Borrego Springs Field Test Summary

Clarum Homes
Borrego Springs, CA
Test Dates: May 16-21, August 2-9, 2006

Table of Contents

List of Tables

Table of Figures

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Introduction

The goal of the Building America Program is to develop innovative system engineering approaches to advanced housing that will enable the U.S. housing industry to deliver affordable and environmentally sensitive housing while maintaining profitability and competitiveness of homebuilders and product suppliers in domestic and overseas markets. For innovative building energy technologies to be viable candidates over conventional approaches, it must be demonstrated that they can cost-effectively increase overall product value and quality while significantly reducing energy use and use of raw materials when used in community scale developments. To make this determination, an extensive program is necessary to develop; test and design advanced building energy systems for all major U. S. climate zones in conjunction with material suppliers, equipment manufacturers, developers, builders, designers, and state and local stakeholders. This program applies system research approaches to the development of advanced energy efficient residential buildings using system performance studies in test houses, pre-production houses, and community scale developments. The final products of each research project shall be performance measurements and cost/performance evaluations in prototype houses, pre-production homes, and community-scale developments. These measurements and evaluations shall lead to development of innovative system concepts that can be applied on a production basis by the industry partners and stakeholders involved in the program.

Test Objectives

The general objective of performance testing in the Building America Program is to support the systems engineering process by providing rapid feedback on building performance for integration of systems innovations into production housing.

The objective of this short-term test is to quantify the performance of the Borrego Springs prototype homes with respect to the Building America Benchmark as well as verification of design intent. The primary items of interest relate to the performance of the wall construction systems and the cooling systems in each home.

Test House Descriptions

The prototype homes were nearly completed in May of 2006 by Clarum Homes when long term monitoring systems were installed and data collection was initiated to track the performance of each home. The four prototypes are referred to according to the adjacent street name, East Star, Wagon, Broken Arrow and DiGiorgio.

Wagon (Lot 96) – High Mass House with Advanced Evaporative Cooling

Walls of this house are constructed using the Dow “T-Mass” product, a pre-cast concrete -foam-concrete sandwich. A radiant floor system using DEG’s “Rapid-Radiant” system, which includes tubing preattached to concrete reinforcing mesh, will provide heating. The heat source is a plate heat exchanger connected to a tankless water heater. The tankless water heater also provides domestic hot water on a priority basis. Cooling is supplied by two systems. An OASys two-stage advanced evaporative cooler will operate during the dry season to provide efficient (~EER 40) cooling. During the monsoon season the owners can switch to a vapor compression system which chills water that flows first through a fan coil to provide dehumidification, and then through the same floor tubing that is used for heating. This design eliminates most of the ducting since the OASys supplies cooled outside air from a single point that flows out of the house through barometric dampers, and the radiant floor system provides distribution during the monsoon season. Ducting for the chilled water fan coil is limited to the kitchen and living area, and is in conditioned space. Figure 1 shows the Wagon home as built.

Figure 1 Wagon Prototype, Completed

Figure 2 shows the monitoring and mechanical system schematic for the Wagon prototype as provided by DEG.

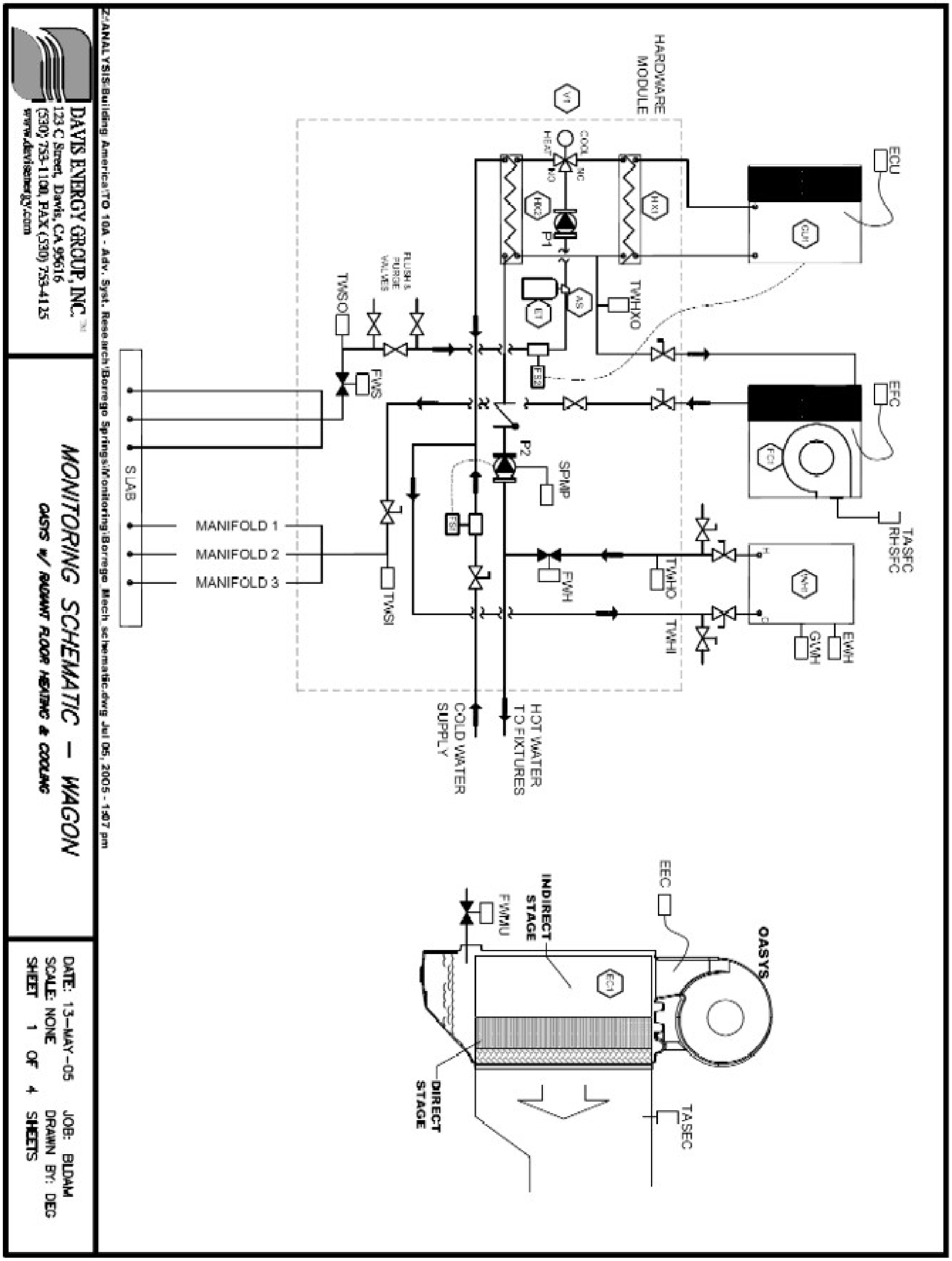

Figure 2 Monitoring and Mechanical Schematic for Wagon

The figure above only shows the monitoring system as relates to the mechanical system for the Wagon home, a complete list of long term monitoring points for the Wagon home is shown in Table 1.

Table 1 Wagon Monitoring Points

Point	Label	Description	Location
1	TAK	Kitchen air temperature	Kitchen

2	RHK	Kitchen air RH	Kitchen
3	TAMB	Master bedroom air temperature	Master bedroom
4	RHMB	Master bedroom RH	Master bedroom
5	TAAT	Attic Air Temperature	Attic
6	TSRF	Roof Underside Surface Temperature	Under surface of roof in Attic (attic access)
7	TASEC	Evaporative cooler supply air temperature	Evaporative cooler
8	TASFC	Fancoil supply air temperature	Fancoil
9	RHSFC	Fancoil supply RH	Plenum
10	TWHI	Water heater entering temperature	Hardware module
11	TWHO	Water heater exiting water temperature	Hardware module
12	TWSI	Slab entering water temperature	Hardware module
13	TWSO	Slab exiting water temperature	Hardware module
14	TWHXO	Heat exchanger exiting water temperature	Hardware module
15	FWH	Hot water flow rate	Hardware module
16	FWS	System water flow rate	Hardware module
17	FWMU	Evaporative cooler makeup water volume	Evaporative cooler
18	FAEC	Evaporative Cooler Air Flow	Evaporative cooler supply duct
19	SPMP	Pump status	Hardware module
20	GWH	Water heater gas use	Water heater
21	EAC	Condensing unit energy use	Condensing unit disconnect or breaker panel
22	EEC	Evaporative cooler energy use	EC disconnect or breaker panel
23	EECfan	Evaporative Cooler Fan	OASys Unit
24	EECpmp	Evaporative Cooler Pump	OASys Unit
25	EFC	Fancoil energy use	Fancoil
26	EWH	Water Heater energy use	Water heater
27	EHS1	Total house energy use (positive)	Main service panel
28	EHS2	Total house energy use (negative)	Main service panel
29	EPV1	Photovoltaic energy delivered	Main service or PV Inverter at Garage
30	EPV2	Photovoltaic energy delivered	Main service or PV Inverter at Garage
31	INSOL1	Incident Insolation	Next to PV array incident to roof slope
32	INSOL2	Incident Insolation	Next to PV array incident to roof slope
33	TFC1	Slab surface - Center of Room	Living Room - Center of Room
34	TFC2	Under Slab - Center of Room	Living Room - Center of Room
35	TFC3	12" Below Slab - Center of Room	Living Room - Center of Room
36	TFC4	36" Below Slab - Center of Room	Living Room - Center of Room
37	TFM1	Slab surface - Middle	Living Rm - Midway between Center and Edge
38	TFM2	Under Slab - Middle	Living Rm - Midway between Center and Edge
39	TFM3	12" Below Slab - Middle	Living Rm - Midway between Center and Edge
40	TFM4	36" Below Slab - Middle	Living Rm - Midway between Center and Edge
41	TFE1	Slab surface - Edge of Slab	Living Room - Exterior Edge of Slab
42	TFE2	Under Slab - Edge of Slab	Living Room - Exterior Edge of Slab
43	TFE3	12" Below Slab - Edge of Slab	Living Room - Exterior Edge of Slab
44	TFE4	36" Below Slab - Edge of Slab	Living Room - Exterior Edge of Slab
45	TGND	Outside - 3 feet below grade	Outside Ground
46	TWI1	Internal Surface - Location 1	Northeast facing wall
47	TWINI1	Internal Insulation - Location 1	Northeast facing wall
48	TWINE1	External Insulation - Location 1	Northeast facing wall
49	TWE1	External Surface - Location 1	Northeast facing wall
50	TWI2	Internal Surface - Location 2	Southwest facing wall
51	TWINI2	Internal Insulation - Location 2	Southwest facing wall
52	TWINE2	External Insulation - Location 2	Southwest facing wall
53	TWE2	External Surface - Location 2	Southwest facing wall

Broken Arrow (Lot 73) – OASys w/ Conventional Ducted AC

The Broken Arrow house is constructed using SIP panels for exterior walls. It will employ a similar system as used for the Wagon house including radiant heating and evaporative cooling using the OASys system. However, cooling (and dehumidification) during monsoon conditions will be provided from a conventional ducted forced air system, with ducts in conditioned space. The floor will not be used for cooling. Figure 3 shows the Broken Arrow home during the construction phase.

Figure 3 Broken Arrow Prototype Under Construction

Figure 4 shows the monitoring and mechanical system schematic for the Broken Arrow prototype as provided by DEG.

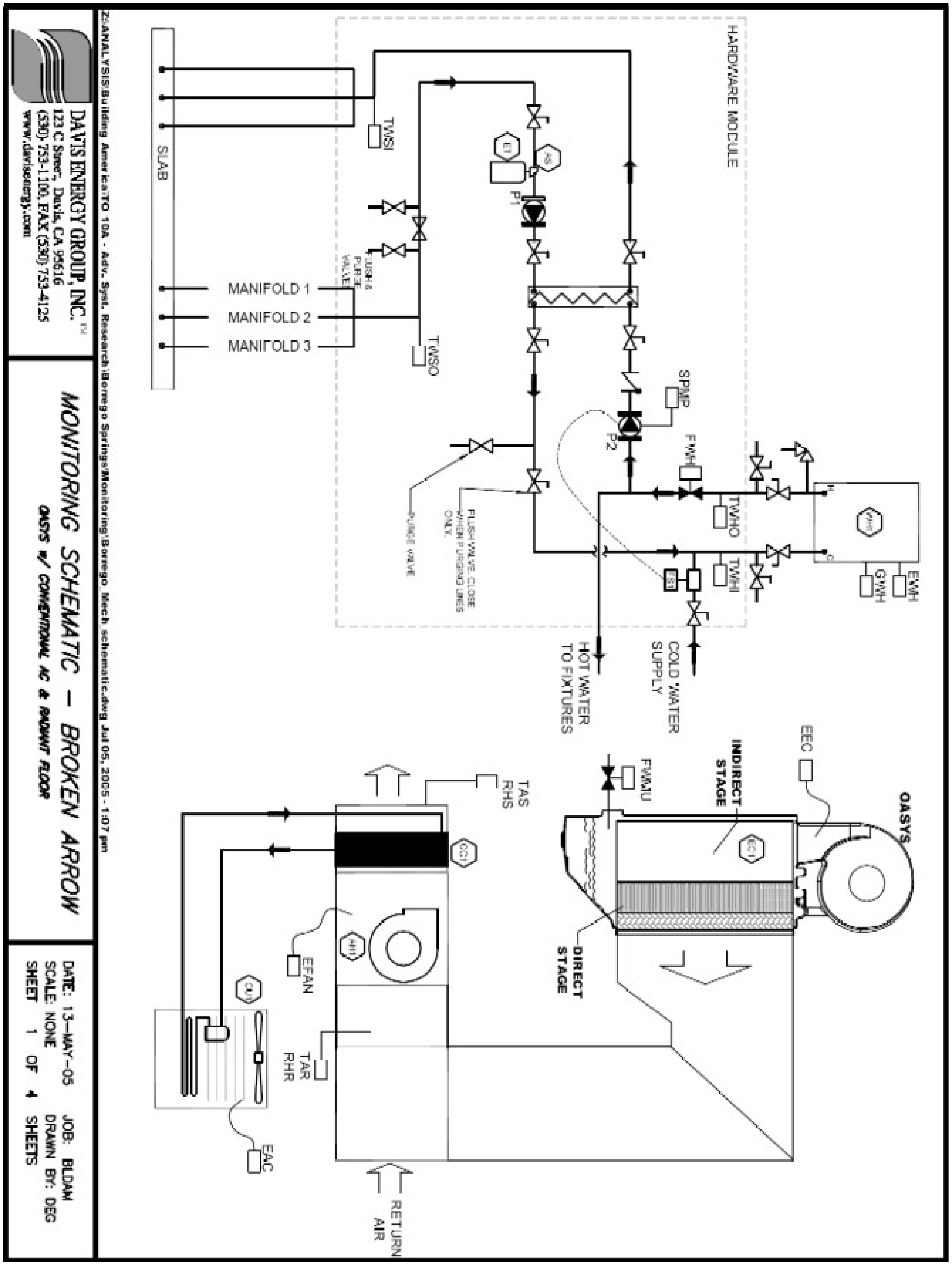

Figure 4 Monitoring and Mechanical Schematic for Broken Arrow Prototype

The figure above only shows the monitoring system as relates to the mechanical system for the Broken Arrow home, a complete list of long term monitoring points for the Broken Arrow home is shown in Table 2.

Table 2 Monitoring Points for Broken Arrow Prototype

Point	Label	Description	Location

1	TAK	Kitchen air temperature	Kitchen
2	RHK	Kitchen air RH	Kitchen
3	TAMB	Master bedroom air temperature	Master bedroom
4	RHMB	Master bedroom RH	Master bedroom
5	TAAT	Attic Air Temperature	Attic
6	TSRF	Roof Underside Surface Temperature	Under surface of roof in Attic
7	TASAH	Supply Air Temperature	Air Handler Supply
8	RHSAH	Supply Air RH	Air Handler Supply
9	TAR	Return air temperature	Air Handler Return
10	RHR	Return air RH	Air Handler Return
11	TWHI	Water heater entering temperature	Hardware module
12	TWHO	Water heater exiting water temperature	Hardware module
13	TWSI	Slab entering water temperature	Hardware module
14	TWSO	Slab exiting water temperature	Hardware module
15	FWH	Hot water flow rate	Hardware module
16	FWMU	Evaporative cooler makeup water volume	Evaporative cooler
17	SPMP	Pump status	Hardware module
18	GWH	Water heater gas use	Water heater
19	EAC	Condensing unit energy use	Condensing unit disconnect or breaker panel
20	EEC	Evaporative cooler energy use	EC disconnect or breaker panel
21	EFAN	Air handler energy use	Air Handler
22	EWH	Water Heater energy use	Water heater
23	EHS1	Total house energy use (positive)	Main service panel
24	EHS2	Total house energy use (negative)	Main service panel
25	EPV1	Photovoltaic energy delivered	Main service or PV Inverter at Garage
26	EPV2	Photovoltaic energy delivered	Main service or PV Inverter at Garage
27	INSOL1	Incident Insolation	Next to PV array incident to roof slope
28	INSOL2	Incident Insolation	Next to PV array incident to roof slope
29	TFC1	Slab surface - Center of Room	Living Room - Center of Room
30	TFC2	Under Slab - Center of Room	Living Room - Center of Room
31	TFC3	12" Below Slab - Center of Room	Living Room - Center of Room
32	TFC4	36" Below Slab - Center of Room	Living Room - Center of Room
33	TFM1	Slab surface - Middle	Living Rm - Midway between Center and Edge
34	TFM2	Under Slab - Middle	Living Rm - Midway between Center and Edge
35	TFM3	12" Below Slab - Middle	Living Rm - Midway between Center and Edge
36	TFM4	36" Below Slab - Middle	Living Rm - Midway between Center and Edge
37	TFE1	Slab surface - Edge of Slab	Living Room - Exterior Edge of Slab
38	TFE2	Under Slab - Edge of Slab	Living Room - Exterior Edge of Slab
39	TFE3	12" Below Slab - Edge of Slab	Living Room - Exterior Edge of Slab
40	TFE4	36" Below Slab - Edge of Slab	Living Room - Exterior Edge of Slab
41	TGND	Outside - 3 feet below grade	Outside Ground
42	TWI1	Internal Surface - Location 1	Northeast facing wall
43	TWE1	External Surface - Location 1	Northeast facing wall
44	TWI2	Internal Surface - Location 2	Southwest facing wall
45	TWE2	External Surface - Location 2	Southwest facing wall

DiGiorgio (Lot APN #140-070-03)

The DiGiorgio house will use the same T-Mass wall system as the Wagon house. This house will include a fully ducted (inside conditioned space) heating and cooling system that uses a NightBreeze integrated system to provide combined hydronic heating, forced air cooling, ventilation cooling, and fresh air ventilation. The tankless water heater will be used as a heat source, and a Freus evaporative condenser will provide cooling via a direct expansion evaporator coil. To reduce cooling loads, the Freus fan and pump will be operated at night during summer and transition seasons to produce cool water that will be piped through coils in the slab floor. This use of the Freus as a cooling tower will be disabled whenever vapor compression cooling is needed. The floor tubing will not be used for heating. Figure 5 shows the DiGiorgio home as built.

