FINAL REPORT

ANALYSIS OF DATA COLLECTED FOR THE FREEWATT MICROCHP SYSTEM
IN
SYRACUSE, NY

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Submitted to:

Syracuse Center of Excellence
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EXECUTIVE SUMMARY

Syracuse University, as part of the Syracuse Center of Excellence (SyracuseCoE), has installed a Freewatt micro-CHP system at a home in the Near Westside neighborhood of Syracuse. This residential-scale combined heat and power (CHP) system has been developed by Climate Energy (http://www.freewatt.com/). The system includes a natural gas-driven engine generator that provides about 1.2 kW of electric power as well as space heat for the home using waste heat from the engine. The system includes a Honda engine generator with a conventional gas furnace for backup or auxiliary heating. On cold days both the engine and the furnace operate together to meet the heating load. The furnace is a 93% efficient, two-stage, 60 MBtu/h furnace. The furnace includes a hot water coil in order to use the waste heat from the engine jacket to provide about 12 MBtu/h of space heating.

The purpose of this field test was to measure and confirm the cost effectiveness and environmental performance of this innovative system.

The data logging system started collecting data in mid-December 2008 and continued through January 2011, for nearly three heating seasons. During the first season, the system operated with without the engine generator. This furnace only operation provided a baseline for comparing to normal Freewatt operation. The collected energy and fuel use data indicate that the Freewatt system performed below expectations in terms of both energy cost savings and emissions impacts. While the freewatt generated about 30% of the power needed by the home, the net cost savings to home owner were only about $210 per year using utility costs of $1.00 per therm and $0.14 per kWh. The Freewatt system actually had slightly higher greenhouse gas emissions than the furnace, even after considering the emissions reductions at the power plant.

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Introduction

A residence in the Near Westside neighborhood of Syracuse recently made the transition from a traditional natural gas furnace to a Freewatt Warm air micro-combined heat and power (MicroCHP) system. The Freewatt MicroCHP system (Model WA-A060) is advertised by its manufacturer, ECR International, as providing an eco-friendly combined heat and power (CHP) energy alternative to traditional, residential-grade furnaces.

Figure 1. Freewatt Warm-air System

The Freewatt system consists of an engine-driven generator and a two-stage auxiliary natural gas furnace (60 MBtu/h, 93% efficient). A simple schematic of the system is shown in Figure 2. The engine generator runs on natural gas and provides up to 1.2 kW of power. The heat produced by the generator, which would normally be discarded as waste heat, is instead pumped into the furnace, via the hot water coil, to assist in heating the residence. This combination is ultimately intended to efficiently use the natural gas to provide both heat and power. The homeowner should expect to see savings in utility bills while also reducing greenhouse gas emissions (particularly carbon dioxide (CO_2)).

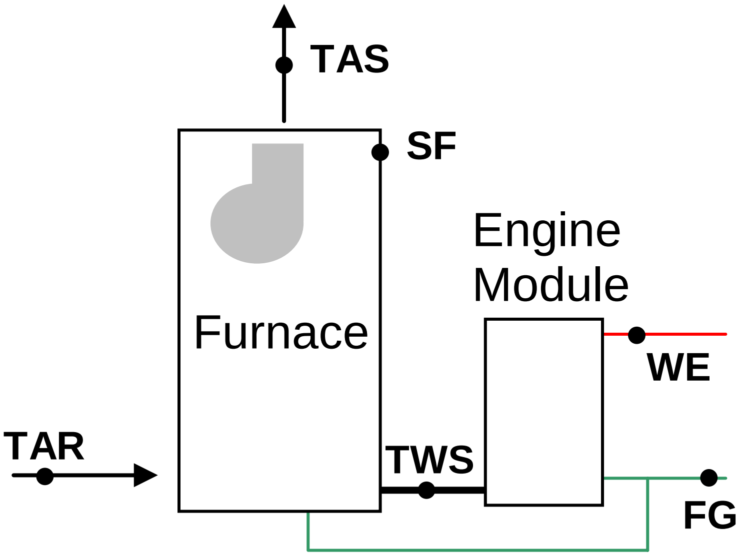

Figure 2. Schematic of Freewatt System with Monitoring Points Shown (defined in the following section)

The Freewatt system was installed in this residence in November 2008. However, the generator was not approved by National Grid for grid interconnection until May 2009, after the heating season had ended. Prior to May 2009, the 93% efficient furnace operated alone to provide heat to the residence. After interconnection approval, the furnace and generator operated together to provide heat and electricity for the 2009–2010 heating season and for part of the 2010–2011 season (until January 2011). This delay provided the opportunity to directly compare the performance of the system with and without the engine generator operating. The electricity exported to the grid is assumed to be “net metered,” meaning the homeowner receives credit for the full retail cost of the exported electricity.

The objective of this project is to determine whether the Freewatt MicroCHP system is an economically viable alternative to a conventional furnace.

Monitoring Approach

The monitoring system installed in the residence was based around a Campbell Scientific CR10X data logger. The CR10X is a fully-programmable, expandable logger capable of performing a variety of measurements and interfacing with many different types of sensors. The data logger sampled all sensors once every 5 seconds and calculated averages and totals for each 15-minute record as appropriate. The logger was called and data downloaded each night by phone modem. The data was loaded into a database at CDH Energy for automatic verification and processing.

Table 1 lists the measured data points collected by the data logger. Appendix A provides full details on the monitoring system. The rationale for installing these points is given below:

Energy Consumption

Power generation by the Freewatt system (**WE**) was measured with a power transducer, as was utility power import (**WTI**) and export (**WTE**). Whole house energy use and grid energy savings may be derived from these values.

Natural Gas Consumption

A pulse-output gas flow meter measured the combined natural gas consumption (**FG**) for the furnace and engine generator.

Air Temperatures

Sensors were installed in the furnace supply and return ducts to measure furnace output temperature (**TAS**) and return air temperature (**TAR**), which is also a good surrogate for the house interior temperature. These provided an indication of the amount of heat added to the house. Ambient outdoor temperature (**TAO**), measured at nearby Syracuse Airport (SYR), were downloaded from the Weather Underground website.

Engine Hot Water Sensor

A sensor was installed to measure the temperature of the hot water (**TWS**) supplied to the furnace from the engine jacket. This indicates when heat recovery is being used to provide space heating.

Fan and Engine Runtimes

The warm air fan status/runtime (**SF**) was measured using a current switch (though this sensor never operated properly). The engine runtime (**SE**) was derived from the generator power output (**WE**). These runtimes precisely indicated when each piece of equipment was on.

Table 1. Summary of Monitored Data Points For Freewatt System

Name	Channel Type	Logger Chan	Name	Description	Eng Units	Instrument
FG	Pulse	P1	FG	Gas Flow to Engine & Furnace	CF	AMCO-250 Gas Meter (0.25/pulse)
WE	Pulse	P2	WE	Power Export from Furnace	kWh	WattNode WNB-3Y-208-P (30 amp CTs)
SF	Status	C1	SF	Fan Status/Runtime	min	Veris H800
SE	Status		SE	Engine Status/Runtime	min	Calculated from WE
WTI	Pulse	C7	WTI	Utility Power Import	kWh	WattNode WNB-3Y-208-P (100 amp CTs)
WTE	Pulse	C8	WTE	Utility Power Export		
TAS	Analog	SE2	TAS	Supply Air Temp. from Furnace	ºF	Watlow Type T-TC AFGCQTA080U825M
TAR	Analog	SE3	TAR	Return Air Temp. to Furnace	ºF	Watlow Type T-TC AFGCQTA080U825M
TWS	Analog	SE4	TWS	Temp. of HW from Engine	ºF	Watlow Type T-TC AFECOTA040U840M

Measured Results

Data collection for the Freewatt system officially began on December 9, 2008 and ended on January 20, 2011. However, the Freewatt engine-generator unit was not able to operate until May 2009; before May 2009 the new system operated in the Furnace Only mode. This provided a baseline to directly compare performance data from before and after activation of the Freewatt engine module.

Energy Use Summary

Table 2 presents a summary of monthly total electricity use, generated power output, and gas use along with the corresponding costs and emissions for the monitoring period. Total house power corresponds to the consumption in home (calculated as: imported + generated – exported).

The total electric use for the house was 11,578 kWh in 2009 and 10,592 kWh in 2010. In 2010 when the generator was fully operational, the generator produced 3,088 kWh. 570 kWh of this generated electricity was exported to the grid.

Net costs and emissions corresponding to heating system operation in the table above were calculated using the formulas below. The energy costs were calculated assuming $1.00 per therm and $0.14 per kWh. Generated power was assumed to displace 0.86 lb CO_2 per kWh at the power plant, while local gas consumption in the house corresponded to 12.06 lb CO_2 per therm. These calculations assume that all the power generated by the system, that is either consumed in the house or exported to the grid, displaces power plant generation (in other words, transmission and distribution losses are neglected). The cost calculations also assume that net metering rules apply (or that exported power is credited to the homeowner at the same retail electric rate charged for imported power).

