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An energy and cost analysis of residential ground-source heat pumps in Iowa

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An energy and cost analysis of residential ground-source heat pumps in Iowa

by

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NOMENCLATURE

A:	area
C:	discharge coefficient of orifice
C_p:	specific heat
LF:	latent factor
MMBtu:	million btu's
N:	number of people
n:	number of days in a month
P:	pressure
$\dot{Q}$:	heat transfer rate
R:	thermal resistance
T:	temperature
U:	heat transfer coefficient
V:	velocity
$\dot{V}$:	volumetric flow rate
$\forall$:	volume
$\dot{W}$:	rate of work
WI:	humidity ratio

SUBSCRIPTS:

c:	cold
h:	hot
i:	inside
inf:	infiltration
int:	internal heat gain
o:	outside

GREEK SYMBOLS

β:	performance of carnot refrigeration cycle
γ:	performance of carnot heat cycle
Δ:	change
η:	efficiency
ρ:	density

LIST OF ABBREVIATIONS

ACH:	air changes per hour
AFUE:	annual fuel utilization efficiency
ARI:	Air-Conditioning and Refrigeration Institute
ASHP:	air source heat pump
ASHRAE:	American Society of Heating, Refrigeration, and Air Conditioning Engineers
COP:	coefficient of performance
DHW:	domestic hot water
DNR:	Department of Natural Resources
DX:	direct exchange
ECI:	energy cost index
EER:	energy efficiency ratio
EPA:	Environmental Protection Agency
EUI:	energy utilization index
EWT:	entering water temperature
GCHP:	ground coupled heat pump
GPH:	gallons per hour
GSHP:	ground source heat pump
GWHP:	ground water heat pump
GX:	geo-exchange
HDD:	heating degree day
HDPE:	high density polyethylene
HSPF:	heating seasonal performance factor
HVAC:	heating ventilation and air conditioning
IEC:	Iowa Energy Center
IECC:	International Energy Conservation Code
IGSHPA:	International Ground Source Heat Pump Association
ISO:	International Organization for Standardization
SEER:	seasonal energy efficiency ratio
SWHP:	surface water heat pump

TMY2: Typical Meteorological Year Data

WLHP: water loop heat pump

SHGC: solar heat gain coefficient

UA: overall heat transfer coefficient

ABSTRACT

The objective of this study was to evaluate residential ground-source heat pumps throughout the state of Iowa and use that information to develop educational opportunities for prospective ground-source heat pump owners. The ground-source heat pumps were evaluated based on performance, efficiency, and economics. The study was limited to similar homes throughout the state of Iowa, recent constructions (1997 to 2001), and vertically or horizontally configured loops.

Energy audits were conducted for each home to obtain building characteristics. Using the characteristics, heating and cooling loads were estimated for each home. Utilizing the heating and cooling loads along with utility bill and weather information, performance data were calculated for each home.

The energy analyses showed that cooling loads are not accurately tracked using this method as a result of occupant schedules. The heating load performance showed that there is a negligible difference between the performance of a vertical and horizontal loop system.

The economic analysis evaluated the cost difference between using a ground-source heat pump and natural gas furnace. The analysis showed that a significant amount of money could be saved during the heating season when using a ground-source heat pump.

It was determined that several homeowners were interested in the installation of a ground source heat pump but did not fully understand the technology. An extensive literature review was completed and an educational document was produced for homeowner's education. Homeowners tend to be highly interested in estimating the amount of money that can be saved using a ground-source heat pump. To estimate a home's annual savings using a ground source heat pump in comparison to other means of conditioning a home, a savings calculator was developed. The calculator was able to closely estimate most homes evaluated in this study.

CHAPTER 1 INTRODUCTION

1.1 Background

With the ever increasing concerns over environmental impact and the rising prices of fuel, many homeowners have begun to look to alternative means of heating and cooling their homes. An increasingly popular method to achieve the aforementioned objectives is through the use of ground-source heat pumps (GSHP). Homeowners and utility companies in Iowa have not been left behind in utilizing and promoting this technology. GSHPs have consistently been hailed to reduce both fossil fuel use and electrical demand. Furthermore, a wide range of installation options are available making them viable for several situations.

1.2 Geothermal

Geothermal energy can be described as the internal heat generation of the earth. Three methods of internal generation are common. The first is a result of the radioactive decay of elements within the earth's crust which release thermal energy. The second method of production is the conduction of thermal energy from deep within the earth, transporting through several layers to reach the surface. Additionally, there are several areas where direct channels bring molten rock and steam to the surface. These direct channels are know as high temperature geothermal and can be used for means of electrical generation.

The last of the heat generation methods is solar radiation. The earth's crust absorbs approximately 47% of the sun's solar radiation, making it a very lucrative energy source. By some estimates, this low energy geothermal is 500 times more energy then all of mankind uses in a year. The annual temperature variability of the ground at 6 feet is little and nearly unnoticeable at depths of 200 feet. Typical Iowa subsoil maintains an annual average of 52°F. The GSHP is able to capitalize on the low grade geothermal energy to heat and cool homes.

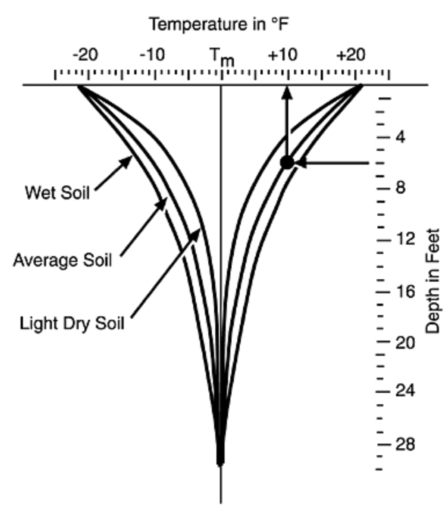

Figure 1:Soil temperature variation (http://www.geo4va.vt.edu/A1/A1.htm)

1.3 Ground-Source Heat Pump

It is the tendency for heat to flow from reservoirs of high energy to that of low energy. The objective of any heat pump is to reverse the flow by transferring energy from reservoirs of low energy to reservoirs of high energy utilizing an input of work. A ground-source heat pump completes this cycle by exchanging thermal energy with the earth.

Two basic types of ground-source heat pumps are currently utilized for residential heating and cooling: water-to-air and water-to-water systems. Both systems utilize one of the many variations of ground heat exchangers to exchange energy with water or air. Water-to-air systems are used to heat and cool air which is delivered through traditional duct systems to spaces for conditioning. Water-to-water units, on the other hand, produce hot water for domestic hot water (DHW), pools, hydronic systems, etc.

Ground-source heat pumps can be further divided into the type of ground loop heat exchanger utilized. Two fundamental systems exist, an open loop and closed loop heat exchanger.

The open loop systems connect to the earth using surface water or ground water to exchange heat with the thermal cycle. Figure 2 shows several examples of open loop systems commonly in use.

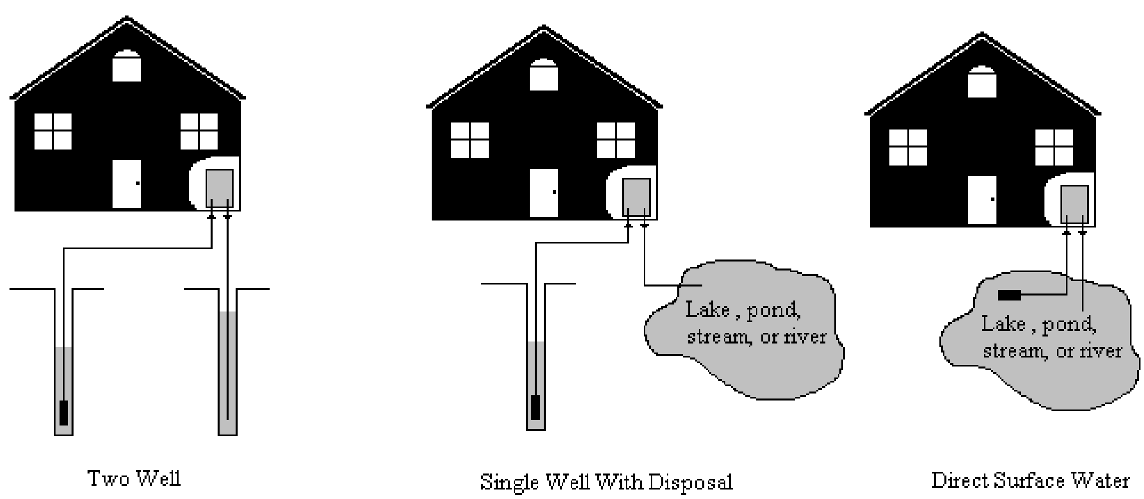

Figure 2: Open loop heat exchangers

Although these systems typically have lower installation cost, attention has to be given to water quality and long-term system maintenance.

Several closed loop systems are currently available on the market. Figure 3 and 4 shows examples of horizontal and vertical closed loop systems.

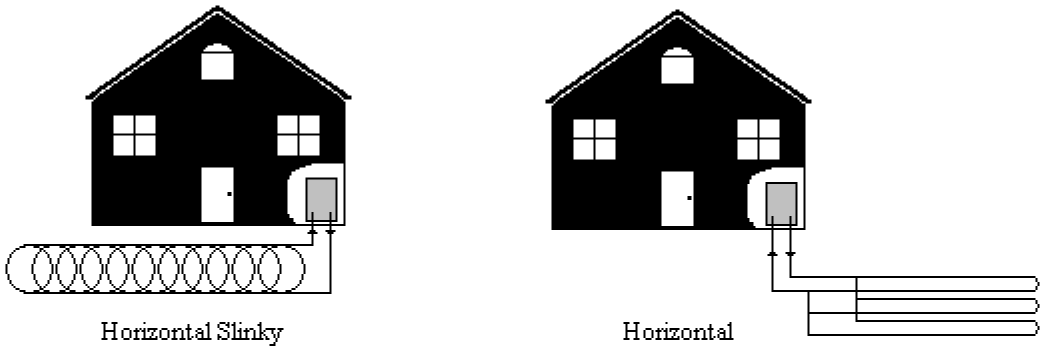

Figure 3: Horizontal closed loop systems

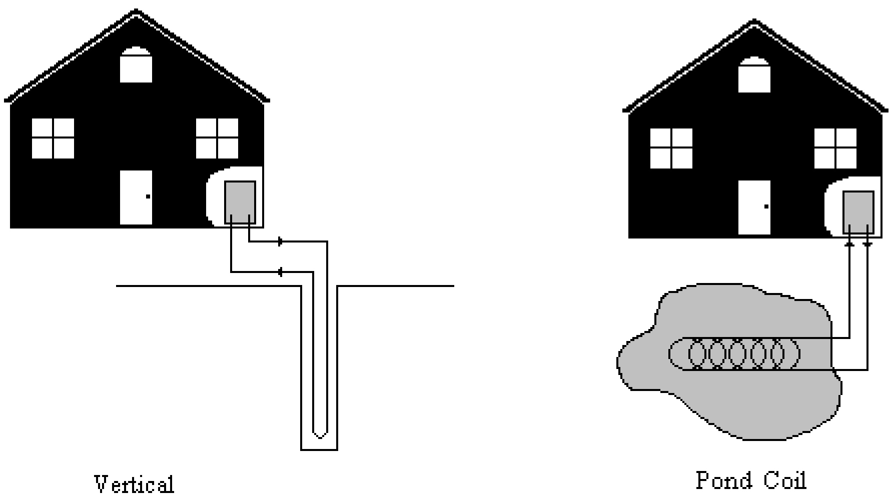

Figure 4: Vertical and pond coil closed loop systems

Closed loop systems are a much more common installation type. The installation of these systems is limited by the amount of land area required. The horizontal systems are typically placed 6 feet below the surface at lengths ranging from 350 to 600 feet per ton. Vertical systems, on the other hand, are bored into the ground to depths of 100 to 300 feet with pipe lengths of 200 to 600 feet per ton. The pond loop, which can be the cheapest of all installations, requires a pond with depths of at least 10 to 12 feet. Piping is coiled in stacks and sunk to the bottom of the pond.

Closed loop systems rely on a high density polyethylene (HDPE) pipe to allow for enhanced thermal transport between the soil and working fluid. Since closed loop systems can drop below 32°F, an antifreeze mixture must be used to prevent freezing. All antifreezes must meet local and state codes, usually being food grade antifreeze to prevent the possibility of ground water contamination (Kavanaugh, 1997).

1.4 Motivation for study

With the increased interest and installations of GSHPs occurring in Iowa, the need has arisen to determine the economic feasibility and performance of these systems for the area. This comprehensive study will consist of three primary objectives, namely (i) comparison of residential GSHPs to that of conventional systems, (ii) comparison of currently operational horizontal and vertical bore GSHPs for energy costs/consumption, and (iii) inform and educate prospective owners about the energy efficiency, energy conservation, and cost savings associated with GSHPs.

A GSHP installation will typically have a higher initial cost than that of a conventional system but lower associated operating cost. It is therefore of interest to determine whether the cost of installation can be offset by the lowered operational expenses. One of the factors that significantly influences the initial cost is the type of loop system that is chosen. Traditionally it has been thought that a vertical loop system would be more efficient because of the ability to deliver a constant temperature to the GSHP. This comes as a result of the depth to which vertical loops are installed and the ability to be influenced very little by ambient conditions. The drawback to the vertical system is in the higher initial cost. Horizontal loops, on the other hand, are typically cheaper to install but come at the cost of higher required installation area. Furthermore, since these systems are installed close to the surface, they can be affected by ambient conditions. A comparison of the vertical and horizontal loops will be completed to determine which is more efficient and cost effective.

The current perception of GSHPs is that lower heating and cooling cost can be achieved over that of conventional systems. A comparison of GSHPs to that of natural gas heating systems and conventional air conditioners will be completed. The study will help a prospective owner of a GSHP weigh the installation cost over the lowered utility costs.

With every emerging technology there is a need to educate the general public both about the benefits and shortcomings. This study will consist of an extensive literature review seeking out the common questions and concerns a homeowner would have. The culmination will be an educational packet to be distributed at the discretion of the Iowa Energy Center (IEC).

As an additional educational tool, a cost savings calculator will be developed. The calculator will help a homeowner look at current savings compared to alternative heating and cooling resources.

1.5 Scope of Study

The GSHP performance and economic evaluation was started by Joe Foster, M.S. 2005. This study will focus on the re-evaluation of the originally collected data, continuation into the comparison of heat pump ratings, and development of homeowner educational documents.

Chapter 2 will discuss the theory of heat pump operation, development of heating and cooling load calculations, and development of the economic analysis. The energy and cost analysis for each GSHP evaluated will be presented in Chapter 3. Additionally, the results of the systems to the manufacturer's rated performance and results of the homeowner educational opportunities will be presented. A summary of the study along with conclusions and recommendations for future work will be presented in Chapter 4.

CHAPTER 2 GROUND-SOURCE HEAT PUMP THEORY

2.1 Thermodynamic Cycle and Performance Characteristics

Heat has a tendency to flow from areas of high thermal energy to that of lower energies. The purpose of a GSHP and any heat pump is to reverse the natural flow of heat through the use of an input of work. The following diagram depicts the system and the heat flow process.

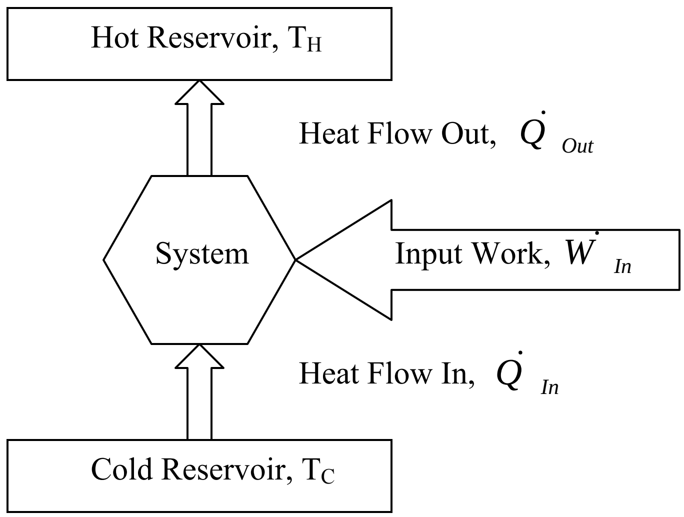

Figure 5: Thermodynamic interactions of heat pump cycle

A GSHP utilizes a vapor compression cycle which can be operated in reverse to generate both heating and cooling effects. A vapor compression cycle uses a refrigerant as a medium to absorb heat at one point and reject it to another. The diagram in Figure 6 depicts a typical GSHP system in a heating cycle with the addition of domestic hot water.

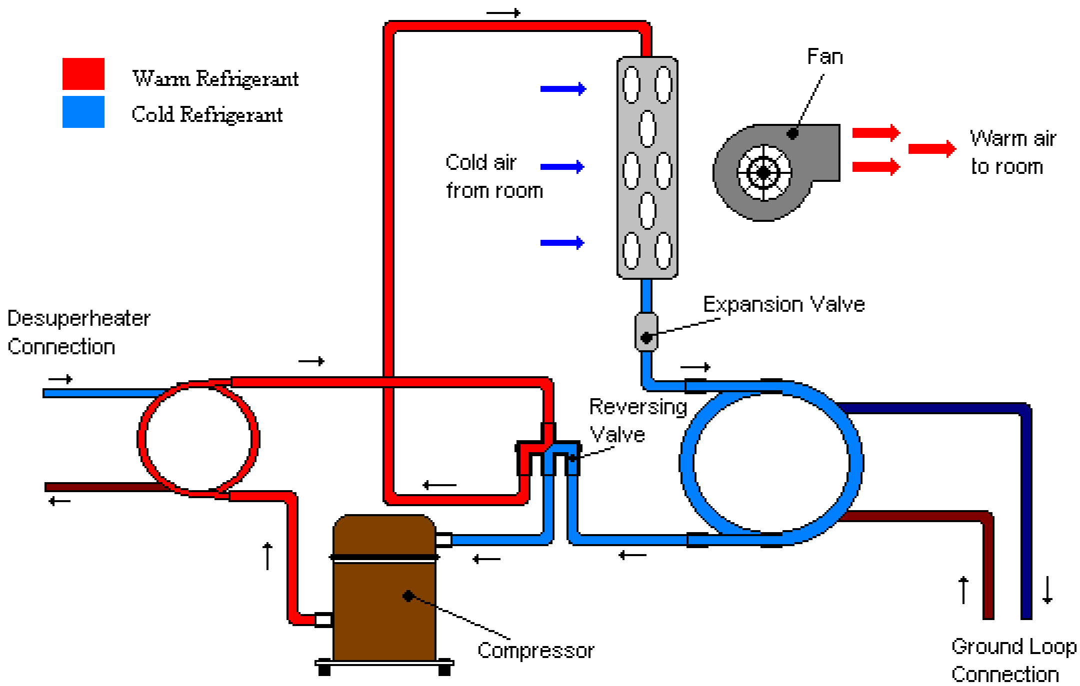

Figure 6: Heating cycle of ground-source heat pump

The cycle starts at the compressor where a refrigerant, typically R-22 or HFC-410a, is compressed, causing it to heat up. Located shortly after the compressor, a heat exchanger called a desuperheater is found. The desuperheater allows a portion of the energy from the hot refrigerant to be exchanged with water. The process produces hot water for use by the home at about 125°F. The hot refrigerant continues to flow to the condenser, allowing cold room air to be heated for the conditioned space. A fan system is used to move the air to the needed location. Following the condenser, an expansion valve is located. The expansion valve causes the refrigerant to expand quickly and cool. The final process is the exchange of thermal energy from the refrigerant to the ground loop further reducing the refrigerants energy. The refrigerant flows back to the compressor, starting the process over. The inclusion of a reversing valve allows the system to produce a cooling effect in the summer.

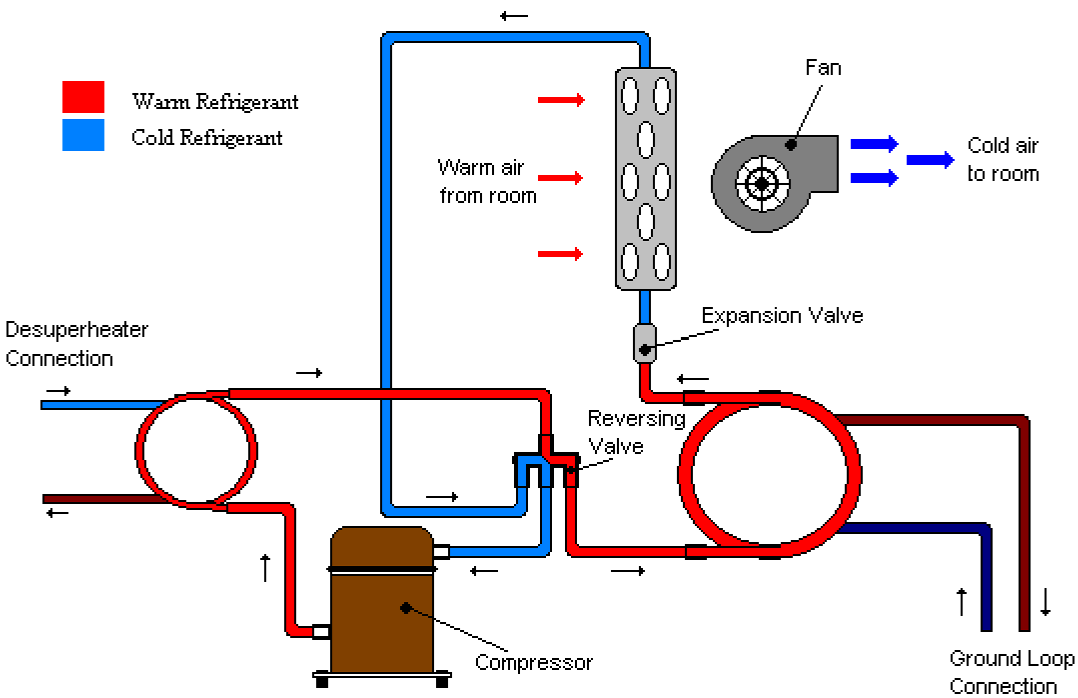

Figure 7: Cooling cycle of ground source heat pump

The maximum efficiency that a heat pump cycle can achieve is defined by the Carnot cycle efficiency. The Carnot efficiency relates the hot reservoir to the cold reservoir and the work required to achieve heat transfer between the two. The efficiency utilizes an absolute temperature scales. For the heating cycle, the coefficient of performance (COP) is defined as:

$$\gamma = \frac{T_H}{T_H - T_C} \tag{2.1}$$

The refrigeration cycle performance is defined as:

$$\beta = \frac{T_C}{T_H - T_C} \tag{2.2}$$

The Carnot efficiency measures the performance of a theoretical heat pump assuming that no losses occur between the two reservoirs. In the real world, heat pumps experience many factors which lead to inefficiencies in the system. The coefficient of performance for GSHPs relates the amount of heat moved to the work required to move that heat.

$$COP = \frac{\dot{Q}}{\dot{W}_{cycle}} \qquad 2.3$$

The heating cycle for GSHPs are typically represented by COP with the both the heat flow rate and work input having units of Btu/hr. To measure the cooling cycle for GSHP, the performance rating of Energy Efficiency Ratio (EER) is used. The EER uses a set point temperature (typically 95°F) which the system must operate at. The EER is then the ratio of the heat flow at the set point in Btu/hr to the input work in units of watts.

$$EER = \frac{\dot{Q}(\text{Btu/hr at } 95^{\circ}\text{F})}{\dot{W}_{cycle}(\text{watts at } 95^{\circ}\text{F})} \qquad 2.4$$

2.2 Load Calculations

To evaluate the energy use of homes, a method for both heating and cooling loads needed be developed. The heating load is defined as the amount of energy that is lost during the winter months while the cooling load is the energy gained by the home during the summer months.

2.3 Heating Load

A building's structure consists of walls, roof, floors, basements and windows or fenestration that allows energy to enter or leave by heat transmission. Collectively these structural characters are deemed the building envelope. The heating load, Q_{HT} consists of 5 dominating heat transfer modes including: 1) sensible heat, thermal conduction through the building envelope, $q_{sensible}$; 2) infiltration of air as a result of cracks in the home, q_{inf}; 3) solar gain through the home's fenestration, q_{solar}; 4) gains generated within the home, q_{int}; 5) domestic hot water (DHW) production from the GSHP, q_{DHW}. The heating load is then defined as:

$$\dot{Q}_{HT} = \dot{q}_{sensible} + \dot{q}_{\inf} - \dot{q}_{solar} - \dot{q}_{\text{int}} + \dot{q}_{DHW} \qquad 2.5$$

2.3.1 Building Envelope Transmission

The heat conduction through the building envelope can be calculated using a heating degree day (HDD) method. Heating degree days are calculated by taking the average daily temperature and finding the difference from 65°F. If the average daily temperature is greater than 65°F, it is then considered a cooling degree day (CDD).

$$HDD = 65°\text{F} - \text{T}_{\text{avg.}} \qquad 2.6$$

The heat transfer through the building envelope can be calculated as a function of the overall heat transfer coefficient (UA) and the HDD. HDD are often reported in monthly totals, as a result it is advantageous to divide by the days per month, n.

$$\dot{q}_{\text{sensible}} = \frac{(UA)(HDD)}{n} \qquad 2.7$$

2.3.2 Winter Infiltration

Infiltration is air which enters the home through uncontrolled cracks and other openings. The entering air must be conditioned to the indoor temperature and can account for a significant heating load. The amount of infiltration is a function of the entry point size, wind speed, and ambient temperature. A commonly used term to describe the amount of infiltration is the number of air changes per hour (ACH). Several approaches exist to estimate and account for ACH. The one which is most adaptable for this study is the approach set forth in the ASHRAE 2001 Fundamentals Handbook. In the 2001 Fundamentals, a linear relationship can be developed based on outdoor air temperature (T_o) and an indoor baseline temperature of 75°F. Additionally, the exterior wind speed is set to a baseline of 15 mph. To account for the size of the air crack in the structure, ASHRAE has developed three construction types of tight, medium, and loose. Table 4 shows the ACH as a function of the construction type and outdoor temperature.

Table 1: ACH based on outdoor air and construction type (ASHRAE Fundamentals, 2001)

Construction Type	Outdoor Temperature (°F)									
	50	**40**	**30**	**20**	**10**	**0**	**-10**	**-20**	**-30**	**-40**
Tight	0.41	0.43	0.45	0.47	0.49	0.51	0.53	0.55	0.57	0.59
Medium	0.69	0.73	0.77	0.81	0.85	0.89	0.93	0.97	1.01	1.05
Loose	1.11	1.15	1.19	1.23	1.27	1.31	1.35	1.39	1.43	1.47

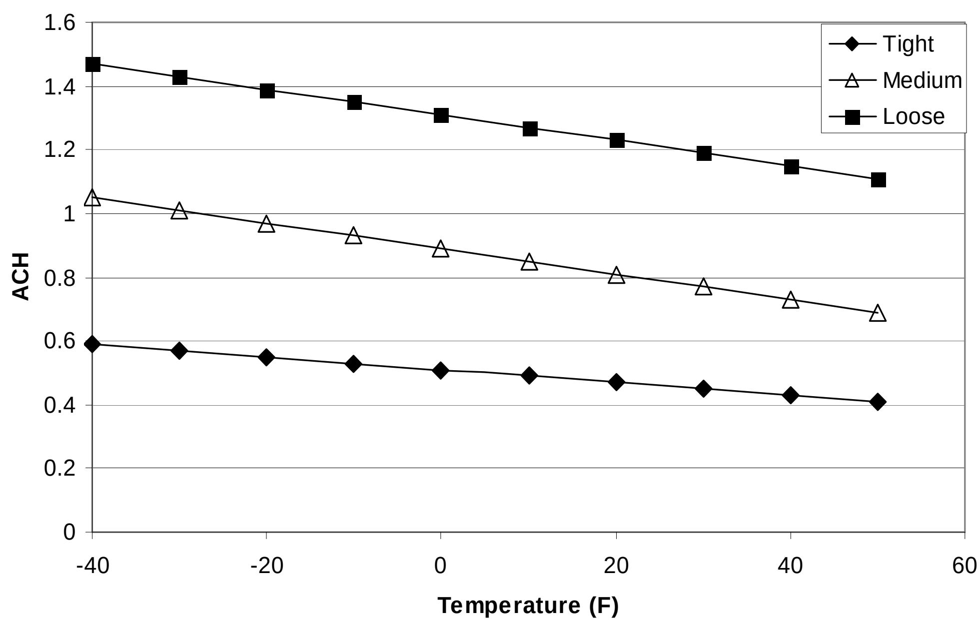

Figure 8: ACH based on outdoor air and construction type

The linear relationships in each construction type can be found as:

Tight: $ACH = -0.002T_O + 0.51$ 2.8

Medium: $ACH = -0.004T_O + 0.89$ 2.9

Loose: $ACH = -0.004T_O + 1.31$ 2.10

Using the volume of the home, $\forall$, the volumetric flow rate, $\dot{V}$, of infiltration entering the structure can be found.

$$\dot{V} = \forall \times ACH \qquad 2.11$$

The phenomenon of infiltration is driven by exterior wind speeds and by the outdoor temperatures. Since the wind creates a pressure against the outside walls of the home and thus a pressure difference, Bernoulli's equation can be used to estimate this effect.

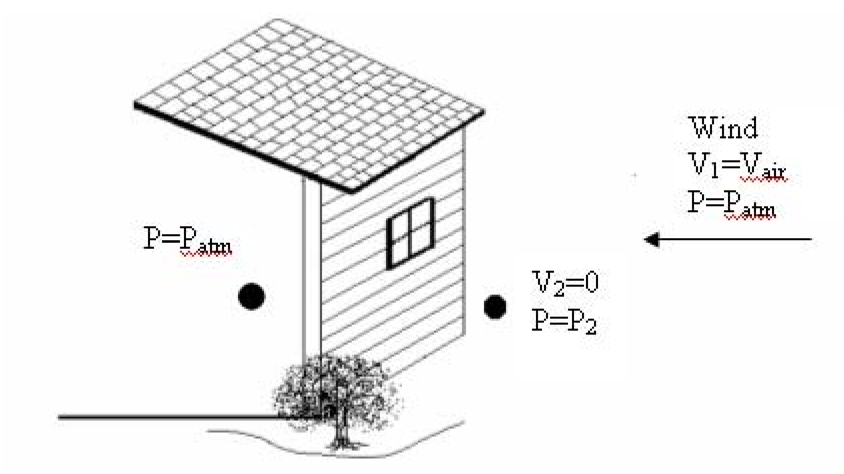

Figure 9: Wind pressure on a home

Assuming that the wind can be modeled as an incompressible fluid, Bernoulli's equation reduces to:

$$P_2 = P_{atm} + \frac{V_{air}^2}{2}\rho_{air} \qquad 2.12$$

The pressure difference across the wall is then found to be:

$$\Delta P = P_2 - P_{atm} = \frac{V_{air}^2}{2}\rho_{air} \qquad 2.13$$

Assuming that the primary location of infiltration is occurring through cracks, the system can be modeled as a single orifice.

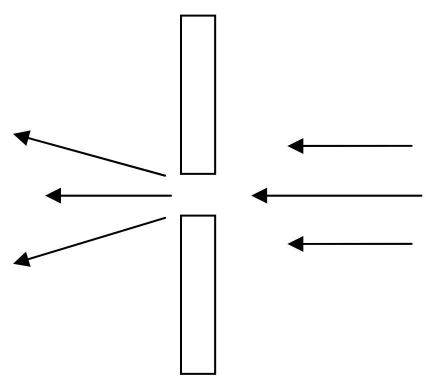

Figure 10: Infiltraton orifice flow

The volumetric flow rate of an orifice can be calculated as:

$$\dot{V} = V_{air} A \qquad 2.14$$

The discharge coefficient of a single orifice in the turbulent flow regime is nearly constant and its pressure difference can be modeled as:

$$C = \frac{\Delta P}{\frac{1}{2}\rho_{air} V_{air}^2} \qquad 2.15$$

Rearranging for velocity and substituting the equation for volumetric flow rate:

$$\dot{V} = A\sqrt{\frac{\Delta P}{\frac{1}{2}\rho_{air} C}} \qquad 2.16$$

Substituting for the change in pressure:

$$\dot{V} = A\sqrt{\frac{\Delta P}{\frac{1}{2}\rho_{air} C}} = \frac{AV_{air}}{\sqrt{C}} \qquad 2.17$$

The heat loss as a result of infiltration is found to be:

$$\dot{q}_{\inf} = c_p \dot{V} \rho \left(T_{inside} - T_{outside}\right) \qquad 2.18$$

The ASHRAE Fundamentals used a reference wind speed of 15 mph for the reported ACH. As a result, it is necessary to correct for the actual wind speed for the heat loss associated with infiltration.

$$\dot{q}_{\inf} = c_p \dot{V} \rho \left(T_{inside} - T_{outside}\right)\left(\frac{V_{wind}}{V_{reference}}\right) \qquad 2.19$$

If the properties of air are assumed to be constant, the specific heat can be approximated as 0.24 Btu/lb-°F and will have a density of 0.075 lb/ft^3. Equation 2.19 can be simplified to:

$$\dot{q}_{\text{inf}} = (0.018)\dot{V}(T_{inside} - T_{outside})\left(\frac{V_{wind}}{V_{reference}}\right) \qquad 2.20$$

2.3.3 Solar Load

The calculation of the solar load, q_{solar}, requires tedious and complex equations. Furthermore, several factors affect the solar load calculations such as the solar heat gain coefficient (SHGC) of the window, shading devices, interior surfaces, etc. With the complexities involved, the solar load is best calculated using a commercially available software package. Energy 10 will be utilized for the calculation of the solar loads in this study.

2.3.4 Internal Gains

People, lights, refrigerators, etc. all produce energy within the building envelope. Collectively they form the internal load, q_{int}. ASHRAE Fundamentals supplies values to estimate various internal gains.

2.3.5 Domestic Hot Water Production

One of the distinct advantages of a GSHP is the ability to supply a home with hot water. In order for the GSHP to produce hot water, a portion of the energy generated is supplied to the process. The required energy can be found by estimating the average hourly hot water consumption per person, GPH. A value of 16.7 gallons per day per person can be assumed for Iowa.

$$\dot{q}_{DHW} = GPH(T_{out} - T_{in})(c_p)(\rho_{water})N \qquad 2.21$$

Where T_{out} and T_{in} are the exiting and entering domestic hot water temperatures, respectively, to the GSHP and the number of people is represented by N.

2.4 Development of Overall Heat Transfer Coefficient

To determine the sensible heat transfer across the building envelope, Equation 2.7 requires the use and development of a heat transfer coefficient, *U*. The overall heat transfer coefficient, UA, sums all "flow paths" of heat through the building as a result of the conduction process. The building envelope experiences 4 major points of conduction through the envelope: ceiling, wall, window, and the basement.

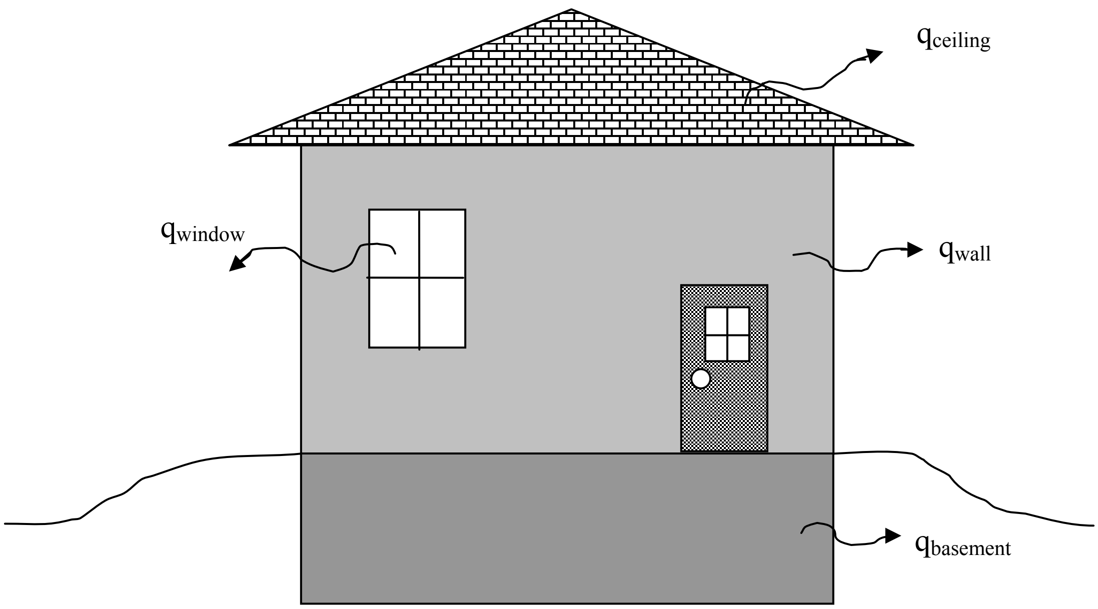

Figure 11: Heat transmission in home

The thermal resistance of most building materials (walls and ceilings) are typically rated using an R-value. The R-value rates the material based on a per unit area basis. These values can be obtained from manufacturers or common tables such as from ASHRAE. Alternatively, heat transfer coefficients or U-values can be used determine the heat transmission. A simple relation between the R-value and U-value is found to be:

$$U = \frac{1}{R} \qquad 2.22$$

If the U-value is multiplied by its respective area, the transmission area for the building envelope is found.

$$UA = \frac{A_{ceiling}}{R_{ceiling}} + \frac{A_{wall}}{R_{wall}} + U_{basement}A_{basement} + U_{window}A_{window} \qquad 2.23$$

2.4.1 International Energy Conservation Code (IECC)

The International Code Council has developed several energy codes for building guidelines. The Department of Energy requires that each state consider adoption of such a code for minimum building energy compliance. At the time of this study, the 2000 IECC was the compliance code for new homes in Iowa. The code provides U-factors and R-values for building materials. The state of Iowa is broken into three zones based on HDD. The following graph depicts the HDD zones for Iowa.

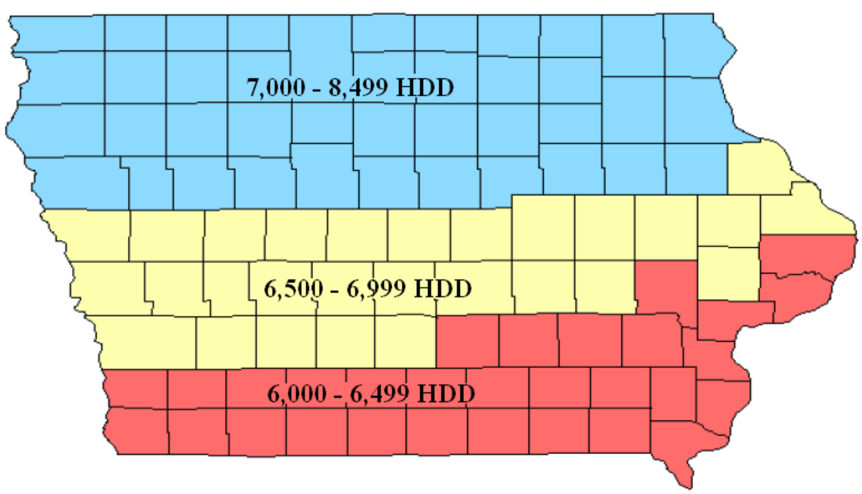

Figure 12: HHD Zones for Iowa

The 2000 IECC provides a table of values for thermal transmittance based on the zone. The values can be used to estimate the thermal transmittance if the actual value is not known. The following table lists those values.

Table 2: 2000 IECC thermal transmittance values

HDD	6,000-6,499	6,500-6,999	7,000-8,499
R_{wall}	18	21	21
$R_{ceiling}$	38	49	49
U_{window}	0.35	0.35	0.35
$U_{basement}$	0.093	0.093	0.095

2.4.2 Prescriptive Method

The 2000 IECC Prescriptive Method uses the window-to-wall ratio along with the annual heating degree days to determine the U- and R-values. The following chart can be used to determine the UA-value for the building.

Table 3: Prescriptive U- and R-values

Window/Wall	HDD	U_{Window}	$R_{Ceiling}$	R_{Wall}	R_{Floor}	$R_{Basement}$	R_{Slab}
0.08	6000	0.45	38	16	19	10	7
	6500	0.43	38	16	19	10	7
	7000	0.42	38	16	19	11	8
0.12	6000	0.4	38	18	19	10	6
	6500	0.4	49	21	19	10	7
	7000	0.4	49	21	19	10	9
0.15	6000	0.35	38	18	21	10	9
	6500	0.35	49	21	21	11	11
	7000	0.35	49	21	21	11	11
0.18	6000	0.34	49	22	19	10	14
	6500	0.33	49	22	25	11	
	7000	0.33	49	25	30	15	
0.2	6000	0.31	49	24	19	10	7
	6500	0.3	49	26	21	11	10
	7000	0.3	49	26	21	11	12
0.25	6000	0.25	49	19	21	10	
	6500	0.25	49	19	21	10	9
	7000	0.25	49	19	30	14	

2.4.3 Energy 10

Energy 10 is an energy and HVAC software package that utilizes the physical characteristics of a home to calculate its energy usage and determine a UA-value. The software utilizes Typical Meteorological Year (TMY2) Data to estimate the energy load. The software allows several parameters of the home to be entered and quickly computed. The Energy 10 will serve as an additional means of comparison for the UA-values.

2.5 Cooling Loads

The cooling load, Qcl, can be calculated in a similar manner to that of the heating load. In the cooling load however, certain thermal transmission modes are treated differently since the cooling equipment must now reject heat. The cooling load then becomes:

$$\dot{Q}_{CT} = \dot{q}_{sensible} + \dot{q}_{\inf} + \dot{q}_{solar} + \dot{q}_{\text{int}} - \dot{q}_{DHW} \qquad 2.24$$

2.5.1 Summer Solar Load

The solar energy which enters the home through fenestration adds thermal energy to the space. As such it must be removed by the cooling equipment and adds to the overall cooling load. As explained in the heating load calculations, the solar load is a complex value to compute. The cooling solar load, q_{solar}, will be calculated in the same manner as the heating solar load utilizing Energy 10.

2.5.2 Summer Infiltration Loads

Similar to winter infiltration, summer infiltration creates a sensible load on the building envelop that must be removed. In addition, summer infiltration consists of a latent load as a result of humidity removal.

$$\dot{q}_{\inf.} = \dot{q}_{latent} + \dot{q}_{sensible} \qquad 2.25$$

An ACH method can be utilized to calculate the summer infiltration load. ASHRAE has developed summer ACH values based on outdoor temperatures and construction type utilizing an outdoor wind speed of 7.5 mph. These values are displayed in Table 4.

Table 4: Winter ACH based on construction type and air temperature (ASHRAE Fundamentals, 2001)

	Outdoor Temperatures					
Construction Type	**85°F**	**90°F**	**95°F**	**100°F**	**105°F**	**110°F**
Loose	0.68	0.7	0.72	0.74	0.37	0.78
Medium	0.46	0.48	0.5	0.52	0.54	0.56
Tight	0.33	0.34	0.72	0.36	0.76	0.78

Graphing the values, equations of best fit can be developed.

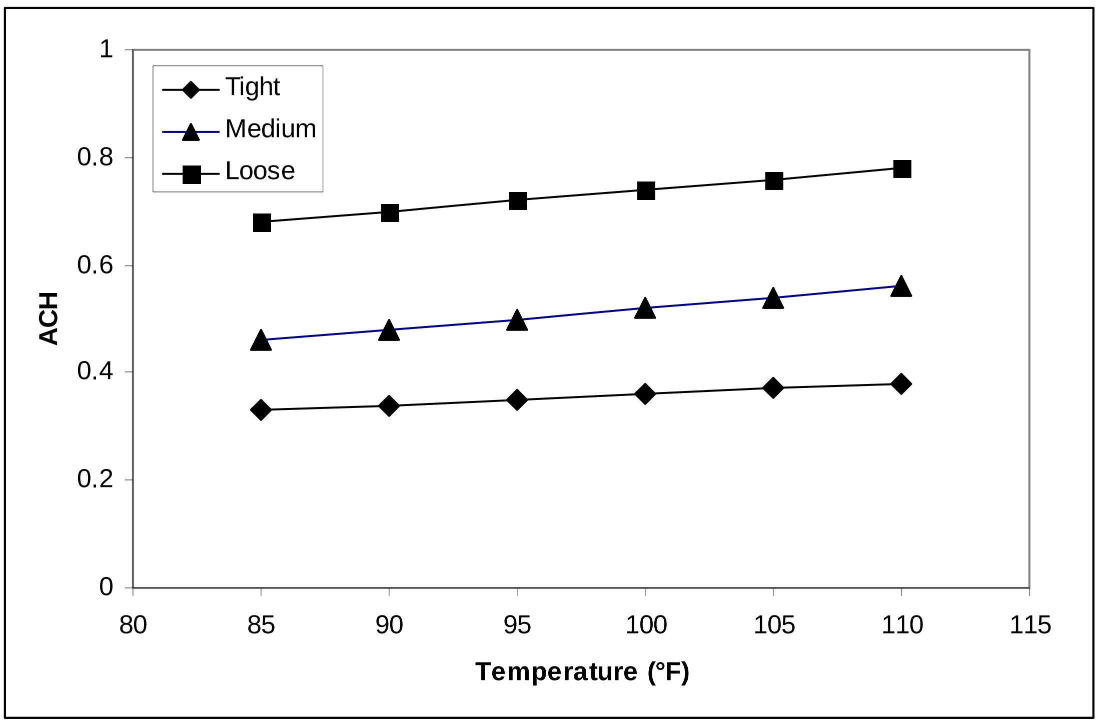

Figure 13: Winter ACH

The linear relationships are each construction type can then found to be:

Tight: $ACH = 0.002T_O + 0.16$ 2.26

Medium: $ACH = 0.004T_O + 0.12$ 2.27

Loose: $ACH = 0.004T_O + 0.34$ 2.28

Utilizing a representative ACH, Equation 2.29 can be used to calculate the sensible heat gain as a result of infiltration.

$$\dot{q}_{sensible} = (0.018)\dot{V}(T_{inside} - T_{outside})\left(\frac{V_{wind}}{7.5mph}\right) \quad 2.29$$

The latent load of the infiltration can be simplified to a latent factor, LF, which can be used as multiplier to the sensible heat gain.

$$\dot{q}_{\inf.} = LF(\dot{q}_{sensible}) \quad 2.30$$

ASHRAE has developed a set of equations to determine the latent factor based on design humidity ratio, WI, and construction type. Humidity ratio can be defined as the ratio of the water vapor mass in moist air to the mass of dry air.

Tight: $LF = 0.65 + 35\mathrm{WI}$ 2.31

Medium: $LF = 0.58 + 42\mathrm{WI}$ 2.32

Loose: $LF = 0.46 + 54\mathrm{WI}$ 2.33

The design humidity ratio for Iowa is 0.017 $lb_{water}/lb_{dry\ air}$. The latent factors for Iowa are then 1.256, 1.294, and 1.378 for tight, medium, and loose constructions, respectively (AHSRAE FUNDAMENTALS, 2001).

While it is possible to determine the latent load of infiltration using ASHRAE standards, a closer examination presents problems within calculation. The outside air temperature in Equation 2.29 represents an average. The typical average daily temperature for an Iowa summer can range from 70°F to 75°F. Many homes have indoor temperatures which would be in similar range to the outdoor temperature. With such a small, average temperature difference, a minimal driving force is created for infiltration. The calculated infiltration is almost negligible although daily temperatures could easily reach 90°F to 100°F generating a large infiltration load. A simulation of each home will be done using Energy 10 and TMY2 data to account for the summer infiltration effect.

2.6 Economics Comparison

Homes currently use various types of heating and cooling equipment ranging from fuel oil furnaces, natural gas furnaces, propane furnaces, electric heat, air source heat pumps, direct expansion air conditioners and even corn burners. One of the most common types of heating equipment, though, is the natural gas furnace. For cost comparison purposes, the GSHP will be compared to a natural gas furnace assuming that the envelope load remains constant for both systems. Currently available natural gas furnaces have annual fuel utilization efficiencies (AFUE) ranging from the Department of Energy's minimum standard of 78% up to highly efficient 97% furnaces. A commonly installed efficiency is 93%, which will be used for comparison to GSHPs.

Utility companies provide natural gas rated on a dollars per therm basis. To determine the cost of using a natural gas furnace, the efficiency of the furnace must be accounted for.

$$Q_{required}\left(\text{Btu}\right) = \frac{Q_{load}\left(\text{Btu}\right)}{\eta_{furnace}} \qquad 2.34$$

The cost of natural gas can now be calculated using Equation 2.35.

$$Cost = \left(\frac{Cost}{therm}\right)\left(\frac{therm}{100{,}000\,Btu}\right)Q_{load}\left(Btu\right) \qquad 2.35$$

The monthly electric utility bills will be used to determine the cost of utilizing a heat pump. The utility bill measures the electricity delivered to the GSHP, taking into account the efficiency of the unit.

$$Cost = \left(\frac{Cost}{kWh}\right)\left(kWh\right) \qquad 2.36$$

To promote the installation of GSHPs, some utility companies will give electrical rate reductions. Two methods are commonly applied. The first method uses two electrical meters, one to measure the GSHP use and one to measure the remainder of the home's electrical use. The meter for the GSHP is then given a separate, lower rate than the rest of the home. In the second method, a staged rate is applied to a single meter taking into account both the GSHP and remainder of the home's electricity. The method will apply a rate up to certain demand, after that demand is met, the remainder of all electrical use is provided at a lower rate. It is common for electrical companies to have two- or three-stage rate structures. Using the rate structures an annual cost to run the GSHP can be found. Taking the difference between the cost of the conventional heating and cooling system with that of the GSHP provides the annual dollar savings.

A certain amount of complexity is introduced to economics comparisons when the home experiences "shoulder" months where nights may appear to require heating and days could require cooling. To account for this situation, the Iowa Energy Center (IEC) has developed a simple tool to analyze homes for comparison on a yearly basis. One metric is the energy cost index (ECI). The ECI sums the yearly cost to heat the home and pro rates it per square foot.

$$ECI = \frac{\sum_{yearly} Cost}{Area} \qquad 2.37$$

Similarly, the site energy utilization index (EUI) can be found. The EUI defines the annual energy used per square foot of home.

$$EUI = \frac{\sum_{yearly} Energy}{Area} \qquad 2.38$$

Homes equipped with natural gas furnaces and DX cooling equipment were monitored by the IEC over the same period of time as the homes in this study. The two groups of homes will be compared on the basis of ECI and EUI.

CHAPTER 3 RESULTS AND DISCUSSION

3.1 Home Selection

The Iowa State University research team of Dr. Francine Battaglia and Joseph Foster identified several potential homes throughout the state of Iowa equipped with GSHPs. Of the homes identified, 32 were chosen to be part of the GSHP study. To maintain consistently in the study, the homes were selected based on several levels of criteria. One of the key criterions was the home was constructed close to the year 2000. This criterion established that the heat pump was functioning properly and had experienced at least one cycle of heating and cooling before monitoring began. Furthermore, having homes near the same age ensured some basic consistency in construction and construction materials. Homes were limited to two common styles: Ranch and 2-story. The ground-source heat pumps in the homes were all water-to-air systems, with 16 units being vertical loops and 16 horizontal loops. Homes were selected throughout the entire state to get a representative data set. Table 5 (Foster, 2005) gives a description of each home.

Table 5: Description of homes

County	Year Built	Style	GSHP Orientation
Benton	1998	2-Story	Horizontal
Calhoun	2001	Ranch	Vertical
Clarke	1997	Ranch	Vertical
	2000	2-Story	Vertical
	1998	Ranch	Vertical
Decatur	1999	Ranch	Horizontal
Lee	1999	2-Story	Horizontal
Dubuque	2001	2-Story	Horizontal
	1998	Ranch	Horizontal
	2001	Ranch	Horizontal
	1997	2-Story	Horizontal
	2001	2-Story	Vertical
	2001	Ranch	Vertical
Fayette	1998	2-Story	Horizontal
Greene	1999	Ranch	Vertical
Ida	2000	Ranch	Vertical
Iowa	2001	Ranch	Vertical
Johnson	1999	Ranch	Horizontal
	2001	Ranch	Horizontal
	2000	Ranch	Horizontal
	1998	Ranch	Horizontal
	2001	Ranch	Vertical
Jones	2000	Ranch	Horizontal
Linn	2001	Ranch	Horizontal
Marshall	2001	Ranch	Vertical
Plymouth	1998	Ranch	Vertical
Polk	1997	Ranch	Vertical
Union	2000	Ranch	Vertical
	2001	Ranch	Vertical

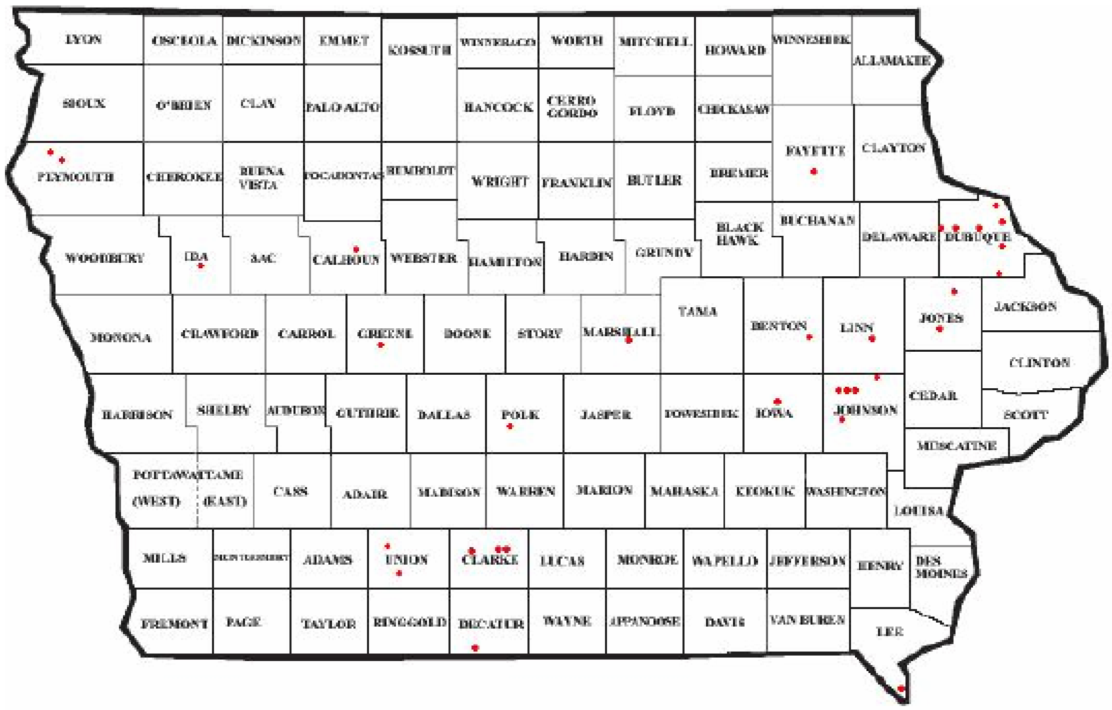

Figure 14: Distribution of homes

As seen in Figure 14, homes were distributed throughout the three climate regions of Iowa.