Figure 5 DiGiorgio Home, Completed

Figure 6 shows the monitoring and mechanical system schematic for the DiGiorgio prototype as provided by DEG.

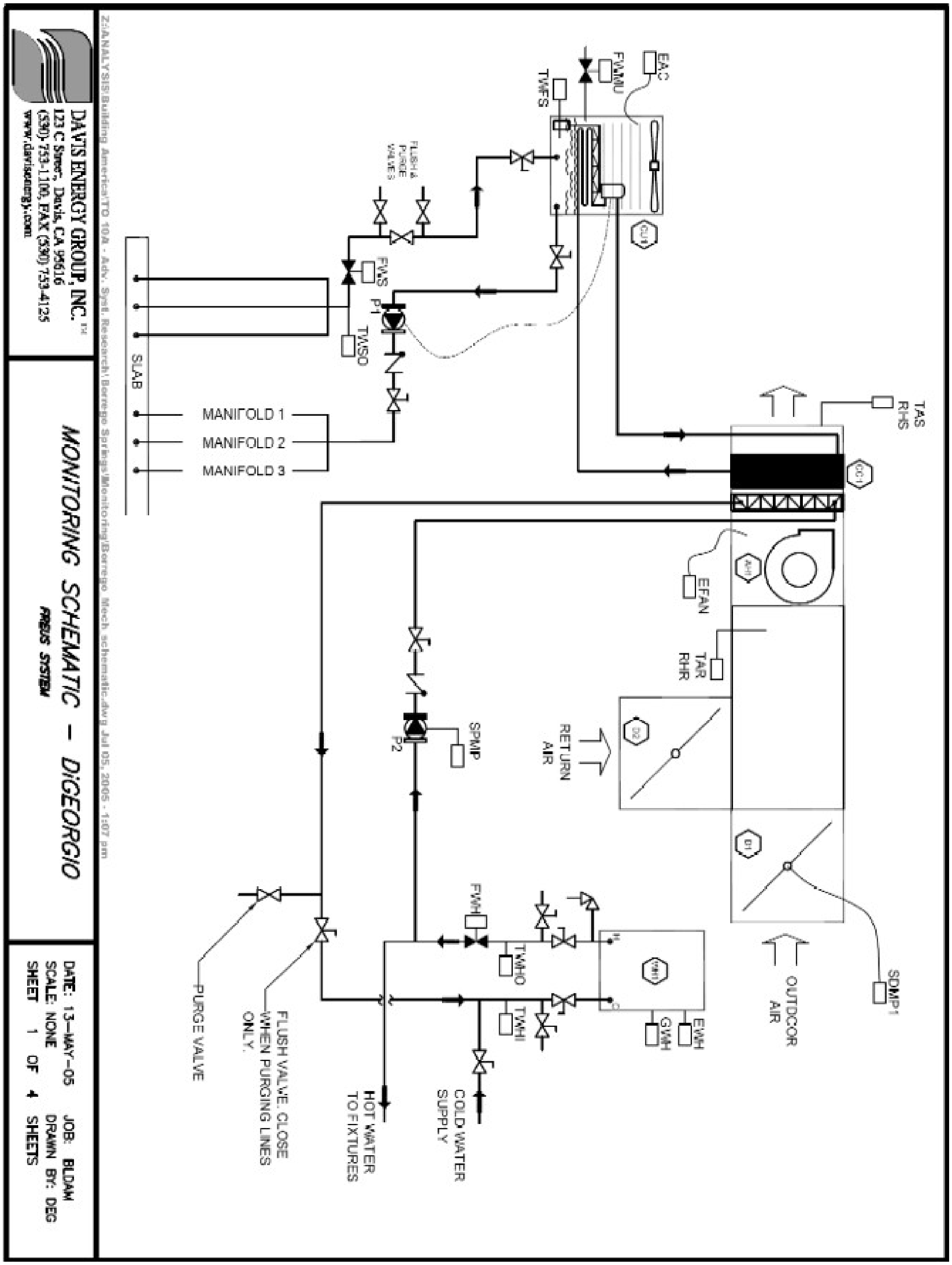

Figure 6 Monitoring and Mechanical Schematic for the DiGiorgio Prototype

The figure above only shows the monitoring system as relates to the mechanical system for the DiGiorgio home, a complete list of long term monitoring points for the Digiorgio home is shown in Table 3. As a result of NREL's involvement in this project, additional monitoring equipment was installed at the DiGiorgio home to evaluate the performance of the Freus evaporatively cooled condensing unit, details of the additional monitoring equipment are contained within NREL TP-39342 (Kutscher et al, 2006).

Table 3 Monitoring Points for the DiGiorgio Prototype

Point	Label	Description	Location
1	TAK	Kitchen air temperature	Kitchen
2	RHK	Kitchen air RH	Kitchen
3	TAMB	Master bedroom air temperature	Master bedroom
4	RHMB	Master bedroom RH	Master bedroom
5	TAAT	Attic Air Temperature	Attic
6	TSRF	Roof Underside Surface Temperature	Under surface of roof in Attic
15	TWFS	Freus Sump Water temperature	Freus Sump
16	TWSO	Slab exiting water temperature	Hardware Module-Floor Return Manifold
17	TWHI	Water heater entering temperature	Hardware Module-Water heater
18	TWHO	Water heater exiting water temperature	Hardware Module-Water heater
19	FWH	Hot water flow rate	Hardware Module-Water heater
20	FWS	Slab water flow rate	Hardware Module-Floor Return Manifold
23	SPMP	Pump status	Hardware module
25	GWH	Water heater gas use	Water heater
30	EWH	Water Heater energy use	Hardware Module-Water heater
31	EHS1	Total house energy use (positive)	Main service panel
32	EHS2	Total house energy use (negative)	Main service panel
33	EPV1	Photovoltaic energy delivered	Main service or PV Inverter at Garage
34	EPV2	Photovoltaic energy delivered	Main service or PV Inverter at Garage
35	INSOL1	Incident Insolation	Next to PV array incident to roof slope
36	INSOL2	Incident Insolation	Next to PV array incident to roof slope
37	TFC1	Slab surface - Center of Room	Living Room - Center of Room
38	TFC2	Under Slab - Center of Room	Living Room - Center of Room
39	TFC3	12" Below Slab - Center of Room	Living Room - Center of Room
40	TFC4	36" Below Slab - Center of Room	Living Room - Center of Room
41	TFM1	Slab surface - Middle	Living Rm - Midway between Center and Edge
42	TFM2	Under Slab - Middle	Living Rm - Midway between Center and Edge
43	TFM3	12" Below Slab - Middle	Living Rm - Midway between Center and Edge
44	TFM4	36" Below Slab - Middle	Living Rm - Midway between Center and Edge
45	TFE1	Slab surface - Edge of Slab	Living Room - Exterior Edge of Slab
46	TFE2	Under Slab - Edge of Slab	Living Room - Exterior Edge of Slab
47	TFE3	12" Below Slab - Edge of Slab	Living Room - Exterior Edge of Slab
48	TFE4	36" Below Slab - Edge of Slab	Living Room - Exterior Edge of Slab
49	TGND	Outside - 3 feet below grade	Outside Ground
50	TWI1	Internal Surface - Location 1	Northeast facing wall
51	TWINI1	Internal Insulation - Location 1	Northeast facing wall
52	TWINE1	External Insulation - Location 1	Northeast facing wall
53	TWE1	External Surface - Location 1	Northeast facing wall
54	TWI2	Internal Surface - Location 2	Southwest facing wall
55	TWINI2	Internal Insulation - Location 2	Southwest facing wall
56	TWINE2	External Insulation - Location 2	Southwest facing wall
57	TWE2	External Surface - Location 2	Southwest facing wall

East Star (Lot 322)

The EastStar house is the only one of the four that will use standard frame wall construction. For heating, a dedicated tankless water heater will deliver warm water to the radiant floor tubing and a second tankless water heater will supply domestic hot water. Cooling will be provided from a fully ducted Lennox AM61V-31B—070 variable speed air handler with a direct-expansion evaporator coil connected to a Lennox XC21 21 SEER condensing unit. All ducts are in conditioned space. No evaporative cooling will be employed at this house. Figure 7 shows the East Star home as built.

Figure 7 East Star Prototype Completed

Figure 8 shows the monitoring and mechanical system schematic for the East Star prototype as provided by DEG.

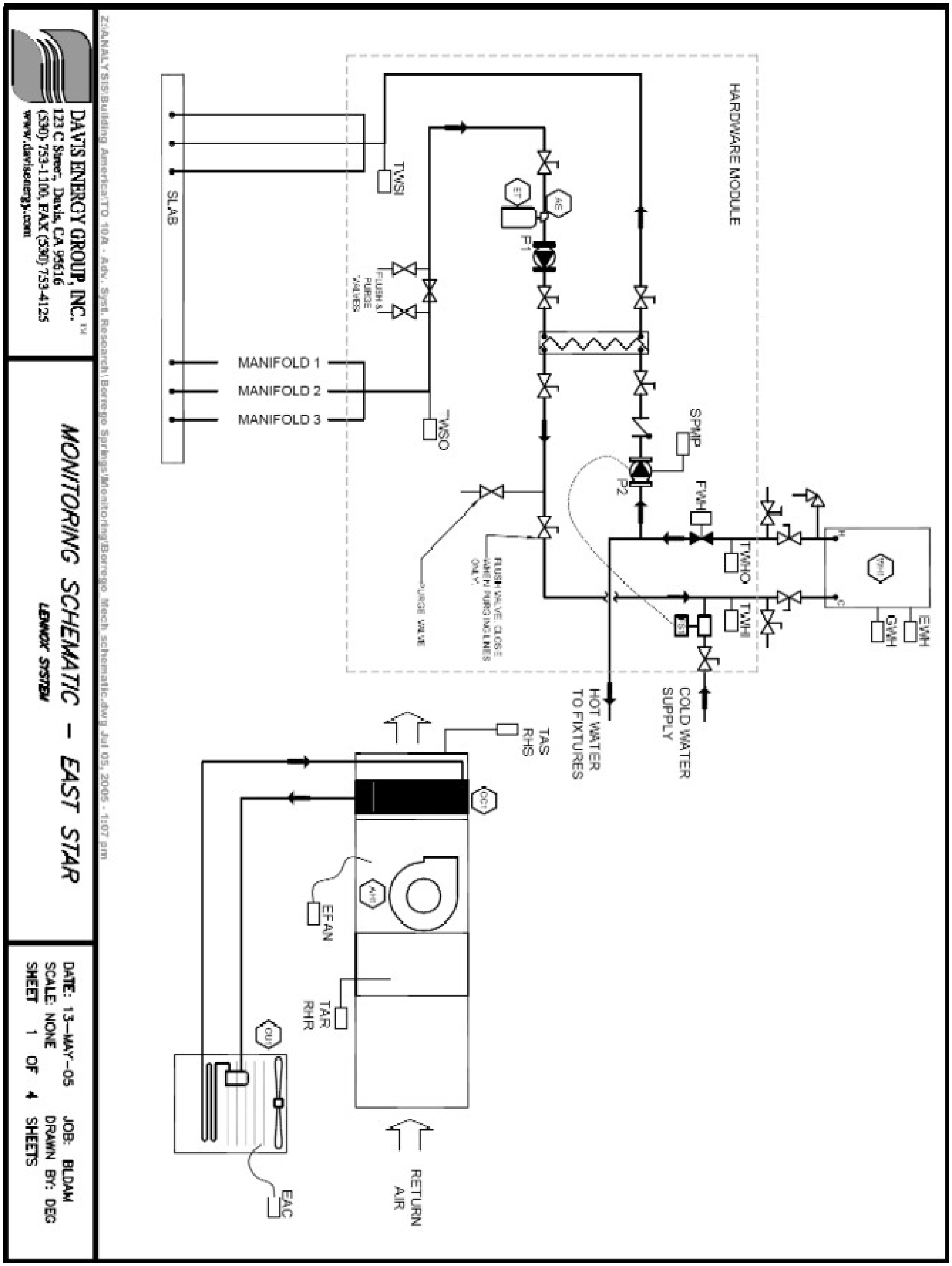

Figure 8 Monitoring and Mechanical Schematic for East Star Prototype

The figure above only shows the monitoring system as relates to the mechanical system for the East Star home, a complete list of long term monitoring points for the East Star home is shown in Table 4.

Table 4 Monitoring Points for East Star Prototype

Point	Label	Description	Location

1	TAK	Kitchen air temperature	Kitchen
2	RHK	Kitchen air RH	Kitchen
3	TAMB	Master bedroom air temperature	Master bedroom
4	RHMB	Master bedroom RH	Master bedroom
5	TAAT	Attic Air Temperature	Attic
6	TSRF	Roof Underside Surface Temperature	Under surface of roof in Attic
7	TAS	Supply air temperature	Air Handler Supply
8	RHS	Supply Air RH	Air Handler Supply
9	TAR	Return air temperature	Air Handler Return
10	RHR	Return air RH	Air Handler Return
11	TWHI	Water heater entering temperature	Hardware module
12	TWHO	Water heater exiting water temperature	Hardware module
13	TWSI	Slab entering water temperature	Hardware module
14	TWSO	Slab exiting water temperature	Hardware module
15	FWH	Hot water flow rate	Hardware module
16	SPMP	Pump status	Hardware module
17	GWH	Water heater gas use	Water heater
18	EAC	Condensing unit energy use	Condensing unit disconnect or breaker panel
19	EFAN	Airhandler Fan Energy Use	Lennox Air Handler
20	EWH	Water Heater energy use	Water heater
21	EHS1	Total house energy use (positive)	Main service panel
22	EHS2	Total house energy use (negative)	Main service panel
23	EPV1	Photovoltaic energy delivered	Main service or PV Inverter at Garage
24	EPV2	Photovoltaic energy delivered	Main service or PV Inverter at Garage
25	INSOL1	Incident Insolation	Next to PV array incident to roof slope
26	INSOL2	Incident Insolation	Next to PV array incident to roof slope
27	INSOLH	Horizontal Insolation	Weather Tower on roof
28	WSPD	Wind Speed	Weather Tower on roof
29	WDIR	Wind Direction	Weather Tower on roof
30	TAO	Outside Air Dry Temperature	Weather Tower on roof
31	RHO	Outside Air RH	Weather Tower on roof
32	TAO2	Outdoor Temp (red.) Naturally aspirated	Weather Tower on roof
33	TAO3	Outdoor Temp (red.) Forced aspiration	Weather Tower on roof
34	TFC1	Slab surface - Center of Room	Living Room - Center of Room
35	TFC2	Under Slab - Center of Room	Living Room - Center of Room
36	TFC3	12" Below Slab - Center of Room	Living Room - Center of Room
37	TFC4	36" Below Slab - Center of Room	Living Room - Center of Room
38	TFM1	Slab surface - Middle	Living Rm - Midway between Center and Edge
39	TFM2	Under Slab - Middle	Living Rm - Midway between Center and Edge
40	TFM3	12" Below Slab - Middle	Living Rm - Midway between Center and Edge
41	TFM4	36" Below Slab - Middle	Living Rm - Midway between Center and Edge
42	TFE1	Slab surface - Edge of Slab	Living Room - Exterior Edge of Slab
43	TFE2	Under Slab - Edge of Slab	Living Room - Exterior Edge of Slab
44	TFE3	12" Below Slab - Edge of Slab	Living Room - Exterior Edge of Slab
45	TFE4	36" Below Slab - Edge of Slab	Living Room - Exterior Edge of Slab
46	TGND	Outside - 3 feet below grade	Outside Ground
47	TWI1	Internal Surface - Location 1	Northeast facing wall
48	TWE1	External Surface - Location 1	Northeast facing wall
49	TWI2	Internal Surface - Location 2	Southwest facing wall
50	TWE2	External Surface - Location 2	Southwest facing wall

Research Questions

The following questions will be addressed by short term and long term testing of each prototype:

Cooling System Testing

- How the cooling systems perform in comparison to manufacturers' performance specifications?
- What are the cooling systems' measured EER and capacity as functions of indoor and outdoor conditions?
- What is the water consumption of the cooling system?
- What is the wet bulb effectiveness of the evaporative systems?
- To what extent is the cooling system capable of maintaining comfortable indoor conditions?

Whole Building Testing

Building leakage and duct leakage

- What is the natural infiltration rate for each home?
- What is the infiltration rate during air handler fan operation?

Dynamic operation testing

- How much time does it take for each of the homes to recover from a thermostat setback condition?
- Are the homes able to shift peak cooling demand?

Normal operation testing

- Do the homes maintain comfortable indoor conditions?
- What is the energy consumption of each home during the week-long test?
- What is the water consumption of each home's cooling system during the week-long test?

Field Test Results

Blower Door Test Results

All estimates of natural infiltration based on blower door results in this section were calculated according to the Simplified Sherman-Grimsrud method (ASHRAE 2001). Table 5 shows the blower door test results for each of the prototypes at Borrego Springs.

Table 5 Borrego Blower Door Test Results

Blower Door Test	Pressure Above Ambient (Pa)	Airflow rate (CFM)
DiGiorgio		
As Built	19	1402
After Sealing	34	1342
East Star		
As Built	18	1427
After Sealing	26	1389
Broken Arrow		
As Built	19	1394
After Sealing	33	1351
Wagon		
As Built	13	1431
After Sealing	38	1288

Unfortunately these homes were found to be very leaky. None of the homes were able to achieve 50 pascals of depressurization.

These homes had a number of custom skylight and window features which were found to be very leaky even after additional caulking was performed to seal the custom copper skylight and window flashing(pictured in figure 9)

Figure 9 Copper Flashed Skylight Typical of Borrego Prototypes

The performance of the homes also suffered due to an air handler location that used these cabinet doors above the kitchen as the “air barrier” between the conditioned space and the attic where the air handler was located in each home with the exception of the Wagon home. Figure 10 shows the typical placement of the air hander in the attic for the Borrego prototypes.


Figure 10 Air Handler Attic Access Cabinet Typical of Borrego Prototypes

This poor placement and air sealing method was not the original design intent but rather how the builder implemented the HVAC installation. Several attempts were made to improve the separation of the air handler space from the rest of the attic in an effort to reduce air leakage, however, the low pitch roof and shallow attic space made completely sealing off the air handler cabinet from the rest of the attic space impossible. Table 6 shows the infiltration estimate for the homes at Borrego Springs after the builder performed addition air sealing on each home.

