



Final Report

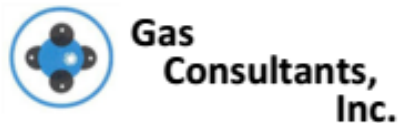
AHRI Report No. 8014

EFFECTS OF LOW RETURN AIR TEMPERATURE ON GAS FIRED FORCED AIR FURNACES

Final Report

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HISTORY/BACKGROUND

The gas fired furnace manufacturers had expressed concerns about life expectancy of their products when the return air to the furnace was below the normally expected household air temperature of 70°F. It has been long known that when persons leave on vacation they very often set their comfort thermostat down to a much lower temperature than 70°F to conserve energy/reduce heating bills. Those temperatures are dependent upon the brand of comfort thermostat they own, but temperature settings to 45 °F are possible with many brands.

At reduced air temperatures in the house and while the occupants are on vacation the return air will be passed over the leading sections of the heat exchanger and cool the flue gas lower than if the return air temperature were at 70°F. With “colder” return air temperatures the concern was that the condition would accelerate the formation of condensate in the heat exchanger which in turn might accelerate the formation of corrosion in the heat exchanger. Additionally, the concerns was that the formation of the condensate in high efficiency furnaces may start to form “earlier” in the pathway of the heat exchanger, i.e. , before the secondary heat exchanger, and form liquid in those portions of the heat exchanger which were not intended to handle combustion condensate.

Since this report is being prepared for the AHRI members it is not necessary that a prolonged discussion of how flue gas condensate forms in a heat exchanger is needed, but a few words have been added without all the technical detail that would be necessary for the layman.

Corrosion had been one of the two leading causes of premature failure of the heat exchanger in the past. The other cause being heat related stress which is currently addressed in Section 2.36, Heating Element Cycling Test.

Two forms of acid formation may occur in gas furnaces:

- The odorant added to natural and LP gas is a sulfur based compound and combines with the moisture of combustion. Hence, if the moisture of the combustion process condenses in the heat exchanger, sulfuric acid is formed.
- The use of chlorine and fluorine compounds in cleaning solutions and spray aerosol propellants was found to be a leading contributor to the corrosion of conventional heat exchangers prior to the advent of condensing or high efficiency furnaces. These compounds, when passed through a flame and combined with the moisture of combustion can form hydrochloric and hydrofluoric acid.

Improperly designed or adjusted low efficiency furnaces (non-condensing) can also end up with acid condensate in the heat exchanger. High efficiency furnaces by their very nature have condensate in the heat exchanger and must be designed with materials resistant to acid attack in those portions of the heat exchanger where the condensate will form (specifically in the secondary heat exchanger).

To address all the possible sources of acid attack on both low and high efficiency furnaces, the gas furnace industry addressed the issue by the implementation of an accelerated corrosion life test. The general approach used to accelerate the corrosion beings:

- The first step is to shorten the operational “On” cycle, combine it with a long off cycle and keep the circulating room air blower in continuous operation throughout the entire On/Off cycle time.
This process causes an environment favorable to allowing condensate to form inside the heat exchanger and flue gas passageways.
- The second step for accelerating the test is accomplished by “spiking” the fuel gas with hydrofluoro/chlora-carbons, thereby, increasing the acidity of the normal flue gases found in North America.

This test process gave the industry/mmanufacturer a design tool for predicting the effects of flue gas corrosion on their heat exchanger design.

The accelerated corrosion test is 800 hours of burner “On” time over 100 days of operation. The test is conducted at normal household ambient air temperatures (nominally 70°F) and uses a 4 minutes on and 8 minutes off burner cycle with the furnace circulating blower in operation continuously to accelerate the cooling of the heat exchanger. The spiking gas concentration of chlorine compounds is predicated on either using indoor air for the combustion process or using outdoor air. Indoor air has been shown to contain more compounds such as household cleaners, etc. that contain higher levels of chlorine and which adds to the possibility of additional corrosion. Therefore, two levels of spiking gas concentration are used depending upon the combustion air supply/design of the furnace.

A search of the internet did not reveal any prior research or work done on the effect of low ambient air temperatures on conventional furnace heat exchangers. Therefore, AHRI’s Furnace Advisory Group requested that a study be conducted to look at any possible issues that might result from long term operation of a furnace with sub-comfort levels of return air. This condition might be encountered while the occupants are away for an extended period of time (vacation) and the comfort thermostat is set to a “low” ambient temperature to conserve energy.