On-site energy audits were conducted by Foster to gain building characteristics of each home. The homes were evaluated for window area, wall and attic insulation, floor area, wall construction, and home orientation. Additionally, the GSHP model and features were obtained during the site visit.

Table 6 (Foster) provides a summary of each home's building characteristics. For purposes of data processing and homeowner anonymity, a labeling system was developed. The first letter, "H" or "V", indicates a horizontal- or vertical-loop system. The following character indicates if the system was equipped with a desuperheater, denoted by a "1" or the absence of a desuperheater denoted by "0". The final number is a counter of the particular home in the study.

Table 6: Building characteristics of homes

Home Number	Age	Style	Floor Area (ft2)	Exterior Wall Area (ft2)	Ceiling R-Value	Window Area (ft2)
H-1-2	4	Ranch	1250	1409	46	326.15
H-1-3	6	Ranch	1506	1980	52	218.7
H-0-4	7	2-Story	3107	2980	46	298.47
H-0-5	4	Ranch	2279	2167	38	394.69
H-1-7	6	2-Story	3685	3784	38	500.25
H-1-8	5	Ranch	1800	2011	38	331.53
H-1-10	8	2-Story	2598	2751	55	283.92
H-1-11	4	Ranch	2048	1875	44	277.29
H-1-12	7	Ranch	1515	1232	36	276.83
H-1-13	5	Ranch	1654	1191	40	126.37
H-0-14	4	2-Story	2282	2411	38	385.46
H-1-15	7	Ranch	1735	2144	38	420.71
H-1-16	6	Ranch	2404	1573	38	310.66
H-1-17	5	Ranch	2024	1632	38	202.74
H-0-18	7	2-Story	3988	3518	29	425.13
H-1-20	8	2-Story	2866	2781	59	304.87
V-1-1	4	Ranch	2283	2001	55	157.92
V-1-2	4	Ranch	1500	1605	35	213.26
V-1-4	5	2-Story	1257	2725	30	185.37
V-1-5	4	Ranch	1483	1810	60	173.68
V-1-6	4	2-Story	2889	2294	29	256.94
V-1-7	7	Ranch	2053	1529	38	201.14
V-1-8	7	Ranch	1350	1537	48	179.78
V-1-9	8	Ranch	1837	1429	35	188.39
V-1-11	7	Ranch	1800	1440	35	151.46
V-1-12	5	Ranch	2067	1376	38	194.79
V-1-13	5	Ranch	1650	1400	43	113.27
V-0-14	4	Ranch	1554	1336	40	227.85
V-1-16	4	Ranch	2069	1744	25	246.32
V-0-17	4	Ranch	2218	1824	55	336.13
V-1-18	8	Ranch	1874	1696	60	354.58
V-1-20	6	Ranch	2408	1834	52	366.08

3.2 Collection of Electrical Usage

Working closely with both the utility companies and homeowners, Foster collected electrical data for each home. The monthly electrical usage was found for years 2002-2004. The homes equipped with one-meter required the electrical usage to be separated from the general household use and the GSHP use. The two-metered homes were used as a base comparison to determine the GSHP electrical use for a one-meter home. Figure 15 shows a sample two-meter home.

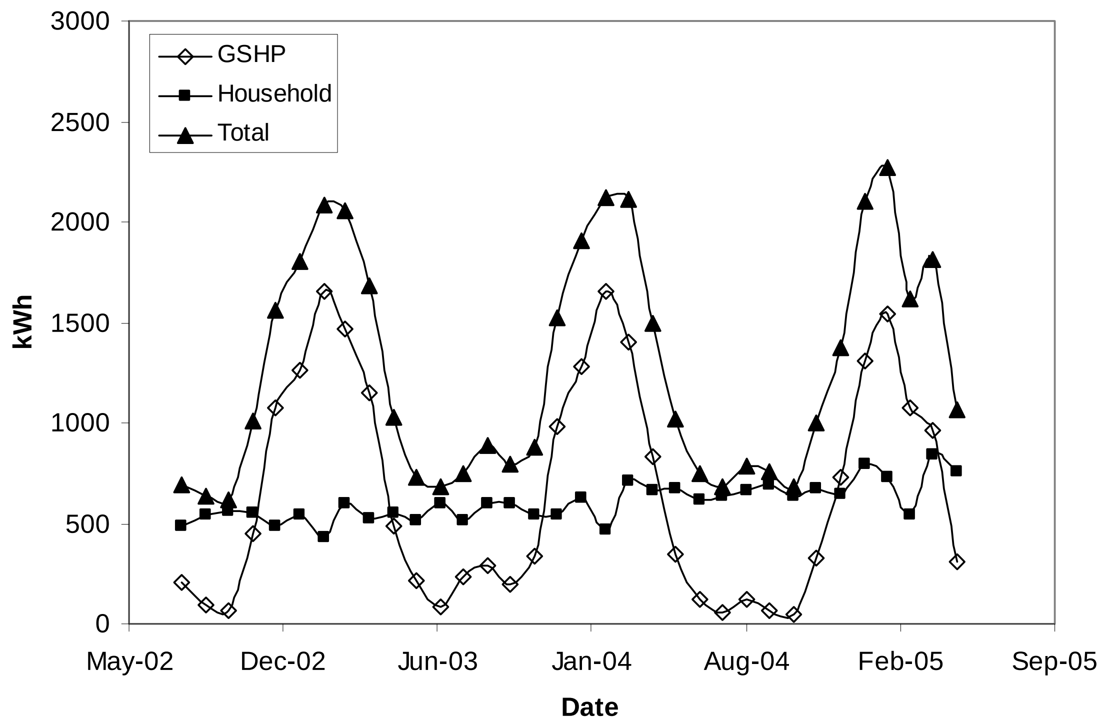

Figure 15: Electrical use for a sample two-meter home

The graph of a two-meter homes shows that the household electrical usage maintains a consistent level regardless of the time of year. It can also be seen that the GSHP appears to have times of the year where it is minimally used. These months can be considered transitional months where the home requires little heating or cooling. The same phenomenon occurs for the electrical usage in a one-metered home.

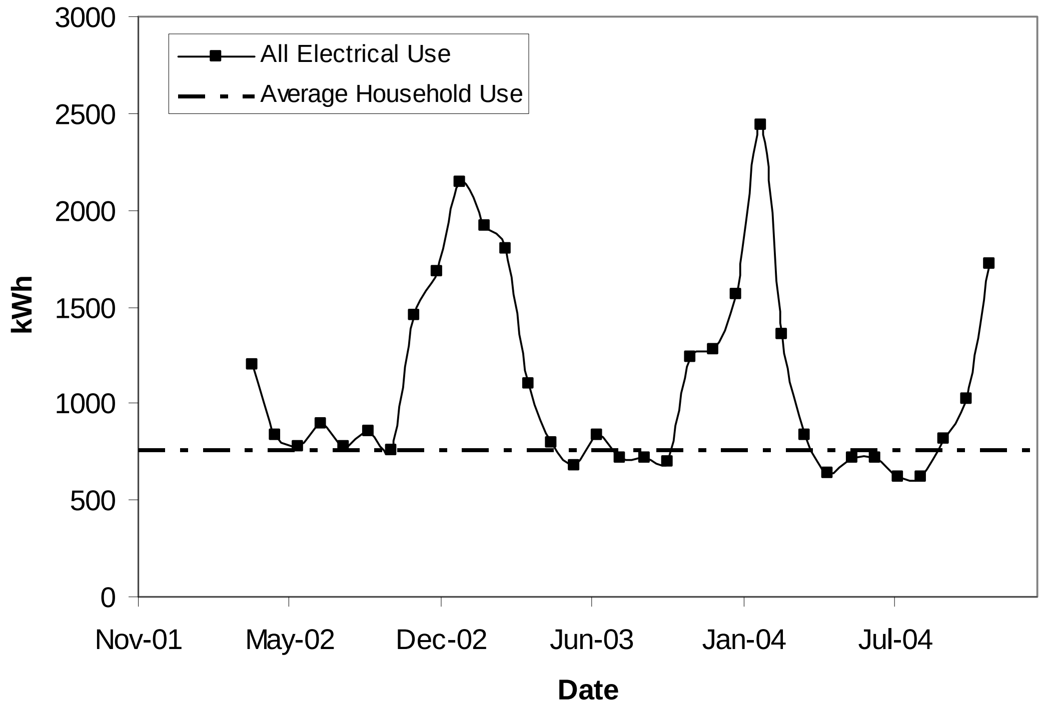

Figure 16: Sample one-meter home electrical use with household baseline

If the transitional months are averaged, a good estimation of the household electrical use can be found. The GSHP electrical use can then be found by subtracting the average household use from the total use.

$$W_{\mathrm{GSHP}} = W_{\mathrm{Total}} - W_{\mathrm{Average\,Transitional}} \qquad 3.1$$

The following graph of a two-metered home illustrates the difference between actual GSHP electrical use and the predicted method presented above.

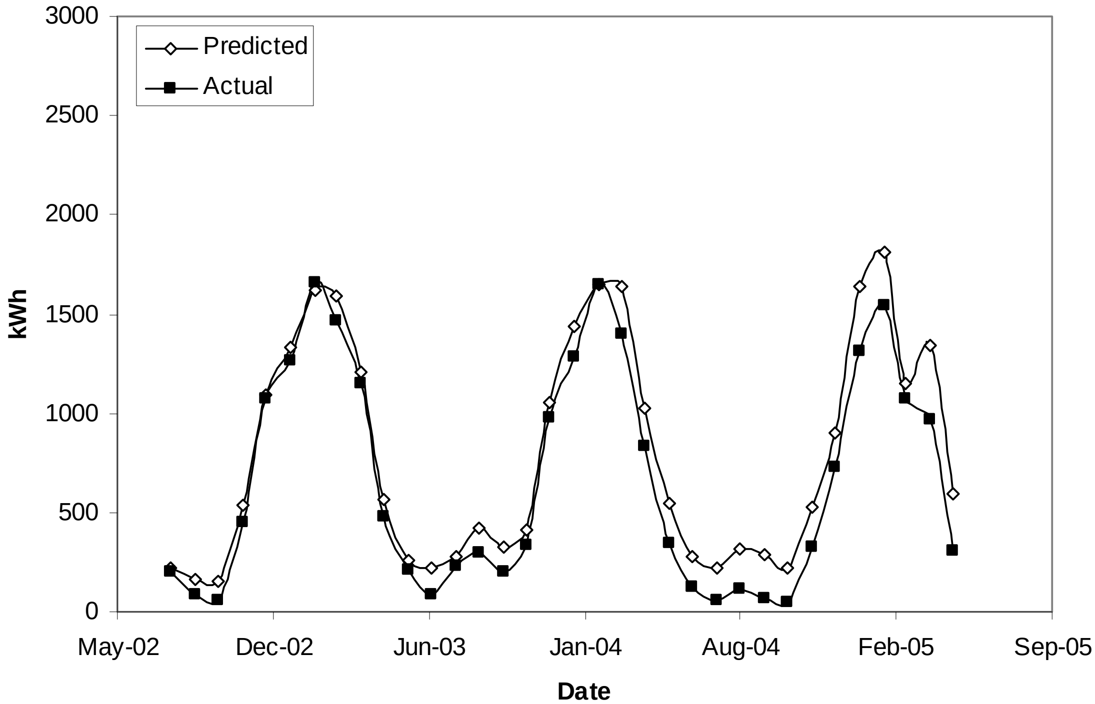

Figure 17: Actual and predicted electrical use for a sample two-meter home

The above graph displays a close correlation between the actual and predicted GSHP electrical use supporting the method developed. All one-meter homes will have this methodology applied to determine GSHP electrical use. The graphs also show that the months to consider for heating and cooling calculations should be November through March for winter months and June through August for summer. The remaining months will be considered transitional months and not be part of any load calculation.

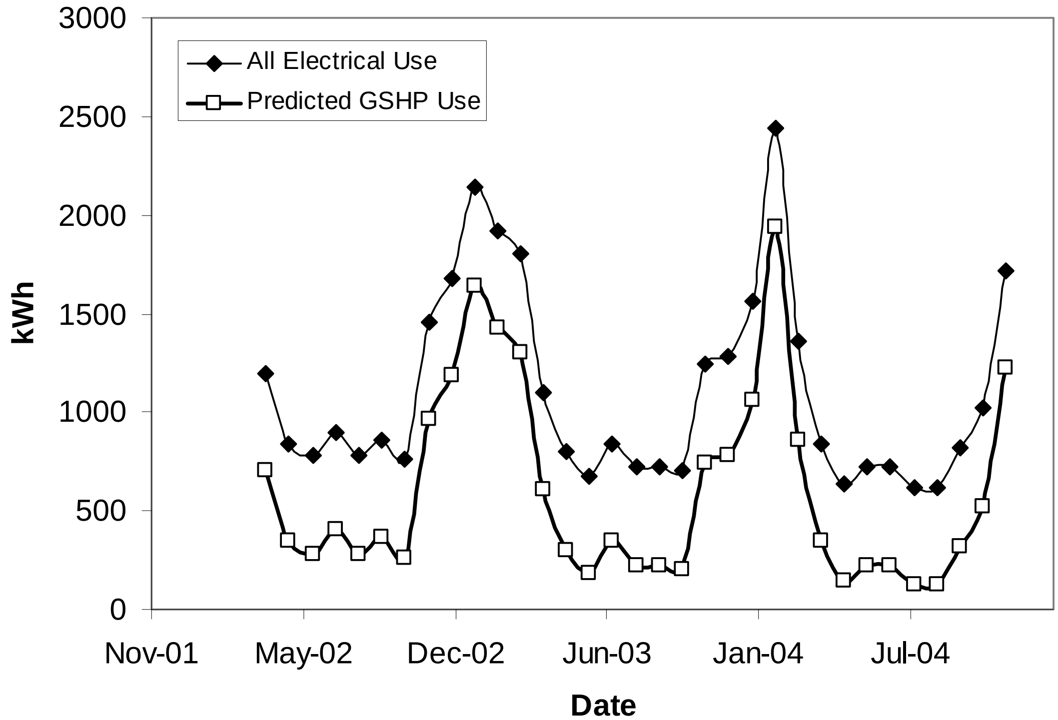

Figure 18: All electrical use and predicted GSHP use for a sample one-meter home

3.3 Weather Data

The National Oceanic and Atmospheric Administration (NOAA) tracks and collects weather data from across the United States. NOAA provides annual summaries including HDD, CDD, average temperatures and wind speeds, all of which are required to perform load calculations for the homes. Data are available for several locations throughout the state of Iowa. The home's climate data were chosen based on the closet available location (National Climate Data Center, 2004).

The Energy 10 simulation software utilizes typical meteorological year data (TMY2). TMY2 data represents a collection of selected weather data from 1961 to 1990 to describe a locations "typical" weather. TMY2 data attempts to summarize the extremes in weather while also maintaining average conditions for the location. This study utilizes both TMY2 data and actual weather data to develop load calculations. Foster found an average percent difference of 6.6% between the TMY2 data and actual data. The small difference makes using the two data types in combination justifiable (Foster, 2005).

3.4 Calculation of the Overall Heat Transfer Coefficient

The various methods presented in the load calculation section were employed to develop overall heat transfer coefficients, UA. During the re-evaluation process, it was discovered that the basement walls were accounted for but the basement slab was not examined. To account for the additional loading as a result of the floor, ASHRAE Fundamentals 2001 was consulted. Assuming the basements are approximately 7 foot below grade, a U-factor of 0.03 Btu/hr-ft^2-°F provides a close approximation for all homes used in the study. Equation 2.23 for the UA value becomes:

$$UA = \frac{A_{ceiling}}{R_{ceiling}} + \frac{A_{wall}}{R_{wall}} + U_{basement} A_{basement} + U_{window} A_{window} + U_{Floor} A_{Floor} \qquad 3.2$$

The addition of the basement floor creates a significant change in the UA-value. Using a normalized percent difference, Equation 3.3, the old and new UA-values can be compared.

$$\%_{Difference} = 2\left| \frac{UA_{old} - UA_{new}}{UA_{old} + UA_{new}} \right| \qquad 3.3$$

Table 7: UA comparison with/without basement slab

	Known UA Values		
	Without Basement Floor	With Basement Slab	Percent Difference
H-1-2	347	384	10.2%
H-1-3	317	362	13.2%
H-0-4	460	516	11.5%
H-0-5	425	487	13.7%
H-1-7	645	718	10.8%
H-1-8	420	474	12.2%
H-1-10	361	403	10.9%
H-1-11	355	407	13.6%
H-1-12	326	368	12.2%
H-1-13	281	332	16.7%
H-0-14	433	480	10.3%
H-1-15	518	570	9.5%
H-1-16	410	482	16.2%
H-1-17	320	372	14.9%
H-0-18	520	579	10.8%
H-1-20	449	508	12.4%

	Known UA Values		
	Without Basement Floor	With Basement Slab	Percent Difference
V-1-1	396	465	15.9%
V-1-2	347	412	17.1%
V-1-4	386	424	9.4%
V-1-5	313	357	13.2%
V-1-6	431	497	14.2%
V-1-7	373	434	15.1%
V-1-8	309	349	12.3%
V-1-9	331	386	15.3%
V-1-11	318	372	15.7%
V-1-12	316	378	18.0%
V-1-13	292	342	15.7%
V-0-14	285	311	8.8%
V-1-16	433	495	13.4%
V-0-17	451	512	12.6%
V-1-18	412	468	12.8%
V-1-20	427	493	14.3%

Energy 10 requires that a user supply specific inputs which could easily vary from user to user. As a result, it was decided to not re-evaluate the Energy 10 results and use the values found by Foster. Table 8 depicts the UA-values found for the re-evaluation of the four methods.

Table 8: Re-evaluated UA-values using all methods

	UA Values			
	2000 IECC	**Prescriptive Method**	**Energy 10**	**Known Values**
H-1-2	487	336	411	384
H-1-3	497	396	385	362
H-0-4	729	438	525	516
H-0-5	636	636	457	487
H-1-7	977	638	645	718
H-1-8	612	440	469	474
H-1-10	602	330	477	403
H-1-11	543	405	388	407
H-1-12	450	316	331	368
H-1-13	416	358	313	332
H-0-14	645	429	537	480
H-1-15	717	455	638	570
H-1-16	590	438	421	482
H-1-17	483	361	397	372
H-0-18	803	462	650	579
H-1-20	717	418	516	508
V-1-1	620	498	461	465
V-1-2	532	399	439	412
V-1-4	602	399	409	424
V-1-5	496	403	355	357
V-1-6	643	397	451	497
V-1-7	539	427	425	434
V-1-8	462	330	354	349
V-1-9	480	374	369	386
V-1-11	467	396	360	372
V-1-12	487	320	353	378
V-1-13	442	357	358	342
V-0-14	405	263	379	311
V-1-16	586	460	482	495
V-0-17	655	423	397	512
V-1-18	603	420	490	468
V-1-20	635	438	410	493

During the evaluation process, the 2000 IECC method was found to have R-values for walls and ceilings that lead to high UA-values. The UA-value generated by the prescriptive method was found to be significantly lower as a result of high R-values for the wall. Furthermore, the Energy 10 and known UA-values generally fell between the other two methods and were relatively close to one another. As a result, an average of the Energy 10 and known UA were used. Table 9 shows the average and percent difference of the Energy 10 and known UA-values.

Table 9: Average UA-value and percent difference

	UA Values			
Home	Energy 10	Known Values	Average	Percent Difference
H-1-2	411	384	398	6.7%
H-1-3	385	362	373	6.2%
H-0-4	525	516	520	1.8%
H-0-5	457	487	472	6.5%
H-1-7	645	718	682	10.8%
H-1-8	469	474	472	1.1%
H-1-10	477	403	440	16.9%
H-1-11	388	407	397	4.8%
H-1-12	331	368	350	10.6%
H-1-13	313	332	323	5.9%
H-0-14	537	480	508	11.2%
H-1-15	638	570	604	11.3%
H-1-16	421	482	452	13.6%
H-1-17	397	372	384	6.6%
H-0-18	650	579	615	11.5%
H-1-20	516	508	512	1.5%

	UA Values			
Home	Energy 10	Known Values	Average	Percent Difference
V-1-1	461	465	463	0.8%
V-1-2	439	412	425	6.4%
V-1-4	409	424	416	3.6%
V-1-5	355	357	356	0.7%
V-1-6	451	497	474	9.7%
V-1-7	425	434	430	2.1%
V-1-8	354	349	352	1.3%
V-1-9	369	386	377	4.5%
V-1-11	360	372	366	3.4%
V-1-12	353	378	366	6.9%
V-1-13	358	342	350	4.5%
V-0-14	379	311	345	19.5%
V-1-16	482	495	489	2.7%
V-0-17	397	512	454	25.2%
V-1-18	490	468	479	4.5%
V-1-20	410	493	451	18.3%

3.5 Infiltration Comparison

Investigation into the construction type was conducted. Reviewing the home audits from the original study, only one home owner knew the Energy Star rating of their home. This led to the question of whether the homes were being properly modeled with consideration to their construction type. The original analysis considered all homes to have a tight rating.

Information regarding construction types was reviewed using ASHRAE Fundamentals 2001 and 2005 along with Air Conditioning Contractors of America (ACCA)

Manual J. All three sources listed very stringent criteria for tight homes, e.g., construction supervised by air-sealing specialist, single story, all penetrations sealed. Alternatively, a medium rating for a home required a significantly less amount of building requirements, e.g., two-story, greater then 1500 ft^2, older then 10 years.

The Tight/Medium and Loose/Medium rating was developed by interpolating between the respective ASHRAE established ACH values.

Tight/Medium: $ACH = -0.003T_O + 0.7$ 3.4

Loose/Medium: $ACH = -0.004T_O + 1.1$ 3.5

Table 10 demonstrates the effect each construction type has on the percent of infiltration in the heat loss calculation. Based on these results and the criteria of ASHRAE and ACCA J, the analyses will use a Tight/Medium construction to best represent the homes used in the study.

Table 10: Construction type comparison

	Construction Type				
Home	Loose	Loose/Med.	Medium	Tight/Med.	Tight
H-1-2	33.5%	29.3%	24.5%	20.4%	16.0%
H-1-3	40.1%	35.6%	30.2%	25.6%	20.3%
H-0-4	47.4%	42.5%	36.7%	31.5%	25.4%
H-0-5	42.6%	37.9%	32.4%	27.5%	21.9%
H-1-7	48.5%	43.6%	37.6%	32.4%	26.2%
H-1-8	41.1%	36.4%	31.0%	26.3%	20.8%
H-1-10	46.5%	41.7%	36.1%	30.9%	24.8%
H-1-11	42.2%	37.6%	32.1%	27.3%	21.7%
H-1-12	40.1%	35.6%	30.3%	25.6%	20.3%
H-1-13	43.5%	38.9%	33.3%	28.4%	22.6%
H-0-14	40.8%	36.2%	30.9%	26.1%	20.7%
H-1-15	28.9%	25.1%	20.8%	17.2%	13.3%
H-1-16	42.9%	38.2%	32.6%	27.8%	22.1%
H-1-17	45.2%	40.4%	34.7%	29.7%	23.8%
H-0-18	46.8%	42.0%	36.3%	31.2%	25.1%
H-1-20	43.5%	38.8%	33.3%	28.3%	22.6%
V-1-1	39.8%	35.2%	30.0%	25.3%	20.0%
V-1-2	40.3%	35.7%	30.3%	25.6%	20.3%
V-1-4	34.2%	29.9%	25.1%	21.0%	16.4%
V-1-5	38.4%	33.8%	28.6%	24.1%	19.0%
V-1-6	48.4%	43.6%	37.9%	32.6%	26.3%
V-1-7	36.3%	32.1%	27.3%	23.1%	18.3%
V-1-8	39.7%	35.2%	30.1%	25.5%	20.3%
V-1-9	40.8%	36.2%	30.8%	26.1%	20.7%
V-1-11	40.4%	35.9%	30.5%	25.8%	20.4%
V-1-12	42.2%	37.5%	32.1%	27.2%	21.7%
V-1-13	39.7%	35.3%	30.2%	25.6%	20.4%
V-0-14	41.2%	36.6%	31.2%	26.5%	21.0%
V-1-16	39.5%	34.9%	29.7%	25.1%	19.8%
V-0-17	41.9%	37.2%	31.8%	27.0%	21.4%
V-1-18	33.4%	29.2%	24.5%	20.4%	16.0%
V-1-20	44.4%	39.7%	34.1%	29.1%	23.2%

3.6 Performance Data

The heating and cooling performance data were calculated for the 32 homes over the 2 years of data collected. The building loads were calculated using Equation 2.24. The utility usage collected along with the load could then be directly substituted into Equation 2.4 to find the cooling performance.

Figure 19 shows the CDD for a sample home. The graphs shows cooling peaks occur during the months of July, August, and September. During other months the unit would run at partial loads or not at all. As a result only those 3 months will be evaluated.

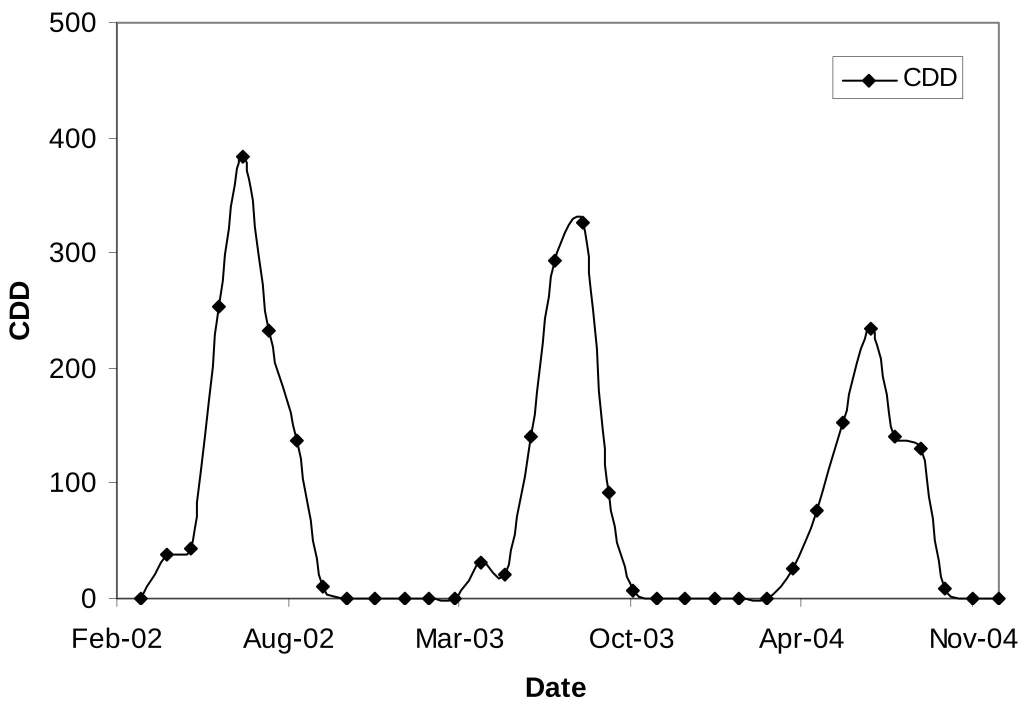

Figure 19: Sample home CDD

Table 11: Cooling EER

	Cooling EER			
Homes	**Minimum**	**Maximum**	**Average**	**ARI/ISO Rating**
H-1-2	15.96	24.53	20.28	--------
H-1-3	11.56	23.93	15.98	13.10
H-0-4	8.78	43.39	22.37	21.21
H-0-5	15.09	124.01	51.74	21.21
H-1-7	5.19	16.74	10.99	--------
H-1-8	2.46	12.22	7.33	--------
H-1-10	5.86	30.41	15.28	--------
H-1-11	8.54	29.49	14.78	17.21
H-1-12	7.80	25.31	17.69	18.71
H-1-13	10.08	25.97	17.78	18.71
H-0-14	8.12	20.37	14.21	13.70
H-1-15	29.39	103.97	62.21	--------
H-1-16	11.19	41.73	22.28	--------
H-1-17	8.76	46.50	22.93	--------
H-0-18	4.52	31.92	18.94	11.70
H-1-20	11.42	53.17	25.86	--------

	Cooling EER			
Homes	**Minimum**	**Maximum**	**Average**	**ARI/ISO Rating**
V-1-1	7.61	11.40	9.49	17.31
V-1-2	2.78	12.82	9.16	17.21
V-1-4	17.10	90.00	50.65	15.60
V-1-5	5.32	9.77	7.34	17.31
V-1-6	6.02	16.46	12.14	18.71
V-1-7	9.13	22.49	14.46	--------
V-1-8	5.89	10.66	7.84	--------
V-1-9	18.03	25.20	22.11	--------
V-1-11	8.19	15.28	10.85	--------
V-1-12	0.64	26.57	11.20	--------
V-1-13	5.62	8.02	6.67	15.80
V-0-14	11.78	20.62	15.86	15.40
V-1-16	10.87	33.21	19.02	15.40
V-0-17	25.59	40.58	32.59	21.21
V-1-18	12.16	28.78	20.97	--------
V-1-20	9.79	16.17	12.16	--------

Table 11 shows the calculated cooling EER for the all homes. The result shows extreme swings between the minimum and maximum EER. Furthermore, the averages can be extremely high when compared with the ARI/ISO rating benchmark as seen in Figure 20. It is evident that the cooling performance calculations are drastically affected by homeowner’s summer use. This is most likely a result of occupants being on vacation during the summer months or simply not using mechanical cooling. Figure 21 supports this suggestion showing that even though the cooling load is increasing, the electrical load stays nearly constant.

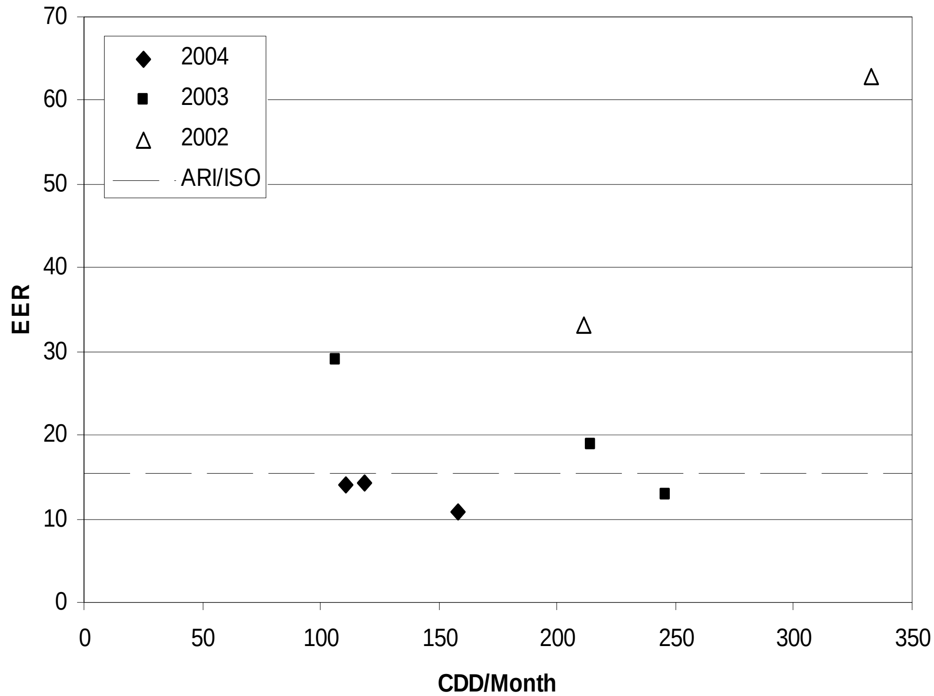

Figure 20: Sample home EER versus CDD/Month

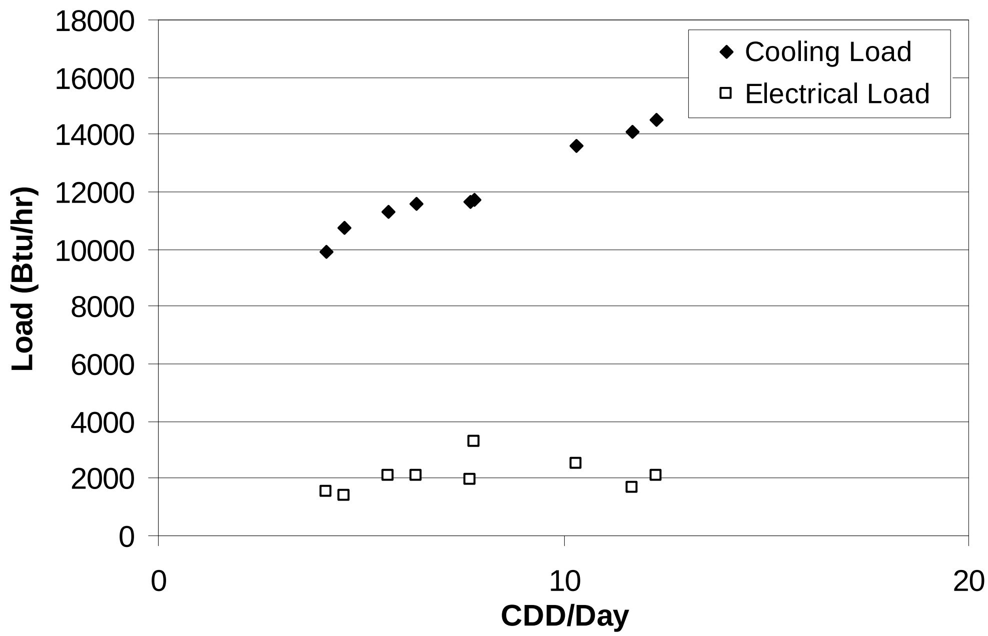

Figure 21: Sample Load versus CDD/Day

Table 12: Cooling EER Comparison

	All	Vertical	Horizontal
Average	19.47	16.41	22.54
Std. Dev.	13.12	11.38	14.36

The comparison of the loop systems, reveal a performance advantage using the horizontal loop system. With the large standard deviations and uncertainty in the data, little support can be given to the validity of this conclusion.

The heating COP evaluation was completed using the winter utility information converted to a Btu/hr rate. Figure 22, shows the annual HDD for a typical home. Months November through March were selected for heating evaluation as they appeared to be the heating dominant months. While other months still may experience HDD, homeowners may not necessarily utilize the GSHP because the temperatures are still comfortable.

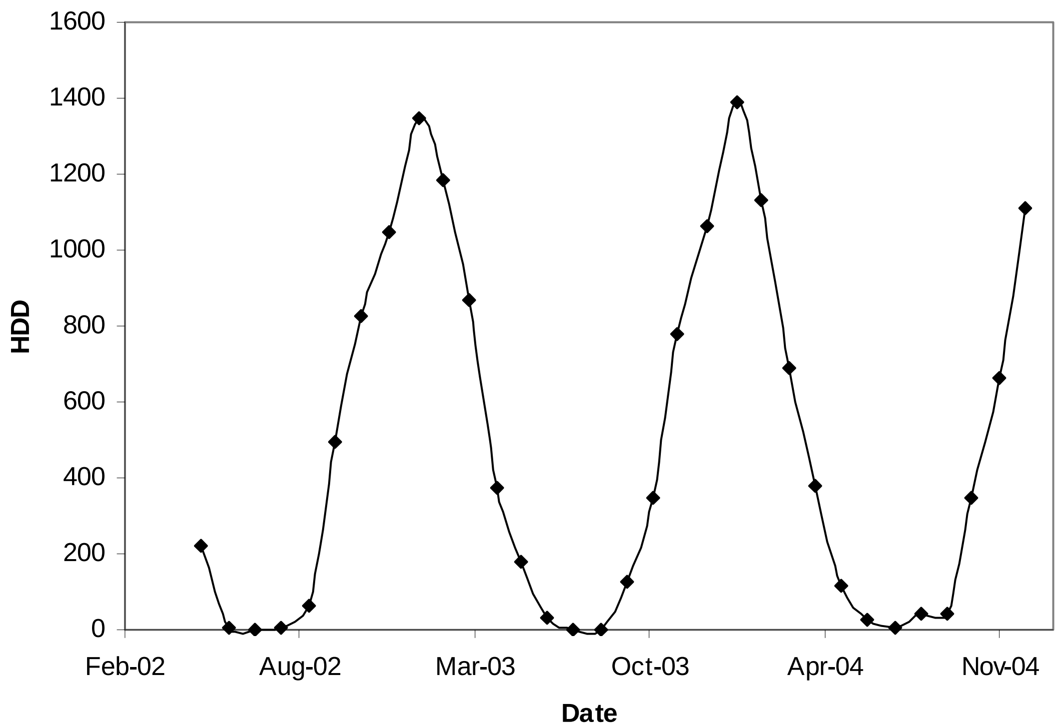

Figure 22: Sample home HDD

Table 13: Heating COP summary

	Minimum	Maximum	Average	ARI/ISO Rating
H-1-2	1.28	2.87	2.23	-----
H-1-3	2.23	3.19	2.77	3.3
H-0-4	2.56	3.23	2.87	4.2
H-0-5	2.53	4.49	3.43	4.2
H-1-7	0.90	1.94	1.37	-----
H-1-8	1.76	3.74	2.52	-----
H-1-10	2.14	4.03	2.97	-----
H-1-11	2.83	6.79	4.75	3.5
H-1-12	3.99	4.54	4.27	4
H-1-13	2.28	4.17	3.19	4
H-0-14	2.02	4.70	3.10	3.4
H-1-15	1.50	3.51	2.04	-----
H-1-16	2.51	3.65	3.13	-----
H-1-17	1.53	3.60	2.45	-----
H-0-18	2.70	3.89	3.31	3.3
H-1-20	2.20	6.04	3.60	-----

	Minimum	Maximum	Average	ARI/ISO Rating
V-1-1	2.83	3.86	3.44	3.8
V-1-2	1.63	8.56	4.44	3.5
V-1-4	2.78	3.07	2.92	3.7
V-1-5	2.37	3.78	3.09	3.8
V-1-6	2.08	3.87	2.83	4
V-1-7	1.93	3.47	2.82	-----
V-1-8	3.48	3.96	3.76	-----
V-1-9	3.28	4.27	3.66	-----
V-1-11	3.15	3.97	3.52	-----
V-1-12	3.55	5.19	4.28	-----
V-1-13	2.51	3.48	3.05	3.5
V-0-14	1.99	2.92	2.52	3.4
V-1-16	1.70	3.10	2.29	3.4
V-0-17	1.87	4.20	2.76	4.2
V-1-18	2.84	3.86	3.37	-----
V-1-20	1.88	2.49	2.13	-----

Table 14: Heating COP comparison

	All	Vertical	Horizontal
Average	3.09	3.18	3.00
Std. Dev.	0.74	0.66	0.82

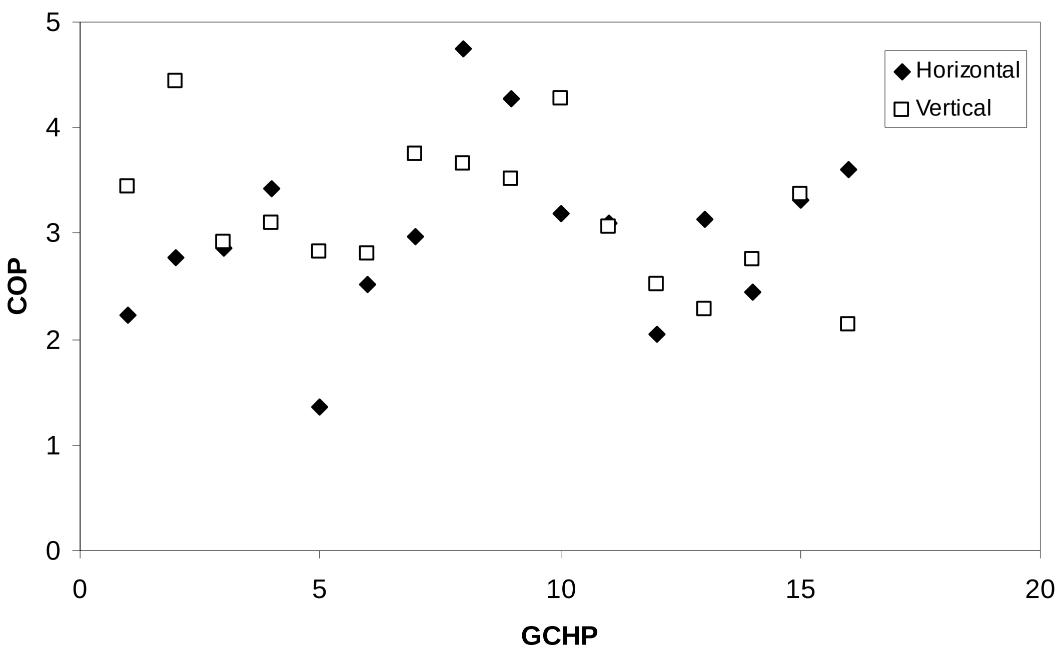

Figure 23: Horizontal and vertical average COP

The average heating COP reveals a slight performance advantage when using a vertical loop system. However, the standard deviations for each system overlap making the difference negligible. The small standard deviations also provide confidence in the heating load calculations and COPs. Figure 24 shows that when benchmarking COP values calculated against the ARI/ISO rating, a correlation is found. On average, the calculated COPs were about 90% of the rated ARI/ISO rating. Figures in Appendix A show the COP benchmarking for each home. When no ARI/ISO rating was found, the rating was set to 0.

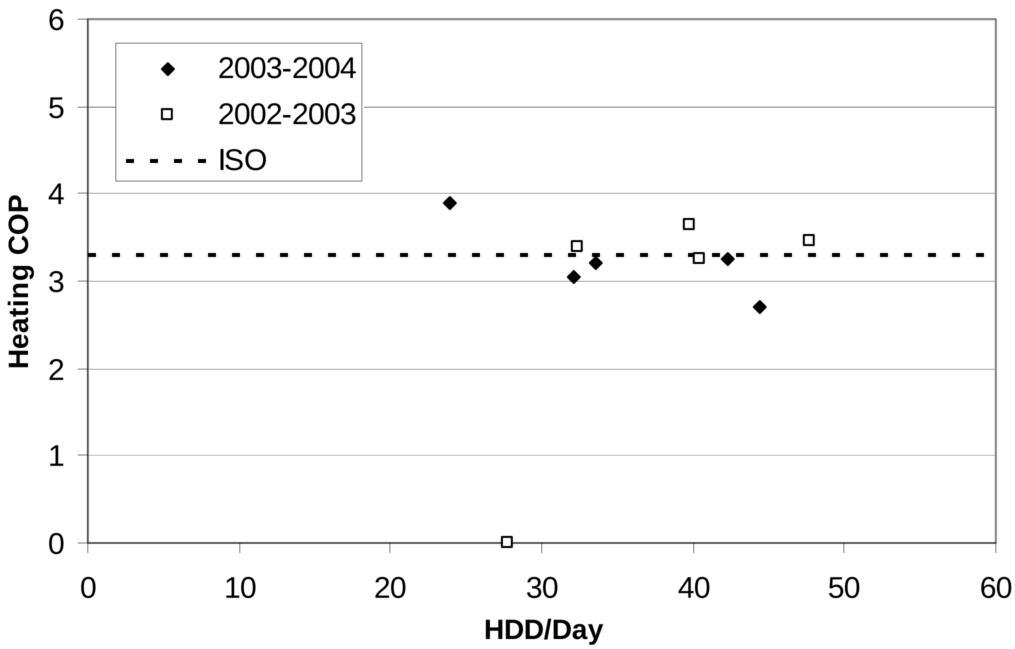

Figure 24: Sample home monthly heating COP

Figure 25 shows that the electrical and heating load increases as HDD/Day increase. This expected trend supports the correction made to the 1-meter homes.

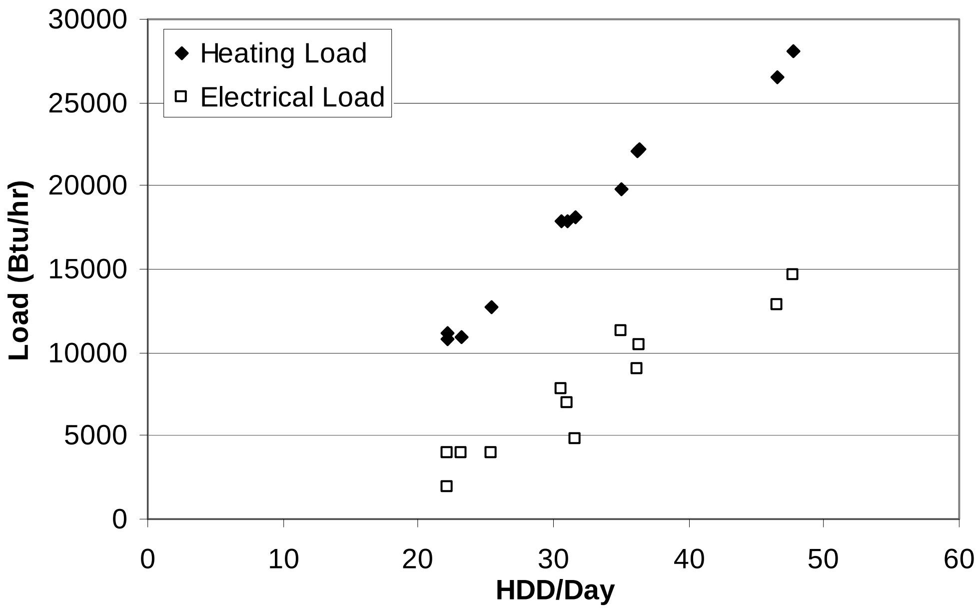

Figure 25: Sample home heating and electrical load versus HDD/Day

Figure 26 was generated to give a visual representation of the average heating COP for each home by location. The COPs appeared to have little correlation to a specific location throughout the sate.

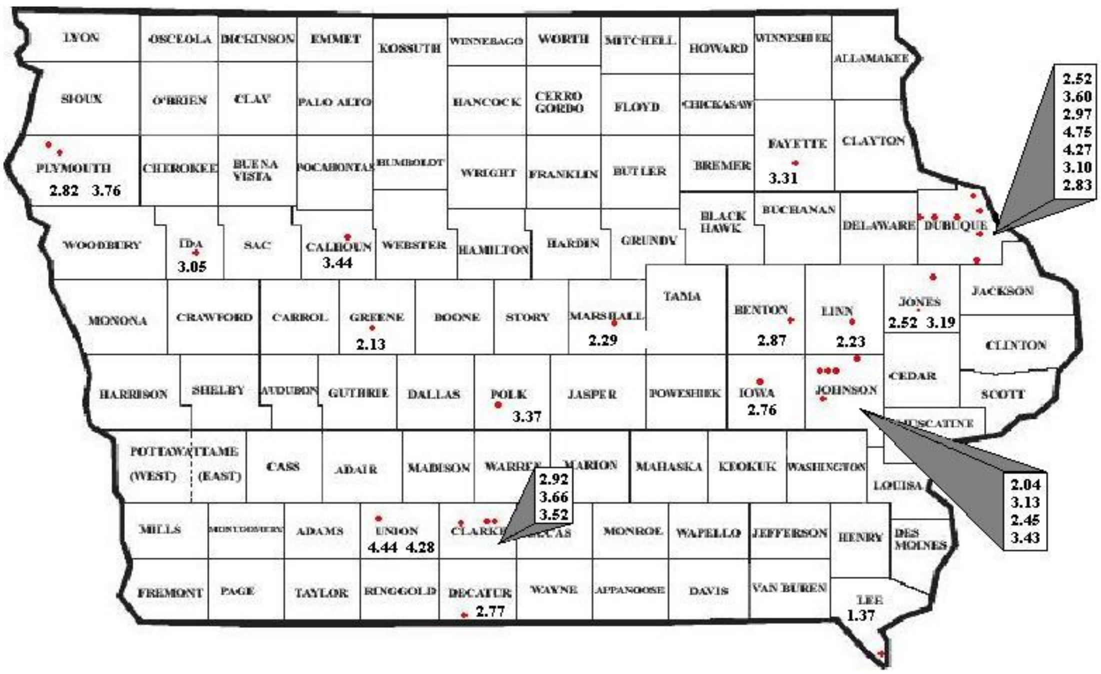

Figure 26: COP locations throughout the state

3.7 Performance Comparisons: ARI and ISO

Manufacturers rate their equipment based on standards set by the Air Conditioning Research Institute (ARI). ARI established the ARI 330 rating for GSHPs. The ARI 330 rating evaluated GSHP based on 32°F entering water temperature (EWT) for heating and 77°F EWT for cooling. The ARI 330 standard, however, did not include performance penalties for pumps and fans. In 2000, ARI established the ARI/ASHRAE/ISO 13256-1 standard for GSHPs which maintained the EWT but introduced penalties for circulating pumps and fans. With the introduction of the penalties, many units experienced a higher COP and EER rating. It should be noted that the performance ratings are evaluated for average national heating and cooling conditions. The ARI/ISO data are not intended for comparison in actual operation but for a comparison amongst manufacturers during the purchasing process.

Since the homes in this study were constructed shortly before or after the year 2000, many of the GSHP manufacturers were in the transition between the two performance rating systems. As a result, the original study by Foster reported a mixture of performance ratings between the ARI 330 and ARI/ASHRAE/ISO 13256-1 standards. An effort was made to separate these two standards and update where appropriate. Since many of the homes were constructed before 2000, ARI/ISO ratings simply do not exist for the unit. Conversely, only ARI/ISO performance data was available for homes built after 2000.

The following table displays the ARI 330 and the ARI/ISO COP ratings found for the units in this study.

Table 15: ARI and ARI/ISO COP ratings

Home	ARI 330	ARI/ISO	Calculated COP
H-1-2	----	----	2.23
H-1-3	3.1	3.3	2.77
H-0-4	3.2	4.2	2.87
H-0-5	3.2	4.2	3.43
H-1-7	----	----	1.37
H-1-8	3.1	----	2.52
H-1-10	3.0	----	2.97
H-1-11	----	3.5	4.75
H-1-12	----	4.0	4.27
H-1-13	----	4.0	3.19
H-0-14	----	3.4	3.1
H-1-15	3.1	----	2.04
H-1-16	3.1	----	3.13
H-1-17	3.1	----	2.45
H-0-18	3.0	3.3	3.31
H-1-20	3.1	----	3.6

Home	ARI 330	ARI/ISO	Calculated COP
V-1-1	----	3.8	3.44
V-1-2	----	3.5	4.44
V-1-4	----	3.7	2.92
V-1-5	----	3.8	3.09
V-1-6	----	4.0	2.83
V-1-7	3.1	----	2.82
V-1-8	3.1	----	3.76
V-1-9	3.1	----	3.66
V-1-11	3.0	----	3.52
V-1-12	3.0	----	4.28
V-1-13	3.0	3.5	3.05
V-0-14	3.2	3.4	2.52
V-1-16	3.2	3.4	2.29
V-0-17	3.2	4.2	2.76
V-1-18	----	----	3.37
V-1-20	3.0	----	2.13

3.8 Fouling/Degradation

Any mechanical system will experience fouling or degradation with time and use. A GSHP is not exempt from this effect. An interesting result of this study is the comparison between yearly performance data of each unit.

Table 16: Annual COP comparison

	Annual COP		Difference		Annual COP		Difference
Home	02-03	03-04	(Recent-Old)	Home	02-03	03-04	(Recent-Old)
H-1-2	2.19	2.01	-0.19	V-1-1	3.48	3.02	-0.46
H-1-3	2.87	2.67	-0.20	V-1-2	4.33	4.55	0.23
H-0-4	3.03	2.86	-0.17	V-1-4	2.81	2.92	0.11
H-0-5	3.46	3.40	-0.06	V-1-5	3.10	3.08	-0.02
H-1-7	1.50	1.23	-0.26	V-1-6	2.89	3.45	0.56
H-1-8	2.27	3.26	0.99	V-1-7	2.90	2.73	-0.17
H-1-10	3.11	3.25	0.14	V-1-8	3.76	3.65	-0.10
H-1-11	5.21	4.29	-0.92	V-1-9	3.80	3.22	-0.58
H-1-12	4.31	5.71	1.40	V-1-11	3.42	3.62	0.20
H-1-13	3.20	3.18	-0.03	V-1-12	4.17	4.40	0.23
H-0-14	2.81	3.39	0.58	V-1-13	3.26	3.06	-0.20
H-1-15	2.65	1.85	-0.81	V-0-14	2.59	2.45	-0.14
H-1-16	3.09	3.16	0.07	V-1-16	2.27	2.31	0.04
H-1-17	2.53	2.38	-0.15	V-0-17	2.45	3.06	0.61
H-0-18	3.89	3.22	-0.67	V-1-18	3.33	3.16	-0.17
H-1-20	5.05	3.12	-1.92	V-1-20	2.11	2.33	0.22

When comparing 03-04 to 02-03 data, the majority of the homes show a drop in the COP. Some of drops were significant, nearing 2 COP. While many factors such as weather and occupants influence these values, the question arises as to how fast a GSHP loses its ability to efficiently perform and what factors contribute, e.g. mechanical, loop fouling, etc. While only two heating seasons could be evaluated, the data create reason to further evaluate the systems for longer periods of time to establish a trend.

3.8 Cost Analysis

The dollar savings were calculated for a GSHP compared to a natural gas furnace. Only the heating savings were calculated as result of the lack of confidence in the cooling data. As seen in the COP calculations, the months of November through March experienced most of the heating loads. During the other months homeowners may utilize alternative heating schedules giving inaccurate data.

During utility data collection, the rate structure for each home was also collected. It was determined for a 1-meter home, the average rate structures is as follows:

Table 17: 1-meter electrical rate structure

Electrical Use	0-500 kWh	500-1017 kWh	> 1017 kWh
Average Rate	$0.0703	$0.0618	$0.0361

During the evaluation of the 2-metered home's electrical usage for GSHPs, it was determined that a home would generally use a similar amount of monthly electricity whether the system was running or not. From the analysis, it is reasonable to assume that the home would consume the first 500 kWh to power such things as TVs, computers, stoves, etc. All additional electrical is consumed by the GSHP. Adjusting for the household electrical consumption, a rate structure for the GSHPs with 1-meter can be developed.