Table 6 Natural Infiltration Estimates for Borrego Springs Homes.

Model Inputs				DiGiorgio	East Star	Broken Arrow	Wagon	Benchmark
Month	Amb. Temp (°F)	Indoor Temp. (°F)	Wind Speed (mph)	ACH After Sealing	ACH After Sealing	ACH After Sealing	ACH After Sealing	ACH Benchmark
Jan	56	72	5.4	0.25	0.31	0.26	0.22	0.42
Feb	60	72	6.0	0.26	0.33	0.27	0.24	0.42
Mar	63	72	6.8	0.28	0.34	0.29	0.25	0.45
Apr	68	72	7.1	0.27	0.34	0.28	0.24	0.44
May	76	72	7.2	0.28	0.34	0.28	0.25	0.44
Jun	85	72	7.0	0.30	0.37	0.31	0.27	0.48
Jul	91	72	6.8	0.31	0.38	0.32	0.28	0.50
Aug	90	72	6.7	0.31	0.38	0.31	0.27	0.49
Sep	84	72	6.4	0.28	0.34	0.29	0.25	0.44
Oct	75	72	5.7	0.22	0.27	0.23	0.20	0.36
Nov	64	72	5.3	0.23	0.28	0.24	0.20	0.37

Dec	56	72	5.1	0.25	0.31	0.26	0.22	0.40
Annual	72.3	72	6.3	0.27	0.33	0.28	0.24	0.43

Figure 11 plots the estimated average infiltration rates for each home before and after the builder performed additional air sealing.

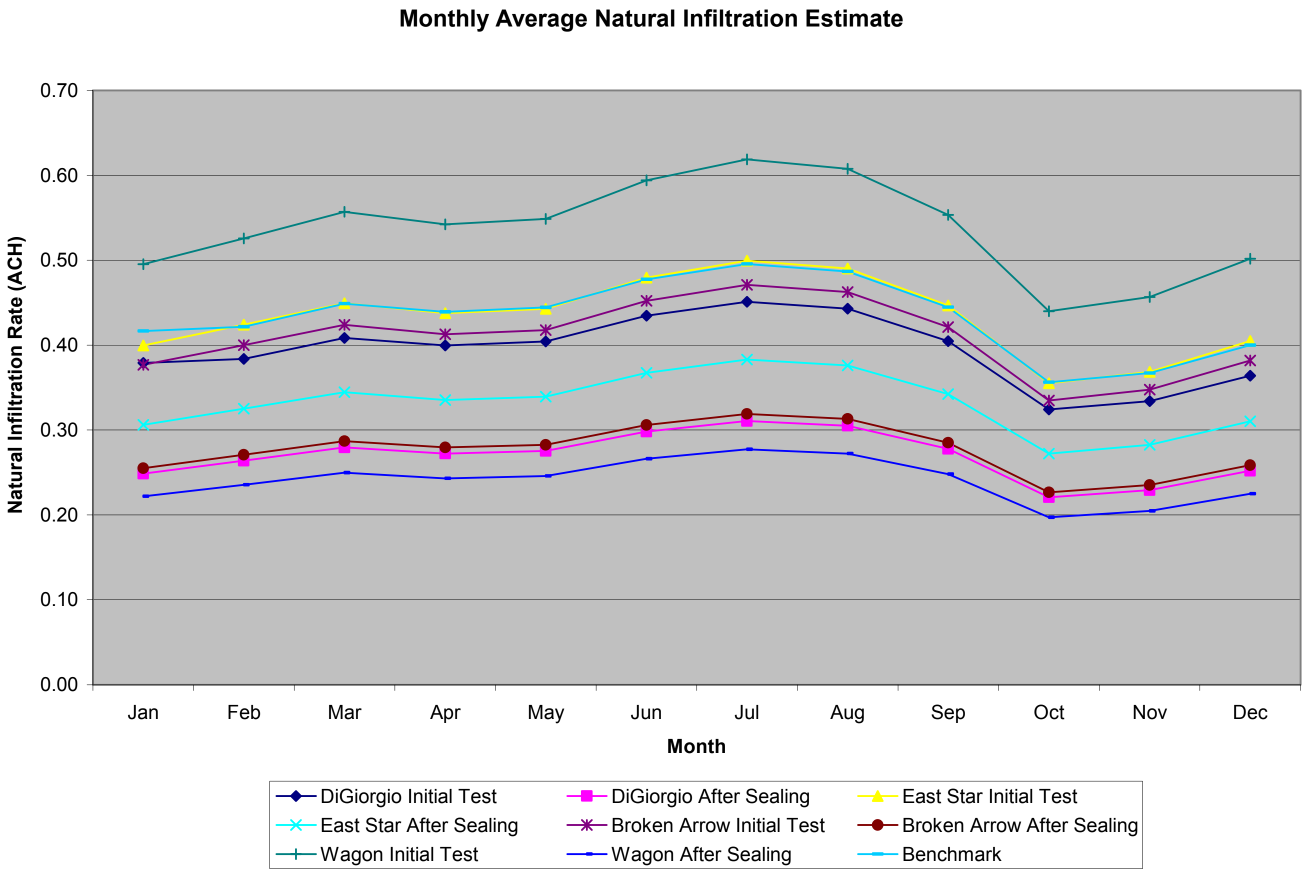

Figure 11 Natural Infiltration Estimate Plot for Borrego Springs Homes before and after Additional Air Sealing.

Sealing efforts made by the builder did make a difference in the air tightness of the homes. Table 7 shows the estimated leakage area (ELA) for each home before and after sealing and the percent reduction in ELA.

Table 7 ELA for Borrego Homes

Home	**ELA Before Sealing Measures (in^2)**	**ELA After Additional Sealing Measures (in^2)**	**% Improvement**
DiGiorgio	**145**	**95**	**34%**
East Star	**152**	**117**	**23%**
Broken Arrow	**144**	**97**	**32%**

Wagon	**189**	**85**	**55%**

Initial Tracer Gas Test Results

During a site visit at the end of May 2006, NREL staff performed tracer gas testing on two of the homes. At this time additional sealing measures had not been implemented. Unfortunately the test data is incomplete for several reasons. During the May site visit contractors were still working on all of the homes, this meant that tracer gas testing was performed largely at night to avoid interfering with work on the homes and safeguard test equipment. In addition, long term monitoring systems were just coming on line, and there were issues with the stability of the datastream from the Datataker dataloggers. Windspeed measurements were not available until 8/8/2006 due to difficulties associated with the initial windspeed sensor installation so a comparison of blower door infiltration estimates to directly measured infiltration from tracer gas testing is not possible for this timeframe due to the absence of site windspeed data. Initial tracer gas test results show both houses tested to be quite leaky. Figure 12 and 13 plot measured infiltration for the East Star and Broken Arrow homes. Tracer gas testing was not performed at the DiGiorgio home at the request of the homeowner who was simply not comfortable with the details of the testing.

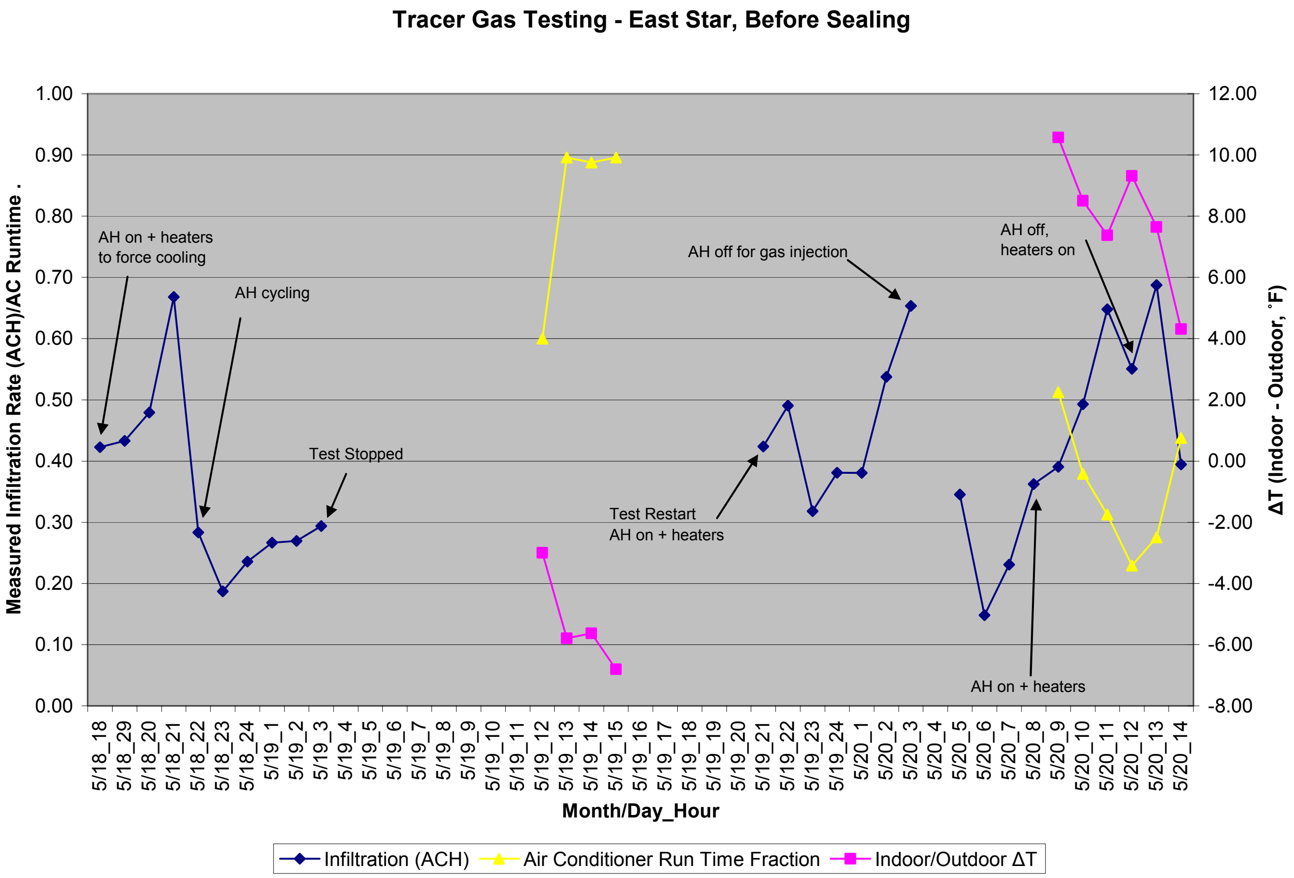

Figure 12 Tracer Gas Test Results for East Star, May 2006

During this test long term data acquisition for the East Star home was unreliable, as a result limited data for air conditioner runtime fraction and indoor/outdoor temperature differential are available. To force air conditioner operation during this test NREL staff used several small electric heaters to place a cooling load on the home so that infiltration could be measured during air conditioner operation.

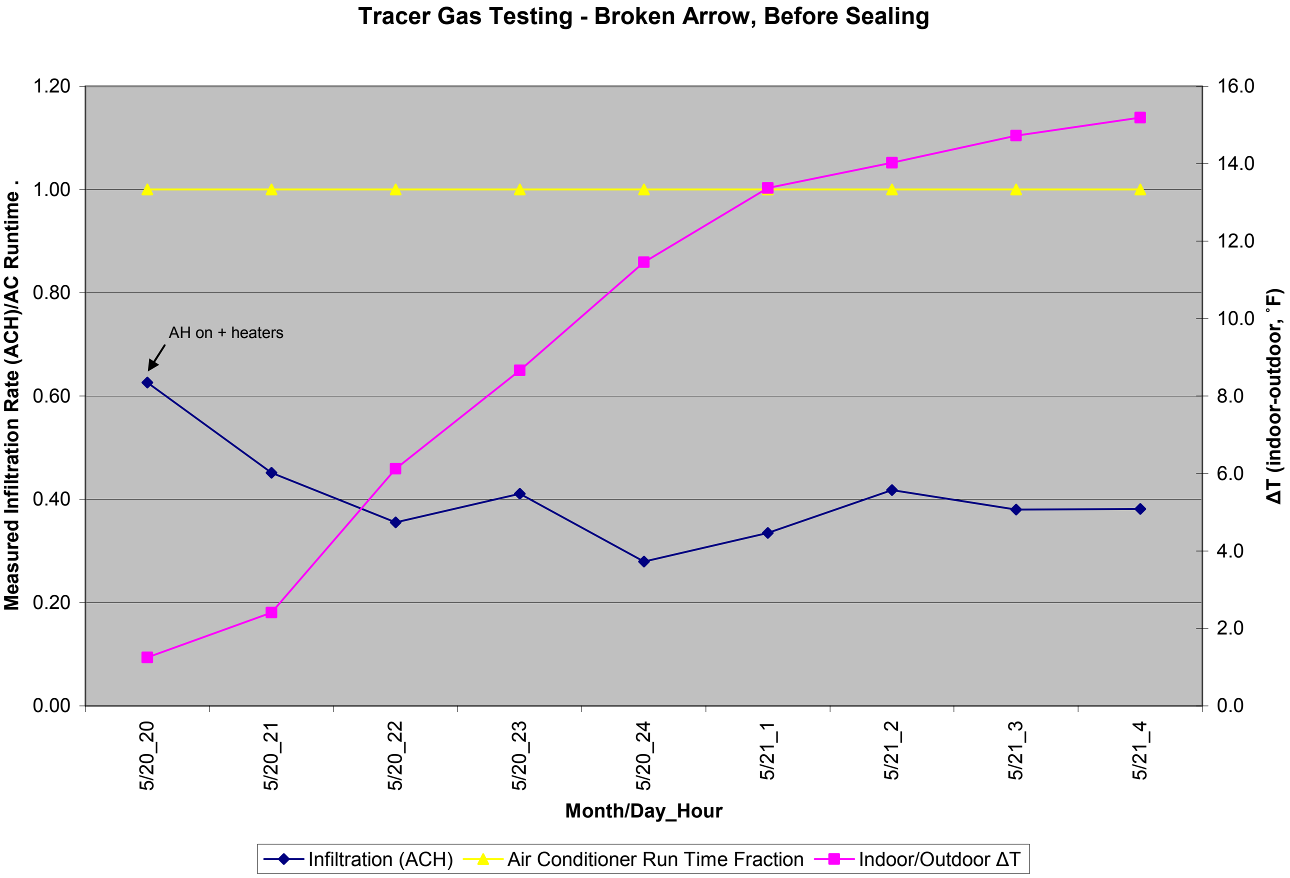

Figure 13 Tracer Gas Test Results for Broken Arrow, May 2006

Figures 12 & 13 support the blower door based infiltration estimates shown in Figure 11, indicating that the initial infiltration performance of the homes was much worse than expected. CONSOL staff communicated the air leakage testing results to the builder and the builder responded by implementing additional sealing measures on each of the homes. In August of 2006 NREL staff returned to Borrego Springs for another round of testing, repair and installation of instrumentation. Additional air sealing of the homes had been completed. Blower door testing shows that additional air sealing had improved the infiltration performance of the homes, however, the prototypes at Borrego have noticeably reduced infiltration performance compared to other current prototype homes in the Building America program. Figure 14 shows the infiltration performance for the East Star home after additional air sealing measures.

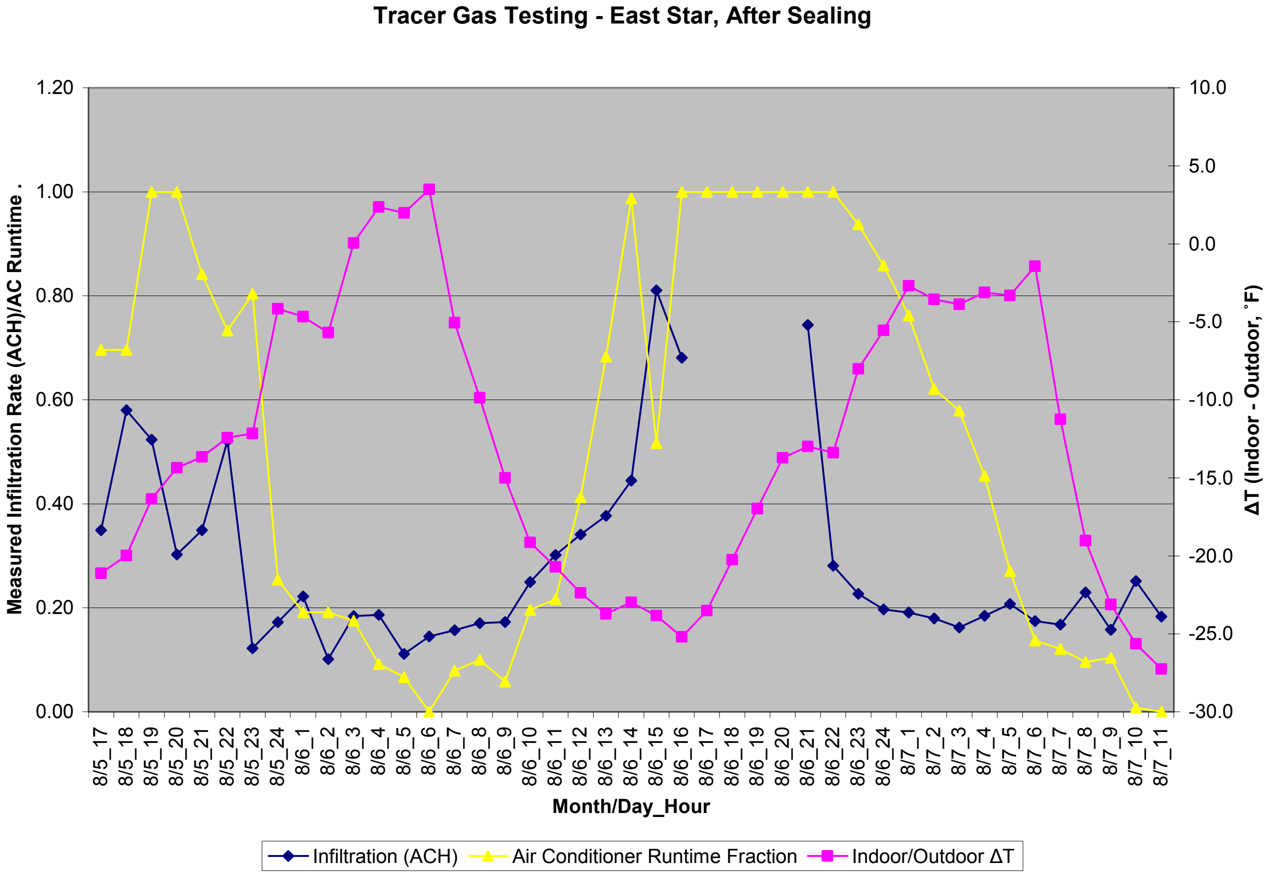

Figure 14 East Star Infiltration After Sealing

The East Star home has a fairly standard duct system and the influence of the air handler (AH) operating on the infiltration rate can be seen in Figure 14. Figure 15 also shows the influence of the temperature differential across the envelope, as the outdoor temperature climbs relative to the indoor temperature (larger negative value of ΔT on the secondary Y-axis) the measured infiltration increases, the effect of increasing ΔT can also be seen on the AH run time. From this limited data set it is difficult to separate the effect of duct leakage during AH run time from the influence of the temperature differential across the envelope. Since no windspeed data is available for this timeframe or the May 2006 testing for East Star, the effect of windspeed cannot be accounted for in either of these datasets.