Net Htg
Costs = Gas Costs - Electric Savings

= [Gas Use, therm] x ($/therm) - [Generated Power, kWh] x ($/kWh)

Net Htg
Emissions = Local Emissions - Reduced Power Plant Emissions

= [Gas Use, therm] x (lb CO_2/therm) - [Generated Power, kWh] x (lb CO_2/kWh)

Table 2. Monthly Energy Use and Costs

	Month	Total House Power (kWh)	Imported Power (kWh)	Exported Power (kWh)	Generated Power (kWh)	Gas Use (therms)	Net Heating Costs	Net Heating GHG Emissions (lb CO2)
Furnace Only	Dec-08	1,113.6	1,113.6	-	-	94.4	$94	1,138
	Jan-09	1,046.3	1,046.3	-	-	148.5	$148	1,791
	Feb-09	970.5	970.5	-	-	105.4	$105	1,271
	Mar-09	1,033.7	1,033.7	-	-	88.3	$88	1,065
	Apr-09	980.9	980.9	-	-	48.3	$48	582
FreeWatt System	May-09	881.2	880.5	-	0.7	1.2	$1	14
	Jun-09	870.4	870.4	-	-	-	$0	-
	Jul-09	894.3	894.3	-	-	-	$0	-
	Aug-09	907.5	907.5	-	-	-	$0	-
	Sep-09	778.1	778.1	-	-	0.0	$0	0
	Oct-09	979.9	586.7	62.0	455.2	77.2	$13	539
	Nov-09	998.4	596.7	58.3	460.0	89.7	$25	687
	Dec-09	1,236.9	706.8	49.0	579.1	168.3	$87	1,531
	Jan-10	1,040.8	452.8	97.7	685.7	184.5	$89	1,636
	Feb-10	951.2	484.4	59.1	525.9	162.0	$88	1,501
	Mar-10	884.4	515.7	80.8	449.5	111.3	$48	956
	Apr-10	787.0	681.4	54.0	159.6	27.8	$5	198
	May-10	729.8	697.2	17.1	49.6	9.1	$2	66
	Jun-10	725.6	725.6	-	-	-	$0	-
	Jul-10	900.2	900.2	-	-	-	$0	-
	Aug-10	915.8	915.8	-	-	-	$0	-
	Sep-10	911.5	911.5	-	-	-	$0	-
	Oct-10	930.6	831.5	30.6	129.6	20.3	$2	133
	Nov-10	851.0	523.0	130.0	458.0	73.2	$9	488
	Dec-10	964.7	435.2	100.5	630.0	143.3	$55	1,186
Total:	*2009*	*11,578.1*	*10,252.4*	*169.3*	*1,495.0*	*726.9*	*$518*	*7,481*
	2010	*10,592.5*	*8,074.3*	*569.7*	*3,088.0*	*731.5*	*$299*	*6,166*

Comparison of Heating Systems

Figure 3 and Figure 4 compare system gas consumption and purchased electric use during the Furnace-only and Freewatt operating periods. The two Freewatt seasons (2009-10 and 2010-11) are also shown separately. For this analysis the data were summarized into daily values; each data point on the plots represent an individual day. Figure 3 shows the trend for daily gas use versus ambient outdoor temperature and Figure 4 shows the trend of daily imported power use. As expected, the Freewatt generator increases gas use and decreases the need to import electricity from the grid.

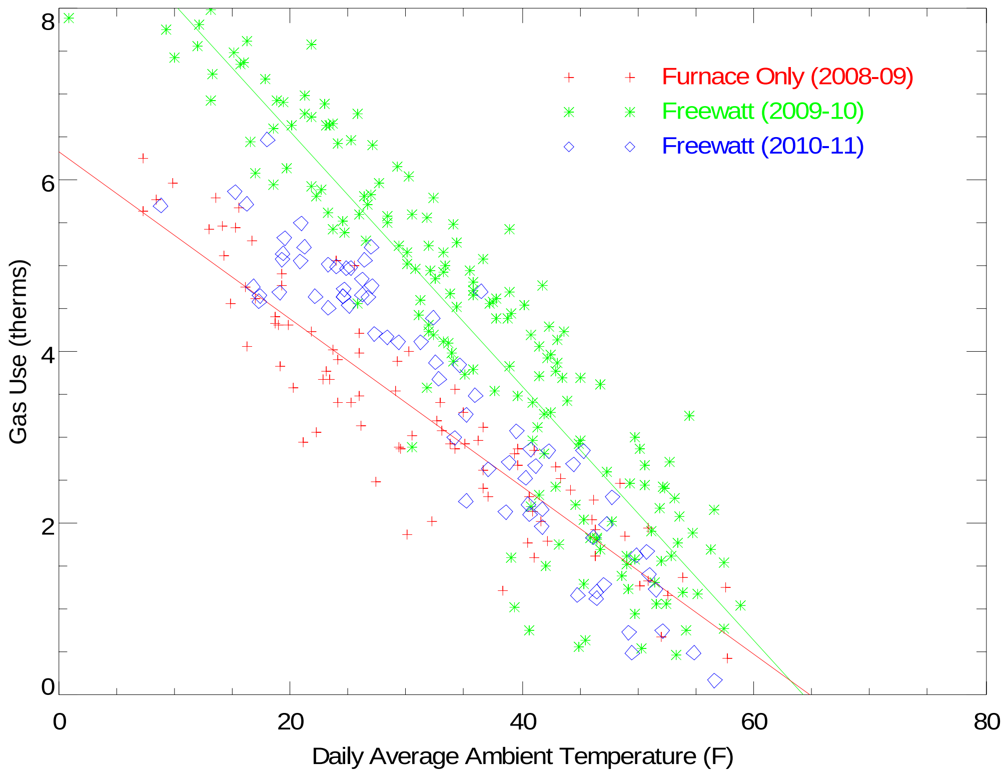

Figure 3. Trend of Gas Use with Outdoor Temperature for Each Heating Season

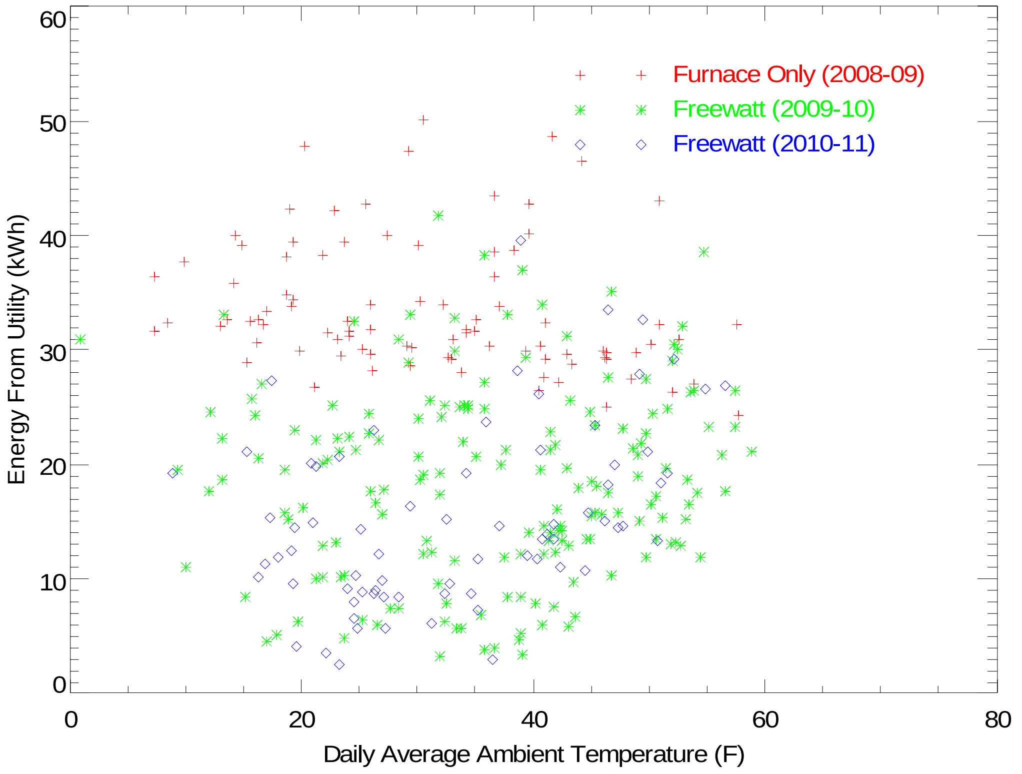

Figure 4. Trend of Imported Power with Outdoor Temperature for Each Heating Season

The performance trends for the Freewatt system were different between the two seasons. The analysis in Appendix B shows that the change was most likely due to a change in the building heating load between the two heating seasons. It appears that insulation was added or windows were replaced sometime before the 2010-11 heating season. Therefore the economic and environmental analysis below compares Furnace Only operation to Freewatt operation in the first season of operation (2009-10).

Figure 5 and Figure 6 compares Freewatt (green *) and Furnace Only (red +) operation in terms of net heating costs and net CO_2 emissions. The daily cost and emissions were calculated using the equations given above. A best fit line was applied to these data sets to establish a trend for each season (or system). Then the two trend lines were used with the daily temperatures from the 2009-10 heating season to determine annual costs (taking only values greater than zero). The annual savings are the difference between these annual costs predicted for each system. Each figure includes the total annual cost and emissions savings attributable to the Freewatt system. By this analysis method the annual cost savings are $190 but the CO_2 emissions are actually increased by 455 lbs per year.