To evaluate the effects of low return air temperature on furnace heat exchangers, the AHRI Furnace Advisory group requested that the standard corrosion test be conducted with both the return air and combustion air at 45°F with all other conditions as detailed in the standard corrosion resistance test (ANSI Z21.47-2012, CSA2.3-2012, section 2.15, titled *Corrosion Resistance*).

Although the normal furnace On/Off cycle would probably be substantially different with an interior house temperature of 45°F (shorter “on” cycle and a longer “off” cycle) it was believed that the current cycle timing detailed in Z21.47, CSA2.3 would be a “worst” case scenario and should be a reliable pointer of potential issues.



EXECUTIVE SUMMARY

Five production furnaces were subjected to 100 days of cycling time, or 12 000 cycles, with the spiking gas adjusted for indoor air levels of spiking gas. The conditions of tests were those detailed in section 2.15 *Corrosion Resistance* (Exhibit G) of ANSI Z21.47-2012, CSA2.3, Standard for gas-fired central furnaces. The only difference was that the return air temperature **and** combustion air temperature were maintained at $45^{\circ}\text{F} \pm 5^{\circ}\text{F}$, with most of the time spent at $45^{\circ}\text{F} \pm 2^{\circ}\text{F}$ and a period average of 46.1°F .

Preliminary work was conducted to ensure that heat exchanger temperatures tracked inlet air temperatures, thus cold spot heat exchanger tests were conducted at 55°F , 50°F , 45°F and 40°F . It was found that for every drop of 1 degree in inlet air temperature there was a corresponding drop of approx. 1 degree on the coldest spot on the heat exchanger.

One furnace (Furnace 5) being a “rooftop” product (non-condensing) and although designed only to be installed outdoors, the spiking gas concentration was set as if it were using inside combustion air in order to evaluate the heat exchanger design which is also used on conventional indoor furnaces.

The remaining four furnaces (samples 1-4) were conventional, upflow, indoor household products. Two were condensing products (samples 1 and 2) and two were non-condensing (samples 3 and 4).

The AHRI committee selected various furnace designs which would give the broadest evaluation with respect to manufacturing process (tubular heat exchangers vs. formed/stamped heat exchangers), condensing and non-condensing products, and single and two stage input / rate operation. All furnaces utilized inshot burners in conjunction with induced combustion air blowers.



FURNACE SPECIFICATIONS

Furnace Sample No.	Max. Input (BTU/Hr.)	Lo Fire Input (BTU/Hr.)	Type Furnace	Type Heat Exchanger	Rise: Hi Fire / Lo Fire & Test Rise
1	56,000	39,200	Condensing (96%)	Tubular	30-60/20-50 45/35
2	60,000	39,000	Condensing (97%)	“Clamshell”	35-65/35-65 50/50
3	60,000	39,000	Non-condensing (80%)	Squashed Tubular	30-60/20-50 45/35
4	66,000	43,500	Non-condensing (80%)	“Clamshell”	30-60/30-60 45/45
5	60,000	Nat Applicable	Rooftop –Non-condensing (81%)	Tubular	30-60 45

Table 1

Upon completion of the corrosion cycling program, the heat exchangers of all furnaces were examined for damage. No cracks, holes or perforations were found in any portions of any of the condensing furnaces’ (Furnaces 1 and 2) flue collector boxes or either the primary or secondary heat exchangers. All three non-condensing furnace’s (Furnaces 3, 4 and 5) flue collector boxes had perforations due to corrosion. Additionally, Furnace 4 had a perforation in the heat exchanger near where it joined the collector box.

Post cycling measurement of the flue gases showed that the air free CO levels were still passing the ANSI Z21.47CSA 2.3 test criteria of 0.04% (400 ppm) as shown below.

BASELINE AND POST TEST CO AIR FREE DATA

Furnace Sample No.	1	2	3	4	5
Initial /Baseline					
CO ₂ (%)	6.43	6.35	4.31	7.88	6.03
CO (ppm) air free	63	13	17	139	32
Post Corrosion Test					
CO ₂ (%)	5.65	5.80	4.19	5.85	5.38
CO (ppm) air free	29	1	1	13	12

Table 2



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Note: Variations in values between pre and post cycling are normal variations due to the difference in method of test setup. Pre-cycling is the standard ANSI Z21.47/CSA 2.3 combustion test protocol vent stack and post cycling was done in situ with all the vent lengths and other apparatus used for the cycling test still in place. Of concerns is only whether the air free CO values exceed 0.04% (400 ppm).



