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Geothermal Heat Pump Consortium

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Task 4 Memorandum
Field Evaluation of Early Problem Sites

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Introduction

The Ground Source Heat Pump Consortium has commissioned a study of customer complaints within the first year after heat pump installation. The fourth task in this study was an on-site evaluation of problem systems. The site visits have been completed and the results are outlined in this document, and detailed in the Appendices.

Customer Selection

Ten customers were selected for on-site evaluations from the pool of eighteen phone survey participants. The selected sites are representative of the most common problems reported in the phone surveys. Eight of the ten of the customers reported they had unresolved problems at the time of the phone survey.

The ten customers live in five states (all in the northeast section of the country). Five of the selected customers have open loop systems and five have closed loop systems. Seven of the customers have newly constructed homes and the remaining three homes have a retrofit GHP. Two of the three retrofit GHP homes had new duct systems installed at the time of the GHP installation.

On-Site Evaluation Description

The on-site evaluation was comprehensive enough to both determine the deficiency causing the customer complaint and also other deficiencies that may be hidden to the customer. The on-site testing was more comprehensive than the diagnostics needed to evaluate the cause of the customers complaint. For example all houses had an ACCA Manual J design heat gain/loss calculation completed and the results compared to installed capacity at design conditions.

The parameters measured/gathered included:

1. Detailed information regarding the customers complaint and the contractors actions taken to address the complaint.
2. Detailed information on customer thermostat control patterns.
3. Site plans and specifications, to the extent available, for GHP system sizing, duct system sizing and design, ground loop heat exchanger sizing and design.
4. Equipment manufacturer and model numbers for GHP and manufacturers specifications for the equipment.
5. ACCA Manual J design heat loss and gain.
6. Building shell leakage measured with a blower door.
7. Supply and return duct leakage , measured with a Duct Blaster™.
8. Total air flow through the indoor coil measured with a Duct Blaster™ or with a strip heat air flow test.
9. Air flow from problem supply registers, measured with a flow hood.
10. Ground loop antifreeze type and concentration (where identifiable through on-site tests).
11. System refrigerant charge, based on subcooling or superheat.
12. System heating capacity - air side and ground loop.
13. Electrical input for GHP and circulating pump, measured with the utility house meter.
14. System Coefficient of Performance (COP).

Reported Problems

Customer reported problems fell into four groups; high operating cost, customer discomfort, system shut down, and noisy operation. For the on-site sample, the original phone survey ranked the occurrence of the problems as;

- High operating cost (8)
- Shut down (5)
- Discomfort (3)
- Noisy system (2)

Based on the on-site interviews, the order of reported problems changed to;

- Discomfort (10)
- High operating cost (9)
- Shut down (7)
- Noisy system (5)

All of the customers reported some thermal discomfort associated with their GHP. The most common problem is lack of conditioning in specific areas of the home (i.e. a certain room or even an entire level of the home).

Identified Causes

All of the homes received extensive testing to determine the deficiencies. Every home in the sample had multiple problems. Appendix A contains house by house problem tabulations and customer reported problems. Figure 1 presents the predominant significant causes of the customer complaints.

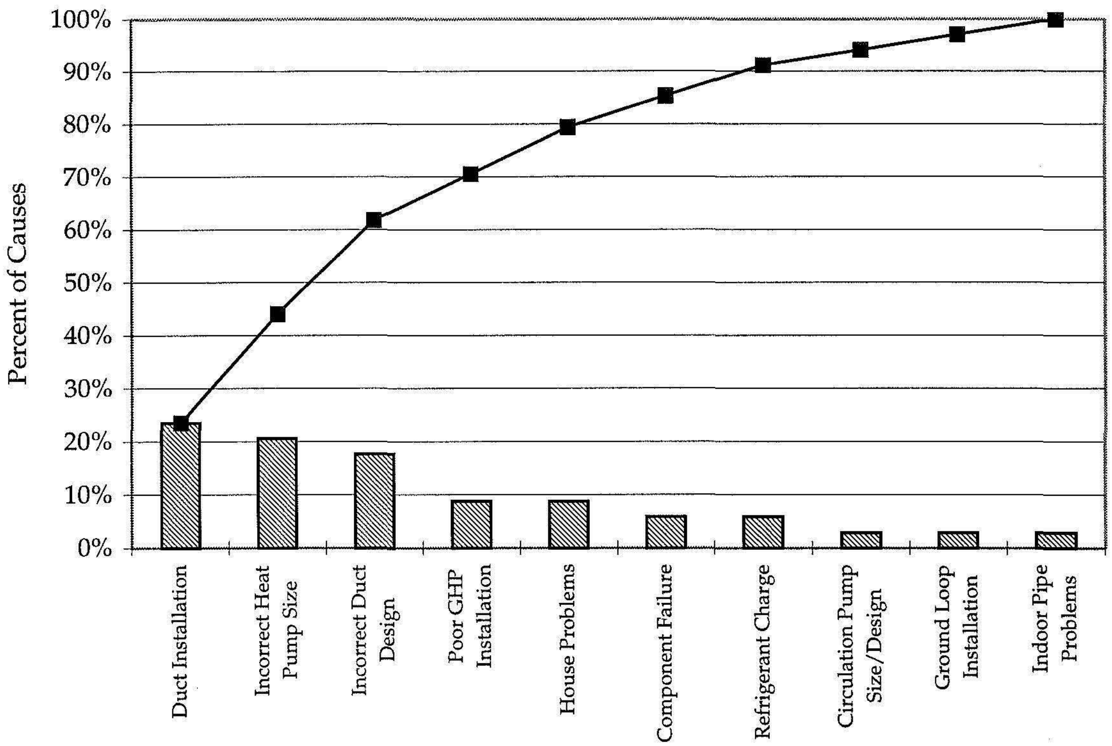

Figure 1. Predominant Causes of Early Complaints

Duct Installation

Duct leakage was measured using the Duct Blaster™ (as described in Appendix B). The investigators found significant total leakage[1] and leakage to outside the structure. The total supply leakage averaged 340 CFM and the average return leakage was 302 CFM. Each of these represent about 25% of the system flow. Total leakage indicates how much conditioning energy is being delivered in an uncontrolled manner (often resulting in temperature imbalances in the home). Duct leakage to outside has the most detrimental effects, resulting in lost capacity and increased infiltration. The average supply system leakage to outside was 10.7% of the system flow. The average return system leakage to outside was 10.1% of the system flow.

