drainpipe and using the supplied connectors. The coils become a part of your freshwater supply line by diverting it to the Power-Pipe. For more information please download the Power-Pipe Installation Manual from our website www.renewability.com.



How Does the Power-Pipe® Work?
Fresh water from the city supply is quite cold and a lot of energy is required to heat that water to the comfortable temperature required for showering. Without the Power-Pipe you are wasting all of that valuable energy down the drain. Drain water naturally clings to the inner wall of the Power-Pipe in a very thin film that falls quickly. As you take a shower this thin film of warm drain water readily transfers its heat energy to the inner wall of the Power-Pipe. The Power-Pipe safely transfers that heat energy to the cold freshwater flowing through the outer tubes. No pumps are needed, no maintenance is required, and the Power-Pipe will have a very long service life in your home.

Should we be concerned about a Loss of Water Pressure when using the Power-Pipe®?
No. The Power-Pipe was specifically designed to cause an insignificant loss in water pressure in a typical home. Before developing the Power-Pipe, we sold a 1st Generation single coil DWHR unit but quickly stopped as customers were not able to attain sufficient flow in their homes. Measurements undertaken by the Canadian Government illustrate the huge gap in pressure loss between DWHR unit designs.





How Efficient is the Power-Pipe®?
Efficiency at a given equal flowrate is the standard for comparison between units. Heat exchanger effectiveness is used by some of our competitors and misrepresents performance.

The Power-Pipe is second to none in efficiency (according to a study* completed by the Government of Canada) primarily because it is a counter-flow heat exchanger.

It should be mentioned that efficiency is also dependent upon the length, the diameter, and the water flowrate. The shortest unit that should be considered is 30in, however we suggest that you consider installing the longest Power-Pipe that you can fit into your home (up to 6 feet in length). Large sizes are also available. A 60in (152cm) long Power-Pipe unit can bring the cold water temperature from 50°F (10°C) up to about 77°F (25°C) under equal flow conditions. If connected to only the water heater or only the cold side of the water fixtures (unequal flow conditions), the savings are less, but the temperature of the cold water is brought up to about 82°F (28°C).

How Much Does the Power-Pipe® Cost and How Much Does it Save?
The total installed cost for a Power-Pipe is normally between $600 and $1,200. With an annual "return on investment" in the range of 15-50%, the Power-Pipe is normally at least 4x more cost effective than solar water heating. In a typical home the Power-Pipe will save 25%-40% on water heating. This primarily depends upon the efficiency of the unit, how it is installed (refer to our Installation Manual), and how hot water is used.

There are many other benefits from owning a Power-Pipe®, including:
● you will likely never run out of hot water because your hot water capacity will be much greater (it takes less energy and time to heat the water since the incoming water is preheated by the Power-Pipe).
● a Power-Pipe will reduce your family's greenhouse gas emissions by up to 1 ton/year
● the Power-Pipe works great in combination with "instantaneous" (on demand) water heaters which sometimes have difficulty in meeting demand either in the winter or when two showers are running
● the Power-Pipe reduces "sweating" on your cold water pipes in your home
● the Power-Pipe looks great!

RenewABILITY Energy: We design, manufacture and sell the patent pending Power-Pipe® Drain Water Heat Recovery system and are the . recognized leader in this field. There are Power-Pipes installed in many homes and apartment buildings in Canada, the U.S., Europe and Asia. The company was founded in July 2000.

*Reference: "Drain Water Heat Recovery Characterzation and Modeling", Charles Zaloum et al, Sustainable Buildings and Communities Group, Natural Resources Canada, Ottawa, July 19, 2007

Appendix J - House Drawings

LEGEND

ELECTRICITY

- ELECTRIC PANEL
- 120v. PLUG
- SWITCH CONTROLED PLUG
- WEATHER PROTECTED PLUG
- PLUG WEATHER PROTECTED AND W/ GROUND FAULT INTERRUPTOR
- PLUG W/ GROUND FAULT INTERRUPTOR
- 120v./240v. PLUG
- SINGLE POLE SWITCH
- 3-WAY SWITCH
- 4-WAY SWITCH
- DIMMER SWITCH
- LIGHT W/ FIXTURE
- WALL HUNG LIGHT
- EXTERIOR WALL HUNG LIGHT
- PULL CHAIN LIGHT
- RECESSED LIGHT
- CEILING LIGHT W/ PADDLE FAN
- LIGHT (BOX ONLY)
- WALL HUNG LIGHT (BOX ONLY)
- 300 W ELECTRICAL BASEBOARD
- 3'-0" HOT WATER BASEBOARD
- HRV/R HEAT RECOVERY VENTILATION SERVICING 1st STOREY
- HRV/E HEAT RECOVERY VENTILATION SERVICING 2nd STOREY
- A.E. AIR EXCHANGER
- PHONE JACK
- T.V. JACK
- COMPUTER JACK
- BATHROOM FAN
- BATHROOM FAN WITH INFRA-RED LIGHT
- TIMER (HRV)
- HUMIDISTAT
- DOOR BELL
- SMOKE DETECTOR
- AC/DC SMOKE DETECTOR
- AC/DC AND PHOTOELECTRIC SMOKE DETECTOR
- CARBON MONOXIDE DETECTOR
- THERMOSTAT
- RANGE HOOD FAN (150 CFM)
- THERMOSTAT WIRE
- ELECTRICAL WIRE FOR UNLISTED APPLIANCES
- T.C. TRASH COMPACTOR

ARCHITECTURAL

- A.A. ATTIC ACCESS
- WINDOWS
- SINGLE DOOR
- PATIO DOOR
- GARDEN DOOR
- GARDEN DOOR
- HALF-WALL
- HALF-WALL & POSTS
- FULL HEIGHT WALL
- RAILING
- HANDRAIL
- BASEMENT POSTS
- SILL PLATE
- STRUCTURAL SUPPORT

PLUMBING

P.A.	PUMP ACCESS
L.T.	LAUNDRY TRAY
D.S.	DOUBLE SINK
K.S.	SINGLE SINK
W.C.	WATER CLOSET
BATH	BATH WITHOUT SHOWER
B/S	BATH & SHOWER
SHO.	SHOWER
LAV.	LAVATORY
E	CONFORM TO MEANS OF EGRESS REQUIREMENTS
Bd	BIDET
G.D.	GARBAGE DISPOSAL
D.W.	DISHWASHER
	3" MAIN STACK
	2" VENT
	1 1/2" VENT
V	VACUUM OUTLET
	EXTERIOR FAUCET

SECTION IDENTIFICATION

A= SECTION NUMBER
B= SHEET WHERE THE SECTION COMES FROM
C= SHEET WHERE THE SECTION IS FOUND

DETAIL IDENTIFICATION

A= DETAIL NUMBER
B= SHEET WHERE THE DETAIL COMES FROM
C= SHEET WHERE THE DETAIL IS FOUND

LES MAISONS Alouette HOMES

LES INDUSTRIES STE-ANNE DE LA ROCHELLE INC.
316, Principale Ouest / Ste-Anne-De-La-Rochelle, Qc / J0E 2B0
www.maisonalouette.com www.alouettehomes.com

CODE	: CANADIAN NATIONAL BUILDING CODE
CONSTRUCTION TYPE	: WOOD FRAMING
PROVINCE	: QUEBEC
CITY	: EASTMAN
HABITABLE FLOOR SURFACE	: 1517 SQ.FT.
FLOOR LIVE LOAD	: 40lbs PER SQUARE FOOT
TOTAL ROOF LIVE LOAD	: 34.7 lbs PER SQUARE FOOT
DIFFERENTIAL TEMPERATURE (DT)	: 93 °F

THIS HOME WILL BE MANUFACTURED IN ACCORDANCE WITH THE 1995 EDITION OF THE NATIONAL BUILDING CODE OF CANADA.

THE HOMEBUYER, BEING RESPONSIBLE FOR OBTAINING ALL BUILDING PERMITS, MUST VERIFY WITH THE APPROPRIATE AUTHORITIES THE VALIDITY OF THE ABOVE, AND IF ANY ADDITIONAL MUNICIPAL REQUIREMENTS MUST BE MET, THOSE REQUIREMENTS MUST BE COMMUNICATED TO ALOUETTE HOMES PRIOR TO PRODUCTION OF THE HOME.

R.B.Q. LICENSE No.: 2843-8877-09
G.S.T. No.: 142 095 645 RT
Q.S.T. No.: 1020571001 TQ 0001

APCHQ Association Provinciale des Constructeurs d'Habitation du Québec inc.

PLANS DE GARANTIE ACQ

Canadian Standards Association

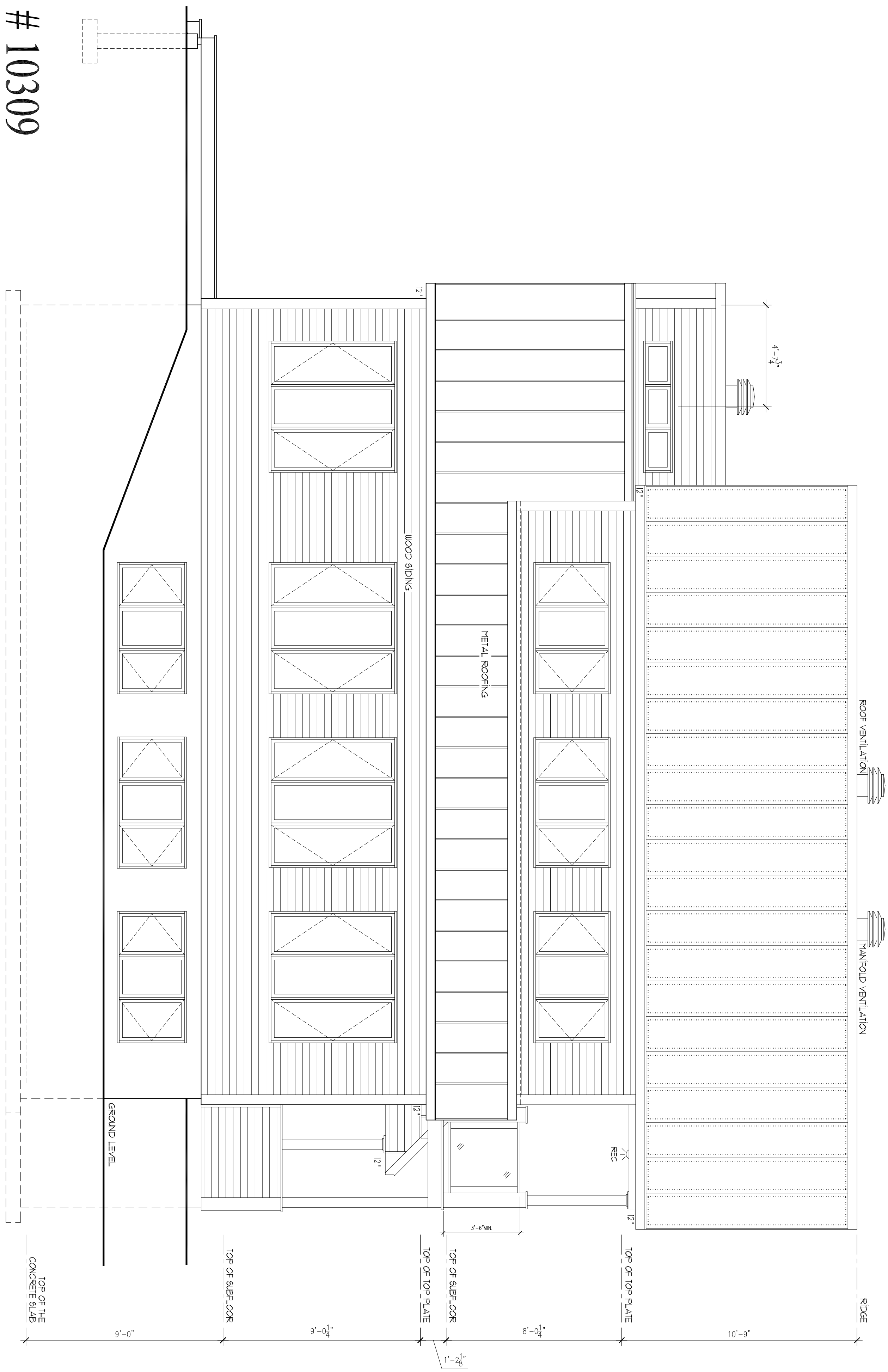
PFS Corporation

ASSOCIATION OF HOME BUILDERS NATIONAL OF THE UNITED STATES BUILDING SYSTEMS COUNCILS

10309

FILE NAME:	NZEHH INITIATIVE
MODEL:	ECOTERRA
DIM.:	36'-0" x 27'-0"
DATE:	REV.: 07/06/14 NO. OF SHEETS: 13

10309



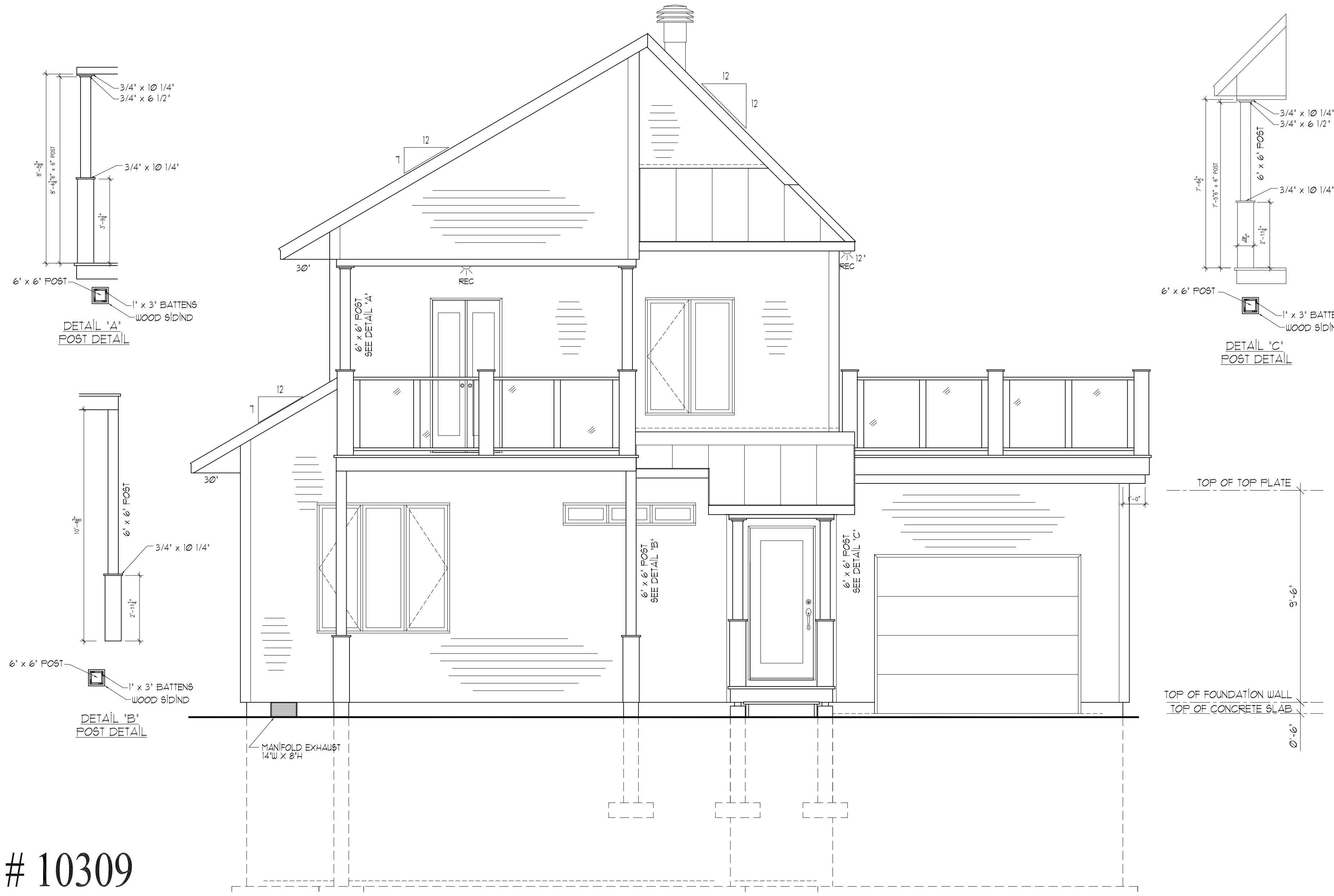
1 / 13 Of / De	Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE	Representative / Representant: ALOUETTE		
	Title / Titre: FRONT ELEVATION	Scale / Echelle: 1/4" = 1'-0"	Project / Projet: 07-0015	

Rev:	Date:	Description:	D.	V.
	06/11/15	PRELIMINARY PLAN	A.L.	
	06/12/19	SIGNED PLAN	A.L.	
	07/06/14	2e SIGNED PLAN	A.L.	