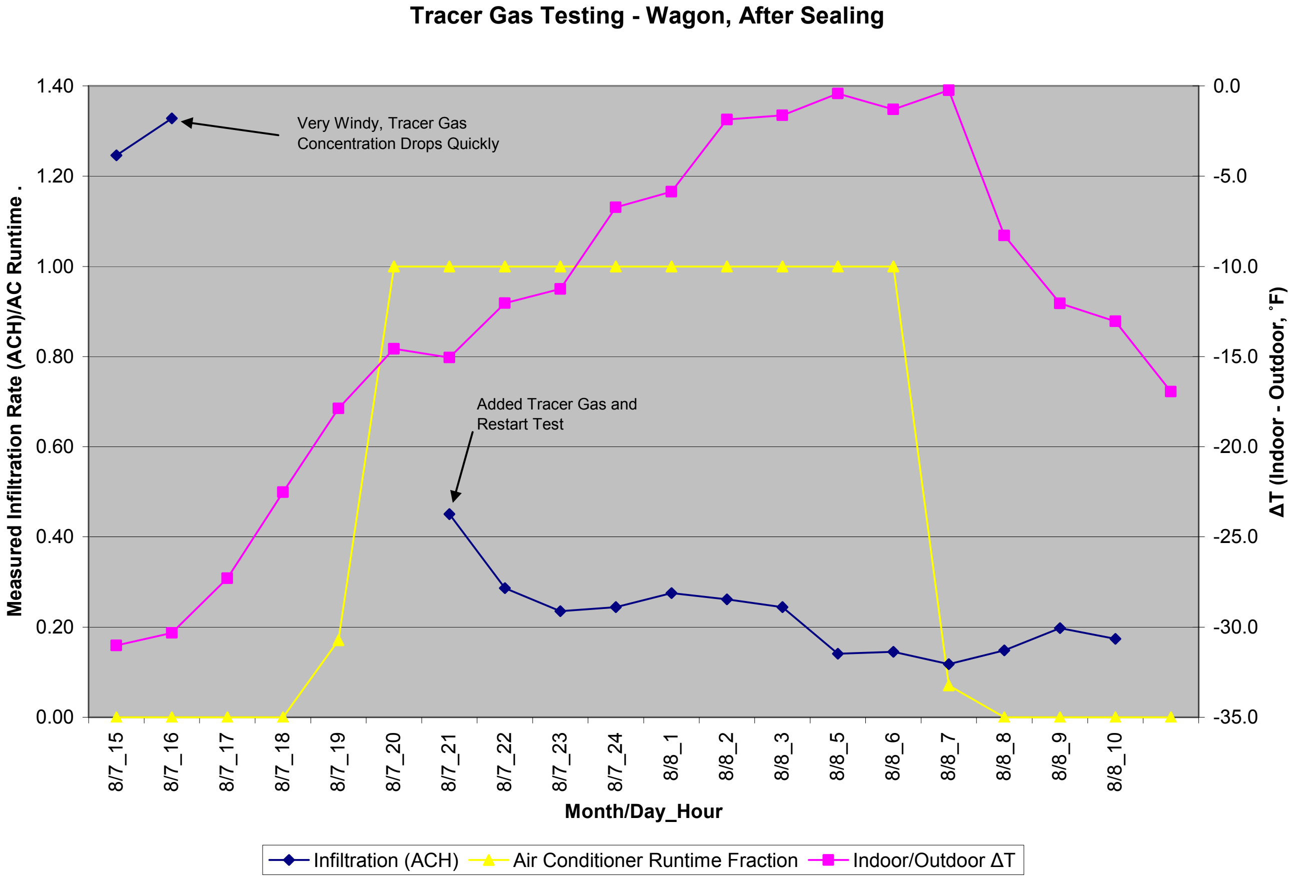

Figure 15 Wagon Infiltration after Sealing

From Table 7 the Wagon home showed the largest improvement as a result of air sealing. The Wagon home mechanical design differs from the other prototypes at Borrego Springs in that there is not an extensive duct system installed. For cooling the Wagon home utilizes an OASys indirect/direct evaporative cooler with a compact short run large diameter three supply register duct system. Backup cooling is provided by a nominal SEER 13 condensing unit coupled to a refrigerant/water plate style heat exchanger. Chilled water is then circulated through a small fan coil (to provide dehumidification) and PEX tubing cast into the floor slab for cooling. The air conditioner run time shown in Figure 15 represents floor cooling run time. During mild temperature differential periods, such as the morning of 8/8/2006 the Wagon home achieved measured hourly average infiltration rates as lows as 0.12ACH. On the previous day infiltration rates were very high, over 1ACH, during this time NREL staff observed high winds, but were not able to quantify the actual wind speed at that time. Since the Wagon home does have an indirect/direct evaporative cooler as the primary cooling system NREL staff suspects that the actual infiltration performance will be much worse than is indicated in Figure 15. The evaporative cooling system is essentially a large duct open to the outside and pressure relief exhaust ducts open to the attic there is a greater potential for air leakage than in a more conventional duct system. Hours 15 and 16 on 8/7 show measured infiltration rates exceeding 1ACH during a windy period. NREL staff returned to Wagon late that evening to check on the progress of the tracer gas test only to find that all the tracer gas had left the building. The test could only be restarted after additional gas was added to the space. While it may be reasonable to install covers to block pressure relief dampers and evaporative cooler outdoor air intake ducts during winter months when no cooling is called for in order to reduce infiltration it is not practical to expect occupants to reinstall covers during the cooling season in-between cooling calls to address infiltration in the cooling season. Figure 16 shows the infiltration performance of the Broken Arrow home during the August testing.

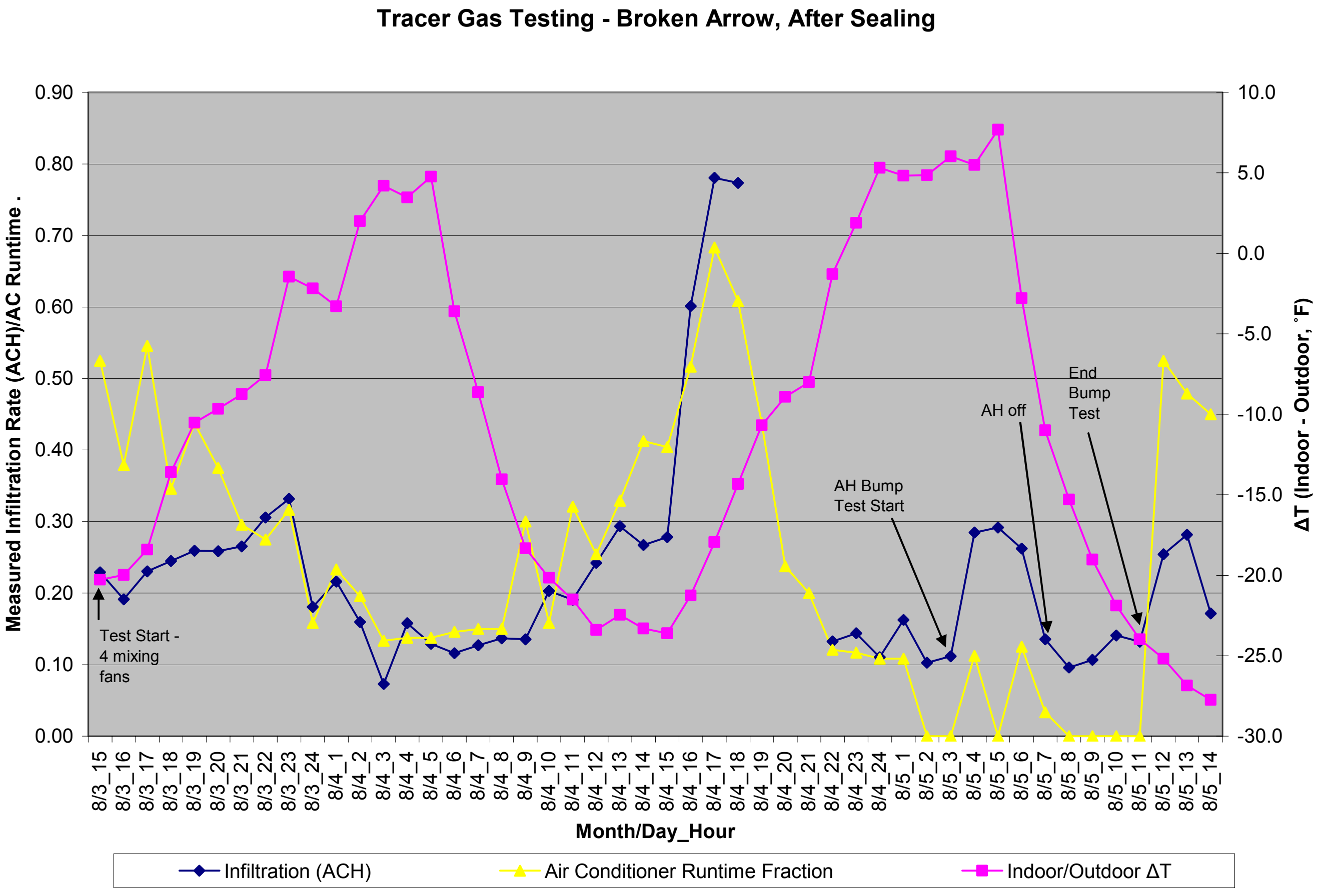

Figure 16 Broken Arrow Infiltration After Sealing

At Broken Arrow the tracer gas testing did include an air handler bump test. This test shows the infiltration associated with the air handler and duct system. On 8/5 at 2am PST the air handler was off and the measured hourly average infiltration was about 0.1 ACH. During the 3am hour the air conditioner was turned on and the measured infiltration jumped to roughly 0.28 ACH, the air handler was turned off during the 7am hour and by 8am the measured infiltration returned to 0.1 ACH. This would indicate that the air handler and duct system are responsible for roughly 0.18 ACH when the air conditioner runs. Using a building volume of 17,576ft^3 this translates into a duct leakage to the outside of 52CFM, or roughly 5% of the air handler fan flow. Broken Arrow shows similar trends to the East Star home in that the infiltration increases during air conditioner operation and large indoor/outdoor ΔT values. Both the East Star and Broken Arrow homes show high infiltration (measured values of roughly 0.8ACH which translates into 234CFM for both homes) during periods of high indoor/outdoor ΔT and high fractions of air conditioner run time. The Broken Arrow home also includes an indirect/direct evaporative cooler that is connected to the conventional supply duct system. One of the primary differences between the Broken Arrow duct system and the ducting system at the Wagon home in terms of infiltration performance is that when the indirect/direct evaporative cooler is off at Broken Arrow a damper closes the supply duct from the evaporative cooler and blocks unintentional airflow from traveling through the evaporative cooler and entering the conditioned space. The Wagon home does not have a damper that prevents unintentional airflow from the outside from entering the conditioned space.

In January 2008 a final set of tracer gas testing was performed at the East Star and Arrow homes (the Wagon home was occupied and was coupled with windspeed and envelope temperature differential data.

Duct Blaster Test Results

Duct Blaster testing was not performed on these homes.

Air Flow Rate Measurements

Air flow rate measurements were performed at each of the prototype homes in Borrego Springs. The primary purpose for performing the airflow rate measurements was to calibrate airflow sensors installed as part of the long term monitoring systems at the Wagon and DiGiorgio homes and to establish the airflow rate at the East Star and Wagon homes for the purpose of calculating cooling system capacity and energy efficiency ratio for each piece of cooling equipment present at the Borrego site.

Airflow Measurements at DiGiorgio:
During the short term test at the DiGiorgio house airflow rates were measured using two different methods; at the supply registers with an Alnor LoFlo Balometer **(reference Balometer Manual)** and at each supply register with a duct blaster fan **(Reference Duct Blaster manual)** configured as a fan assisted flow hood at each supply register and in some cases at the return grill. Table 8 shows test results for the DiGiorgio house in cooling mode for both airflow test methods.

Table 8 Comparison of Supply Airflow as Measured by Balometer and Fan Assisted Flow Hood

Supply Register Flow Rate w/ Fan Assisted Flow Hood				**Supply Register Flow Rate w/ Alnor LoFlo Balometer**					
				Supply Test 1			**Supply Test 2**		
Location	Measured Flow Rate at Supply Registers (CFM)	Volumetric Flow Rate at Supply Registers (ACFM)	Supply Air Temp (°F)	Measured Flow Rate at Supply Registers (CFM)	Volumetric Flow Rate at Supply Registers (ACFM)	Supply Air Temp (°F)	Measured Flow Rate at Supply Registers (CFM)	Volumetric Flow Rate at Supply Registers (ACFM)	Supply Air Temp (°F)
Kitchen	124	124	62.1	102	101	57.20	116	116	58.6
Dining	172	172		165	164		158	158	
Living Room	212	213		207	206		202	201	
Master Bed Room	116	116		110	109		102	102	
Master Bath	140	140		130	129		128	128	
1/2 Bath	61	61		58	58		55	55	
Main Bath	68	68		67	67		60	60	
Powder Room	60	60		56	56		52	52	
Bed Room 1	187	187		168	167		163	163	

Bed Room 2	193	194		168	167		176	176	
Totals	**1333**	**1336**		**1231**	**1224**		**1212**	**1205**	

Air flow was also measured at the return grill using the fan assisted flow hood, the volumetric air flow rate was found to be 1236CFM. Table 9 compares the volumetric flow rate as measured at the supply registers with the fan assisted flow hood to the other air flow measurements.

Table 9 Percent Difference in Measured Airflow Relative to Fan Assisted Flow Hood at Supply Registers

% Difference in measured airflow relative to 1336 CFM (Fan Assisted Flow Hood at Supplies)	
Balometer test 1	8%
Balometer test 2	10%
Flow hood @ Return	7%

These two methods were used to evaluate the use of either tool to measure airflow rates in the other homes and to develop a calibration curve for the long term monitoring equipment. Seeing agreement within 10% NREL staff decided that using the Lo Flo Balometer was adequate for characterizing air handler fan flowrates. Air flow rates measured at the supply registers or return register will differ from actual fan air flow unless the duct system has no leakage. For the purpose of developing calibration curves and measuring air flow rates NREL staff decided that measuring air flows at the supply registers would be the most representative of the airflow rate associated with the actual cooling delivered to the house. The NREL data acquisition system at DiGiorgio had been measuring airflow with a pitot tube traverse sensor and pressure transducer since May of 2006, however this measurement proved inaccurate for reasons described in NREL-TP 39342 (Kutscher et al, 2006). The NREL data acquisition system had also been configured, with assistance form DEG, to measure fan rotational speed as an alternative strategy to monitor airflow continuously. Table 10 shows the results of the Balometer airflows and fan RPM calibration for the Nightbreeze air handler.

Table 10 Nighbreeze Air Handler Calibration Test Results

Rotational Speed (RPM)	Airflow (CFM)
436	445
734	830
1101	1224
1361	1586
0	0

Figure 17 shows the calibration curve for fan rotational speed vs. measured airflow that was developed for the DiGiorgio house.

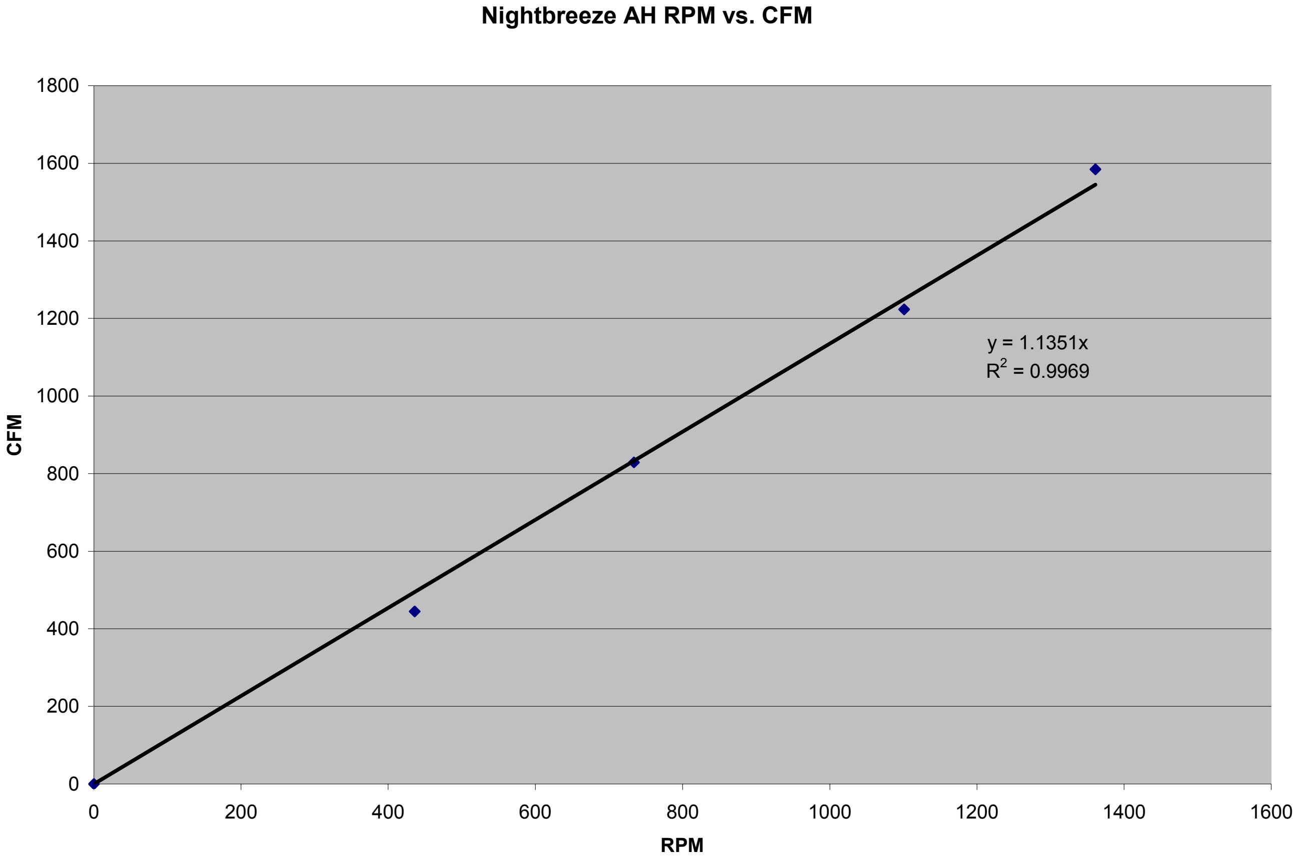

Figure 17 Air Handler Rotational Speed vs. Air Flow Curve from Test Results

At the Wagon home airflow testing included the use of a fan assisted flow hood to measure the supply airflow of the indirect/direct evaporative cooler and the fan coil. Since the OASys indirect/direct evaporative cooler delivered supply air flow rate is very sensitive to supply duct back pressure, the use of a Lo Flo Balometer was deemed inappropriate as increased supply duct backpressure results in more of the OASys total airflow being exhausted to the outdoors through the indirect evaporative section, this would result in an inaccurate measure of the supply air flowrate delivered to the conditioned space. DEG and NREL engineers decided early in the project that the airflow rate of the OASys would need to be monitored continuously in order to get reasonable capacity and performance data on the OASys unit at Wagon. In a March 2006 site visit NREL engineers installed a pitot tube traverse type sensor and pressure transducer on the OASys supply trunk duct similar to those used at the DiGiorgio home. Due to a concern about accuracy at low flow rates an additional hot wire type airflow station was installed in the supply trunk in an April 2006 site visit. Both sensors were connected to Davis Energy Group's Datataker datalogging system. Over the summer of 2006 DEG engineers noted that the sensors were giving different airflow rates. To correct this situation NREL staff performed fan assisted flow hood measurements of airflow rate at the three supply registers at various fan speeds and recorded the voltage output of the pressure transducer and hot wire type airflow station. This data was used to develop calibration curves which were implemented in the DEG datalogger program. Table 10 shows the recorded data used for the calibration of the airflow sensors at Wagon.

