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# Investigation of Coil Failures - A Whole Systems Approach

Prepared for:
Geothermal Heat Pump Consortium

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## Executive Summary

In early 1998 the Ground Source Heat Pump Consortium requested that Proctor Engineering Group (PEG) investigate a cluster of indoor coil failures on Geothermal Heat Pumps in one subdivision. The climate in that area has high winter humidity and moderate temperatures which provides high potential for corrosion when contaminants are present.

The coil failures at this subdivision were similar to previous failures that have occurred sporadically in other locations. The earlier coil failures had been traced to corrosion from the exterior surface of the tubes. Metallurgical investigation had found chlorine present and the probable cause of the corrosion. The source of the chlorine had not been determined.

Proctor Engineering Group reviewed the existing data, visited the site, and performed diagnostic testing on four homes. In particular, the investigators were interested in determining how the entire system (home, equipment, distribution system, and occupants) interacted. Each home provided insight into the problem.

The home with the highest failure rate had been a model home for the development and, since that time, had been continuously occupied by the same family. The family complained about high bills, the repeated failures, and comfort problems.

The kitchen, bath, and utility rooms of this house contained a wide variety of chemicals. Of particular interest was the presence of a dry cleaning fluid often used on the carpet. Chlorine bleach was used for regular cleaning as well as in clothes washing.

The washing machine and clothes dryer were located in a utility room in the center of the house. This room had an exhaust fan vented into the attic space. When the heat pumps were on, pressure measurements showed that the dryer vent was connected into the return system. This connection occurred via leakage of the dryer vent and return leakage from the interstitial spaces. The investigators found dryer lint on the coil.

Investigators found a high rate of return system duct leakage (656 cfm of unbalanced return leakage). Most of this leakage is in the return that makes extensive use of interstitial spaces.

The most likely cause of the coil failures in this home is the combination of:

- the presence of corrosive household chemicals
- the delivery of clothes washing chemicals and moisture through leakage of the dryer vent into the return system
- the excessive return leakage bringing in moisture from outside
- the excessive return leakage increasing the run time of the heat pump

Some of the causes of the high bill complaints are:

- the excessive return leakage bringing in moisture from outside
- the excessive return leakage bringing in hot air in summer and cold air in winter
- the excessive house leakage allowing high levels of summer and winter infiltration
- the increased air infiltration in the summer due to the attic power ventilators

Considering the metallurgical reports, the field data on all four investigated homes, the warranty data, the dates of failure, and the climate data, Proctor Engineering Group concludes that:

- The indoor coil failures are most likely caused by corrosion aggravated by stress as the temperature and pressure of the coil are cycled.
- Ordinary and, in some cases, extraordinary household pollutants are being brought to the coil by the return system. The dryer in some cases is supplying both pollutants (chlorine and

Proctor Engineering Group recommends that the basic design of the heat pump reduce the corrosion rate to an acceptable level. We recommend that an accelerated test be developed which will expose the coil to high concentrations of airborne moisture and household chemicals.

Proctor Engineering Group further recommends that changes in home design and construction are necessary to achieve proper function of the entire system. Specifically: ducts must leak less than 3% of air handler flow, building cavities must not be used as air returns, and exhaust vents must be leak free and terminate outside the building shell.

## Introduction

In early 1998 the Ground Source Heat Pump Consortium requested that Proctor Engineering Group (PEG) investigate a rash of indoor coil failures on Geothermal Heat Pumps in one subdivision. The failures were of a similar nature to other indoor coil failures occurring sporadically in other geographic locations. The earlier coil failures had been traced to corrosion from the exterior surface of the tubes. Metallurgical investigation had found chlorine present and the probable cause of the corrosion. The source of the chlorine had not been determined.

On April 6 and 7, 1998 Proctor Engineering Group performed diagnostic testing on four Geothermal Heat Pump homes in the problem subdivision. The representatives of Proctor Engineering Group were accompanied by a local HVAC contractor familiar with these homes and a manufacturer's representative.