LES MAISONS Alouette HOMES

TEL: (450) 539-3100

10309

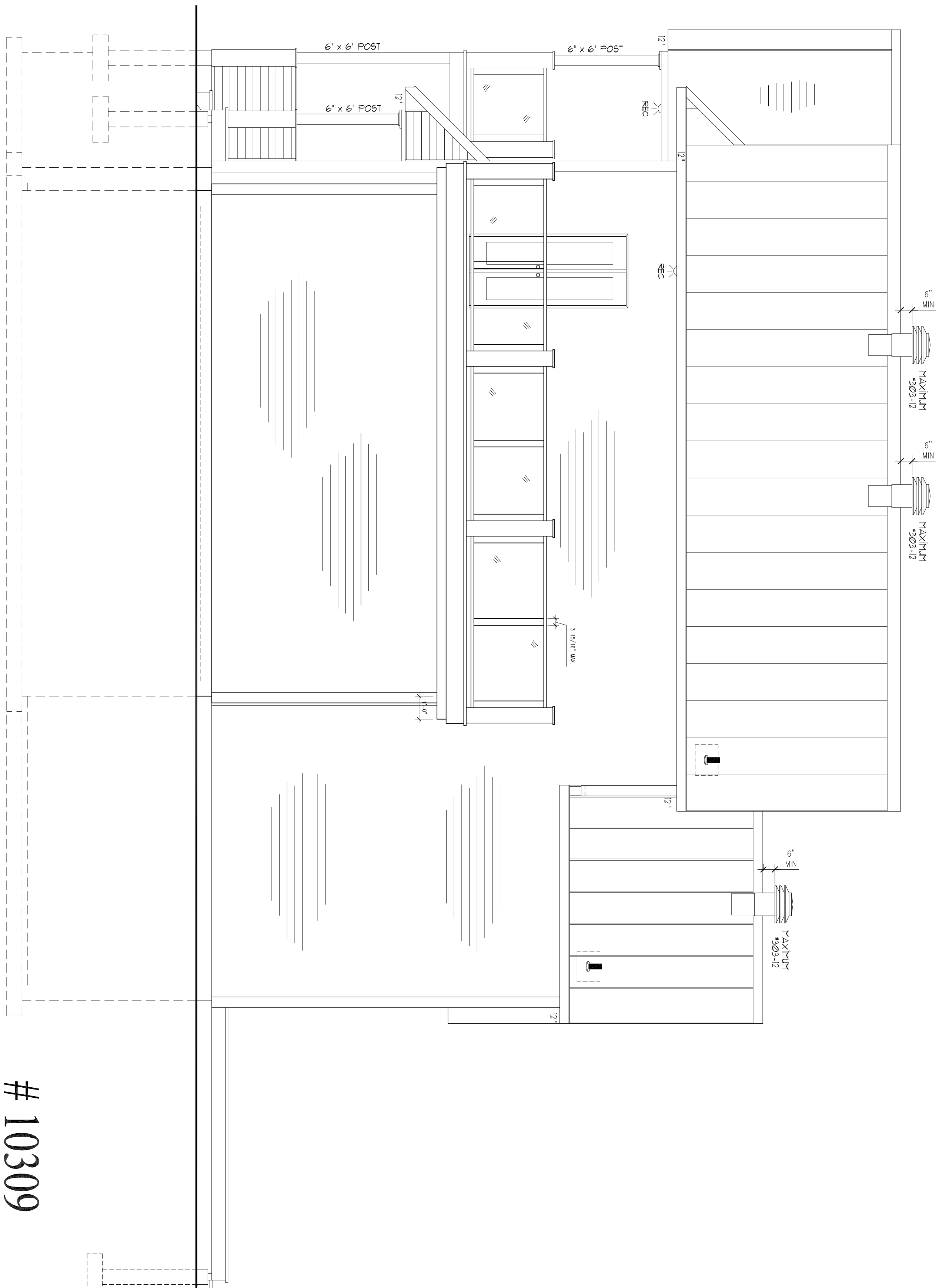


Customer(s) / Client(s):	Representative / Representant:	
ECOTERRA ALOUETTE HOUSE	ALOUETTE	
Title / Titre:	Scale / Echelle:	Project / Projet:
RIGHT ELEVATION	1/4" = 1'-0"	07-0015

Rev:	Date:	Description:	D.	V.
	06/11/15	PRELIMINARY PLAN	A.L.	
	06/12/13	SIGNED PLAN	A.L.	
	07/06/14	2e SIGNED PLAN	AL	

LES MAISONS Alouette HOMES
TEL: (450) 539-3100

2 Of / De: 13



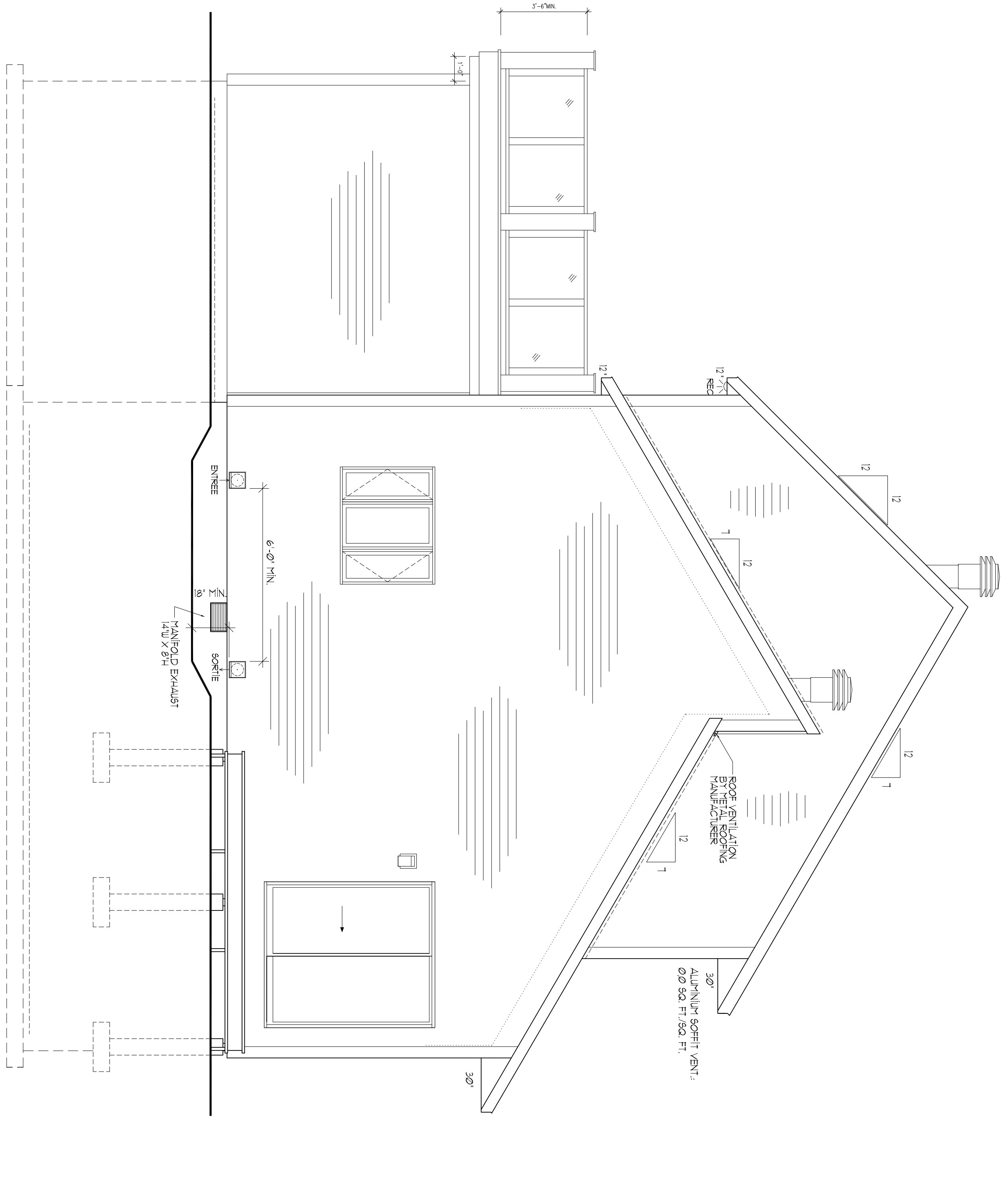
Sheet	Customer(s) / Client(s):	Representative / Representant:	
3 of / de 13	ECOTERRA ALOUETTE HOUSE	ALOUETTE	
	Title / Titre:	Scale / Echelle:	Project / Projet:
	REAR ELEVATION	1/4" = 1'-0"	07-0015

Rev:	Date:	Description:	D.	V.
	06/11/15	PRELIMINARY PLAN	A.L.	
	06/12/13	SIGNED PLAN	A.L.	
	07/06/14	2e SIGNED PLAN	AL	

LES MAISONS Alouette HOMES

TEL: (450) 539-3100

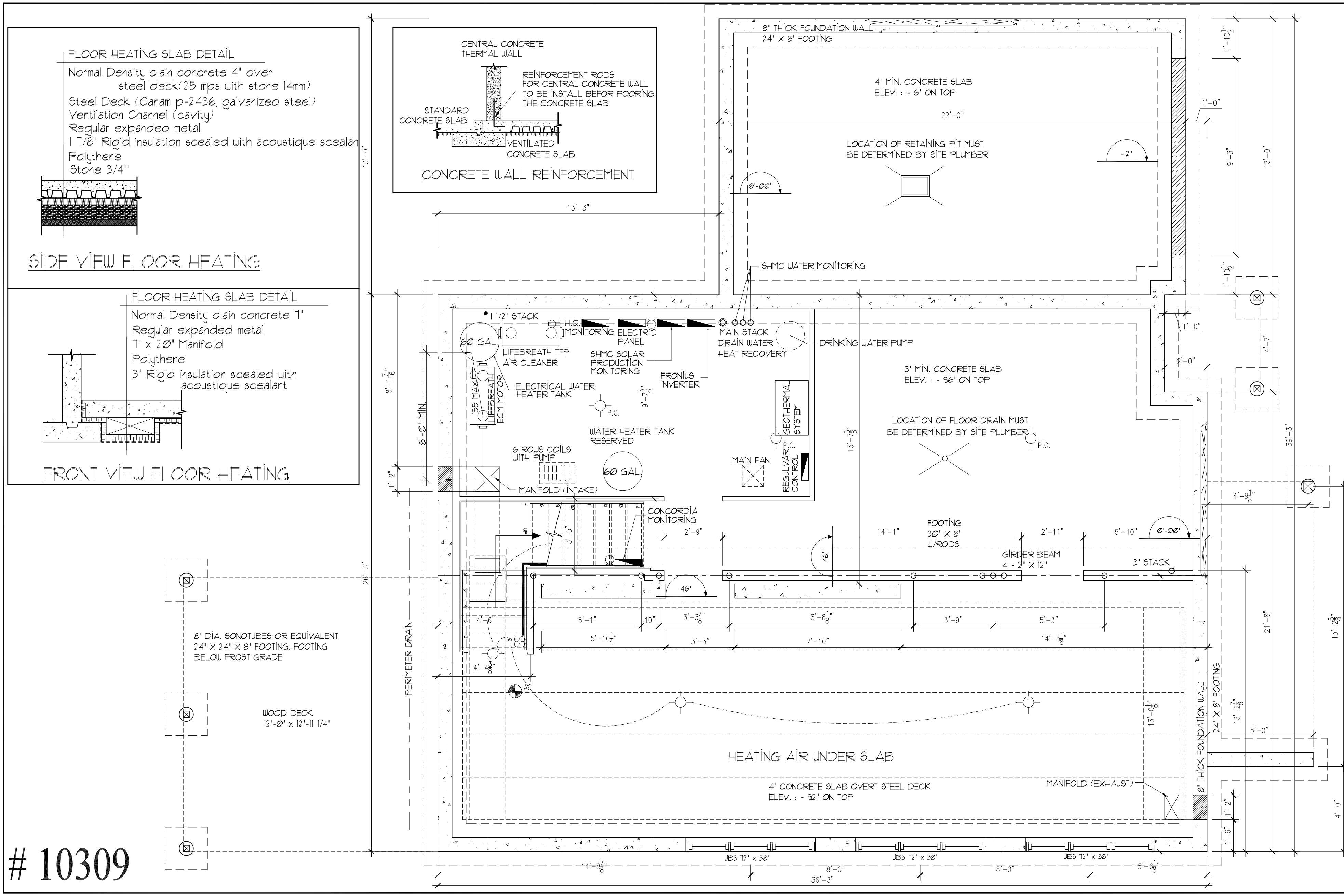
10309



4 of 13	Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE	Representative / Representant: ALOUETTE	
	Title / Titre: LEFT ELEVATION	Scale / Echelle: 1/4" = 1'-0"	Project / Projet: 07-0015

Rev:	Date:	Description:	D.	V.
	07/09/19	CHANGE HEIGHT KITCHEN WINDOW	J.B.	
	06/12/19	SIGNED PLAN	A.L.	
	07/06/14	2e SIGNED PLAN	AL	
	07/06/19	ADD GRILL EXIT FOR MANIFOLD	AL	

LES MAISONS Alouette HOMES
TEL: (450) 539-3100



10309

Customer(s) / Client(s):	Representative / Représentant:	Rev:	Date:	Description:	D.	V.
ECOTERRA ALOUETTE HOUSE	ALOUETTE		07/07/05	ADD DETAIL REINFORCEMENT CONCRETE WALL	N.L.	
Title / Titre: FOUNDATION	Scale / Echelle: 1/4" = 1'-0"		07/06/13	2nd SIGNED PLAN	A.L.	N.L.
	Project / Projet: 07-0015		07/06/13	ADD OPENING/CHANGE CONCRETE SLAB ELEV.	A.L.	
			07/06/20	HARDWOOD STAIR	A.L.	