Table 10 Airflow Sensor Calibration Data for Wagon OASys Unit

Fan Assisted Flow Hood										
Speed/ OASys thermostat position	**Air Relative Humidity (%)**	**Air Temperature (°F)**	**Kitchen Supply Airflow (CFM)**	**Dining Room Supply Airflow (CFM)**	**Living Room Supply Airflow (CFM)**	**Total Supply Airflow (Standard density CFM)**	**Total Volumetric Flow Rate (ACFM)**	**DC Output Voltage (hotwire sensor)**	**DC Output Voltage (differential pressure transducer)**	**Power (W)**
off						**0**	**0**	**0.406**	**0.4**	**7**
1/Covering "t" in hot	**80.3%**	**61.1**	**205**	**168**	**286**	**659**	**660**	**1.12**	**0.525**	**190**
2/Covering "/"	**81.2%**	**64**	**257**	**211**	**363**	**831**	**837**	**1.34**	**0.61**	**330**
3/Covering "c" in cold	**83.0%**	**65.8**	**336**	**278**	**530**	**1145**	**1157**	**1.67**	**0.76**	**630**
4/Full on	**80.3%**	**66.3**	**354**	**297**	**596**	**1247**	**1262**	**1.92**	**0.83**	**780**
5/Covering "h" in hot	**81.2%**	**65.4**	**134**	**108**	**221**	**462**	**467**	**0.86**	**0.45**	**110**

Figure 18 shows the calibration curve for the pitot tube traverse sensor and pressure transducer.

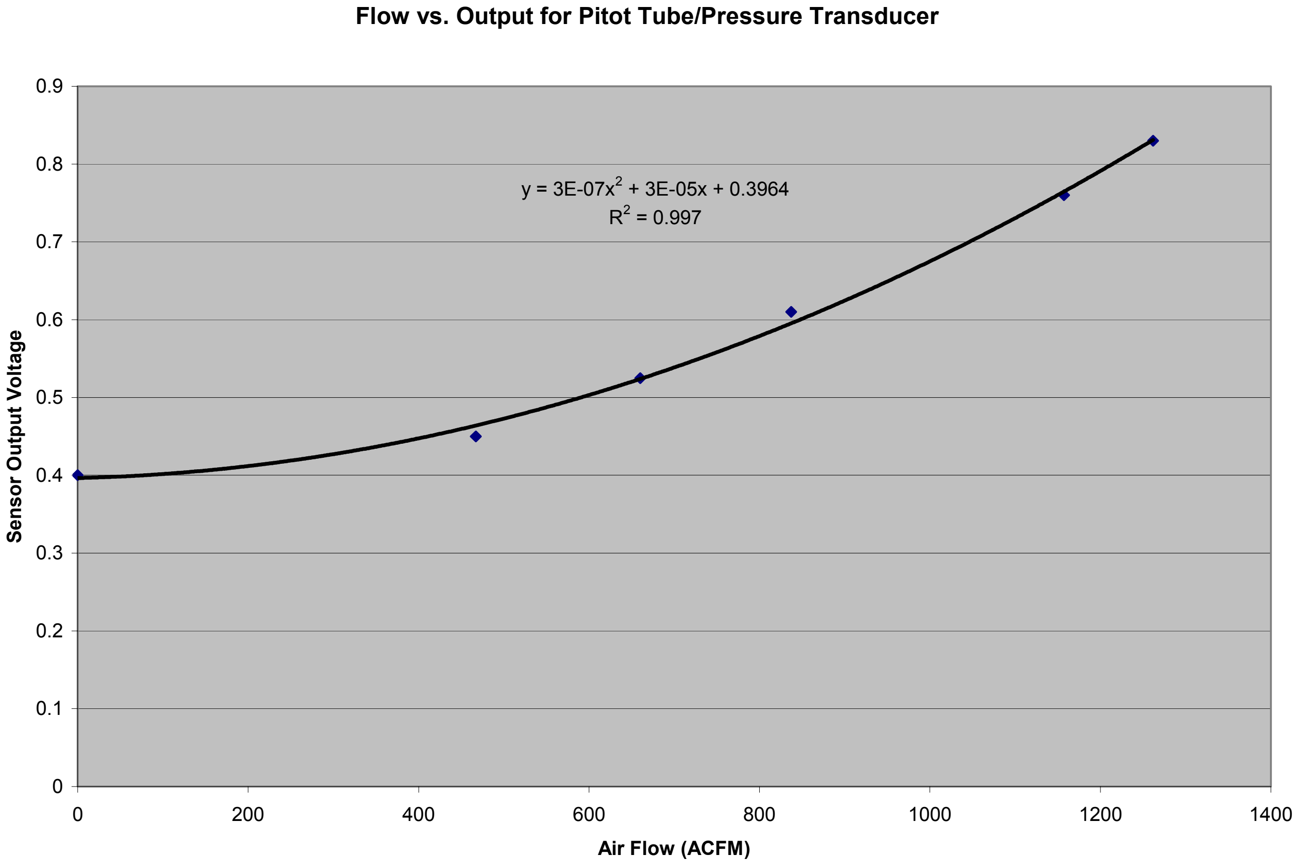

Figure 18 Calibration Curve for Pitot Tube Traverse Sensor and Pressure Transducer

Figure 19 shows the calibration curve for the hot wire type airflow station.

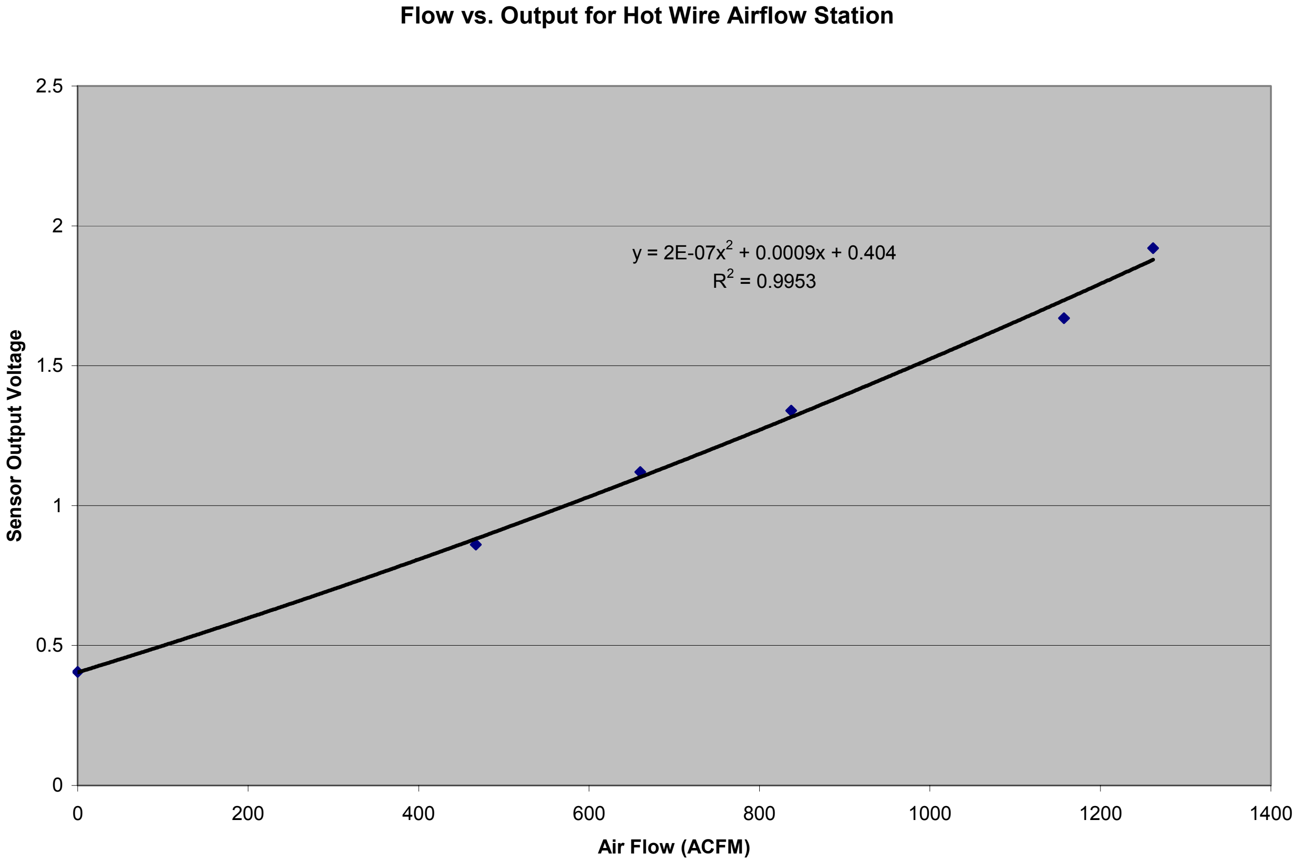

Figure 19 Calibration Curve for Hot Wire Type Airflow Station

The Wagon home also incorporates a refrigerant based compressor cooling system as a backup cooling system so that the occupants can remain comfortable on days when the evaporative cooling system cannot meet the cooling load. This backup system uses a 3 ton SEER 13 air source condensing unit and a refrigerant/water flat plate heat exchanger to chill water. Cold water is then circulated through a hydronic fan coil located in a drop plenum near the kitchen then into PEX tubing which is embedded in the concrete floor slab to provide floor cooling. DEG engineers requested that NREL measure the airflow rate from the fan coil and corresponding power as the fan coil has three speeds. Due to the shape of the supply grill on the fan coil it was not possible to use a Lo-Flo Balometer to measure the airflow, instead a fan assisted flow hood was used to measure the airflow from the fan coil unit. Table 11 shows the results of the fan coil airflow testing.

Table 11 Fan Coil Air Flow Rates and Power

Fan Coil Flowrates - Fan Assisted Flow Hood						
Speed	**Air Relative Humidity (%)**	**Air Temperature (°F)**	**Air Density (lbm/ft^3)**	**Total Supply Airflow (Standard density CFM)**	**Total Volumetric Flow Rate (ACFM)**	**Power (W)**
off	**41%**	**60**	**0.0744**	**0**	**0**	**17**
Low	**41%**	**60**	**0.0744**	**620**	**625**	**152**
Med	**41%**	**60**	**0.0744**	**640**	**645**	**172**
Hi	**41%**	**60**	**0.0744**	**760**	**766**	**197**

The fan assisted flow hood consists of a digital manometer, a duct blaster fan, flex duct and custom site built capture hoods. Figure 20 shows the duct blaster fan attached to the capture hood used for the fan coil air flow measurements, the second capture hood (directly behind flex duct in Figure 20) was built to match the supply register dimensions at Wagon.

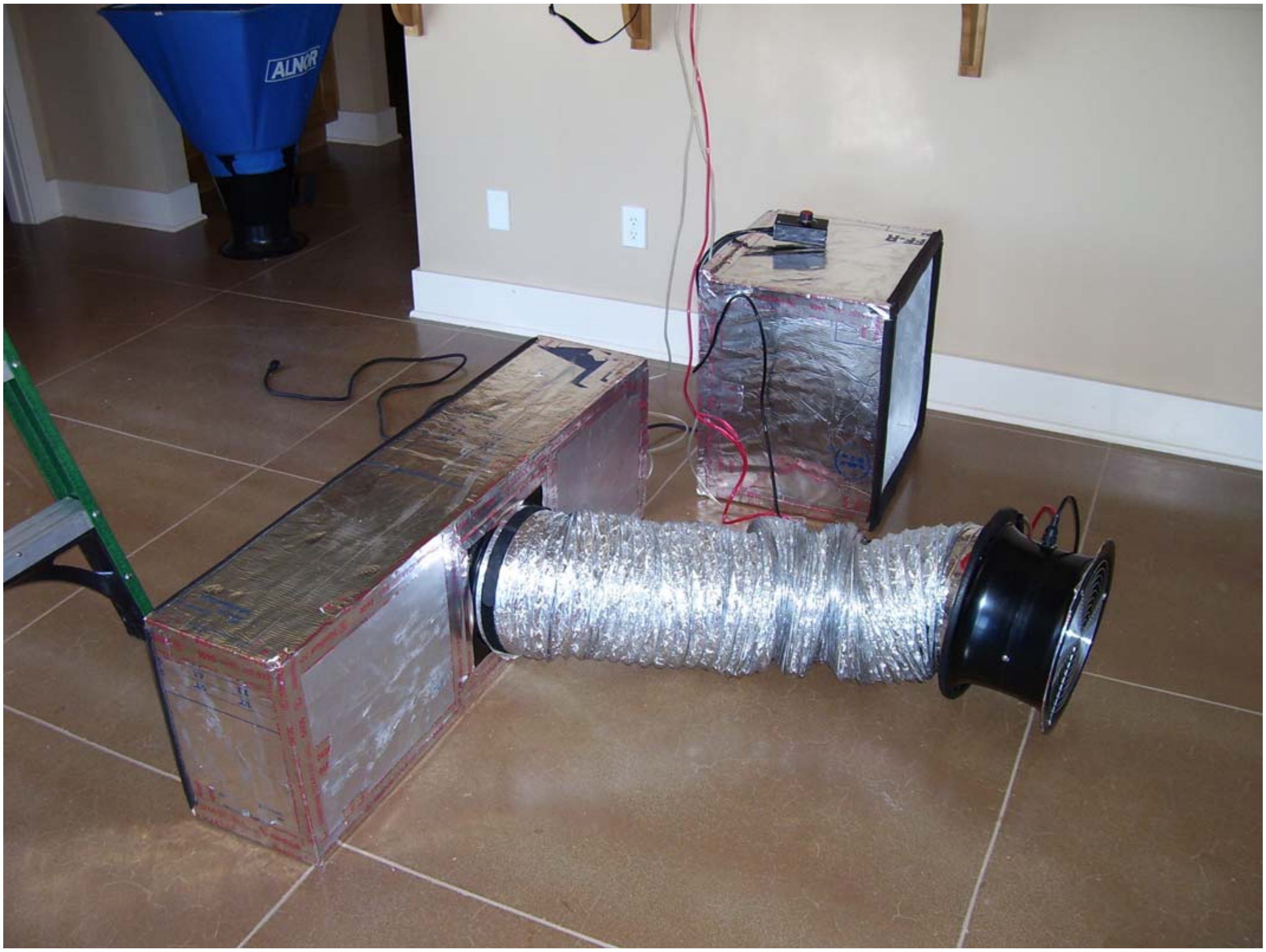

Figure 20 Fan Assisted Flow Hood Test Equipment

At the East Star home NREL staff performed several airflow test. In May 2006 the Lo-Flo Balometer was used to determine the air flow rate of the 3 ton SEER 21 air conditioner installed at that site. This particular air conditioner utilizes an electronically commutated motor for the air handler fan and NREL staff noted that the indoor coil is a 4 ton unit. Initial test data was shared with DEG engineers who recognized that the unit was not delivering proper airflow. The engineering manual for the air handler was consulted, NREL staff recorded the jumper settings and documented the expected airflow rates. Tables 12 and 13 show the Jumper settings and expected airflow rates from the expanded engineering data.

Table 12 Jumper Setting for East Star Air Handler

Jumper Settings 5/22/06	
Adjust Jumper	**"norm"**
Heat Speed	**1**
Cool Speed Jumper	**3**

Delay Jumper	**3**

The “adjust” jumper acts as a modifier to the “speed” jumpers giving the installer the ability to change the airflow by roughly ± 10% of the “speed” jumper settings. The “delay” jumper specifies how the air handler fan operates as part of dehumidification functionality. The “delay” jumper in position 3 has the following operational mode; the motor runs at 82% of capacity for 7-1/2 minutes then 100% of capacity until demand is met, after the demand is met the motor ramps down to a stop. Since this system has a 2 stage outdoor unit the air handler fan has at least 2 operating speeds. The engineering manual indicates that in first stage cooling mode the air handler delivers 60% of the cool speed air volume. With these jumper settings the expected airflows are given in Table 13

Table 13 Expected Airflow Rates for East Star Air Handler

Expected Result Cooling Airflow from Engineering Manual (CFM)		
Low Speed Startup	**Low Speed**	**High Speed**
888	**1083**	**1805**

It was clear after the initial test on 5/22/06 that the second stage cooling mode was not enabled. Table 14 shows test results for the jumper settings as configured on 5/22/06.