[1] Total duct leakage includes unintended leakage to inside the structure and leakage to outside the structure.

Customer C008 provides an example of the problems found in the duct systems. The customer complained that the bedrooms were cold and hard to heat. The problem system had supply system leakage to outside of 23.3% of the system flow and a return system leakage to outside of 38.4% of the system flow. An examination of the duct system found obvious leakage areas that could have easily been addressed including the duct run to the sons bedroom which was partially disconnected. The customers complaints to the installing contractor about the discomfort and high utility bills were not satisfactorily addressed so they called in a second contractor. While the second contractor did not find the duct leakage problems they did find that the installing contractor disabled the auxiliary strip heat in an attempt to lower the customers utility bills. Neither contractor noticed that the first stage compressor was locked out on the low water temperature cut out.

Incorrect Heat Pump Size

The equipment sizing problem was mainly associated with high operating cost complaints. Heat pumps were often undersized for the heating load of the house, further compounded by poor installation quality resulting in the capacity of the system not meeting the manufacturers specifications. The exact cause of the inadequate sizing was not determined - no documentation was available of original design load calculations. The undersizing may be an attempt to reduce first costs or it may be due to inaccurate load calculations.

Heat pump sizing was the main cause of the customer complaint at four sites. These units were undersized an average of 40% in heating. Seven of the ten sites had heat pumps with design capacities[2] less than 75% of calculated design heating load. Four of the five closed loop systems were inadequately sized for heating. Ground loop cost minimization may contribute to undersizing.

Customer C012, for example, has a heat pump rated at 63% of design heating load. The customer had expected annual heating costs around $700. This customer's winter electric bills in are as high as $600 per month. The customer now sets the thermostat at 67° to reduce the bills. The spouse is uncomfortable preferring temperatures in the 69° to 70° range.

None of the customers had concerns about cooling costs. All sites had excess cooling capacity. The excess capacity averaged 1.7 tons (in high speed). Several of the GHP systems had dual stage compressors. The amount of oversizing in the cooling mode might not be that severe, assuming the system was operating correctly.

Duct System Design

Duct system design problems caused both high operating costs and discomfort. Duct problems included failure to condition particular areas, high static pressure, and noise.

The primary duct design issue was poor delivery of conditioned air to sections of the home. Restrictive duct runs to the problem areas and/or duct leakage are the primary causes of this problem.

The external static pressures in the duct systems were at the upper end of the acceptable range. The average external static pressure for the systems was 0.41 inches of water column. The

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[2] Based on a entering water temperature of 50°F for open loop systems and 30°F for closed loop systems.

standard rate of flow through the indoor coil is usually 400 CFM per nominal ton of cooling capacity. The average air flow was 344 CFM per ton, with the worst system measured at only 275 CFM per ton. The average flow rate is 14% below the target.

An additional problem was noise from high velocity discharge at registers. Three of the ten sites had customer complaints about the noise from at least one register. Customer C011 had a combination of a noisy return and a hard to condition section of the house. The contractor said the problem was the fan motor. He later told the customer that it was the well pump. After several battles with the contractor, return grilles were added. This modification produced additional conditioning in the problem area and reduced return system noise.

Poor GHP Installation and Service

The thirdmost common cause of problems was the quality of the installation and subsequent service visits. The numerous installation problems included: incorrect refrigerant charge, incorrect control wiring, misdiagnosis of control problems, leaky ground loop connections, pump problems, and on and on. Many of the customers interviewed did not have faith in the installing contractors ability to correctly install or service the GHP system.

Customer C014 had problems with their system shutting down within a week of installation. After several trips the contractor discovered that the dip switch had been set for the wrong type of system so the system was shutting down on the low temperature cut out. This was just the beginning of their problems. There were problems with the piping, system component failure, the duct system and equipment and ground loop sizing. The problems were eventually solved by having the contractor install a larger GHP, more ground loop and fix the duct system. The cost of the changes to the system were $30,000.

Water Heating Problems

Nine of the customers had a domestic hot water heating option. Three of these customers did not use the water heating option. Two customers had their domestic hot water option turned off to "save money and supply more heat to the house" and one had it turned off due to continual control problems with a prototype on demand hot water system.

Customer in the Middle Problems

Five of the customers reported conflicts with the contractor and/or manufacturer while trying to get their systems fixed. Conflicts centered around the contractor and manufacturer "passing the buck". Contractors sometimes blamed the problems on faulty components while manufacturers sometimes refused to honor warranties and/or delayed replacement part delivery because the component failure was due to the contractors actions. Most of the reported problems between installing contractors and manufacturers left the customer caught in the middle of the dispute with a system that didn't function properly.

For example, Customer C008 had a heat pump installed in an unconditioned attic. The heat exchanger froze and ruptured, sending water onto the customers ceiling. The installing contractor attempted to get the manufacturer to replace the heat exchanger but the manufacturer refused because the contractor had not followed their policies in installing the unit. The customer subsequently insulated the attic area and the contractor cut a hole in the supply plenum to heat the attic. The contractor repaired the heat exchanger on his own but created a blockage in the heat exchanger (this system has a double heat exchanger and two compressors). The first stage compressor is now continuously locked out on the low temperature cut out and the system runs on only one compressor. This results in excessive resistance back up heating and high bills. This customer had one month with an electric bill of $1500.