LES MAISONS Alouette HOMES

TEL: (450) 539-3100

5

13 Of / De:

10309

LINTELS DESCRIPTION

LN: NON-BEARING LINTEL
L1: 1-2" X 12"
L3: 2-2" X 12"
L5: 1 - 2" X 10"
L6: 2 - 2" X 10"
L7: 3 - 2" X 10"
L8: 2 - 2" X 8"

L10: 1- 1 3/4" X 9 1/2" LVL
L11: 1- 1 3/4" X 11 7/8" LVL
L12: 1- 1 3/4" X 14" LVL
L13: 1- 1 3/4" X 16" LVL

L20: 2- 1 3/4" X 9 1/2" LVL
L21: 2- 1 3/4" X 11 7/8" LVL
L22: 2- 1 3/4" X 14" LVL
L23: 2- 1 3/4" X 16" LVL

L30: 3- 1 3/4" X 9 1/2" LVL
L31: 3- 1 3/4" X 11 7/8" LVL
L32: 3- 1 3/4" X 14" LVL
L33: 3- 1 3/4" X 16" LVL

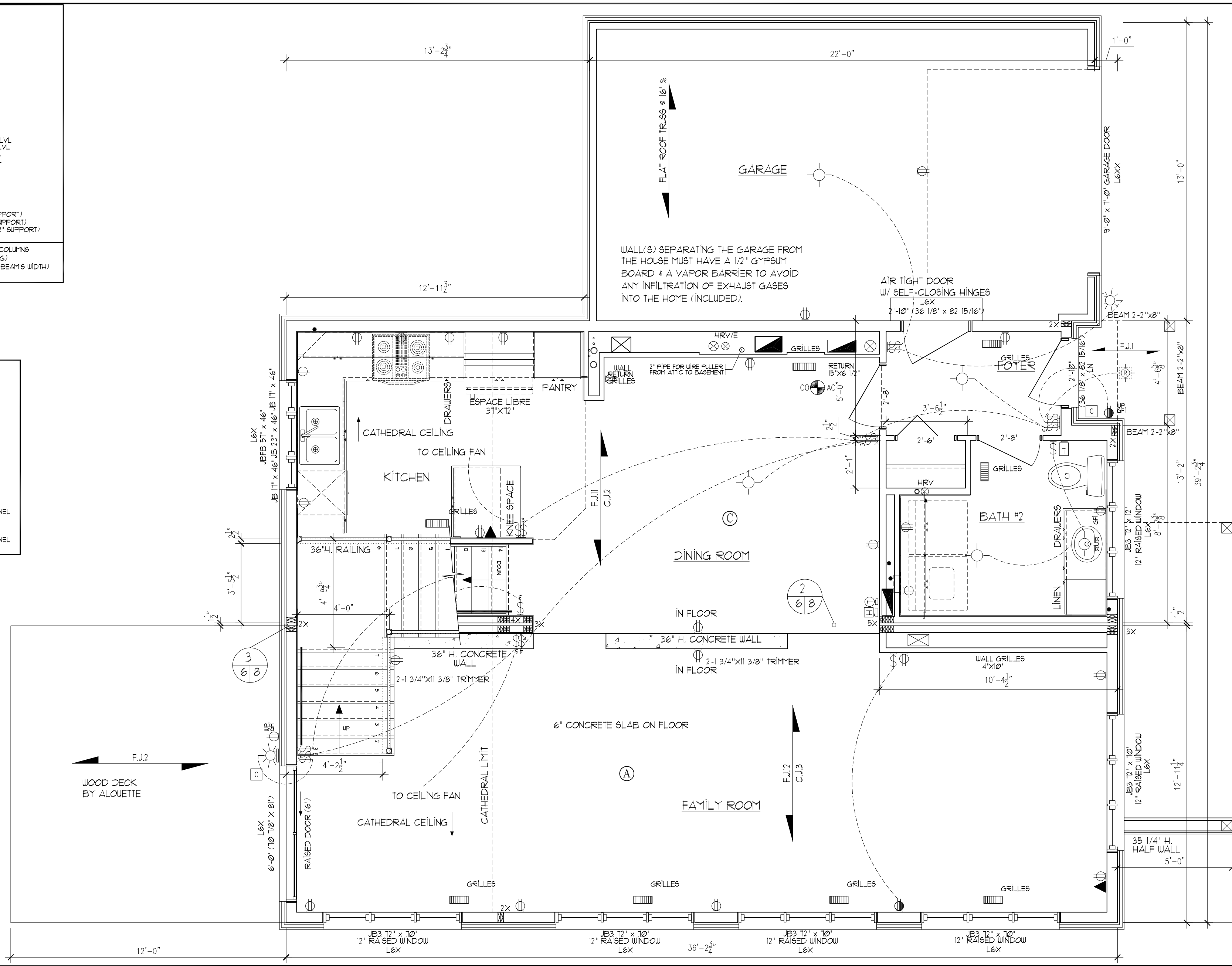
LINTELS IN EXTERIOR WALL MUST BE INSULATED

L_: LINTEL BY TRUSS MANUFACTURER
A: LINTEL UNDER ROOF TRUSS OR FLOOR JOIST
B: LINTEL CAST IN ROOF TRUSS OR FLOOR JOIST
X: 1 JACK STUD AT BOTH ENDS OF LINTEL (OR 1 1/2" SUPPORT)
XX: 2 JACK STUDS AT BOTH ENDS OF LINTEL (OR 3" SUPPORT)
XXX: 3 JACK STUDS AT BOTH ENDS OF LINTEL (OR 4 1/2" SUPPORT)

BLOCKING MUST BE PROVIDED UNDERNEATH BUILT-UP COLUMNS WHEN IT IS NEEDED (IN FLOOR OR/AND IN FALSE CEILING) (WHEN BUILT-UP COLUMN'S WIDTH EXCEEDS PERIMETER BEAM'S WIDTH) (WIDTH=3.5"AND MORE)

JOISTS DESCRIPTION

F.J.1: FLOOR JOISTS 2" X 8" @ 16" O.C. SPF #2 MIN.
F.J.2: FLOOR JOISTS 2" X 8" @ 12" O.C. SPF #2 MIN.
F.J.3: FLOOR JOITS 2" X 8" @ 9.25" O.C. SPF #2 MIN.
F.J.4: FLOOR JOISTS 2" X 10" @ 16" O.C. SPF #2 MIN.
F.J.5: FLOOR JOISTS 2" X 10" @ 12" O.C. SPF #2 MIN.
F.J.6: OPEN JOISTS 9 3/8" @ 19.2" O.C.
F.J.7: OPEN JOISTS 9 3/8" @ 16" O.C.
F.J.8: OPEN JOISTS 9 3/8" @ 12" O.C.
F.J.9: FLOOR TRUSSES 9 3/8" @ 19.2" O.C.
F.J.10: FLOOR TRUSSES 9 3/8" @ 16" O.C.
F.J.11: FLOOR TRUSSES 11 3/8"x 3 1/2" @ 19.2" O.C.
F.J.12: FLOOR TRUSSES 11 3/8"x 3 1/2" @ 16" O.C.
C.J.1: CEILING JOISTS 2" X 4" @ 19.2" O.C. SPF #2 MIN
C.J.2: CEILING JOISTS 2" X 4" @ 19.2" O.C. SPF #2 MIN WITH Ø.36 GALV. STEEL 21 Ga. "U" SHAPE CHANNEL ON ONE SIDE
C.J.3: CEILING JOISTS 2" X 4" @ 16" O.C. SPF #2 MIN WITH Ø.36 GALV. STEEL 21 Ga. "U" SHAPE CHANNEL ON ONE SIDE



Rev:	Date:	Description:	D.	V.
	07/06/21	ADD FLOOR COVERING	A.L.	
	07/09/13	CHANGE HEIGHT KITCHEN WINDOW	J.B.	
	07-06-14	2e SIGNED PLAN	A.L.	
	07/06/20	HARDWOOD BASEMENT STAIR	A.L.	

Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE

Title / Titre: GROUND FLOOR PLAN

Representative / Représentant: ALOUETTE

Scale / Échelle: 1/4" = 1'-0"

Project / Projet: 07-0015

LES MAISONS Alouette HOMES

TEL: (450) 539-3100

6 Of / De 13

10309

LINTELS DESCRIPTION

LN: NON-BEARING LINTEL
L1: 1-2" X 12"
L3: 2-2" X 12"
L5: 1 - 2" X 10"
L6: 2 - 2" X 10"
L7: 3 - 2" X 10"
L8: 2 - 2" X 8"

L10: 1- 1 3/4" X 9 1/2" LVL
L11: 1- 1 3/4" X 11 7/8" LVL
L12: 1- 1 3/4" X 14" LVL
L13: 1- 1 3/4" X 16" LVL

L20: 2- 1 3/4" X 9 1/2" LVL
L21: 2- 1 3/4" X 11 7/8" LVL
L22: 2- 1 3/4" X 14" LVL
L23: 2- 1 3/4" X 16" LVL

L30: 3- 1 3/4" X 9 1/2" LVL
L31: 3- 1 3/4" X 11 7/8" LVL
L32: 3- 1 3/4" X 14" LVL
L33: 3- 1 3/4" X 16" LVL

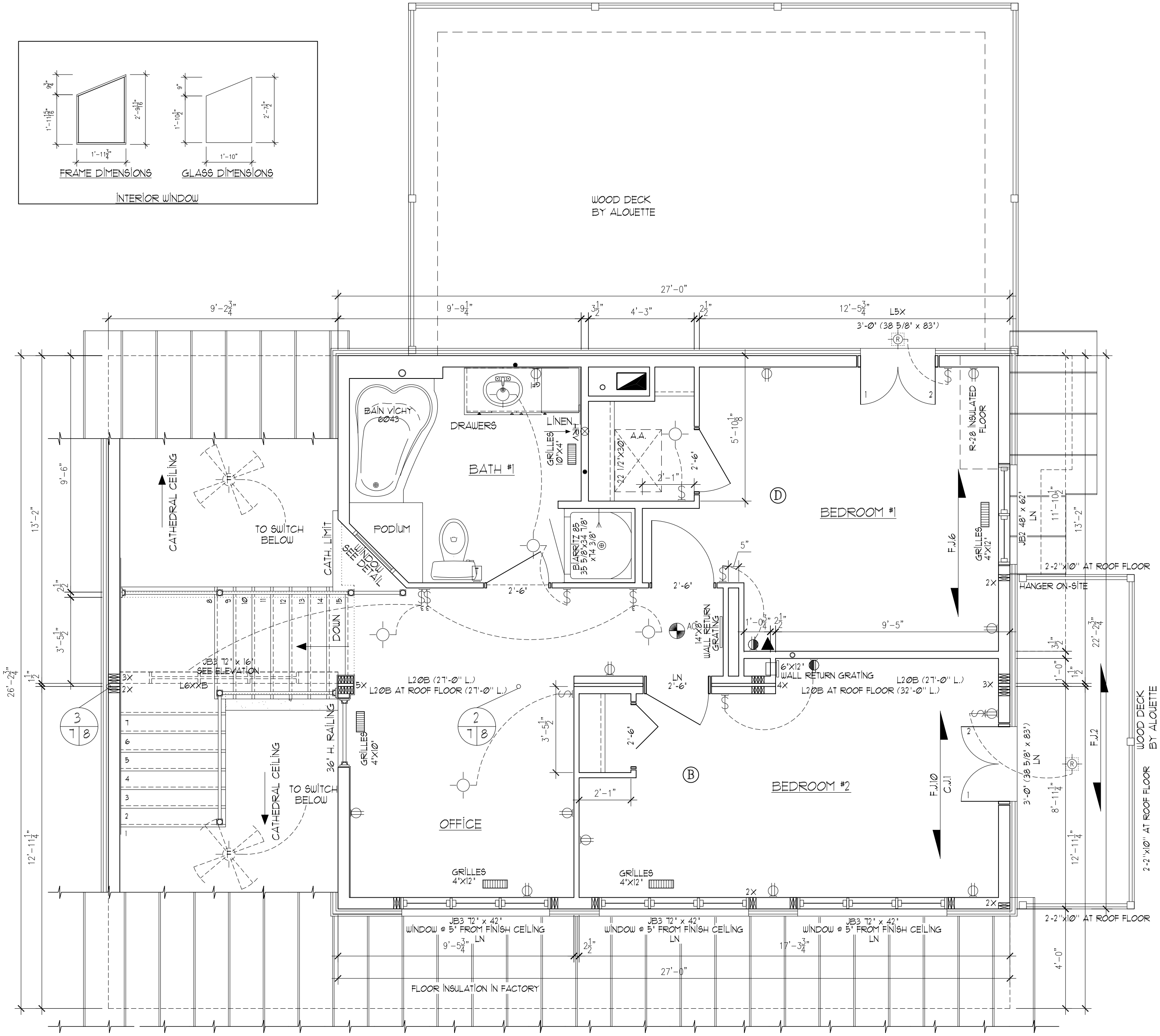
LINTELS IN EXTERIOR WALL MUST BE INSULATED

L_: LINTEL BY TRUSS MANUFACTURER
A: LINTEL UNDER ROOF TRUSS OR FLOOR JOIST
B: LINTEL CAST IN ROOF TRUSS OR FLOOR JOIST
X: 1 JACK STUD AT BOTH ENDS OF LINTEL (OR 1 1/2" SUPPORT)
XX: 2 JACK STUDS AT BOTH ENDS OF LINTEL (OR 3" SUPPORT)
XXX: 3 JACK STUDS AT BOTH ENDS OF LINTEL (OR 4 1/2" SUPPORT)

BLOCKING MUST BE PROVIDED UNDERNEATH BUILT-UP COLUMNS WHEN IT IS NEEDED (IN FLOOR OR/AND IN FALSE CEILING) (WHEN BUILT-UP COLUMN'S WIDTH EXCEEDS PERIMETER BEAM'S WIDTH) (WIDTH=3.5"AND MORE)