Prior to the site vists, Proctor Engineering reviewed metallurgy reports on the coil failures as well as warranty and service data available for the homes in the development. Figure 1 shows the number of failure incidents in each month for a sample of 64 ground source heat pumps with warranty reports. Twenty of the units had no reports of coil failures, while the remaining 44 had 62 reported coil failures. Some of the homes in the investigation also had service records which showed additional coil failures not recorded in the warranty data.

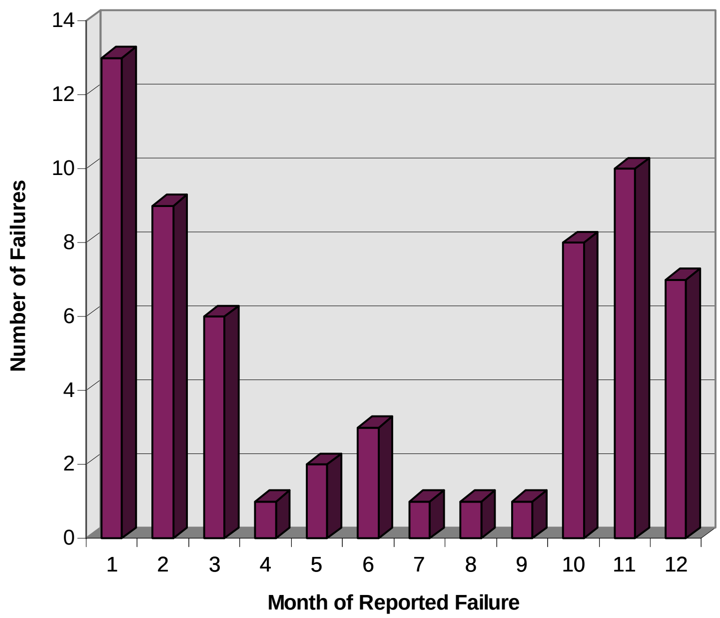


**Figure 1. Month of Reported Coil Failure**

These heat pumps are used less in heating than they are in cooling and the electrical bills reflect this. Nevertheless, the coil failures were substantially higher in the winter. The hypothesis that the corrosion occurred in the summer with higher winter coil pressures causing the refrigerant leaks was examined in light of this data. While there is a peak at winter startup (October and November), the higher failure rates in January and February do not support that hypothesis. The data supports the hypothesis that corrosion is present in the winter as well as summer.

The climate where these heat pumps are installed has high humidity in the winter and moderate temperatures.

This area has an average of 337 winter hours with an outdoor dry bulb temperature less than 60°F and an outdoor dew point of over 50°F. These are hours with high potential for corrosion due to moist coil conditions. The distribution of these hours in an average year is shown in Figure 2.