Table 18: GSHP rate structure

Electrical Use	517 kWh	>517 kWh
Average Rate	$0.0618	$0.0361

The rate structure for 2-metered homes could be directly averaged from the GSHP meter. The average rate was found to be $0.0357 per kWh. It was determined from the Iowa Department of Natural Resources that the average natural gas price was $1.42 per therm for 2004-2005. Each home was evaluated using the 1- and 2-meter rate structure for comparison purposes. Table 19 summarizes the heating savings for horizontal loop systems and Table 20 summarizes vertical loop systems.

Table 19: Horizontal loop cost savings

	November 2002-March 2003					November 2003-March 2004				
		1-Meter		2-Meter			1-Meter		2-Meter	
Home	Natual Gas Cost	Cost	Savings	Cost	Savings	Natual Gas Cost	Cost	Savings	Cost	Savings
H-1-2	$567.22	$240.50	$326.71	$172.20	$395.01	$514.10	$208.18	$305.92	$153.38	$360.72
H-1-3	$773.40	$253.72	$519.68	$185.28	$588.11	$769.99	$267.42	$502.57	$198.85	$571.14
H-0-4	$1,126.09	$323.19	$802.90	$267.21	$858.88	$1,301.25	$380.93	$920.32	$311.20	$990.05
H-0-5	$971.66	$266.99	$704.67	$198.42	$773.24	$973.83	$262.62	$711.20	$194.10	$779.73
H-1-7	$1,309.02	$712.21	$596.81	$639.07	$669.94	$1,214.74	$752.07	$462.67	$678.52	$536.21
H-1-8	$1,278.07	$493.00	$785.08	$408.94	$869.13	$1,089.53	$362.25	$727.28	$292.70	$796.82
H-1-10	$1,118.74	$332.28	$786.47	$263.04	$855.71	$787.14	$248.49	$538.65	$193.28	$593.86
H-1-11	$1,061.18	$211.51	$849.66	$143.51	$917.66	$1,000.43	$233.88	$766.55	$165.65	$834.78
H-1-12	$912.11	$213.68	$698.43	$145.66	$766.45	$751.76	$177.29	$574.47	$122.81	$628.95
H-1-13	$864.97	$256.24	$608.73	$187.78	$677.18	$806.11	$251.91	$554.20	$183.50	$622.61
H-0-14	$1,069.68	$354.35	$715.33	$284.89	$784.80	$1,009.42	$286.54	$722.88	$217.77	$791.65
H-1-15	$931.49	$369.07	$562.42	$312.62	$618.87	$1,029.91	$457.87	$572.03	$387.35	$642.56
H-1-16	$936.88	$275.61	$661.27	$206.95	$729.93	$941.11	$277.27	$663.84	$208.60	$732.51
H-1-17	$925.36	$324.77	$600.59	$255.61	$669.75	$917.67	$346.45	$571.22	$277.07	$640.60
H-0-18	$1,405.79	$338.16	$1,067.63	$282.03	$1,123.76	$1,562.18	$415.94	$1,146.24	$345.84	$1,216.34
H-1-20	$1,113.91	$253.51	$860.40	$198.24	$915.67	$1,180.00	$327.79	$852.21	$258.59	$921.41
Average	$1,022.85	$326.17	$696.67	$259.47	$763.38	$990.57	$328.56	$662.02	$261.83	$728.75

Table 20: Vertical loop savings

	November 2002-March 2003					November 2003-March 2004				
		1-Meter		2-Meter			1-Meter		2-Meter	
Home	Natual Gas Cost	Cost	Savings	Cost	Savings	Natual Gas Cost	Cost	Savings	Cost	Savings
V-1-1	$1,259.68	$316.41	$943.28	$247.33	$1,012.35	$1,067.85	$273.06	$794.79	$217.59	$850.26
V-1-2	$943.15	$238.21	$704.95	$169.93	$773.22	$916.82	$217.47	$699.36	$149.40	$767.42
V-1-4	$828.72	$249.94	$578.78	$194.71	$634.01	$942.12	$288.02	$654.10	$219.23	$722.88
V-1-5	$782.49	$241.63	$540.85	$173.32	$609.16	$771.14	$237.70	$533.44	$169.43	$601.71
V-1-6	$1,344.97	$403.41	$941.56	$333.44	$1,011.53	$1,069.99	$328.96	$741.03	$272.93	$797.07
V-1-7	$1,031.54	$316.77	$714.78	$247.69	$783.85	$995.16	$323.22	$671.94	$254.08	$741.08
V-1-8	$861.18	$225.94	$635.24	$157.79	$703.38	$746.13	$189.91	$556.21	$135.30	$610.82
V-1-9	$863.91	$223.13	$640.78	$155.01	$708.90	$734.71	$199.11	$535.60	$144.41	$590.31
V-1-11	$947.14	$259.67	$687.47	$191.17	$755.97	$921.91	$246.39	$675.51	$178.04	$743.87
V-1-12	$894.09	$214.36	$679.73	$146.33	$747.75	$885.06	$206.97	$678.09	$139.02	$746.04
V-1-13	$723.38	$217.69	$505.70	$162.79	$560.59	$910.67	$269.95	$640.72	$201.35	$709.32
V-0-14	$864.64	$301.43	$563.22	$232.51	$632.14	$844.53	$301.03	$543.50	$232.11	$612.42
V-1-16	$1,170.60	$437.13	$733.47	$366.82	$803.78	$1,131.95	$419.82	$712.14	$349.68	$782.27
V-0-17	$925.36	$301.51	$623.85	$232.59	$692.78	$819.09	$261.11	$557.98	$192.60	$626.49
V-1-18	$922.09	$262.10	$659.99	$193.58	$728.51	$806.18	$216.45	$589.73	$345.84	$460.33
V-1-20	$1,186.95	$461.91	$725.04	$391.34	$795.60	$1,013.83	$384.19	$629.64	$327.58	$686.24
Average	$971.87	$291.95	$679.92	$224.77	$747.10	$911.07	$272.71	$638.36	$220.54	$690.53

Table 21: Average dollar savings

	1-Meter			2-Meter			Average
	02-03	03-04	Average	02-03	03-04	Average	Difference
Vertical	$696.67	$662.02	$679.35	$763.38	$728.75	$746.06	$66.72
Horizontal	$679.92	$638.36	$659.14	$747.10	$690.53	$718.81	$59.68
All	$688.30	$650.19	$669.24	$755.24	$709.64	$732.44	$63.20

Depending on the meter type installed, homes averaged between approximately $670 and $730 per heating season in savings. The vertical loop homes showed a slight economic advantage over the horizontal loop homes.

3.9 Energy Cost Index and Energy Utilization Index Comparison

Utilizing the energy cost index (ECI) and energy utilization index (EUI), 13 homes analyzed by the Iowa Energy Center (IEC) were compared to the 32 GSHP homes. The 13 homes from IEC were built in similar years as the homes in this study and assumed to have similar building characteristics. The IEC homes were equipped with natural gas furnaces and air conditioners. All homes were evaluated using the same IEC utility rates of 6.86¢ for June through September and 3.58¢ for October through May and a natural gas rate of $1.42 per therm. The Table 22 summarizes the results of the comparison. The IEC homes carry a label of “IEC.”

The GSHP homes consistently showed a better energy utilization index. As to be expected, the IEC homes consistently cost more to heat and cool on per area basis.

Table 22: Energy Cost and Utilization Index

	EUI (kBtu/sqft-yr)
H-1-20	9.7
H-1-11	10.3
IEC-1	10.4
H-0-18	10.8
V-1-12	10.9
H-0-5	11.2
H-1-16	11.2
H-1-12	11.5
V-0-17	11.6
V-1-9	11.9
H-0-4	12.2
H-1-10	12.6
V-1-6	13.0
V-1-11	13.2
H-1-13	13.8
V-1-2	14.2
V-1-18	14.5
V-1-4	15.4
IEC-2	15.6
V-1-1	15.9
H-1-17	16.0
H-0-14	16.4
IEC-3	16.8
V-1-7	17.2
IEC-4	17.6
H-1-3	18.5
IEC-5	18.9
H-1-2	19.4
IEC-6	19.4
V-0-14	19.4
V-1-20	19.5
IEC-7	19.5
IEC-8	19.7
IEC-9	20.1
V-1-13	20.2
V-1-8	20.6
V-1-5	20.7
IEC-10	20.9
V-1-16	21.4
H-1-7	22.4
IEC-11	22.5
H-1-8	22.9
H-1-15	25.8
IEC-12	26.7
IEC-13	32.0

	ECI (¢/ sqft-yr)
H-1-20	11.3
H-1-11	12.4
H-0-18	12.9
V-0-17	13.4
H-1-12	13.5
H-1-16	13.5
V-1-9	14.2
V-1-12	14.5
H-0-4	14.7
H-1-10	14.8
V-1-6	15.1
H-1-13	15.6
H-0-5	16.2
V-1-11	16.3
V-1-4	17.2
V-1-2	17.8
V-1-18	18.1
H-1-17	18.6
V-1-1	19.6
H-0-14	20.2
V-1-7	21.2
H-1-3	23.2
V-0-14	23.4
V-1-20	23.5
H-1-2	23.6
V-1-16	24.8
V-1-13	25.7
H-1-7	26.7
V-1-5	26.9
V-1-8	27.0
H-1-8	27.8
H-1-15	28.4
IEC-1	51.3
IEC-5	63.5
IEC-7	76.1
IEC-3	85.5
IEC-8	86.3
IEC-11	88.4
IEC-4	90.4
IEC-6	90.5
IEC-12	93.1
IEC-2	96.7
IEC-9	101.3
IEC-10	113.7
IEC-13	120.6

3.10 Installer Survey

One of the most frequently asked questions by a prospective GSHP owner is how much an installation will cost. To gain a better understanding of typical installation cost, a survey (Appendix B) was generated to interview Iowa installers. Approximately 75 installers were contacted via email and telephone. Only 6 installers responded to the survey most likely do to the changing prices of equipment and hesitation to openly supply company information for comparison purposes. Additionally, installations can vary vastly from one project to another. As a result it can be difficult to generate an "average" installation cost. The following table summarizes the cost information reported.

Table 23: GSHP installer cost survey

Installer	Unit Cost ($/ton)	Horizontal Loop ($/ton)	Vertical Loop ($/ton)	Pond Loop ($/ton)
1	1,000	1,500	1,800	NA
2	4,000	1,000	1,300	NA
3	2,400	NA	1,500	NA
4	3,000	1,200	1,500	1,200
5	2,625	625	1,500	3,300
6	2,375	NA	1,400	NA

3.11 Homeowner Education

The installation of a ground source heat pump can be an intimidating process for a homeowner. In an effort to answer common homeowner questions and to provide basic heat pump information, the document entitled "A Residential Homeowner's Guide to Ground Source Heat Pumps" was produced (Appendix C). GSHP manuals and websites were used to develop a list of commonly asked question and information sought by prospective GSHP owners. This extensive literature review was summarized in the document. The results of the GSHP performance analysis and installation cost survey were also included in the document. The final product was submitted to the Iowa Energy Center for dissemination at their discretion.

3.12 Homeowner Saving's Estimator

Gaining an accurate representation of a home's annual GSHP dollar savings requires a significant amount of data and a skilled person to analyze it. Yet many homeowners would rely heavily on the projected annual savings to make a decision concerning the installation of a GSHP. Furthermore, by allowing a user to personalize a calculation to their home, the interactivity will impress upon them the potential savings.

Utilizing the data found in this study, a simple estimator was developed to calculate a typical Iowa home's annual dollar savings for a GSHP. Key factors had to be considered before developing such a tool. First, it had to be made apparent the tool would be an estimator and simply get the homeowner in the range of dollar savings they could expect. Second, the calculator had to rely on simple inputs. Homeowners do not universally understand energy calculations and requirements to produce a reliable estimate. As seen in the performance calculations, determination of the cooling load is difficult and will need careful consideration. For presentation purposes, the tool was developed in Excel with a final intent being an online based tool for the IEC.

To maintain simplicity, a heating degree day method will be used. The first step in development of the tool was to estimate a home's UA-value based on the square footage. An average UA was found using the data from the study based on 6 home sizes.

Table 24: UA value based on area

Area (ft^2)	UA
1500	380
2000	430
2500	480
3000	530
3500	590
4000	640

The user has the option to select the approximate area of their home and county in which they reside. The county selection is linked to the average annual HDD experienced in the location. Since the HDD day method does not incorporate loading factors such as solar, internal gains, or infiltration, a correction factor is required. ASHRAE Fundamentals provides for a correction factor to the HDD to account for these parameters.

$$HDD_{adjusted} = \frac{0.07}{4200}(HDD) + 0.65 \qquad 3.6$$

The HDD adjustment is based on the infiltration rating of Tight/Medium, the value experienced by the homes studied. The adjusted HDD can now be used to estimate the annual heating load on the home.

$$Q = HDD_{adjusted}(UA) \qquad 3.7$$

Since it is unreasonable to assume that all homes would fall under the infiltration rating of Tight/Medium, an additional correction factor was made. Using the data from the homes studied, a percent infiltration of the total load was developed. Table 25 describes each construction type and the percentage of load that infiltration creates on it.

Table 25: Infiltration load

Construction Type	Description	% Infiltration
Loose	Old home, poorly maintained, drafty	35%
Medium/Loose	Old home, well maintained	25%
Medium	Slightly older home, requires little infiltration improvements	10%
Tight/Medium	Typical new home	0%
Tight	Infiltration testing completed by specialist	-10%

The infiltration adjustment can now be applied to the load, Q.

$$Q_{adjusted} = (Q)\%_{Infiltration} \qquad 3.8$$

One additional factor can be easily estimated for the load experienced, domestic hot water. The user has the option to select if the GSHP will produce hot water. If selected, equation 2.21 will be used to calculate the estimated hot water production.

Air conditioning can be estimated to be approximately 50% of the heating load. Homeowners who were more conservative about using their air conditioning were approximated at 30% of heating load, and those gone during the summer were set to 0%. Conventional air conditioners were considered for comparison to GSHP. A significantly lower savings should be expected with air conditioning when comparing a GSHP to a conventional air conditioner as performance data in close range to one another. Furthermore, each system uses the same input source, electricity. As such, the rules of thumb for estimating cooling can be considered good approximations.

For comparison purposes to GSHPs, 5 other heating types were selected: natural gas, propane, fuel oil, electric heat, and corn. The option allows users to select the type of fuel they are currently using or would expect to use if not installing a GSHP.

For homeowners who have access to their utility information, an additional selection is provided so that they can enter actual utility information (i.e. therms, gallons, bushels). Utility rates are automatically provided based on current averages but users are allowed to change the input for customization. For comparison purposes, utility rates and fuel cost were set to reflect 2006 averages.

Table 26: Fuel cost

Fuel	Cost
Natural Gas	$1.42 /therm
Propane	$1.48 /gallon
Fuel Oil	$2.28 /gallon
Electric Heat	$0.05 /kWh
Corn	$4.00 /bushel

Each system type has a predefined efficiency associated with it, Table 27, based on an approximate age. The total heat load is divided by the appropriate efficiency to find the required input of the fuel. For example, if the home requires 50 MMBtu for heating and uses a GSHP with a COP of 3.1 then:

$$W_{input} = \frac{50MMBtu}{3.1} = 16.13MMBtu \quad 3.9$$

A 93% efficient gas furnace yields:

$$W_{input} = \frac{50MMBtu}{.93} = 53.76MMBtu \quad 3.10$$

Table 27: Fuel efficiencies

	Fuel Type					
Age	**Natural Gas**	**Propane**	**Fuel Oil**	**Electricity**	**Corn Burner**	**A/C SEER**
Less than 10 years old	93%	93%	90%	100%	75%	16
10 to 20 years old	82%	82%	70%	100%	50%	13
Greater than 20 years old	60%	60%	50%	100%	50%	11

Using the fuels respective energy content per unit, Table 28, the fuel input is multiplied by the cost rate. The difference is found between the cost of the GSHP and the alternative fuel to produce an annual savings.

Table 28: Fuel energy content

Fuel	Energy Content
Natural Gas	100000 Btu/therm
Propane	91600 Btu/gallon
Fuel Oil	13900 Btu/gallon
Electric Heat	3412 Btu/kWh
Corn	392000 Btu/bushel

Figure 27 gives is an example of the calculator using Microsoft Excel.

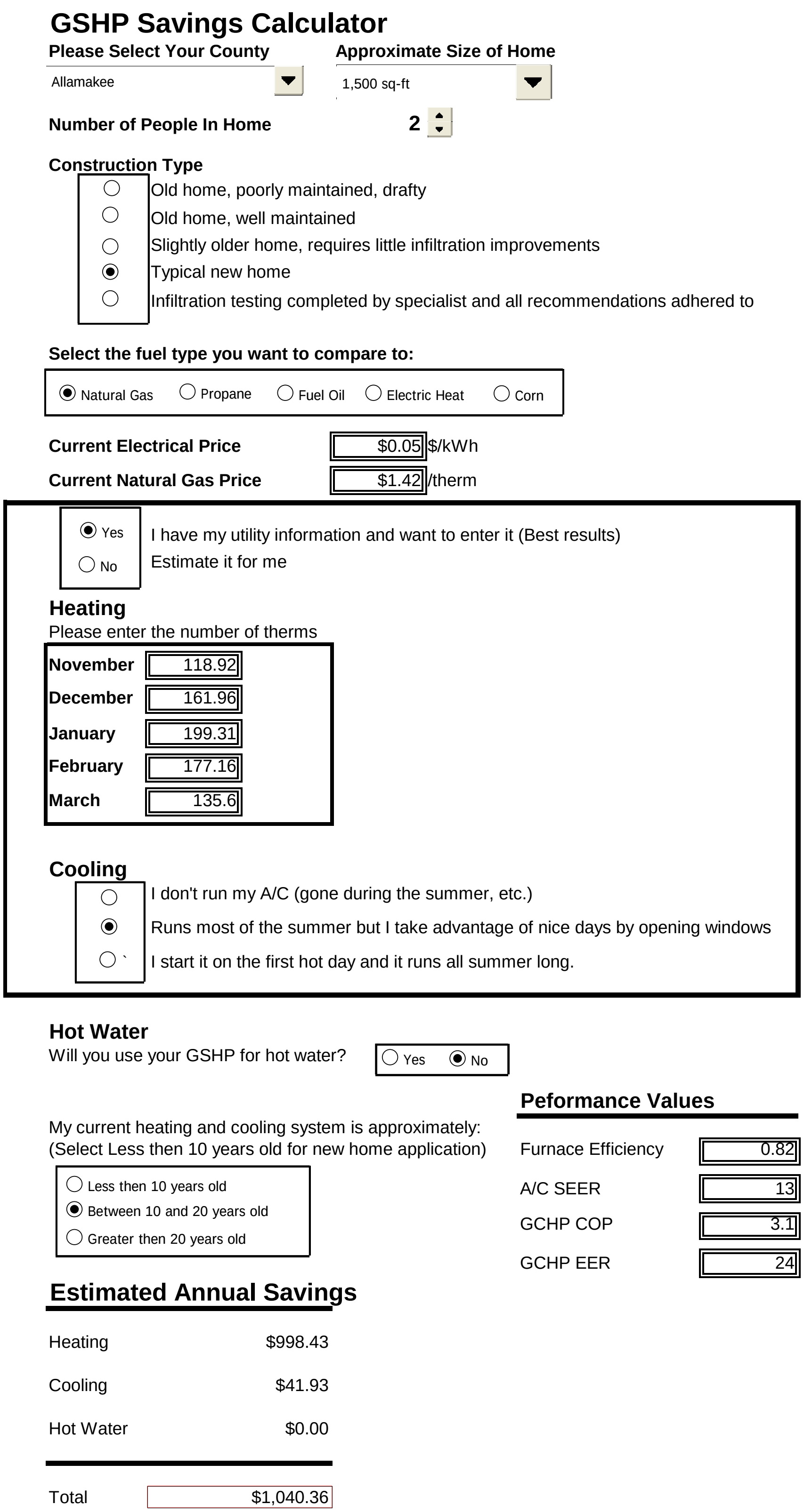

Figure 27: GSHP savings calculator with sample home

3.13 Saving's Estimator Justification

To justify the use of the simplified method presented in the saving's estimator, a comparison was completed between the 2-meter savings of the study and those same homes estimated in the saving's calculator. The 2-metered homes of the study were originally evaluated at $0.0357/kWh. The homes were all adjusted to the $0.05/kWh used in the calculator to maintain a similar cost baseline. Table 29 shows the study savings versus the calculator savings.

Table 29: Study versus calculator savings

Home	Study	Calculator	Percent Difference
H-1-2	$399.79	$502.81	22.83%
H-1-3	$614.72	$727.43	16.80%
H-0-4	$924.47	$943.08	1.99%
H-0-5	$776.48	$730.78	6.06%
H-1-7	$600.34	$1,155.27	63.22%
H-1-8	$937.97	$1,033.58	9.70%
H-1-10	$768.79	$1,033.58	29.38%
H-1-11	$946.86	$1,067.29	11.96%
H-1-12	$718.86	$772.18	7.15%
H-1-13	$673.44	$734.80	8.71%
H-0-14	$788.22	$768.82	2.49%
H-1-15	$651.71	$908.65	32.93%
H-1-16	$754.61	$824.72	8.88%
H-1-17	$678.72	$834.77	20.62%
H-0-18	$1,170.05	$1,143.67	2.28%
H-1-20	$940.46	$995.72	5.71%
V-1-1	$983.42	$1,202.36	20.03%
V-1-2	$794.18	$809.81	1.95%
V-1-4	$720.60	$950.29	27.49%
V-1-5	$640.75	$757.71	16.73%
V-1-6	$936.84	$1,125.86	18.33%
V-1-7	$785.32	$899.40	13.54%
V-1-8	$677.48	$779.61	14.02%
V-1-9	$670.60	$748.03	10.92%
V-1-11	$773.31	$813.21	5.03%
V-1-12	$710.07	$782.54	9.71%
V-1-13	$655.65	$829.53	23.42%
V-0-14	$622.28	$619.08	0.51%
V-1-16	$840.89	$1,068.72	23.86%
V-0-17	$671.37	$594.49	12.15%
V-1-18	$646.92	$896.97	32.39%
V-1-20	$783.23	$1,121.83	35.55%
		Average	16.14%

The comparison found that most of the homes fell within a 20% difference of actual values and estimated calculator values. A few of the homes experienced a large variation in savings, showing that the calculator may not be right for estimating all homes.

CHAPTER 4 SUMMARY AND CONCLUSIONS

4.1 Summary

In this study, Iowa homes equipped with ground source heat pumps were evaluated for energy performance and cost effectiveness. Homes were selected from across the state and selected based on home type (2-story, ranch) to generate a representative data set. Each home's heating and cooling loads were calculated and used in combination with utility information to generate an average performance value. The study utilized two metrics of comparisons: vertical versus horizontal loop GSHP performance and an economics comparison of GSHPs to natural gas furnaces.

Heating and cooling loads were developed using a heating degree day method combined with solar loads, infiltration, and hot water production. Solar loads were generated using the simulation software Energy 10. Infiltration was calculated using average daily temperatures and wind speeds. The hot water production was found by estimating the daily water use of occupants.

To develop an overall heat transfer coefficient for the homes, on-site energy audits were completed to gain the building characteristics of the homes. The overall heat transfer coefficient was found by averaging the known thermal resistance method and values gained from Energy 10.

The internal load generation as a result of occupant levels and equipment generation (television, stoves, etc) could not be accurately calculated. Consequently, the internal loads were omitted from the study.

The manufacturer's performance data were collected for each unit. The manufacturer's data were used for comparison to the performance values found in this study. The comparison also sought to show the difference between the old ARI 330 and the current ARI/ASHRAE/ISO 13256-1 rating.

The information gained in the study was used to prepare an informational document for prospective homeowners of ground-source heat pumps. An additional interactive tool was developed for use by homeowners to financially compare various heating and cooling means with GSHPs.

4.2 Conclusions

Iowa, being a heating dominant climate, creates difficulty in estimating performance calculations for cooling loads. Many homeowners will take advantage of comfortable outside air during the cooling season or possibly leave on vacation. These homeowner effects will generate inaccurate performance data for cooling. In order to gather accurate data, a new method may be required such as instrumenting a GSHP with monitoring equipment.

The study has shown that a vertical loop has an average COP of 3.18 while a horizontal loop has an average COP of 3.00, with a standard deviation of 0.66 and 0.82, respectively. As a result, a negligible performance advantage can be seen by utilizing one system over another in Iowa, helping to limit the number of variables during the loop selection process.

When economically compared to a natural gas furnace, a home equipped with a GSHP can expect to save approximately $670 to $730 per year. This comes as result of the higher energy requirements of a natural gas furnace. Additionally, some utility companies offer lower rates to homes equipped with GSHPs, further lower energy cost.

It was found that there is still a significant amount of discrepancies in manufacturer's performance data. This comes as a result of a change made to performance ratings in 2000. Many manufacturers still have old performance data available leading to inaccurate representations of their equipment. It was found that the new ratings system creates higher performance data as a result of included pumping and fan penalties.

Many homeowners do not understand the technology of ground-source heat pumps. This can significantly lower their interest in perusing a GSHP installation. The generation and availability of a homeowner's guide will give many people the opportunity to fully evaluate their decision.

One major concern of prospective GSHP owners, is the cost of installation and savings. While it was difficult to gain representative installer cost, a reasonable estimation can be quickly found for GSHP savings over alternative heating and cooling methods. The completion of the savings calculator will further enhance a homeowner's ability to make an educated decision on the economic feasibility of a GSHP for their home.

4.3 Recommendations for Future Study

As a recommendation, future studies of GSHPs should be completed to gain data which closer represents actual load conditions. Units should be monitored by collecting entering and leaving water temperatures along with the flow rate. Additionally, the electrical demand, entering air temperature, leaving air temperature, and air flow rate should be collected. The collected data would allow not only for a closer examination of heating performance, but an accurate representation of cooling performance. A wide selection of homes should be used to gain an accurate representation of all climate zones within Iowa. To evaluate the validity of the simplified method used in this study, building characteristics, loop type, and soil type should be logged. To explain discrepancies in the cooling load, detailed occupant levels and activity should be recorded. Furthermore, it is recommended that any new study be conducted over a time period of at least two years so an average set of data is observed.

Collection of additional data may also lead to development of fouling or degradation values for ground source heat pumps. The degradation factor could be utilized in developing more accurate life estimates of ground-source heat pumps and life time savings.

As found during the development of the homeowner's guide, most individuals are concerned about the cost savings and the capital cost required to install a GSHP. To gain further insight into the cost of Iowa installations, additional installer surveys should be completed. For comparison purposes, the survey should also include the cost of conventional heating and cooling equipment along with projected maintenance cost for all systems.

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Thank you to the Iowa Energy Center and Curt Klassen for providing the research grants to make this project possible.