JOISTS DESCRIPTION

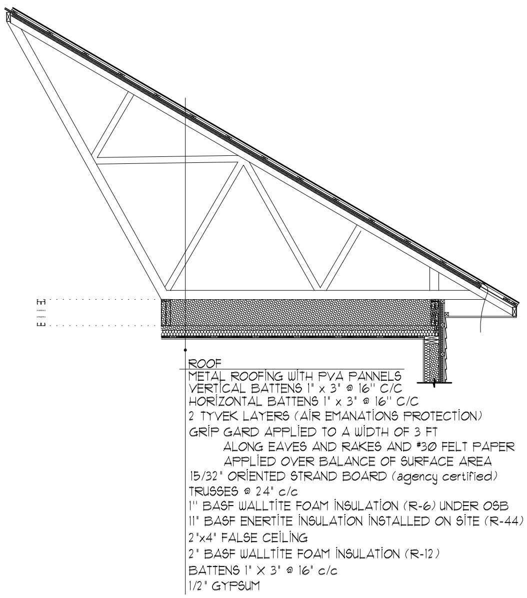
F.J.1: FLOOR JOISTS 2" X 8" @ 16" O.C. SPF #2 MIN.
F.J.2: FLOOR JOISTS 2" X 8" @ 12" O.C. SPF #2 MIN.
F.J.3: FLOOR JOITS 2" X 8" @ 9.25" O.C. SPF #2 MIN.
F.J.4: FLOOR JOISTS 2" X 10" @ 16" O.C. SPF #2 MIN.
F.J.5: FLOOR JOISTS 2" X 10" @ 12" O.C. SPF #2 MIN.
F.J.6: OPEN JOISTS 9 3/8" @ 19.2" O.C.
F.J.7: OPEN JOISTS 9 3/8" @ 16" O.C.
F.J.8: OPEN JOISTS 9 3/8" @ 12" O.C.
F.J.9: FLOOR TRUSSES 9 3/8" @ 19.2" O.C.
F.J.10: FLOOR TRUSSES 9 3/8" @ 16" O.C.
F.J.11: FLOOR TRUSSES 11 3/8"x 3 1/2" @ 19.2" O.C.
F.J.12: FLOOR TRUSSES 11 3/8"x 3 1/2" @ 16" O.C.
C.J.1: CEILING JOISTS 2" X 4" @ 19.2" O.C. SPF #2 MIN
C.J.2: CEILING JOISTS 2" X 4" @ 19.2" O.C. SPF #2 MIN WITH 0.36 GALV. STEEL 21 Ga. "U" SHAPE CHANNEL ON ONE SIDE
C.J.3: CEILING JOISTS 2" X 4" @ 16" O.C. SPF #2 MIN WITH 0.36 GALV. STEEL 21 Ga. "U" SHAPE CHANNEL ON ONE SIDE



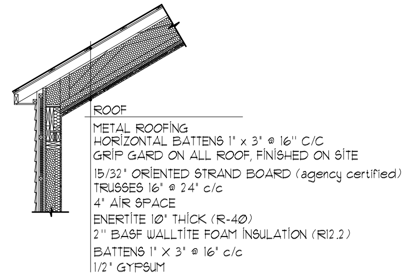
Customer(s) / Client(s):	Representative / Représentant:		Rev:	Date:	Description:	D.	V.
ECOTERRA ALOUETTE HOUSE	ALOUETTE			07/06/21	ADD FLOOR COVERING	A.L.	
Title / Titre:	Scale / Echelle:	Project / Projet:		07/07/10	ALIGN GARAGE BALCONY WITH 1ST FLOOR	N.L.	
1st FLOOR PLAN	1/4" = 1'-0"	07-0015		07/06/14	2e SIGNED PLAN	A.L.	
				07/06/20	ADD WINDOW DETAIL	A.L.	

LES MAISONS Alouette HOMES
TEL: (450) 539-3100

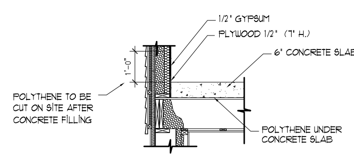
13 Of / De:



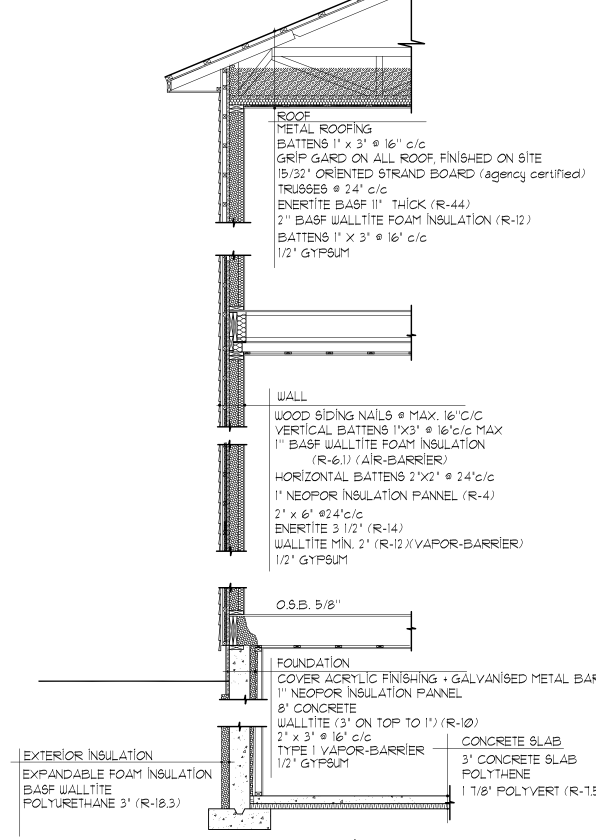
ROOF SECTION (UNDER PVA)



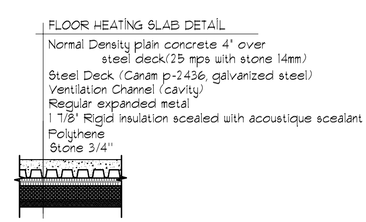
CATHEDRAL DETAIL



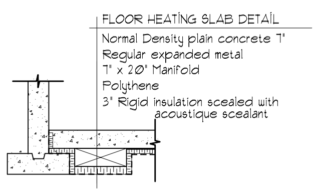
FIRST FLOOR CONCRETE SLAB DETAIL
(FAMILY ROOM)



WALL SECTION



SIDE VIEW FLOOR HEATING



FRONT VIEW FLOOR HEATING

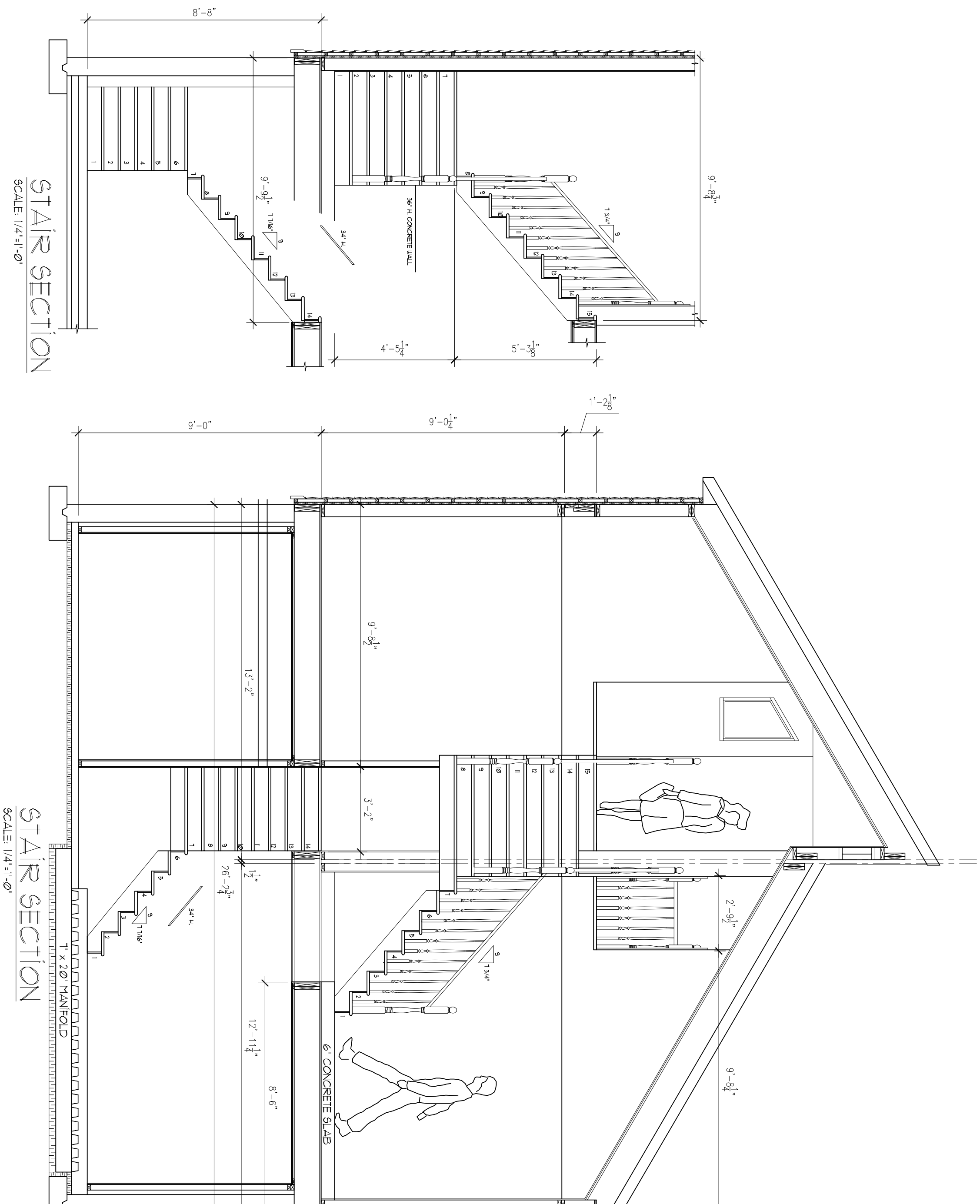
10309

Rev:	Date:	Description:	D.	V.
8-A-1	07/08/28	CHANGE FURRING ON EXT. WALLS	N.L.	
	07/08/13	1" NEOPOR + REMOVE UNIFIX ON CONC. WALL	N.L.	
	2007/06/14	2e SIGNED PLAN	AL	
	2007/07/12	SPECIFIED STYROFORE INSULATION PANNEL	N.L.	

Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE
Title / Titre: WALL SECTION & DETAILS
Representative / Representant: ALOUETTE
Scale / Echelle: NO SCALE
Project / Projet: 07-0015

LES MAISONS Alouette HOMES
TEL: (450) 539-3100

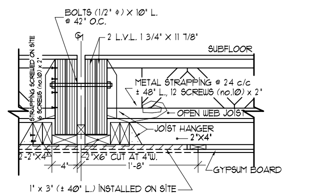
10309



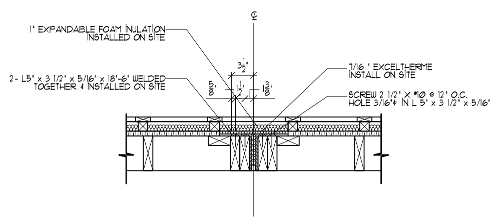
9 Of / De: 13	Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE	Representative / Representant: ALOUETTE
	Title / Titre: STAIR SECTIONS	Scale / Echelle: 1/4" = 1'-0" — Project / Projet: 07-0015

Rev:	Date:	Description:	D.	V.
	07/07/12	ADJUST STAIR SECTION	A.L.	
	06/12/13	SIGNED PLAN	A.L.	
	07/06/14	2e SIGNED PLAN	AL	
	07/06/20	ADJUST RISER HEIGHT	A.L.	

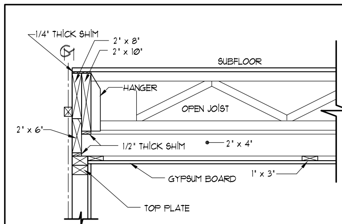
LES MAISONS Alouette HOMES
TEL: (450) 539-3100



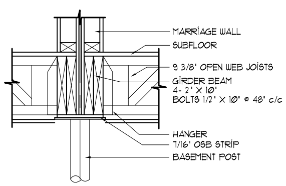
2 | 6,7 8 PCE21-SECOND STOREY BEAM
DETAIL 7658



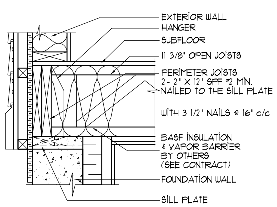
3 | 6,7 8 WALLS JONCTION FOR 2 STOREY HOUSE



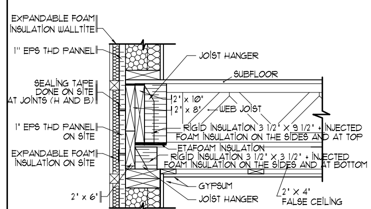
A | B C PCE1-SECOND STOREY BEAM
DETAIL 7651



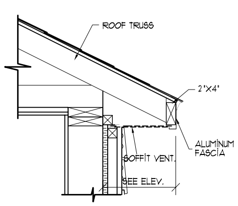
4 | 8 8 PC23-4- 2" X 10" GIRDER BEAM
DETAIL 7615



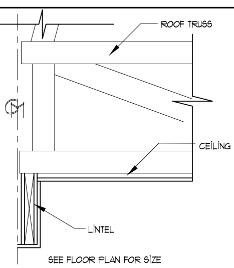
5 | 8 8 S-P03 PERIMETER BEAM



6 | 8 8 S-PE01-2nd STOREY PERIMETER
EQUILIBRIUM HOUSE



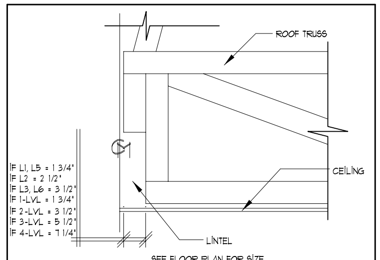
7 | 8 8 S-F03-FASCIA 2" X 4"
DETAIL 7813



SEE FLOOR PLAN FOR SIZE

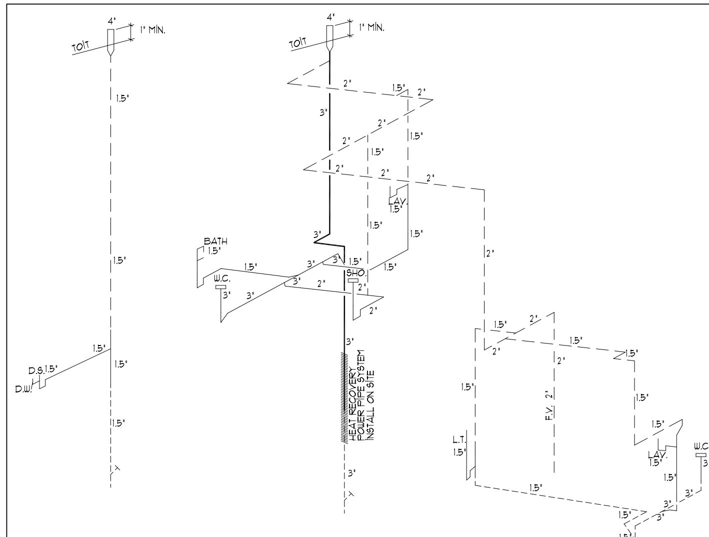
8 | 8 8 LINTEL TYPE A
DETAIL 7201

IF L1, L5 = 1 3/4"
IF L2 = 2 1/2"
IF L3, L6 = 3 1/2"
IF 1-LVL = 1 3/4"
IF 2-LVL = 3 1/2"
IF 3-LVL = 5 1/2"
IF 4-LVL = 7 1/4"



SEE FLOOR PLAN FOR SIZE

9 | 8 8 LINTEL TYPE B
DETAIL 7202



THE PLUMBING SYSTEM INSTALLED IN FACTORY IS TESTED AS REQUIRED BY CODE. HOWEVER, THE COMPLETE PLUMBING SYSTEM MUST BE TESTED BY "ON SITE" PLUMBER & APPROVED BY YOUR LOCAL INSPECTOR BEFORE ANY FINISHING WORK.