Three of the customers reported that the installing contractor was either unresponsive or unqualified to rectify the deficiencies in their system. All three had to contact outside parties to get their installing contractor to attempt to fix deficiencies with their system, one customer had to go to the state regulatory board to get action. It was generally felt that many of the technicians did not have a good grasp of the of geothermal heat pumps, their installation, and their service requirements.

APPENDIX A

CUSTOMER TABULATIONS

Customer # C002

Contractor/Manf/Customer Conflict	Loop Type	House Type	Water heater present	Water heater used	Water heater problems
Yes	Open	Retrofit	Yes	Yes	No

Problem	Comfort Problems	High Operating Cost	Shut Down	Noisy System	Complaint Resolved
Customer Reported Problem	Yes	Yes	Yes	Yes	No

	Causes					
1	Customer Understanding					
2	Customer Operation					
3	Incorrect Heat Pump Size	Yes	Yes			
4	Incorrect Duct Size/Design	Yes	Yes		Yes	
5	Ground Loop Size/Design					
6	Circulation Pump Size/Design		Yes			
7	GHP Equipment Installation				Yes	
8	Duct Installation (leakage, R-value)	Yes	Yes			
9	Ground Loop Installation					
10	Circulation Pump Installation					
11	Other Well Problems					
12	Component Failure	Yes	Yes	Yes		
13	Control Problems					
14	House Problems	Yes				
15	Low Capacity		Yes			
16	Low COP		Yes			
17	Refrigerant Charge	Yes	Yes	Yes		
18	Compressor noise				Yes	
19	Indoor piping problems				Yes	

Main cause	# 1 cause	# 2 cause	# 3 cause	# 4 cause
Incorrect Heat Pump Size	3	17	8	14

Notes:

Customer stated main problem is heat pump doesn't meet the load of the house when outdoor temperature is below 30 degrees. Unit is sized at 67% of Manual J. Overcharged refrigerant system is suspected of causing component failure. Supply system total leakage is 22% of system flow, return system total leakage is 32% of system flow. 175 year old stone house with little insulation.

Customer # C004

Contractor/Manf/Customer Conflict	Loop Type	House Type	Water heater present	Water heater used	Water heater problems
No	Closed	Retrofit	Yes	Yes	Yes

Problem	Comfort Problems	High Operating Cost	Shut Down	Noisy System	Complaint Resolved
Customer Reported Problem	Yes	Yes	No	Yes	No

	Causes					
1	Customer Understanding					
2	Customer Operation		Yes			
3	Incorrect Heat Pump Size	Yes	Yes			
4	Incorrect Duct Size/Design	Yes	Yes			
5	Ground Loop Size/Design					
6	Circulation Pump Size/Design		Yes		Yes	
7	GHP Equipment Installation					
8	Duct Installation (leakage, R-value)	Yes	Yes		Yes	
9	Ground Loop Installation					
10	Circulation Pump Installation		Yes		Yes	
11	Other Well Problems					
12	Component Failure					
13	Control Problems	Yes	Yes			
14	House Problems	Yes				
15	Low Capacity		Yes			
16	Low COP		Yes			
17	Refrigerant Charge					
18	Compressor noise					
19	Indoor piping problems		Yes			

Main cause	# 1 cause	# 2 cause	# 3 cause	# 4 cause
Incorrect Heat Pump Size	3	4	8	6

Notes:
Main problem is that the heat pump is not correctly sized. Unit is sized at 65% of Manual J. This problem is compounded by low operating capacity and COP. The return duct system is undersized (return operating static pressure is 0.42" w.c.). Customer has had several problems with the indoor portion of the loop (noise and leaks), a second contractor said the design had too much restriction. Also installation included the wrong type of circulating pump (jet pump) which is noisy and inefficient.

Customer # C006

Contractor/Manf/Customer Conflict	Loop Type	House Type	Water heater present	Water heater used	Water heater problems
No	Open	New	Yes	No	Yes

Problem	Comfort Problems	High Operating Cost	Shut Down	Noisy System	Complaint Resolved
Customer Reported Problem	Yes	Yes	Yes	Yes	No

	Causes					
1	Customer Understanding					
2	Customer Operation					
3	Incorrect Heat Pump Size					
4	Incorrect Duct Size/Design			Yes		
5	Ground Loop Size/Design					
6	Circulation Pump Size/Design					
7	GHP Equipment Installation					
8	Duct Installation (leakage, R-value)	Yes				
9	Ground Loop Installation					
10	Circulation Pump Installation					
11	Other Well Problems		Yes			
12	Component Failure			Yes		
13	Control Problems					
14	House Problems					
15	Low Capacity					
16	Low COP					
17	Refrigerant Charge					
18	Compressor noise				Yes	
19	Indoor piping problems					

Main cause	# 1 cause	# 2 cause	# 3 cause	# 4 cause
Component Failure	12			

Notes:

The customers main complaint is the amount of component failure that has taken place. They are unhappy with the manufacturers quality of product and support (customer stated "he would be willing to join a class action suit in a heartbeat"). To date demand hot water system has totally failed, blower motor has failed four times, reversing valve has failed and compressor sounds like it's ready to fail. Customer has been told by the contractor that the compressor and heat exchanger are no longer available.

Customer # C007

Contractor/Manf/Customer Conflict	Loop Type	House Type	Water heater present	Water heater used	Water heater problems
No	Open	New	Yes	Yes	No

Problem	Comfort Problems	High Operating Cost	Shut Down	Noisy System	Complaint Resolved
Customer Reported Problem	Yes	Yes	Yes	No	No

	Causes					
1	Customer Understanding					
2	Customer Operation		Yes			
3	Incorrect Heat Pump Size	Yes	Yes			
4	Incorrect Duct Size/Design	Yes	Yes			
5	Ground Loop Size/Design					
6	Circulation Pump Size/Design					
7	GHP Equipment Installation					
8	Duct Installation (leakage, R-value)	Yes	Yes			
9	Ground Loop Installation					
10	Circulation Pump Installation					
11	Other Well Problems					
12	Component Failure					
13	Control Problems	Yes	Yes	Yes		
14	House Problems		Yes			
15	Low Capacity					
16	Low COP		Yes			
17	Refrigerant Charge					
18	Compressor noise					
19	Indoor piping problems					

Main cause	# 1 cause	# 2 cause	# 3 cause	# 4 cause
Incorrect Heat Pump Size	3	4	8	14

Notes:
Main problem is the size of the heat pump serving one zone of the house. The whole house sizing is adequate but the one zone the customer complains about is sized at only 67% of manual J. Customer is conditioning a sunroom that was not part of the original design. Supply system leakage to outside is 11% of system flow, return system leakage from outside is 26% of system flow. Customer expressed a concern that they have done all they can but the system still uses a lot of auxillary heat.