Table 14 Measured Supply Airflows for East Star Air Handler

Location	Supply Airflow, Low Speed Startup, 5/22/2006			Supply Airflows, Low Speed, 5/22/2006			Supply Air Flow, High Speed, 8/5/2006		
	Measured Air Flow (SCFM)	Volumetric Flow Rate (CFM)	Supply Temperature (ºF)	Measured Air Flow (SCFM)	Volumetric Flow Rate (CFM)	Supply Temperature (ºF)	Measured Air Flow (SCFM)	Volumetric Flow Rate (CFM)	Supply Temperature (ºF)
Master Bed Room	74	74		98	98		146	147	
Master Bath	63	63		82	82		120	121	
1/2 Bath	35	35		45	45		66	66	
Living Room	164	164		215	215		315	317	
Kitchen	94	94	61	125	125		175	176	63.7
Dining	176	176		230	230		350	352	
Powder	23	23		29	29		50	50	
Main Bath	22	22		28	28		40	40	
Bed Room 1	132	132		165	165		238	240	
Bed Room 2	93	93		115	115		175	176	
Totals	**876**	**878**		**1132**	**1134**		**1675**	**1687**	

As shown in Table 14 the high speed air flow rate was actually measured during the August 2006 visit. Comparing expected flow rates to realized flow rates show reasonable agreement between the engineering manual expected flow rates and measured flow rates for the low speed start up and low speed cooling airflows. The measured high speed airflows did not compare as well the expected values, differing by roughly 6% of the expected air flow rate. After the initial testing in May 2006 DEG contacted the HVAC contractor to find out why the second stage cooling for this unit was not enabled. The HVAC contractor had installed a thermostat that was not of the same make as the air conditioner and had not wired the thermostat to control and air conditioner with 2 stage cooling. The HVAC contractor rewired the thermostat to control 2 stage cooling in July 2006. In August of 2006 NREL staff were able to complete airflow measurements of second stage cooling. NREL staff also observed that the unit settings were on the order of 600CFM/ton, after consulting DEG engineers NREL staff reset the jumpers on the air handler to reflect roughly 400CFM/ton which is a more typical value and retested the various cooling modes for airflow. Table 15 shows the revised jumper settings for the East Star air handler.

Table 15 Modified Jumper Settings for East Star Air Handler

Jumper Settings 8/6/2006	
Adjust Jumper	"-"
Heat Speed	1
Cool Speed Jumper	2
Delay Jumper	3

Table 16 shows the expected cooling airflows according to the engineering manual.

Table 16 Measured Air Flow Rates for East Star Air Handler w/ Modified Jumper Settings

Expected Result Cooling Airflow from Engineering Manual (CFM)		
Low Speed Startup	Low Speed	High Speed
677	825	1375

Table 17 shows the measured air flows after the jumper settings were changed.

Table 17 Measured Air Flow Rates for East Star After Jumper Setting Revision

	Supply low speed startup 8/6/2006			Supply low speed 8/6/2006			Supply high speed 8/6/2006		
Location	Measured Air Flow (SCFM)	Volumetric Flow Rate (CFM)	Supply Temperature (ºF)	Measured Air Flow (SCFM)	Volumetric Flow Rate (CFM)	Supply Temperature (ºF)	Measured Air Flow (SCFM)	Volumetric Flow Rate (CFM)	Supply Temperature (ºF)
Master Bed Room	55	55		70	70		108	108	
Master Bath	47	47		58	58		88	88	
1/2 Bath	25	25		33	33		49	49	
Living Room	120	121		153	153		225	225	
Kitchen	68	68	62.49	90	90	61.53	128	128	60.81
Dining	132	133		166	166		250	250	
Powder	20	20		24	24		32	32	
Main Bath	17	17		21	21		30	30	
Bed Room 1	88	88		120	120		176	176	
Bed Room 2	67	67		85	85		130	130	
Totals	**639**	**642**		**820**	**822**		**1216**	**1218**	

Making the same comparison as the previous dataset from the original jumper settings the expected flow rates show good agreement for the low speed start up and low speed cooling air flow rates. The measured high speed airflows did not compare as well the expected values differing by roughly 11% of the expected air flow rate. From long term data it also appears that there is a 4th air flow rate which would be a high speed cooling startup mode and would have an expected flow rate of 1128CFM which would run for the first 7-1/2 minutes of a call for cooling that forced the air conditioner immediately into second stage cooling mode. NREL and DEG staff did not anticipate this as a possible mode and the engineering manual does not clearly define this as a possible operational mode. No air flow rate measurements are currently available for this mode, additional testing will be required to define this mode. Without direct measurements of the additional airflow rate, cooling capacities and EER for second stage operation will be overstated except for data recorded during long runtimes. NREL staff has also noticed that the datalogger program for East Star did not appear to recognize the low speed startup air handler fan operation, this issue may be related to the resolution of the power metering equipment installed to measure the energy consumption of the air handler fan. NREL staff and DEG engineers have decided to simplify the air handler fan operation by altering the jumper settings to disable the low speed startup mode rather than invest significant time and expense in order to monitor air handler air flow rate at East Star continuously in a manner similar to Wagon or DiGiorgio.

Air Conditioner Performance

Data was collected and air conditioner performance was evaluated over the summer of 2006. Not all the systems were operated through the summer. The OASys indirect/direct evaporative coolers were shut off from June until mid October, this was in part related to an interest in getting a reasonable amount of data for the homes running side by side in cooling mode using compressor cooling systems, observations in late May indicating that the evaporative systems were having difficulty cooling the homes during the hottest part of the day, a number of unexpected issues with the mechanical systems and the availability of CONSOL, DEG and NREL staff to be on site in order to make changes in cooling system operation as the homes with OASys evaporative coolers were unoccupied through the summer.

Summer 2006 data was evaluated to answer the specific cooling system research questions as follows:

- How the cooling systems perform in comparison to manufacturers' performance specifications?
- What are the cooling systems' measured EER and capacity as functions of indoor and outdoor conditions?
- What is the water consumption of the cooling system?
- What is the wet bulb effectiveness of the evaporative systems?
- To what extent is the cooling system capable of maintaining comfortable indoor conditions?

Manufacturer's performance data was collected from engineering and specifications manuals which were found on site and the results were plotted against the measured data collected from the long term monitoring systems.

At the Arrow site there are 2 cooling systems, an OASys indirect/direct evaporative cooler and a Carrier SEER13 air conditioner with an air source condensing unit. These systems share the same supply duct system within the home and a damper is used to switch the return duct configuration from a return duct which draws air from the house in the DX-AC cooling mode to a supply duct for the evaporative cooler. Most of the data collected in the ’06 cooling season represents operation of the SEER13 air conditioner which was evaluated as the reference air conditioner for this test (currently split system air conditioners are required to have SEER rating of 13 according to NAECA standards, http://www.energycodes.gov/residential_ac_hp.stm). Data from the Arrow site was evaluated to determine if the cooling system was performing according to the manufacturers expectations. Figure 21 shows the comparison of Manufacturer’s power draw data to field monitored data for the SEER 13 air conditioner at the Arrow site.

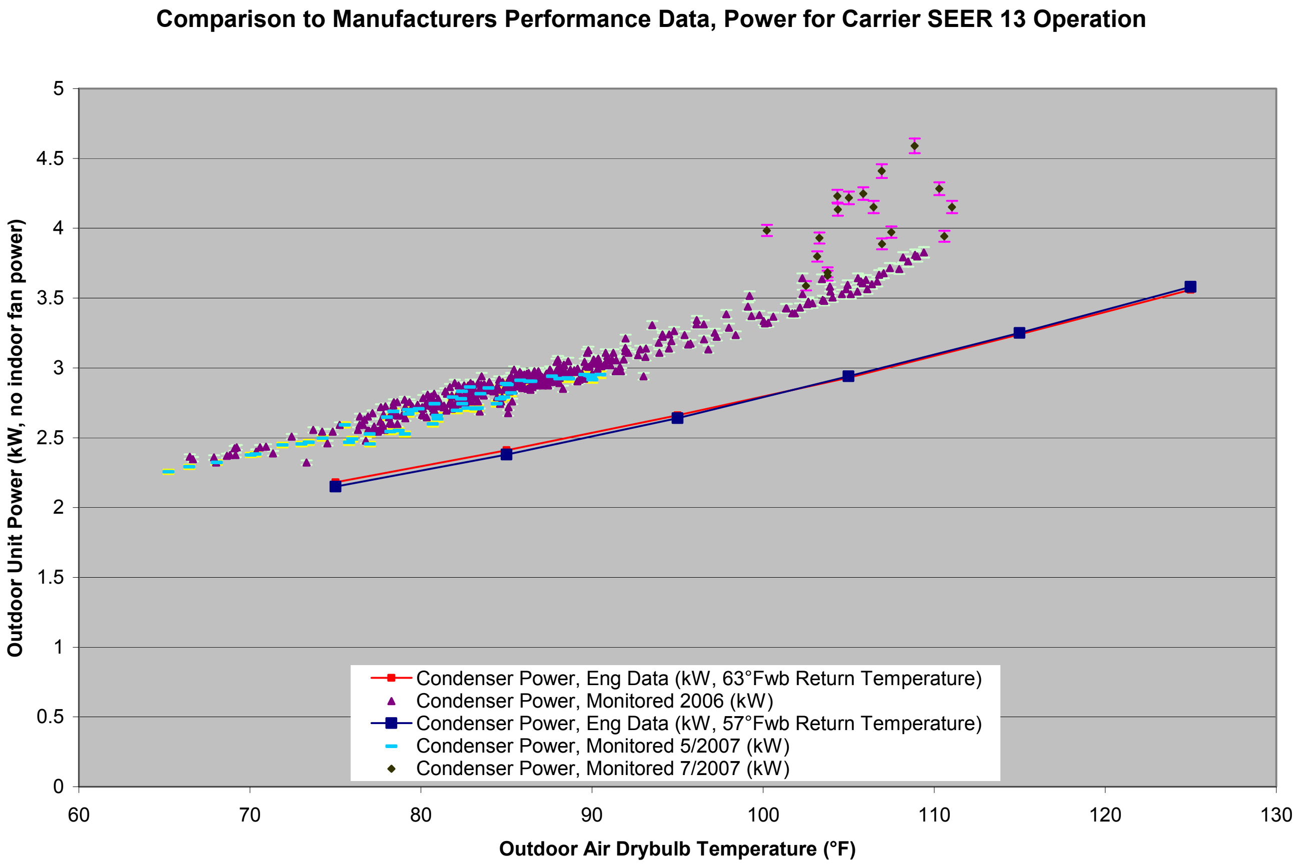

Figure 21 SEER 13 Outdoor Unit Power Comparison

The comparison to manufacturers power draw is presented for the condensing unit only as including the air handler in the comparison would complicate the comparison unnecessarily due to the difficulty in knowing the duct system static pressure when the system operates (currently there is no measurement of duct system static pressure).

Data for the SEER 13 air conditioner was only valid from August 2006 until the end of the 2006 cooling season due to a temperature and relative humidity sensor failure that was corrected during the August site visit, data from some of the warmer parts of the summer is not available. The comparison shows the measured power of the condensing unit to be higher than would be expected from the manufacturer’s data and may indicate incorrect refrigerant charge. Figure 22 shows the cooling capacity comparison for the SEER 13 air conditioner.

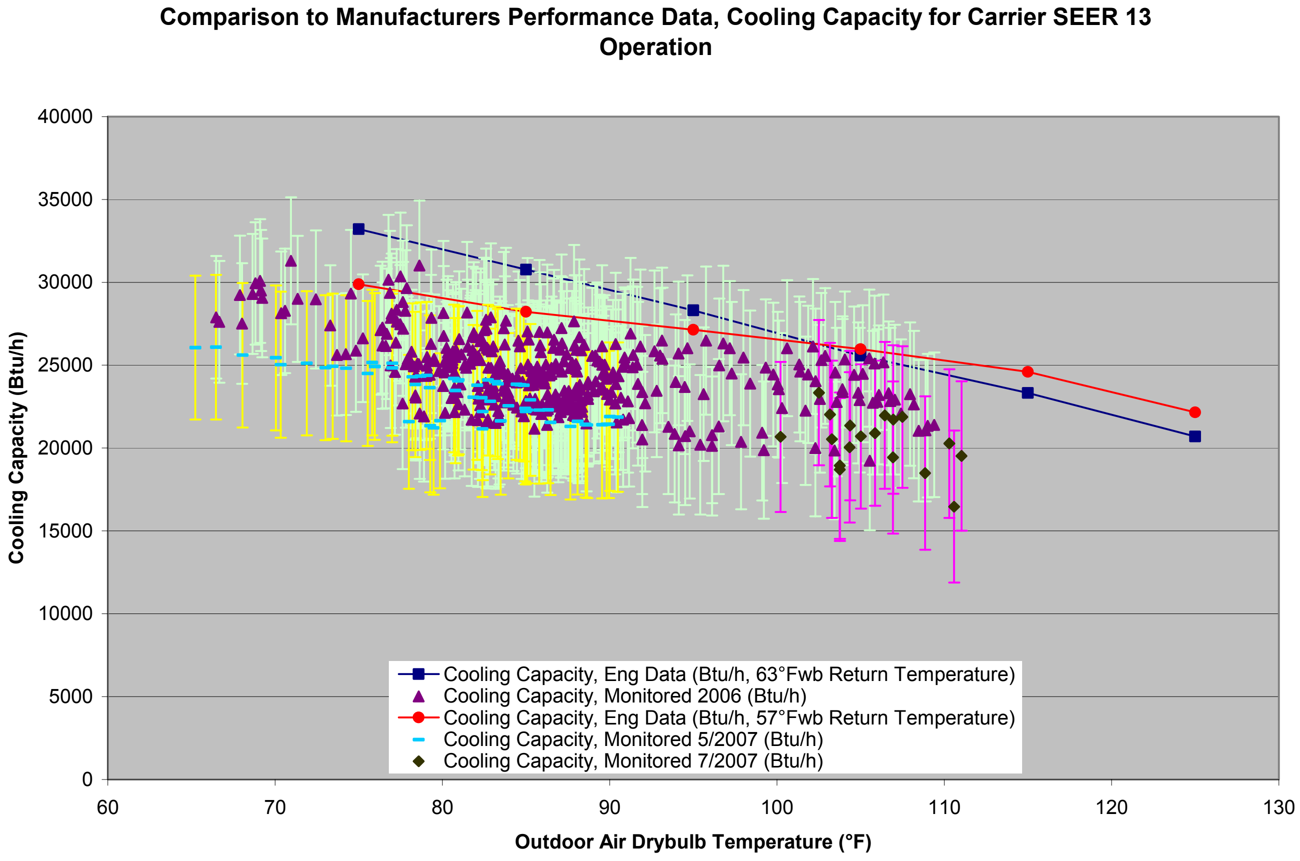

Figure 22 Total Cooling Capacity Comparison for SEER 13 Air Conditioner

The measured total cooling capacity seems to be closer to the manufacturer’s data in the context that the measurement of the air side cooling delivered is less accurate than the measurement of condenser power. Figure 23 shows the sensible cooling capacity comparison for the SEER 13 air conditioner.

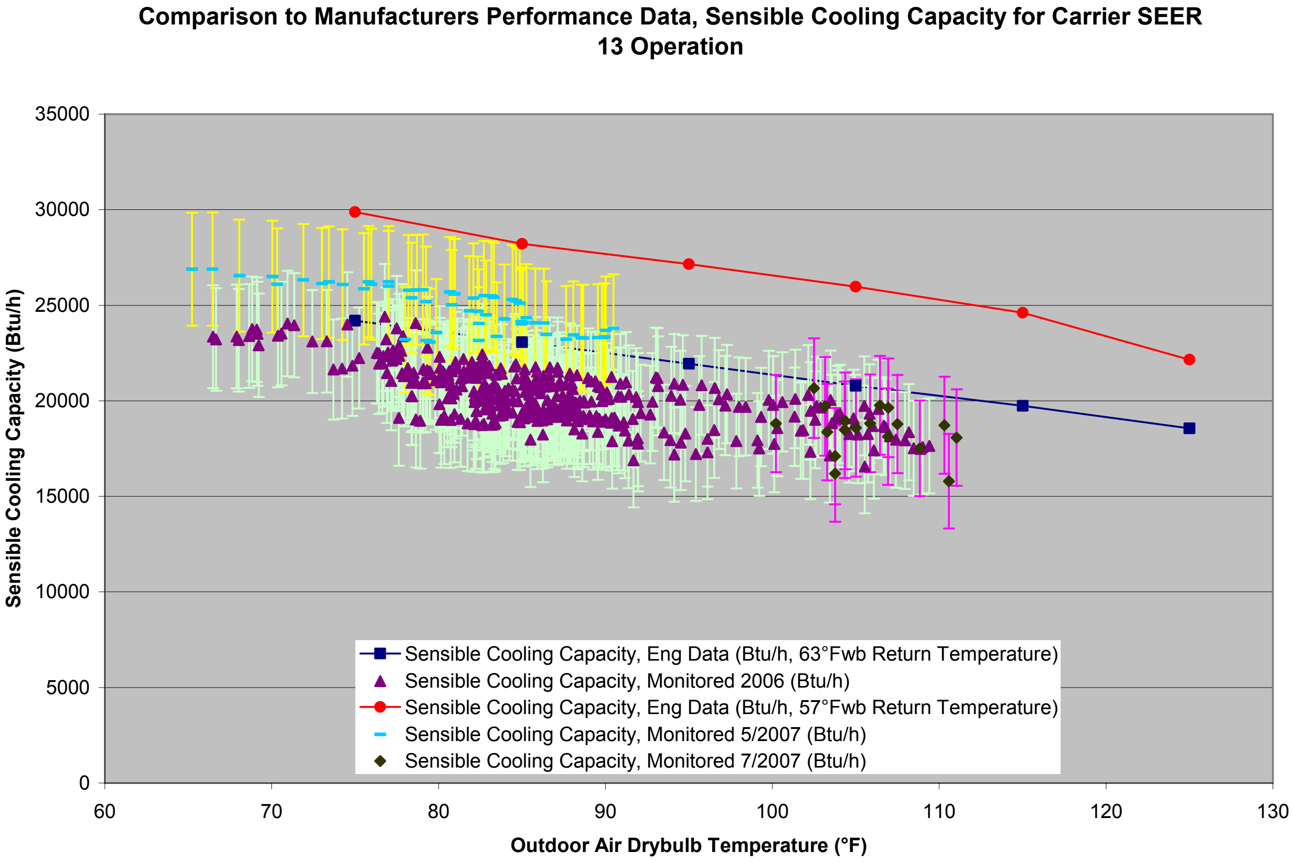

Figure 23 Sensible Cooling Capacity Comparison for SEER 13 Air Conditioner

The measured sensible cooling capacity has less uncertainty associated with the measured values and still shows a reasonable comparison to the manufacturer's data. Figure 24 shows the EER comparison for the SEER 13 air conditioner.