10309

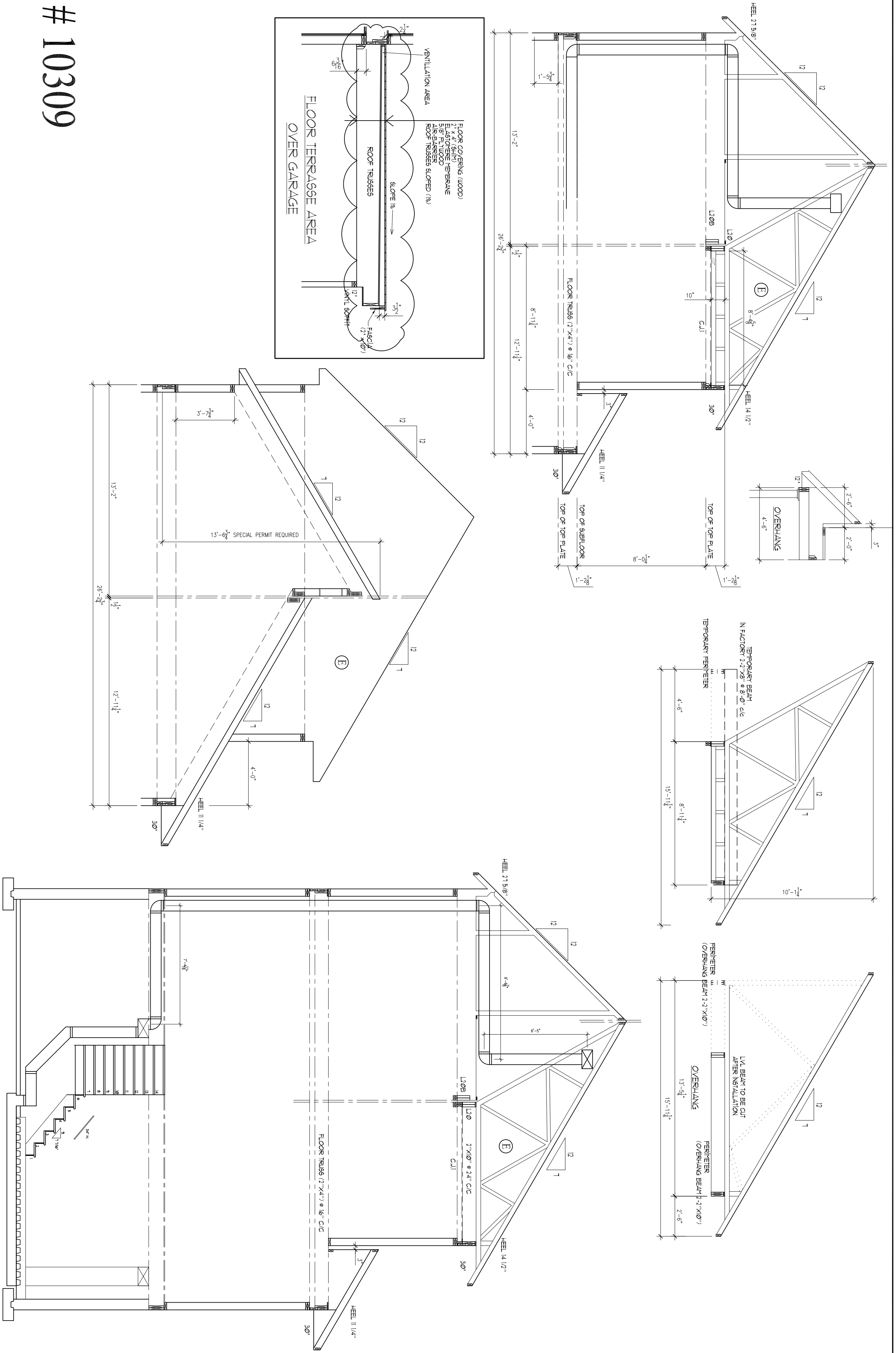
Rev:	Date:	Description:	D.	V.
	06/11/15	PRELIMINARY PLAN	A.L.	
	06/12/19	SIGNED PLAN	A.L.	
	07/06/14	2e SIGNED PLAN	NL	

LES MAISONS Alouette HOMES
TEL: (450) 539-3100

Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE
Title / Titre: WALL SECTION & DETAILS
Representative / Representant: ALOUETTE
Scale / Echelle: NO SCALE
Project / Projet: 07-0015

10 / 13 Of / De:

10309

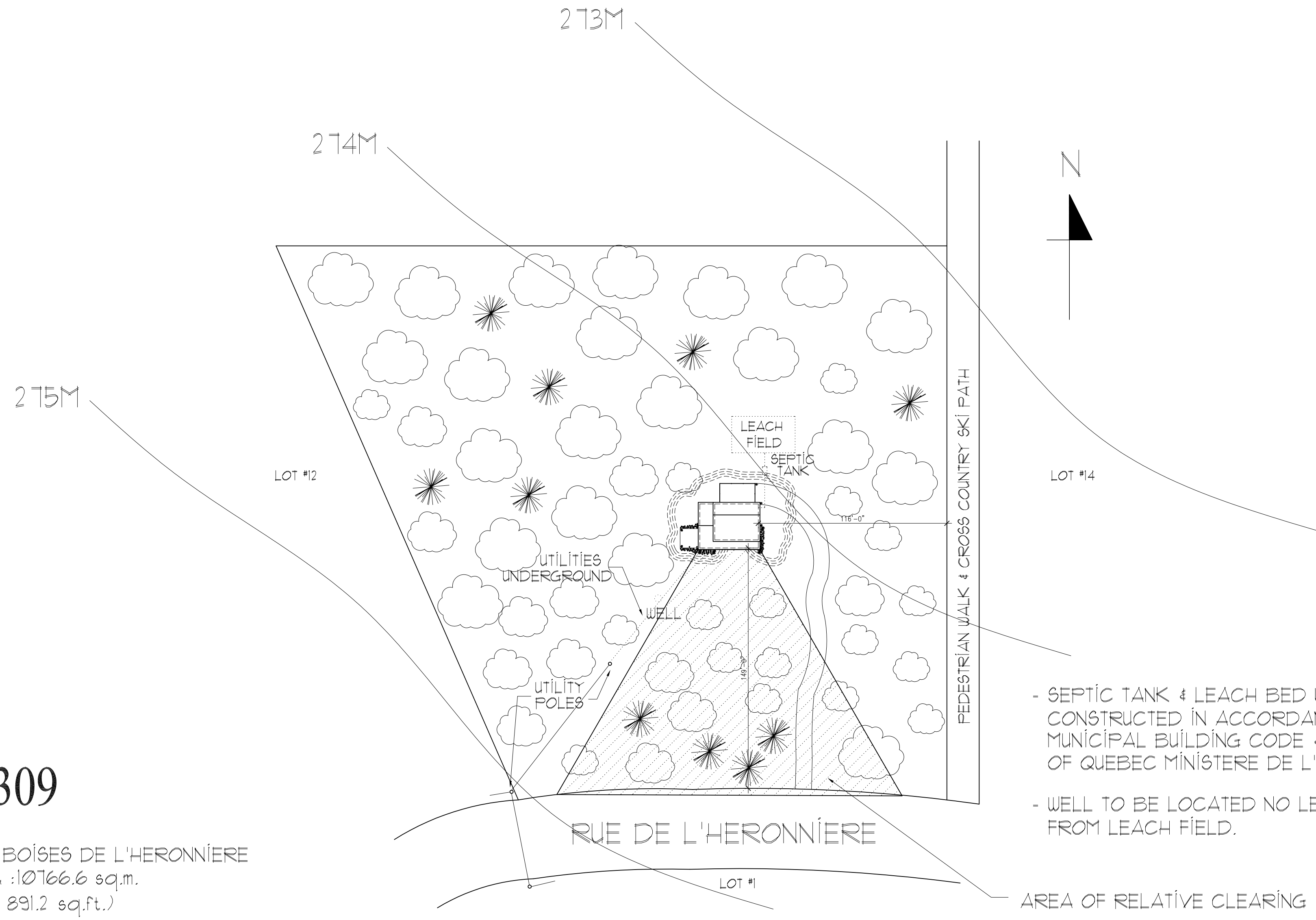


Customer(s) / Client(s):	Representative / Representant:		Rev:	Date:	Description:	D.	V.	LES MAISONS Alouette HOMES
ECOTERRA ALOUETTE HOUSE	ALOUETTE			06/11/15	PRELIMINARY PLAN	A.L.		
Title / Titre:	Scale / Echelle:	Project / Projet:		06/12/13	SIGNED PLAN	A.L.		
TRUSSES SECTION & DETAILS	1/4" = 1'-0"	07-0015		07/06/14	2e SIGNED PLAN	A.L.		
				07/06/20	ADJUST RISER HEIGHT	A.L.		TEL: (450) 539-3100

11 — 13 Of / De

10309

LOT # 13 : BOISES DE L'HERONNIERE
AREA :10766.6 sq.m.
(115 891.2 sq.ft.)
CADASTRAL : #38000583
SCALE: 0 50'



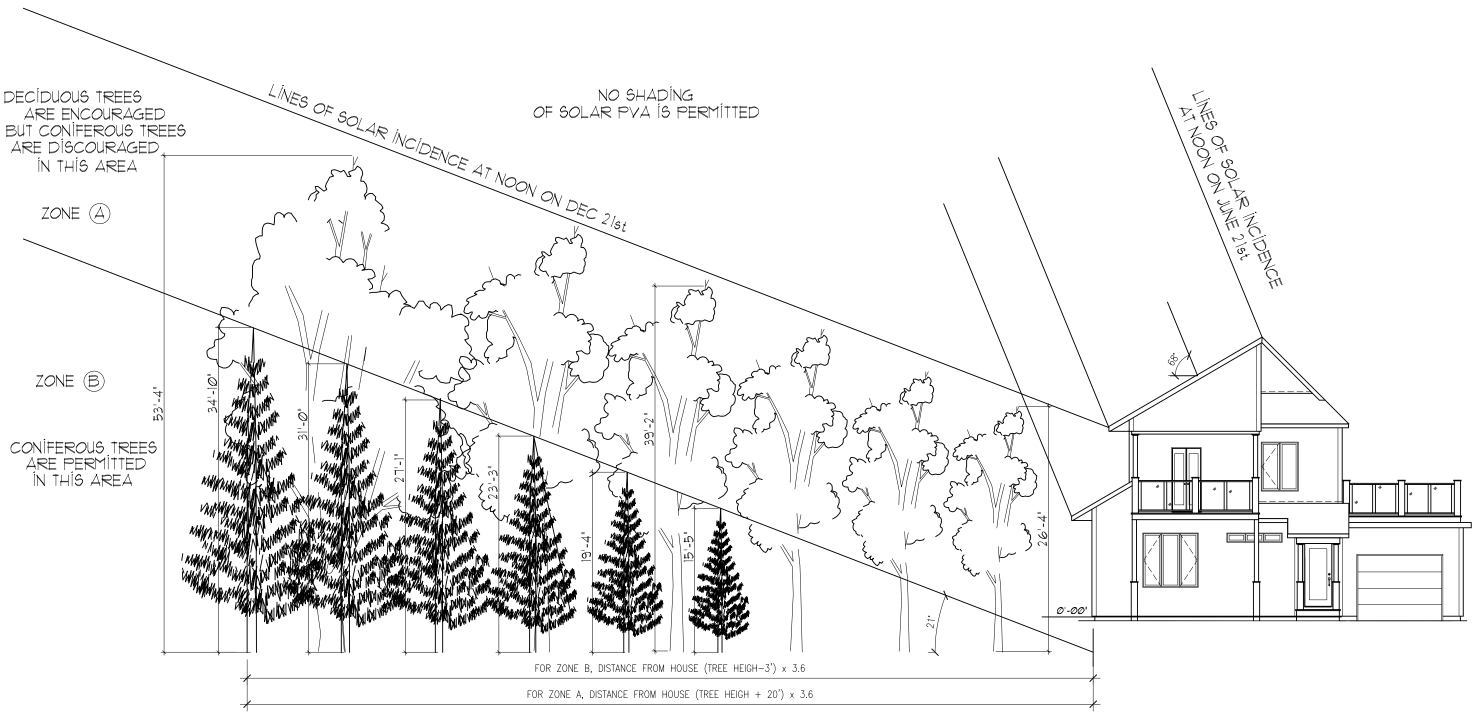
- SEPTIC TANK & LEACH BED WILL BE CONSTRUCTED IN ACCORDANCE WITH MUNICIPAL BUILDING CODE & REGULATIONS OF QUEBEC MINISTERE DE L'ENVIRONNEMENT.
- WELL TO BE LOCATED NO LESS THAN 100' FROM LEACH FIELD.

Rev:	Date:	Description:	D.	V.
	06/12/19	SIGNED PLAN	A.L.	
	07/01/10	IMPLANTATION	A.L.	

Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE
Title / Titre: IMPLANTATION
Representative / Representant: ALOUETTE
Scale / Echelle: 3/16" = 1'-0"
Project / Projet: 07-0015

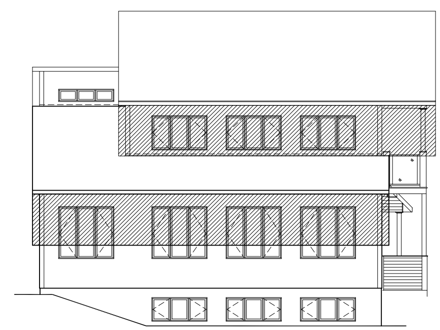
LES MAISONS Alouette HOMES
TEL: (450) 539-3100

12 Of / De 13



SOLAR ANGLE OF INCIDENCE

AT NOON ON DEC 21st & ON JUNE 21st



SUMMER SHADOW CAST

WINTER SHADOW CAST

10309

Rev:	Date:	Description:	D.	V.
	06/12/19	SIGNED PLAN	AL.	
	07/01/10	SOLAR ANGLE OF INCIDENCE AT NOON	AL.	
	07/06/14	2e SIGNED PLAN	AL	

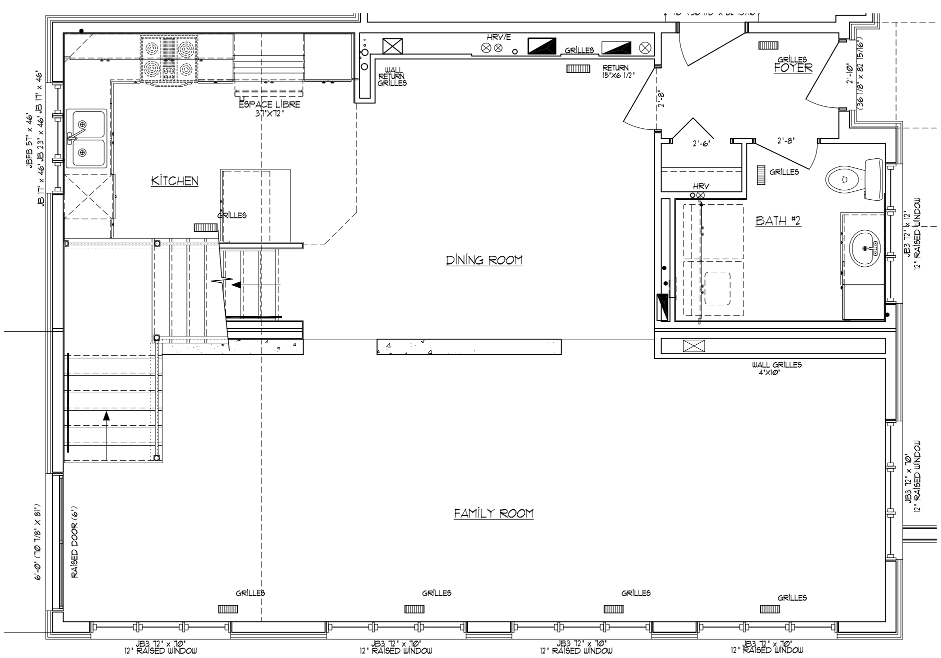
LES MAISONS Alouette HOMES
TEL: (450) 539-3100

Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE
Title / Titre: SOLAR ANGLE
Representative / Representant: ALOUETTE
Scale / Echelle: NONE
Project / Projet: 07-0015

13
13 Of / De:

PLUMBING CHECK LIST

HOOK-UPS TO BE COMPLETED	HOOK-UPS COMPLETED AND VERIFIED	HOOK-UPS IDENTIFICATION NUMBER	PLUMBING CHECK LIST
		1	TOILET DRAIN PIPE
		2	TOILET VENTILATION PIPE
		3	BATH DRAIN PIPE
		4	BATH VENTILATION PIPE
		5	SHOWER DRAIN PIPE
		6	SHOWER VENTILATION PIPE
		7	BATH. LAVATORY DRAIN PIPE
		8	BATH LAVATORY VENTILATION PIPE
		9	WASHING MACHINE DRAIN PIPE
		10	WASHING MACHINE VENTILATION PIPE
		11	KITCHEN SINK DRAIN PIPE
		12	KITCHEN SINK VENTILATION PIPE
		13	FUTUR VENTILATION PIPE
		14	1 1/2" VENTILATION PIPE
		15	2" VENTILATION PIPE
		16	3" VENTILATION PIPE
		17	4" VENTILATION PIPE AT ROOF
		18	3" SANITARY PIPE
		19	HOT WATER HEATING SYSTEM PIPE
		20	IN FOR HOT WATER HEATING SYSTEM PIPE
		21	OUT FOR HOT WATER HEATING SYSTEM PIPE
		22	COLD WATER SUPPLY PIPE
		23	HOT WATER SUPPLY PIPE
		24	AIR EXCHANGER 6" GALVANIZED DUCT
		25	AIR EXCHANGER 4" GALVANIZED DUCT
		26	
		27	



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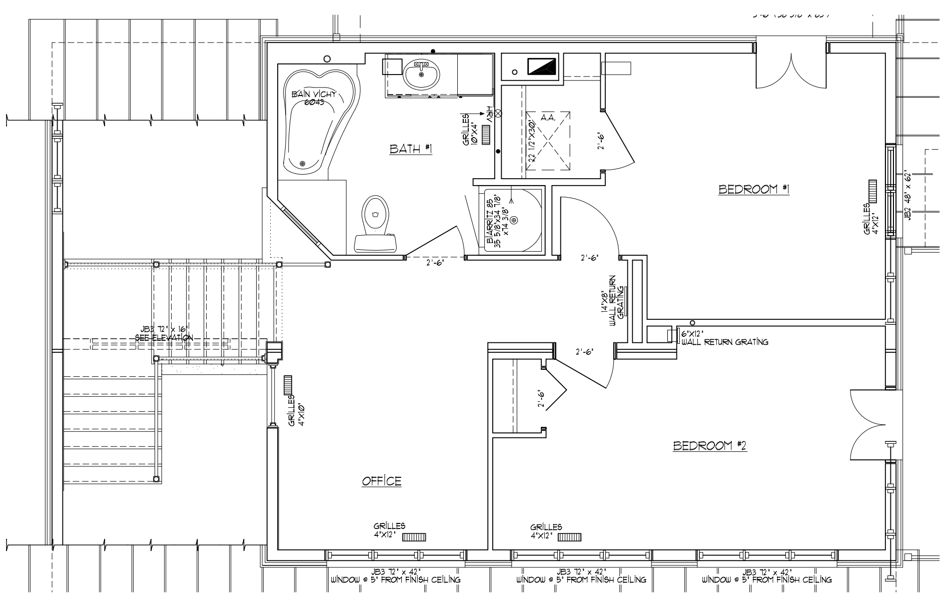
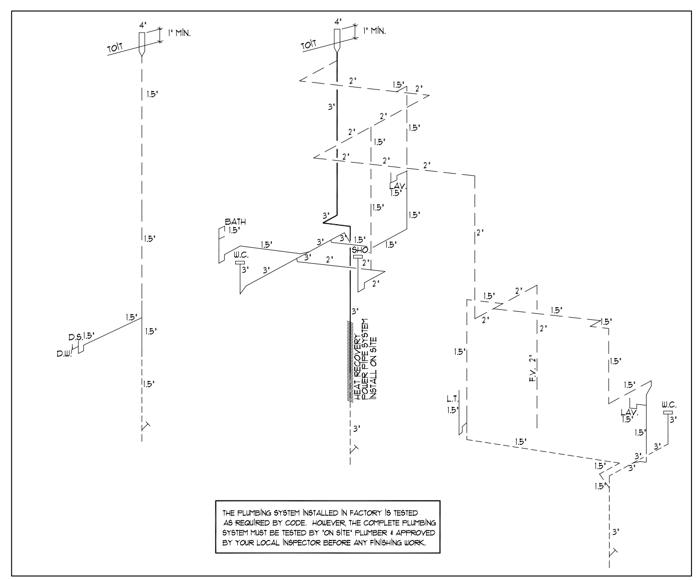


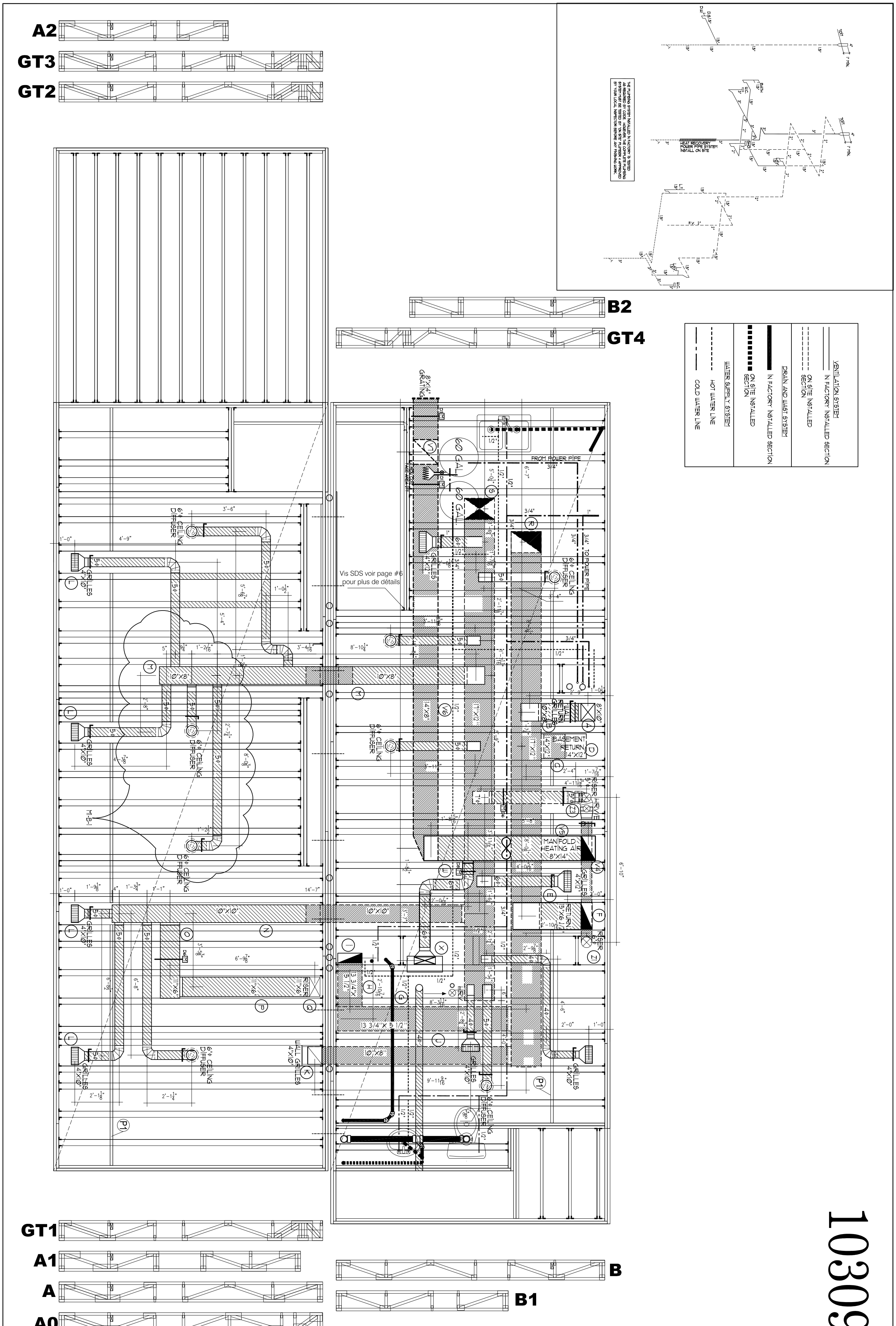


Rev:	Date:	Description:	D.	V.
	06/12/13	SIGNED PLAN	S.P.	
	06/12/13	SIGNED PLAN	A.L.	
	07/06/14	2e SIGNED PLAN	N.L.	

Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE
Title / Titre: PLUMBING CHECK
Representative / Representant: ALOUETTE
Scale / Echelle: 3/16" = 1'-0"
Project / Projet: 07-0015

LES MAISONS Alouette HOMES
TEL: (450) 539-3100

Of / De:

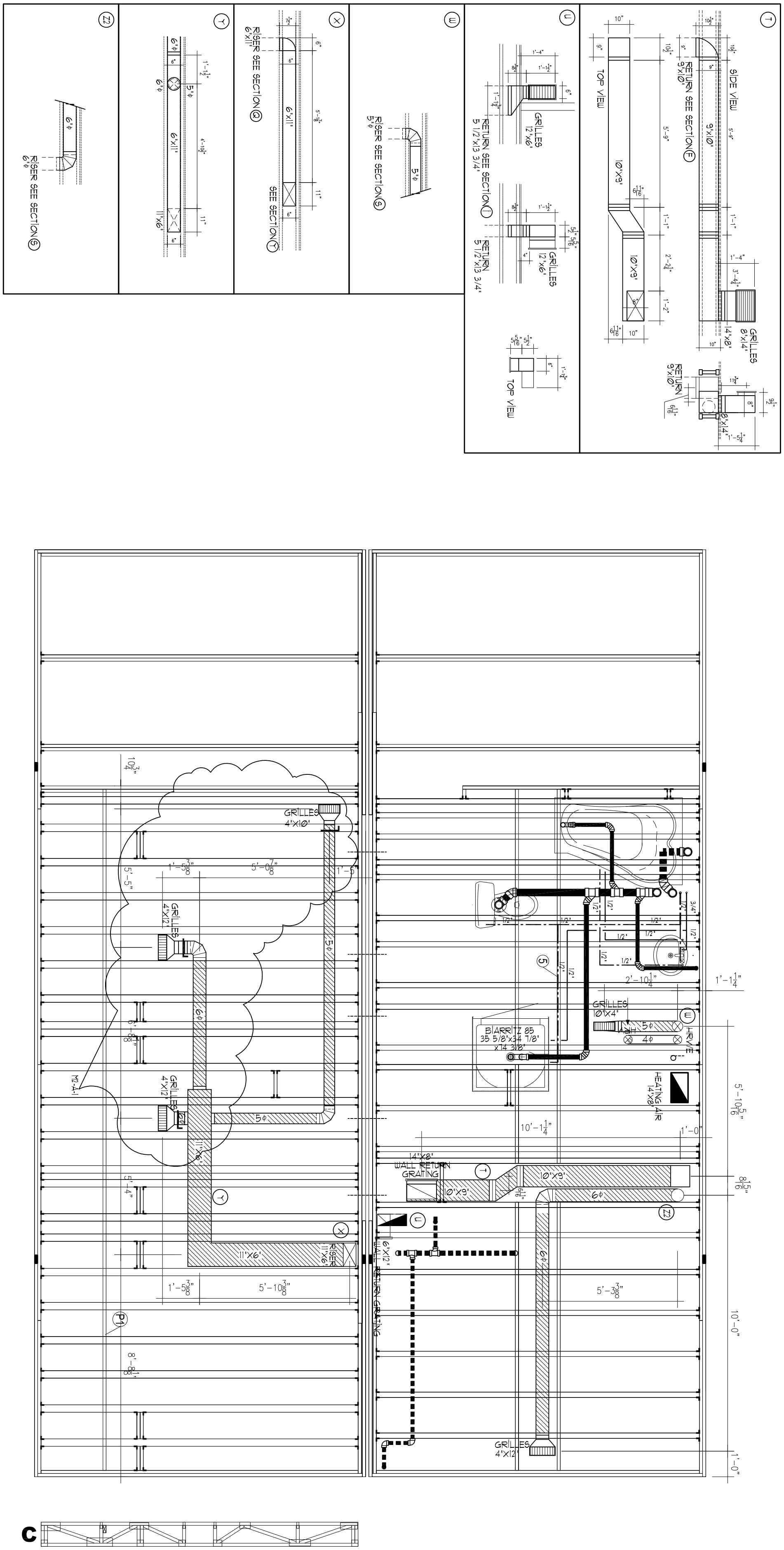


Customer(s) / Client(s):	Representative / Representant:	
EQUILIBRIUM	ALOUETTE	
Title / Titre:	Scale / Echelle:	Project / Projet:
GROUND FLOOR MECHANICAL	1/4"=1'-0"	07-00115

Rev:	Date:	Description:	D.	V.
MI-A-1	2007/08/08	PLAN DE MECANIQUE ETAGE REVISE	J.L.	P.B.
MI-B-1	07-08-07	PLAN MECANIQUE REVISE	S.P.	S.P.