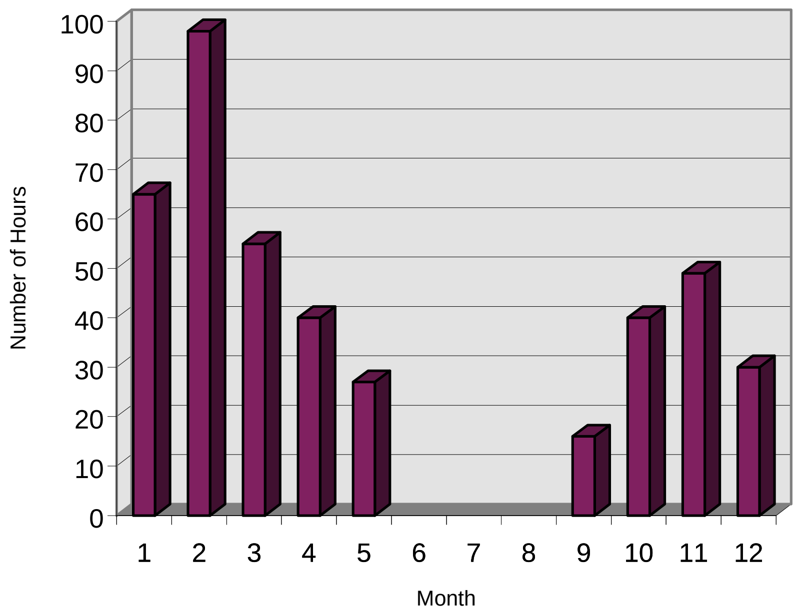


**Figure 2 Hours with Outdoor Temperature <60°F and Dew Point >50°F (Average Year)**

## Field Methods

The field tests were designed to gather the maximum amount of information about the problem homes. In particular, Proctor Engineering Group was interested in determining how the entire system (home, equipment, distribution system, and occupants) interacted. The field investigation was allotted two days. The largest amount of time was allocated to the house with the highest number of failures. Considering the metallurgical reports supplied by the manufacturer and a review of the warranty data, the following field tests were included:

- an occupant interview
- capacity and efficiency tests of the heat pump
- heating and cooling load data collection and calculation
- duct system pressures and air flow tests
- building shell leakage and pressurization tests
- potential contaminant investigation

Corrosion was viewed as the most likely cause of the coil failures. Various HVAC manufacturers supply lists of potential airborne contaminants. These lists regularly include:

- Permanent wave solutions
- Chlorinated waxes and cleaners
- Chlorine-based swimming pool chemicals
- Water softening chemicals
- De-icing salts or chemicals
- Carbon tetrachloride
- Halogen type refrigerants
- Cleaning solvents (such as perchloroethylene)

- Printing inks, paint removers, varnishes, etc.
- Hydrochloric acid
- Cements and glues
- Antistatic fabric softeners for clothes dryers
- Masonry acid washing materials

## House #1:

This house was considered the “smoking gun” house. This house had experienced six coil failures on its two heat pumps over seven years. This home had been a model home for the development and since that time had been continuously occupied by the same family. The family complained about high bills, the repeated failures, and comfort problems.

Temperatures are kept constant and rather high in the winter (77°F).

The wife of the household described herself. “I’m a cleaner”, she said. The home was carpeted with white carpet and she complained about the dark stains on the carpet along all the walls (both exterior and interior). She also complained about the dust that she found all around the home, regardless of how often she dusted. The investigation found that much of the dust was lint from the dryer.

The kitchen, bath, and utility rooms had a wide variety of chemicals. This included: floor cleaners, sink cleaner with bleach, and many others. Of particular interest was the presence of a dry cleaning fluid used to clean up after a sick dog. This dog had been sick for the whole time the family occupied the home and regularly made messes on the carpet that needed to be cleaned with the dry cleaning fluid. A point of additional interest was that the wife used bleach on a regular basis for regular cleaning as well as in clothes washing. Anti-static fabric softener sheets were also used on a regular basis.

The husband had a hobby of model building. In his work room (in the upstairs of the home) many paints and a few bottles of thinner were found on the table.

The washing machine and clothes dryer were located in a utility room in the center of the house. This room had a ventilation exhaust fan that was vented into the attic space. All the exhaust vents terminated in the attic space.

The dryer had a long flex duct from the dryer termination to the vent opening in the utility room. When the dryer was pushed into place, the termination and the vent opening were within four inches from each other, but at somewhat different levels. The result was that the flex duct was at least 50% restricted, possibly more. The remainder of the dryer vent was inside the wall and ceiling (between the first and second floor). The dryer vent terminated outside the home with a back draft dampered termination.

When the heat pumps were on, the pressure in the dryer duct dropped by 2.5 pascals. This was similar to the pressure drop measured in many of the returns near the grilles. The return system of the downstairs heat pump is connected to the dryer vent (via leakage of the dryer vent in the wall and ceiling to return leakage from the interstitial spaces or otherwise). An inspection of the coil found dryer lint on the coil.

The attic spaces had very little ventilation to outside when built and the HVAC contractor had added powered attic fans to exhaust air from the attic. Even with additional attic ventilation area, the attic was closely connected to the living space (air flow/pressure boundary). The leakage area to the house was diagnosed as 40% of the attic ventilation area. This connection was made clear when the attic power ventilators were active. With the power attic ventilators on, the house was significantly depressurized (-.02 inches WC , -4.5 pa.). The attic ventilators are pulling conditioned house air into the attic. This results in additional infiltration into the home.