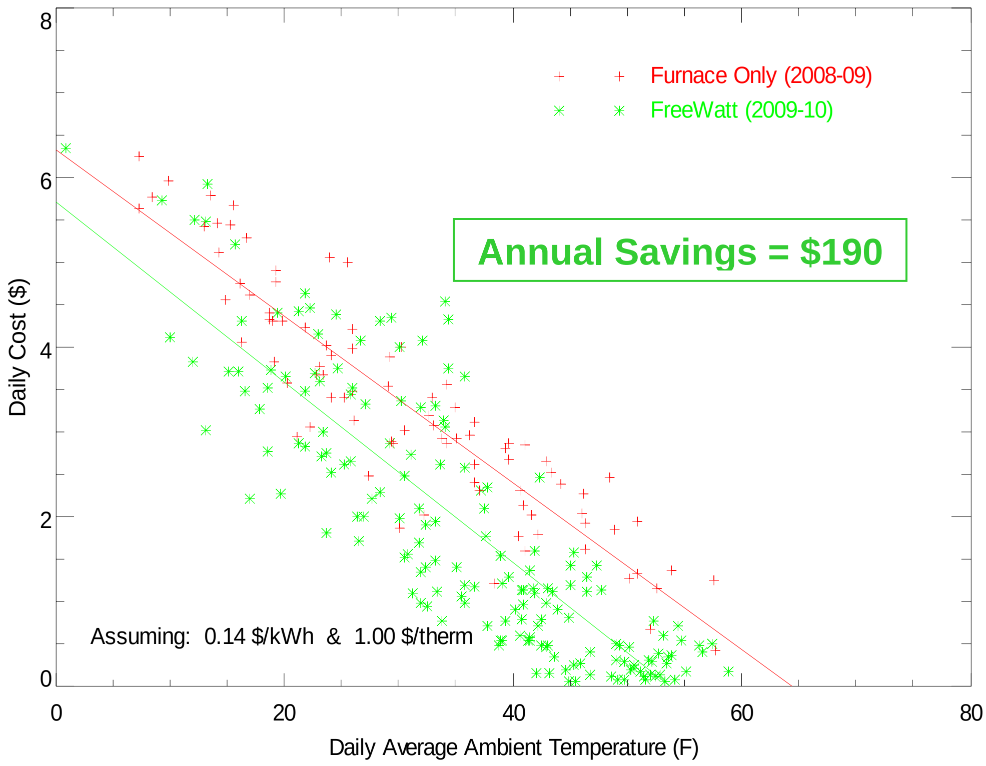

Figure 5. Impact of Freewatt on Daily Operating Costs

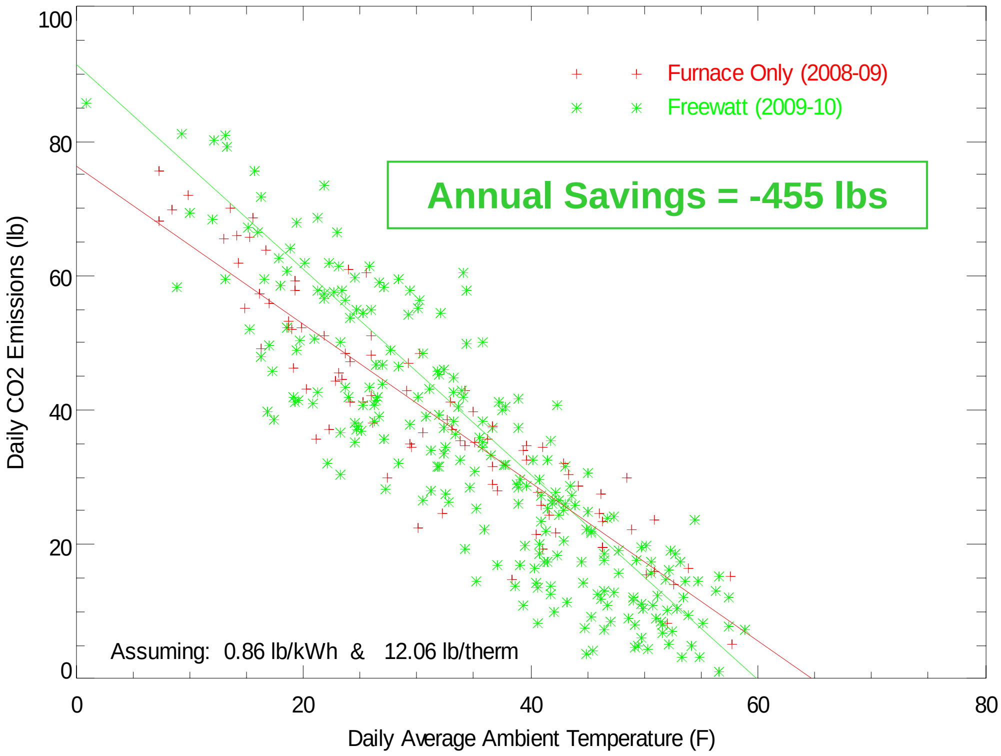

Figure 6. Impact of Freewatt on Daily CO_2 Emissions

One potential concern with this analysis approach is that it assumes that the house was maintained at the same indoor temperature for both seasons. Figure 7 compares the furnace return temperature – which represents the air temperature inside the house – for both operating periods. The data shows that there was some variation in the indoor temperatures maintained in the home, especially during the period with Furnace Only operation.

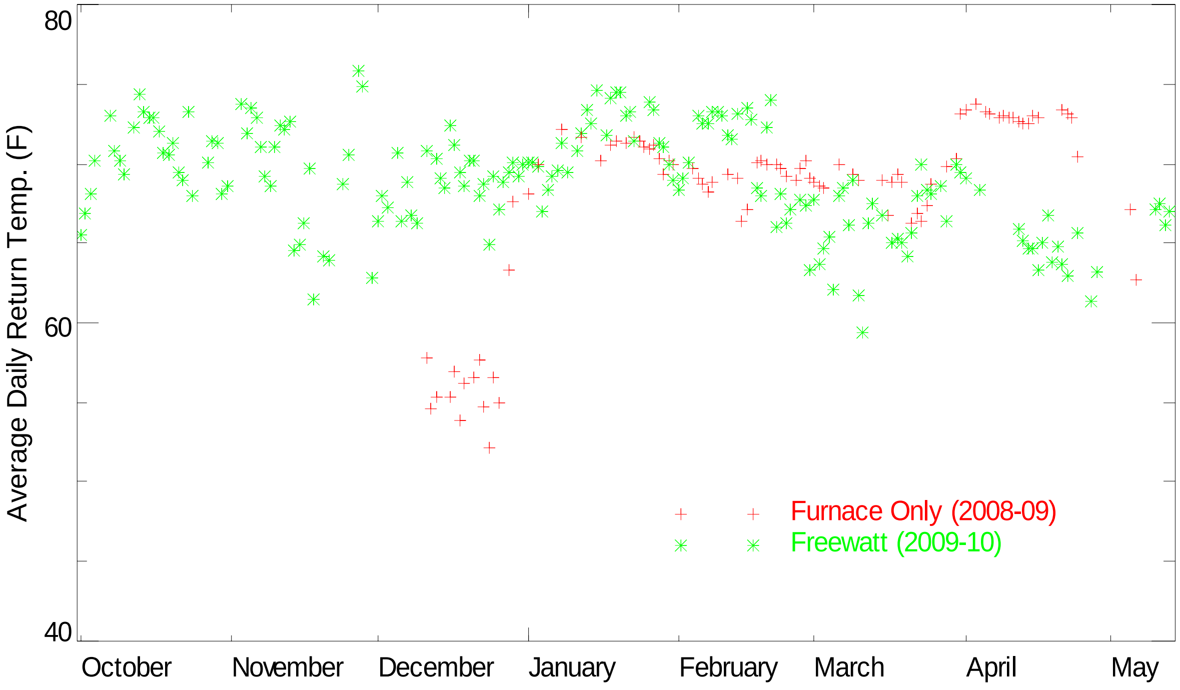

Figure 7. Comparing Return Air Temperatures for the Two Operating Periods

In order to normalize for this variation, we used the temperature difference between return and outdoor air temperatures as the independent variable instead of the outdoor temperature. Figure 8 and Figure 9 repeat the analysis described above using the temperature difference. The annual cost savings increase modestly to $210. The predicted impact of CO_2 emissions becomes a smaller penalty of 231 lbs per year.