APPENDIX A – LOAD AND PERFORMANCE

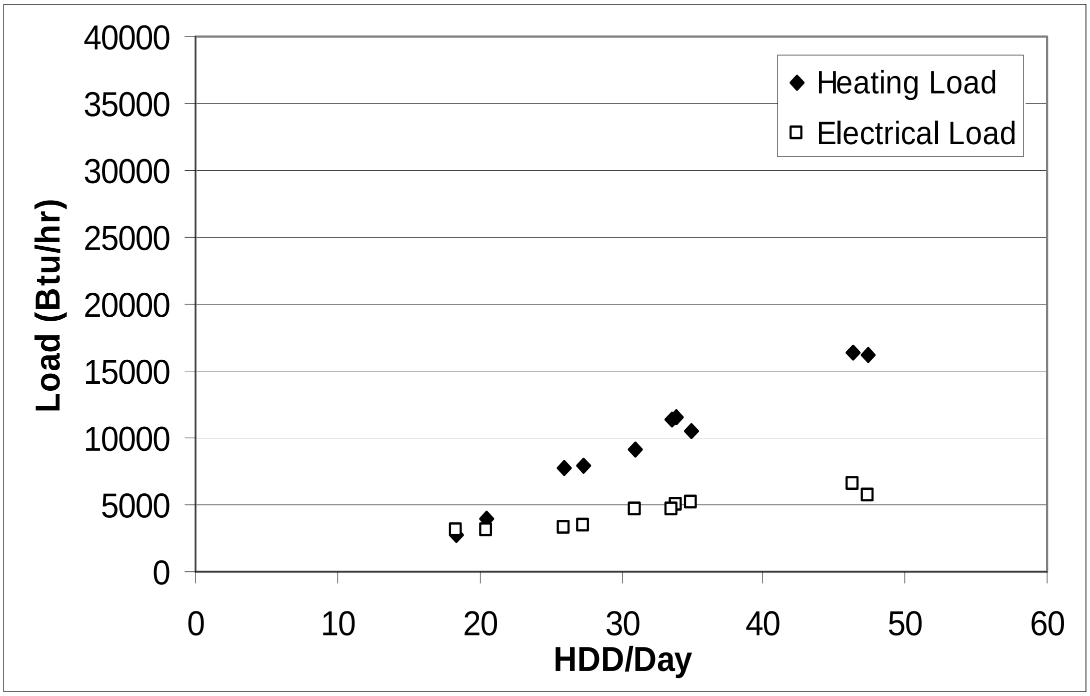

Figure B.1: Home H-1-2 heating and electrical load versus HDD/Day

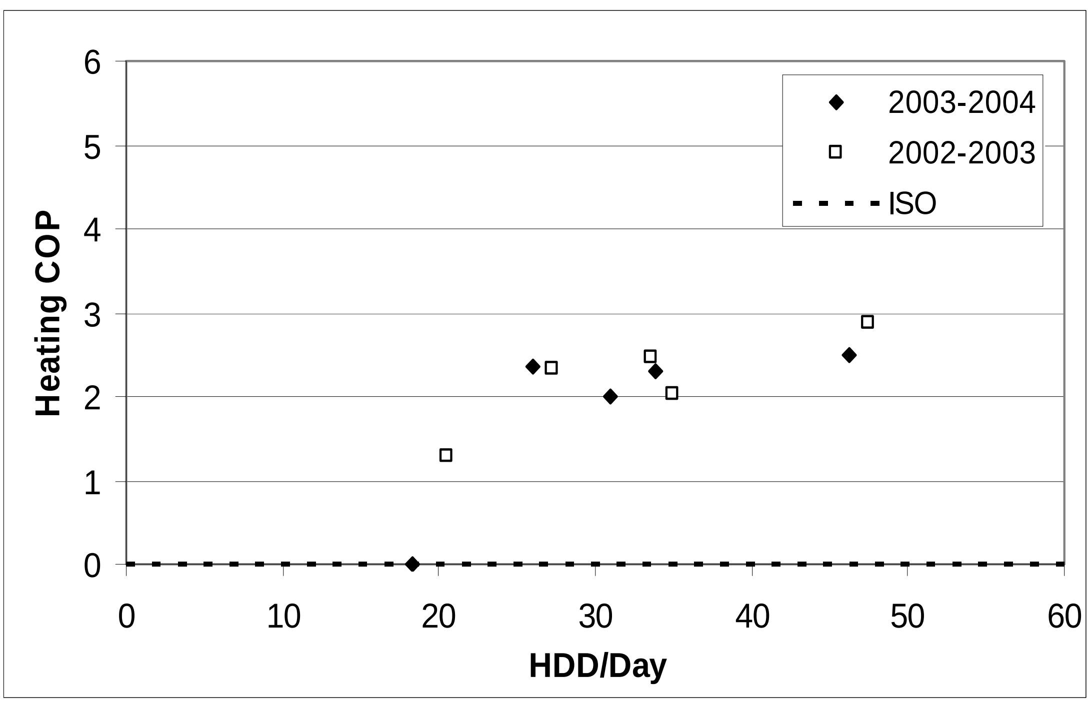

Figure B.2: Home H-1-2 ISO/ARI rating with heating COP versus HDD/Day

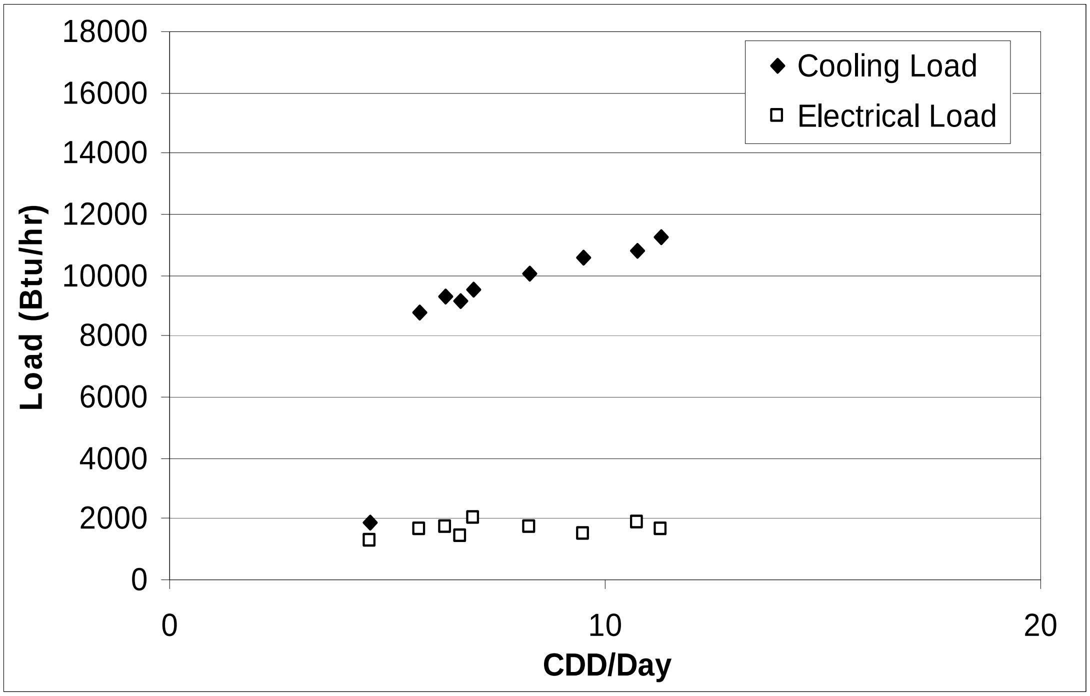

Figure B.3: Home H-1-2 cooling and electrical load versus CDD/Day

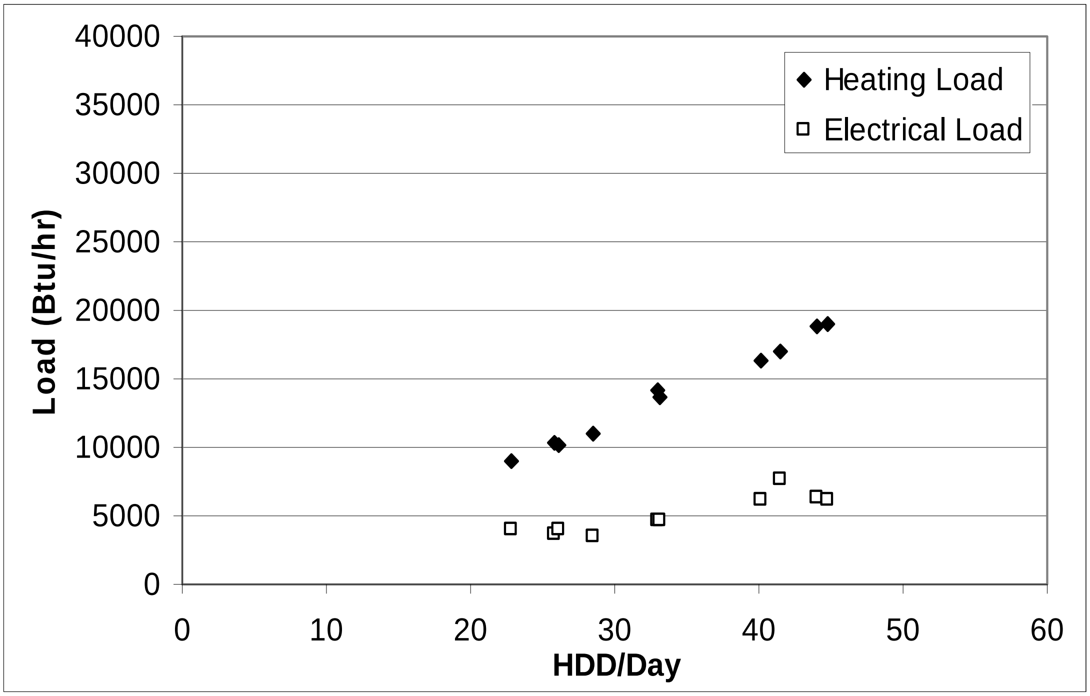

Figure B.4: Home H-1-3 heating and electrical load versus HDD/Day

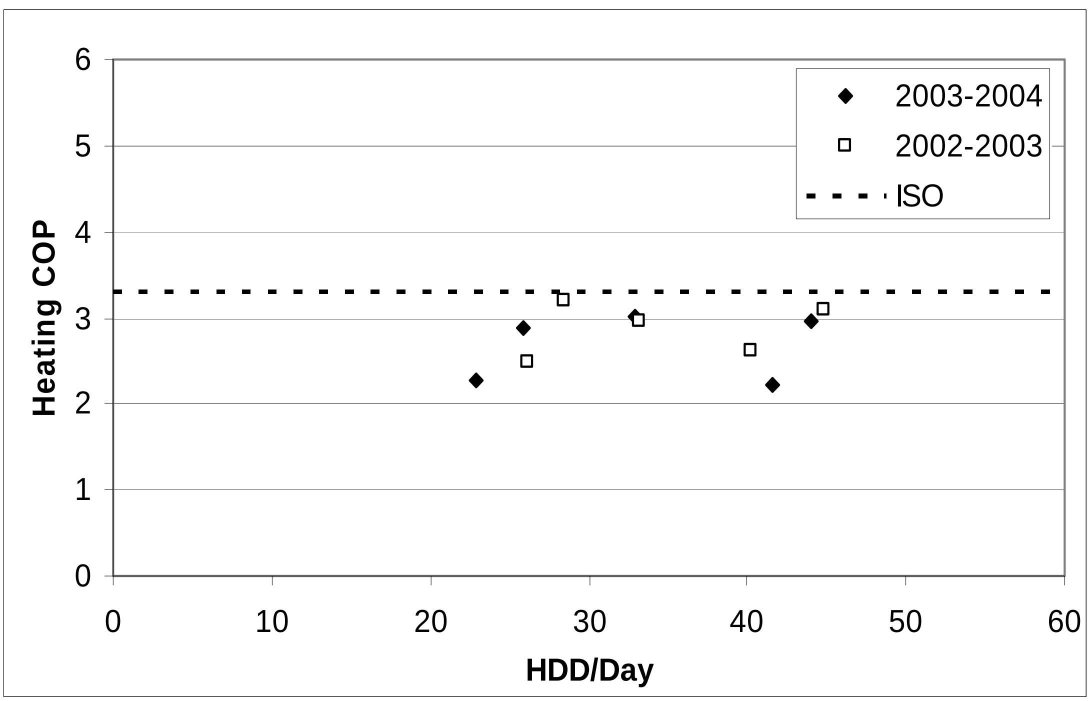

Figure B.5: Home H-1-3 ISO/ARI rating with heating COP versus HDD/Day

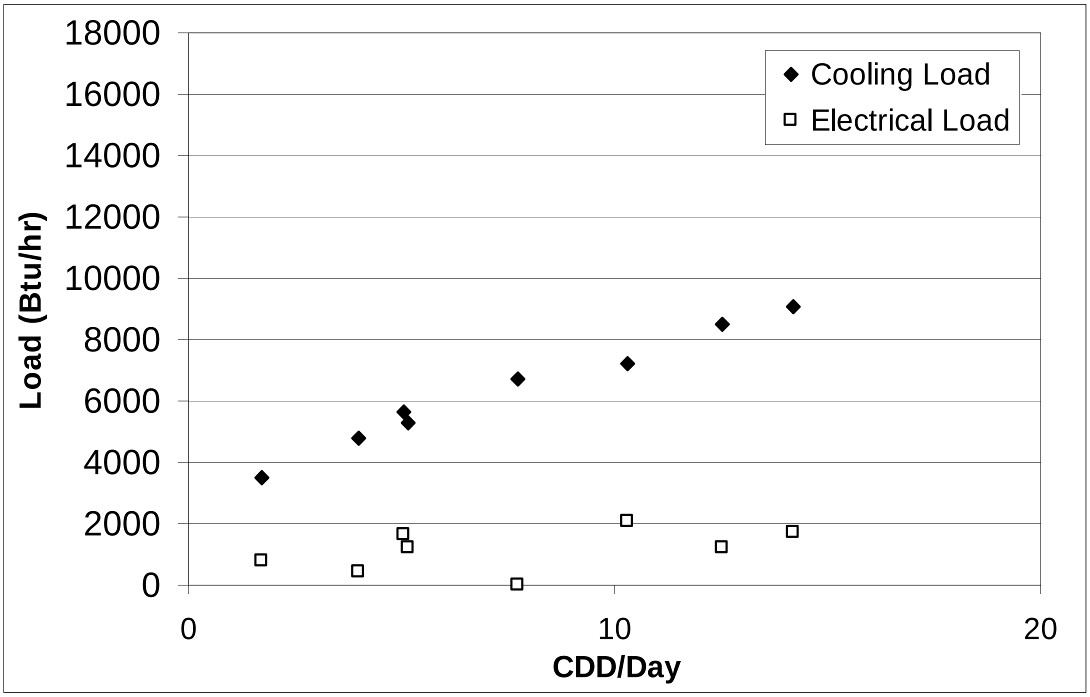

Figure B.6: Home H-1-3 cooling and electrical load versus CDD/Day

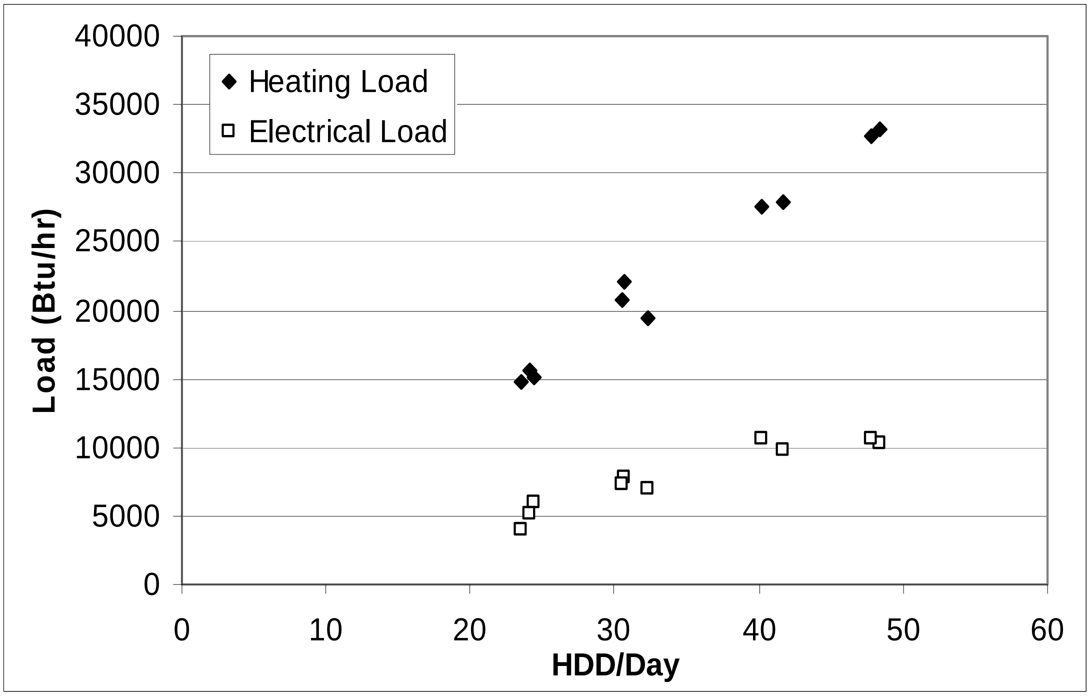

Figure B.7: Home H-0-4 heating and electrical load versus HDD/Day

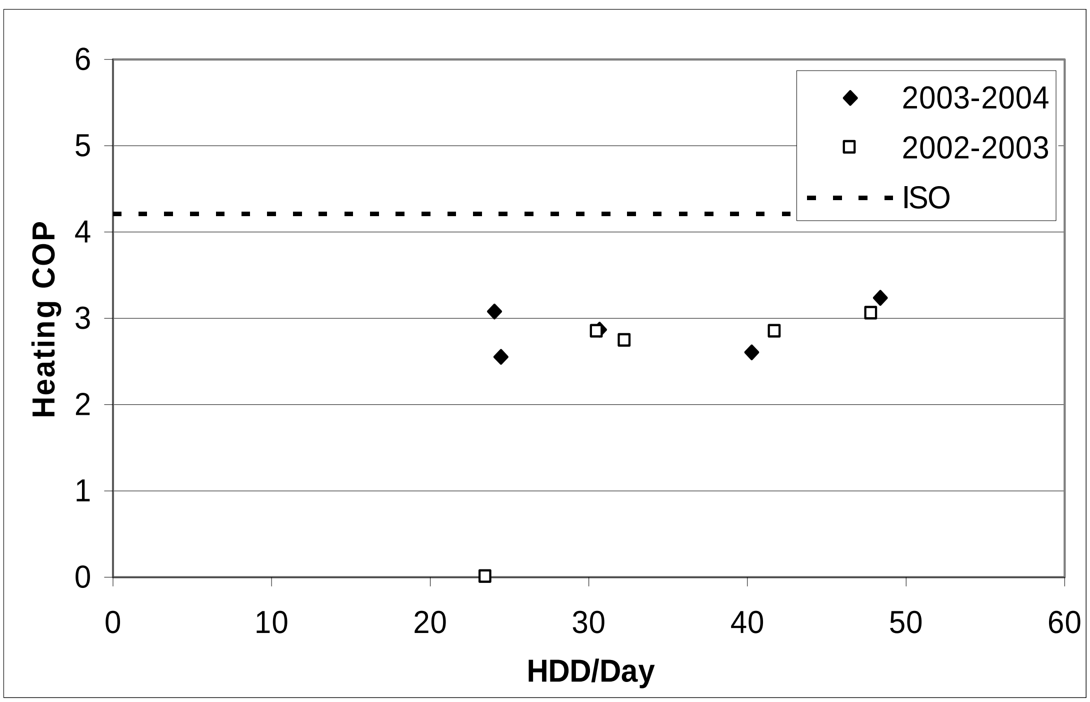

Figure B.8: Home H-0-4 ISO/ARI rating with heating COP versus HDD/Day

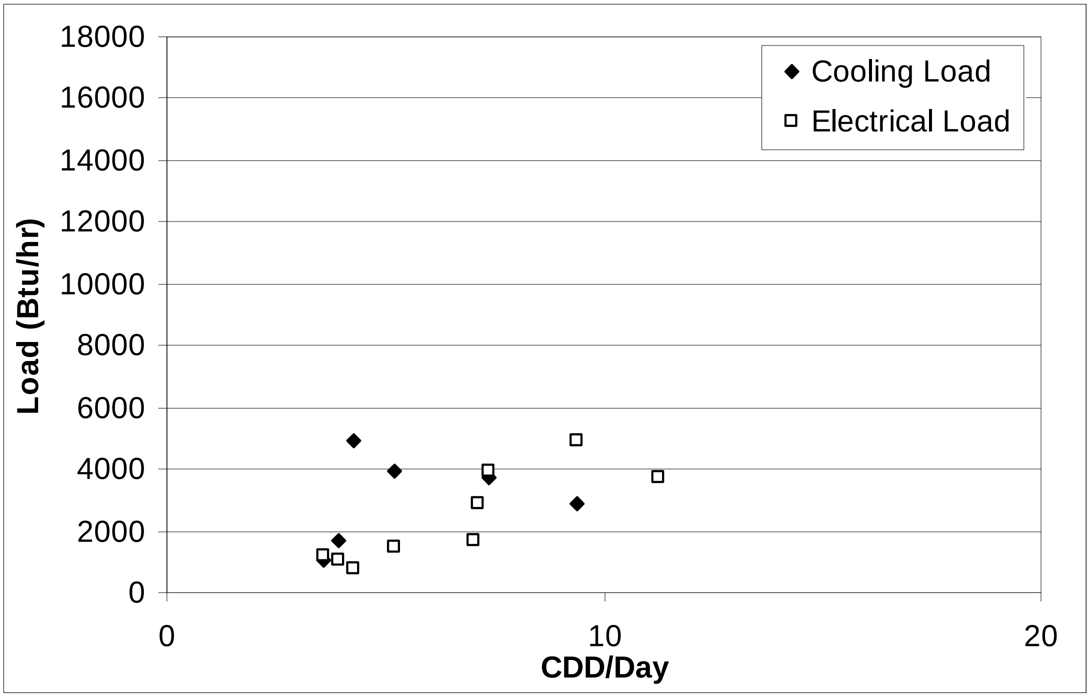

Figure B.9: Home H-0-4 cooling and electrical load versus CDD/Day

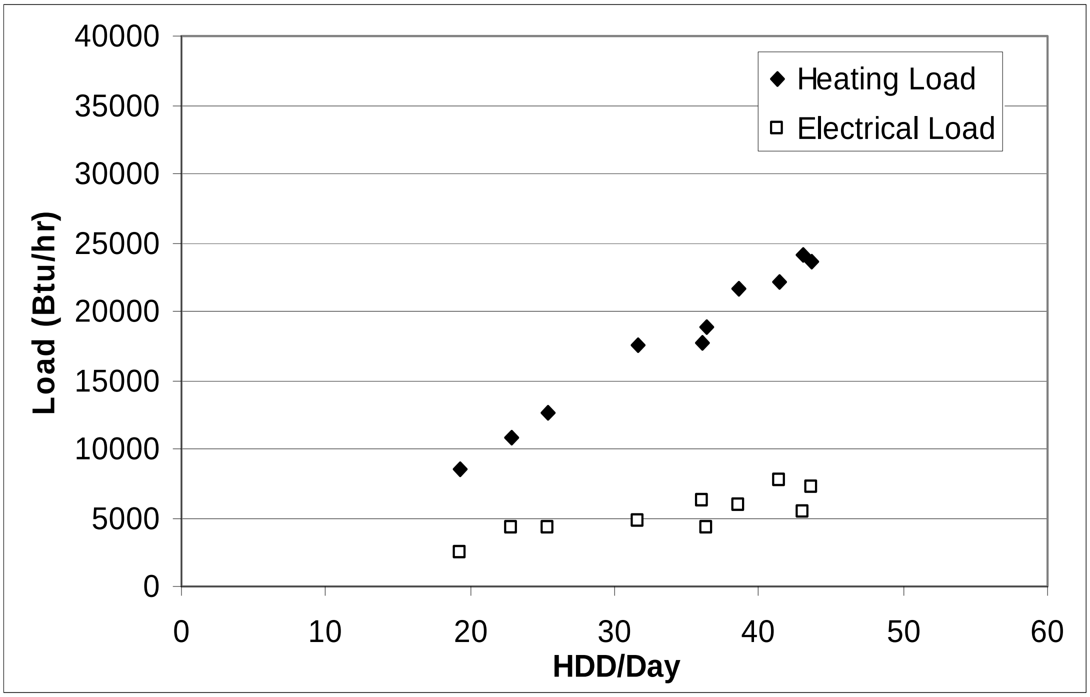

Figure B.10: Home H-0-5 heating and electrical load versus HDD/Day

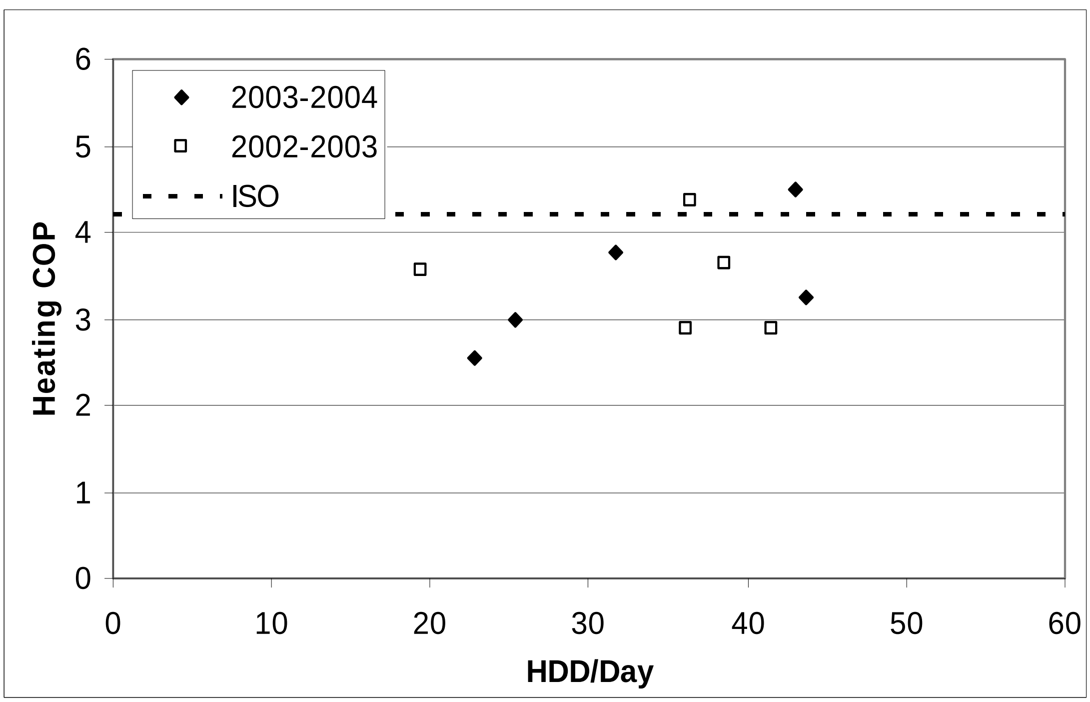

Figure B.11: Home H-0-5 ISO/ARI rating with heating COP versus HDD/Day

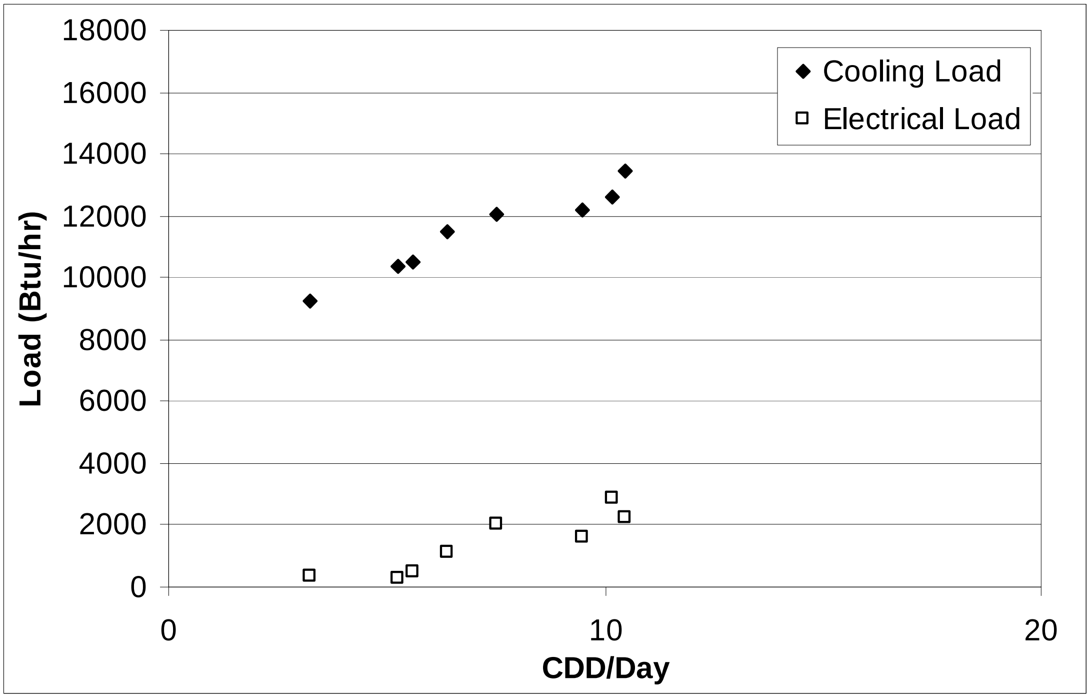

Figure B.12: Home H-0-5 cooling and electrical load versus CDD/Day

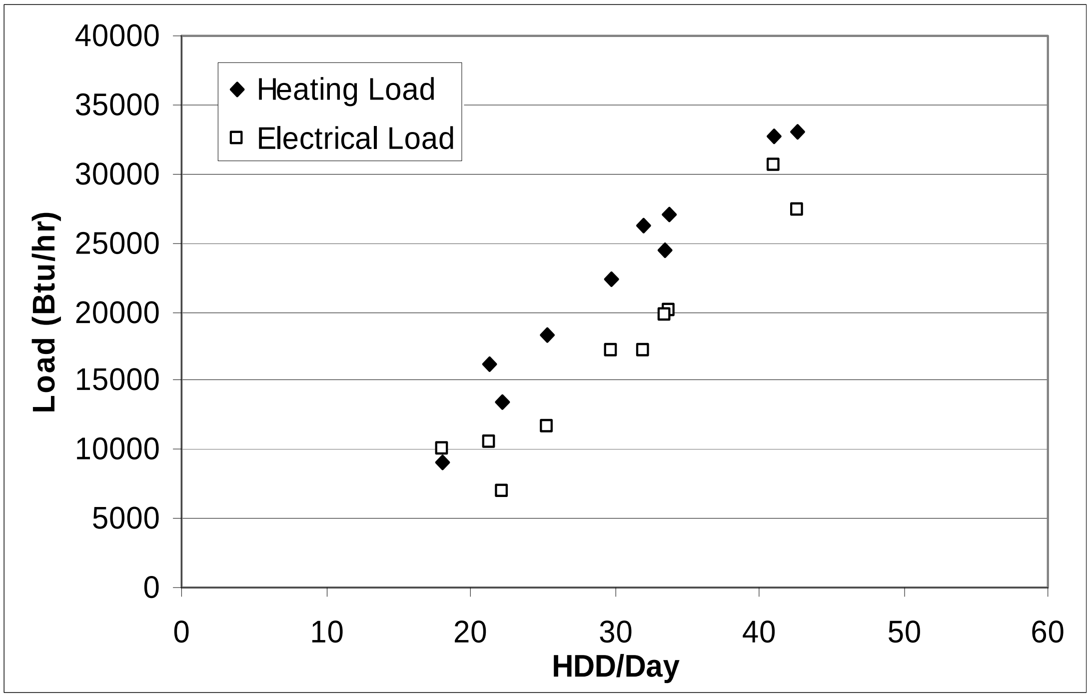

Figure B.13: Home H-1-7 heating and electrical load versus HDD/Day

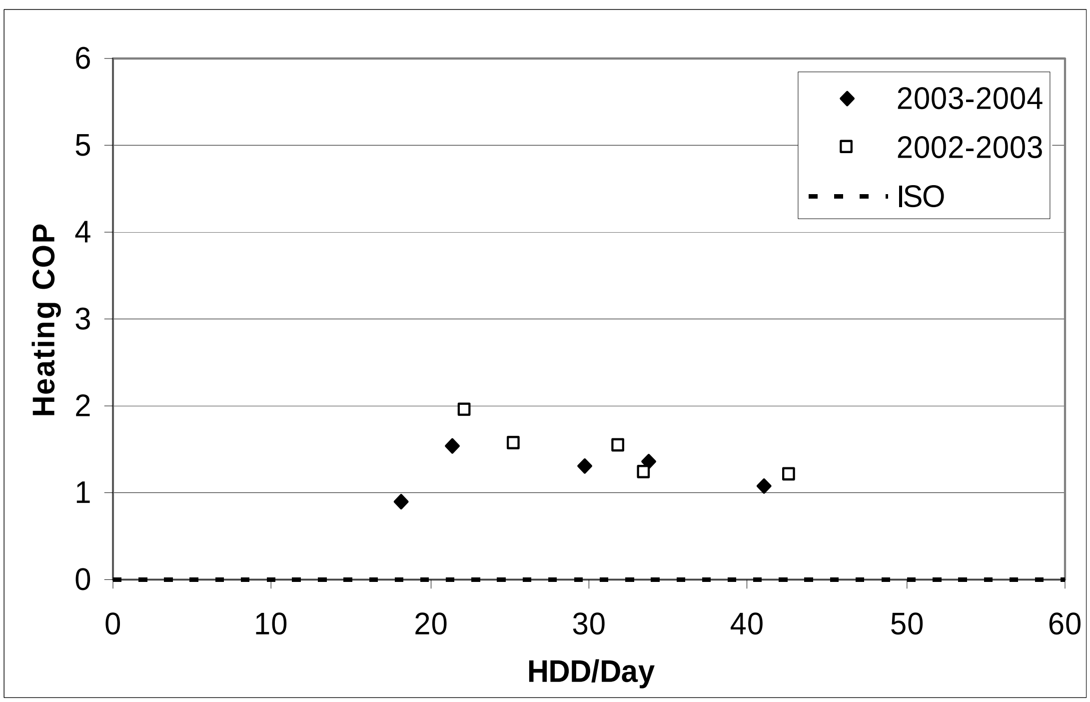

Figure B.14: Home H-1-7 ISO/ARI rating with heating COP versus HDD/Day

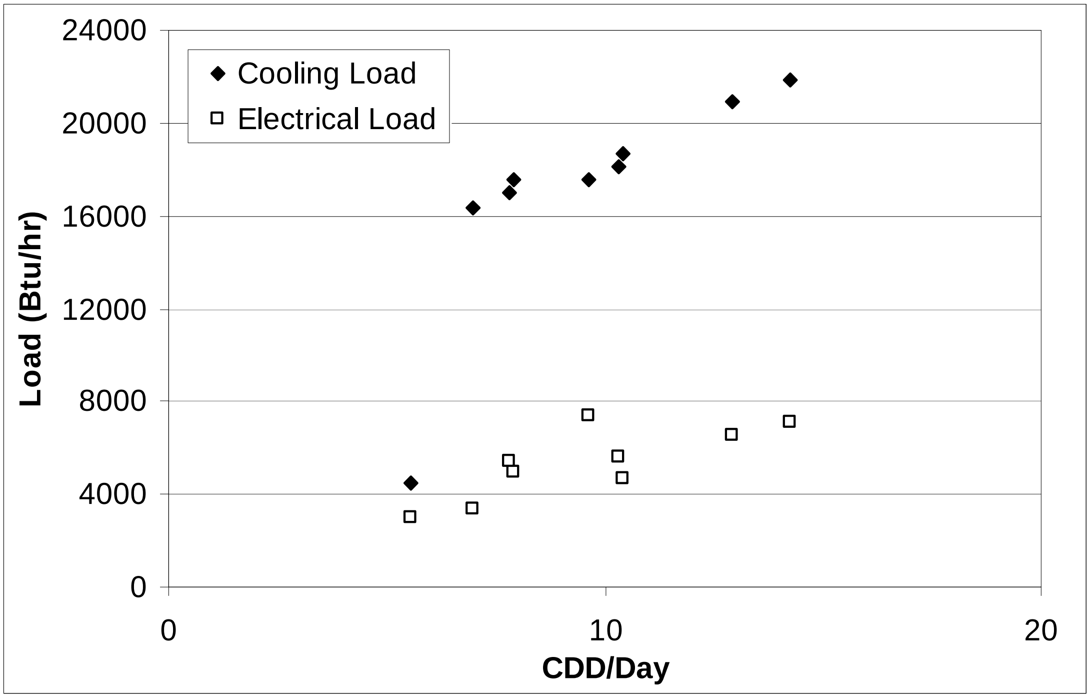

Figure B.15: Home H-1-7 cooling and electrical load versus CDD/Day

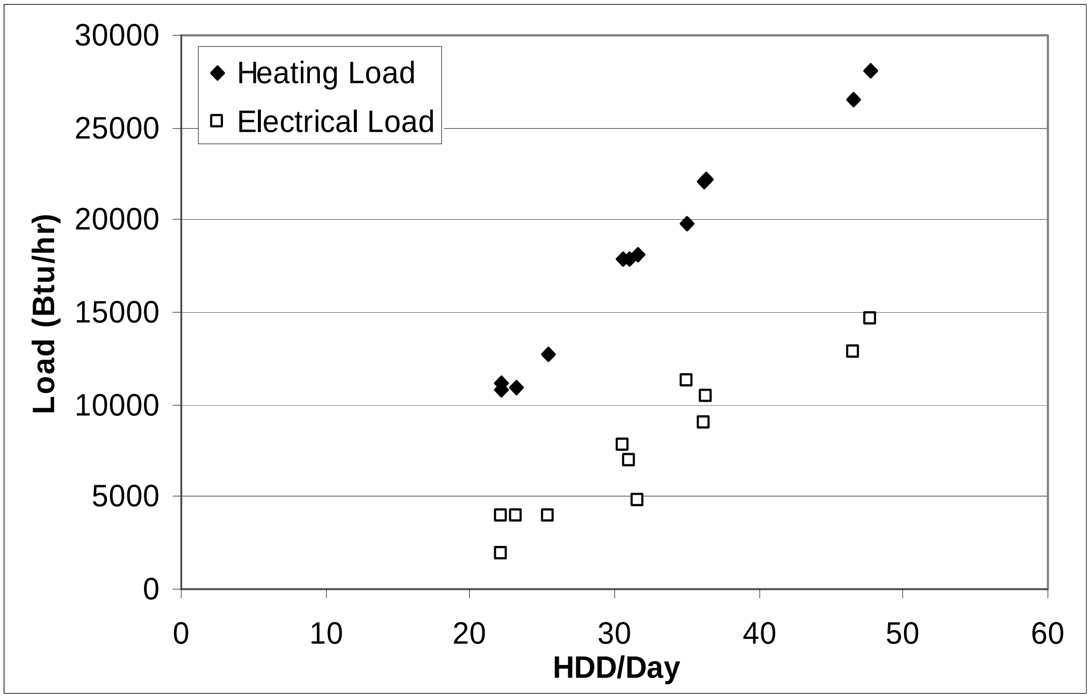

Figure B.16: Home H-1-8 heating and electrical load versus HDD/Day

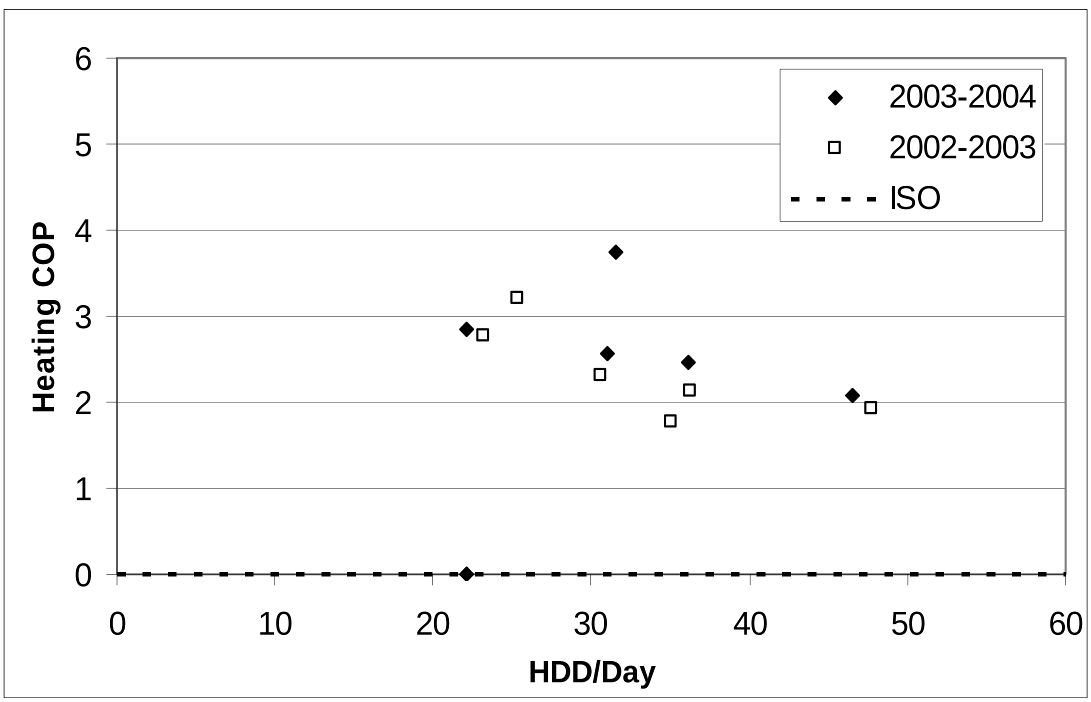

Figure B.17: Home H-1-8 ISO/ARI rating with heating COP versus HDD/Day

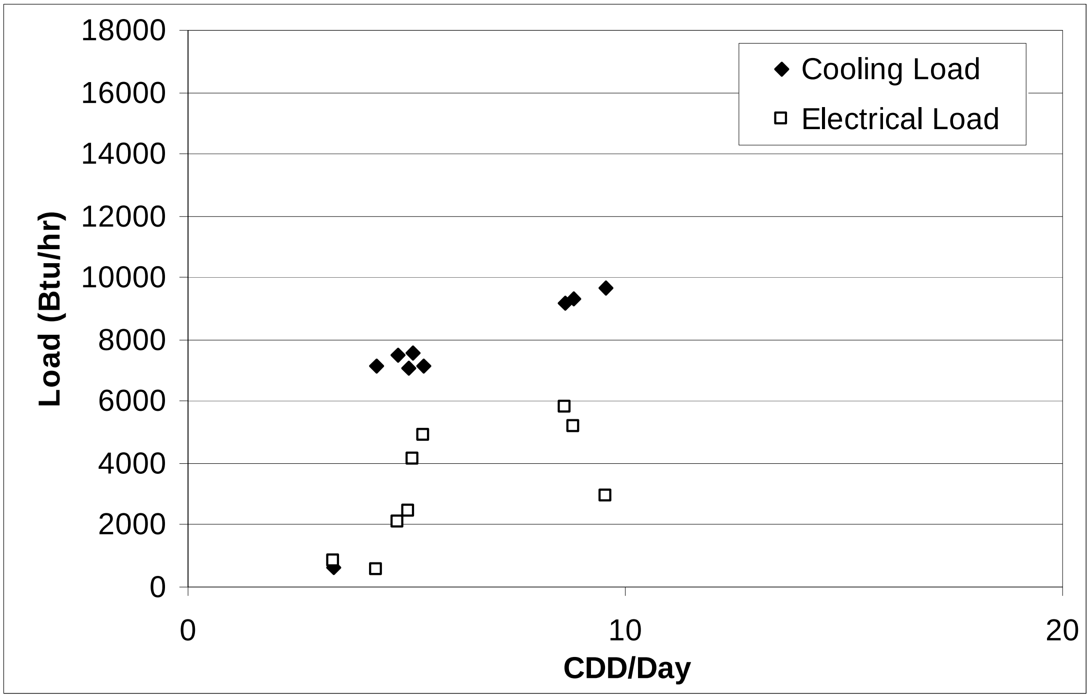

Figure B.18: Home H-1-8 cooling and electrical load versus CDD/Day

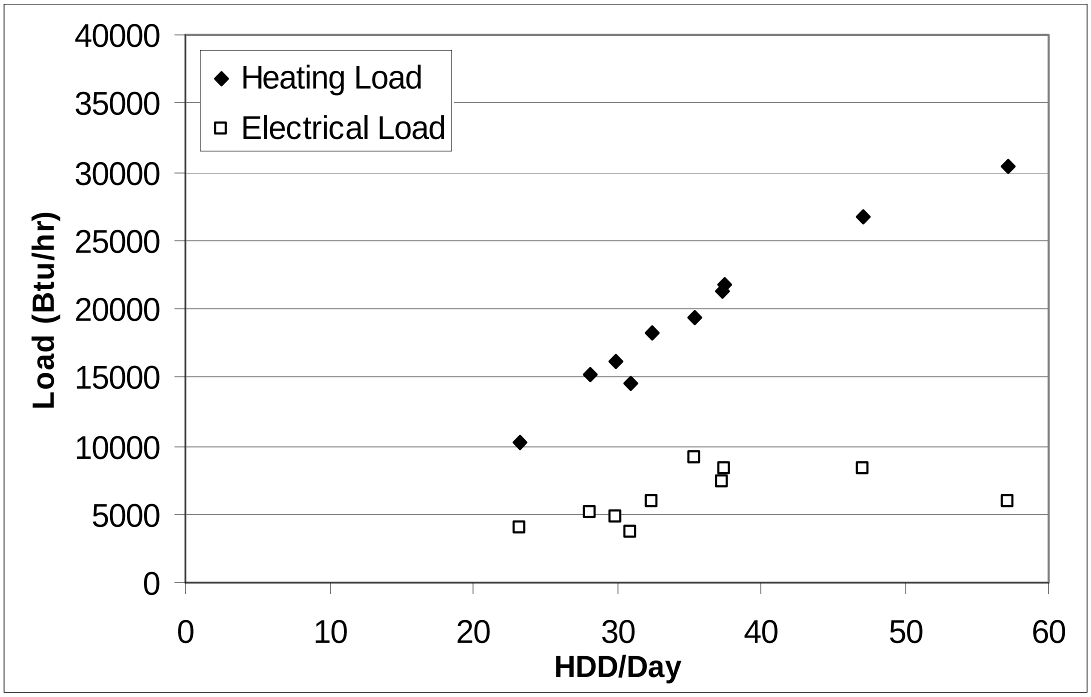

Figure B.19: Home H-1-10 heating and electrical load versus HDD/Day

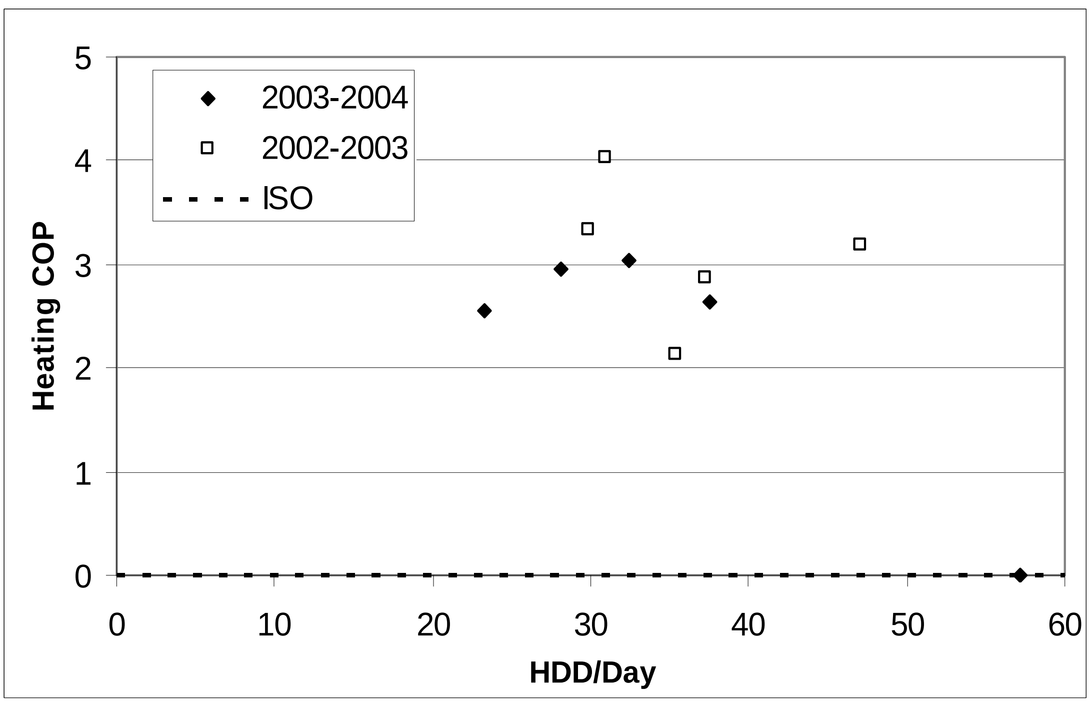

Figure B.20: Home H-1-10 ISO/ARI rating with heating COP versus HDD/Day

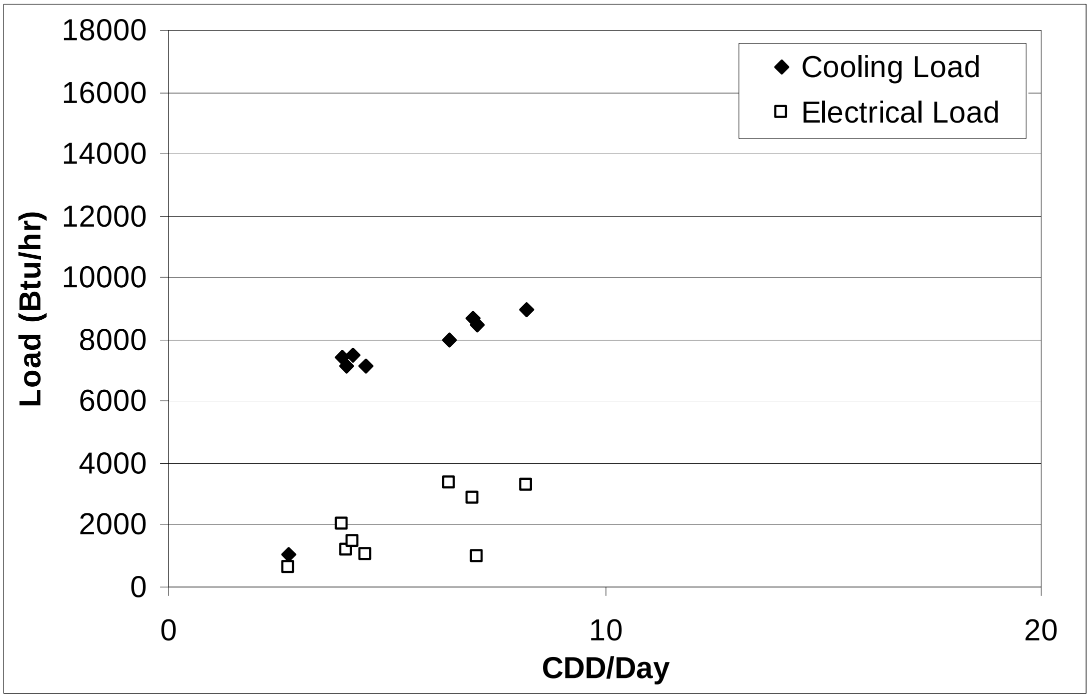

Figure B.21: Home H-1-10 cooling and electrical load versus CDD/Day

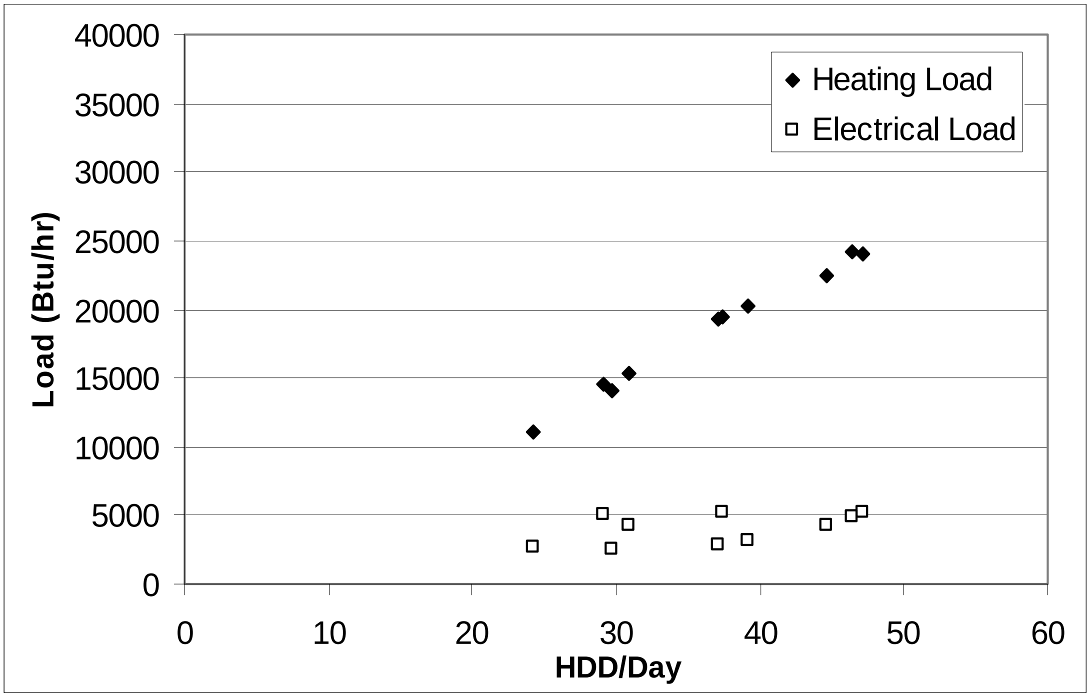

Figure B.22: Home H-1-11 heating and electrical load versus HDD/Day

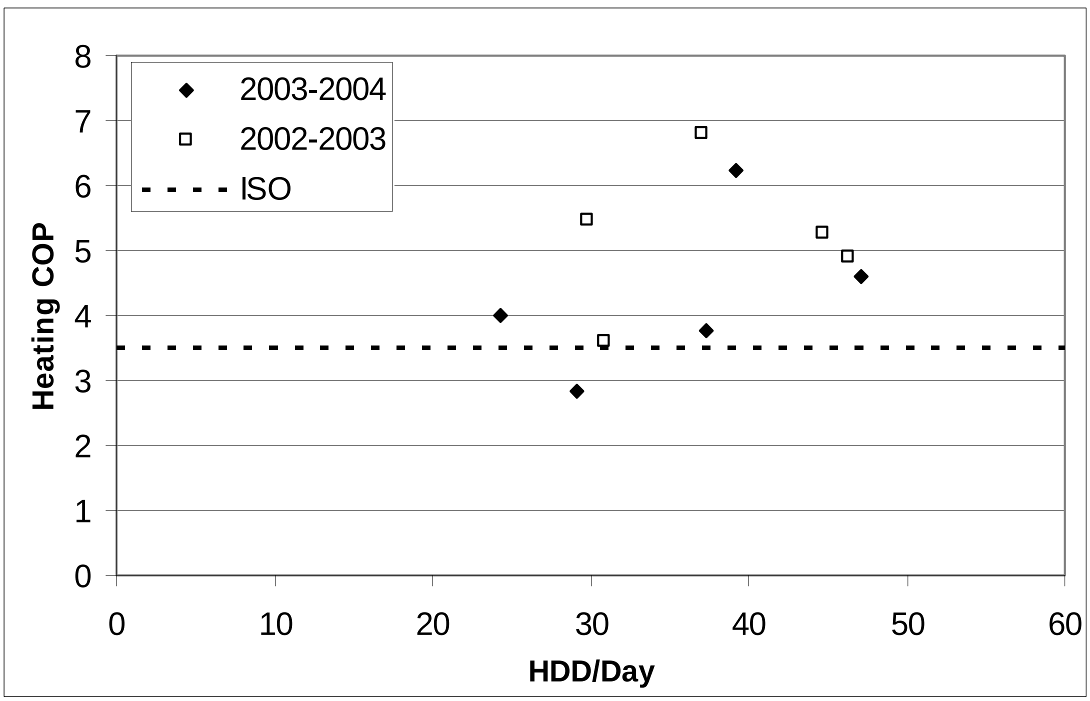

Figure B.23: Home H-1-11 ISO/ARI rating with heating COP versus HDD/Day

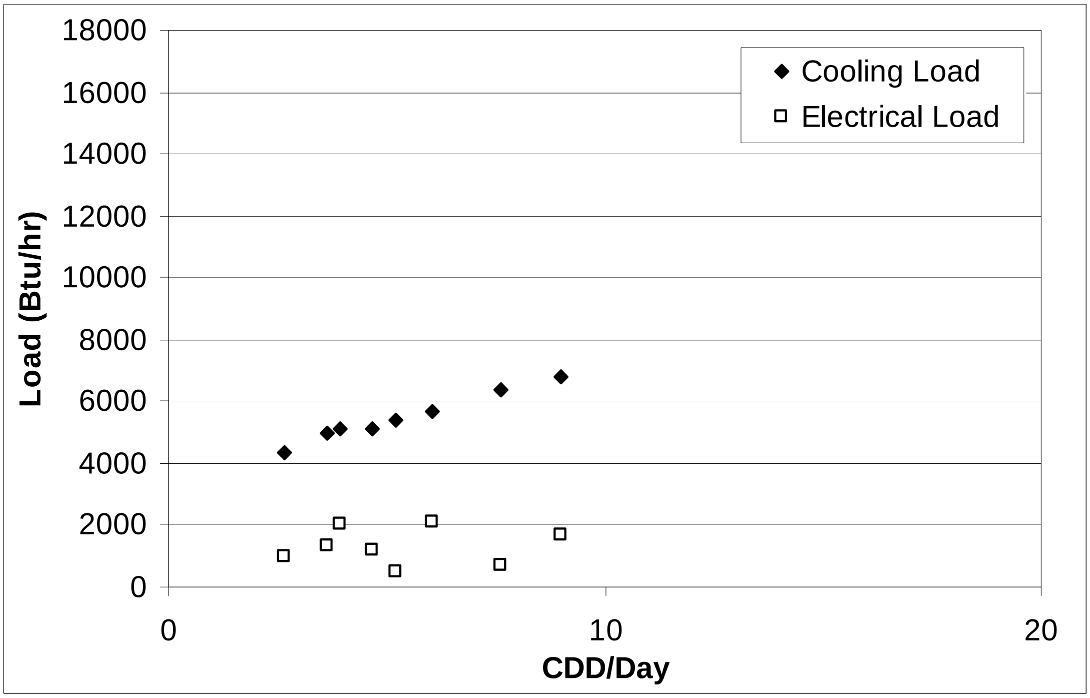

Figure B.24: Home H-1-11 cooling and electrical load versus CDD/Day

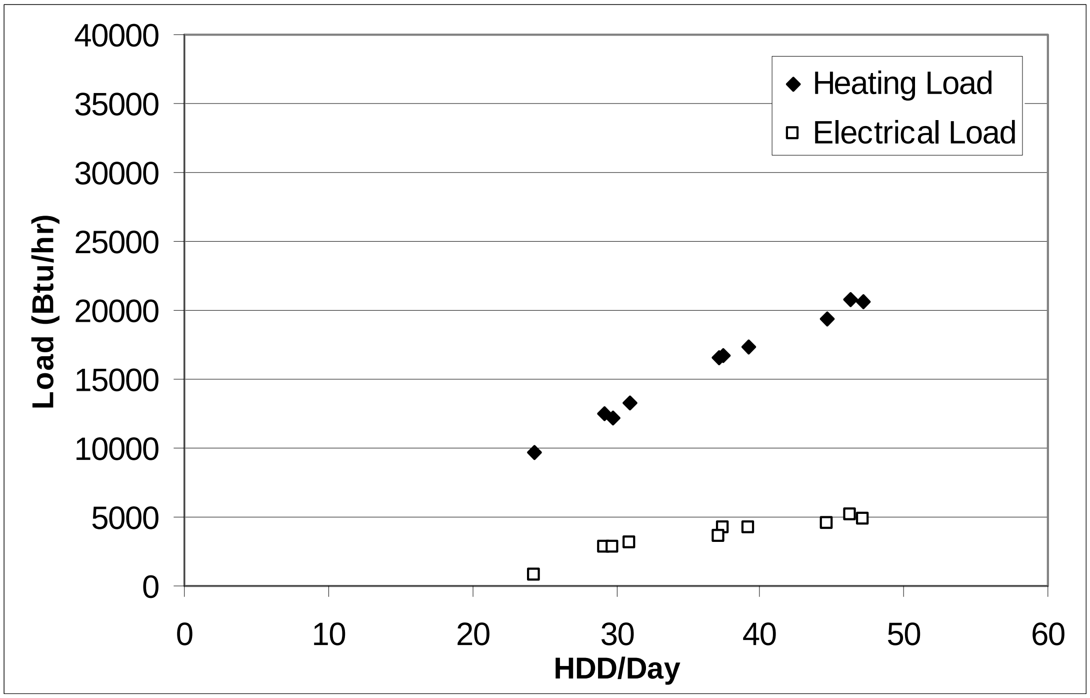

Figure B.25: Home H-1-12 heating and electrical load versus HDD/Day

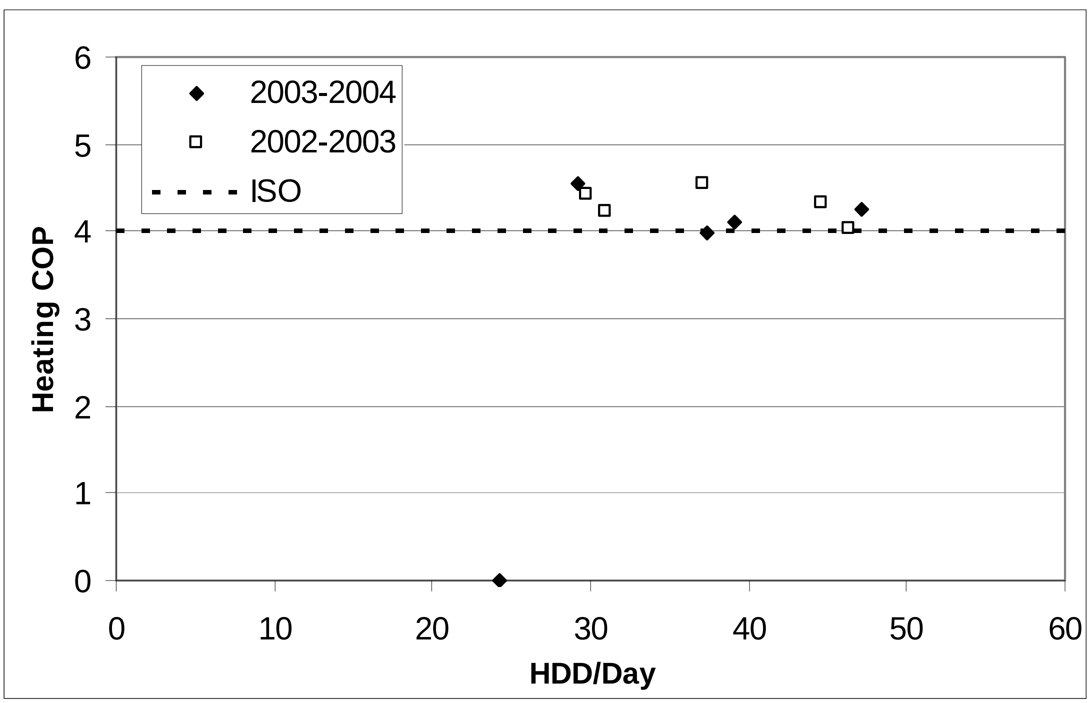

Figure B.26: Home H-1-12 ISO/ARI rating with heating COP versus HDD/Day

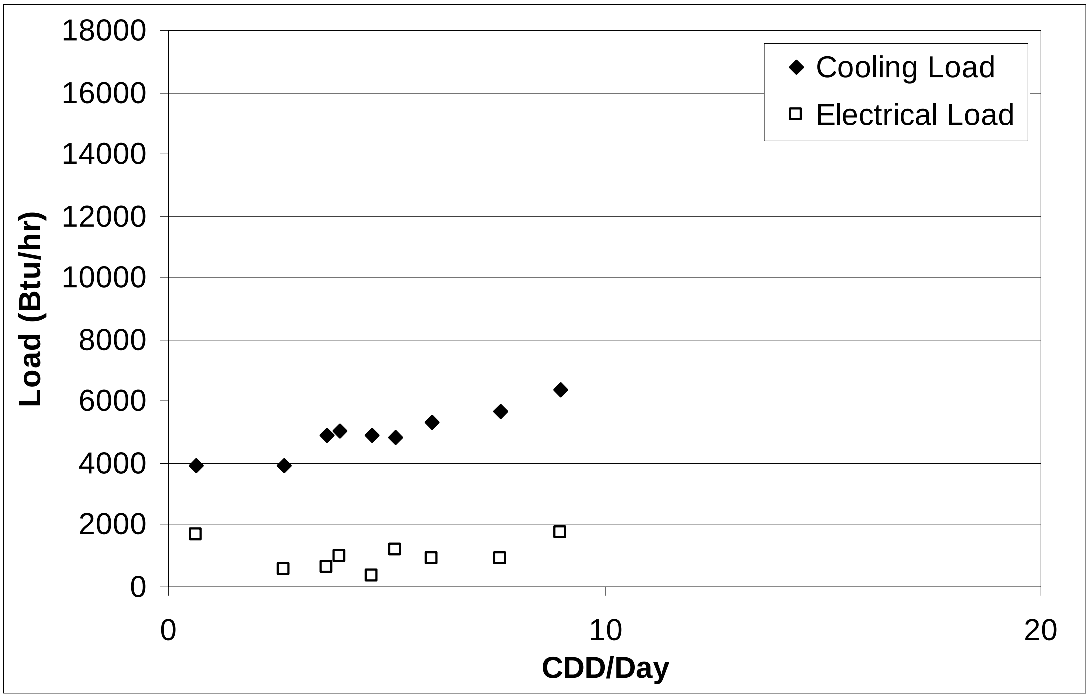

Figure B.27: Home H-1-12 cooling and electrical load versus CDD/Day

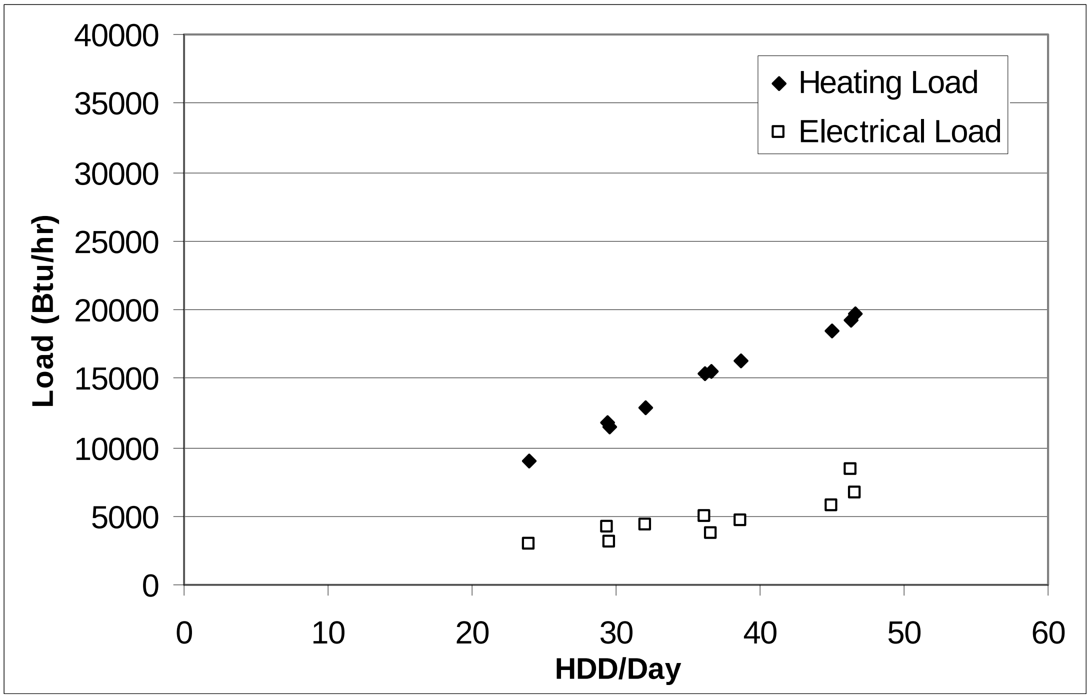

Figure B.28: Home H-1-13 heating and electrical load versus HDD/Day

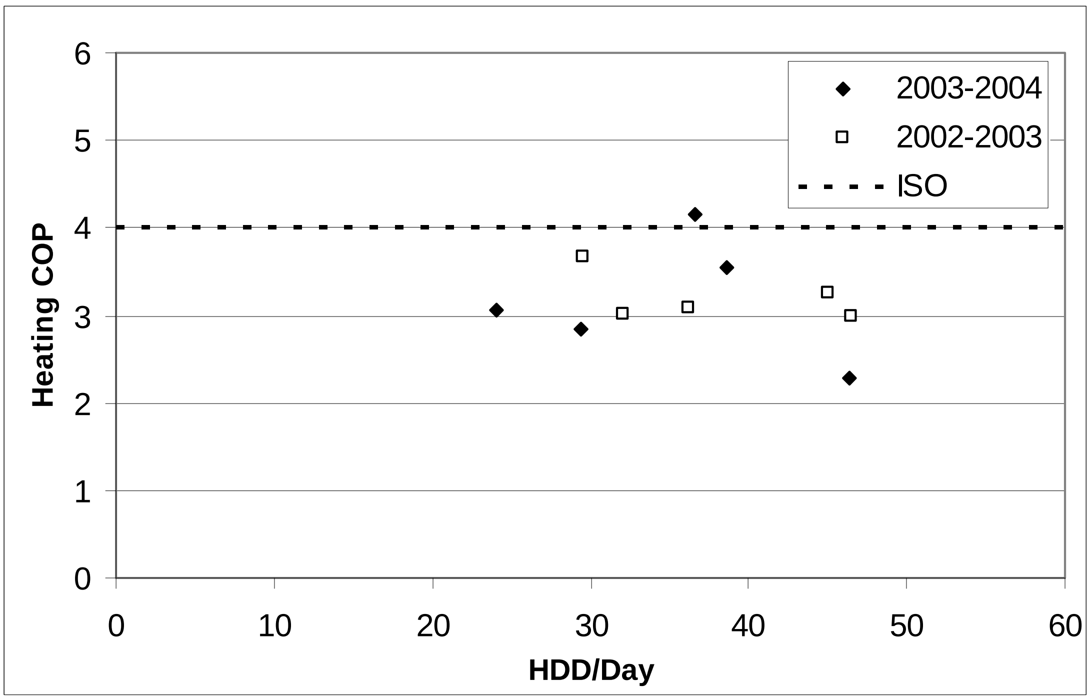

Figure B.29: Home H-1-13 ISO/ARI rating with heating COP versus HDD/Day

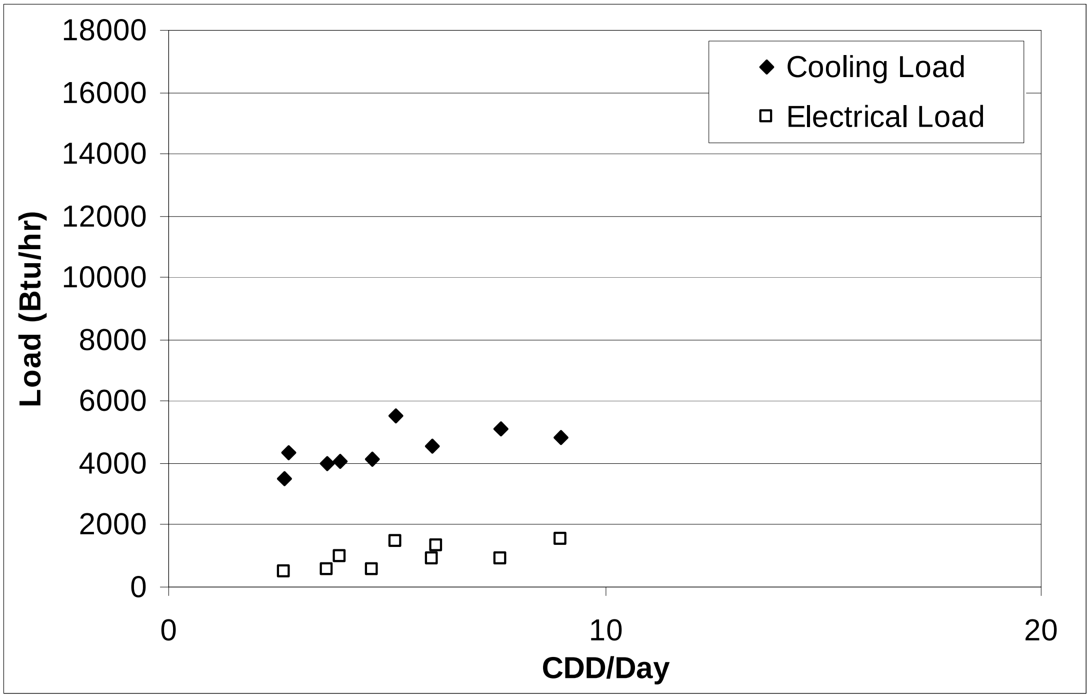

Figure B.30: Home H-1-13 cooling and electrical load versus CDD/Day

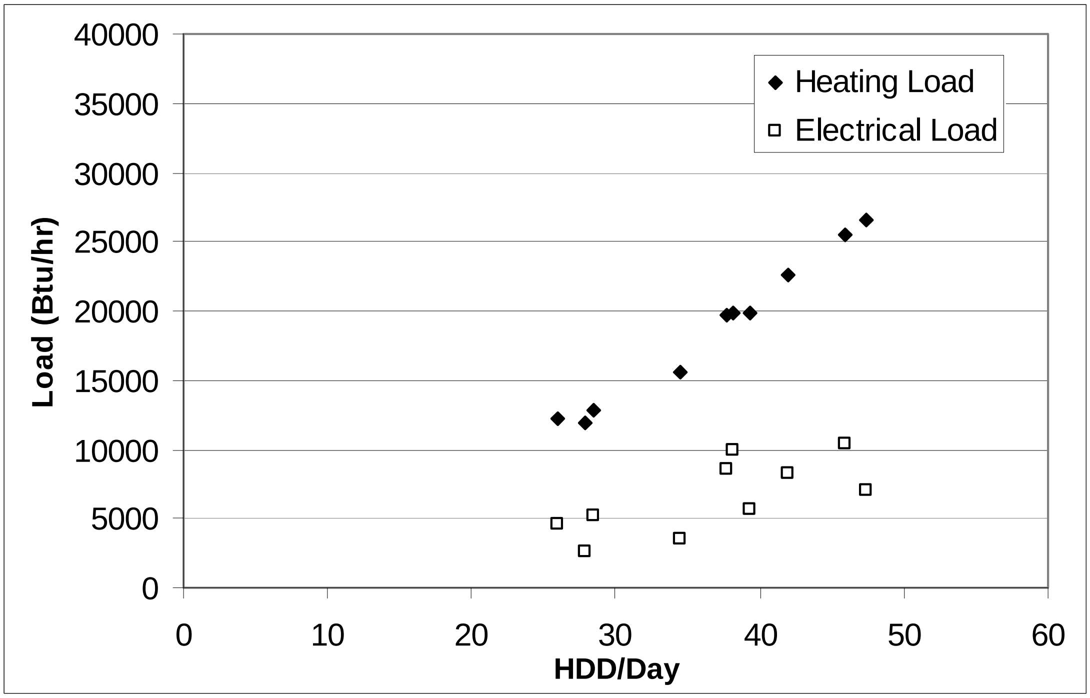

Figure B.31: Home H-0-14 heating and electrical load versus HDD/Day

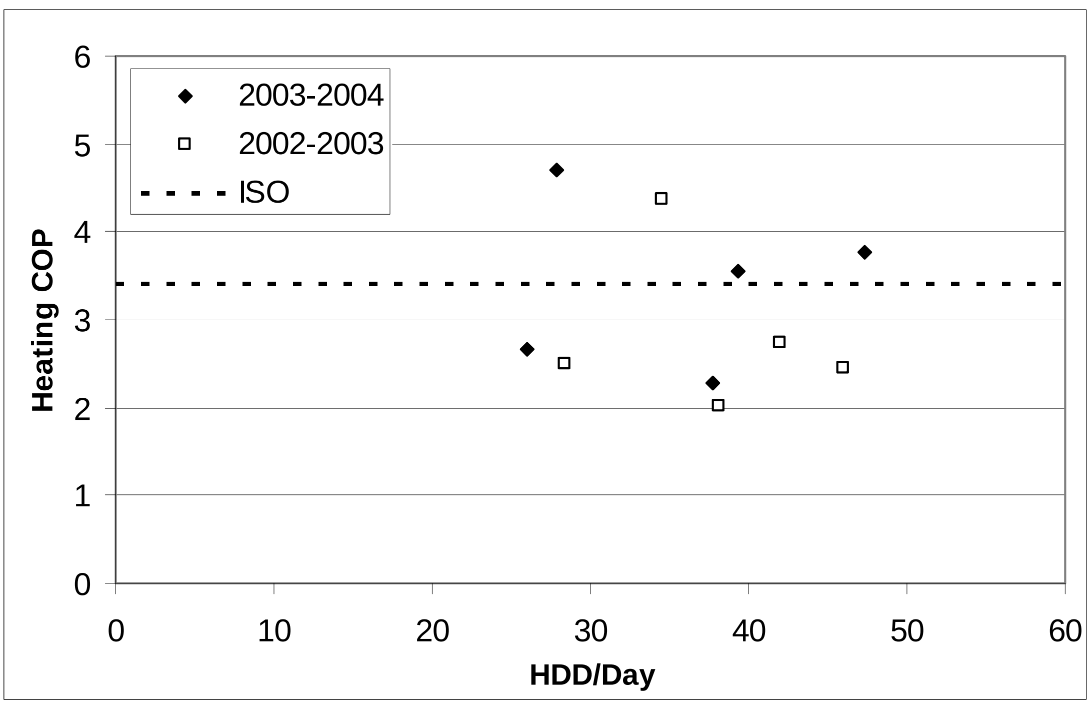

Figure B.32: Home H-0-14 ISO/ARI rating with heating COP versus HDD/Day

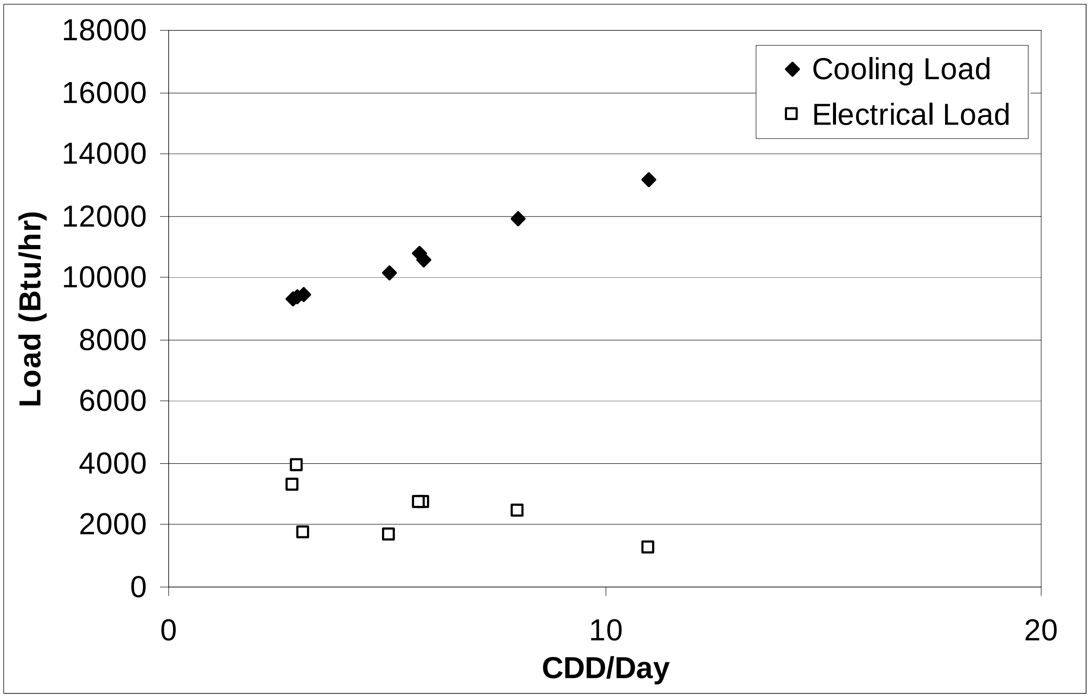

Figure B.33: Home H-0-14 cooling and electrical load versus CDD/Day

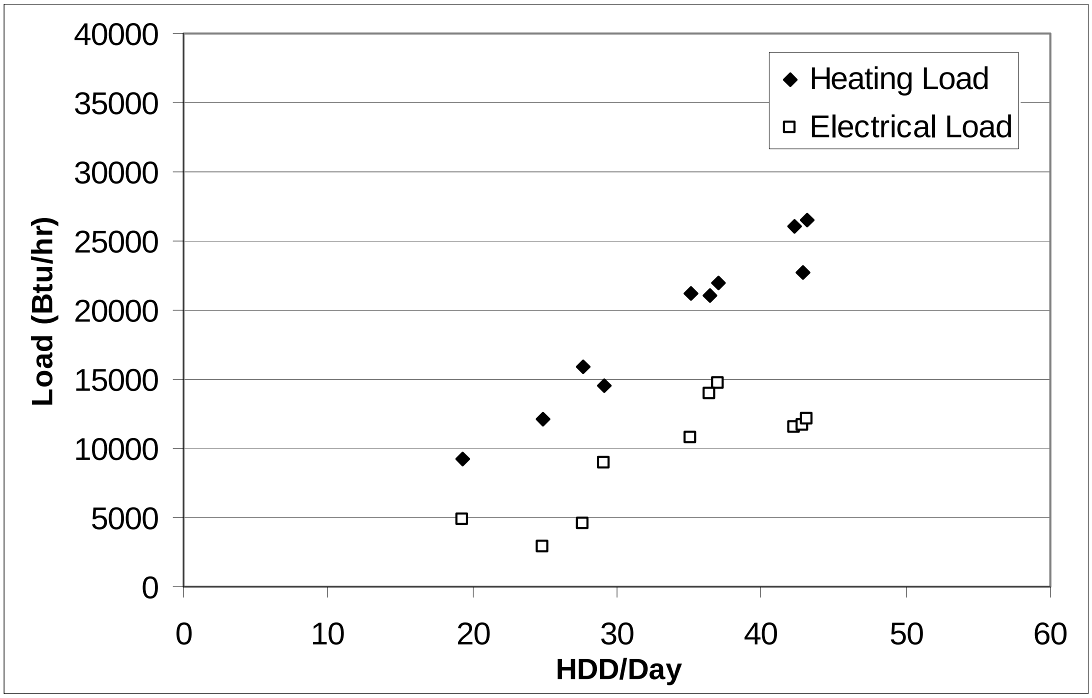

Figure B.34: Home H-1-15 heating and electrical load versus HDD/Day

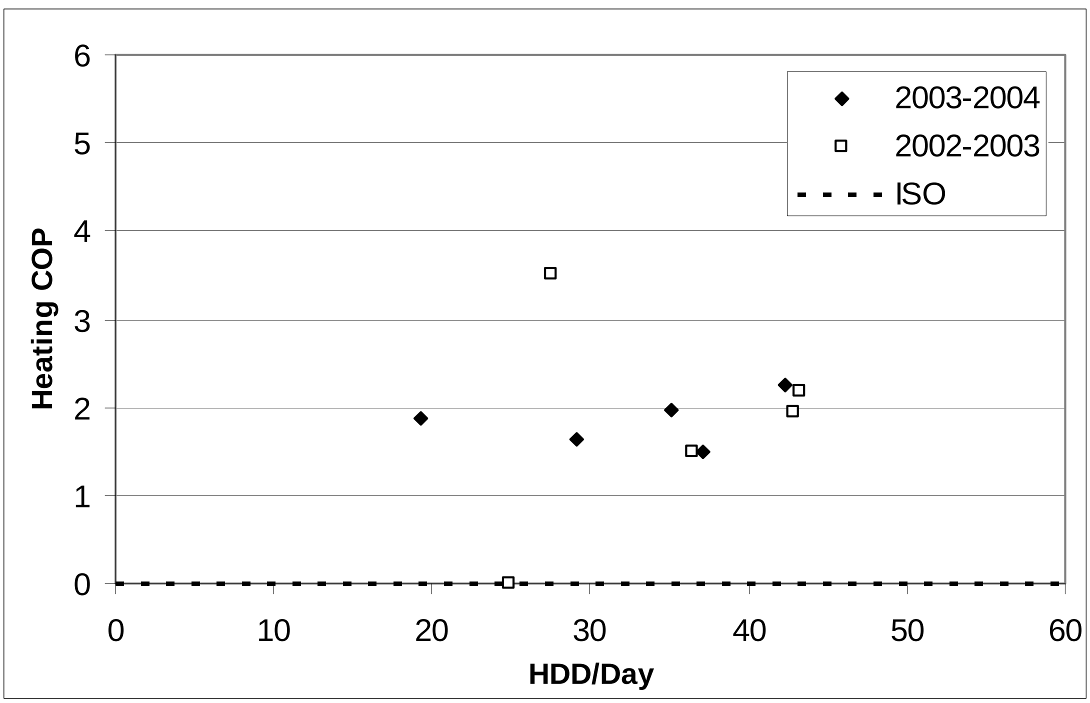

Figure B.35: Home H-1-15 ISO/ARI rating with heating COP versus HDD/Day

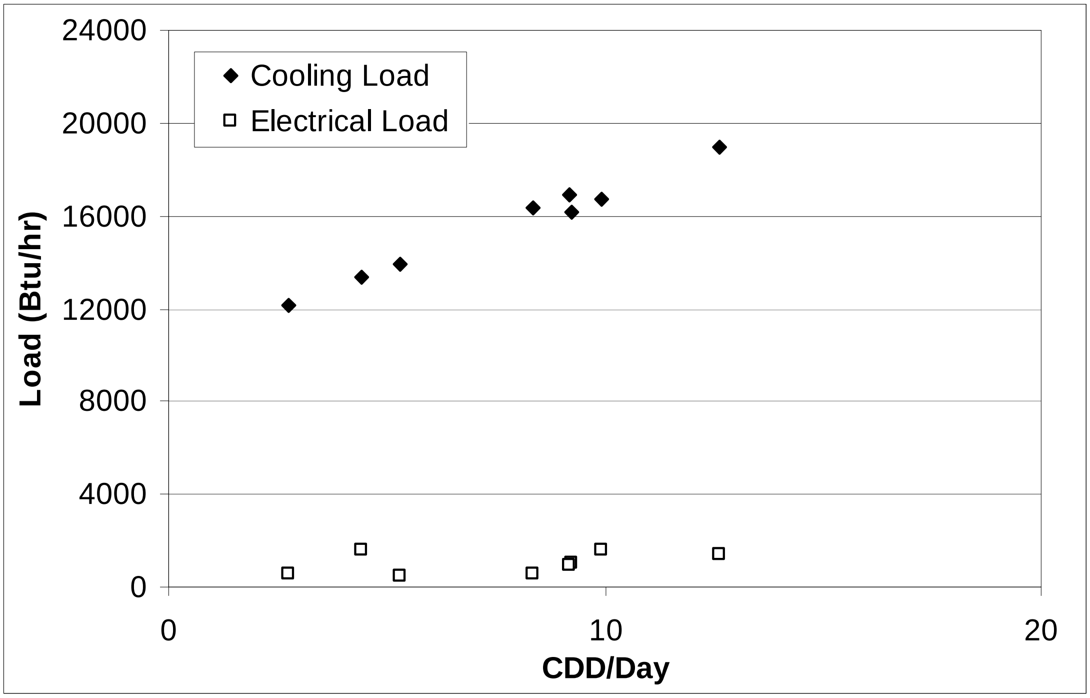

Figure B.36: Home H-1-15 cooling and electrical load versus CDD/Day

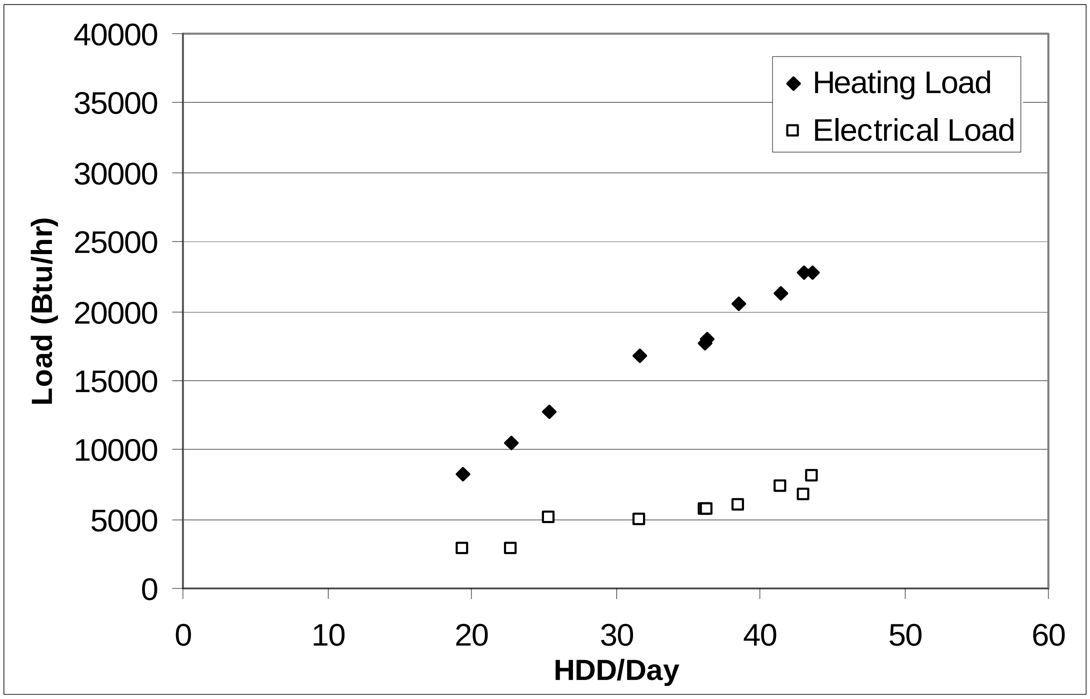

Figure B.37: Home H-1-16 heating and electrical load versus HDD/Day

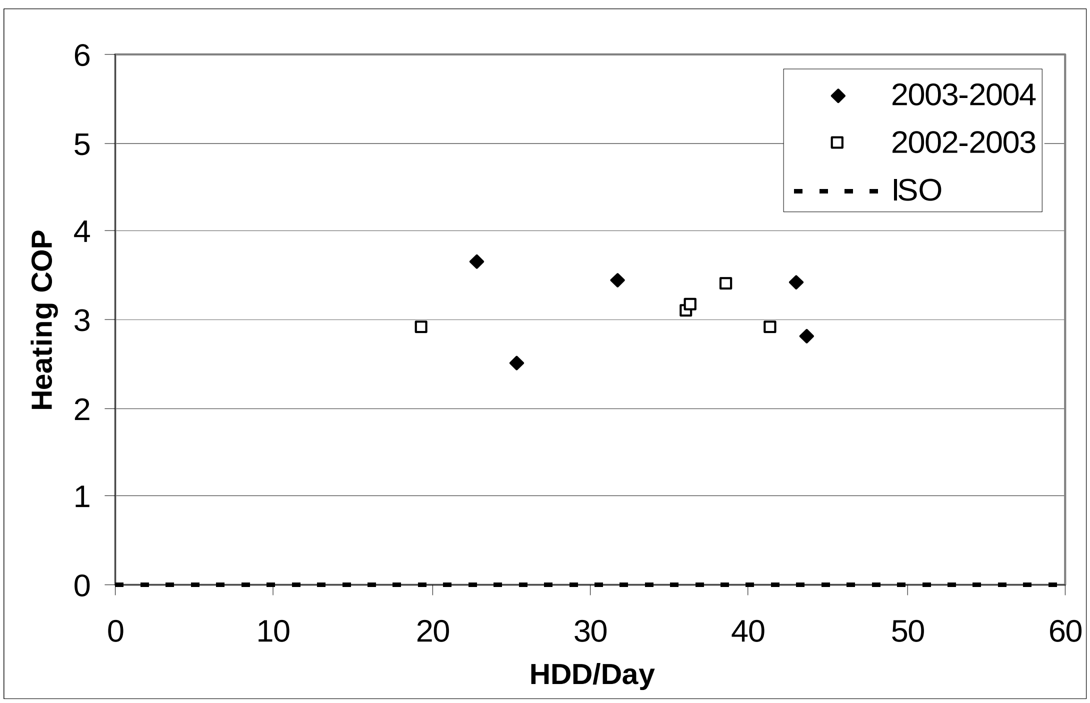

Figure B.38: Home H-1-16 ISO/ARI rating with heating COP versus HDD/Day

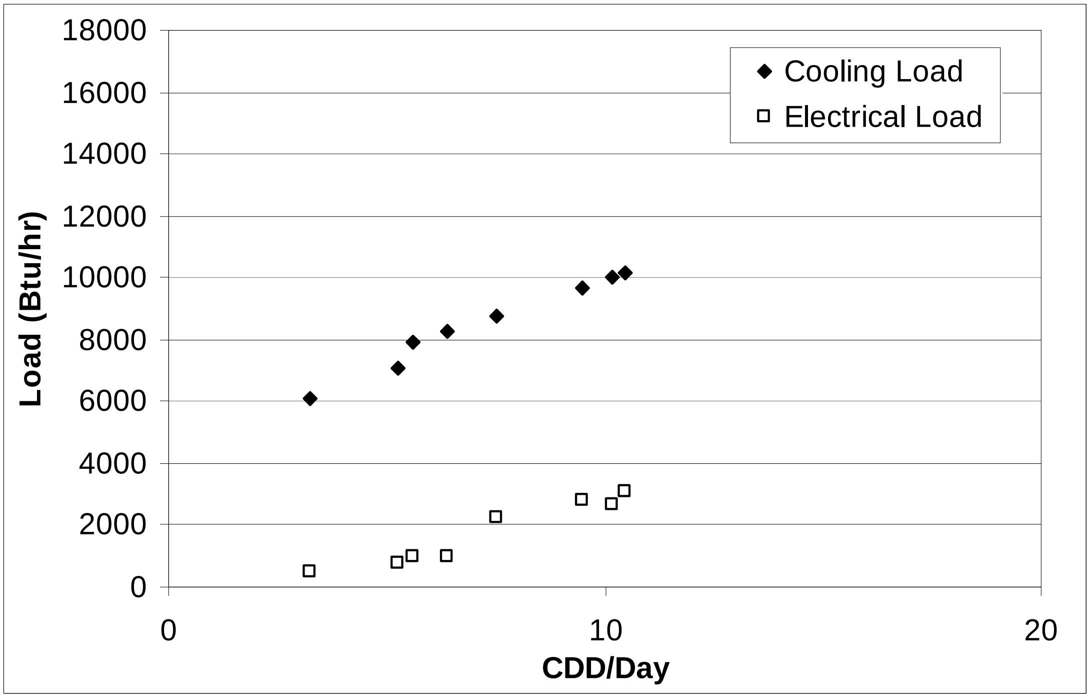

Figure B.39: Home H-1-16 cooling and electrical load versus CDD/Day

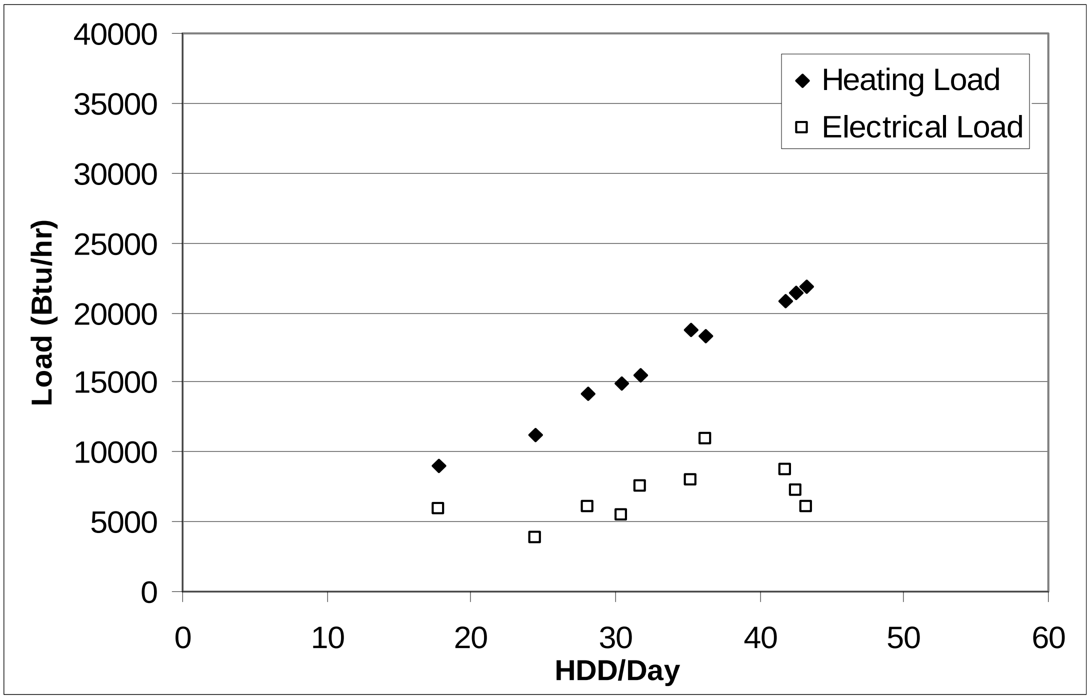

Figure B.40: Home H-1-17 heating and electrical load versus HDD/Day

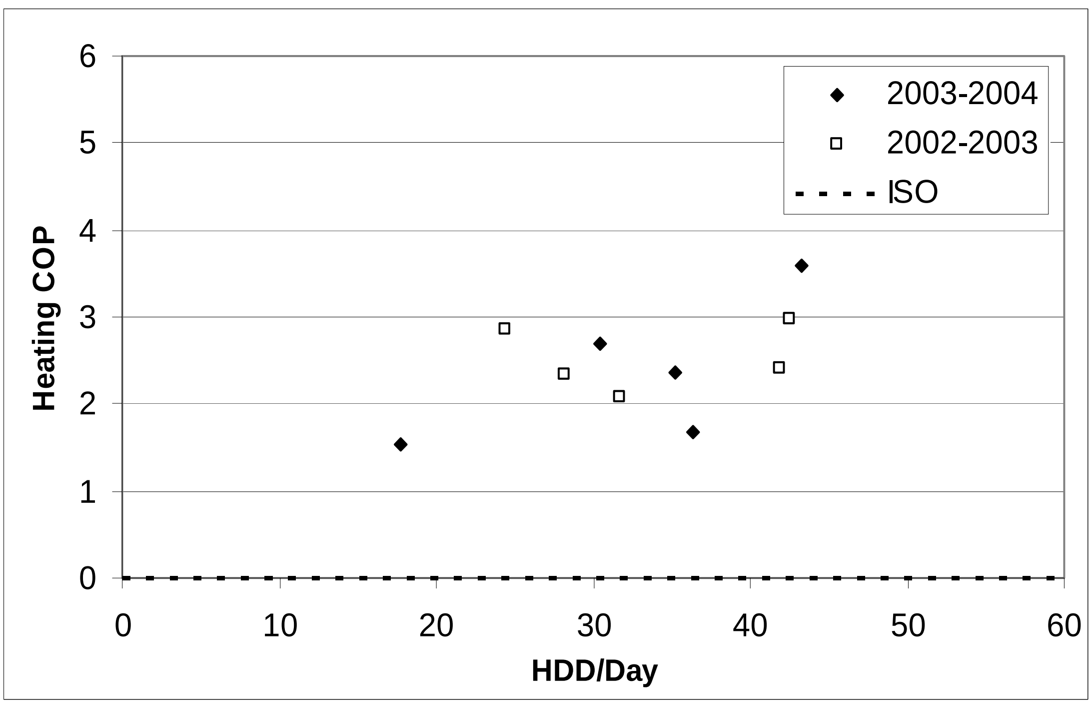

Figure B.41: Home H-1-17 ISO/ARI rating with heating COP versus HDD/Day

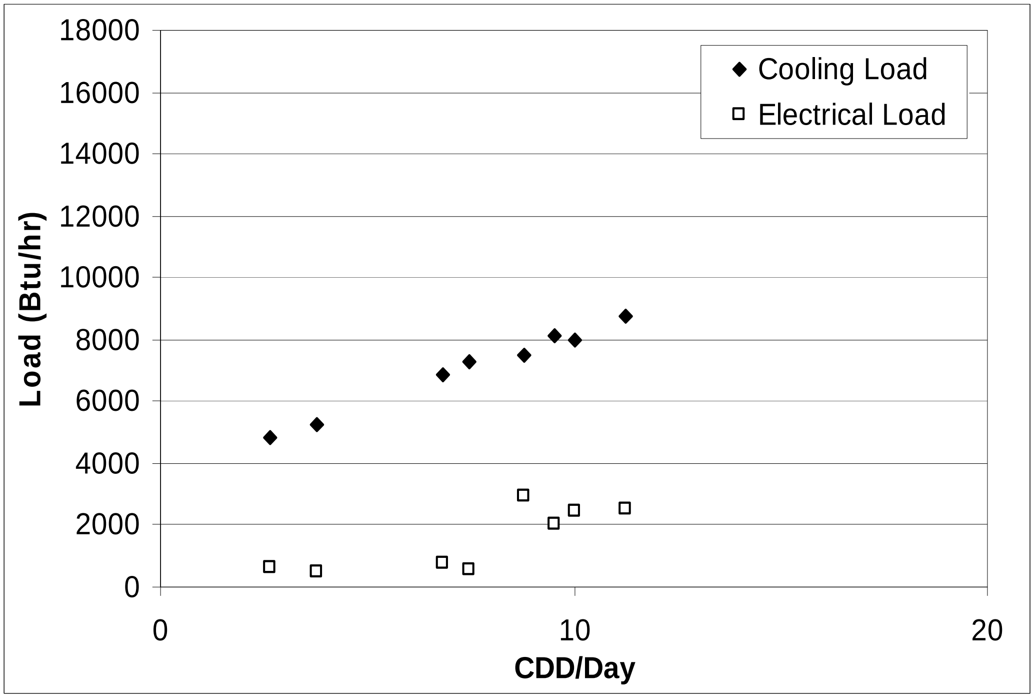

Figure B.41: Home H-1-17 cooling and electrical load versus CDD/Day

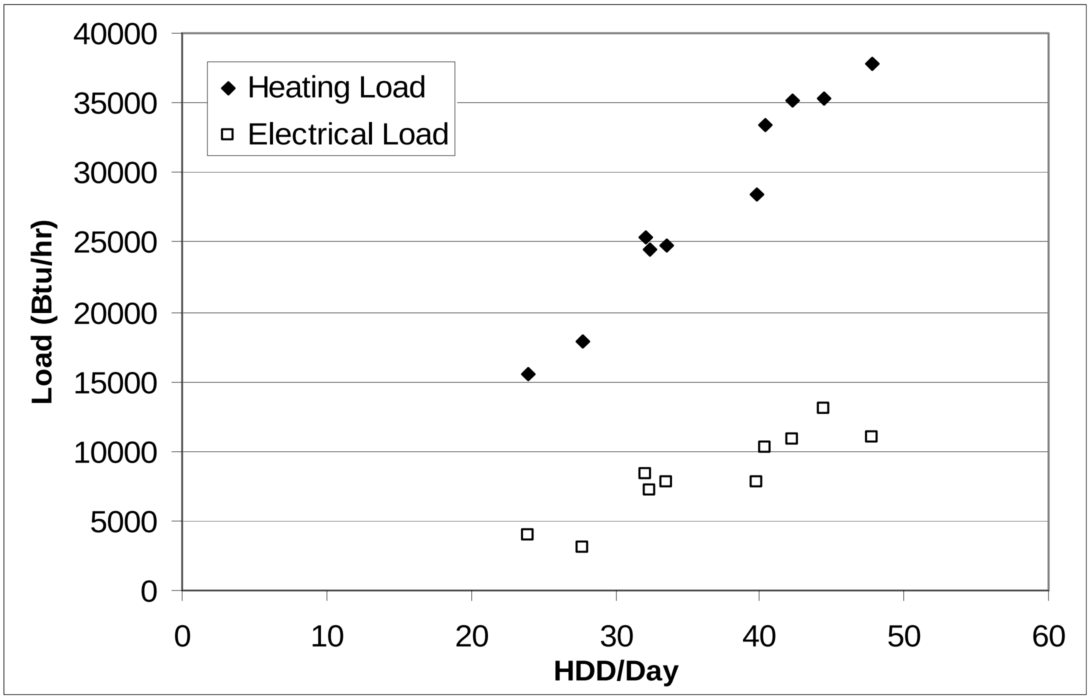

Figure B.43: Home H-0-18 heating and electrical load versus HDD/Day

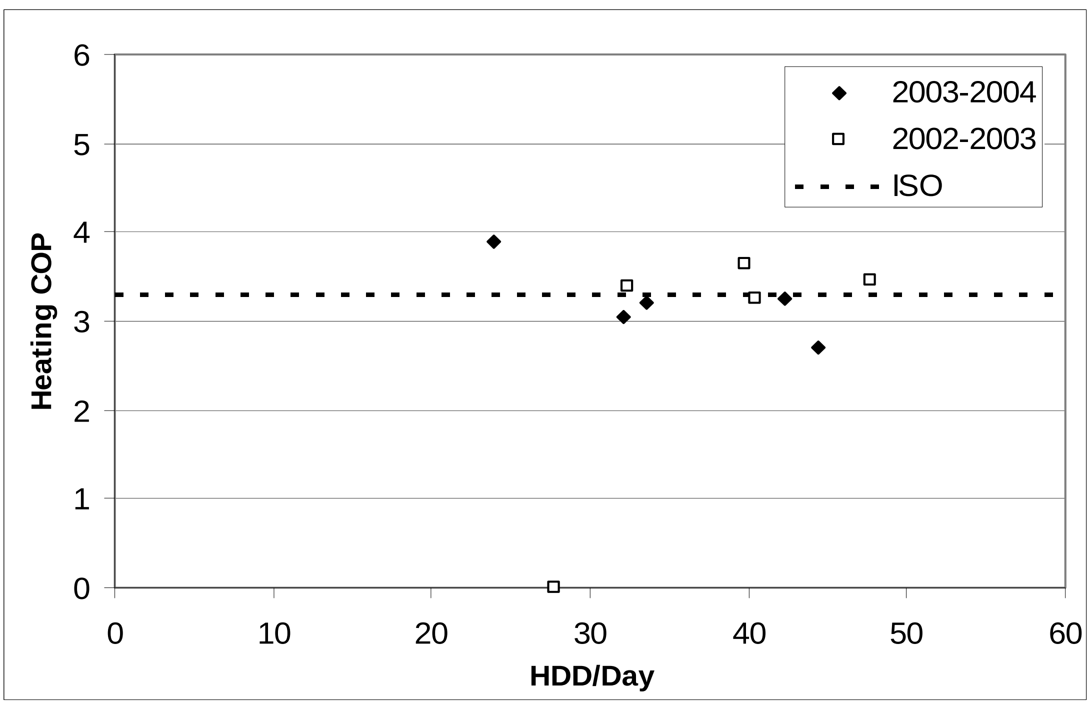

Figure B.44: Home H-0-18 ISO/ARI rating with heating COP versus HDD/Day

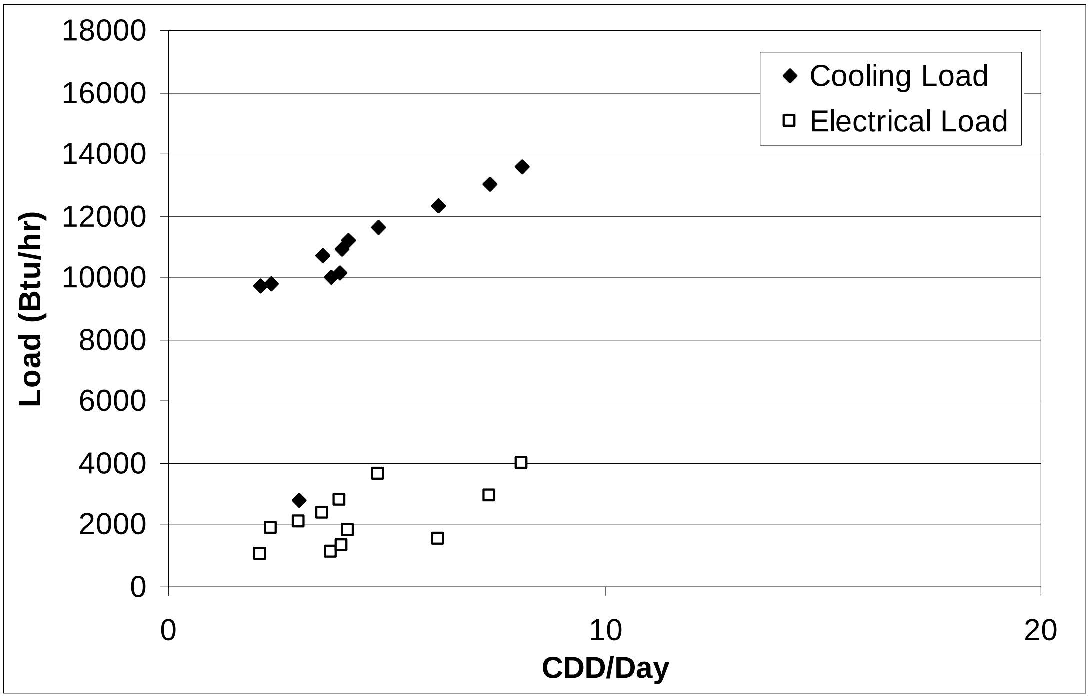

Figure B.45: Home H-0-18 cooling and electrical load versus CDD/Day

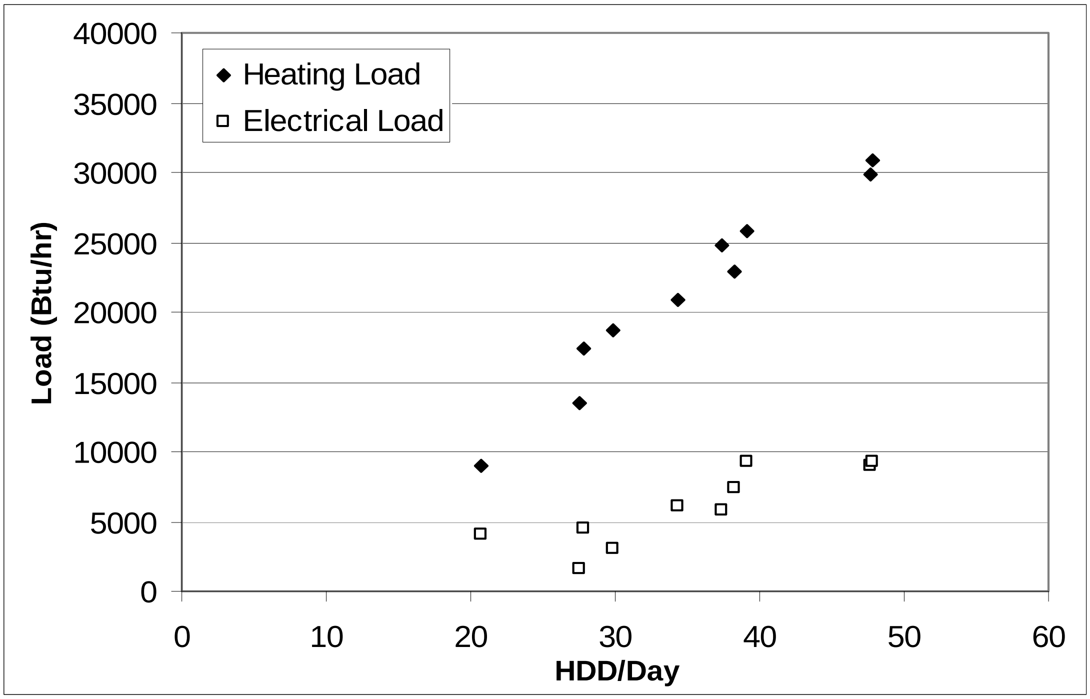