This home had the supply ducts sealed by an HVAC contractor. The return system was not sealed and there was high return system duct leakage. Based on the diagnostic tests, the unbalanced return leakage from outside the structure for both air handlers operating is 656 cfm. Most of this leakage is in the downstairs system that makes extensive use of interstitial spaces for the return. The supply leakage area was approximately 30% of the return leakage area. The return leakage caused house to be pressurized when the downstairs air handler was operated.

The space between the first and second floors is depressurized when the downstairs heat pump is run. This also indicates significant leakage from the return system. In addition, the floor space is as connected to outside as it is to inside (the floor space should be connected only to inside).

This home is very leaky to outside (3400 cfm at 0.20 inches WC pressure differential).

The downstairs heat pump was tested on this home and the equipment was found to be within normal operating specifications.

**Findings:**

The most likely cause of the coil failures in this home is the combination of:

- the presence of corrosive household chemicals
- the delivery of clothes washing chemicals and moisture through leakage of the dryer vent into the return system
- the excessive return leakage bringing in moisture from outside
- the excessive return leakage increasing the run time of the heat pump

Some of the causes of the high bill complaints are:

- the excessive return leakage bringing in moisture from outside
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- the increased air infiltration in the summer due to the attic power ventilators

The staining on the carpet was caused by ordinary household dirt deposited on the carpet at the exit paths from the house. Due to the pressurization of the house when the heat pump is on and the general leakiness of the house, all the joints between the floor and walls lead to outside the structure. The exiting air is filtered by the carpet, resulting in stains.

## House #2:

The second home had no coil failures. In that respect it provided a “clean baseline” to house number one. This house had loop pump failure and loop leaks. The current occupants were a family of three (a couple with one young child). The previous occupant was single and spent much of her time out of town. The family complained about comfort problems in the master bedroom and bath. They used a portable heater in the winter.

The family used daytime temperature set backs and set ups by season. The occupied temperature was rather high in the winter (75 to 78°F).

The current occupants used few cleaning products, did use bleach occasionally in the laundry. This family did not use fabric softener. The dryer vent in this home showed no signs of leakage into the home or into the return system. However, a restriction of the flex duct from the dryer to the wall inlet was noted similar to home number one.

The duct system was much better than in house number 1. The blocked return test verified this observation.

Based on the diagnostic tests, there was little or no unbalanced duct leakage. The house pressure remained neutral when the air handlers were operated.

The space between the first and second floors was more connected to inside than outside. This is an improvement over house number 1.

This home is moderately leaky to outside (2600 cfm at 0.20 inches WC pressure differential).

The heat pumps on this home were not tested, but the ground loop is leaking, causing the pumps to run dry, tripping off the heat pump, and causing pump failures.

**Findings:**

This home had comfort problems due poor duct design and installation.

This home has a loop leak.

## House #3:

This home has had two coil failures on one unit and none on the other.

This home has high return system duct leakage (Based on the diagnostic tests, the unbalanced return leakage from outside the structure for both air handlers operating is 724 cfm). These return leaks are largely due to the use of interstitial spaces for the return. The supply leakage area was approximately 35% of the return leakage area. The return leakage caused house to be pressurized when the each air handler was operated. With both air handlers operating the house is significantly pressurized due to return leaks.

This home is very leaky to outside. 3450 cfm a 0.20 inches WC pressure differential.

The occupants of this home do approximately 7 loads of clothes per week and use fabric softener in the process. The pressure in the dryer vent was not affected by the operation of the air handlers, indicating no significant leakage to the return system from the dryer vent.

The house has a pool and a hot tub. The pool and hot tub are on the windward side of the house and both are treated with potentially corrosive chemicals (chlorine for the pool, and bromine for the hot tub). The occupants also use muriatic acid for cleaning stains around the pool and “Chem-dry” carpet cleaner. The pool chemicals are stored in the garage where the odor is detectable. The original owners had stored the pool chemicals outside.

The first recorded coil leak occurred four years after the home was built. The second coil leak occurred two years later. Both coil leaks occurred with the current occupants.