LES MAISONS Alouette HOMES

TEL: (450) 539-3100



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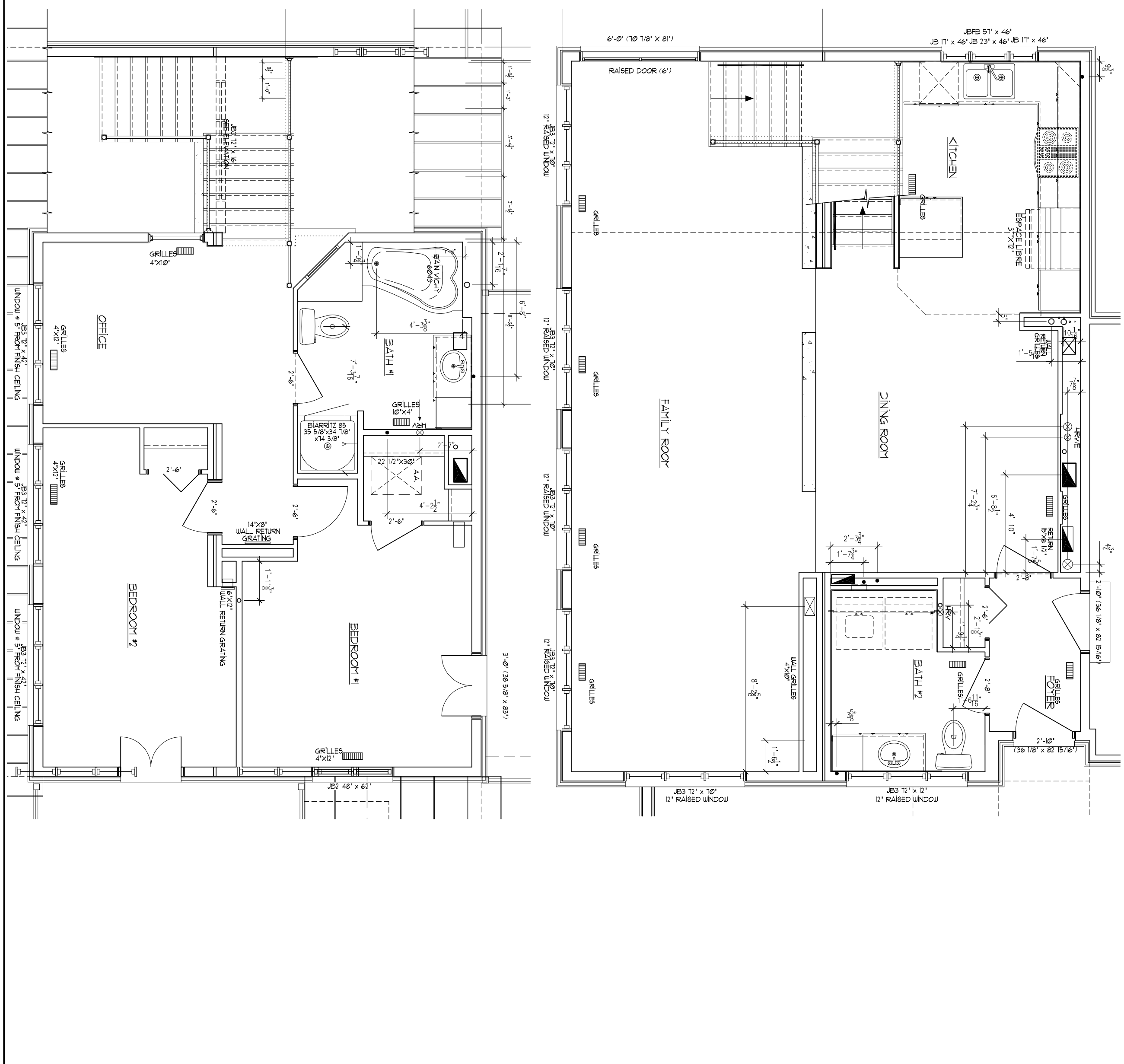
Customer(s) / Client(s):	Representative / Representant:		Rev:	Date:	Description:	D.	V.	LES MAISONS Alouette HOMES
EQUILIBRIUM	ALOUETTE		M2-A-1	2007/08/08	PLAN DE MECANIQUE RDC REVISE	J.L.	P.B.	
Title / Titre:	Scale / Echelle:	Project / Projet:	M2-B-1	07-08-07	AJOUT DE CLEF DE BALANCEMENT	S.P.	S.P.	
1st FLOOR MECHANICAL	1/4"=1'-0"	07-00115						TEL: (450) 539-3100

M2

1 Of / De 1

10309

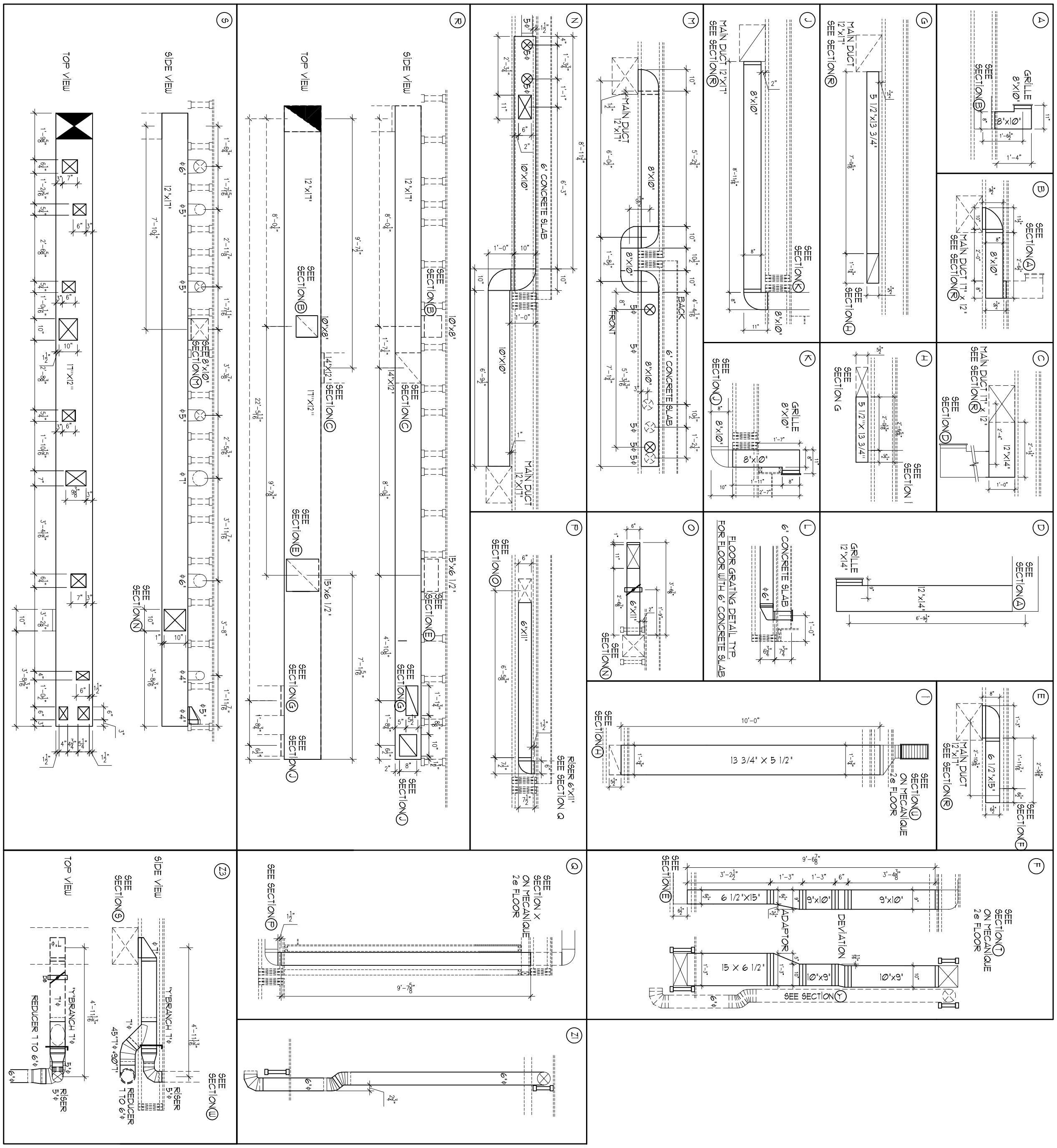


Customer(s) / Client(s):	Representative / Représentant:		Rev:	Date:	Description:	D.	V.
ECOTERRA ALOUETTE HOUSE	ALOUETTE			06/12/13	SIGNED PLAN	S.P.	
Title / Titre:	Scale / Echelle:	Project / Projet:		06/12/13	SIGNED PLAN	A.L.	
MECHANICAL DIM.	3/16" = 1'-0"	07-0015		07/06/14	2e SIGNED PLAN	SP	

M3 Of / De 1

LES MAISONS Alouette HOMES

TEL: (450) 539-3100



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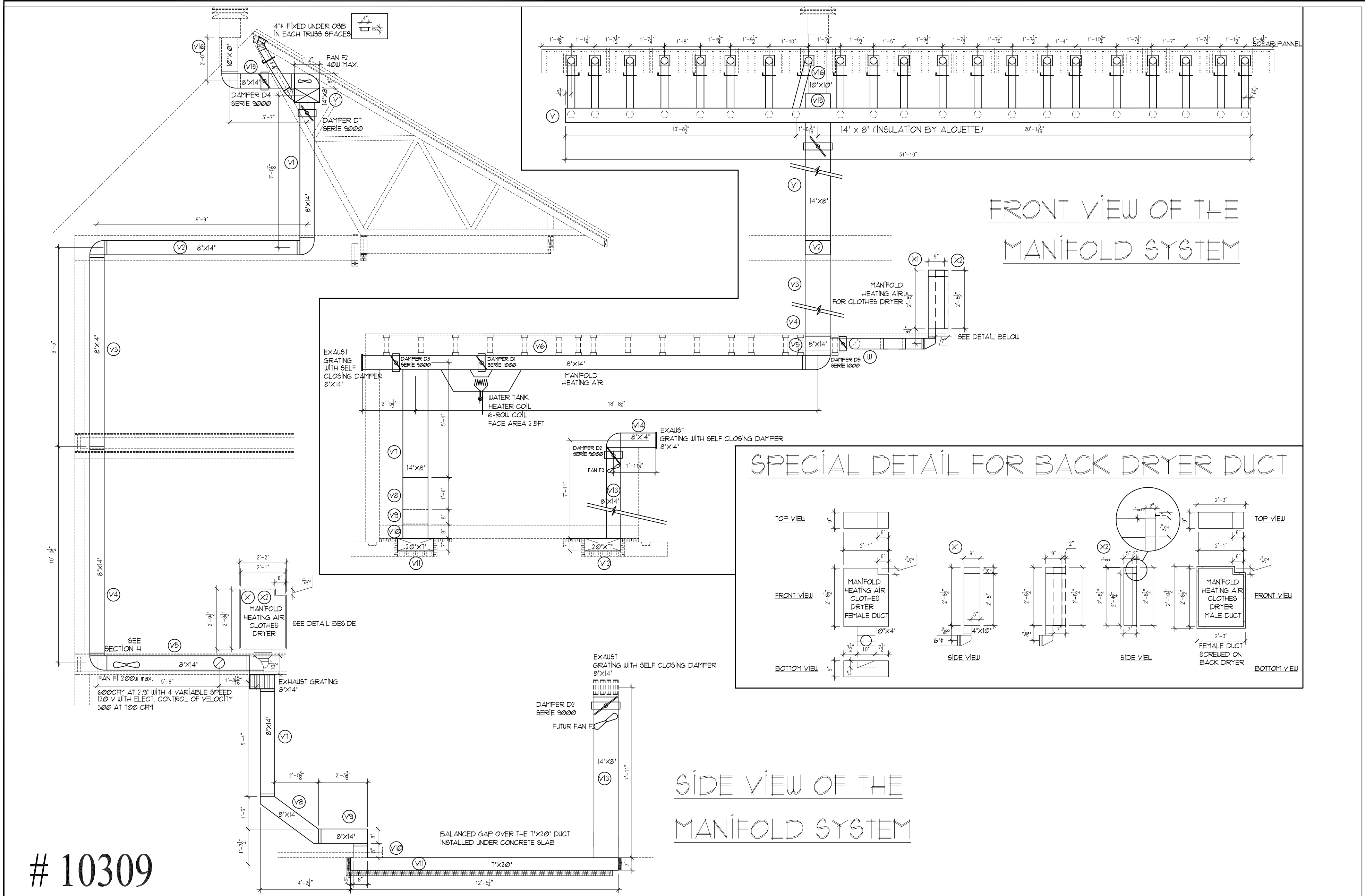
M4	Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE	Representative / Representant: ALOUETTE	
1 Of / De	Title / Titre: GROUND FLOOR MECHANICAL 2nd	Scale / Echelle: 1/4" = 1'-0"	Project / Projet: 07-0015

Rev:	Date:	Description:	D.	V.
	07/06/14	SIGNED PLAN	N.L.	
	07/06/28	ADD DAMPER TO 'O' + ADD Z3 DETAIL	N.L.	
M4-A-1	07-08-07	MODIFICATION DETAIL	S.P.	S.P.

LES MAISONS Alouette HOMES

TEL: (450) 539-3100



Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE

Title / Titre: MANIFOLD MECANIC DETAIL

Representative / Representant: ALOUETTE

Scale / Echelle: 1/4" = 1'-0"

Project / Projet: 07-0015

Rev:	Date:	Description:	D.	V.
	07/06/14	2e SIGNED PLAN	N.L.	
	07/06/28	Change location for slab damper	N.L.	
	07/09/05	change 4-row for 6-row coils	N.L.	