Figure B.46: Home H-1-20 heating and electrical load versus HDD/Day

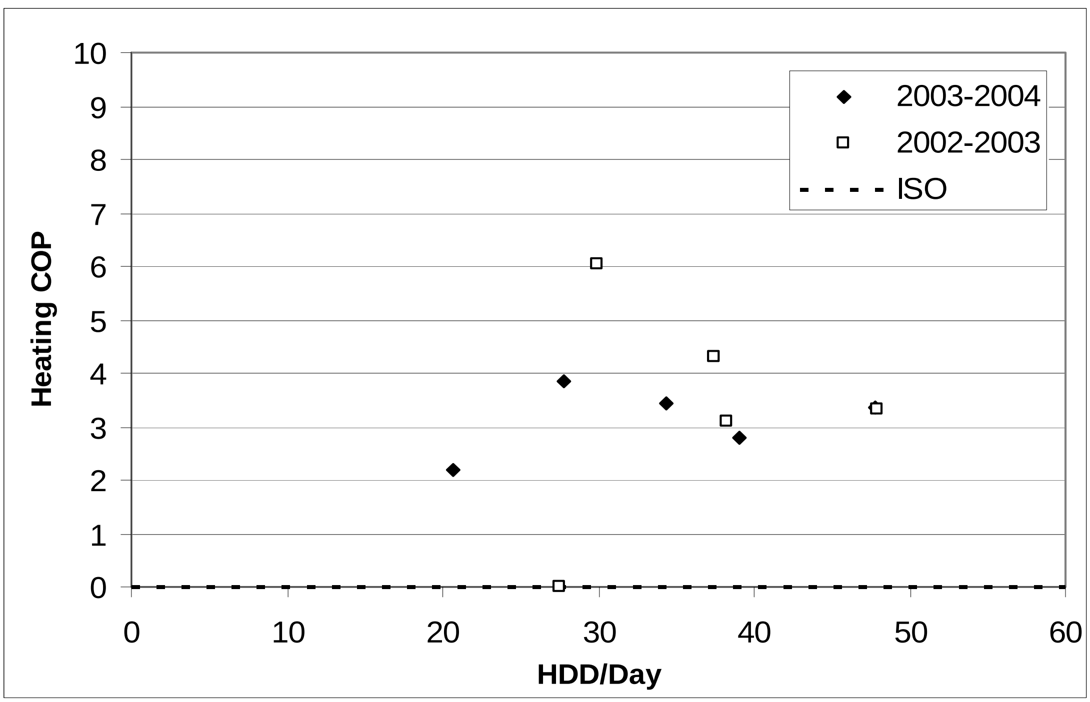

Figure B.47: Home H-1-20 ISO/ARI rating with heating COP versus HDD/Day

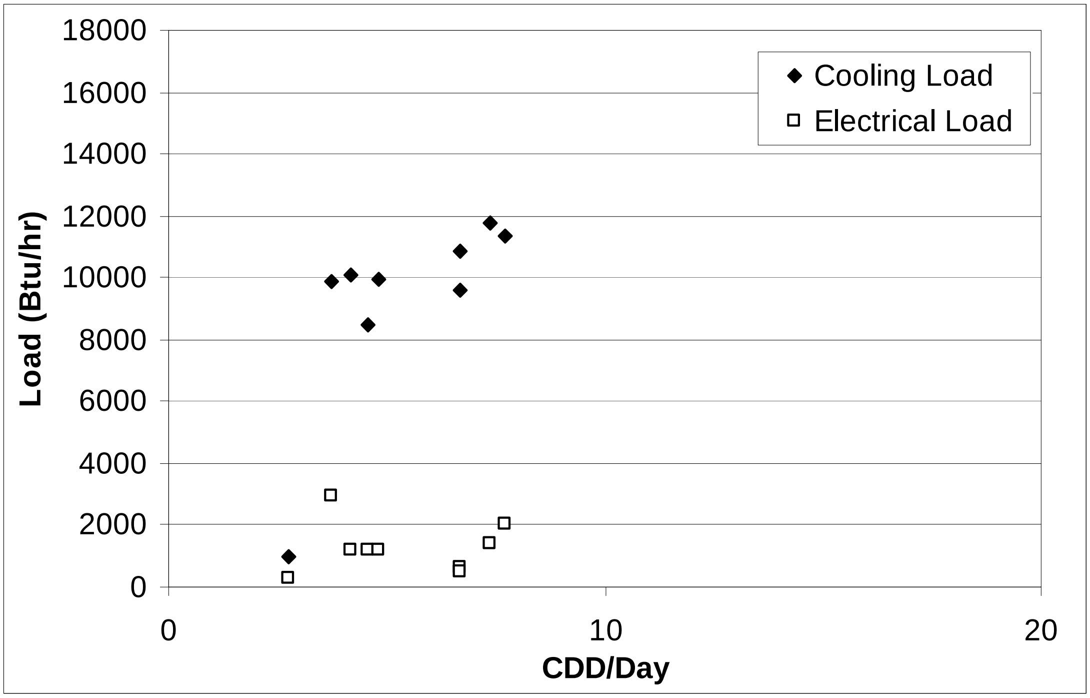

Figure B.48: Home H-1-20 cooling and electrical load versus CDD/Day

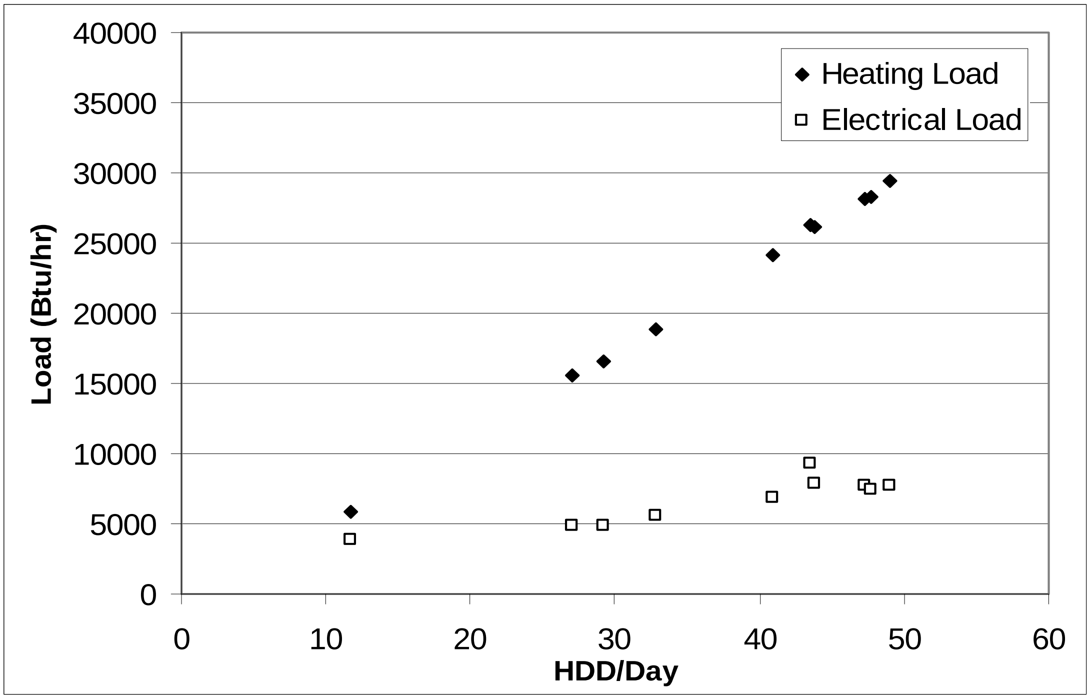

Figure B.49: Home V-1-1 heating and electrical load versus HDD/Day

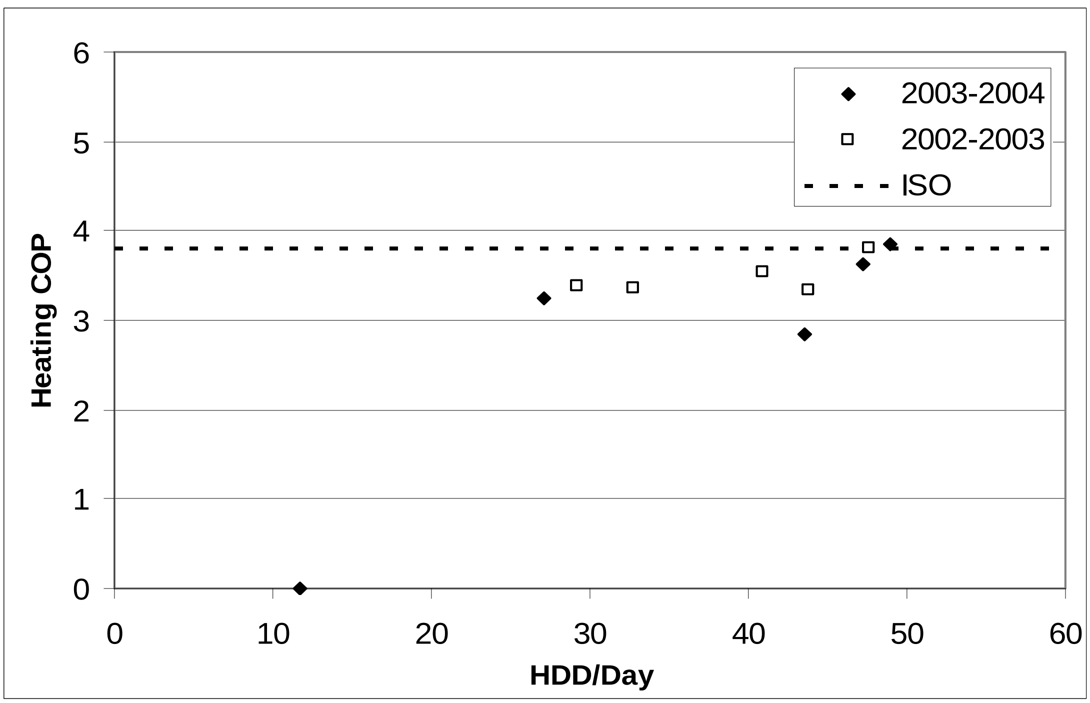

Figure B.50: Home V-1-1 ISO/ARI rating with heating COP versus HDD/Day

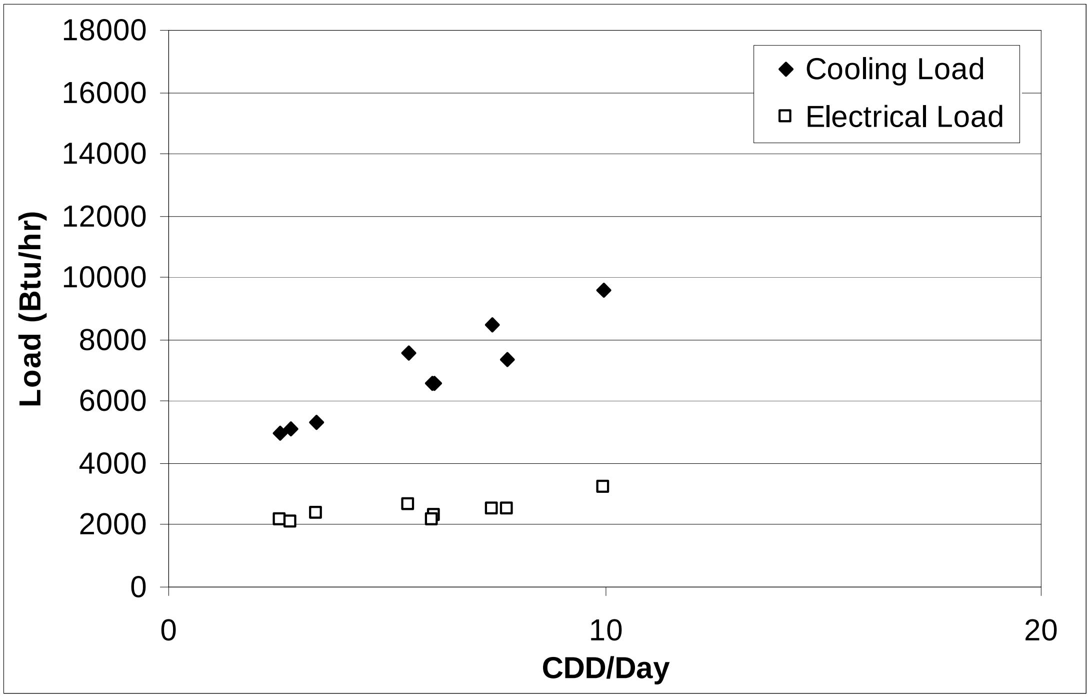

Figure B.51: Home V-1-1 cooling and electrical load versus CDD/Day

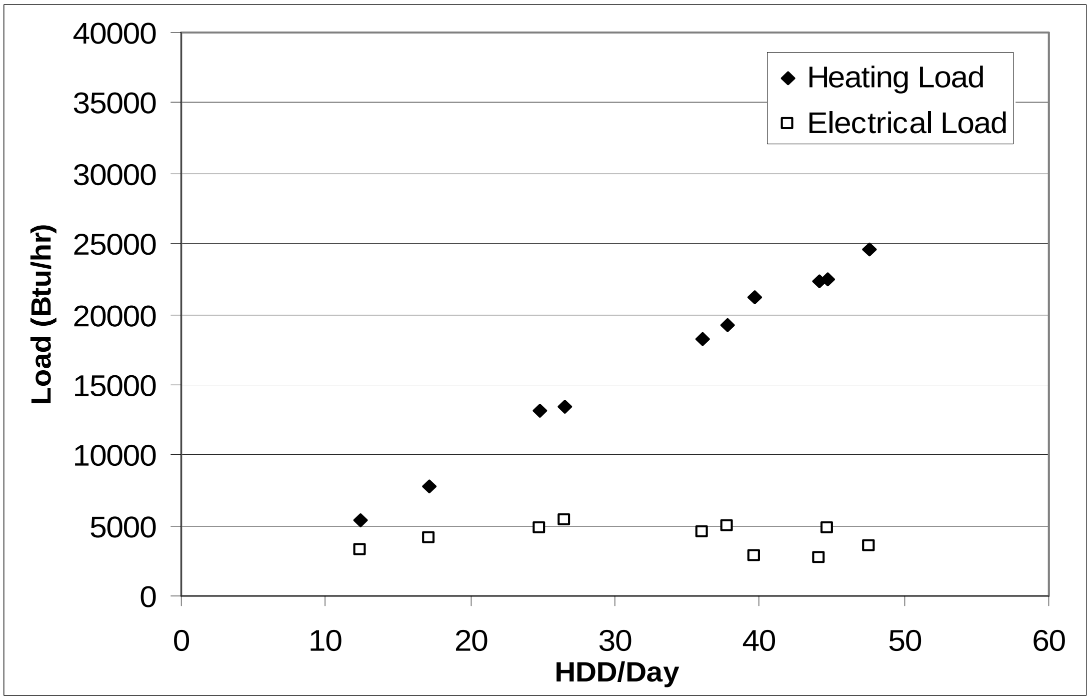

Figure B.52: Home V-1-2 heating and electrical load versus HDD/Day

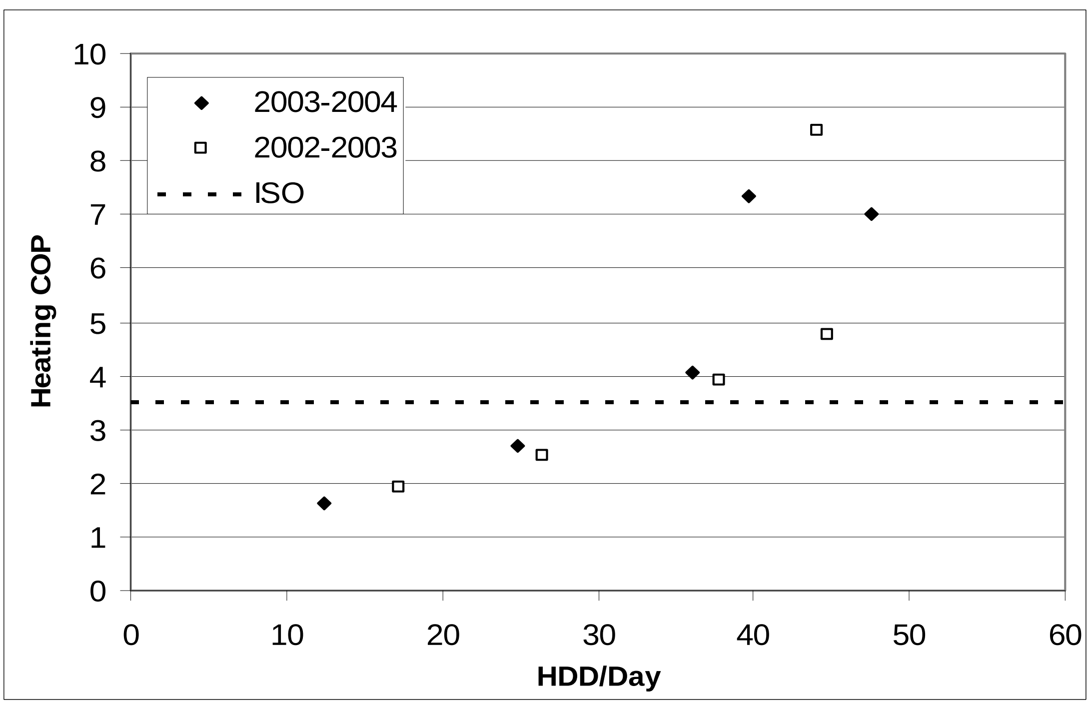

Figure B.53: Home V-1-2 ISO/ARI rating with heating COP versus HDD/Day

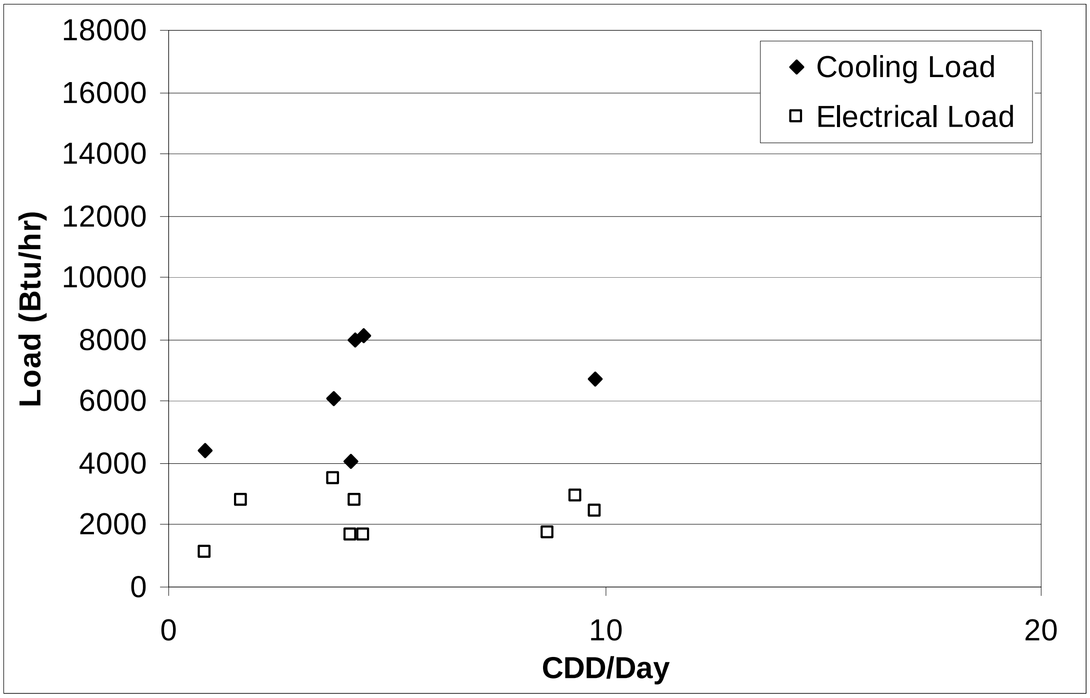

Figure B.54: Home V-1-2 cooling and electrical load versus CDD/Day

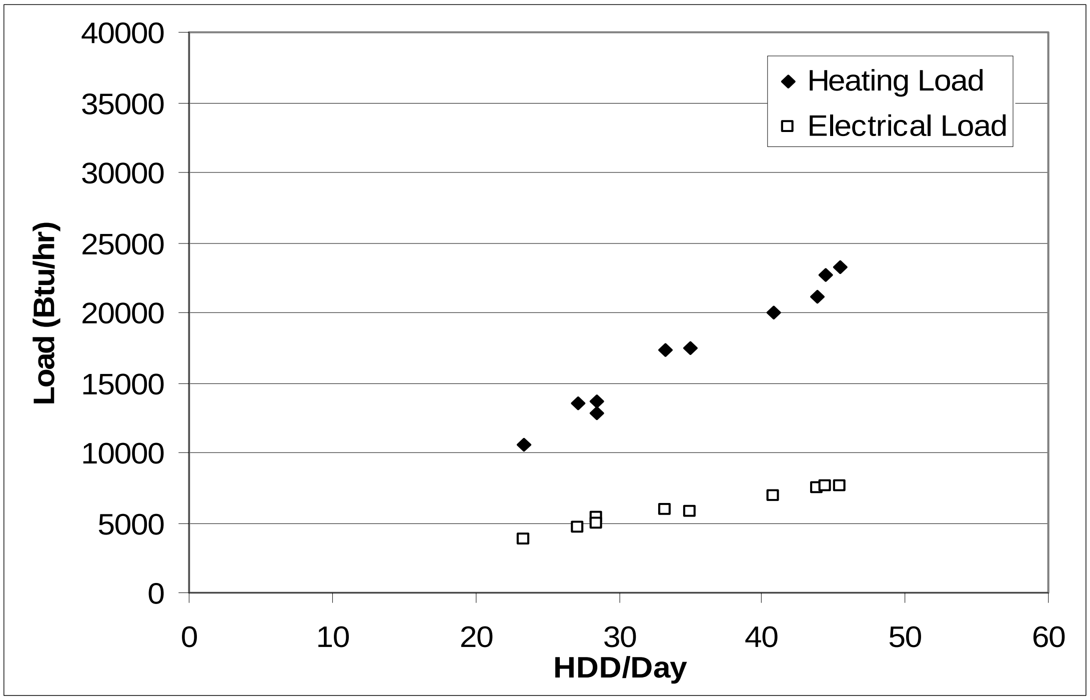

Figure B.55: Home V-1-4 heating and electrical load versus HDD/Day

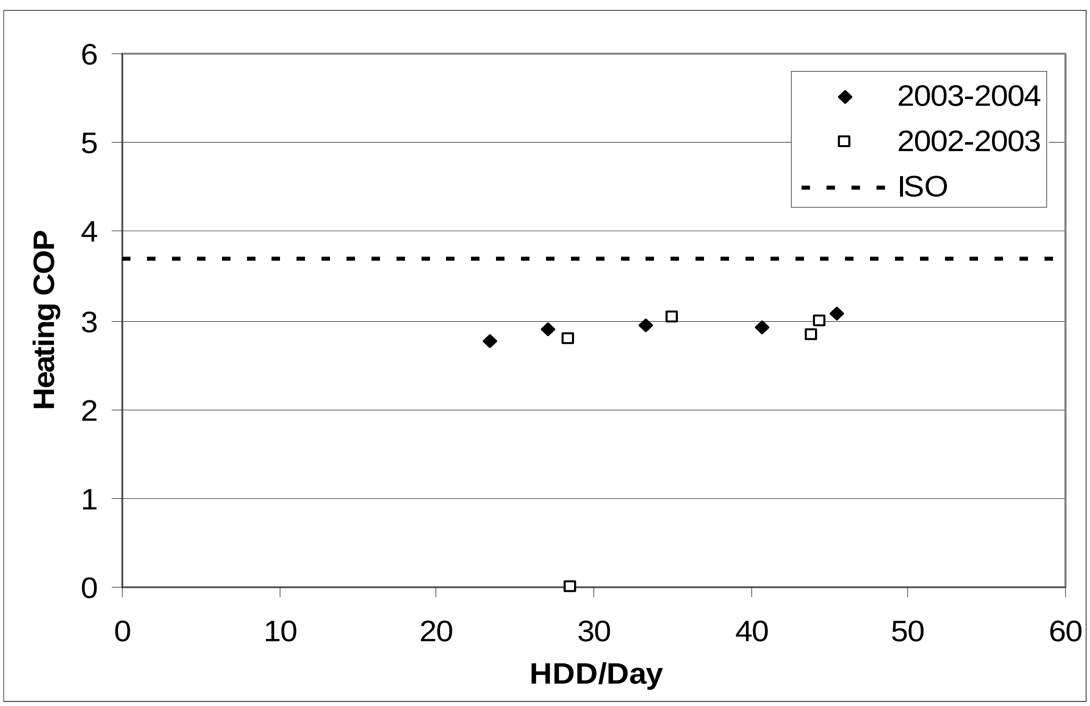

Figure B.56: Home V-1-4 ISO/ARI rating with heating COP versus HDD/Day

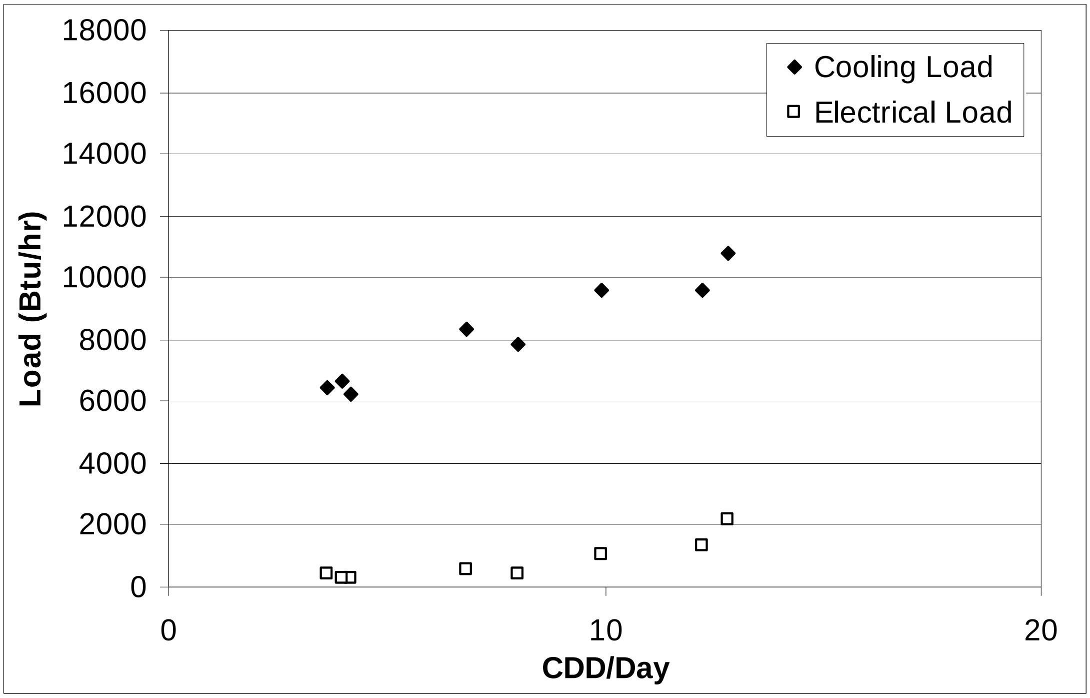

Figure B.57: Home V-1-4 cooling and electrical load versus CDD/Day

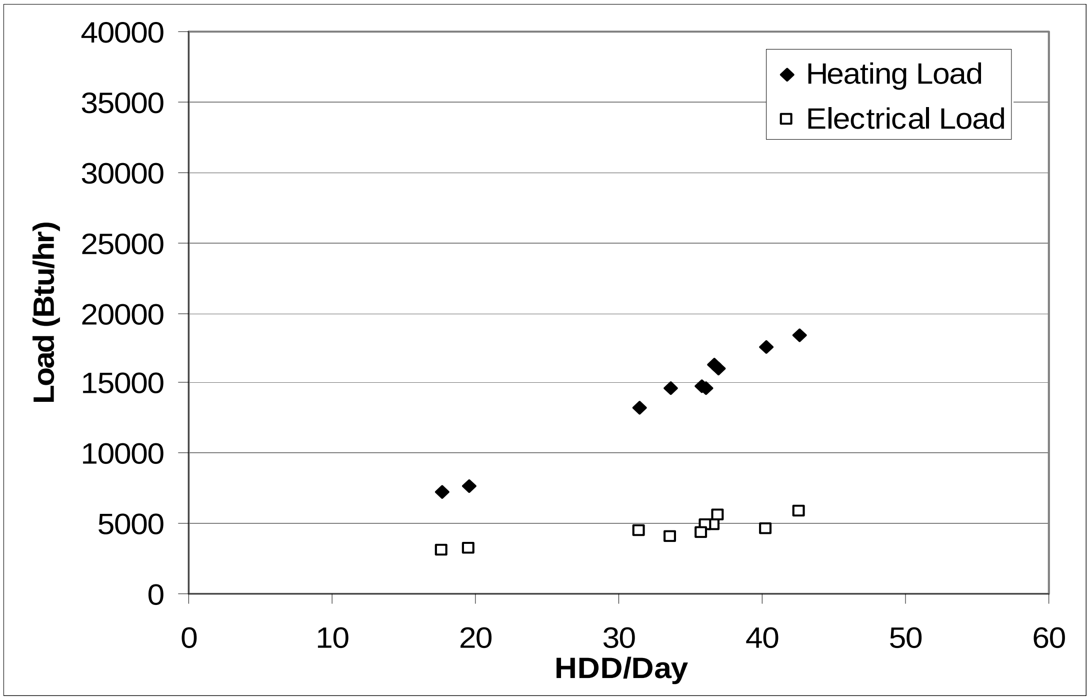

Figure B.58: Home V-1-5 heating and electrical load versus HDD/Day

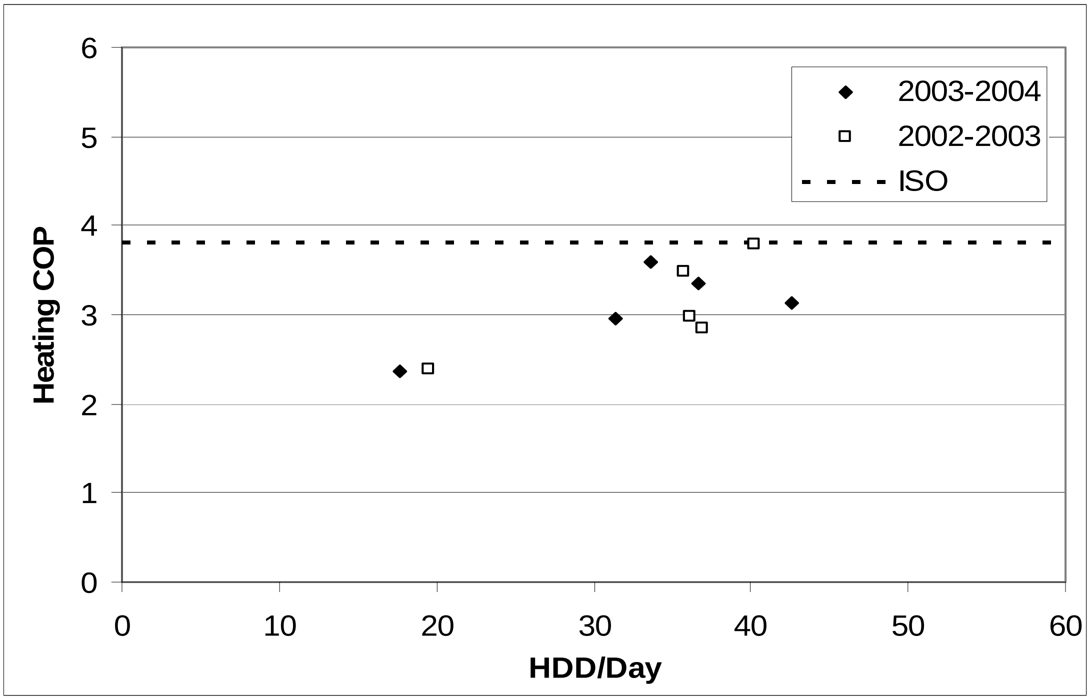

Figure B.59: Home V-1-5 ISO/ARI rating with heating COP versus HDD/Day

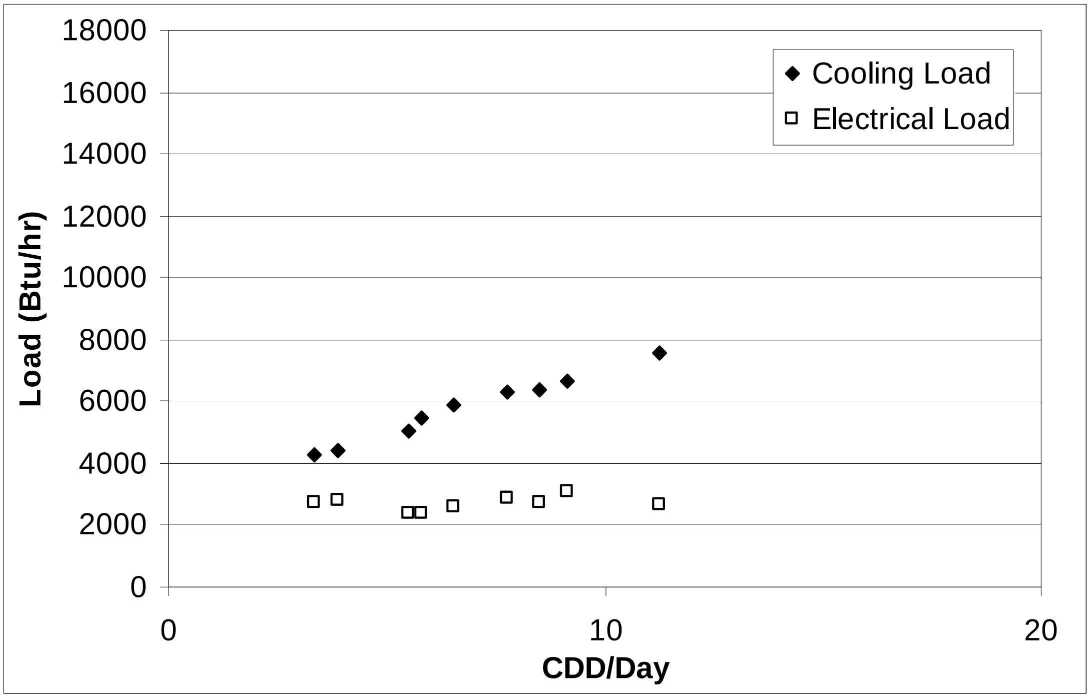

Figure B.60: Home V-1-5 cooling and electrical load versus CDD/Day

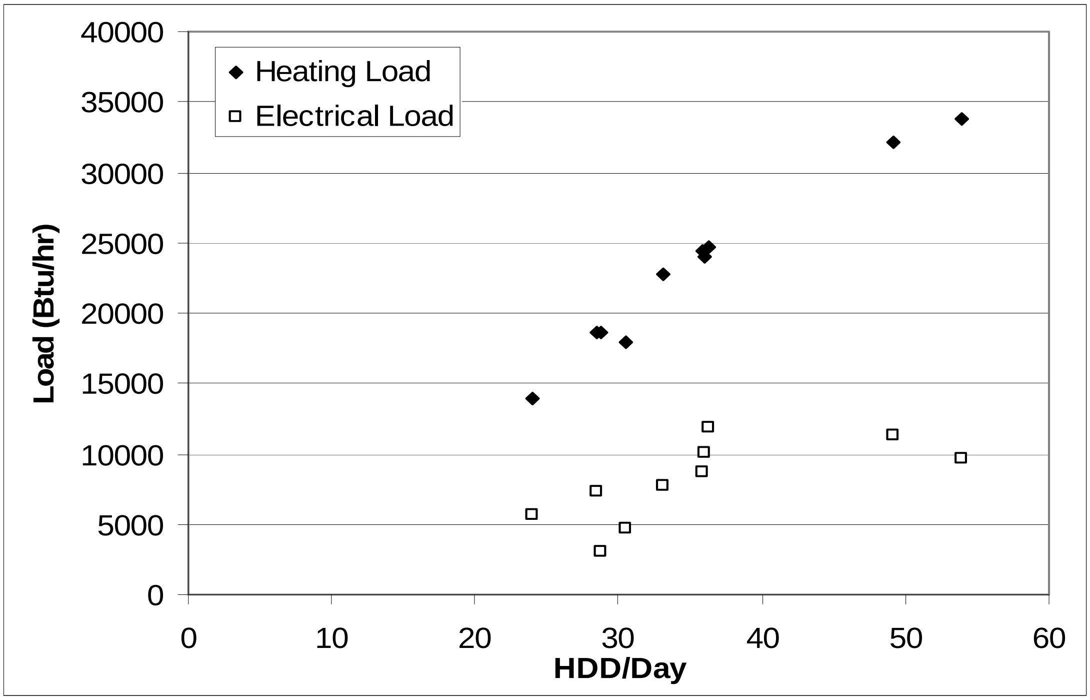

Figure B.61: Home V-1-6 heating and electrical load versus HDD/Day

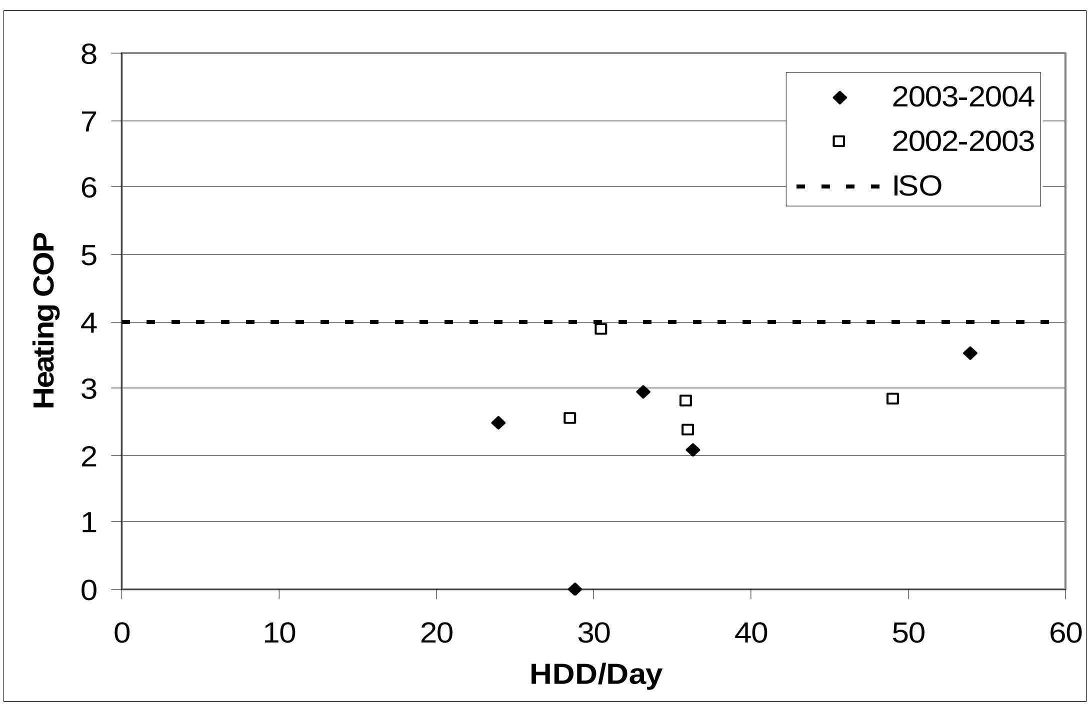

Figure B.62: Home V-1-6 ISO/ARI rating with heating COP versus HDD/Day

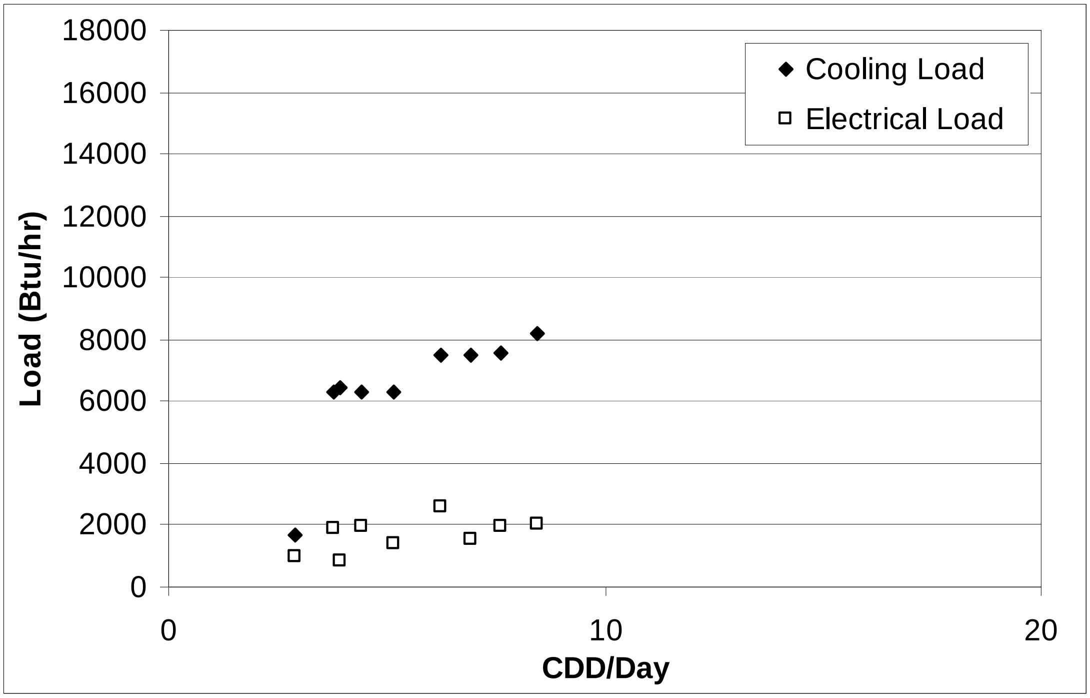

Figure B.63: Home V-1-6 cooling and electrical load versus CDD/Day

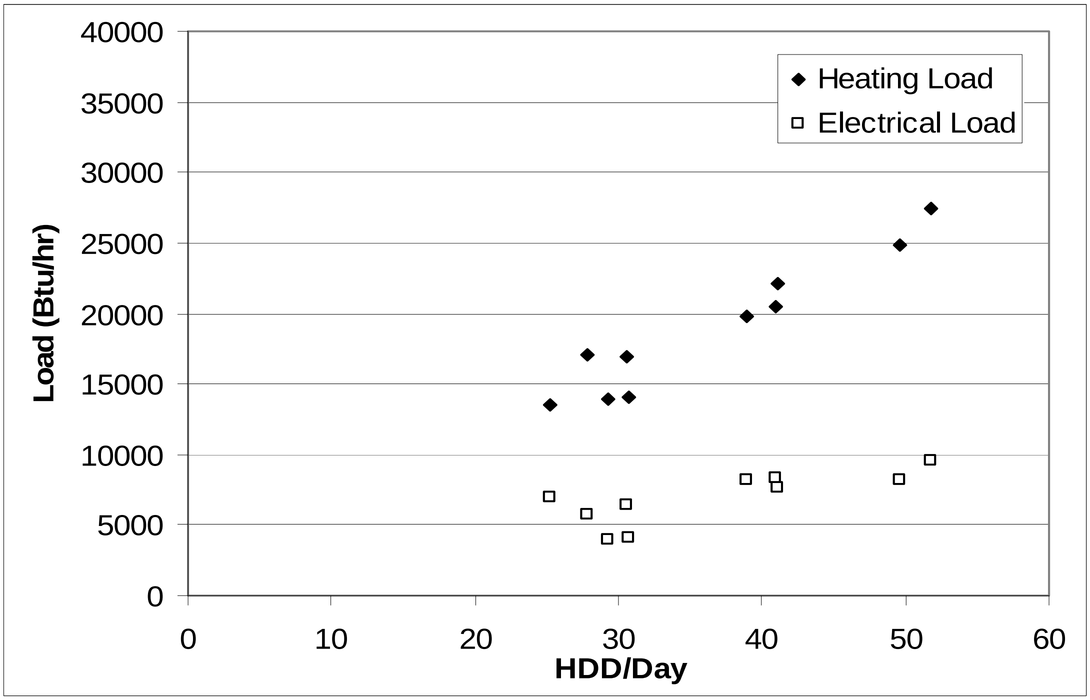

Figure B.64: Home V-1-7 heating and electrical load versus HDD/Day

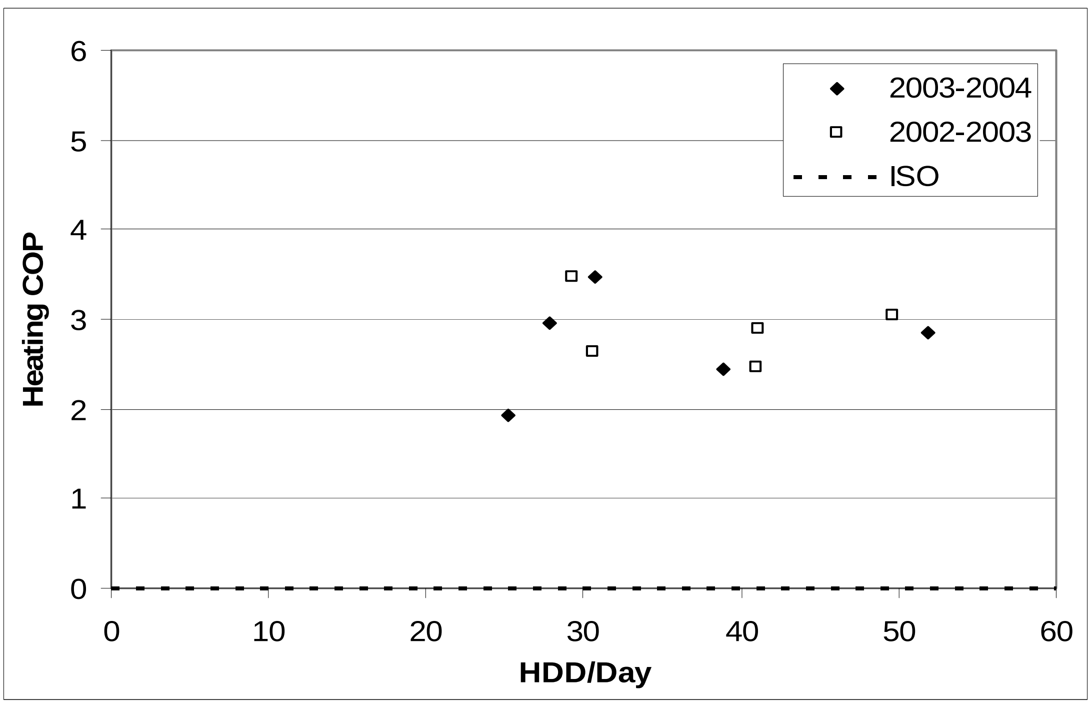

Figure B.65: Home V-1-7 ISO/ARI rating with heating COP versus HDD/Day

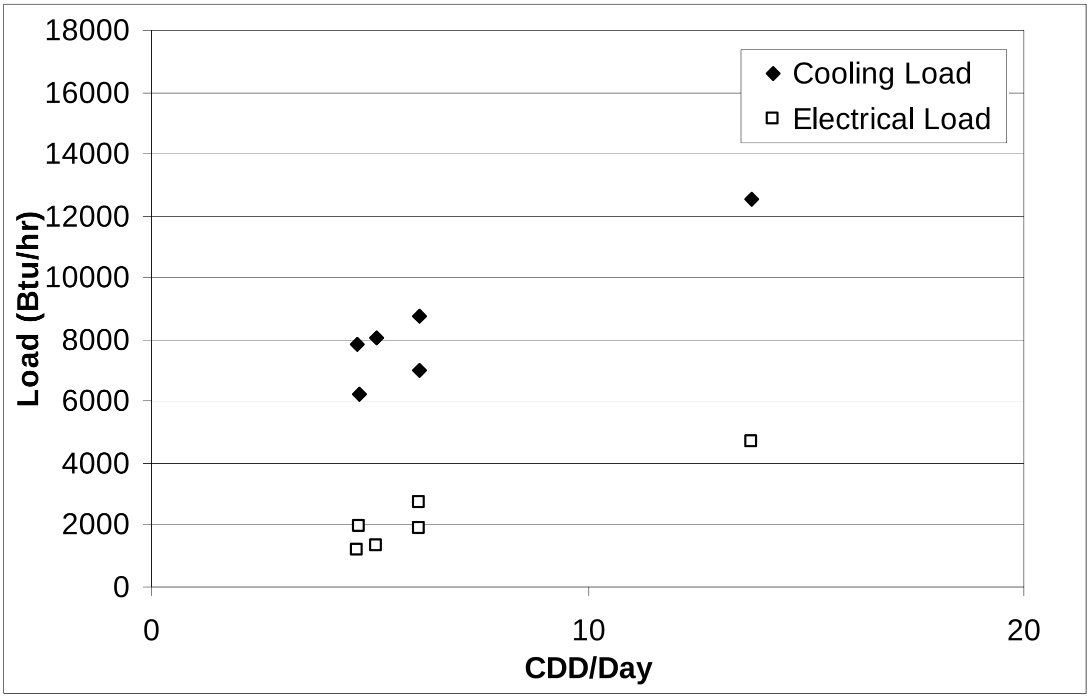

Figure B.66: Home V-1-7 cooling and electrical load versus CDD/Day

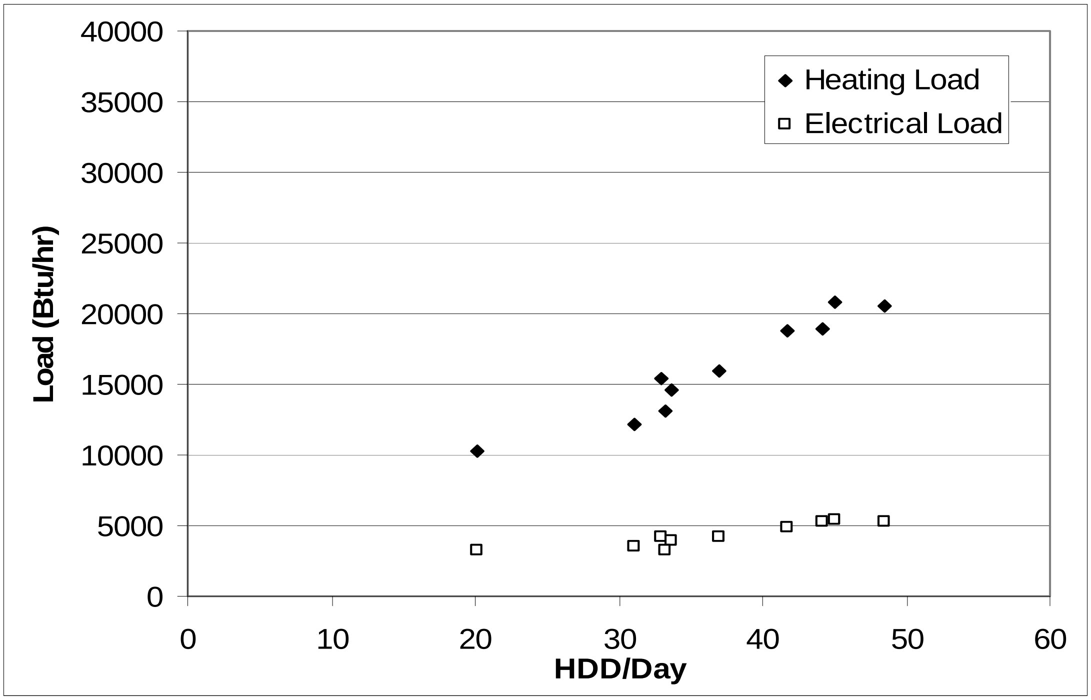

Figure B.67: Home V-1-8 heating and electrical load versus HDD/Day

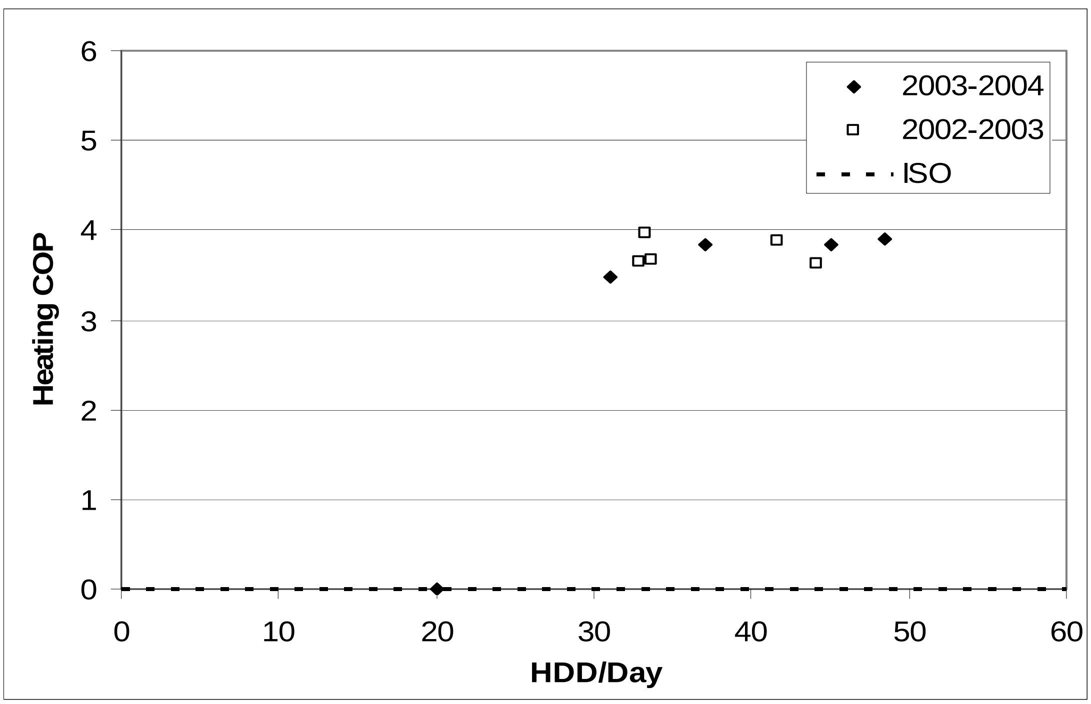

Figure B.68: Home V-1-8 ISO/ARI rating with heating COP versus HDD/Day

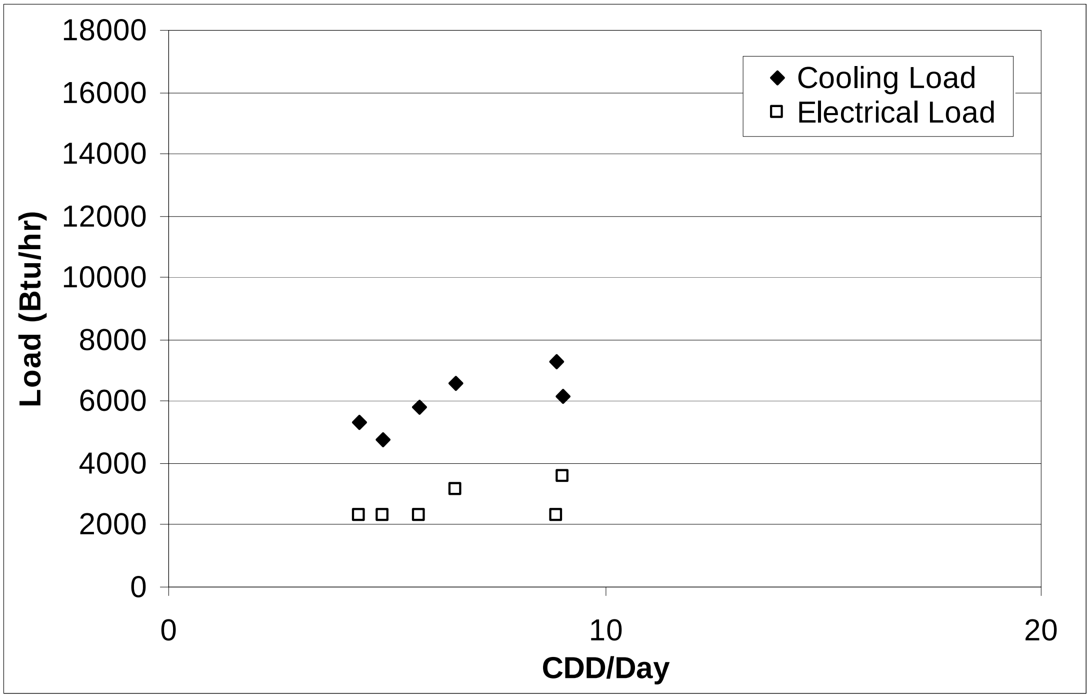

Figure B.69: Home V-1-8 cooling and electrical load versus CDD/Day

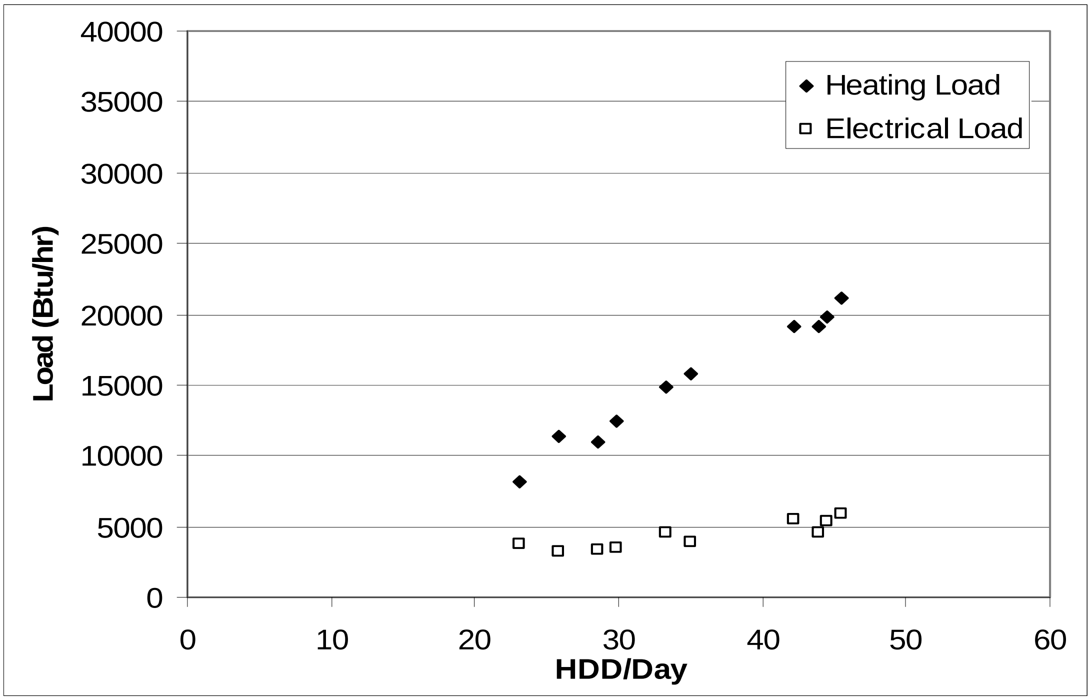

Figure B.70: Home V-1-9 heating and electrical load versus HDD/Day

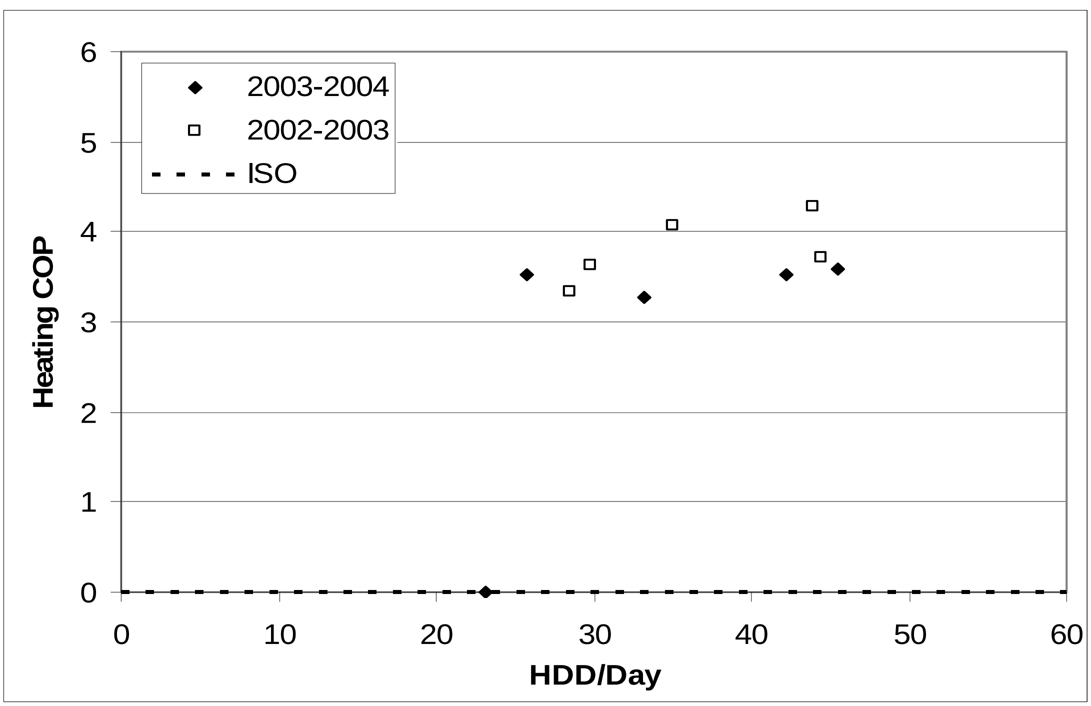

Figure B.71: Home V-1-9 ISO/ARI rating with heating COP versus HDD/Day

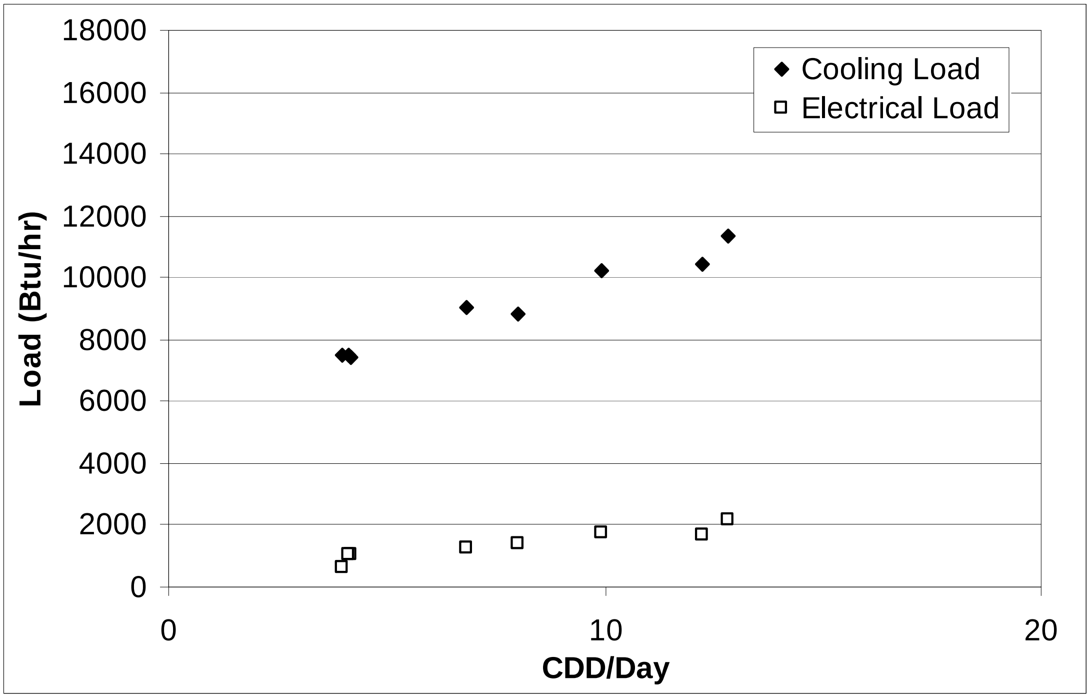

Figure B.72: Home V-1-9 cooling and electrical load versus CDD/Day

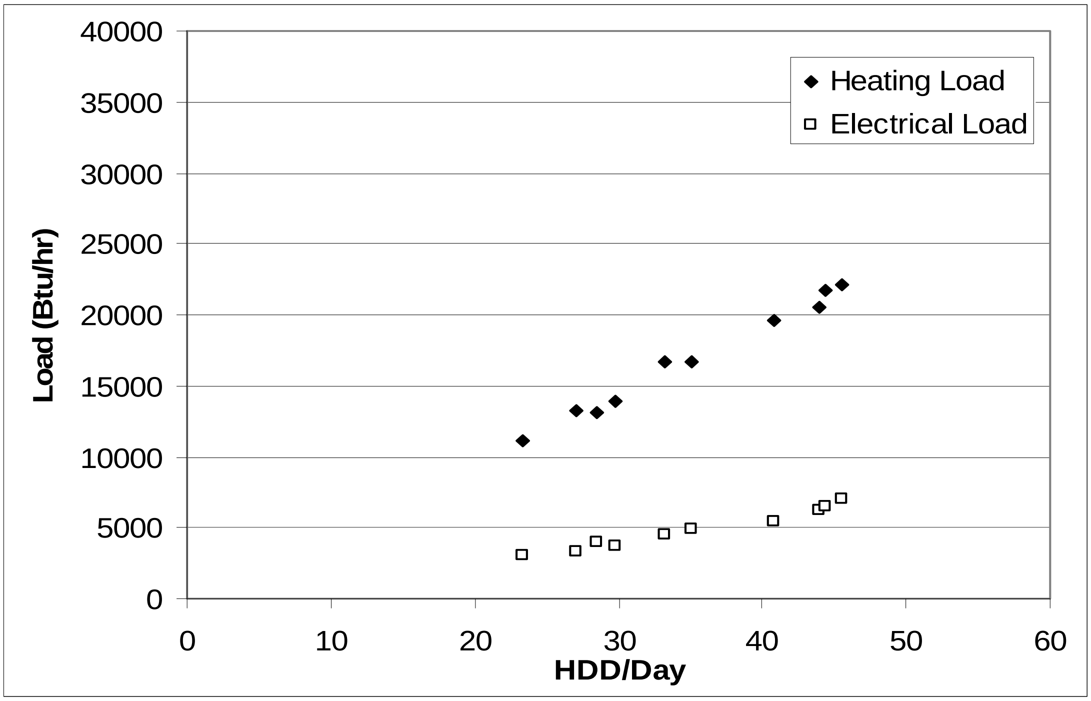

Figure B.73: Home V-1-11 heating and electrical load versus HDD/Day

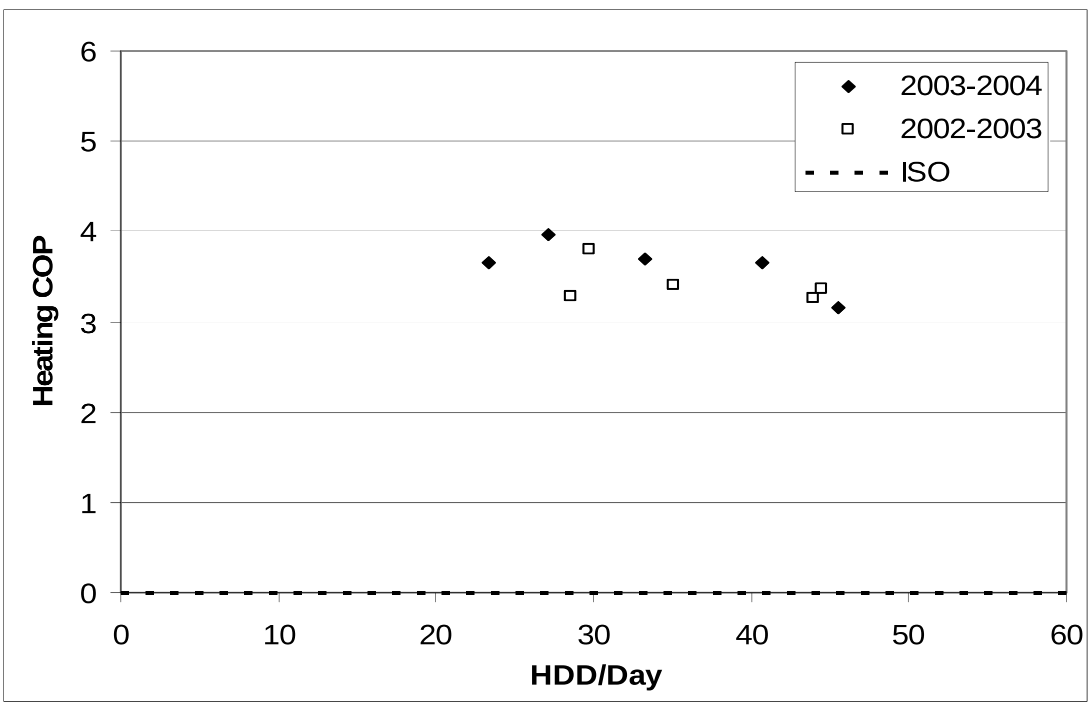

Figure B.74: Home V-1-11 ISO/ARI rating with heating COP versus HDD/Day

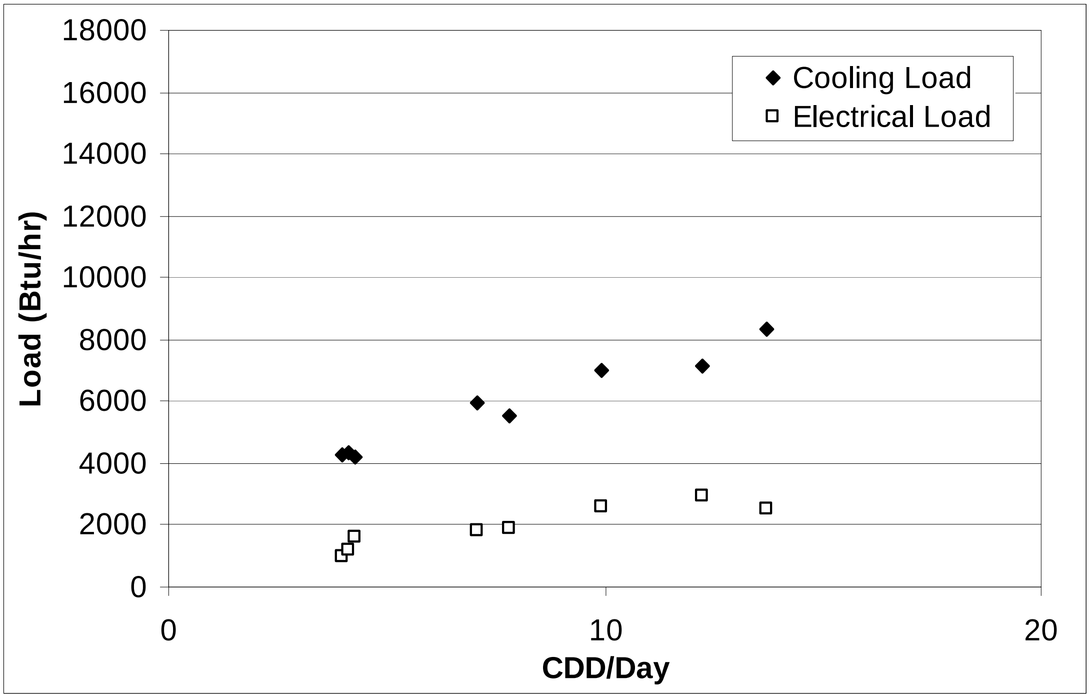

Figure B.75: Home V-1-11 cooling and electrical load versus CDD/Day

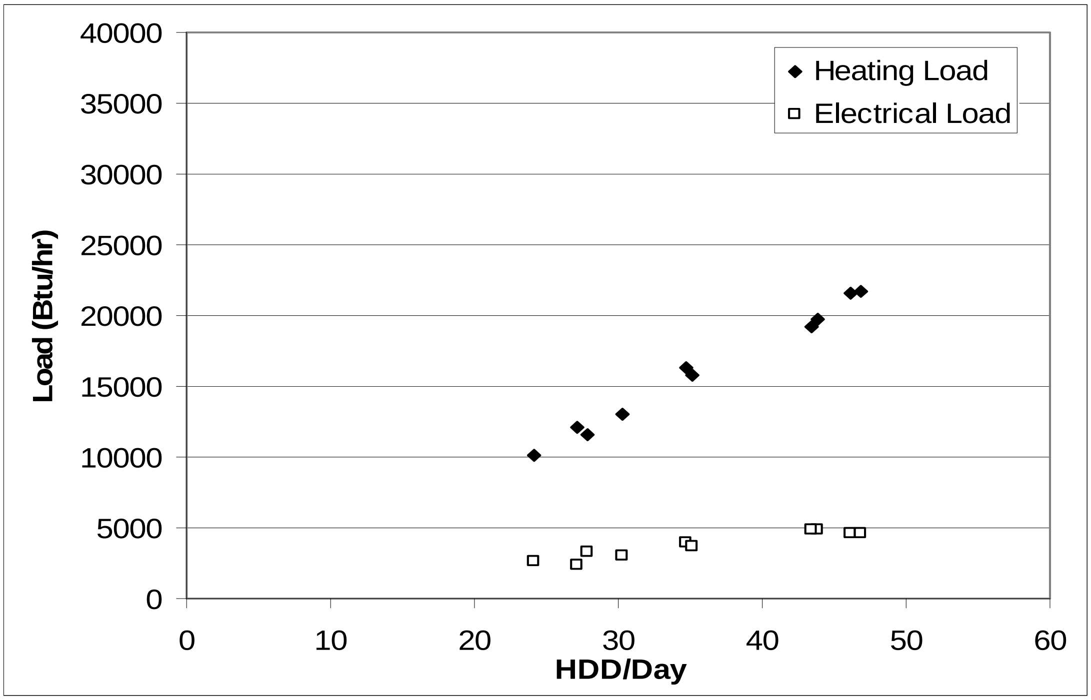

Figure B.76: Home V-1-12 heating and electrical load versus HDD/Day

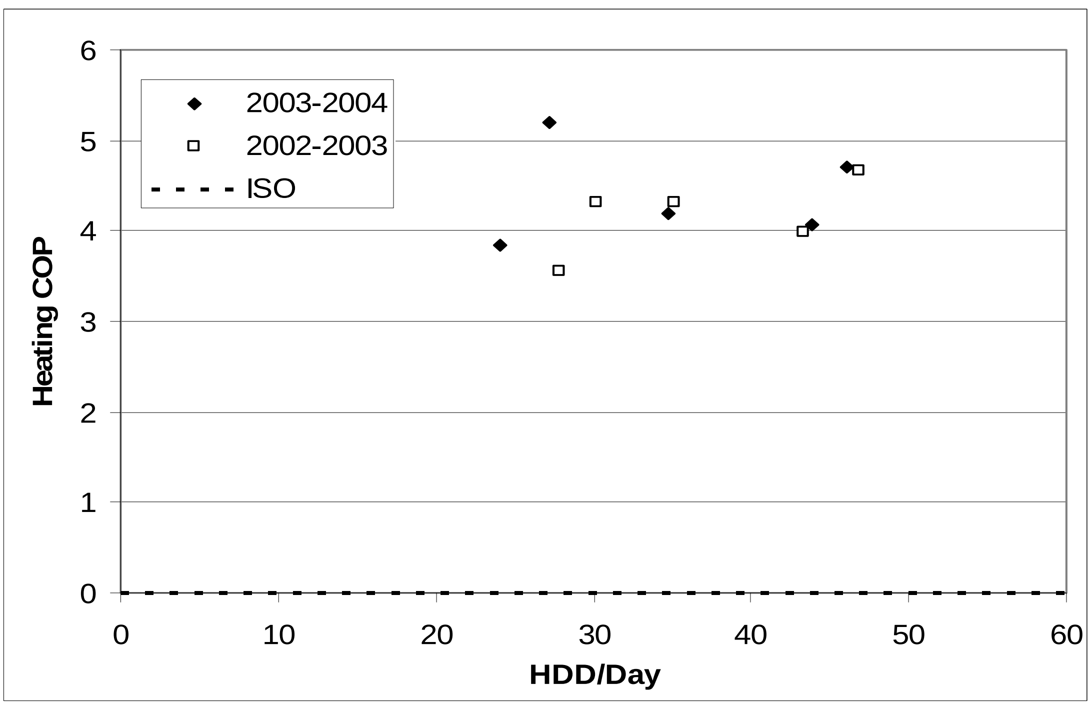

Figure B.77: Home V-1-12 ISO/ARI rating with heating COP versus HDD/Day

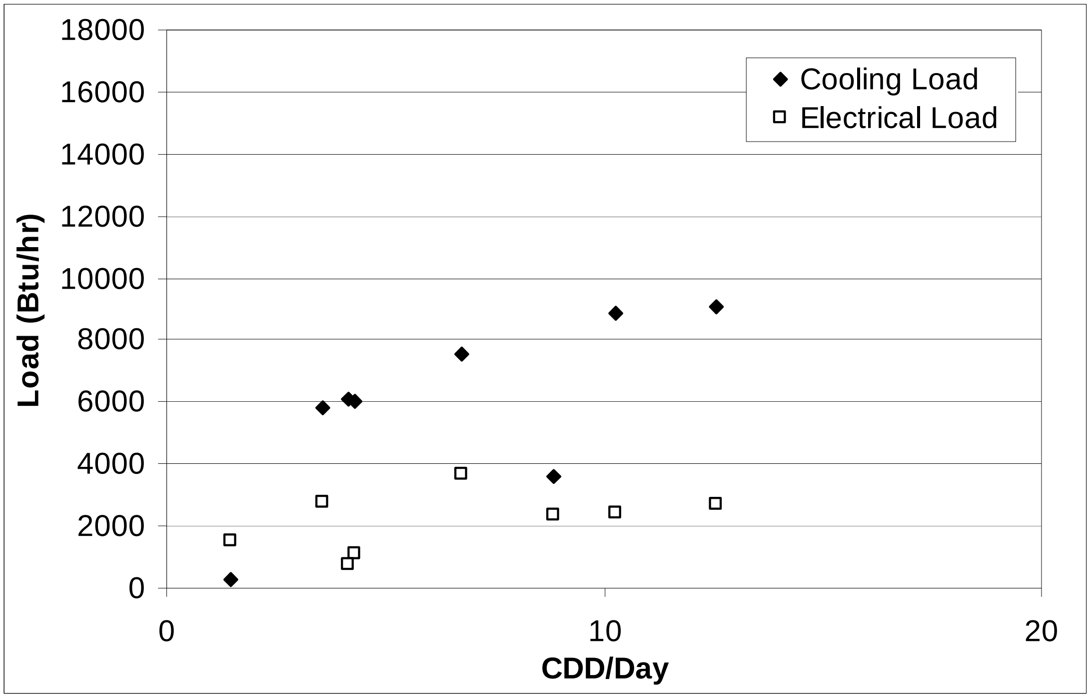

Figure B.78: Home V-1-12 cooling and electrical load versus CDD/Day

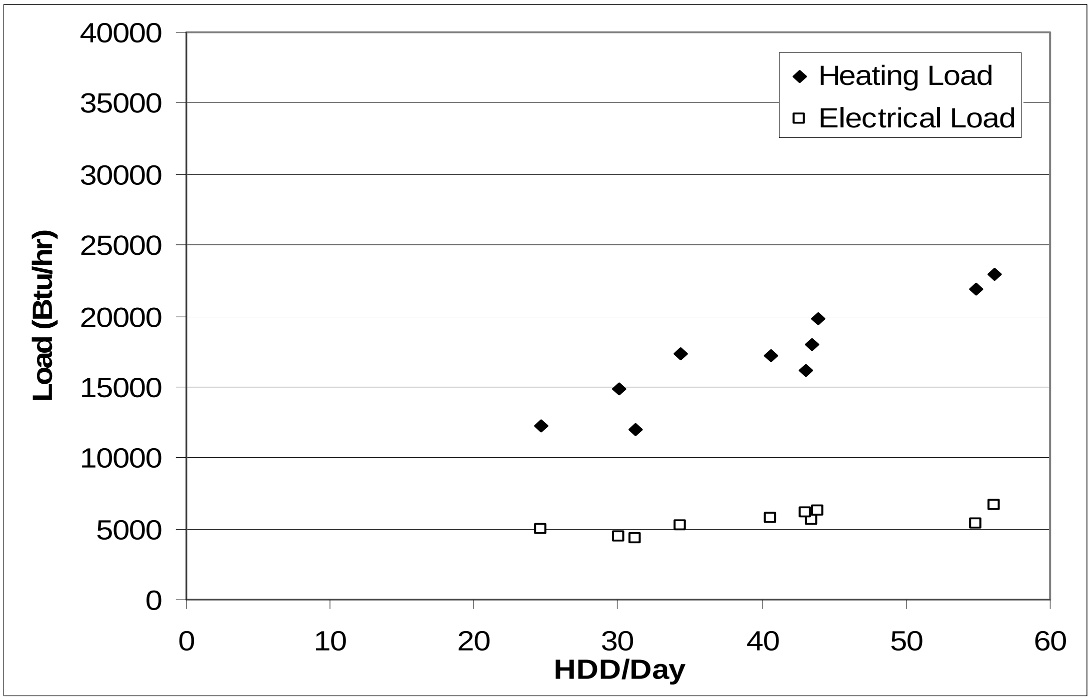

Figure B.79: Home V-1-13 heating and electrical load versus HDD/Day

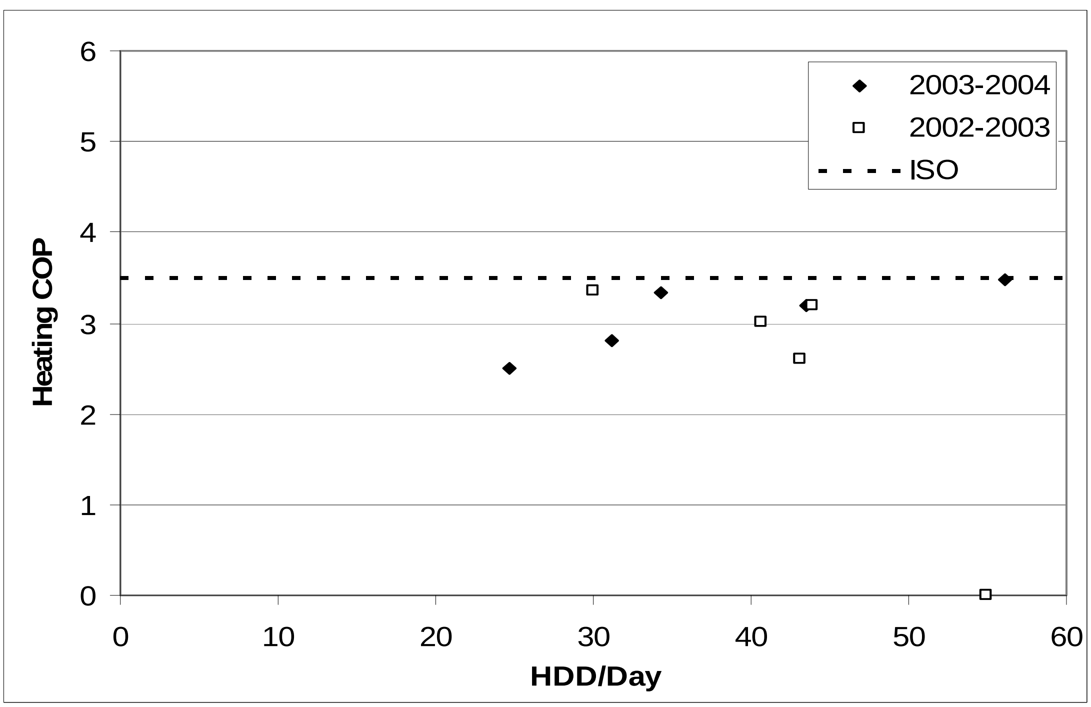

Figure B.80: Home V-1-13 ISO/ARI rating with heating COP versus HDD/Day

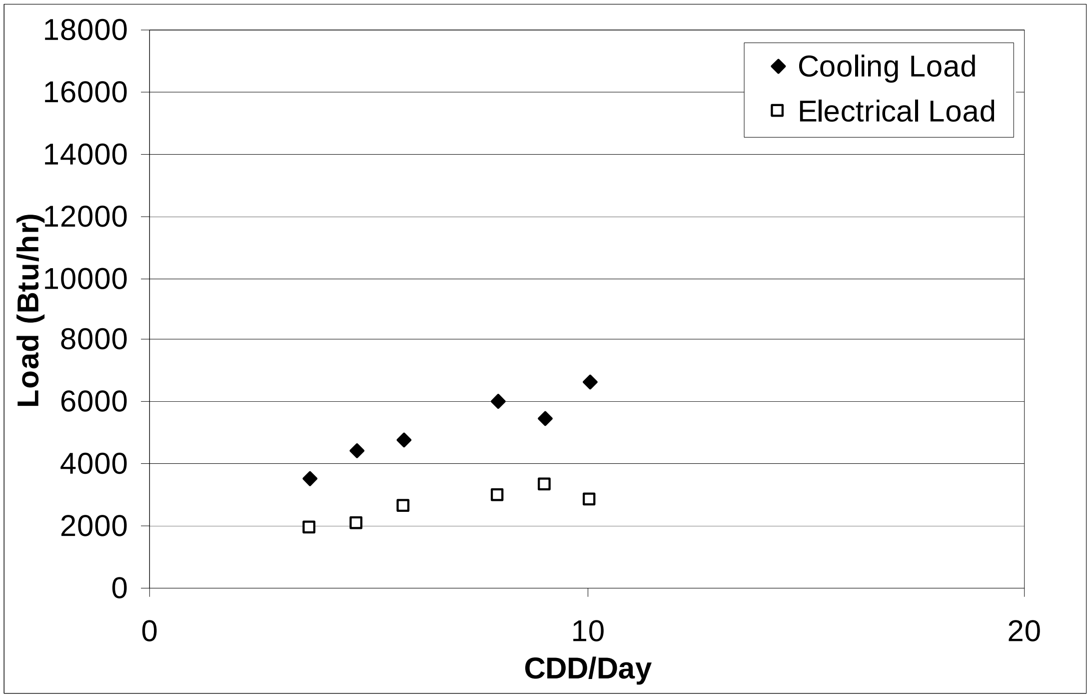

Figure B.81: Home V-1-13 cooling and electrical load versus CDD/Day

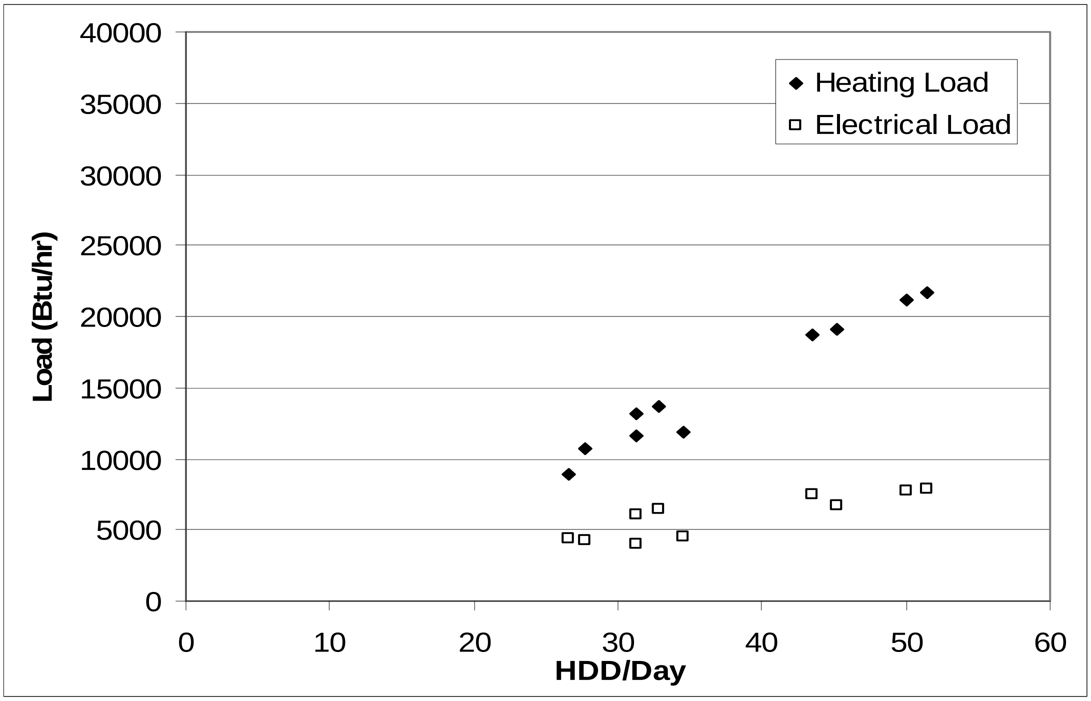

Figure B.82: Home V-0-14 heating and electrical load versus HDD/Day

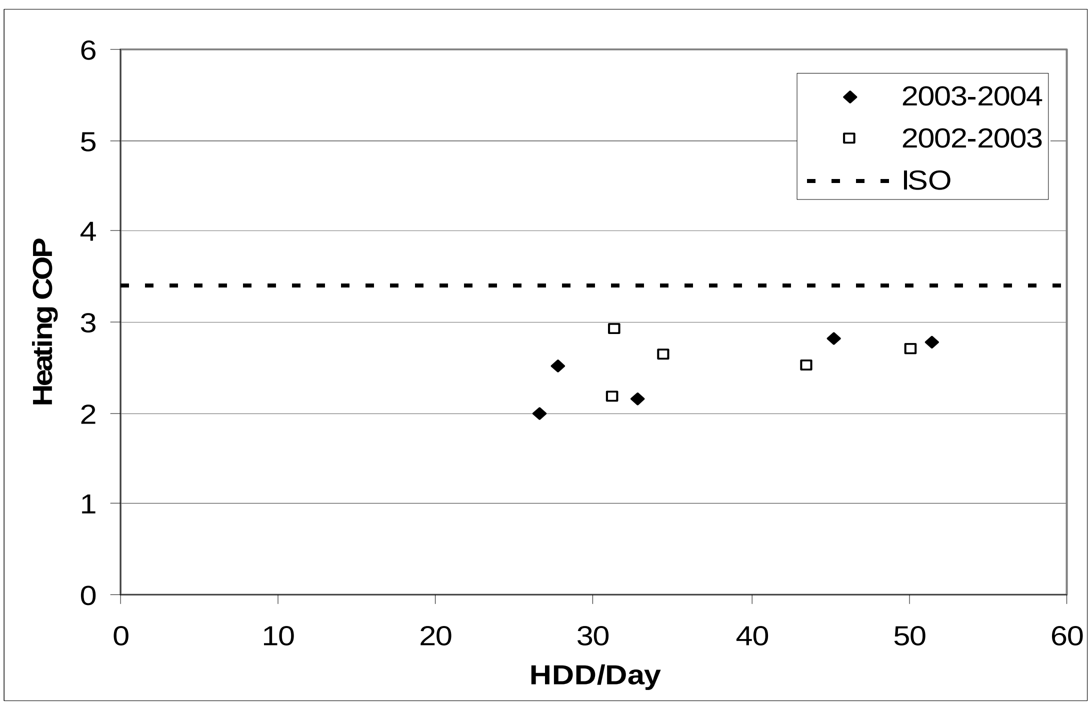

Figure B.83: Home V-0-14 ISO/ARI rating with heating COP versus HDD/Day

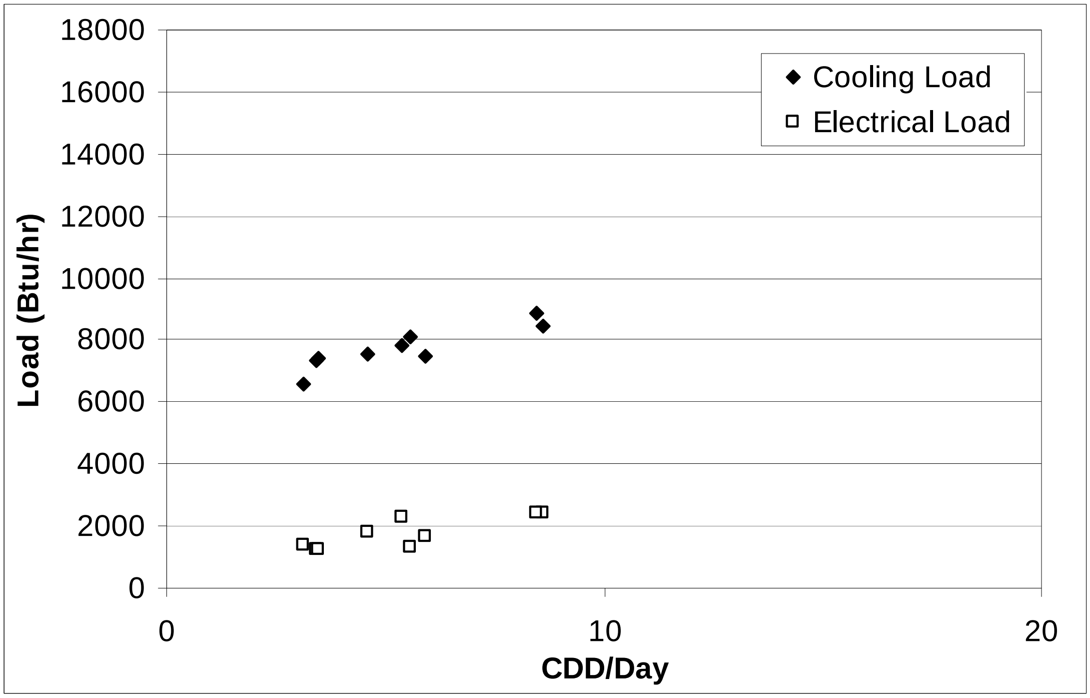

Figure B.84: Home V-0-14 cooling and electrical load versus CDD/Day

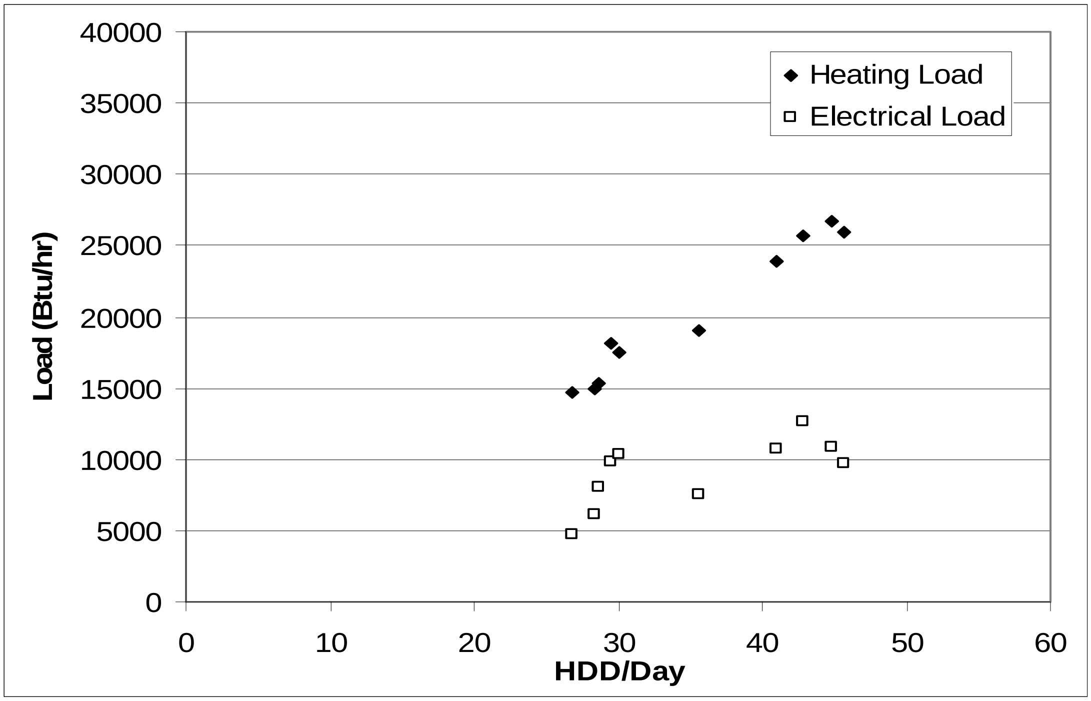

Figure B.85: Home V-1-16 heating and electrical load versus HDD/Day

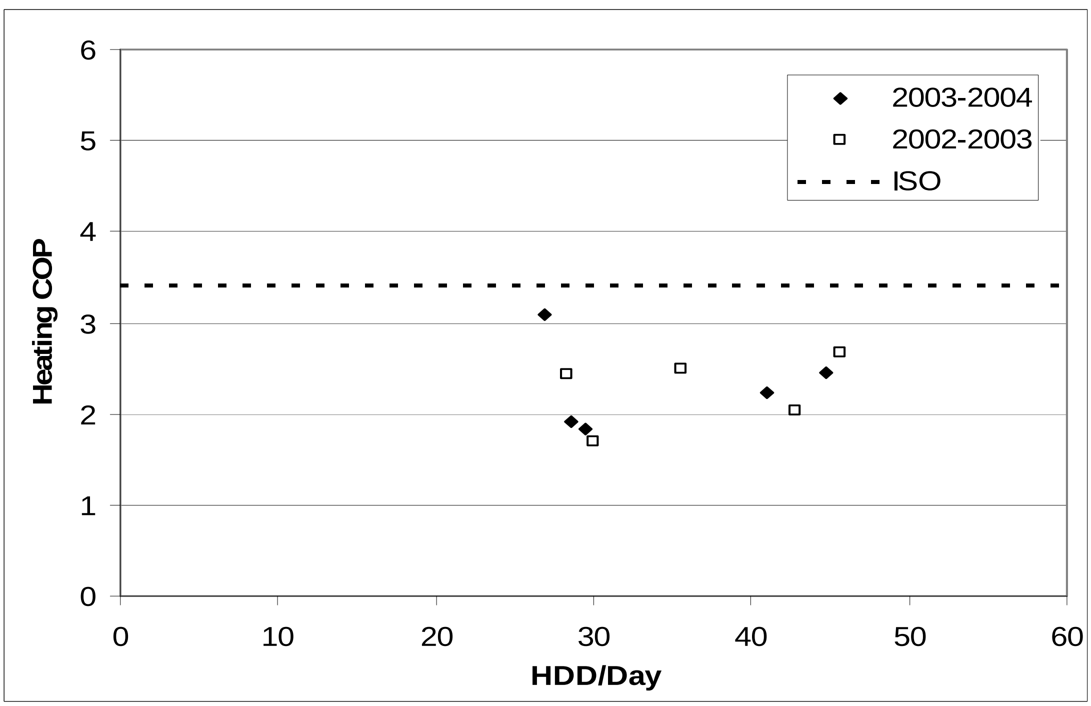

Figure B.86: Home V-1-16 ISO/ARI rating with heating COP versus HDD/Day

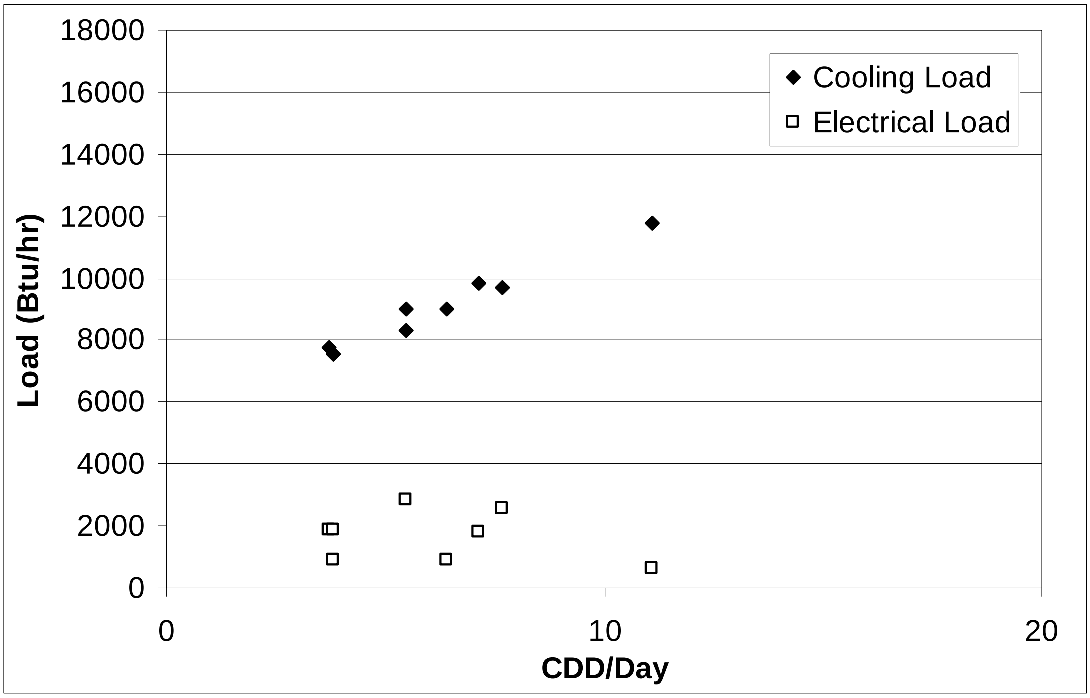

Figure B.87: Home V-1-16 cooling and electrical load versus CDD/Day

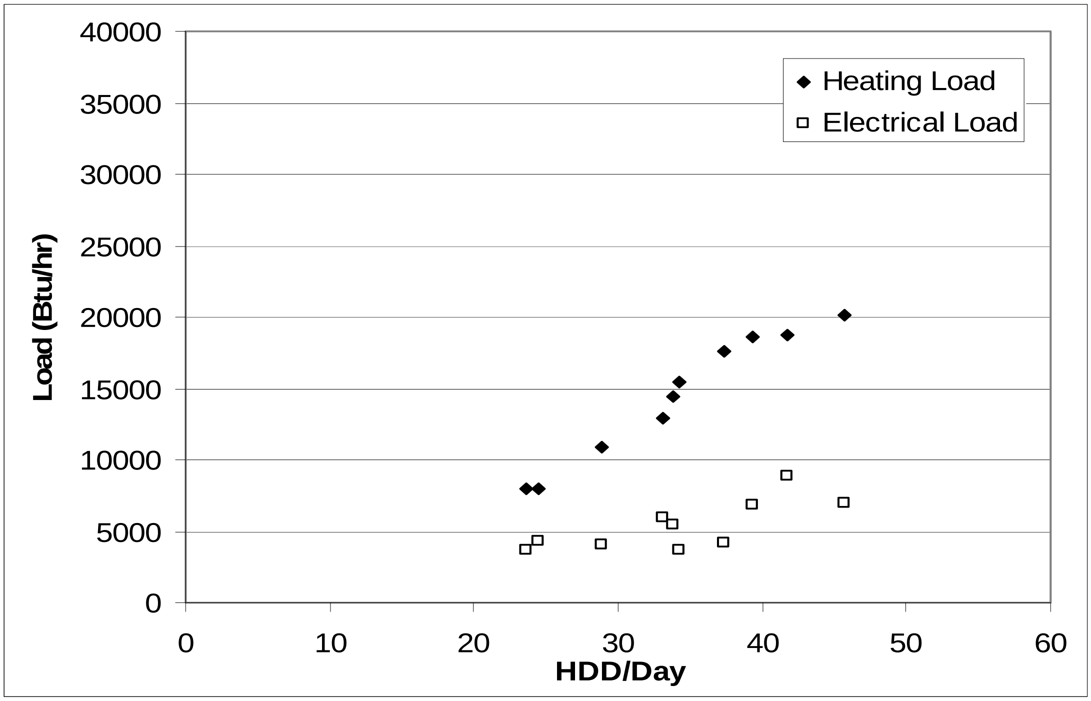

Figure B.88: Home V-0-17 heating and electrical load versus HDD/Day

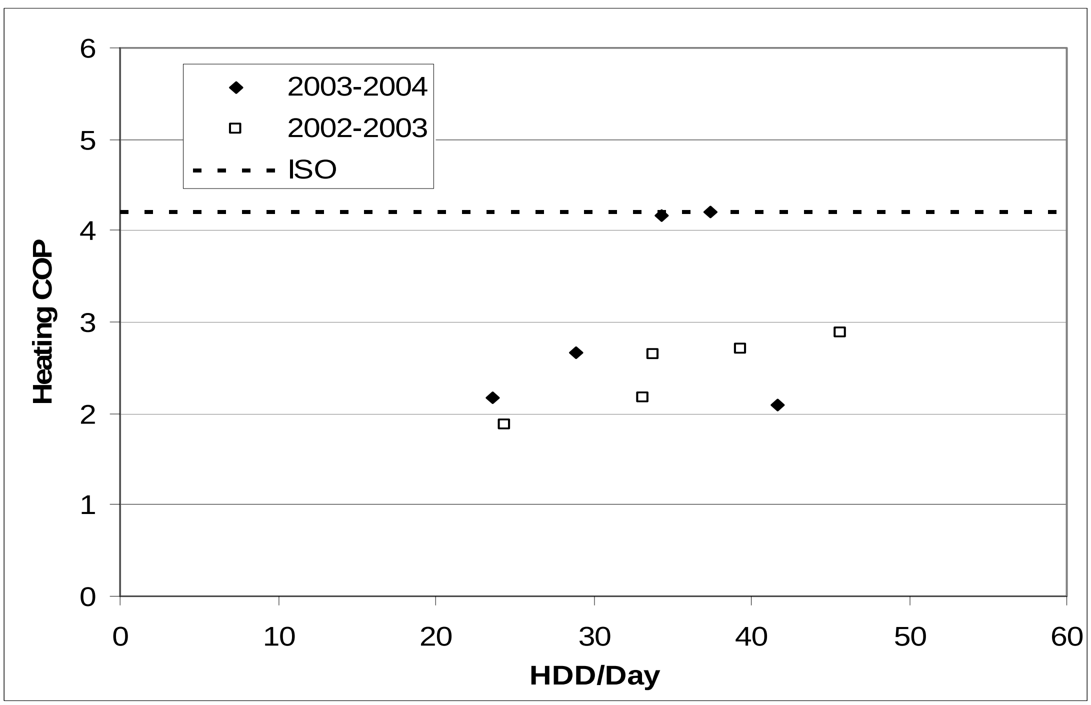

Figure B.89: Home V-0-17 ISO/ARI rating with heating COP versus HDD/Day

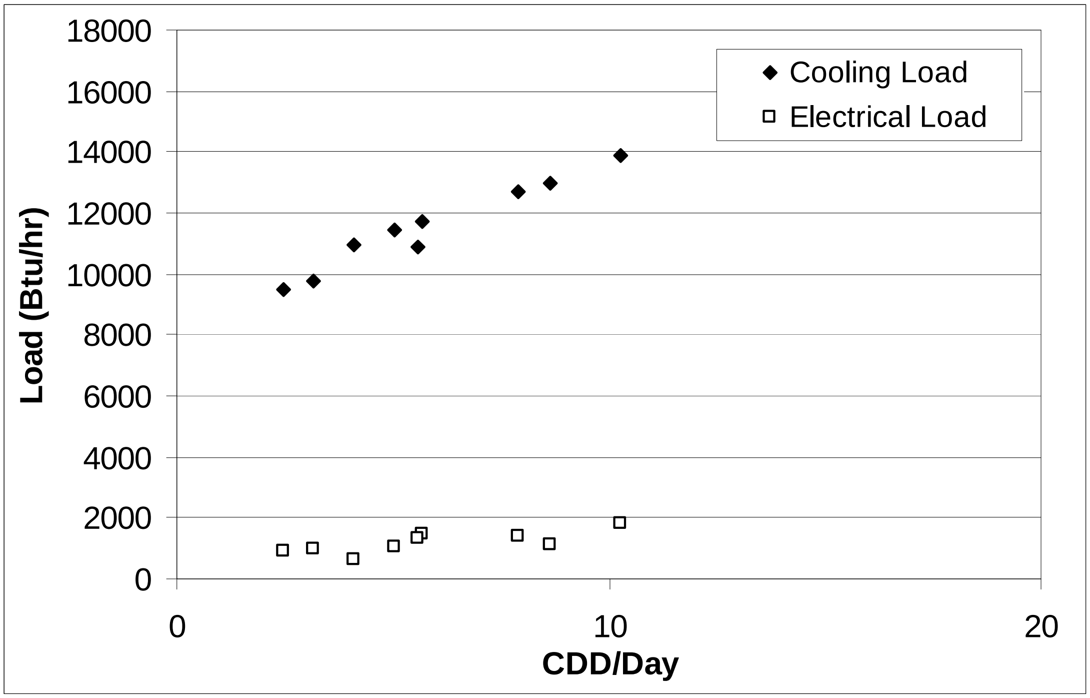

Figure B.90: Home V-0-17 cooling and electrical load versus CDD/Day

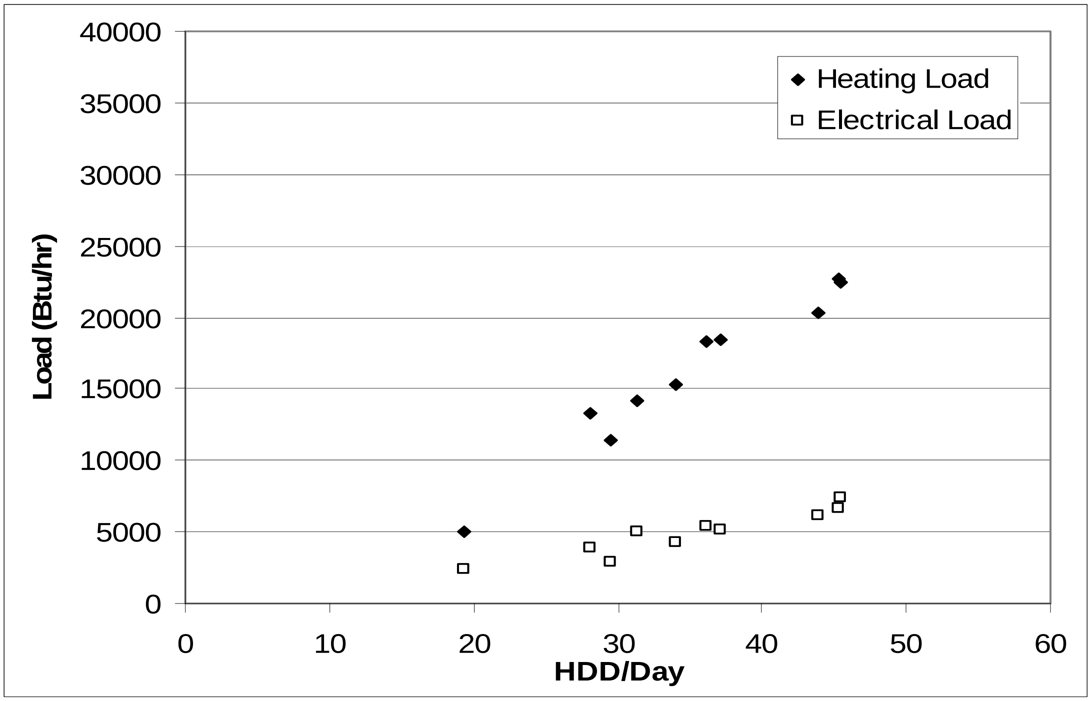

Figure B.91: Home V-1-18 heating and electrical load versus HDD/Day