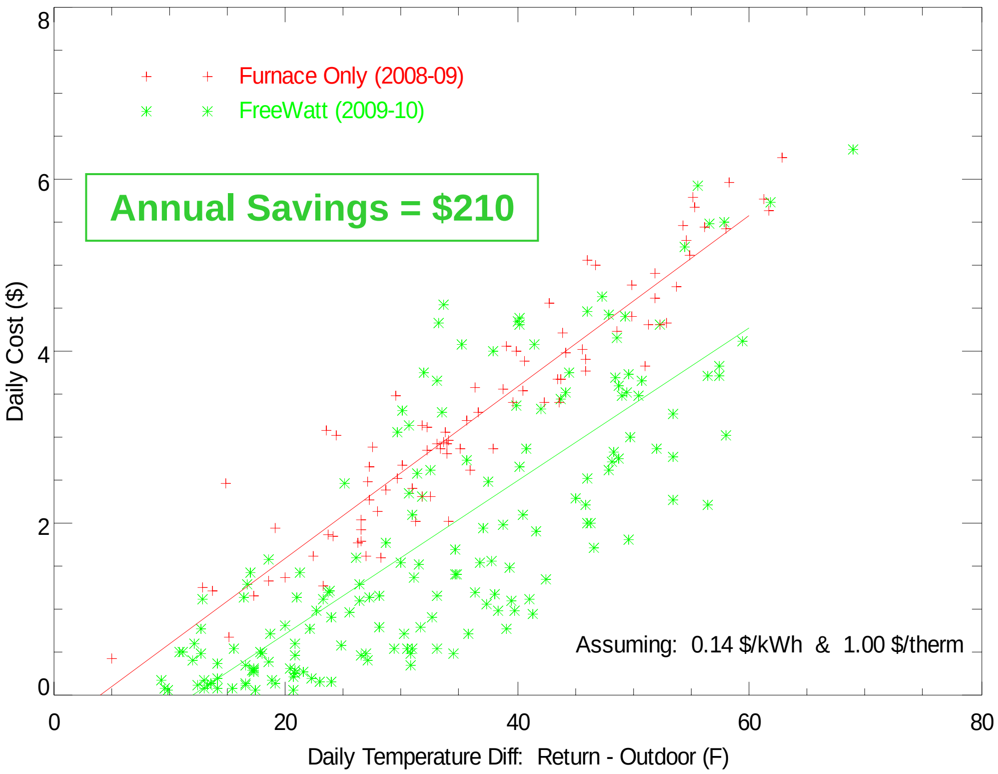

Figure 8. Impact of Freewatt on Daily Operating Costs – Normalized

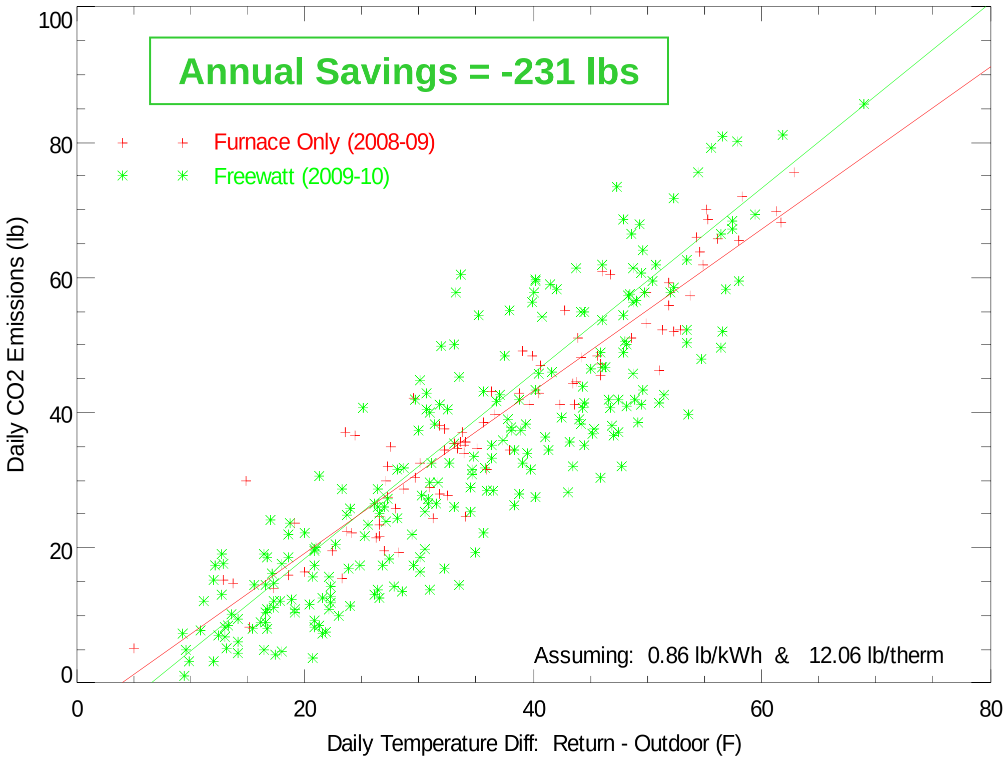

Figure 9. Impact of Freewatt on Daily CO_2 Emissions – Normalized

Power and Efficiency

Figure 10 shows the trend of daily generated power with ambient temperature. A reference line has been added to show the maximum daily power expected for the generator based on the nominal output. The plots shows that the generator produced close to the expected power output of 1.2 kW, or 28.8 kWh per day.

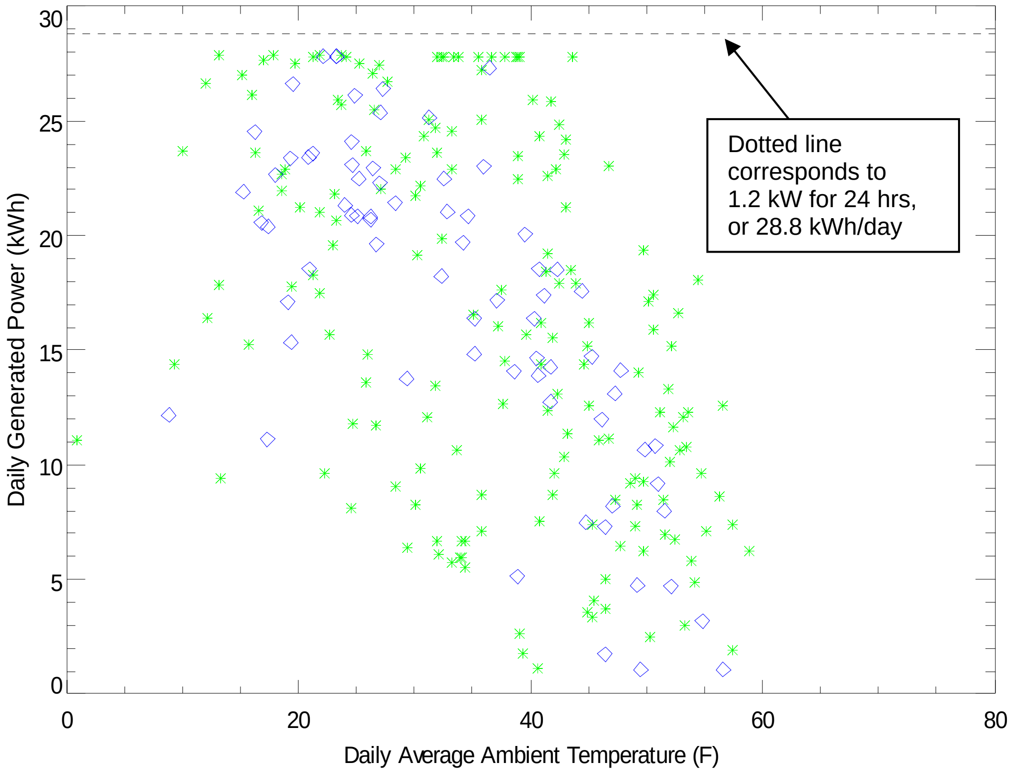

Figure 10. Trend of Daily Generator Output with Ambient Temperature

Figure 11 shows the trend of generator electrical efficiency of the Freewatt system at various outdoor temperatures. The data on this plot only has meaning when the furnace is off and all gas is used by the engine generator (i.e., the data at the top of the trend). The electrical efficiency implied by this analysis is approximately 22%. The Freewatt literature does not provide this performance metric in its specifications. The plot also suggests there is a slight loss in electrical efficiency as the outdoor temperature increases.