CONCLUSION

Based upon the testing performed under low return air conditions of nominally 45°F, the condensing furnaces tested showed no signs of adverse wear or operation that would shorten their life expectancy or cause any concerns for the safety of the occupants of the building in which the product may be installed. There were no signs of loss of heat exchanger integrity.

Therefore, all evidence indicates that the use of low temperature comfort thermostats in northern climates will not cause any harm to or shortening of the life expectancy of the heat exchangers of gas fired condensing furnaces of current design (circa 2015) when indoor comfort air temperatures are set for low temperatures while the owners are on away from their home for an extended period of time.

For non-condensing furnaces, low return air temperatures of 45°F coupled with the corrosion test protocol of ANSI Z21.47, section 2.15 (Exhibit G) resulted in deterioration of the collector boxes of the furnaces. Given that these designs are currently listed which in turn means they were previously tested per the established protocol at a base temperature of 75°F ± 10°F, this requested low return air temperature investigation does show that the low return air temperatures have a negative impact compared to previous test results. Hence, it appears that low return air temperatures should be avoided if using a non-condensing furnace as that operation will cause more rapid deterioration of the furnace than will operation at normal comfort levels of ambient air (65°F to 75°F). All metal parts of the sample non-condensing furnaces that were in contact with flue gases were manufactured with aluminized steel which is considered corrosion resistant to normal water but not to the acids of combustion.



BASIC EVALUATION PROCESS

The basic process of conducting the low return air temperature evaluation consisted of the following protocol:

- Initial Setup of each furnace to specified rate and air temperature rise conditions
- Evaluate heat exchanger cold spot temperatures at various inlet air temperatures
- Set up the circulating air system for the selected return air temperature
- Set up the corrosion test apparatus per the Z21.47/CSA 2.3 (Appendix G) standard using indoor air as the test concentration of the spiking gas
- Periodically measure the CO₂ and CO during the nominal 100 day cycling process
- Periodically visually examine the critical portions of heat exchanger to look for signs of corrosion
- Upon completion of the cycle period measure the emissions (CO₂ and CO air free)
- Upon completion of the cycle period visually inspect each heat exchanger and collector box for signs of damage, i.e., cracks, perforations, or any indication of damage to the metal of the heat exchanger
- If visual inspection of the heat exchanger indicated any questionable potential issues, evaluate with penetrating dye or other means to confirm metal penetration due to corrosion, including sectioning of the heat exchanger if necessary



BASELINE DATA PRIOR TO CORROSION CYCLING

A quick check was made of the furnaces to see that they were performing satisfactorily and then the heat exchangers were removed and thermocouples installed on the heat exchangers at points that would most likely be the coldest spots and hottest spots. Since the furnaces were already listed, the goal was not to identify the most critical temperatures but to find the general trend of temperatures change as the inlet air temperatures were varied for later portions of this program.

After attachment and documentation of the thermocouples the furnaces were reassembled and the furnaces were setup for baseline testing.

All upflow furnaces (samples 1 thru 4) were attached to appropriate duct work as specified in ANSI Z21.47/CSA 2.3. Since all furnaces vented vertically, the appropriate flue exhaust pipe as specified in section 2.2.3 was attached to furnaces 3 and 4, consisting of an elbow, 2 feet of horizontal pipe, another elbow and sufficient vertical pipe to terminate between 5 feet and 5 feet, six inches above the flue discharge of the furnace. Furnaces 1 and 2 used their maximum specified length of PVC pipe.

The roof top packaged furnace had the appropriate duct work attached but the testing of emissions was done directly at the discharge of the flue vent.

All furnaces were adjusted to their specified data plate input ($\pm 2\%$) per the procedures outlined in Z21.47/CSA 2.3 and then adjusted to their rise conditions at both maximum and minimum input (as appropriate). It was generally found that the low fire conditions were within specification when received.

Baseline normal CO₂ and air free CO was recorded after 15 minutes of operation from room temperature. The flue gas temperatures were also recorded at steady state conditions.

Since the program ultimately would focus on the low fire operation of Furnace 1 through 4, the “critical” setup condition was to obtain minimum input and minimum rate rise conditions. The high fire condition would only be important for conduction of the post CO air free values at normal input.