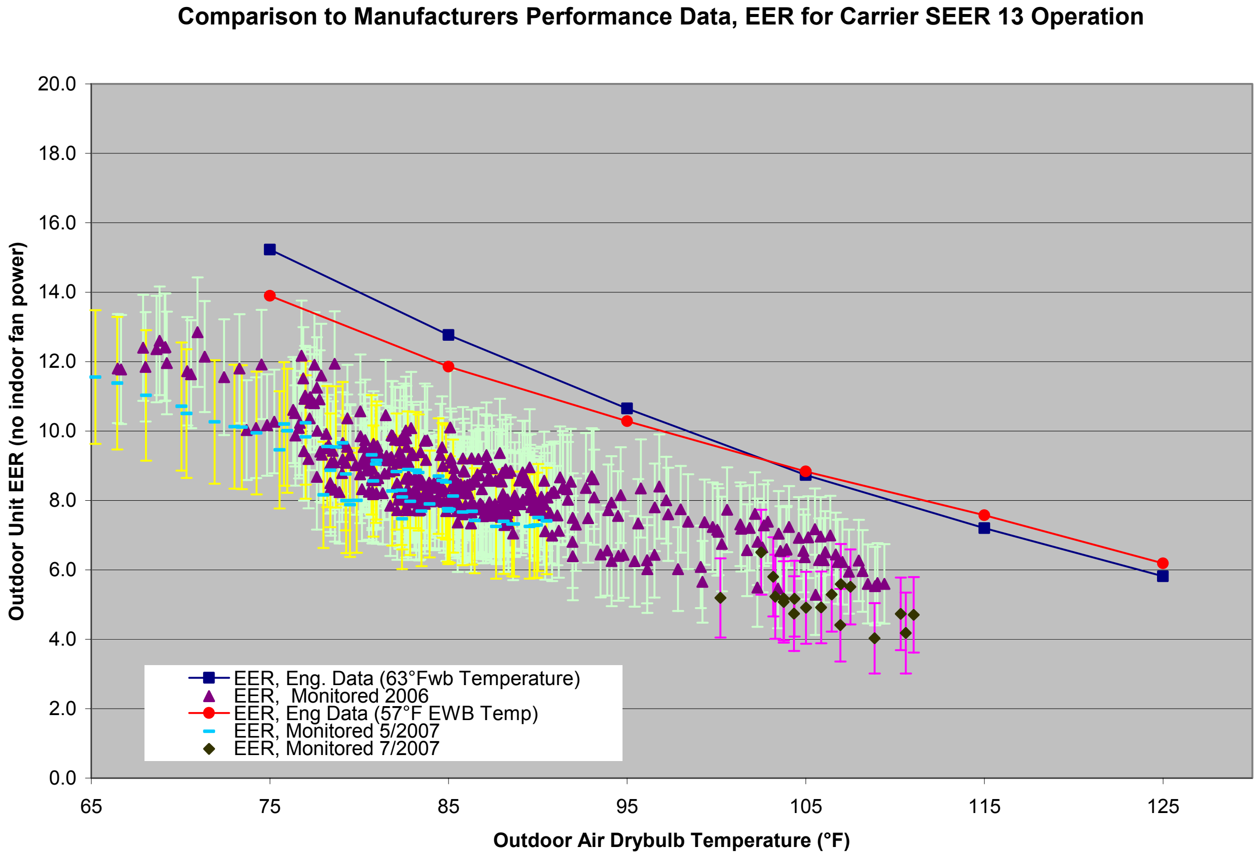

Figure 24 EER Comparison for SEER 13 Air Conditioner

Figure 24 shows the measured EER to be lower than the manufacturer's data would indicate. The reason for the higher than expected outdoor unit power has not been determined at this time but the manufacturer has become involved in analyzing the data and is aware of the discrepancy.

At the East Star site there is only one cooling system installed. A SEER 21 Lennox air conditioner was selected to represent the highest efficiency air conditioner currently available to the residential market. This cooling system features 2 stage operation such that the air handler, compressor and condenser fan will operate at 2 speeds giving a 1st stage cooling capacity or roughly 2 tons and a 2nd stage cooling capacity of roughly 3 tons. Figure 25 shows the comparison of Manufacturer's power draw data compared to field monitored data for the SEER 21 air conditioner in 1st stage cooling at the East Star site.

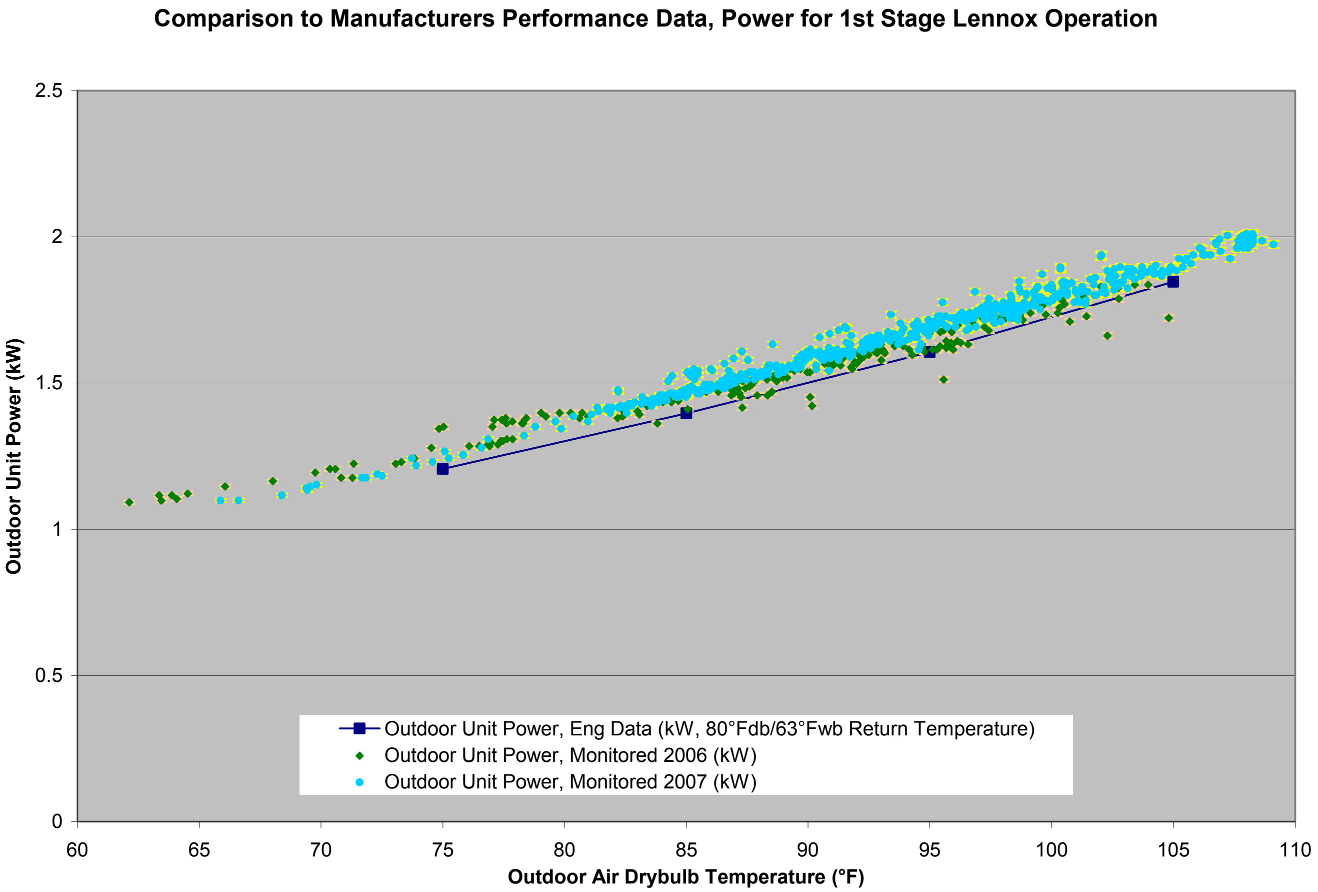

Figure 25 SEER 21 Power Comparison, 1st Stage Operation

The manufacturer's data agrees with the field monitored data for power draw, with the filed data only showing a very slight trend towards a higher power draw during 1st stage operation. Figure 26 shows the comparison of Manufacturer's total cooling capacity data compared to field monitored data for the SEER 21 air conditioner in 1st stage cooling at the East Star site.

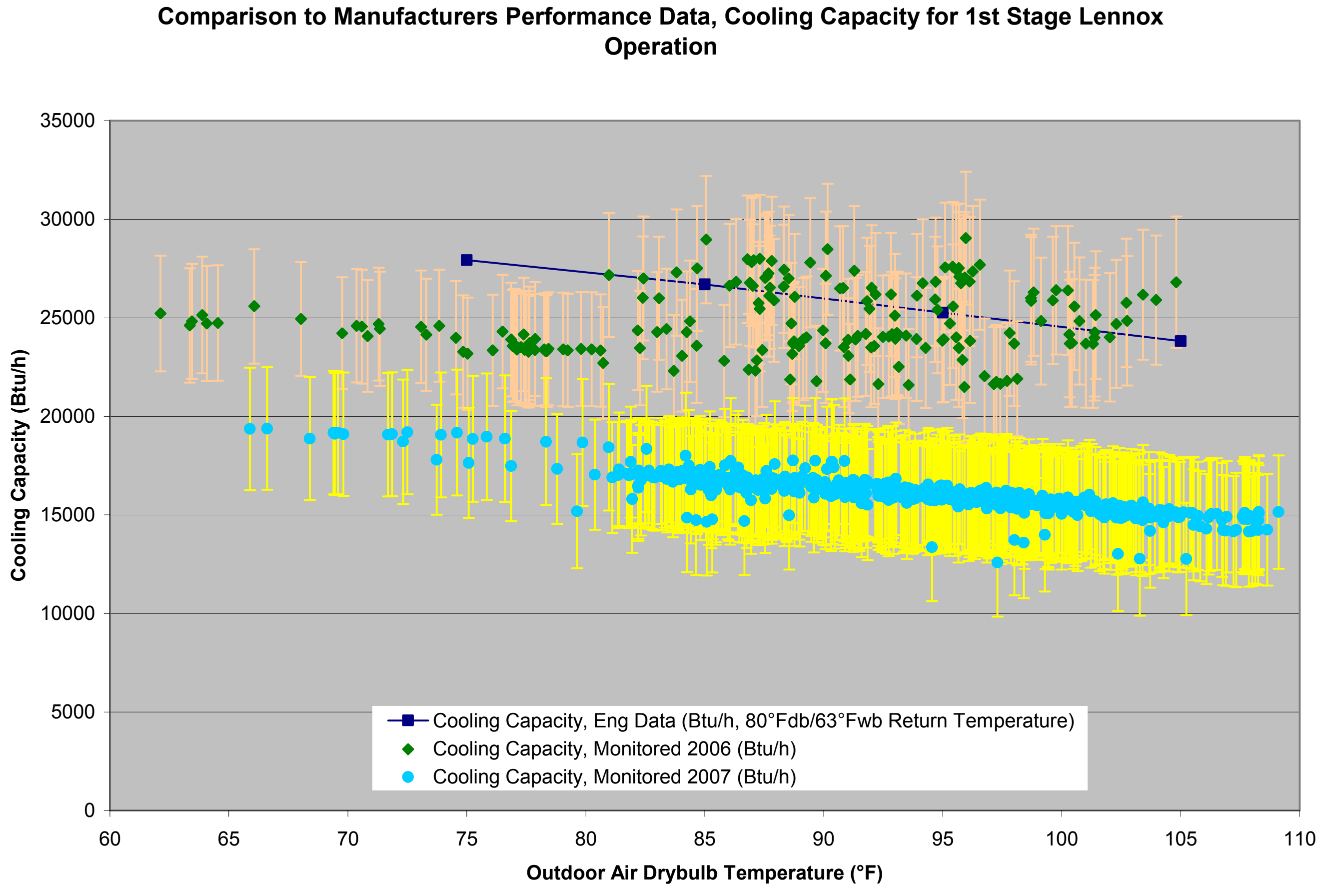

Figure 26 SEER 21 Total Cooling Capacity Comparison, 1st Stage Operation

The 2006 total cooling capacity data compared well with manufacturer's data, however the supply and return duct temperature and relative humidity sensors were replaced at this location before the summer 2007 cooling season. NREL staff suspected that the sensors installed for the 2006 cooling season were giving false readings and replaced the sensors in January and May of 2007.

Insert Thermal Test Facility HVAC loop to Viasala T&RH sensor comparison data here

Figure 27 shows the sensible cooling capacity comparison for the SEER 13 air conditioner.

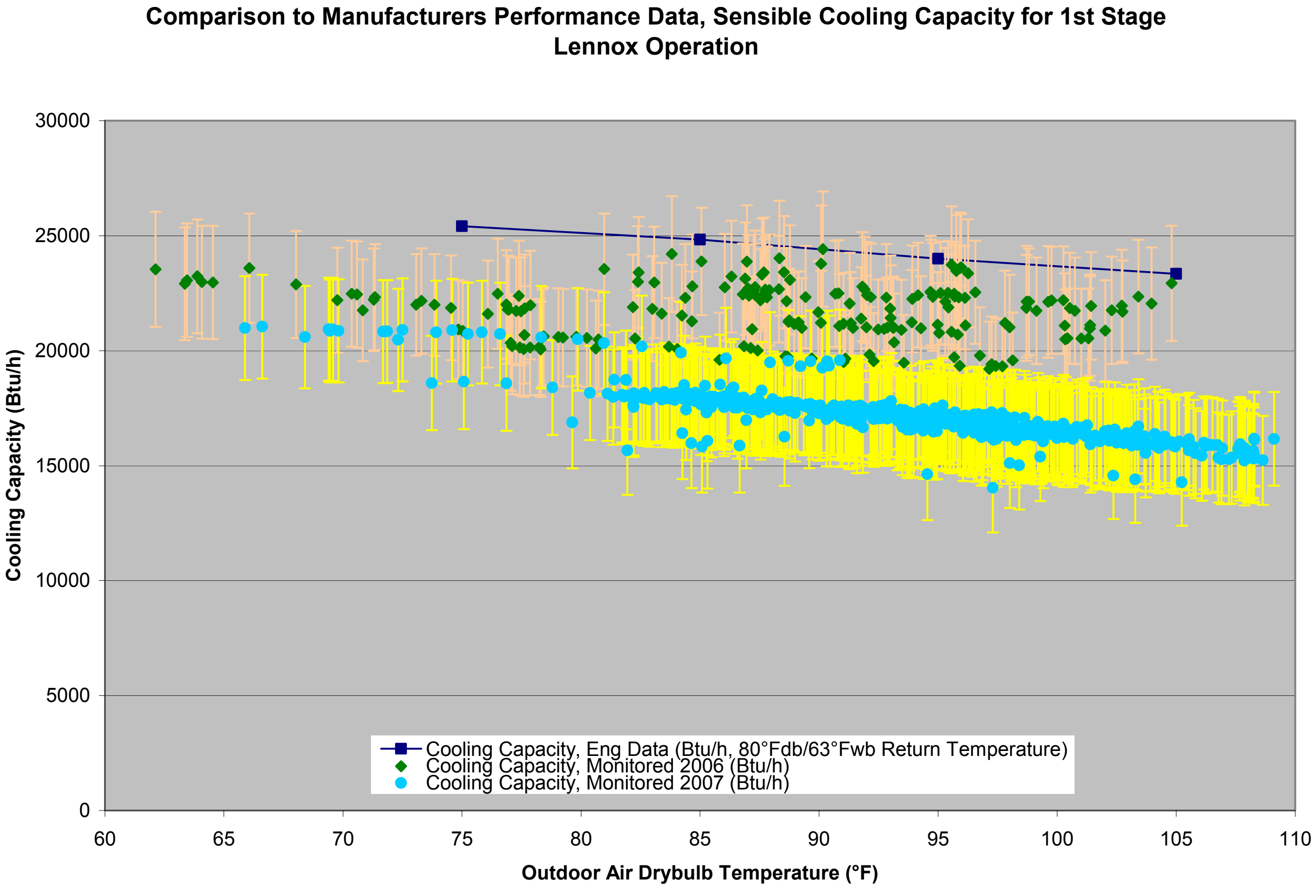

Figure 27 Sensible Cooling Capacity Comparison for SEER 13 Air Conditioner

Sensible cooling capacity for 1st stage operation shows a similar difference in performance of the unit from 2006 to 2007 that we currently believe to be sensor related as described above.

Figure 28 shows the comparison of Manufacturer's power draw data to field monitored data for the SEER 21 air conditioner in 2nd stage cooling at the East Star site.

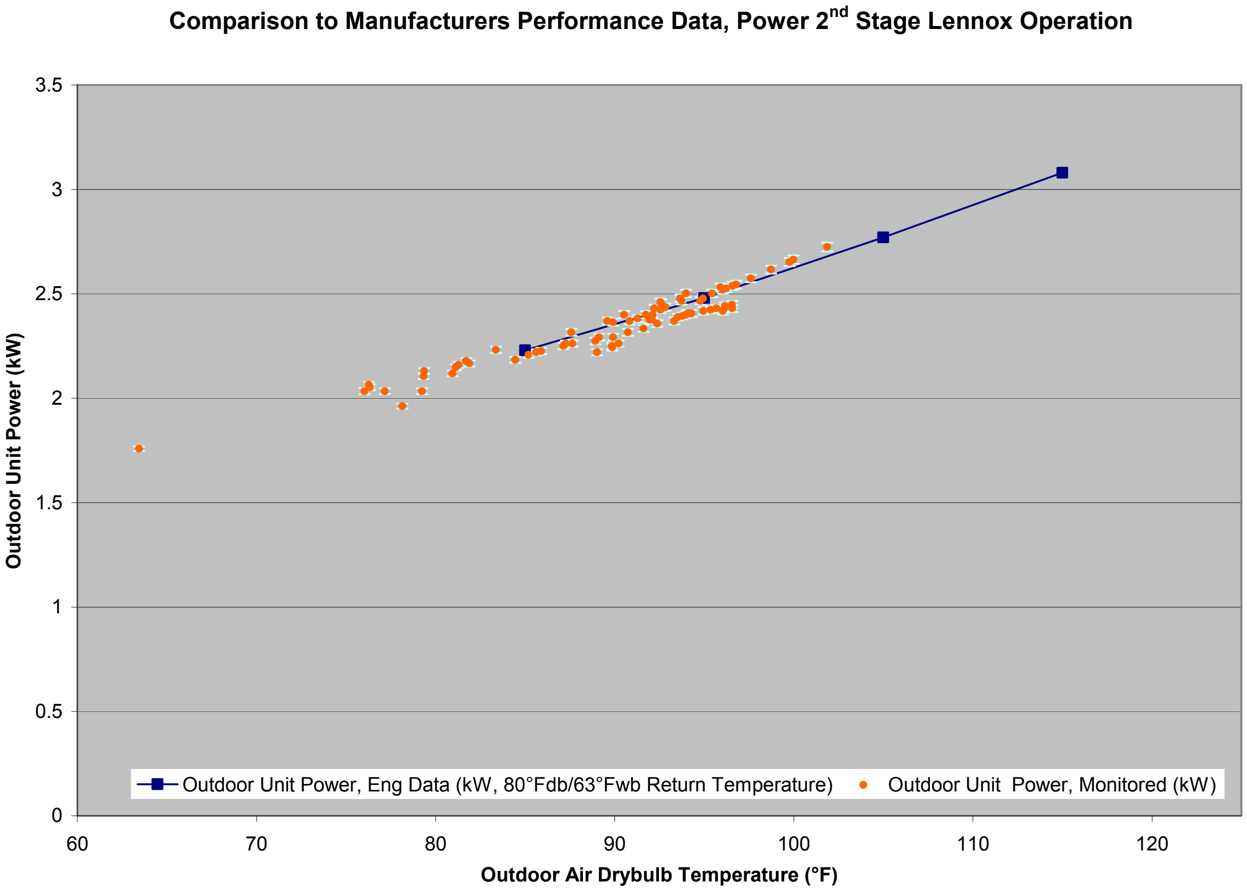

Figure 28 SEER 21 Outdoor Unit Power Comparison, 2nd Stage Operation

The comparison to manufacturers power draw is presented for the condensing unit only as including the air handler in the comparison would complicate the comparison unnecessarily due to the difficulty in knowing the duct system static pressure when the system operates (currently there is no measurement of duct system static pressure). Overall in 1st or 2nd stage the field measurements show good agreement to the manufacturer’s data.