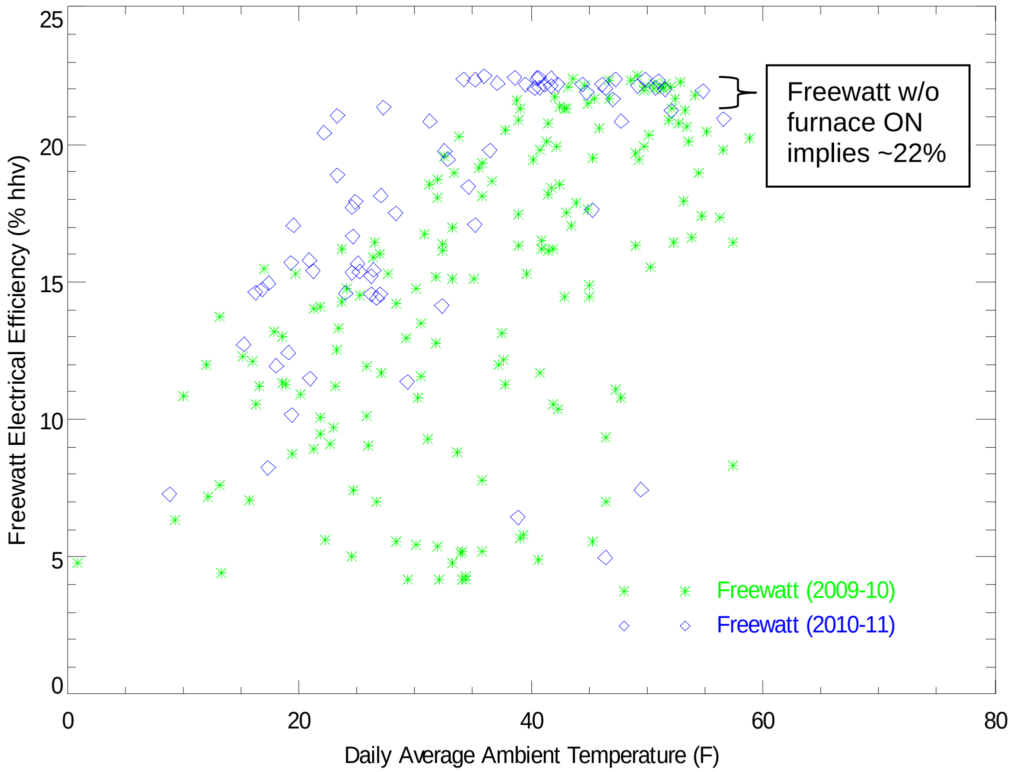

Figure 11. Trend of Generator Electrical Efficiency with Ambient Temperature

Conclusions

The cost savings from the Freewatt system relative to a conventional 93% efficient, two stage gas furnace are about $210 per year. One reason for the relatively low savings is the modest electrical efficiency of the unit. The measured electrical efficiency of Freewatt is about 22% based on higher heating value (HHV). In contrast larger, conventional power generation systems in the 75 kW range typically have electrical efficiencies of 28% HHV.

The cost of purchasing and installing a Freewatt system is approximately $13,000[i]. Assuming that a typical furnace installation would cost about $5,000-$7,000 to install, the incremental costs are $6,000 to 8,000 for the Freewatt system. Therefore the simple payback of the system is 29-38 years. The simple payback is longer than the expected life of 15-20 years for this type of system. Therefore this system provides no economic advantage to the customer.

Environmental Benefits

The Freewatt system actually increased CO_2 emissions by about 231 lb per year. Therefore the system does not provide any environmental benefit. This unexpected result was due to the low electrical efficiency. Low efficiency results in lower power production per therm of gas consumed and therefore less displaced emissions at the power plant.

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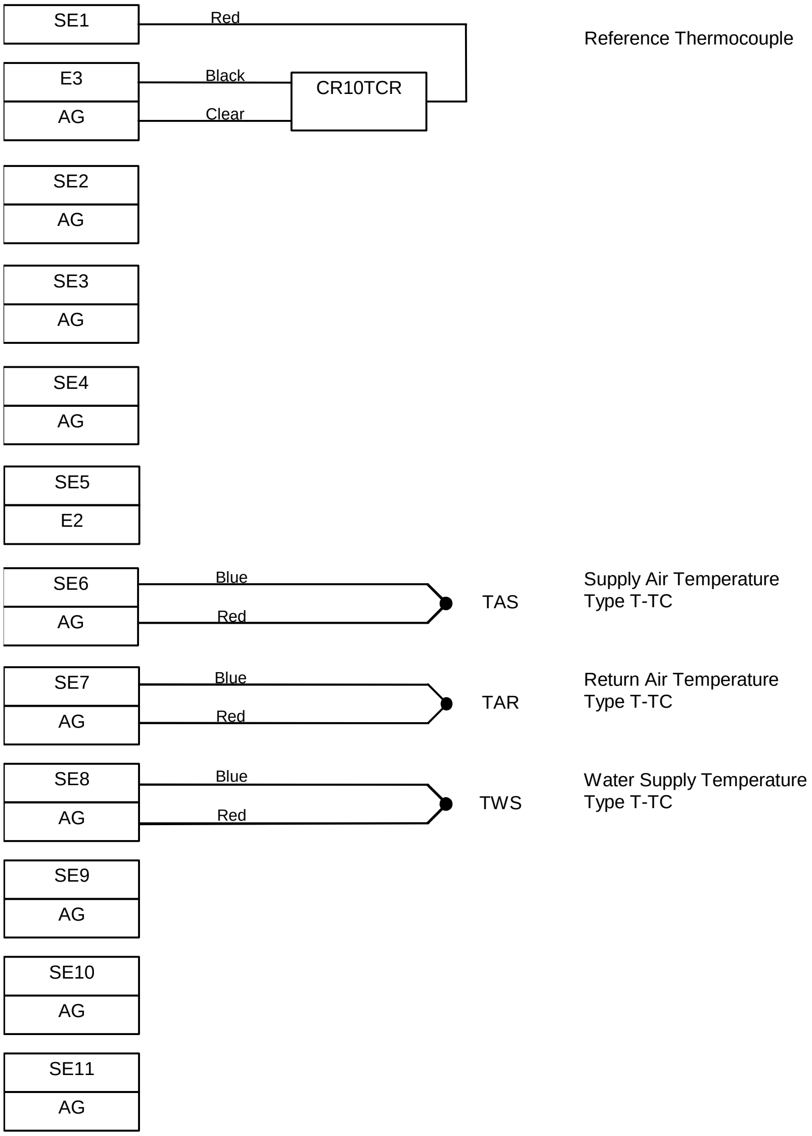
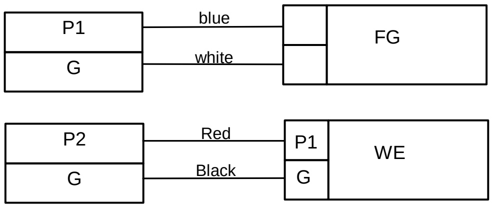
[i] According to Treehugger.com: http://www.treehugger.com/files/2007/04/honda_and_clima.php

APPENDIX A – Monitoring Details

CR10X Data Logger
Analog Terminals



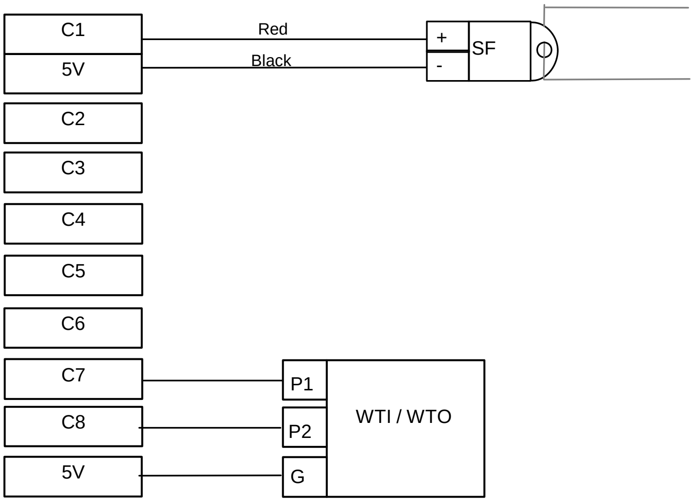
CR10X Data Logger
Pulse Terminals



Gas Meter
AM250 with Pulser (0.25 CF/p)