Customer # C008

Contractor/Manf/Customer Conflict	Loop Type	House Type	Water heater present	Water heater used	Water heater problems
Yes	Open	New	Yes	No	No

Problem	Comfort Problems	High Operating Cost	Shut Down	Noisy System	Complaint Resolved
Customer Reported Problem	Yes	Yes	Yes	No	No

	Causes					
1	Customer Understanding					
2	Customer Operation					
3	Incorrect Heat Pump Size		Yes			
4	Incorrect Duct Size/Design	Yes		Yes		
5	Ground Loop Size/Design					
6	Circulation Pump Size/Design					
7	GHP Equipment Installation	Yes	Yes	Yes		
8	Duct Installation (leakage, R-value)	Yes	Yes			
9	Ground Loop Installation					
10	Circulation Pump Installation					
11	Other Well Problems					
12	Component Failure					
13	Control Problems					
14	House Problems	Yes				
15	Low Capacity					
16	Low COP					
17	Refrigerant Charge					
18	Compressor noise					
19	Indoor piping problems					

Main cause	# 1 cause	# 2 cause	# 3 cause	# 4 cause
GHP Equipment Installation	7	4	8	3

Notes:

Main problem is that one of the water coils has no flow through it. This was missed by the installer and another contractor who had recently looked at unit; even though one compressor was locked out due to the lack of flow. Duct system design causes unbalanced heating and cooling of house. Duct system operating static pressure is 0.76"w.c. Supply system leakage to outside is 23% of system flow, return system leakage from outside is 38% of system flow.

Customer # C011

Contractor/Manf/Customer Conflict	Loop Type	House Type	Water heater present	Water heater used	Water heater problems
Yes	Open	New	Yes	Yes	No

Problem	Comfort Problems	High Operating Cost	Shut Down	Noisy System	Complaint Resolved
Customer Reported Problem	Yes	No	Yes	Yes	No

	Causes					
1	Customer Understanding					
2	Customer Operation					
3	Incorrect Heat Pump Size				Yes	
4	Incorrect Duct Size/Design	Yes			Yes	
5	Ground Loop Size/Design					
6	Circulation Pump Size/Design					
7	GHP Equipment Installation			Yes		
8	Duct Installation (leakage, R-value)	Yes		Yes	Yes	
9	Ground Loop Installation					
10	Circulation Pump Installation					
11	Other Well Problems					
12	Component Failure			Yes		
13	Control Problems					
14	House Problems					
15	Low Capacity					
16	Low COP					
17	Refrigerant Charge					
18	Compressor noise					
19	Indoor piping problems			Yes	Yes	

Main cause	# 1 cause	# 2 cause	# 3 cause	# 4 cause
Duct Installation (leakage, R-value)	3	8	4	19

Notes:

Customers main problem was with the noise created by system. Installing contractor has replaced the original heat pump with a smaller heat pump and made modifications to the ducts to reduce noise. Remaining noise is due to pipe vibrations and duct system velocity.

Customer # C012

Contractor/Manf/Customer Conflict	Loop Type	House Type	Water heater present	Water heater used	Water heater problems
No	Closed	New	No	No	No

Problem	Comfort Problems	High Operating Cost	Shut Down	Noisy System	Complaint Resolved
Customer Reported Problem	Yes	Yes	No	Yes	No

	Causes					
1	Customer Understanding					
2	Customer Operation					
3	Incorrect Heat Pump Size		Yes			
4	Incorrect Duct Size/Design		Yes		Yes	
5	Ground Loop Size/Design					
6	Circulation Pump Size/Design					
7	GHP Equipment Installation					
8	Duct Installation (leakage, R-value)		Yes			
9	Ground Loop Installation					
10	Circulation Pump Installation					
11	Other Well Problems					
12	Component Failure					
13	Control Problems		Yes			
14	House Problems		Yes			
15	Low Capacity					
16	Low COP					
17	Refrigerant Charge					
18	Compressor noise				Yes	
19	Indoor piping problems					

Main cause	# 1 cause	# 2 cause	# 3 cause	# 4 cause
Incorrect Duct Size/Design	4	3	8	

Notes:
Main problem is that the heat pump is not correctly sized. Unit is sized at 63% of Manual J. Noise from duct system is also a problem for the customer. Installing contractor has made modifications but customer is still not satisfied with the noise associated with the comfort problems are due to customer keeping thermostat set point lower than spouses desired set point to avoid high bills. Supply system total leakage is 13% of system flow, return system total leakage is 14% of system flow.