Figure 29 shows the comparison of Manufacturer’s total cooling capacity data compared to field monitored data for the SEER 21 air conditioner in 2nd stage cooling at the East Star site.

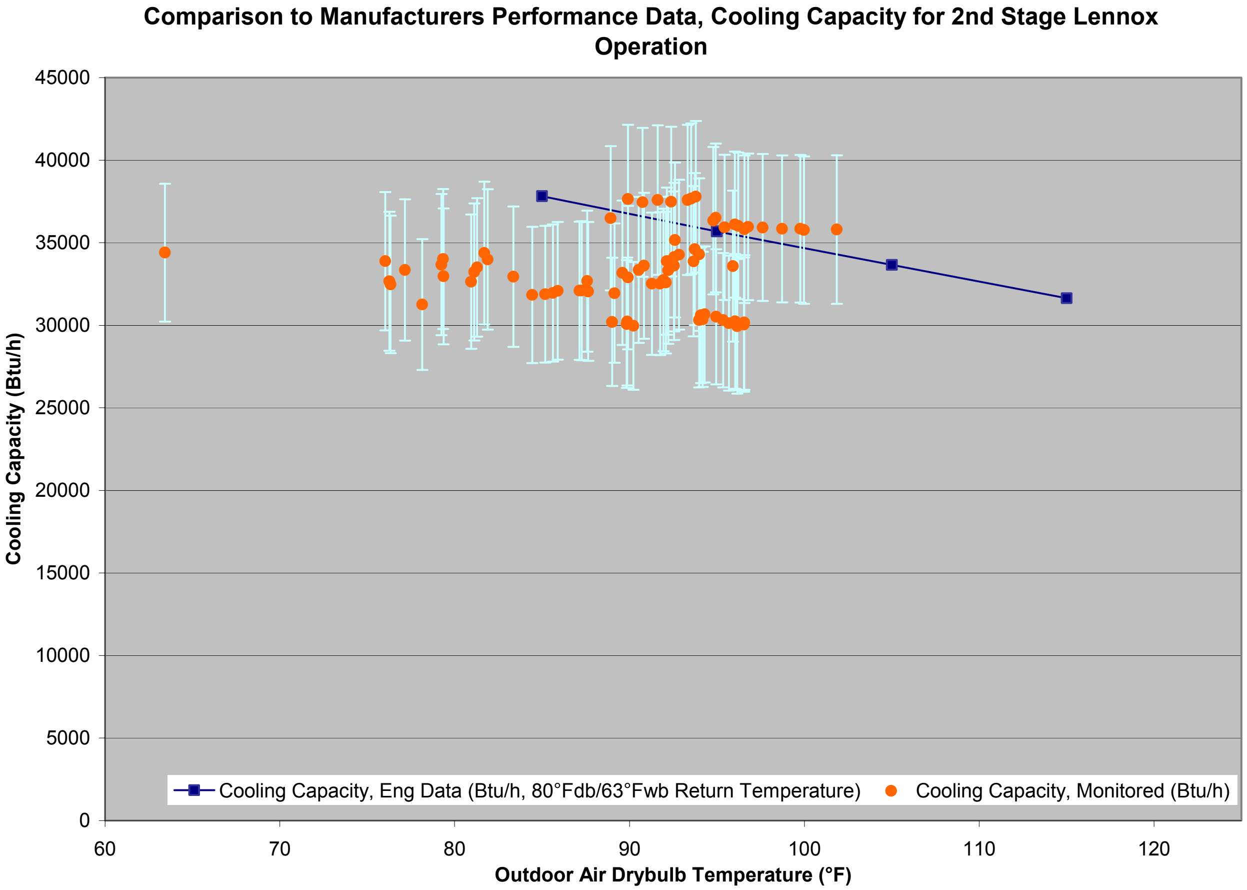

Figure 29 SEER 21 Total Cooling Capacity Comparison, 2^{nd} Stage Operation

Figure 30 shows the sensible cooling capacity comparison for the SEER 13 air conditioner.

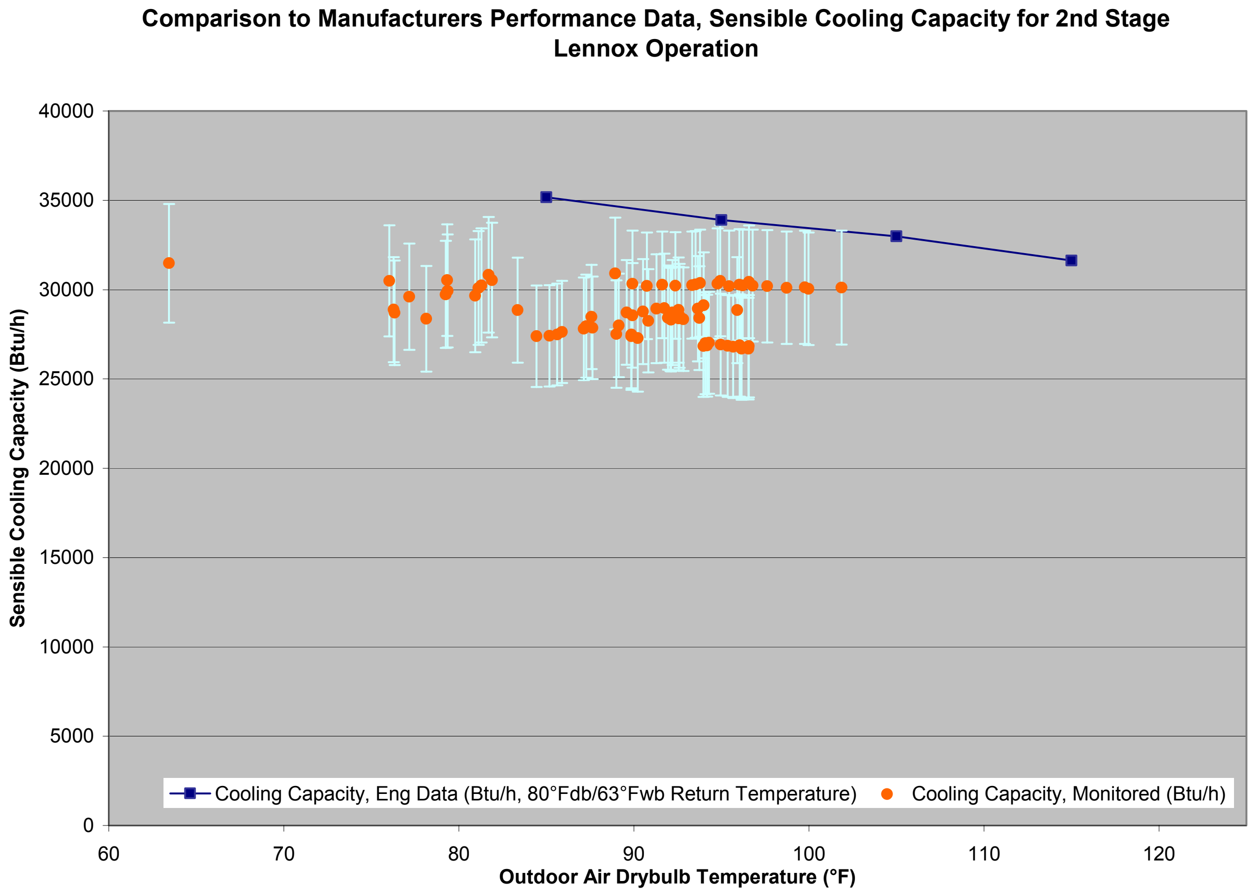

Figure 30 Sensible Cooling Capacity Comparison for SEER 13 Air Conditioner

Data for the SEER 21 air conditioner was only considered from August 2006 until the end of the 2006 cooling season in Borrego due to a relative humidity sensor that appeared to be calibrated incorrectly. As a temporary fix DEG engineers put the air handler fan into “fan only” operation and compared the RH measurement at the supply duct to the RH measurement on the suspect return sensor. DEG engineers modified the datalogger program to included an offset in the RH measurement at the return after collecting several hours of fan only data and accounting for fan heat added to the air stream by the air handler fan. Unfortunately, data from some of the warmer parts of the summer are not available due to the problem with the return RH sensor. This sensor was replaced by NREL staff in a January 2007 site visit in preparation for the 2007 cooling season testing. The comparison shows the measured power for first and second stage operation of the condensing unit appears to agree with the measured data. The measured cooling capacity during 1st and 2nd stage operation is somewhat suspect due to the limitations of the fix that was performed on the return sensor RH measurement. During the May 2007 visit the new return sensor, the old supply sensor and an extra temperature and relative humidity sensor were compared and in consultation with DEG engineers the original supply sensor was replaced so that the original sensor could be evaluated in the NREL HVAC test loop. 2nd stage cooling was disabled for the first half of the 2007 cooling season in order to focus on 1st stage performance.

Figure 31 shows the EER comparison for the SEER 21 air conditioner in 1st stage operation.

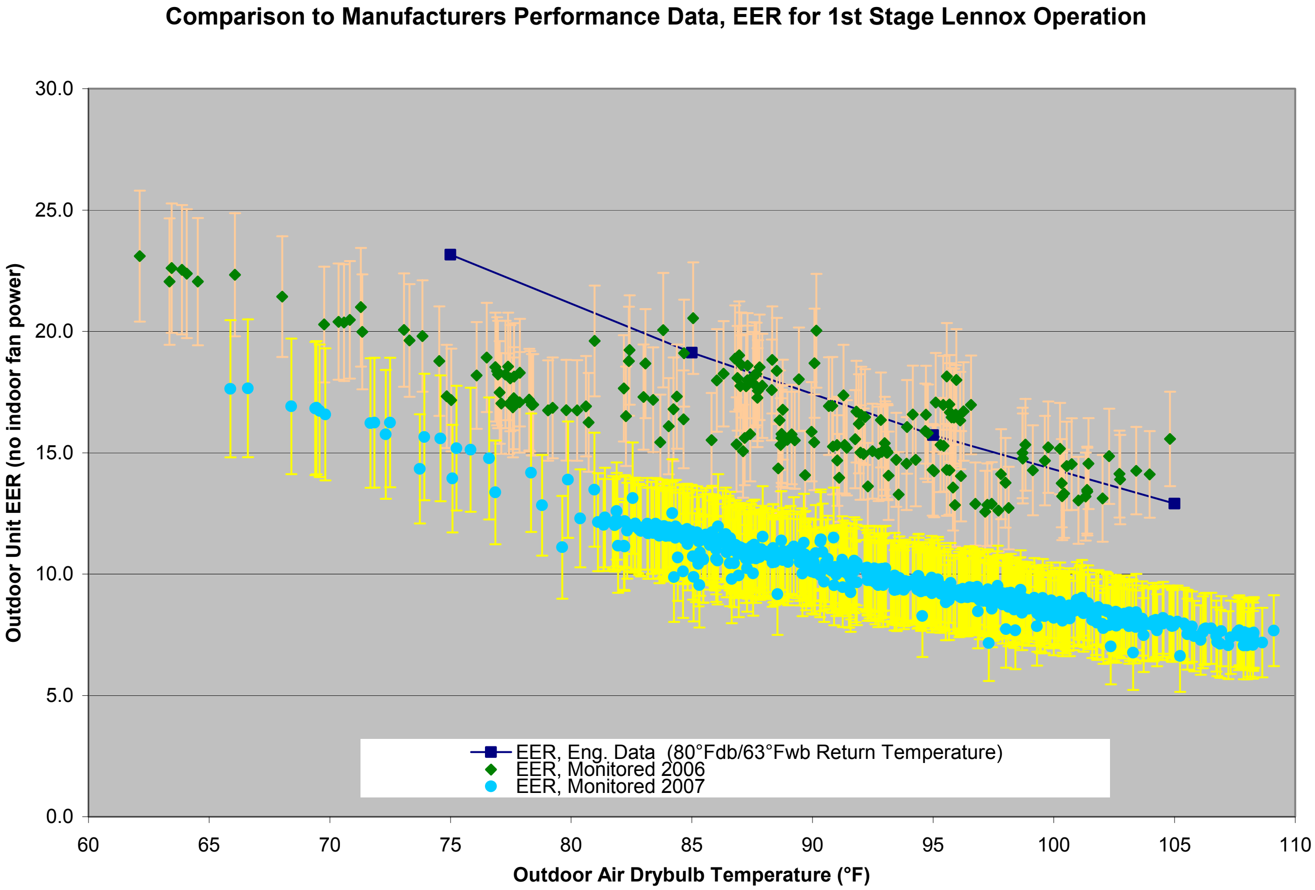

Figure 31 EER Comparison for SEER 21 Air Conditioner, 1st Stage Operation

Figure 32 shows the EER comparison for the SEER 21 air conditioner in 2nd stage operation.

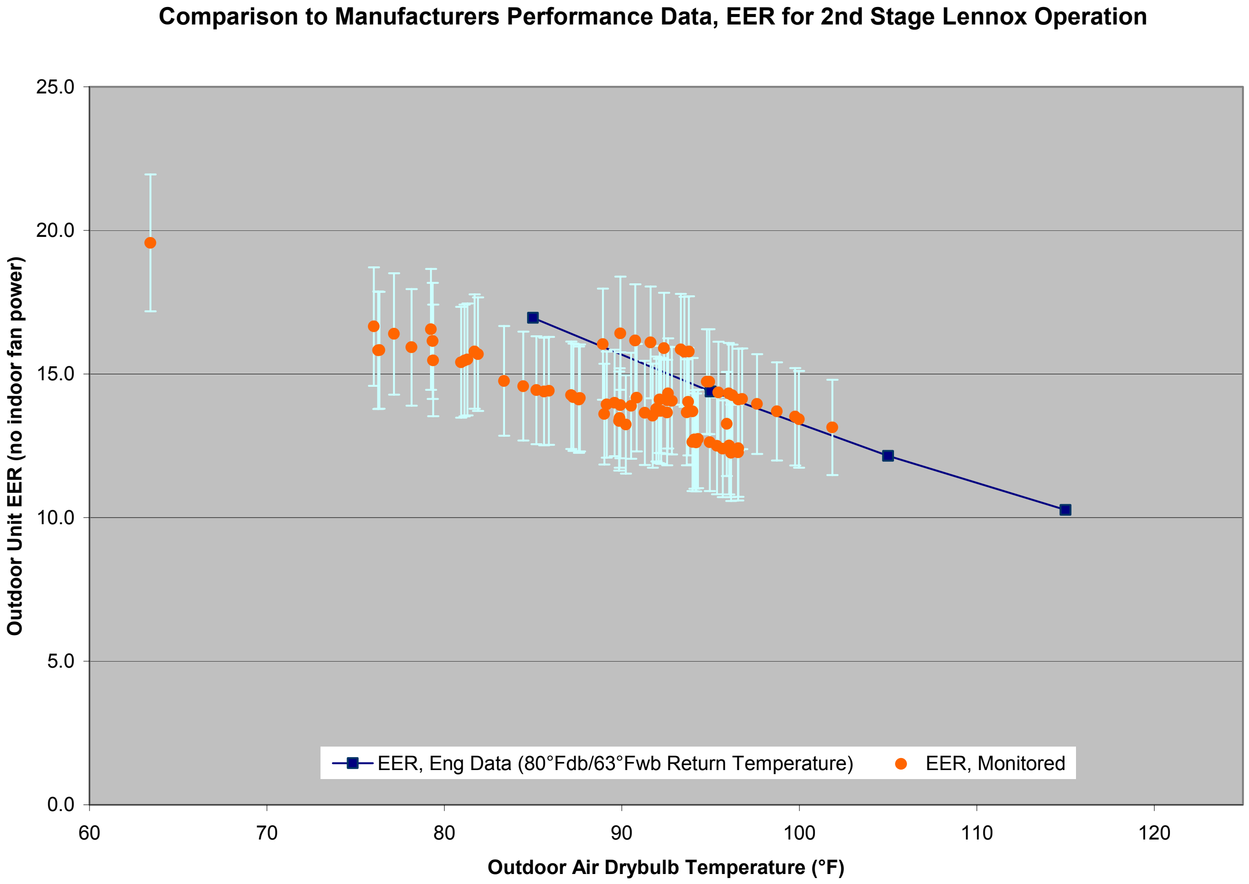

Figure 32 EER Comparison for SEER 21 Air Conditioner, 2nd Stage Operation

The measured EER during 1st and 2nd stage operation is somewhat suspect due to the limitations of the fix that was performed on the return sensor RH measurement and the potentially false readings from the supply and return temperature and relative humidity sensors. While the measured EER appears to be in line or exceeding the manufacturer's expectations for 2006, our approach would be to gather additional data during the 2007 cooling season in order to verify the EER of the Lennox unit before arriving at a conclusion as to whether the unit performs according to manufacturer's expectations on not.

Conclusions

Several important observations can be made based on the preceding test and analysis results:

Infiltration

Duct Leakage

Airflows

Exhaust Ventilation

Thermal Performance

HVAC Energy Consumption

Summary

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