Engine Power Output
WattNode WNB-3Y-208-P, 30 amp CTs
Multiplier = 0.00075 kWh/p

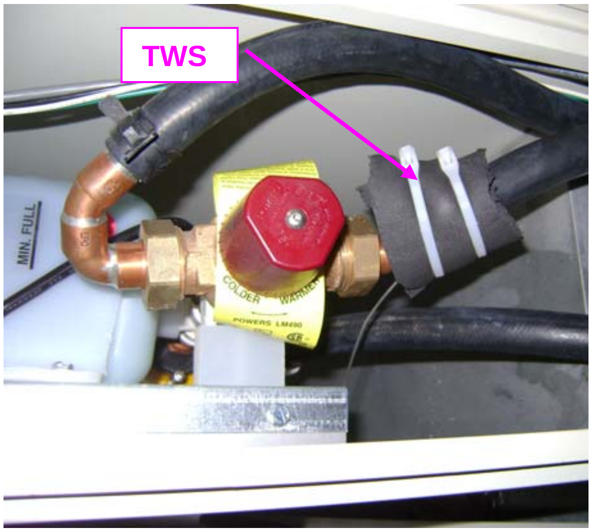
CR10X Data Logger
Digital Terminals



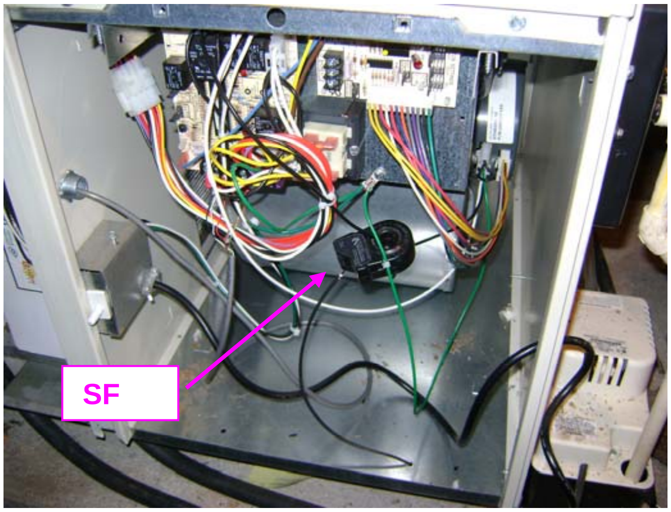
Supply Fan Status/Runtime
Veris H800

Home Meter Import/Export

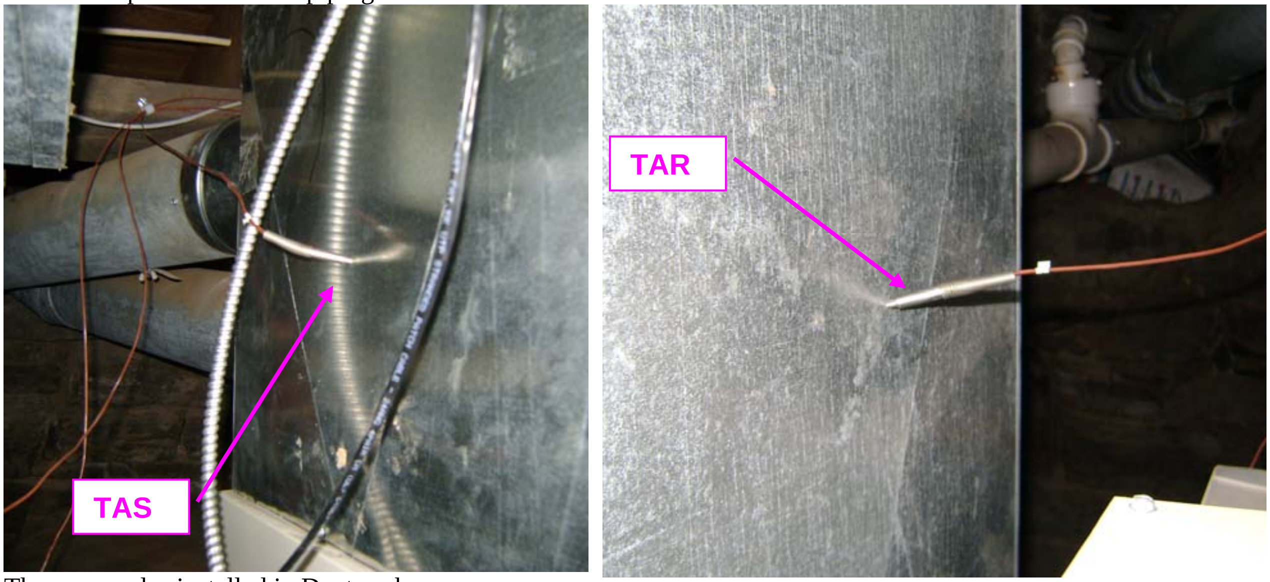
WattNode WNB-3Y-208-P, 100 amp CTs
Multiplier = 0.025 kWh/p



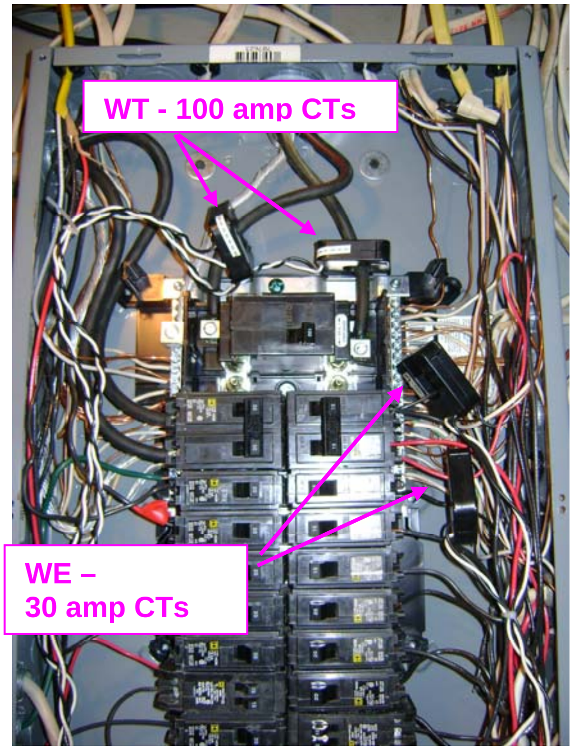
Thermocouple on hot water piping



CT status sensor on fan wiring



Thermocouples installed in Ductwork



CTs installed inside electrical panel

Power Transducers installed near electric panel

Campbell Program

```
;
;
;  FreeWatt Demonstation Site, 419 Marcellus St, Syracuse
;
;       Output Array
;       1       xx      Campbell Output Code
;       2       ID      Record ID (0 - 15 minute)
;       3       Year
;       4       HHMM
;       5       Day
;       6       Sec
;       7       TAS     Supply Air Temperature from Furnace     SE6
;       8       TAR     Return Air Temperature to Furnace       SE7
;       9       TWS     Temperature of Hot Water from Engine    SE8
;       10      SF      Fan Status/Runtime                      C1
;       11      SE      Generator Module Status/Runtime         C2
;       12      FG      Gas Flow to Engine & Furnace            P1
;       13      WE      Power Export from Furnace               P2
;       14      WTI     Utility Power Import                    C7
;       15      WTO     Utility Power Export                    C8
;       16      VBAT    Battery Voltage                         --
;       17      TREF    Reference Thermocouple Temperature (C)  SE1
;
*Table 1 Program
  01: 5         Execution Interval (seconds)

; - SCAN RATE CONSTANTS

1:  Z=F x 10^n (P30)
 1: 60       F
 2: 0        n, Exponent of 10
 3: 1        Z Loc [ SIXTY     ]

2:  Z=F x 10^n (P30)
 1: 5        F
 2: 0        n, Exponent of 10
 3: 2        Z Loc [ SCAN_SEC  ]

3:  Z=X/Y (P38)
 1: 2        X Loc [ SCAN_SEC  ]
 2: 1        Y Loc [ SIXTY     ]
 3: 3        Z Loc [ SCAN_MIN  ]

4:  Z=X/Y (P38)
 1: 3        X Loc [ SCAN_MIN  ]
 2: 1        Y Loc [ SIXTY     ]
 3: 4        Z Loc [ SCAN_HR   ]

; - BATTERY VOLTAGE

5:  Batt Voltage (P10)
 1: 5        Loc [ VBAT      ]

; Reference Thermocouple

6:  Temp (107) (P11)
 1: 1        Reps
 2: 1        SE Channel
 3: 3        Excite all reps w/E3
 4: 6        Loc [ TREF_C    ]
 5: 1.0      Mult
 6: 0.0      Offset

; Gas Flow to Engine
; NEED MULTIPLIER

7:  Pulse (P3)
 1: 1        Reps
 2: 1        Pulse Channel 1
 3: 2        Switch Closure, All Counts
 4: 7        Loc [ FG        ]
 5: 1.0      Mult
 6: 0.0      Offset

; Power Export from Furnace
; Wattnode WNB-3Y-208-P
; NEED MULTIPLER

8:  Pulse (P3)
 1: 1        Reps
 2: 2        Pulse Channel 2
 3: 2        Switch Closure, All Counts
 4: 8        Loc [ WE        ]
 5: 0.00075  Mult
 6: 0.0      Offset

9:  Thermocouple Temp (SE) (P13)
 1: 3        Reps
 2: 22       7.5 mV 60 Hz Rejection Range
 3: 6        SE Channel
 4: 1        Type T (Copper-Constantan)
 5: 6        Ref Temp (Deg. C) Loc [ TREF_C    ]
 6: 11       Loc [ TAS       ]
```

```
 7: 1.8      Mult
 8: 32       Offset

; Status Sensors
;   C1 - Supply Fan
;   C2 - Generator Module Status


10:  Set Port(s) (P20)
 1: 8800     C8..C5 = input/input/low/low
 2: 0088     C4..C1 = low/low/input/input

11:  Read Ports (P25)
 1: 1        Mask (0..255)
 2: 14       Loc [ SF_ST     ]

12:  Read Ports (P25)
 1: 2        Mask (0..255)
 2: 15       Loc [ SE_ST     ]

; WTI, WTO
; Wattnode WNB-3Y-208-P
; NEED MULTIPLIER

13:  Pulse (P3)
 1: 2        Reps
 2: 7        Control Port 7 (switch closure only)
 3: 2        Switch Closure, All Counts
 4: 9        Loc [ WTI       ]
 5: 0.0025   Mult
 6: 0.0      Offset

14:  Beginning of Loop (P87)
 1: 0        Delay
 2: 2        Loop Count

     15:  If (X<=>F) (P89)
      1: 14    -- X Loc [ SF_ST     ]
      2: 2        <>
      3: 0.0      F
      4: 30       Then Do

          16:  Z=X (P31)
           1: 3        X Loc [ SCAN_MIN  ]
           2: 16    -- Z Loc [ SF_MIN    ]

     17:  Else (P94)

          18:  Z=F x 10^n (P30)
           1: 0.0      F
           2: 00       n, Exponent of 10
           3: 16    -- Z Loc [ SF_MIN    ]

     19:  End (P95)

20:  End (P95)

; Accumulator Logic

21:  If Flag/Port (P91)
 1: 12       Do if Flag 2 is High
 2: 30       Then Do

     22:  Z=X+Y (P33)
      1: 22       X Loc [ HR_ACC    ]
      2: 4        Y Loc [ SCAN_HR   ]
      3: 22       Z Loc [ HR_ACC    ]

     23:  Beginning of Loop (P87)
      1: 0        Delay
      2: 4        Loop Count

          24:  Z=X+Y (P33)
           1: 18    -- X Loc [ FG_ACC    ]
           2: 7     -- Y Loc [ FG        ]
           3: 18    -- Z Loc [ FG_ACC    ]

          25:  Z=X/Y (P38)
           1: 18    -- X Loc [ FG_ACC    ]
           2: 22       Y Loc [ HR_ACC    ]
           3: 23    -- Z Loc [ FG_CFH    ]

     26:  End (P95)

27:  Else (P94)

     28:  Beginning of Loop (P87)
      1: 0000     Delay
      2: 9        Loop Count

          29:  Z=F x 10^n (P30)
           1: 0.0      F
           2: 00       n, Exponent of 10
           3: 18    -- Z Loc [ FG_ACC    ]
```

```
     30:  End (P95)

31:  End (P95)

32:  Do (P86)
 1: 1        Call Subroutine 1

*Table 2 Program
  02: 0.0000    Execution Interval (seconds)

*Table 3 Subroutines

1:  Beginning of Subroutine (P85)
 1: 1        Subroutine 1

     2:  If time is (P92)
      1: 0        Minutes (Seconds --) into a
      2: 15       Interval (same units as above)
      3: 10       Set Output Flag High (Flag 0)

     3:  Z=F x 10^n (P30)
      1: 0.0      F
      2: 00       n, Exponent of 10
      3: 28       Z Loc [ ID        ]

     4:  Sample (P70)
      1: 1        Reps
      2: 28       Loc [ ID        ]

     5:  Real Time (P77)
      1: 1111     Year,Day,Hour/Minute,Seconds (midnight = 0000)

     6:  Resolution (P78)
      1: 1        High Resolution

     7:  Average (P71)
      1: 3        Reps
      2: 11       Loc [ TAS       ]

     8:  Totalize (P72)
      1: 2        Reps
      2: 16       Loc [ SF_MIN    ]

     9:  Totalize (P72)
      1: 4        Reps
      2: 7        Loc [ FG

     10:  Average (P71)
      1: 2        Reps
      2: 5        Loc [ VBAT      ]

     11:  Do (P86)
      1: 20       Set Output Flag Low (Flag 0)

12:  End (P95)

End Program

1      [ SIXTY     ]  RW--   2       1      ----- ------ ---
2      [ SCAN_SEC  ]  RW--   1       1      ----- ------ ---
3      [ SCAN_MIN  ]  RW--   2       1      ----- ------ ---
4      [ SCAN_HR   ]  RW--   1       1      ----- ------ ---
5      [ VBAT      ]  RW--   1       1      ----- ------ ---
6      [ TREF_C    ]  RW--   2       1      ----- ------ ---
7      [ FG        ]  RW--   2       1      Start ------ ---
8      [ WE        ]  RW--   1       1      ----- ------ ---
9      [ WTI       ]  RW--   1       1      Start ------ ---
10     [ WTO       ]  RW--   1       1      ----- ------ ---
11     [ TAS       ]  RW--   1       1      Start ------ ---
12     [ TAR       ]  RW--   1       1      ----- Member ---
13     [ TWS       ]  RW--   1       1      ----- ------ End
14     [ SF_ST     ]  ----   0       0      ----- ------ ---
15     [ SE_ST     ]  ----   0       0      ----- ------ ---
16     [ SF_MIN    ]  RW--   1       1      Start ------ ---
17     [ SE_MIN    ]  R---   1       0      ----- ------ End
18     [ FG_ACC    ]  -W--   0       2      ----- ------ ---
19     [ WE_ACC    ]  ----   0       0      ----- ------ ---
20     [ WTI_ACC   ]  ----   0       0      ----- ------ ---
21     [ WTO_ACC   ]  ----   0       0      ----- ------ ---
22     [ HR_ACC    ]  RW--   2       1      ----- ------ ---
23     [ FG_CFH    ]  -W--   0       1      ----- ------ ---
24     [ WE_KW     ]  ----   0       0      ----- ------ ---
25     [ WTI_KW    ]  ----   0       0      ----- ------ ---
26     [ WTO_KW    ]  ----   0       0      ----- ------ ---
27     [ _________ ]  ----   0       0      ----- ------ ---
28     [ ID        ]  RW--   1       1      ----- ------ ---
29     [ _________ ]  ----   0       0      ----- ------ ---
30     [ _________ ]  ----   0       0      ----- ------ ---
31     [ _________ ]  ----   0       0      ----- ------ ---
```