Customer # C014

Contractor/Manf/Customer Conflict	Loop Type	House Type	Water heater present	Water heater used	Water heater problems
Yes	Closed	New	Yes	Yes	No

Problem	Comfort Problems	High Operating Cost	Shut Down	Noisy System	Complaint Resolved
Customer Reported Problem	Yes	Yes	Yes	No	Yes

	Causes					
1	Customer Understanding					
2	Customer Operation					
3	Incorrect Heat Pump Size	Yes	Yes			
4	Incorrect Duct Size/Design	Yes	Yes			
5	Ground Loop Size/Design					
6	Circulation Pump Size/Design					
7	GHP Equipment Installation	Yes	Yes	Yes		
8	Duct Installation (leakage, R-value)	Yes	Yes			
9	Ground Loop Installation					
10	Circulation Pump Installation					
11	Other Well Problems					
12	Component Failure					
13	Control Problems			Yes		
14	House Problems	Yes	Yes			
15	Low Capacity					
16	Low COP					
17	Refrigerant Charge					
18	Compressor noise					
19	Indoor piping problems					

Main cause	# 1 cause	# 2 cause	# 3 cause	# 4 cause
Incorrect Heat Pump Size	3	7	8	4

Notes:

Main problem was heat pump sizing. Customer is now happy that they have gotten more ground loop and a larger heat pump installed the duct system rebuilt and insulation added to the house. The cost of the additional work to make the customer happy was approximately $30,000. Customer has had numerous problems with the installing contractors inability to correct the deficiencies.

Customer # C015

Contractor/Manf/Customer Conflict	Loop Type	House Type	Water heater present	Water heater used	Water heater problems
Yes	Closed	New	Yes	Yes	No

Problem	Comfort Problems	High Operating Cost	Shut Down	Noisy System	Complaint Resolved
Customer Reported Problem	Yes	Yes	Yes	No	No

	Causes					
1	Customer Understanding					
2	Customer Operation					
3	Incorrect Heat Pump Size					
4	Incorrect Duct Size/Design	Yes	Yes			
5	Ground Loop Size/Design					
6	Circulation Pump Size/Design					
7	GHP Equipment Installation					
8	Duct Installation (leakage, R-value)	Yes	Yes			
9	Ground Loop Installation		Yes	Yes		
10	Circulation Pump Installation		Yes			
11	Other Well Problems					
12	Component Failure					
13	Control Problems					
14	House Problems					
15	Low Capacity		Yes			
16	Low COP		Yes			
17	Refrigerant Charge		Yes			
18	Compressor noise					
19	Indoor piping problems					

Main cause	# 1 cause	# 2 cause	# 3 cause	# 4 cause
Ground Loop Installation	9	8	17	

Notes:
Main problem is that there are five vertical bore loops in close proximity to each other - drilling contractor didn't follow site plans. They had to replumb the loops and have a total of four pumps to get turbulent flow. System refrigerant charge does not meet manf. specifications. Supply system total leakage is 47% of system flow, return system total leakage is 71% of system flow.

Customer # C016

Contractor/Manf/Customer Conflict	Loop Type	House Type	Water heater present	Water heater used	Water heater problems
No	Closed	Retrofit	Yes	No	No

Problem	Comfort Problems	High Operating Cost	Shut Down	Noisy System	Complaint Resolved
Customer Reported Problem	Yes	Yes	No	No	No

Causes

1	Customer Understanding					
2	Customer Operation		Yes			
3	Incorrect Heat Pump Size	Yes	Yes			
4	Incorrect Duct Size/Design	Yes	Yes			
5	Ground Loop Size/Design					
6	Circulation Pump Size/Design					
7	GHP Equipment Installation		Yes			
8	Duct Installation (leakage, R-value)	Yes	Yes			
9	Ground Loop Installation					
10	Circulation Pump Installation					
11	Other Well Problems					
12	Component Failure		Yes			
13	Control Problems		Yes			
14	House Problems		Yes			
15	Low Capacity		Yes			
16	Low COP		Yes			
17	Refrigerant Charge					
18	Compressor noise					
19	Indoor piping problems					

Main cause	# 1 cause	# 2 cause	# 3 cause	# 4 cause
Incorrect Heat Pump Size	3	12	7	14

Notes:

Main problem is that the heat pump is not correctly sized. Unit is sized at 41% of Manual J. Customers only concern is that the savings are not what he was told they would be. Operating capacity and COP are both below the manufacturers specifications. Part of the high operating costs due to pump failure, one of the two pumps is not operating (but is drawing current intermittently)

APPENDIX B

DUCT LEAKAGE TEST PROCEDURE

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MINNEAPOLIS

DUCT BLASTER™

OPERATION MANUAL

MANUFACTURED BY THE ENERGY CONSERVATORY

CHAPTER 5

OPERATING THE DUCT BLASTER - PRESSURIZATION TEST PROCEDURES:

The test procedures presented below are preliminary and are currently being refined by field practitioners and researchers. It is our intent to keep our customers updated as these procedures evolve, or as new procedures are developed.

During a duct **pressurization** test, the duct system will be positively pressurized by the Duct Blaster fan (i.e. the fan is blowing air into the duct system). The Duct Blaster fan should be installed and the supply and return registers sealed as described in Chapter 4, Section 4.1, 4.3 and 4.4.

5.1 Measuring Total Duct Leakage (Pressurization Mode)

This procedure is used to measure the total amount of leakage in the duct system including leakage to the outside as well as leakage to the inside. Leakage should be measured at a duct reference pressure which is specified by your program test protocol. Commonly used target duct reference pressures are 25 Pa, 50 Pa or the average actual operating pressure in the duct system being tested.

FINAL PREPARATION:

A. Open Exterior House Door and Crawlspace/Attic Vents:

If there are large leaks between the duct system and outside, pressurizing the duct system with house air may depressurize the house relative to outside. We want to prevent this from happening because the pressure difference across duct leaks will be different for leaks to the inside of the house compared with leaks to the outside. Opening a door or window between the house and outside will keep the house at outside pressure and eliminate this problem. Similarly, if the ducts leak to a crawlspace, attic, garage or other unconditioned space that is relatively airtight, this space may be pressurized by the duct leaks. Opening vents, access panels, or garage doors between the unconditioned space and the outside will typically eliminate pressurization problem during the test procedure. **Note:** If access door or vents between the crawlspace or attic do not exist or are extremely difficult to open, conduct the test without providing pressure relief but try to measure pressure changes in the unconditioned space during the test to quantify any pressurization problems.