**Findings:**

Household pollutants (particularly pool and hot tub chemicals) are being brought to the coil by the return system. Combined with high outside humidity in the winter, corrosion is accelerated.

## House #4

This home has had two coil failures on one unit and one on the other.

This home has high return system duct leakage (Based on the diagnostic tests, the unbalanced return leakage from outside the structure for both air handlers operating is 461 cfm). These return leaks are largely due to the use of interstitial spaces for the return. The supply leakage area was approximately 40% of the return leakage area. The return leakage caused house to be pressurized when the each air handler was operated. With both air handlers operating the house is significantly pressurized due to return leaks.

The return leaks were confirmed by the blocked return test.

This home is moderately leaky to outside. 2700 cfm at 0.20 inches WC pressure differential.

The occupants of this home do approximately 10 loads of clothes per week and use fabric softener in the process. The pressure in the dryer vent was not affected by the operation of the air handlers, indicating no significant leakage to the return system from the dryer vent.

The two heat pumps in this home were plumbed in parallel off a single ground loop. Initial inspection indicated that no provisions were made to ensure that water was flowing only through the operating heat pump.

The filter for one of the heat pumps was nearly inaccessible. The filter on that unit was clogged and the coil very dirty. Low air flow has been reported as a continuing problem in this house. Low air flow increases coil temperatures and pressures in the winter.

Both units have had coil leaks. The first coil leak occurred five years after installation. The second coil leak occurred one year later.  The third occurred the year after that.

**Findings:**

Ordinary household pollutants are being brought to the coil by the return system. Combined with high outside humidity in the winter, corrosion is accelerated.

## Conclusions:

The coil failures are most likely caused by corrosion of the indoor coil aggravated by stress as the temperature and pressure of the coil are cycled. The highest failure rates occur in the winter in spite of the mild winters (less than 2300 degree days). The operating pressure in the coil is much higher in the winter (200+ psi) during operation vs. approximately 75 psi in the summer. The temperature of the coil is higher during the winter approximately 105°F in the winter and 48°F during the summer. Corrosion is taking place at a higher rate in the winter due to the increased stress and the higher temperatures. While corrosion proceeds at different rates at different levels of moisture and temperature, the ASHRAE Handbook of Applications 1995 states “corrosion can proceed at relative humidities of 50% and above.” As a rule of thumb, corrosion rates double for each 18°F increase in temperature.

Ordinary and, in some cases, extraordinary household pollutants are being brought to the coil by the return system. The dryer in some cases is supplying both pollutants (chlorine and fabric softener for example) and moisture to the coil. In other cases, the chemicals and moisture may be bypassing the vent due to restrictive venting.

This type of corrosion should exist wherever these conditions are duplicated. For example the same corrosion failures should occur on air conditioning systems (potentially at a lower rate because of the lower temperature and pressure). Discussions with factory representatives of a number of major manufacturers have indicated that such failures do occur in moist climates. This anecdotal information indicates that air conditioner failures of this type are relatively rare and seem to begin beyond five years of installation. Air source heat pumps should see similar failures under the same conditions, potentially at a somewhat reduced rate due to the lower average coil temperature. (Ground source heat pump capacity and coil temperature are nearly constant while air source capacity and temperature drop substantially as the outside temperature drops.)

## Recommendations:

Coil Failures

Since the conditions which promote most of these failures (household chemicals and moisture) are outside the control of the heat pump manufacturer, Proctor Engineering Group recommends that the basic design of the heat pump reduce the corrosion rate to an acceptable level. We recommend that an accelerated test be developed which will expose the coil to high concentrations of airborne moisture and household chemicals. The unit should be continuously cycled through heating and cooling modes under these conditions. A baseline accelerated time to failure can be established. Testing of alternative designs can take place in a short time period, the least costly approach can be determined and the improved durability can be estimated.

Building Design and Construction

Duct systems need to be sealed to less than 3% of air handler flow.
Building cavities must not be used as air returns.
All exhaust vents must be leak free and terminate outside the building shell (not in the attic, crawlspace, between floors, or in walls).