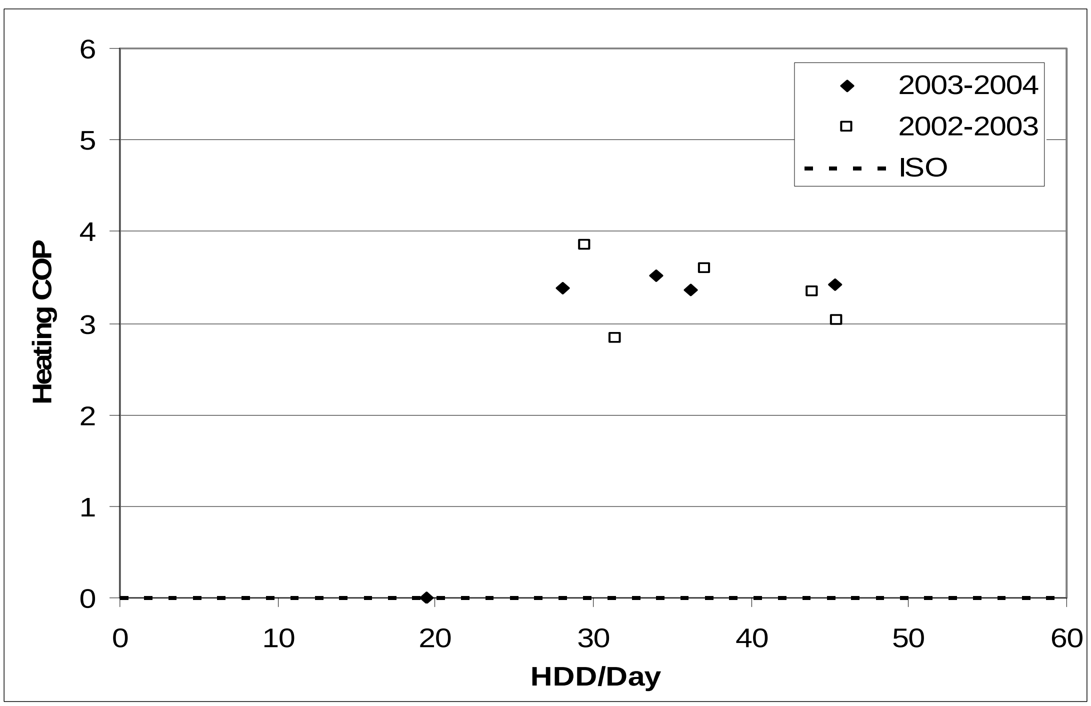

Figure B.92: Home V-1-18 ISO/ARI rating with heating COP versus HDD/Day

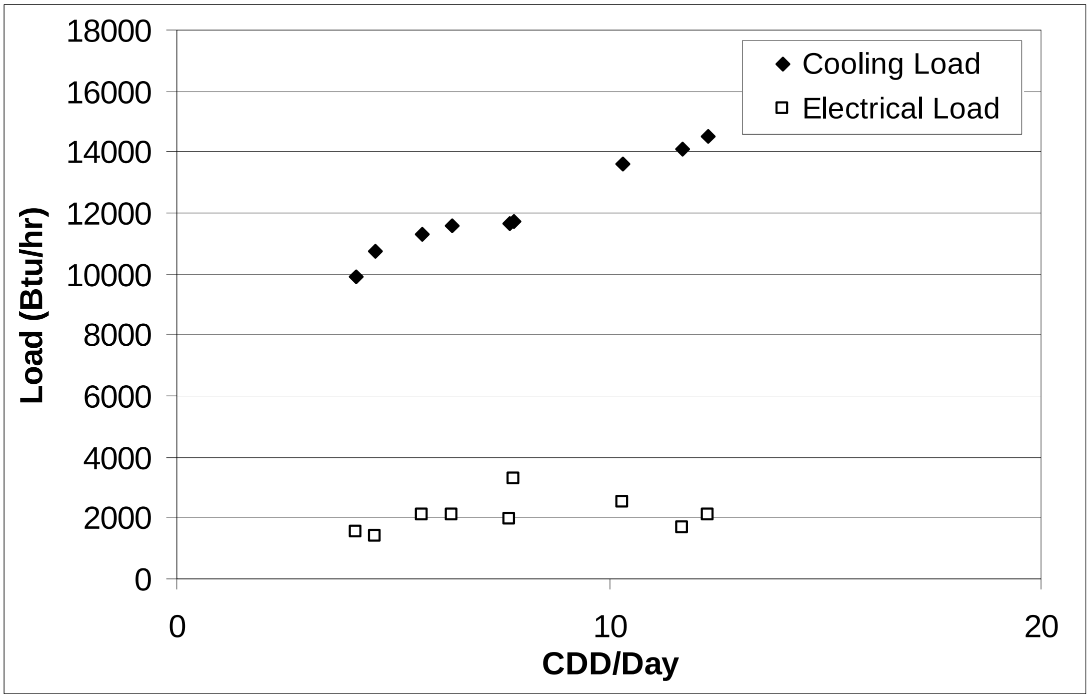

Figure B.93: Home V-1-18 cooling and electrical load versus CDD/Day

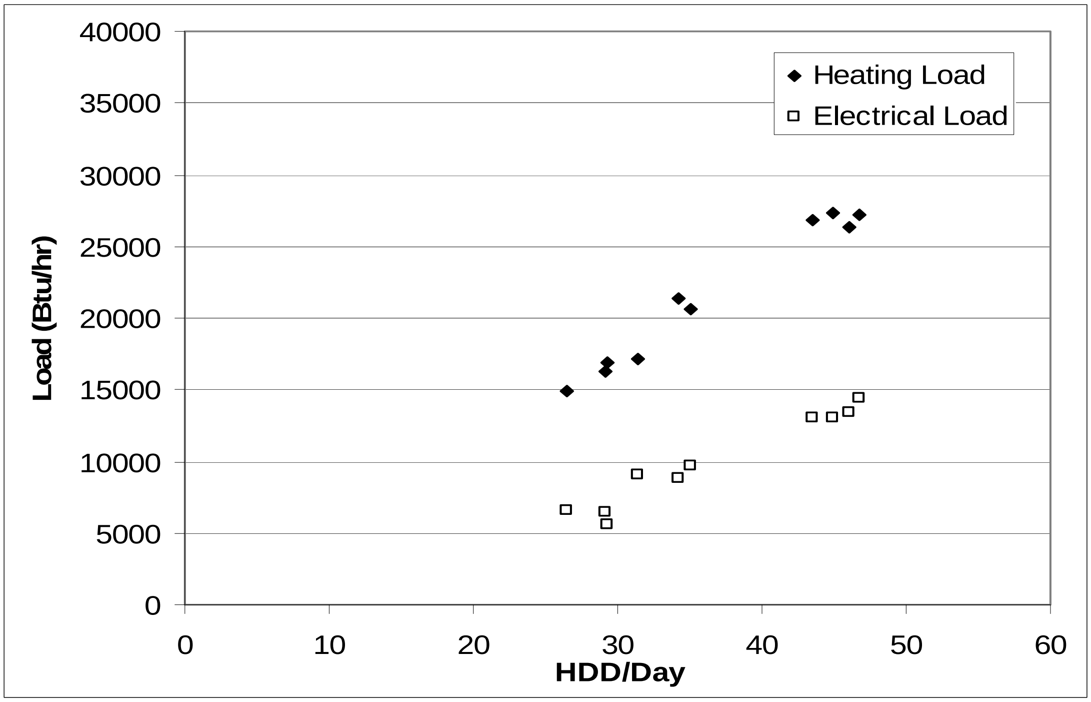

Figure B.94: Home V-1-20 heating and electrical load versus HDD/Day

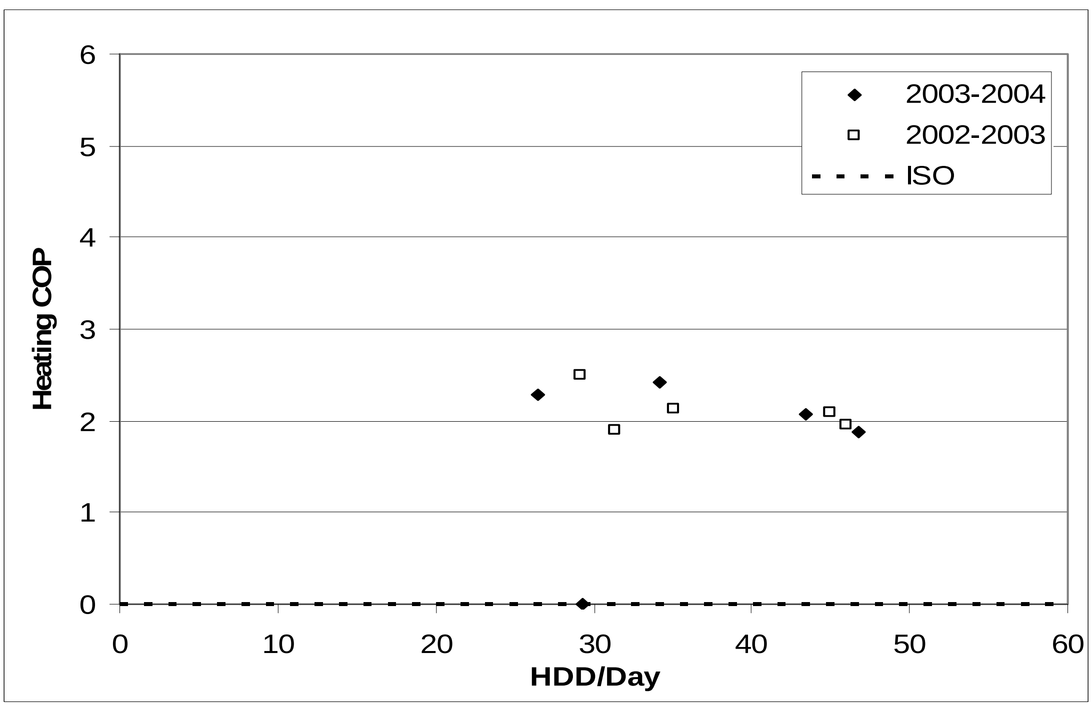

Figure B.95: Home V-1-20 ISO/ARI rating with heating COP versus HDD/Day

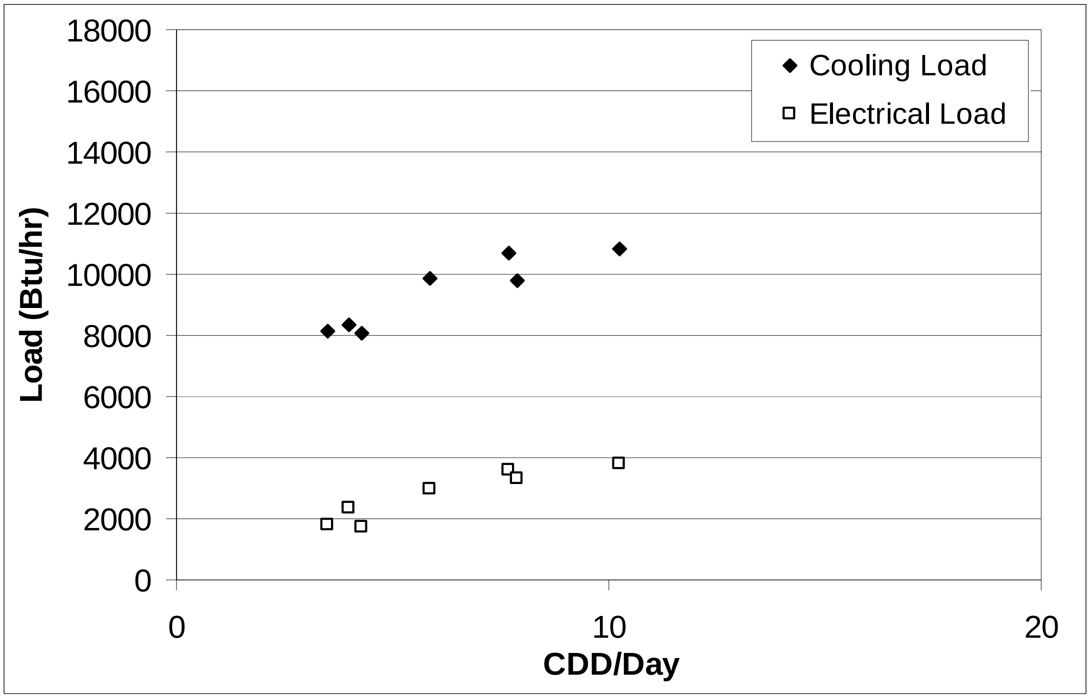

Figure B.96: Home V-1-20 cooling and electrical load versus CDD/Day

APPENDIX B – INSTALLER COST SURVEY

Iowa State University Energy Project
Installer Survey

1. How many years has your company installed GCHPs?

2. What brand(s) of GCHP is installed?

3. What is the approximate installation cost of the indoor unit (including pump packages, desuperheater, thermostat; exclude ductwork) for a:
   3-ton unit: $
   4-ton unit: $
   5-ton unit: $

4. What style of horizontal loop system is used, e.g. slinky, trenching, single line?

5. What is the approximate cost of the horizontal loop system, e.g. piping, ground work, for a:
   3-ton unit: $
   4-ton unit: $
   5-ton unit: $

6. What is the approximate cost of a vertical closed loop system, e.g. piping, ground work, for a:
   3-ton unit: $
   4-ton unit: $
   5-ton unit: $

7. What is the approximate cost of a pond loop system, e.g. piping, ground work, for a:
   3-ton unit: $
   4-ton unit: $
   5-ton unit: $

8. How do you determine the loop and unit size? Please give a brief description.
   ☐Rule of thumb:
   ☐Program:
   ☐Other:

APPENDIX C – HOMEOWNER'S GUIDE

A Residential Homeowner's Guide to Ground Source Heat Pumps

"Digging into Renewable Energy"

By
Matt Swenka
Francine Battaglia, Ph. D.
Iowa State University

Acknowledgment

The work herein was fully supported by the Iowa Energy Center. The author wishes to thank the sponsors for their generosity and support. Special thanks is extended to Curt Klaassen for his suggestions and advice during the project.

Disclaimer

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Acronyms

AFUE:	annual fuel utilization efficiency
ARI:	Air-Conditioning and Refrigeration Institute
ASHP:	air source heat pump
COP:	coefficient of performance
DNR:	Department of Natural Resources
DX:	direct exchange
EER:	energy efficiency ratio
EPA:	Environmental Protection Agency
EWT:	entering water temperature
GCHP:	ground coupled heat pump
GSHP:	ground source heat pump
GWHP:	ground water heat pump
GX:	geo exchange
HDPE:	high density polyethylene
HSPF:	heating seasonal performance factor
IGSHPA:	International Ground Source Heat Pump Association
ISO:	International Organization for Standardization
SEER:	seasonal energy efficiency ratio
SWHP:	surface water heat pump
WLHP:	water loop heat pump

Table of Contents

Introduction

Background

Ground source heat pumps are becoming an ever popular method of heating and cooling homes across the United States, and Iowa has not been left behind in this trend. The allure of ground source heat pumps has come as a result of efficiency, environmental friendliness, and home owner comfort.

The objective of this packet is to inform potential residential ground source heat pump owners about the technology. It will explore whether this style of heat pump is feasible for your application and present common questions that arise pre- and post-installation.

Geothermal

The term geothermal is derived from the Greek words for earth (geo) and heat (therme). Geothermal can then be described as internal heat generation from the earth. There are 3 common methods of producing geothermal energy. One method is a result of the earth experiencing radioactive decay and releasing thermal energy. The second method is a transport phenomenon in which heat is conducted through the earth's layers to the surface. Additionally, there are areas of the earth with direct channels that bring molten rock and steam to the surface. These areas are coined "high temperature geothermal" and can be exploited for electrical production. The final heat generation method is solar radiation. Approximately 47% of the sun's radiation is absorbed by the surface of the earth. This stored energy is considered to be low temperature geothermal but is estimated to be 500 times more energy than all of mankind uses in a year. As shown in Figure 1, as the depth of soil increases the variation in soil temperature decreases [1]. The energy has little annual variability below 6 feet and is nearly at constant temperature 200 ft below the surface. Iowa is considered to have an average subsoil temperature of 52°F. This low grade geothermal energy can be utilized in a ground source heat pump to heat and cool your home [2].

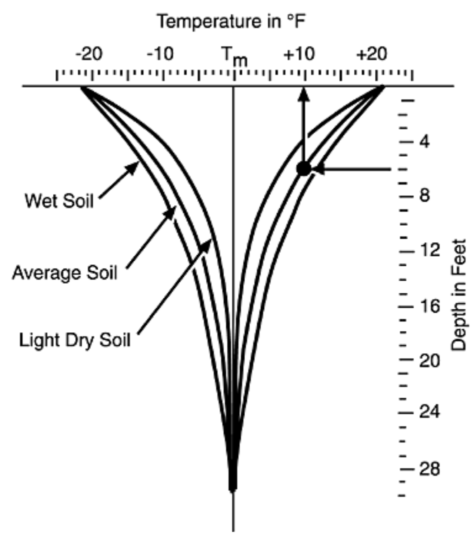


Figure 1: Soil temperature variation [1].

Basic Terminology

With every technology, there are technical hurdles to overcome so that the general public may understand it. One of these hurdles is what exactly to call this heating and cooling method. Throughout the years, many terms have been used to describe the system, adding to the confusion among industry and the general public.