Appendix B
Comparing Freewatt Operation in the 2009-10 and 2010-11 Heating Seasons

The gas consumption of the Freewatt unit changed considerably between the two heating seasons as shown by Figure B-1 (which is the same as Figure 3 in the main report). However, the data imply the change is most-likely due to a reduction in the heating load for the building as opposed to a change in Freewatt performance.

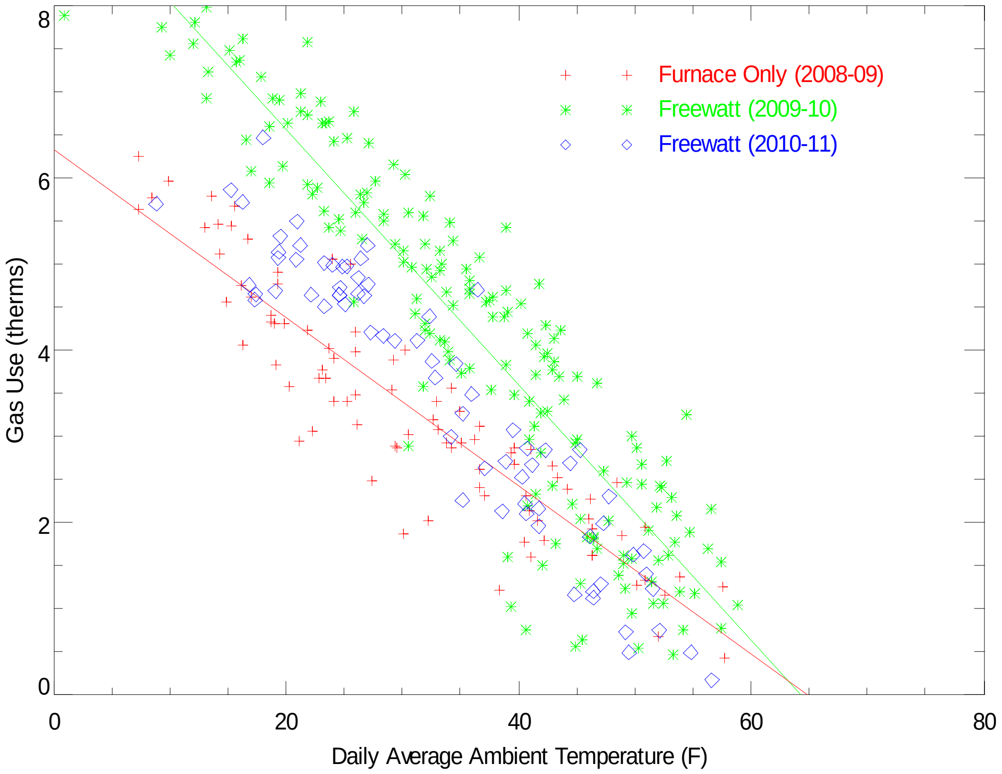


Figure B-1. Comparing Gas Use Trend for Three Different Heating Seasons

Figure B-2, B-3 and B-4 compare the return temperature, supply temperature, and air-side temperature rise (Supply-Return) for the three seasons. These plots confirm that the operating conditions in the house (i.e., the return temperature) were essentially unchanged between the two Freewatt heating seasons. Similarly, the temperature rise across the entire unit (the furnace and hot water coil combined) was the same in both periods, confirming that the heating capacity provided by the unit was unchanged.

Figure B-5 compares the Freewatt electrical efficiency between the two heating seasons. Only the maximum values on the plot have meaning (these maximum values occur when the furnace component is off). The trend for the maximum values are the same in both cases, implying that the unit electrical efficiency is the same in both periods. In the 2010-11 season the system ran with only the hot water coil (without the furnance) down to lower outdoor air temperature. This implies that the heating load on the building was lower in the second season.