B. Determine Location of the Duct Reference Pressure Measurement:

During the pressurization test we will need to measure the reference pressure in the duct system with respect to (WRT) the outside (or to the house if you have opened an outside door or window, or you have determined that the house is not depressurized by the Duct Blaster fan). The best location for measuring duct pressure is often in or near the supply or return plenum. Choose a location which is on the opposite side of the duct system from the Duct Blaster fan. For example, if the Duct Blaster is connected to a return register, the supply plenum is a good reference pressure location. If the Duct Blaster is installed at the air handler access door, choose a location which is a couple of feet away from the supply plenum in a main supply trunk. Drill a small (1/4" to 3/8" OD) into the plenum to allow a pressure hose to be installed.

If the duct system is quite airtight, duct pressures can be measured at any supply or return register (except the register where the Duct Blaster attached). In this case, we measure duct pressure through a hole punched in the tape or paper covering the register (a basketball pump needle works well as a pressure sensor for this application).

C. Magnahelic Gauges

If you are using the Magnahelic gauges perform the following final set-up procedures:

- The top 60 Pa gauge will be used to measure duct reference pressure WRT outside. Connect a clear plastic hose to the top pressure tap on the 60 Pa gauge. "Warm Up" the 60 Pa gauge by blowing on the hose connected to the top pressure tap until the gauge reads 60 Pa and then release the pressure.
- Take the top 60 Pa gauge hose and feed the open end into the pressure sensing hole in the duct system where you will measure duct reference pressure (see Duct Reference Pressure Measurement above).
- Leave the bottom tap on the 60 Pa gauge open to the house if you have opened an outside door or window, or you have determined that the house is not depressurized by the Duct Blaster fan. Otherwise you will need to connect a hose to the bottom 60 Pa pressure tap and run the house to the outside. (In very windy weather, you may want to run this hose to the same space as most of the suspected duct leaks (e.g. in the attic if most of the suspected duct leaks are in the attic.)
- Connect a hose to the bottom pressure tap of the 500 Pa gauge. "Warm-up" the two fan pressure gauges by sucking on the hose connected to the bottom gauge until the bottom gauge reads about 500 Pa. Release the pressure. Leave the hose unconnected. The top pressure taps on the bottom two fan pressure gauges should remain open to the space where the Duct Blaster fan is installed.
- Install the "shower cap" on the inlet of the Duct Blaster fan to seal off the fan opening. Now "Zero" the duct reference and fan pressure gauges for the Duct Blaster by turning the adjustment screw near the bottom of the faceplate of each gauge with a small screwdriver until the gauge reads zero. Gently tap the face plate of the gauge and re-adjust to zero if necessary.
- Connect the bottom 500 Pa gauge hose to the pressure tap on the Duct Blaster fan (Figure 18).
- The proper hose connections for the 3 magnahelic gauges when measuring Total Duct Leakage in the Pressurization Mode are shown in Figure 19.

D. Digital Gauge

We will use CHANNEL "A" to measure duct reference pressure, and CHANNEL "B" to measure fan pressure (or fan flow). Connect a hose leading from the duct system pressure measurement location (see Duct Pressure Measurement above) to the "A" INPUT pressure tap. Insert the open end of this hose into the hole in the duct system where you will measure duct pressure. Leave the "A" REFERENCE tap open to the house if you have opened an outside door or window, or you have determined that the house is not depressurized by the Duct Blaster fan. Otherwise you will need to connect a hose to the "A" REFERENCE tap and run the house to the outside. (In very windy weather, you may want to run this hose to the same space as most of the suspected duct leaks (e.g. in the attic if most of the suspected duct leaks are in the attic.)

Next, connect a hose from the "B" INPUT pressure tap to the pressure tap on the Duct Blaster fan (Figure 18). Leave the "B" REFERENCE tap open to the space where the Duct Blaster fan is installed. CHANNEL B is now set up to measure fan pressure. Figure 20 shows the proper hose connections for the digital gauge when measuring Total Duct Leakage in the Pressurization Mode.

With the Duct Blaster fan still off, turn the **CHANNEL** selection knob to "A" so that we can measure the "baseline duct pressure". The "baseline duct pressure" is the pressure difference between the duct system and outside caused solely by stack and wind effects. This "baseline pressure" will need to be added to the target duct reference pressure in order to compensate for the stack and wind effects on the test. With the Duct Blaster fan off and the fan sealed with the shower cap, record the "baseline duct pressure" WRT outside.

CONDUCTING THE TOTAL LEAKAGE TEST (PRESSURIZATION MODE):

The Duct Blaster fan has 4 different flow capacity ranges depending on the configuration of Low-Flow Rings in the fan inlet. Before beginning the test, install the Low-Flow Ring which you think best matches the needed capacity of the fan and will provide a fan pressure over 25 Pa. Refer to Table 2 which shows the flow range of the fan under each of the 4 inlet configurations.

Turn on the Duct Blaster fan by slowly turning the fan controller clockwise. As the fan speed increases the fan pressure and the duct reference pressure should also increase. Increase the fan speed until the duct system is pressurized to the target reference pressure. If you are using the Digital Pressure Gauge, you will need to add the "baseline duct pressure" to your target duct reference pressure to account for stack and wind effects.

> *For example, if the program specifies a pressurization test with a target duct reference pressure of +25 Pa (WRT outside), and you measure a "baseline duct pressure" of -2 Pa with the digital gauge, the adjusted target duct reference pressure becomes 23 Pa (25 + (-2)). In other words, 23 Pa becomes the "target pressure" to achieve on Channel A of the digital gauge.*
>
> ***Note:*** *If you are using magnahelic gauges, this adjustment is not necessary because wind and stack effects were eliminated when "zeroing" the magnahelic gauges.*

Duct reference pressure is measured using the 60 Pa magnahelic gauge or CHANNEL A on the digital gauge if you set the gauges up according to the procedure presented above. Commonly used target duct reference pressures are 25 Pa, 50 Pa or the average actual operating pressure in duct system being tested. Refer to your program test protocol for the target duct reference pressure to be used for your test.