The all-inclusive term to describe these systems is ground source heat pump (GSHP). This broad term covers systems that use the ground, surface water, and well water as a heat source. The first of the systems is aptly named ground coupled heat pump (GCHP), which indicates the heat pump is connected to the ground through a *closed-loop* system. The surface water heat pump (SWHP) uses rivers, lakes, and ponds as a heat source. The last of the three, ground water heat pumps (GWHP), uses well water as a heat source.

Geo or geothermal is a commonly used term amongst installers. As previously mentioned, it is a general term used to describe the earth's heat source. To avoid confusion with the different heat pump technologies, this guide will not use this terminology. Other commonly used terms include geo exchange (GX), water-source heat pump, and direct exchange (DX). The DX GCHPs use a direct connection between the refrigerant loop and the ground. Since this style of GSHP is not commonly used, it won't be discussed in this publication either [3].

Heating and Cooling Terminology

To adequately understand ground coupled heat pumps, one must first begin by understanding a few of the basic concepts in heating and cooling terminology. The capacity rating commonly associated with heating is the British Thermal Unit per hour (Btu/hr). A Btu is the amount of energy that is required to raise the temperature of one pound of water, one degree Fahrenheit. The cooling capacity is rated in terms of tons where one ton is equivalent to 12,000 Btu/hr.

The GSHP uses two performance ratings, as described by the Air Conditioning and Refrigeration Institute (ARI), one to describe the heating cycle and one to describe the cooling cycling. The heating cycle's performance rating is called the coefficient of performance (COP). The COP is the ratio of the amount of energy output to the energy input consumed to produce the desired heat. It typically has units of kilowatt-hour (kW·h) per kilowatt-hour. The cooling cycling is described by the energy efficiency ratio (EER). The EER is the ratio of the amount of energy output in Btu/hr per watts of energy input at the operation condition of 95°F.

Since air source heat pumps (ASHP) experience varying air temperatures, it is more practical to describe the system performance over the entire season. The Department of Energy established the ratings of heating seasonal performance factor (HSPF) and seasonal energy efficiency ratio (SEER). The HSPF can be computed as Btu of energy used over the entire heating season per watt-hour of electricity used over the season. The SEER is the Btu of energy over the cooling season per watt-hour of electricity used. The Department of Energy enforces a minimum rating of 13 SEER and 8 HSPF for an ASHP. Unfortunately, there is not a way to quickly compare an ASHP to a GSHP. The best method is to perform a computer modeling simulation to determine the performance and cost.

The performance of a conventional system such as a gas or boiler furnace can be described in terms of steady state efficiency and annual fuel utilization efficiency (AFUE). AFUE is the energy input over the energy output used in the entire season. The steady state efficiency is described in the same manner, but does not consider the on/off cycling like that of AFUE.

Air conditioners, like the ASHP, are rated using the SEER performance measurement. According to federal law, air conditioners must have a rating of at least 13 SEER.

GSHP Ratings

There have been various attempts at developing universal performance ratings for GSHPs. The original performance ratings were developed by ARI and consisted of separate ratings for open-loop systems (ARI 325) and closed-loop systems (ARI 330). In 2000, the ISO 13256-1 rating was introduced to both unify and update the performance characteristics. The new ISO rating system introduced penalties for pumps and fans. The ratings were done at various temperatures to reflect the performance of the three systems: water loop heat pump (WLHP), ground water heat pump (GWHP), and ground loop heat pump (GLHP). GLHP tends to be the most useful rating and it is commonly installed. The GLHPs are rated at 32°F entering water temperature (EWT) for heating and 77°F EWT for cooling. The entering water temperature refers to the temperature of the fluid coming from the buried loops to the unit and these values were developed to reflect national averages. As such, reported values are useful for comparing one unit to another. In no way, though, should this be considered the actual performance of the GSHP when it is installed. Several factors, including required heating or cooling loads and loop temperatures, will determine actual performance. In today's market, there is a large range in performance values for GSHP units, ranging from a COP of 3 to 5 and EERs from 15 to 30. These ranges are only approximate ranges; as manufacturers improve their equipment, their energy efficiencies are expected to increase [4].