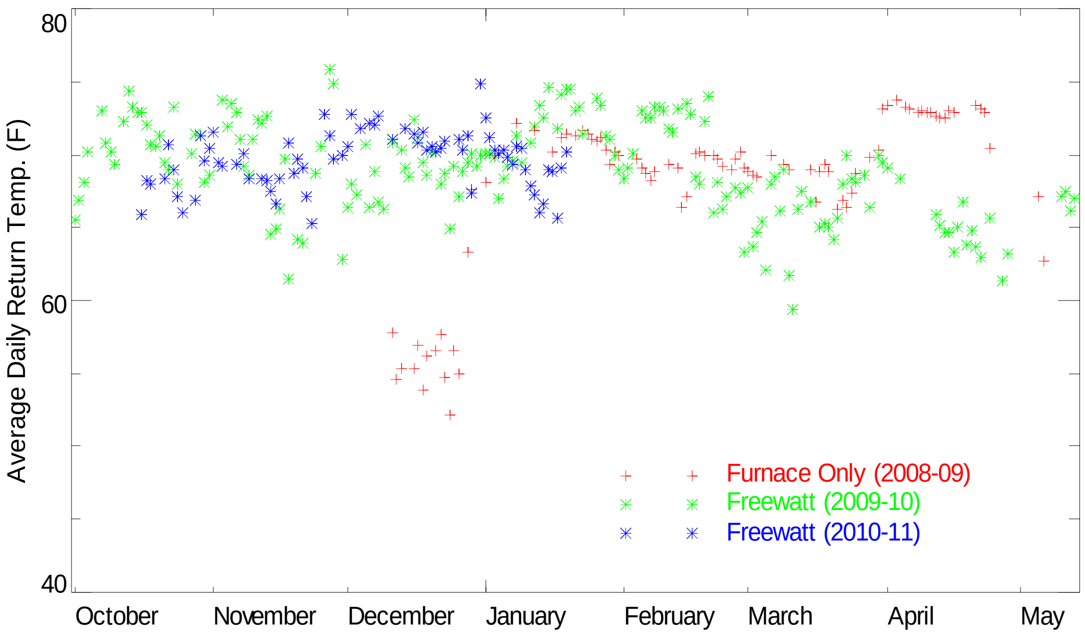


Figure B-2. Comparing Return Air Temperatures for the Three Heating Seasons

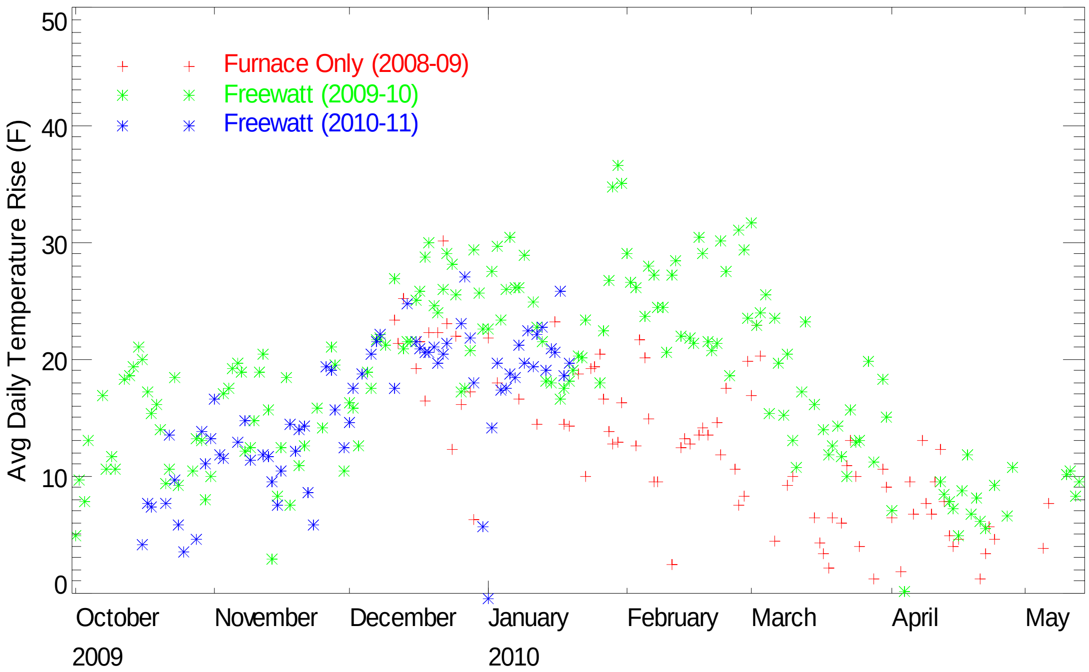


Figure B-3. Comparing Supply Air Temperatures for the Three Heating Seasons

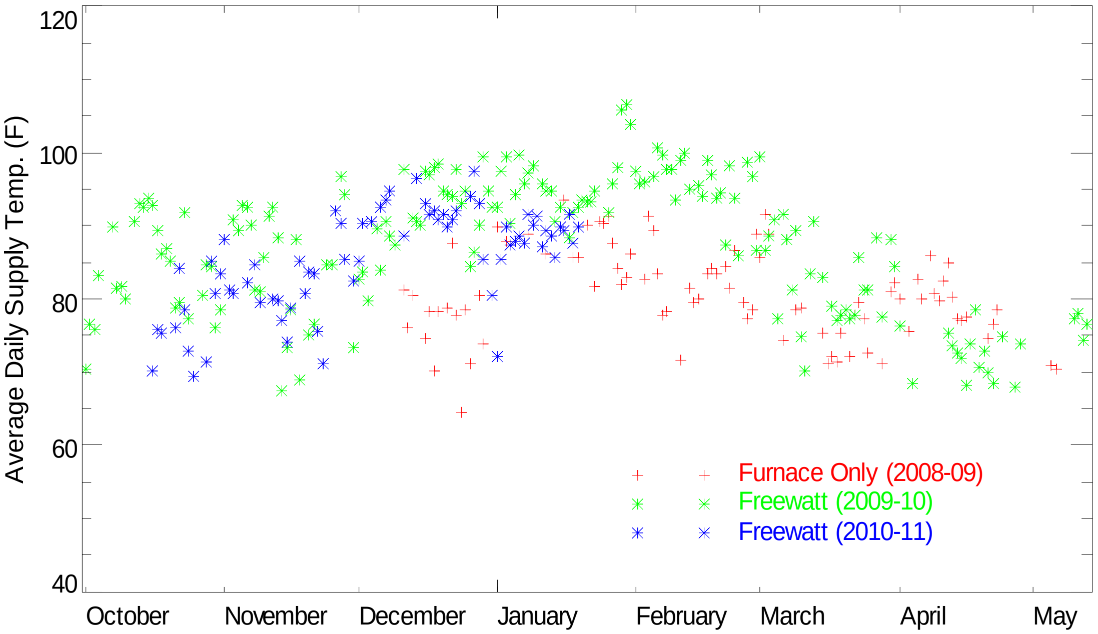


Figure B-4. Comparing Supply Air Temperatures for the Three Heating Seasons

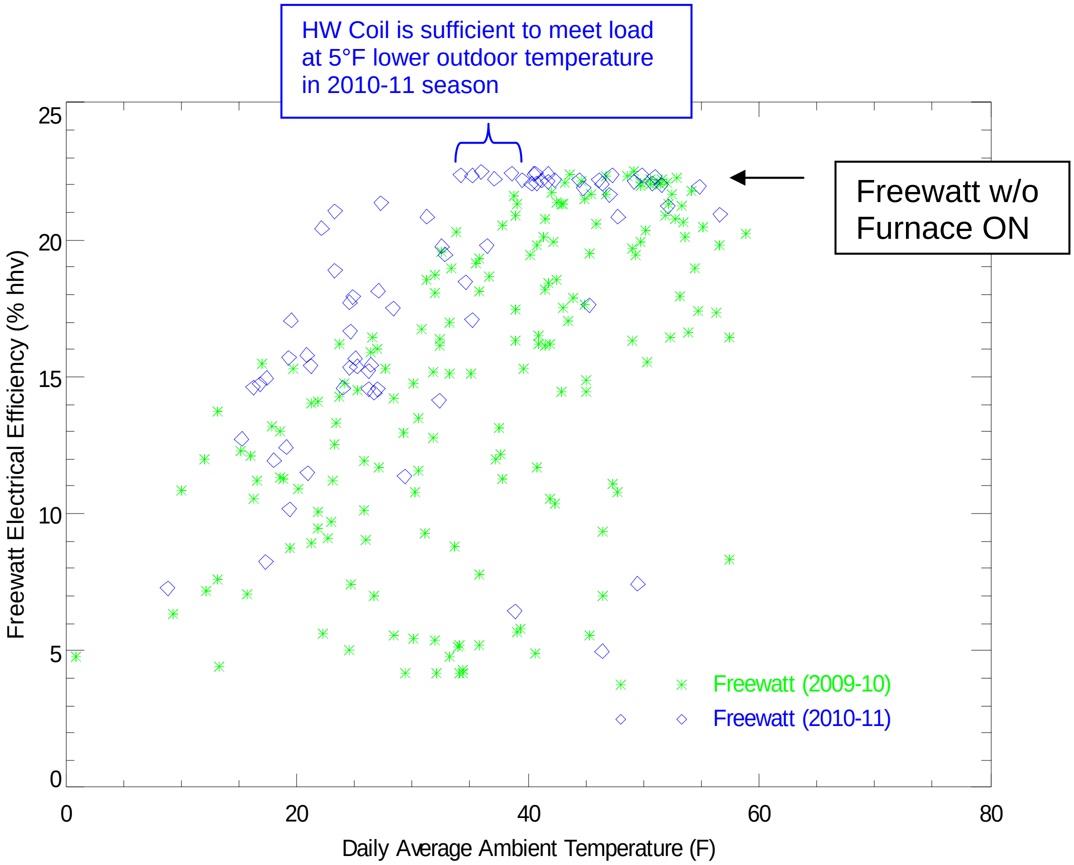


Figure B-5. Comparing Efficiency Trend for 2009-10 and 2010-11 Heating Seasons