Record the duct reference pressure. Now record the Duct Blaster fan pressure needed to pressurize the duct system to the target reference pressure. Fan pressure can be read from either of the bottom magnahelic gauges (always use the 125 Pa gauge when it is less than full scale), or CHANNEL B on the digital gauge. If the Duct Blaster was unable to achieve the target duct reference pressure in the duct system because the ducts are extremely leaky, record the highest reference pressure achievable and the corresponding fan pressure. If you were unable to achieve the target reference pressure because the Duct Blaster was operating with a Low-Flow Ring installed, install a Low-Flow Ring which provides more fan capacity, or remove the Rings and run the fan in the "open" configuration. If the fan pressure is less than 25 Pa, install a Low-Flow Ring with a smaller nozzle (Ring 1 has the largest nozzle, Ring 3 has the smallest nozzle).

Once you've recorded the fan pressure necessary to achieve the target duct reference pressure, convert the fan pressure reading to flow in CFM (see Chapter 3 - Section 3.1). This fan flow value is the measurement of ***Total Duct Leakage*** (in CFM) at the target duct reference pressure. **Note:** When using the digital gauge, fan pressure readings will display as a negative value on Channel B. Use the absolute value of this fan pressure reading when using the flow conversion table or calibration formulas (e.g. -100 Pa becomes +100 Pa).

5.2 Measuring Duct Leakage to the Outside (Pressurization Mode)

This procedure is used to measure duct leakage to the outside only (including attics, crawlspaces and other zones that are open to the outside). Use of a blower door along with the Duct Blaster is required to perform the procedure below.

FINAL PREPARATIONS:

A. Set-Up Blower Door in House:

We will be using a blower door to pressurize the house (WRT outside) to eliminate any flow between duct leaks and the inside of the house during the duct leakage test. This is accomplished by first pressurizing the house with the blower door to the target reference duct pressure, and then pressurizing the duct system with the Duct Blaster until there is ***zero pressure between the duct system and the inside of the house.*** By eliminating duct leakage to the inside, the duct leakage test will now measure only duct leakage to the outside (or unconditioned spaces open to the outside).

Install the blower door in a centrally located exterior door. Set up the blower door fan to pressurize the house (i.e. blowing air into the house). We will need to measure house pressure WRT outside, but will not need to measure blower door fan flow. For a Minneapolis Blower Door, this means the fan can be installed in its normal depressurization configuration, except the fan direction switch should be reversed to blow air into the house. Refer to your blower door manual for complete instructions on blower door installation.

B. Opening Crawlspace/Attic Vents:

If the ducts leak to a crawlspace, attic, garage or other unconditioned zone that is relatively airtight, this zone may be pressurized by the duct leaks when the Duct Blaster is operating, and by house leaks from the blower door. We want to prevent this from happening because the pressure difference across duct leaks will be different for leaks to the zone compared with other leaks to the outside. Opening vents, access panels, garage doors between the zone and the outside should eliminate pressurization problems if they exist. **Note:** If access door or vents between the crawlspace or attic do not exist or are extremely difficult to open, conduct the test without providing pressure relief but try to measure pressure changes in the unconditioned space during the test to quantify any pressurization problems.

C. Determine Location of the Duct Reference Pressure Measurement:

During the pressurization test we will need to measure the reference pressure in the duct system with respect to (WRT) the inside. The best location for measuring duct pressure is often in or near the supply or return plenum. Choose a location which is on the opposite side of the duct system as the Duct Blaster fan. For example, if the Duct Blaster is connected to a return register, the supply plenum is a good reference pressure location. If the Duct Blaster is installed at the air handler access door, choose a location which is a couple of feet away from the supply plenum in a main supply trunk. Drill a small (1/4" to 3/8" OD) into the plenum to allow a pressure hose to be installed.

If the duct system is quite airtight, duct pressures can be measured at any supply or return register (except the register with the Duct Blaster attached). In this case, we measure duct pressure through a hole punched in the tape or paper covering the register (a basketball pump needle works well as a pressure sensor for this application).

D. Magnaholic Gauges

If you are using the Magnahelic gauges perform the following final set-up procedures:

- The top 60 Pa Duct Blaster gauge will be used to measure duct reference pressure WRT inside the house. Connect a clear plastic hose to the top pressure tap on the 60 Pa gauge. "Warm Up" the 60 Pa gauge by blowing on the hose connected to the top pressure tap until the gauge reads 60 Pa and then release the pressure.
- Take the top 60 Pa gauge hose and feed the open end into the pressure sensing hole in the duct system where you will measure duct reference pressure (see Duct Reference Pressure Measurement above).
- Leave the bottom tap on the 60 Pa gauge open to the house.
- Connect a hose to the bottom pressure tap of the 500 Pa gauge. "Warm-up" the two fan pressure gauges by sucking on the hose connected to the bottom gauge until the bottom gauge reads about 500 Pa. Release the pressure. Leave the hose unconnected. The top pressure taps on the bottom two fan pressure gauges should remain open to the space where the Duct Blaster fan is installed.
- Install the "shower cap" on the inlet of the Duct Blaster fan to seal off the fan opening. Now "Zero" the duct reference and fan pressure gauges for the Duct Blaster by turning the adjustment screw near the bottom of the faceplate of each gauge with a small screwdriver until the gauge reads zero. Gently tap the face plate of the gauge and re-adjust to zero if necessary.
- "Zero" the blower door house pressure gauge with the blower door fan sealed.
- Connect the bottom 500 Pa gauge hose to the pressure tap on the Duct Blaster fan (Figure 18).
- The proper hose connections for the 3 Duct Blaster magnahelic gauges when measuring Duct Leakage to the Outside (Pressurization Mode) are shown in Figure 19.