M5

1 Of / De:

LES MAISONS Alouette HOMES

TEL: (450) 539-3100

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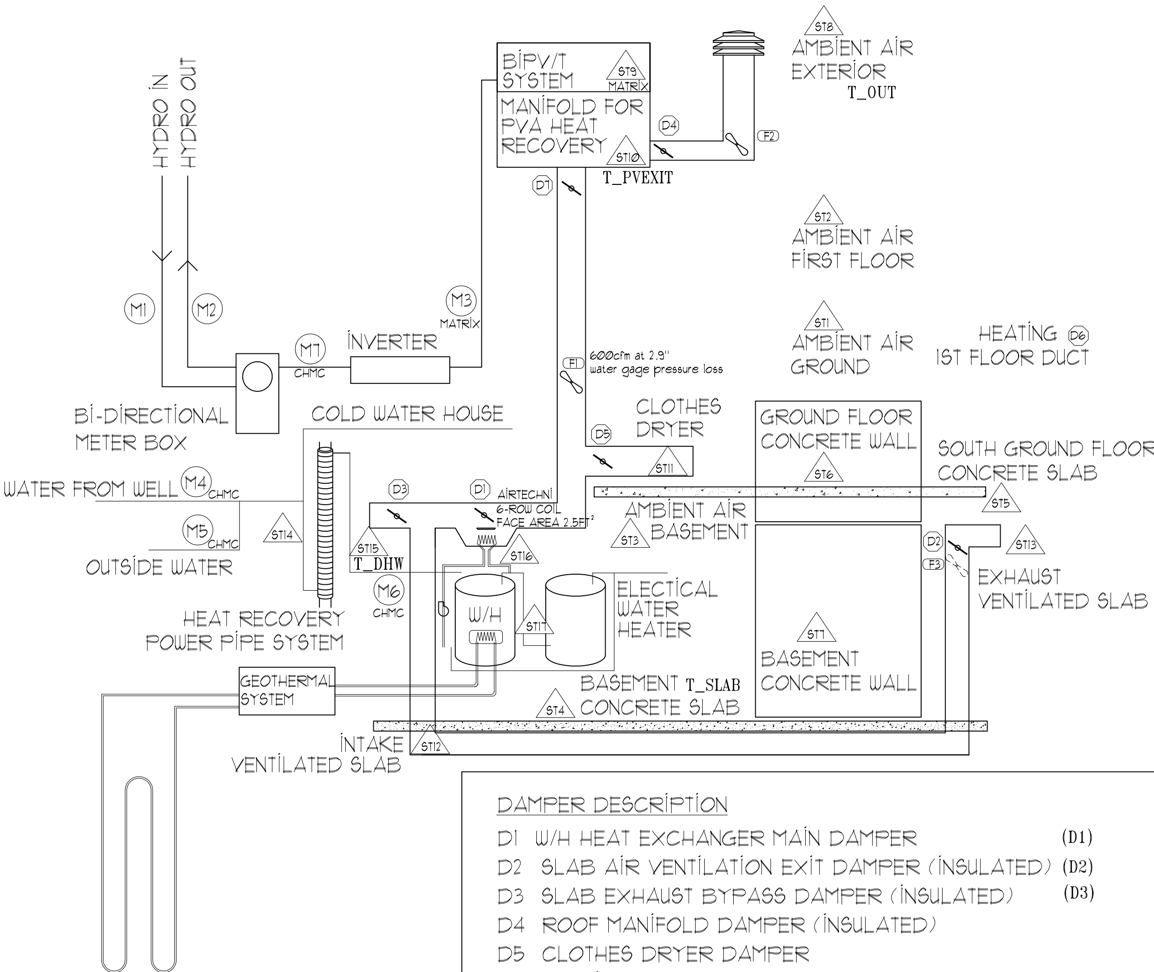


MONITORING EQUIPEMENT DESCRIPTION

M1 - HYDRO ELECTRICITY CONSUMPTION
M2 - HYDRO ELECTRICITY CREDIT
M3 - ELECTRICITY PRODUCTION FROM PVA (CMHC CONTROL)
M4 - TOTAL WATER CONSUMPTION (CHMC CONTROL)
M5 - WATER CONSUMPTION OF OUTDOOR FAUCET
M6 - HOT WATER CONSUMPTION (CMHC CONTROL)
M7 - ELECTRICITY PRODUCTION FROM PVA (CHMC CONTROL)

THERMOMETER DESCRIPTION

ST1 GROUND FLOOR AMBIENT AIR TEMPERATURE
ST2 FIRST FLOOR AMBIENT AIR TEMPERATURE
ST3 BASEMENT AMBIENT AIR TEMPERATURE
ST4 BASEMENT CONCRETE SLAB TEMPERATURE (T_SLAB)
ST5 GROUND FLOOR CONCRETE SLAB TEMPERATURE
ST6 GROUND FLOOR CONCRETE WALL TEMPERATURE
ST7 BASEMENT CONCRETE WALL TEMPERATURE
ST8 EXTERIOR TEMPERATURE (T_OUT)
ST9 PVA PANEL TEMPERATURE
ST10 AMBIENT AIR TEMPERATURE UNDER PVA (T_PVEXIT)
ST11 CLOTHES DRYER INTAKE AIR TEMPERATURE
ST12 INTAKE AIR FOR VENTILATED SLAB TEMPERATURE
ST13 EXHAUST AIR FOR VENTILATED SLAB TEMPERATURE
ST14 WATER INTAKE TEMPERATURE
ST15 TEMPERATURE OF CONDITIONED WATER FROM HEAT RECOVERY POWER PIPE SYSTEM (T_DHW)
ST16 WATER TEMPERATURE OF PREHEATED BY THE PVA HEAT RECOVERY SYSTEM
ST17 TEMPERATURE OF WATER SUPPLY FOR ELECTRICAL W/H

DAMPER DESCRIPTION

D1 W/H HEAT EXCHANGER MAIN DAMPER (D1)
D2 SLAB AIR VENTILATION EXIT DAMPER (INSULATED) (D2)
D3 SLAB EXHAUST BYPASS DAMPER (INSULATED) (D3)
D4 ROOF MANIFOLD DAMPER (INSULATED)
D5 CLOTHES DRYER DAMPER
D6 HEATING ZONE DAMPER FOR SOUTH 1ST FLOOR
D7 MAIN DAMPER FOR PVA HEAT RECOVERY SYSTEM (INSULATED)

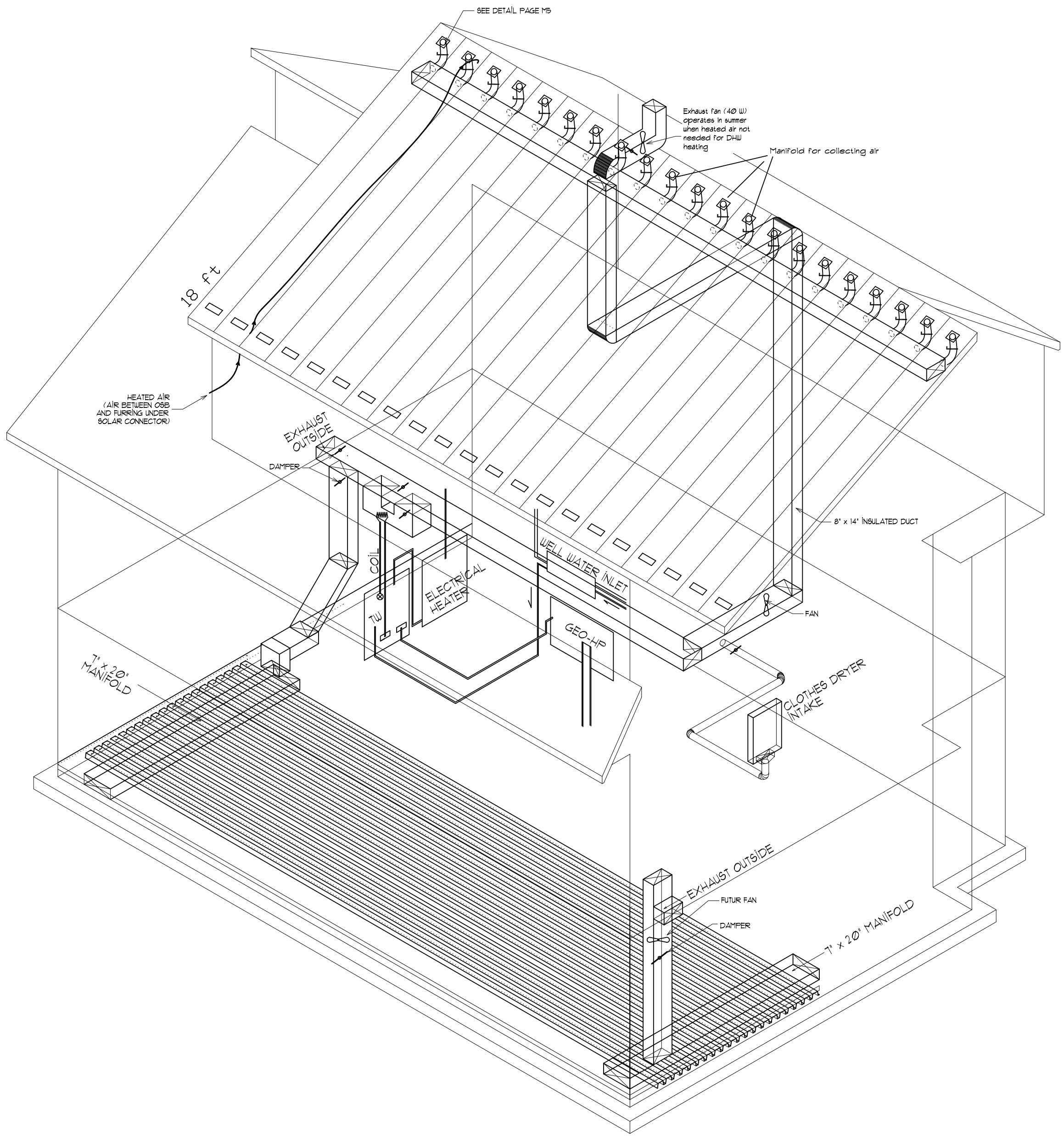
FAN DESCRIPTION

F1 MAIN FAN FOR PVA HEAT RECOVERY SYSTEM (F1)
600cfm at 2.9" water gage pressure loss with with 4 variable speed (120 v) and computor control
Velocity ranges from 300 cfm to 700cfm (200 W max.)
F2 ROOF FAN FOR MANIFOLD (40 W max.) (F2)
F3 FUTUR VENTILATION SLAB FAN (F3)

Rev:	Date:	Description:	D.	V.
	07/09/05	CHANGE 4-ROW FOR 6- ROW COIL	N.L.	
	07/06/22	3 dampers and 1 fan removed	N.L.	
07/06/28	07/06/28	ADD D6 +D7	N.L.	
	07/08/13	MODIFY SHEMATIQUE W/H + GEOTHERMAL	N.L.	

Customer(s) / Client(s): ECOTERRA ALOUETTE HOUSE
Title / Titre: CONTROL SHEMATIC
Representative / Representant: ALOUETTE
Scale / Echelle: 1/4" = 1'-0"
Project / Projet: 07-0015
M6
1 Of / De:

LES MAISONS Alouette HOMES
TEL: (450) 539-3100



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Customer(s) / Client(s):	Representative / Representant:	
ECOTERRA ALOUETTE HOUSE	ALOUETTE	
Title / Titre:	Scale / Echelle:	Project / Projet:
3D VIEW OF MANIFOLD AIR DIST.	1/4" = 1'-0"	07-0015

Rev:	Date:	Description:	D.	V.
	06/11/15	PRELIMINARY PLAN	A.L.	
	06/12/13	SIGNED PLAN	A.L.	
	07/06/14	2e SIGNED PLAN	AL	

LES MAISONS Alouette HOMES
TEL: (450) 539-3100

M7
Of / De:

Appendix K - CUSUM Analysis

K CUSUM ANALYSIS

A common tool used by building energy experts in the cumulative sum of differences (CUSUM) analysis. This method can show if or when there were significant changes to the physical or operational details of a building (Carbon Trust 2010). A CUSUM analysis was performed on ÉcoTerra for the period of December 10, 2009 to June 9, 2010.

The CUSUM analysis involves first determining the balance temperatures for the building. The balance point is then used to calculate the total heating degree days for the specific period. This is then divided by the total heating load to achieve the kWh/HDD ratio. This was calculated in the previous section as 0.91 kWh/HDD. Next, this ratio is used to predict the heating load for each day based on the heating degree days for that day. The difference is then taken between the predicted and actual heating load. This is performed for the entire period with any differences being summed along the way. This cumulative sum of differences is where the method gets its name.

Figure K1 shows the resulting graph of the cumulative sum of differences between the expected heating load, based on the average kWh/HDD, and the actual daily heating load. In an ideal case, this graph would be a straight line at zero, however, it can be seen here that there is under-performance of the heating system (heavy line marked “CUSUM”), compared to the average for the period, in both January and February.

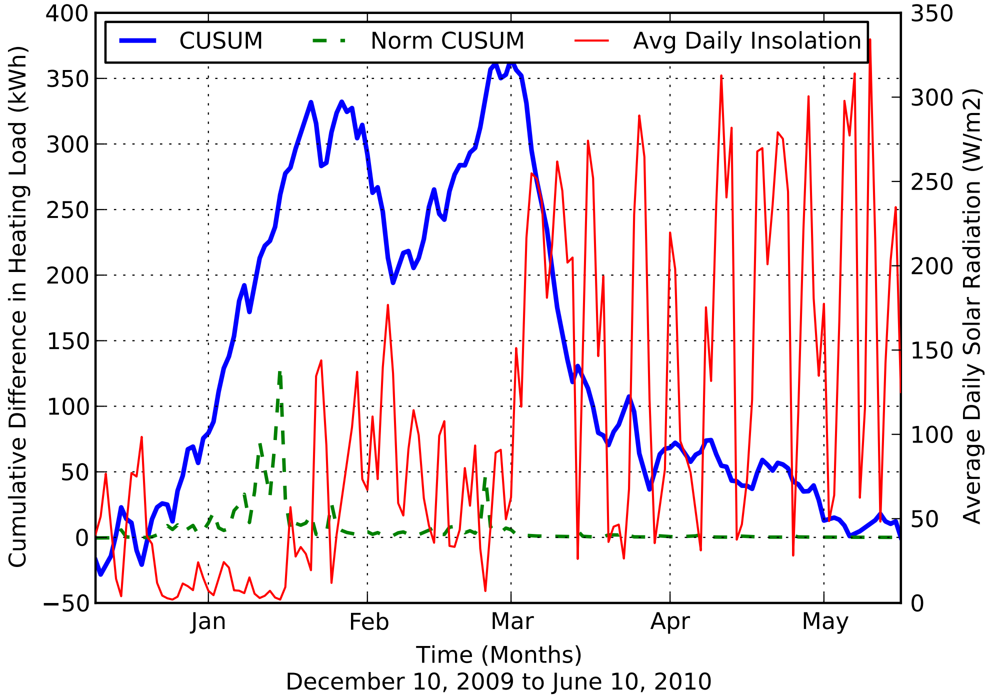

Figure K1: CUSUM and normalized CUSUM

The right-hand axis of Figure K1 shows the average daily solar radiation. It can be seen that the pattern of under-performance in the heating system matches the pattern of lower solar radiation. When the CUSUM is normalized for solar radiation (dashed line marked “Norm CUSUM”), the result shows that the system performed well for most of the period, but there is still some under-performance in the month of January. The CUSUM analysis demonstrates that for a building like ÉcoTerra, designed to rely on solar radiation as a heating source, the performance of the heating system is directly linked to the amount of solar radiation available.