Ground Source Heat Pump Operation and Components

Basic System Types

As the name heat pump implies, it is the goal of the machine to transfer heat. The natural direction of heat flow is from areas of hot temperatures (high energy) to that of cold temperatures (low energy). A heat pump mechanically reverses that process by moving the thermal energy from an area of low energy to high energy.

Ground source heat pumps can be divided into two basic types of systems: water-to-air and water-to-water. In the case of water-to-air, the system exchanges energy with water (or water solution) to heat or cool air which is delivered to a room or space. The water-to-water unit will exchange energy with water to heat another water system. The heated water can be used for domestic hot water, hydronic heating, pools, etc.

As we begin to break the system down, it can be seen that several small "loops" comprise the overall machine. The most prominent loop is the ground heat exchanger or ground loop, which is the part of the unit that exchanges energy with the soil. The ground loop can be further divided into two basic types of systems: the closed-loop and open-loop. The closed-loop circulates a solution of water and antifreeze through piping that is laid or drilled in the ground. The pipes are a high density polyethylene (HDPE), which have conductive thermal characteristics for ground to water heat transfer. The antifreezes commonly used include Methanol and Propylene Glycol. A small pump will be used to circulate the fluid in the loop.

The open-loop will pump surface or well water through the system. These systems can be some of the cheapest to install, but attention to the quantity and quality of water has to be taken into consideration. Insufficient heating and cooling will occur with too little water, while hard water or dirty water will clog heat exchangers. The water quality can be improved by a regularly maintained filtering system.

As a rule of thumb in residential installations, the closed-loop systems are comprised of ¾" diameter piping for loops and 1 ½" headers that connect the loops together. Several factors such as soil type, soil moisture, climate, and system load will affect the sizing of the loops. Additionally, some manufacturers will supply sizing specifications. The lengths of piping presented are only approximate and will need to be sized specifically for each home [5].

Horizontal Loop Systems

The simplest of the horizontal loops is the single pipe system as shown in Figure 2. The pipe is laid in the ground at a depth of 4 to 6 feet. Layering of pipe can also be done with this system, significantly decreasing the amount of land area required. For example, a pipe can be placed at 6 feet, covered with soil and another pipe be placed at 4 feet before completely back-filling the trench. These loops will require 350 to 600 feet of piping per ton of unit. One of the advantages of this system is that it can be trenched, reducing installation costs and damage done to the landscape. In some applications, a large pit will be dug that can house all of the piping needed. Bulldozers will then backfill the area after pipe installation. The drawback to this installation is the large amount of labor involved in removing the soil and the damage done to the landscaping [6].

The horizontal spiral or Slinky™ loop is a widely used method for connecting the heat pump unit to the ground. As the name implies, the loop is wound into a Slinky™ like shape, but flattened, and then placed at the bottom of a trench, as shown in Figure. A typical trench might be 3 foot wide by 6 foot deep with trenches placed at 6 to 15 feet apart on center. The Slinky™ can also be placed on end in a trench. This type of installation requires a large trencher so that the upper portion of the Slinky™ is deep enough in the soil. Installers must pay special attention to this trench style, as the loops can become easily crushed during back filling. The Slinky™ system maximizes the amount of piping that can be placed into a minimal amount of land space, effectively reducing the trench length to about two-thirds of the horizontal two-pipe system [7].

The horizontal drill or borehole method is becoming an increasingly popular choice for people who want to use the horizontal method but are looking to avoid the large scale landscape damage. It can also be integrated into an area where there is an obstruction preventing digging or trenching for horizontal loops. For example, horizontal bores can be created under a group of trees or sidewalks. To achieve a horizontal bore, a rotating drill bit is hydraulically pushed into the ground at about a 30 degree angle using a boring machine. Once to the desired depth, the drilling machine has the steering capabilities to change directions to drill a horizontal hole. The pipe is then pulled back through the hole and the hole is injected with water and sometimes grout. The injected water keeps air from entering the bore and helps maintain the thermal bridge between the loops and the soil. Additionally, this method allows for multiple layers of piping to be placed in the same loop field [5].

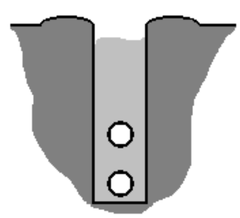


Figure 2: Horizontal installation for a single-pipe system showing two pipes

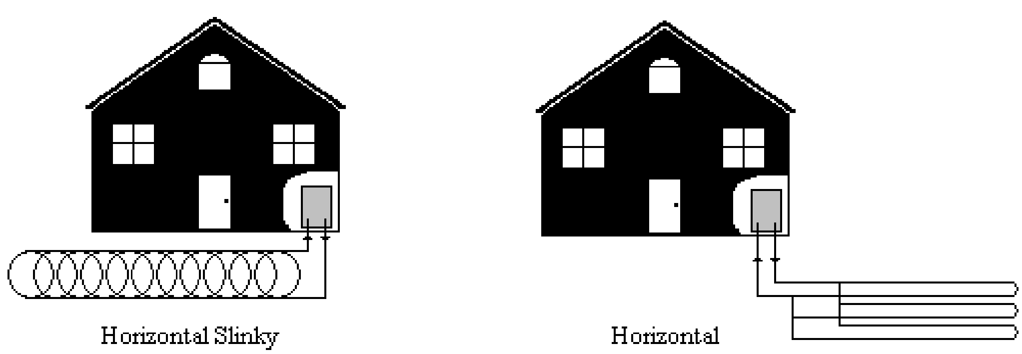


Figure 3: Horizontal closed-loop heat exchanger

Vertical Loop Systems

The vertical loop systems require boring into the earth at depths of 100 to 300 feet and require pipe lengths of 200 to 600 feet per ton as shown in Figure 4. The bore holes will typically be 4 to 5 inches in diameter. Upon completion of drilling, the two pipes along with a tremie pipe are slid down the well. The two pipes are joined at the end by a U-bend which creates the circuit for the fluid to flow back to the top. The tremie pipe serves as a means to pump grouting material to the bottom of the well. As the hole fills with grout the tremie pipe is slowly removed [7].

In this type of installation the grout serves three purposes. As in the case of the horizontally bored loops, the grout serves as a thermal bridge between the piping and the soil. Secondly, the grout will allow the pipes to expand and contract in the hole during the heating and cooling seasons. Finally, the grout will act as a sealer to prevent water flow amongst aquifers. The Department of Natural Resources (DNR) requires that these practices be adhered to by certified well drillers to protect our water supplies [8].

A unique closed-loop alternative is the pond loop (see Figure 4). Coils of the HDPE pipe are sunk to the bottom of a pond. The design requires a sustainable water level of at least 12 feet. A one acre pond can generate between 10 and 20 tons of capacity. The loop installation is considered to be the most cost effective among the closed-loop designs.

Common open-loop systems, shown in Figure 5, consist of a production well and a disposal system, commonly referred to as "pump and dump." The disposal site can be another well, known as an injection well, or a surface water reservoir. These systems require that 1.5 to 2 gallons per minute (GPM) of water be delivered for each ton of capacity. For example, a 4 ton unit operating at 30% runtime could use as much as 100,000 gallons in one month [2].

Another type of open-loop system uses surface water, such as ponds or other surface water reservoirs, to circulate through the unit. The same reservoir can also be used as a disposal site.

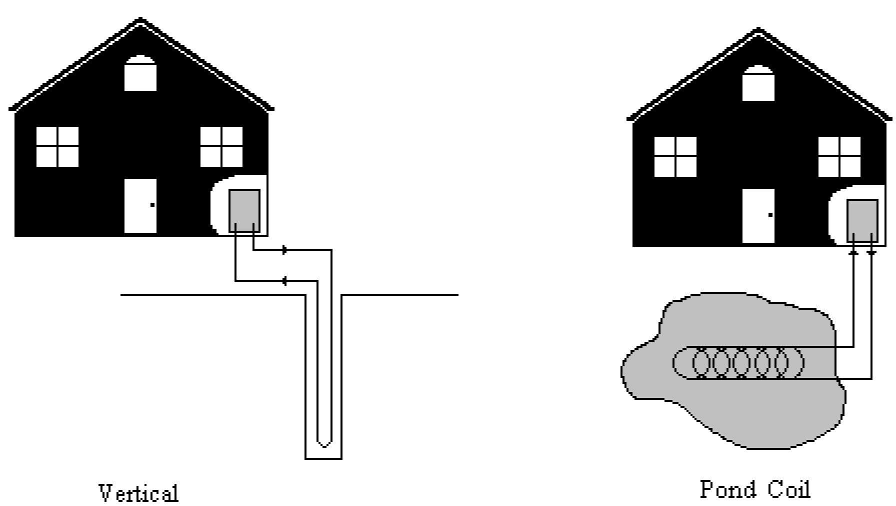


Figure 4: Vertical and pond closed-loop heat exchangers

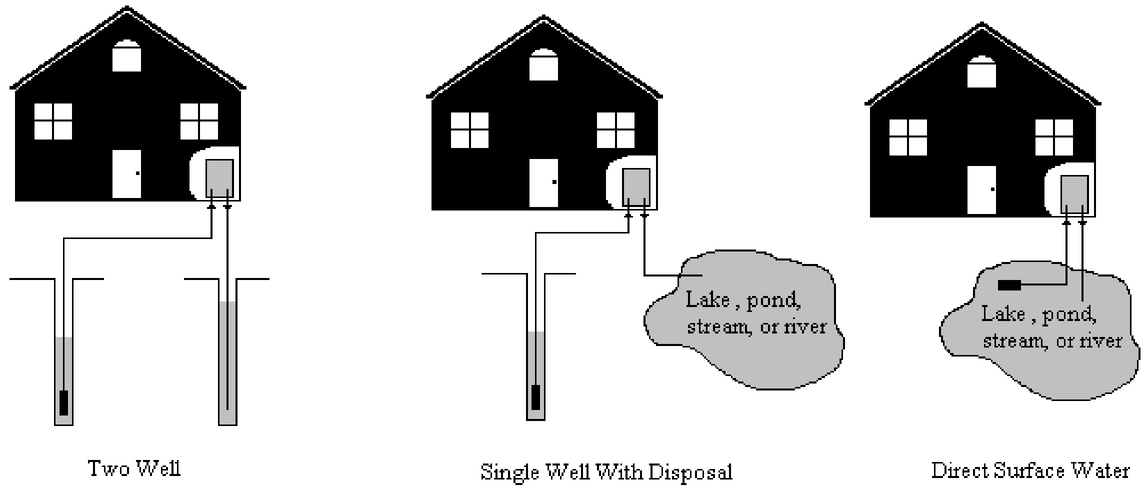


Figure 5: Open-loop heat exchangers

Recall that open-loop systems can be very cost effective installations if three basic criteria are adhered. First, the quality of water must be sufficient. Hard water can cause scaling in the system and reduce efficiency. Additionally, water with large amounts of debris can clog the heat exchanger but this can be corrected with filtration equipment and regular maintenance. Water supply is the second of these criteria. The GSHP simply cannot exchange enough thermal energy without a steady and sufficient water flow. Long term water supply issues have to be considered when installing these systems to prevent poor performance. The final criterion is that all state and local codes, regulations, and ordinances are adhered for environmental protection [5].

The Refrigerant System

Continuing from the ground loop, the heat exchanger couples the ground loop to the refrigerant loop. These two loops will exchange thermal energy with one another. In summer operation the refrigerant loop will reject heat to the ground loop while absorbing heat during winter operation. Within the refrigerant loop is located a reversing valve that changes the flow of refrigerant and determines whether the system is heating or cooling.

Figure 6 is a schematic of the GCHP that operates in heating mode and
Figure 7 shows the operation in cooling mode. The components of the heat pump system include:

- ground loop connection
- compressor
- reversing valve
- expansion valve
- desuperheater
- air loop

- fan

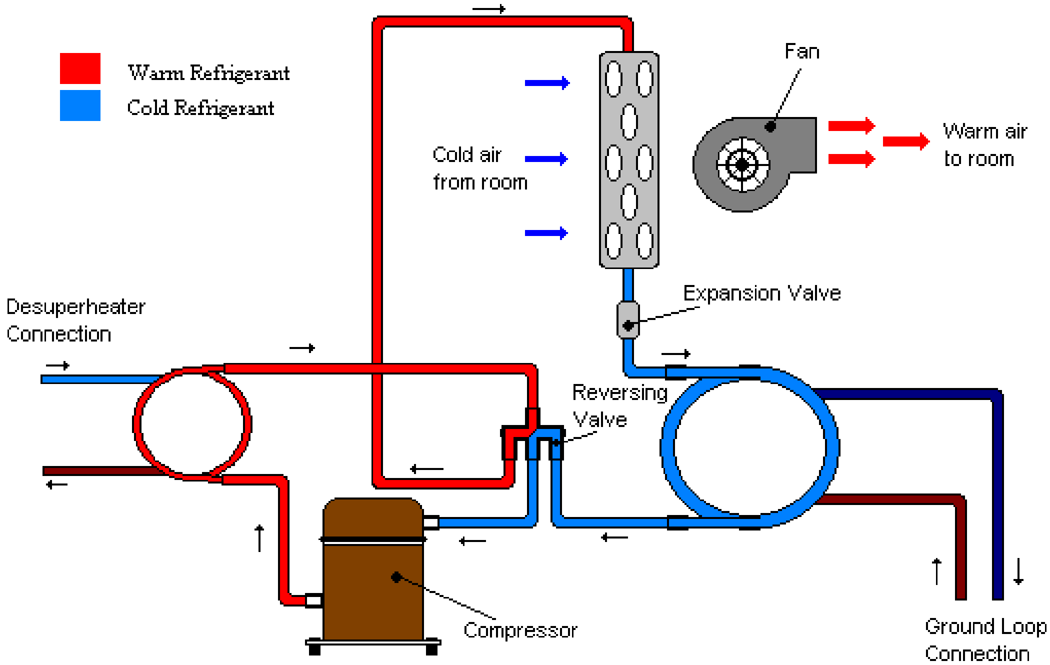


Figure 6: Heating cycle of the ground coupled heat pump

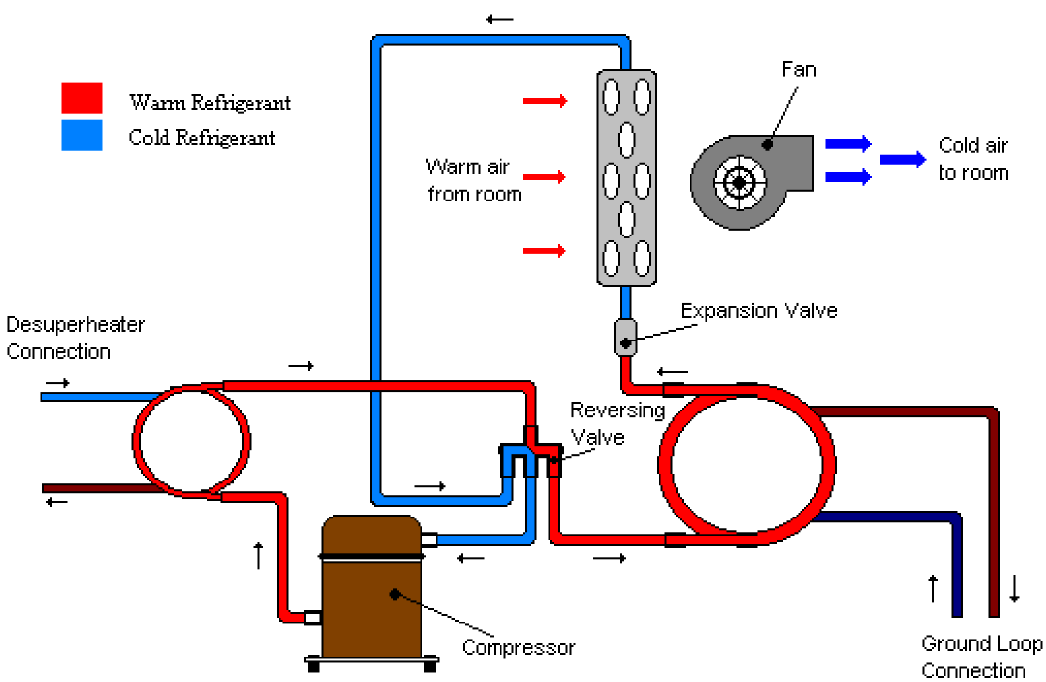


Figure 7: Cooling cycle of the ground coupled heat pump

The refrigerant loop contains a pressurized refrigerant that moves through the system using a compressor. Several refrigerant loops currently use R-22. Some manufactures have made a movement to use more efficient and environmentally safer refrigerants such as HFC-410a. Additionally, HFC-410a has shown to have fewer failures and result in quieter operation in the compressors [9].

Several manufacturers use a scroll compressor over the traditional piston-type compressor. The piston compressor creates a cyclic loading on the motor causing noise, wear, and decreased life. The design of a scroll compressor, on the other hand, maintains a constant load on the motor decreasing or eliminating the aforementioned problems. Manufacturers may also include multi-speed compressors to better match the variable load demand of the GSHP. Additionally, dual compressors may be added to the system to increase efficiency. At partial load demand, only one compressor will run. As the load increases, the second compressor will initiate and make up for the added load [9].

The air loop exchanges thermal energy with the refrigerant system. Driven by an internally installed fan, conditioned air is delivered to the building. It is important to recognize that the air leaving the unit exits through a plenum. The plenum is the initial distribution piece of duct work and should be insulated for noise reduction.

Alternatively, the refrigerant loop can exchange energy with another water loop to create hot or cold water. The hot or cold water can then be piped to air handling units for heating and cooling processes.

An optional desuperheater loop may be placed on the refrigerant loop. The purpose is to exchange thermal energy to heat water for domestic use. On-demand water heating, one optional configuration of the desuperheater, places it in charge of all the home's hot water needs. Other systems will use approximately 10 to 15% of the heat pump capacity for hot water production when the system is in heating and cooling mode. Many manufacturers will supply an internal pump to circulate the water for heating, thus reducing system clutter and increasing ease of installation.

The refrigerant loop works on the principles of a vapor-compression cycle. The cycle consists of a compressor that pressurizes the refrigerant into a hot gas, which can be over 180°F. The hot gas then passes through the condenser to exchange heat with room air. The cooler gas turns into a liquid and passes through an expansion valve to cool it even further. The evaporator, the ground loop in this case, causes the refrigerant to heat back up. The process then starts over at the compressor. In the cooling mode, this process is simply reversed.

Except for the pumps and ground loop, the components of the system are contained inside a single packaged unit located indoors. The complete GSHP unit, as shown in Figure 8, is typically slightly larger than a conventional gas furnace [6].

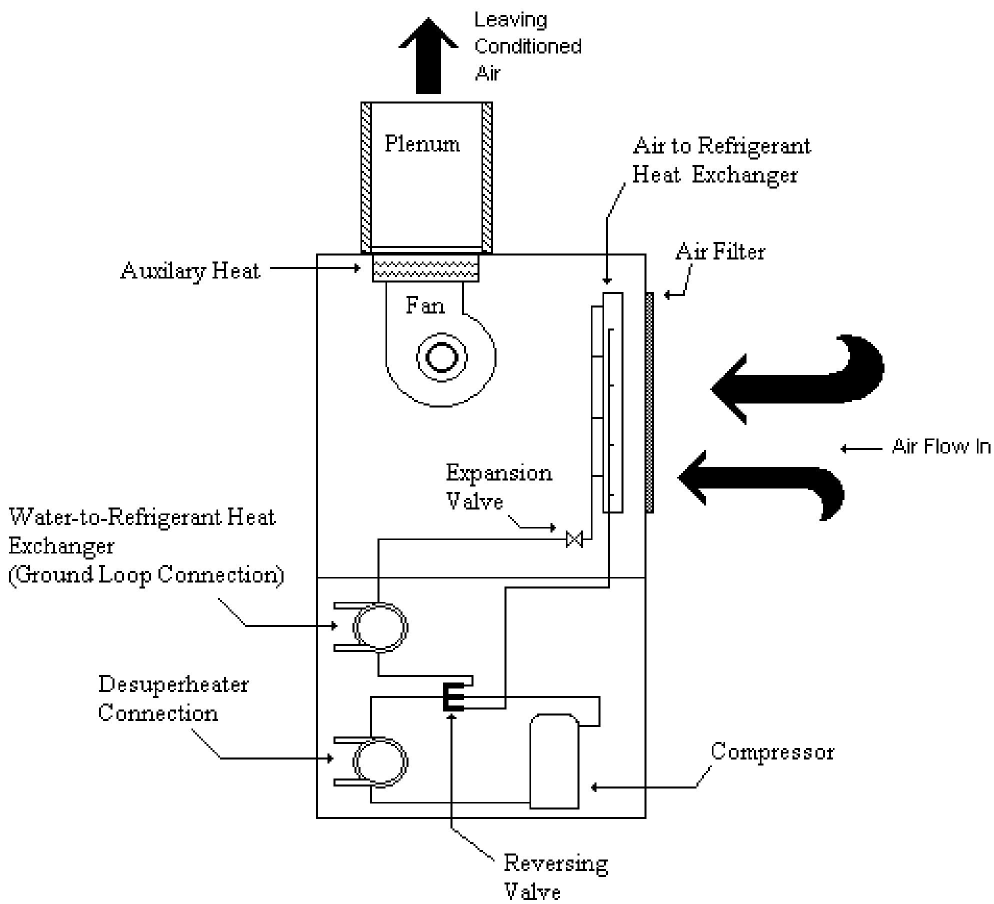


Figure 8: Complete GCHP unit

System Variations

One of the unique aspects of GSHPs is their versatility in design and installations. As discussed in the previous sections, design features include various loop installations, desuperheater accessories, and performance ratings. In the case of large homes, it maybe advantageous to have two or more units located throughout the house instead of having one massive unit. GCHPs have the ability to zone a home using multiple units on a single loop field. Depending on the architecture of a home, it may be difficult to centrally locate a unit and two or more units could be used to circumvent this issue.

Situations also arise where a forced air system is used in conjunction with a hydronics system. In this case, a water-to-air and water-to-water GCHP could be utilized on the same ground loop system.

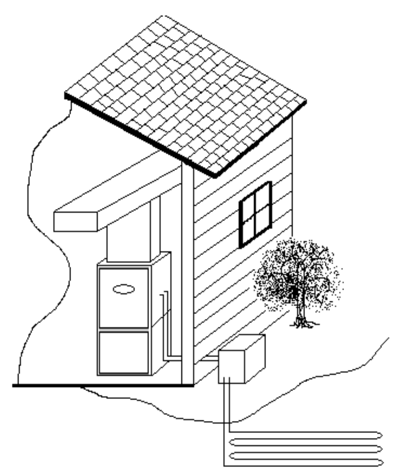


Figure 9: Split GCHP system

Many manufacturers offer a split system as shown in Figure 9. The design is similar to that of an air source heat pump with an outdoor unit housing the compressor, controls and ground loop connections. The indoor components consist of the air handling unit and heat exchanger for room conditioning. This system allows for the use of an existing furnace as the air handling unit and can be implemented as back up heat.

In summary, the numerous variations serve to illustrate the wide number of applications that can be used in the GSHP installation process. The rule of thumb that many installers will use is "keep it simple"; this will help maintain an initial low cost and keep maintenance to a minimum.

Frequently Asked Questions

During the initial consideration phase and installation of a GSHP, many homeowners have similar questions about the technology. The following section touches on some of these questions. If your particular question is not found, refer to the section (p. 161) on gaining more information about ground source heat pumps. Many excellent resources are available for those new to the technology.

How does the GSHP system differ from a conventional unit and air source heat pumps?

The most notable difference between the GSHP in comparison to conventional units and ASHPs is the efficiency and the cost of operation. GSHPs will consistently perform better than ASHPs, whereas ASHPs will perform better than conventional units. On the other hand, the ASHP and conventional unit will typically have a lower initial cost.

While the ASHP is very similar to the GSHP, it has a slightly different component design. The ASHP utilizes a refrigerant loop to exchange thermal energy with the outdoor environment to heat and cool the building. The indoor unit consists of a heat exchanger and air delivery system. The refrigerant loop connects the indoor unit to the outdoor unit. The outdoor unit houses the controls, compressor, heat exchanger and fan. Being exposed to ambient conditions poses a greater risk for damage. A major factor dictating the performance of an ASHP heat pump is inconsistency of the outdoor temperature. Another drawback to the system is the outdoor unit can be loud. Additionally, the refrigerant loop must be field installed. This leads to a larger opportunity for refrigerant leaking and diminished performance.

Conventional units typically consist of a gas fired furnace combined with an air conditioner. Air conditioners are very similar to ASHP but only provide cooling. Air conditioners have similar problems with exposure to the elements and have a higher potential for leakage in the refrigerant loop [4].

Is a GSHP right for me?

Generally, if you want to save money and help the environment, a GSHP is probably a good installation choice for you. The wide range of installations available allows most homeowners to find a system that can meet all of their heating and cooling needs. The biggest limitation is the space required for loop installation and the accessibility of the installation equipment to the area.

Installation of a GSHP in a pre-existing home may require the duct work to be upgraded. An economics study should be considered to see if it is financially feasible for the homeowner to install a GSHP with such upgrades as the duct work.

How much will it cost me?

This is one of most requested and hardest questions to answer. In presenting an answer one must first know the size and type of the system. Additionally, there can be a large variation in cost from installer to installer. The upfront cost of a GSHP will definitely cost more than a conventional gas furnace and air conditioner, however, after a few years, the financial benefits turnaround.

From a survey conducted by the authors of this report, it was determined that in Iowa, installation cost for the indoor unit ranged from $1000 to $4000 per ton (including the ductwork). A horizontal loop installation was valued between $1000 and $1500 while a vertical loop installation fell in the range of $1300 to $1800 per ton. A typical home falls in the range of 3 to 5 tons. With the occasional fluctuation in equipment and labor cost, the most accurate solution to finding out the installed cost is to simply call local dealers.

While the initial cost may seem large, there are several ways to help reduce the cost. First, check with your installer to see if there are rebates through the manufacturer. Additionally, rebates can be found through your utility company. Several utility companies offer rebates based on EER, COP, and inclusion of a desuperheater. One could easily receive over a $1000 in rebates. Additionally, the 2005 Energy Policy Act offers federal tax credit towards the installation. Information regarding this incentive can be found at http://energystar.gov.

It is also important to note that some utility companies/cooperatives offer a lower electric rate for GSHP installations. The utility company will install a separate meter in your home to directly measure the GSHP usage. The rate could be as low as 3.5¢ per kWh compared to the common electrical rate of 5¢ to 10¢ per kWh. Also, consider that eliminating gas usage would consolidate your utility bills.

If a GCHP is financed through a mortgage, loan, or lease, a positive cash flow can usually be realized. This is a result of the money saved from energy and maintenance cost outweighing the monthly payments for the GSHP. During your initial cost estimation of a GSHP, you may want to ask your installer to estimate the price of a conventional gas furnace and air conditioner for comparison. Taking into account the rebates, tax credits, and lower energy rates, you maybe surprised that the system quickly becomes affordable.

How much will I save?

This is another challenging question to answer. One must consider several factors that influence the cost of heating and cooling your home. A mild or extreme, winter or summer, would require less or more energy to be consumed. Thus, there can be a large variation in savings. Additionally, the cost of fuel changes from year to year making a “blanket” value for savings difficult to estimate.

In a research project performed by Iowa State University, 32 newer (only 2-4 years old) Iowan homes equipped with GSHPs were identified. Over the heating seasons of 2002 to 2005, the homes were monitored for performance. These homes were compared to conventional natural gas furnaces rated at 93% efficient. The homes equipped with horizontal ground loops saved an average of $719 with an average COP of 3.0. The vertically equipped homes showed slightly better performance, saving an average of $749 with an average COP of 3.19.

The cost of cooling a home is usually only a fraction of the heating cost (less than 50%). Typically homeowners can expect to save in the range of 20 to 50% in cooling mode while using a GSHP over a conventional central air conditioner. The cooling savings tend to be much more variable as there are several more factors that influence cooling needs. Unpredictable factors include: people opening windows on “nice days,” people doing more vacationing during the summer, variable solar loads, etc.

Hot water savings will be dependent on the type of desuperheater installed. If it is an on-demand desuperheater, all of the domestic hot water is heated by the GSHP. If the desuperheater only runs when the system is heating and cooling, savings in the range of 20-50% can be realized, and is based on the amount of time the system runs.

Table 1 compares various fuel types using 2007 values. Each system is adjusted for approximate system efficiencies based on cost per million Btu. If you would like to make adjustments to the price per million Btu presented in Table 1, the following simple equations can be used:

Table 1: Fuel type comparisons

Systems with Efficiencies

$$\frac{\text{Price/Unit}}{\text{Energy Content} \times \text{Efficiency}} \times 1{,}000{,}000$$

SEER

$$\frac{\text{Price/kW} \cdot \text{h}}{\text{SEER}} \times 1{,}000$$

HSPF

$$\frac{\text{Price/kW} \cdot \text{h}}{\text{HSPF}} \times 1{,}000$$

EER

$$\frac{\text{Price/kW} \cdot \text{h}}{\text{EER}} \times 1{,}000$$

COP

$$\frac{\text{Price/kW} \cdot \text{h}}{\text{COP}} \times 293.1$$

Table 2: Fuel Cost Comparison

Fuel Type	Price ($/Unit)		Energy Content (Btu/Unit)	Annual System Efficiency		Cost ($/MMBTU)
Natural Gas	$1.42	/Therm	100,000	Older Furnace	75%	$18.93
				Mid Efficiency	82%	$17.32
				Ultra-Hi Efficiency	93%	$15.27
Propane	$1.48	/Gallon	91,600	Older Furnace	70%	$23.08
				Mid Efficiency	82%	$19.70
				Ultra-Hi Efficiency	93%	$17.37
Fuel Oil	$2.28	/Gallon	139,000	Standard Efficiency	65%	$25.24
				High Efficiency		
				UltraHi-Efficiency	85%	$19.30
Electricity	$0.05	/kW·h	3,412			
Resistance Heat					100%	$14.65
ASHP				Standard Efficiency HSPF	6	$8.33
ASHP				Hi-Efficiency HSPF	8	$6.25
GSHP				Average COP	3.1	$4.73
GSHP				Hi-Efficiency COP	4.0	$3.66
Air Conditioner					13 SEER	$3.85
ASHP (cooling)					16 SEER	$3.13
GSHP (cooling)					19 EER	$2.63
Wood						
Hardwood	$125	/Cord	20,000,000			
				Standard Fireplace	20%	$31.25
				Air Tight Stove	40%	$15.63
				Hi-Efficiency	70%	$8.93
Wood Pellets	$0.10	/lb	8,200			
				Low Efficiency	55%	$22.17
				Hi-Efficiency	80%	$15.24
Shelled Corn	$3.00	/Bushel	392,000		75%	$10.20

Table 1 can be used to compute the cost of various fuel types in comparison to that of a GSHP. The following example compares the cost of using a conventional system (natural gas furnace and air conditioner) to a GSHP, assuming 60 MMBtu of energy for heating and 30 MMBtu for cooling. Based on the calculated annual cost for each system, there is a projected savings of \$669 using a GSHP

Conventional System

Cost of Hi-Efficiency Natural Gas: \$15.27/MMBtu

Annual Heating Cost: $\left(\$15.27 / \text{MMBtu}\right) \times 60\,\text{MMBtu} = \$916.20$

Cost of 13 SEER Air Conditioner: \$3.85/MMBtu

Annual Cooling Cost: $\left(\$3.85 / \text{MMBtu}\right) \times 30\,\text{MMBtu} = \$115.50$

Total Annual Conventional Cost: \$1031.70

Ground Source Heat Pump

Cost of GSHP with a COP of 4.0: \$3.66/MMBtu

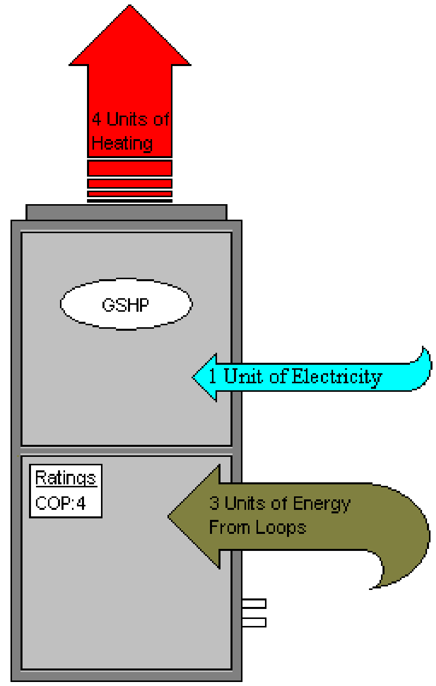
Annual Heating Cost: $\left(\$4.73 / \text{MMBtu}\right) \times 60\,\text{MMBtu} = \$283.80$

Cost of GSHP with an EER of 19: \$2.63/MMBtu

Annual Cooing Cost: $\left(\$2.63 / \text{MMBtu}\right) \times 30\,\text{MMBtu} = \$78.90$

Total Annual GSHP Cost: \$362.70

This performance terminology is so confusing. How can a GSHP be more than 100% efficient?



It is a common in GSHP literature to see efficiencies listed at being more then 100% efficient. In the world of science, it is impossible to have a system that is greater then 100% efficient. This is a case where someone is attempting to put two different measurements into the same context for comparison and some of the meaning is lost. This can most easily be cleared up with a small example: consider a natural gas furnace rated with an AFUE of 93%. For every 1 unit of fuel you put in, there is .93 units of heating out. Remember though, in this example the only input is fuel. A GSHP is approached in a slightly different manner because there is electrical input to power the machine and a heat input from the buried loops. The only cost, though, is the electrical input. Therefore 1 unit of electrical input can provide 4 units of heating back. The buried loops are supplying the difference of 3 units, but you don't have to pay for this! This does not mean that the system is 400% efficient; rather it has a coefficient of performance (COP) of 4.

What should I look for in an installer?

There are two major points you want to look for in an installer, the first being accreditation. The International Ground Source Heat Pump Association (IGSHPA) set standardized practices for installation of GSHPs. Additionally, IGSHPA offers training to installers and accreditation after completing the training. Ask your installer if they possess such accreditation. Secondly, ask your installer how much installation experience they have. Don't hesitate to ask for references. Speaking to someone who has had a system installed will give you good insight into that installer and what to expect.

When shopping around for an installer, be sure to ask what type of guarantee they provide. Be sure to understand the terms of the warranty on the equipment and how long they will back their installation work.

A good installer should be able to provide you with a detailed report of how they performed their heating and cooling load calculations for sizing the system. An even more important piece of information they should be able to provide is a detailed schematic of the where the loop field and equipment has been installed. This will be vital for future ground work that you may do in the area.

A list of contractors and installers can be found on the IGSHPA (http://www.igshpa.okstate.edu/) and Iowa Heat Pump Association (http://www.iaheatpump.org/iaheatpump/) websites [11].

What can I expect in a typical installation?

While every installer will have his or her unique installation process, there is a general outline of events that will take place. One of the first things to be completed is evaluation of the work site to determine the size of the equipment needed and the type and placement of the loop system. This is also the time frame when an installer will be able to supply you with a price and bid for the job. During these initial phases, your involvement with the installer will be beneficial. Describing any future developments in the area of the loop field can save you headaches in the long run. It is very difficult to move loops once they are placed. By law, the installer must have Iowa One Call locate your major underground utilities. One Call can not however locate homeowner improvements such as sprinklers. If possible, help the installer locate these services. You should also make the installer aware of the entry points onto the property you would like them to use. The heavy and large equipment can easily damage driveways, trees, and plants. Finally, you must make the installer aware of indoor unit placement. Having a heating unit in your future closet may not be appealing to most. In this stage, many installers realize that adequate planning is key to a smooth installation.

With the start of the actual installation procedure, the installer may choose to start in several places or have several concurrent events happenings. Regardless of how they proceed, the loops, indoor unit, and ductwork connections will be made at this point. The length of time needed complete these parts of the project is variable. Many unforeseen circumstances such as in site excavation can speedup or hinder progress.

With the system installation complete, the next step is to purge the ground loops of air and remove any debris. In a closed-loop installation, the purging is followed by the adding of antifreeze and pressurizing the system. At this point the system is ready to be started for initial testing procedures. Installation technicians will exam the system through a heating or cooling cycle to ensure that all systems are operating properly. They can also exam the system's performance in accordance with manufacturer's specified ratings.

What type of loop system should I install?

This is a decision that your installer will closely guide you on after proper evaluation of the site. For closed-loop systems, one of easiest and cheapiest solutions is the installation of a pond loop. This of course, will require that a pond be deep enough, large enough, and located close enough for use. If the space is available, a horizontal loop system might be used. A vertical system will be employed if there is a limited amount of space available. Vertical systems have been found to offer a slight performance benefit because they will supply water at a more constant temperature. The performance benefit, however, has to be weighed with the cost of installation. Consideration should be given to the availability of installation equipment. Drilling rigs and excavation equipment are costly pieces of equipment that every installer will not own and limit their ability to install some loop systems.

Open-loop systems, like that of a two well system, tend to be more sensitive installations due to water quality. They require that filtration equipment be installed to prevent clogging, scale build-up, or corroding of the heat exchangers. This presents a long term maintenance issue to ensure the system continuously operates properly. Literature will commonly refer to the use of a

Cupronickel heat exchanger for water quality issues. These heat exchangers will only work for salt water applications and are of little value in commonly encountered problems. The most common water quality issues are iron, carbonate scale, and hydrogen sulphide. Water quality can also be an issue in an injection well. Aerated water that is rich in iron can cause the injection well to go bad. Additionally, open-loop systems require that DNR and local regulations, requirements, and ordinances are met. If your installer decides to install an open-loop, they should know these requirements and conform to them [5].

Can I install the loops myself?

GSHP installation isn't a do it yourself project for many reasons. The HDPE piping requires special and costly fusion tools along with knowledge of how to connect the pipe. If you were to install the piping with mechanical fittings (barbs, crimps) they will eventually result in leaks. The fusion technique melts the pipe and creates a connection that is stronger than the pipe itself. Additionally, an installer will be very mindful when preparing the trench or borehole in which the pipe lays in. (One rock could damage or crimp a pipe and render the system useless.) It is much easier to allow the installer to bear the burden and take responsibility for the system [5].

Are there laws and regulations pertaining to open-loop systems?

Yes. In the case where the loop system is using a well system, certified well drillers must drill and prepare the well as mandated by the Iowa Department of Natural Resources. When surface discharging, local and state requirements and regulations must be met. This may require that certain permits be obtained before work begins. Your installer should bare the burden of knowing the particular requirements and obtaining proper documentation [10].

Won't my loops freeze when the soil freezes?

Properly installed systems have little to no chance of ever freezing. The loops are typically at a depth of at least 6 feet, which is below the frost line. Additionally, installers will add antifreeze to the system to provide adequate freeze protection.

Will the ground loops affect my landscape?

With the initial installation, there will be some damage done with the installation of vertical loops and even more done with horizontal loops. It has been shown, however, that no long term effects will occur to the surrounding grass, trees, shrubbery, etc.

I have to install a new water line/septic system. Can I use the same trenches as part of the ground loop installation?

No. It is possible for the ground loops to experience sub-freezing temperatures. If the ground loops were installed in the same trench with the water line or septic system piping, they could easily freeze. In some cases, it is unavoidable that the loops may come close to these services. In these instances, special care will be given to insulating the piping.

Is there maintenance I can do?

Yes. The most important thing a homeowner can do is ensure the unit has a clean air filter. A clean air filter helps keep the system running at peak performance. It also reduces stresses on the fan and compressor, helping to extend the life of the machine. Many installers can supply a washable filter that can be used for an extended period of time. Ask your installer where the filter is located and how to properly service it.

The heat pump unit is equipped with a condensation pan that collects water when the unit is operating in the cooling mode. The pan has the potential for algae growth and should be periodically checked to ensure that proper drainage is occurring. If a problem is detected, a technician should be called to properly clean it.

One of the important maintenance aspects of a GSHP is that all the mechanical components are located inside. Compared to an air source heat pump, this is a major advantage. The mechanisms are not exposed to wind, hail, debris, vandalism, etc., which can easily damage the coils on an air source heat pump.

It is highly recommended to have a technician inspect the machine after one year of because the unit has had a chance to operate through a heating and cooling cycle. In that time period, the loops will have expanded in cooling mode and contracted in heating mode. Additionally, the earth around the loops will have had a chance to settle. If the loops do not properly expand and contract, there maybe insufficient fluid flow through the pipes, causing cavitation (air bubbling) in the pumps.

One may also want to consider yearly scheduled maintenance visits from their technician. You most likely will have invested a significant amount of money in the unit and the technician fee will be small compared to the years of productivity you will gain out of the unit.

A technician should have a checklist of parameters to evaluate. Consider keeping a log of these visits with the unit for future use. Some good things to include in the list are the loop pressures, compressor current, loop temperatures, air side temperatures, refrigerant pressures, and cleanliness of the coils and filter.

Why are there so many “horror stories” of GSHPs?

Perhaps your neighbor installed a GSHP and claimed it perhaps has problems. The GSHP units on the market are generally well designed and reliable. Problems typically evolve from poor installation practices, which is why it is so important to shop around and research a prospective installer.

How long will the GSHP system last?

The life of a GSHP will vary with installation, manufacturer and most importantly maintenance. The Department of Energy lists an expected life of 25 years for the indoor unit. However, one may want to consider replacement before then due to efficiency degradation and improvements in current products. The loops, on the other hand, can be expected to last the lifetime of the home. Many manufacturers have a warranty of 50 years on their piping products.

What are the environmental benefits of a GSHP?

Consider the data from the U.S. Department of Energy and Environmental Protection Agency citing that 100,000 homes equipped with GSHP would reduce CO_2 emissions by 880,000,000 lb. Such a reduction would go a long way toward reducing the environmental damage that is done by simply heating and cooling our homes.

Is there an environmental concern over the refrigerants and antifreezes?

The popular refrigerant currently in heat pumps is R-22 and its production by-products are known to cause ozone depletion that contributes to global warming. The U.S. EPA has a plan set forth for the reduction and eventual elimination of R-22. As this product is phased out, it may become more expensive to service the refrigerant loop in the heat pump. You may want to consider purchasing a unit which uses an environmentally friendly HFC-410a refrigerant. Furthermore, HFC-410a units can achieve higher efficiencies than that of R-22.

In colder climate regions, it is necessary to add antifreeze to the system. In heating mode the heat pump can extract enough heat from the loop system to cause it to fall below 32°F. There is very little environmental concern over the antifreezes in the loops. The concentrations of the antifreezes are typically very low so that if leakage would occur, limited contamination would be experienced. For vertical systems, the DNR only allows food grade, USP-grade propylene, or calcium chloride to be used in the system as a heat transfer medium. This ensures that if leakage would occur, water supplies would not be contaminated. Similar substances are used in horizontal loops [5].

Can I use the desuperheater for radiant floor heat?

Radiant floor heat is when the floors of a home are sufficiently warm to heat the room air. The heat is produced by running pipes beneath the floor that circulate a hot fluid. The desuperheater can used to supply the hot fluid. Things that should be considered in this installation are whether the desuperheater runs on-demand or only when the airside system is running. To alleviate runtime situations or large heating loads, a water-to-water unit could be considered. Along with the radiant tubing, additional components will be needed like storage tanks and pumps adding to installation cost. Many people, though, find this to be a very comfortable heating alternative.

Homes that currently use a radiator for heating will generally not be able to utilize the desuperheater for heating. Hot water radiators are designed to have a supply water temperature near 180°F. A desuperheater, on the other hand, delivers heated water at a temperature of 125°F which would be inadequate for the radiator [4].

Why does my system run so much?

Homeowners with GSHP will typically comment on the fact that they run more than conventional units and assume that the system is consuming more energy then it should. The system is designed to deliver heating and cooling at a lower rate than that of conventional systems and helps the home to maintain a more consistent temperature. It also reduces the cycling (on/off) of the system which increases efficiency. The reduction in cycling also decreases the stress placed on the equipment, increasing its life expectancy.

In cooling mode, the GSHP is doing two jobs to make the living space comfortable. It is reducing the air temperature and removing humidity from the air. While you could cool the air temperature quickly and shut the conditioning system down, the room would quickly become uncomfortable because of the humidity. The long runtime maintains the humidity control and your overall comfort.

What is auxiliary electric heat and why do I need it?

In many instances, an installer will recommend the inclusion of a small resistive heater that is located near the plenum. The electric heat is used when the GSHP unit cannot supply the needed heat output for extremely cold days.

You will ask why the GSHP unit is not sized to handle the coldest temperature it will experience. Doing so will grossly oversize the unit and cause it to run at partial capacity for most of the year. Partial capacity operation reduces efficiency. The auxiliary heat will take care of those very few days (possibly only hours) that the unit experiences at full capacity. Over sizing the unit in heating mode would also oversize the cooling system which could lead to dehumidification problems during summer months [6].

Will I need to upgrade my electrical service for a GSHP retrofit?

This will be a case by case situation and mostly a concern in a retrofit application. Many homes should be able to support the installation needs of a system especially if it previously had central air conditioning installed. While it rarely runs, the auxiliary heat can be a large electrical load on the service. Your installer will have to evaluate your particular situation and determine your needs.

Are GSHPs noisy in operation?

Air source heat pumps can be a noisy piece of equipment, but are located outside. In contrast, the noise GSHPs make can be virtually unnoticeable. Many manufactures line the interior of the cabinet with insulation and also place isolation pads under the compressor to suppress vibrations. Installers will line the plenum of the duct work with insulation to reduce noise created by the large volume of air the system transfers. It should be noted that, the duct work in retrofit applications may need to be upgraded. Insufficiently sized duct work will create a large amount of noise and cause the system to run less efficiently [9].

I heard GSHPs supply cooler air temperatures for heating. Will I be as comfortable with a GSHP as I am with a gas furnace?

It is true that the a GSHP will deliver lower air temperatures in the range of 90°F to 105°F where a gas furnace will deliver air at 120°F or more. In a conventional gas furnace, the air is delivered in short "blasts" of heating and creates large temperature swings so the home may not heat evenly. A GSHP, on the other hand, delivers a larger volume of air at constant heat for lengthy periods of time, reducing or eliminating the cold spots in home and creating a comfortable living environment.

Do GSHPs require special ductwork? Will I have to install new ductwork when replacing my gas furnace?

GSHPs require essentially the same type of ductwork that other heating and cooling system would use. The biggest difference is that GSHPs circulate larger volumes of air than a conventional system. In some situations replacing a GSHP with an existing gas furnace, requires that ductwork be upgraded to support larger volumes of air.

Installers have become very aware of the importance of sealing ductwork joints with sealants like mastics. Additionally, the importance of insulating ductwork in crawlspaces and unconditioned spaces has been recognized. While these measures should be followed whether the system is a GSHP or conventional system, you should check that your installer is including this in their installation and bid. It will only further enhance the performance of a GSHP.

Will I have to upgrade my home's insulation with the installation of a GSHP?

The short answer is no. Regardless of your previously installed system a ground source heat pump will save energy. Improving your insulation and weatherizing will only help to decrease the amount of energy you need to heat and cool your home and ultimately save you money.

Who is involved with the GSHP industry?

Utility Companies have an ever increasing interest in promoting heat pumps. One of the major issues they face is the reduction of peak power demand which can be lessoned with the energy efficient heat pump. Since heat pumps use electricity as their power source, new installations would also increase sales. Additionally, utility companies look toward becoming leaders in a new technology.

While most of the major advancements in GSHPs have already taken place, manufacturers are constantly working to improve the mechanics of the machine to increase efficiencies and lower your cost. Aside from the machines, plastic pipe manufacturers work to improve the heat transfer properties of the pipe and increase its longevity. Additionally, they search for ways to improve pipe fusion techniques.

Installers, contractors, or dealers are the ones who develop the market for GSHPs. Their goal is to meet the consumer's heating and cooling needs while helping the utility companies and manufacturers sell their product.

Rounding out the industry is the universities and research organizations. These constituents serve many important functions to furthering GSHPs. They research methods to increase efficiency, reduce cost, and eliminate public health concerns. Among many other roles, they develop design criteria, training techniques, and help identify soil properties for installers [5].

Who manufactures the equipment?

The GSHP units available on the market are generally designed in the same manner. Your installer will most likely choose the unit for you. It is recommended to go with their choice as they will have direct knowledge of that specific brand. If you are choosing your own brand of GSHP, there are several key aspects to investigate. The manufacturer's entering water temperature will dictate whether the unit is right for your climate. Some manufactures will design units so that they are more efficient in heating mode for a heating dominate climate and more efficient in cooling mode for a cooling dominate climate. Features of the unit such as domestic hot water production, safety features, etc. should be taken into consideration. The unit should be rated by Underwriter Laboratories (UL) to ensure basic safety under operation. The type of unit will also have to be considered. This would include a water-to-water unit, water-to-air, vertical, or horizontal. Warranty coverage of the unit should also be investigated. Finally, you will want to compare performance ratings to fit your needs. Typically the higher the efficiency, the more costly the unit will be [9].

The following is a list of ground source heat pump manufacturers.

Addison Products Company
P.O. Box 607715
Orlando,FL 32860
Phone: 407-292-4400
http://www.addison-hvac.com

Bard Manufacturing Company
1914 Randolph Dr.
Bryan, OH 43506
Phone: 419-636-1194
Fax: 419-636-2640
http://www.bardhvac.com

Climate Master
P.O. Box 24788
Oklahoma City, OK 73125
Phone: 405-745-6000
http://www.climatemaster.com

Command-Aire/Trane Company
P.O. Box 7916
Waco, TX 76714
Phone: 254-299-6300
http://www.commandaire.com

ECONAR Energy Systems
19230 Evans St N.W.
Elk River, MN 55303
Phone: 612-241-3110
http://www.econar.com

Florida Heat Pump
601 NW 65th Court
Ft. Lauderdale, FL 33309
Phone: 954-776-5471
http://www.fhp-mfg.com

GeoComfort
2506 S. Elm Street
Greenville, IL 62246
www.geocomfort.com

Hydro Delta Corporation
1000 Rico Rd.
Monroeville, PA 15146

Phone: 412-373-5800
Fax: 412-373-7766
http://www.hydroheat.com/

Millbrook Industries-Hydronic Division
41659 - 256th St.
Mitchell, SD 57301
Phone: 605-995-0241
Fax: 605-996-9186
http://www.hydronmodule.com

Northern GeoThermal Corp.
N.966 Spring Valley Drive
Hortonville, WI 54944
Phone: 920-757-1217
www.northerngeothermal.com

Thermal Energy Transfer Corp.
4059 E State Rt 36/37
E Delaware, OH 43015
Phone: 800-468-3826

WaterFurnace International
9000 Conservation Way
Fort Wayne, IN 46809
Phone: 219-478-5667
http://www.waterfurnace.com

Where can I gain more information about GSHPs?

With the increasing popularity of GSHPs, many websites have been developed and dedicated to educating homeowners. The following is a short list of informative and reputable websites available.

International Ground Source Heat Pump Association
374 Cordell South
Still Water, OK 74078
http://www.igshpa.okstate.edu/

Iowa Heat Pump Association
8345 University Blvd Suite F-1
Des Moines, Iowa 50325
Phone: (877) 950-6000
http://www.iaheatpump.org/iaheatpump/

Iowa Energy Center
2006 S. Ankeny Blvd.
Ankeny, IA 50023
Phone:515-965-7055
Fax: 515-965-7056
http://www.energy.iastate.edu/

Geothermal Heat Pump Consortium, Inc.
1050 Connecticut Avenue, NW
Suite 1000
Washington, DC 20036
http://www.geoexchange.org

Alliant Energy Geothermal
www.alliantenergygeothermal.com/

Additionally, many utility companies have resources pertaining to GSHPs. Manufacturers are also excellent resources having informative guides on the basics of installations and equipment descriptions.

Ground Source Heat Pumps at a Glance

The following is a short list of what is typically viewed as advantages and disadvantages to ground source heat pumps.

Advantages
- ♦ Reduces annual heating and cooling cost
- ♦ Energy efficient
- ♦ Excellent comfort control
- ♦ Potential for reduction in cost of hot water
- ♦ Reduces pollution emissions
- ♦ Wide range of installation options
- ♦ Indoor unit requires a limited amount of space
- ♦ No unsightly outdoor equipment which could be damaged
- ♦ Simple design
- ♦ Minimal maintenance
- ♦ Homeowner controls are comparable to conventional systems
- ♦ Long life expectancy
- ♦ Limited or no harmful refrigerants and antifreezes

Disadvantages
- ♦ High installation cost
- ♦ Requires careful selection of installer
- ♦ Limited number of qualified installers
- ♦ Emerging technology
- ♦ Requires space for loops
- ♦ Landscaping will be disturbed
- ♦ May require auxiliary heat
- ♦ Corrosion issues in open-loop systems
- ♦ May require existing ductwork to be upgraded

Glossary of Terms

American Society of Heating Refrigeration and Air Conditioning Engineers: (ASHRAE) A technical society devoted to improving heating, ventilation, air-conditioning, and refrigeration. They provide industry guidelines and standards.

closed-loop system: Ground source heat exchanger system. A fluid is circulated through out the system to transfer heat and is never exposed to the atmosphere.

coefficient of performance: (COP) Energy required to produce a heating effect as a ratio to the energy consumed to produce that effect.

domestic hot water: (DWH) Potable hot water.

desuperheater: A system for recovering heat from a heat pump for purposes of heating water.

entering water temperature: (EWT) from the ground loop heat exchanger.

fusion: The joining of plastic pipe by means of heat and pressure.

grout: A fluid mixture of cement or bentonite with various additives to achieve specified application requirements. In ground coupled heat pumps, used to seal boreholes to prevent water flow, create a thermal bridge, and allow movement of piping.

heat pump: A mechanical system that moves heat from cooler area to that of a warmer area and converts that energy into heating and cooling for a space.

heat sink: The medium which a heat pump will receive heat. This can be in the form of air, water, or soil.

heat source: The medium in which a heat pump extracts heat. This can be in the form of air, water, or soil.

IGSHPA: International Ground Source Heat Pump Association, Technical society that sets standards, requirements, and develops training seminars for ground source heat pumps.

open-loop system: A heat exchanger system where the heat transfer fluid is exposed to the atmosphere.

purge: Flushing a system with water to remove air and debris from a closed-loop heat exchanger.

tremie pipe: A small diameter pipe that carries grout to the bottom of a borehole to prevent the development of air pockets.

refrigerant: A chemical which at high temperatures and pressures will absorb heat during evaporation and releases heat during condensation.

U-bend: A factory or field installed joint placed at the bottom of a vertical heat exchanger for the connection of two pipes. Also used in the horizontal borehole applications.

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