E. Digital Gauge

We will use CHANNEL "A" to measure duct reference pressure WRT inside, and CHANNEL "B" to measure fan pressure (or fan flow). Connect a hose leading from the duct system pressure measurement location (see Duct Reference Pressure Measurement above) to the "A" INPUT pressure tap. Insert the open end of the hose into the hole in the duct system where you will measure duct reference pressure. Leave the "A" REFERENCE tap open to the house. CHANNEL A is now set up to measure the duct reference pressure WRT to inside.

Next, connect a hose from the "B" INPUT pressure tap to the pressure tap on the Duct Blaster fan (Figure 18). Leave the "B" REFERENCE tap open to the space where the fan is installed. CHANNEL B is now set up to measure fan pressure. Figure 20 shows the proper hose connections for the digital gauge when measuring Duct Leakage to the Outside (Pressurization Mode).

CONDUCTING THE OUTSIDE LEAKAGE TEST (PRESSURIZATION MODE):

The Duct Blaster fan has 4 different flow capacity ranges depending on the configuration of Low-Flow Rings in the fan inlet. Before beginning the test, install the Low-Flow Ring which you think best matches the needed capacity of the fan. Refer to Table 2 which shows the flow range of the fan under each of the 4 inlet configurations.

The first step in measuring Duct Leakage to the Outside is to turn on the blower door fan and pressurize the house to the target reference duct pressure. For example, if the target reference duct pressure is + 25 Pa, use the blower door fan to pressurize the house to 25 Pa WRT outside. House pressure WRT outside can be read off the top blower door 60 Pa gauge.

With the house pressurized to the target reference pressure, turn on the Duct Blaster fan by slowly turning the fan controller clockwise. Increase the fan speed until the pressure between the duct system and the inside of the house is zero Pa. Duct pressure WRT inside is measured using the 60 Pa magnahelic gauge or CHANNEL A on the digital gauge if you set the gauges up according to the procedure presented above. Re-check the blower door and re-adjust to maintain the target reference pressure in the house. If the blower door is re-adjusted, re-adjust Duct Blaster to achieve zero pressure between the ducts and inside the house.

Record the house pressure WRT outside from the blower door 60 Pa gauge, the duct reference pressure (should be zero) and the Duct Blaster fan pressure needed to achieve a duct reference pressure of zero. Fan pressure can now be read from either of the bottom magnahelic gauges (always use the 125 Pa gauge when it is less than full scale), or CHANNEL B on the digital gauge. If you were unable to achieve zero reference duct pressure because of insufficient Duct Blaster air flow, install a larger Low-Flow Ring which provides more fan capacity, or remove the Rings and run the "open" fan. If the recorded fan pressure is less than 25 Pa, install a smaller Low-Flow Ring.

Once you've recorded the fan pressure necessary to achieve zero pressure difference between the duct system and the house (with the house pressurized to the target reference pressure), convert the fan pressure reading to flow in CFM (see Chapter 3 - Section 3.1). This fan flow value is the measurement of ***Duct Leakage to the Outside*** (in CFM) at the target duct reference pressure. **Note:** When using the digital gauge, fan pressure readings will display as a negative value on Channel B. Use the absolute value of this fan pressure reading when using the flow conversion table or calibration formulas (e.g. -100 Pa becomes +100 Pa).

5.3 Using the Can't Reach Pressure (CRP) Factors:

If the duct system is very leaky and you are not able to generate a target duct reference (25 or 50 Pa depending on the program testing protocol) with the Duct Blaster fan operating at full capacity ("open fan" inlet configuration and full speed), you can use Table 3 to estimate the 25 or 50 Pa flow. To use Table 3, determine the flow required to maintain the highest achievable duct reference pressure in Column 1. Multiply this flow by the corresponding "Can't Reach Pressure (CRP) Factor" in Column 2 or 3 to estimate the air flow that would be required to maintain a 25 or 50 Pa duct reference pressure. Table 3 assumes the "Duct Leakage Curve" for the duct system being tested has an exponent (or "n value") of 0.65. Preliminary testing suggests that 0.65 roughly approximates the "n value" of typical residential duct systems.

Note: Before using Table 3, try setting up the Duct Blaster fan without the flexible extension duct attached in order to generate more fan flow (see Section 4.1 - Installing The Fan Without The Flexible Extension Duct).

5.4 Finding Duct Leaks

A simple method which may help you determine which duct runs are leaking can be performed while the registers are taped off and the Duct Blaster fan is running. With the ducts pressurized by the Duct Blaster, the pressure drop across each taped register is measured by inserting a small probe connected to a pressure gauge (a basketball pump needle works well). The register with the lowest pressure drop may be near a leakage site. In addition, if a few registers show low pressures relative to the remaining ones, as significant leak may exist near this branch of ducts. Of course, a low pressure reading could also be an indication that the register(s) is simply farthest away from the Duct Blaster fan, or the register is connected to a blocked duct run. Because of this uncertainty, use this method with caution.

5.5 Important Points To Remember

- When making repairs to the duct system with mastic or other curing sealants, allow the sealant to properly cure before conducting a duct leakage test to determine the effectiveness of your sealing efforts. Refer to sealant installation instructions for proper curing times.

- The fan is powerful and potentially dangerous piece of equipment. Carefully examine the fan before each use. If the fan housing, fan guards, blade, controller or cords become damaged, do not operate the Duct Blaster until repairs have been made. Keep people and pets away from the fan when it is operating. If you notice any unusual noises or vibrations, stop the fan for examination and contact The Energy Conservatory if you are unable to locate the source of the problem.

- Periodically check the plastic hoses used with your Duct Blaster for air leaks.

- **Combustion Safety and MAD-AIR Test Procedures:** Sealing air leaks (including duct leaks) in a house can increase the potential for pressure imbalances created by HVAC and exhaust fan operation. These pressure imbalances can result in backdrafting of natural draft combustion appliances and increase the amount of soil gas entering the house. Because of these complicated systemic interactions between air sealing activities and occupant health and safety issues, technicians should familiarize themselves with the Combustion Safety and MAD-AIR testing procedures listed in Chapter 7, in order to reduce the risk of leaving a house with a potential problem.