The results of the baseline setup is shown in the table below



Furnace Sample #		#1	#2	#3	#4	#5
Max. Input Data	Data plate Input (BTU/Hr.)	55,000	60,000	60,000	66,000	60,000
	Rise Range (°F)	30-60	35-65	36-60	30-60	30-60
	Adjusted Rate (BTU/Hr.)	55,400	58,900	59,400	67,200	58,900
	CO ₂ (%)	6.43	6.35	4.31	7.88	6.03
	CO _{AF} (ppm)	63	13	17	139	32
	Flue temp. @ Steady State	82.7	85.5	243.7	265.3	269.5
	Blower Press. ("w.c.)	0.20	0.20	0.20	0.20	0.20
	Rise	45.1	48.2	44.1	45	43.9
	Required Spiking gas flow (mL/Min)					
	Date	12/4/14	1/6/15	1/15/15	12/3/14	1/22/15
Min. Input Data	Data plate Input (BTU/Hr.)	39,200	39,000	39,000	43,500	Not Applicable
	Rise Range (°F)	20-50	35-65	20-50	30-60	
	Adjusted Rate (BTU/Hr.)	38,900	39,000	38,400	42,600	
	CO ₂ (%)	5.49	5.41	3.27	5.64	
	CO _{AF} (ppm)	71	5	15	43	
	Flue temp. @ Steady State	78.3	91.1	201.8	221.4	
	Blower Press. (" w.c.)	0.15	0.10	0.11	44.4	
	Date	12/4/14	1/7/15	1/16/15	12/3/14	

Table 3



PRELIMINARY HEAT EXCHANGER TEMPERATURE EVALUATION

It was requested by the AHRI advisory committee that the “cold spot” heat exchanger temperatures be monitored at return air temperatures of 55°F, 50°F, 45°F. An additional test point was added by GCI staff at 40°F since it was easily accomplished while conducting the other 3 temperature conditions.

To accomplish the lower inlet return air temperature, a cold water transfer chiller coil was inserted into a return air duct of the furnace under test and the chiller water was adjusted by blending the cold water with warm water to maintain the desire inlet return air temperature.

On the basis of the recorded temperature of the heat exchangers, a choice would be made by the AHRI managing committee as to what return air temperature to conduct the corrosion testing. The lowest return air temperature resulted in the coldest heat exchanger temperature but generally the ratio was nearly a one to one reduction meaning the drop in metal temperatures was about equal to the reduction in return air temperature.

The results of this phase of the testing (Heat Exchanger Cold Spots) is presented in the Power Point presentation attached to the Appendix of this report and includes photo of the location of the thermocouples as attached to the heat exchangers.

Shown below are the results (in °F) of the coldest recorded temperature at Lo-Fire for furnaces 1-4, and Hi-Fire for furnace 5. The focus of temperature recording was on the aluminized steel components.

Return Air	55°F	50°F	45°F	40°F
Furnace #				
1*	99	90	98	82
2**	167	164	159	152
3	210	207	189	185
4	165	160	155	145
5	171	167	161	156

Table-4

*Coldest Temperature taken on transition collector box

** Coldest temperature taken on transfer tube



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As can be seen, and as one would expect, the heat exchanger temperatures tracked the inlet air temperature on an almost 1:1 ratio.

Based upon the results of the above recorded temperatures, the AHRI advisory committee agreed that the 45°F inlet air temperature should be the return air temperature and combustion air temperature used for this investigation.



PRELIMINARY EVALUATION

Section G.1.9 of the Corrosion Test in Z21.47/CSA 2.3 requires that the furnace be operated at the lowest rate that the burner can be operated at on a full time basis. Four of the five furnaces (samples 1, 2, 3, and 4) were two stage combustion systems that can remain in the low fire mode indefinitely, hence the corrosion testing would be conducted at the minimum input as detailed on their data plates.

All four units change their combustion blower speed when they operate at the minimum input, hence, the low fire input and flue gas CO₂ was used as the basis of the calculation for establishing the nominal Spiking Gas Flow as determined by using Figure G5 of Z21.47/CSA 2.3 and the following formula given below fig. G5

$$Actual\ Flow\left(\frac{mL}{min}\right) = Nominal\left(\frac{mL}{min}\right) \times \frac{Rated\ Input\ \left(\frac{Btu}{Hr}\right)}{100,000\ Btu/Hr} \times \frac{Nominal\ Spiking\ Gas\ Mixture\ ppm\ or\ \%}{Actual\ Spiking\ Gas\ Mixture\ ppm\ or\ \%}$$

The cylinders of spiking gas delivered were within the ±2% tolerance required, hence, the formula is reduced to:

$$Actual\ Flow\left(\frac{mL}{min}\right) = Nominal\left(\frac{mL}{min}\right) \times \frac{Rated\ Input\ \left(\frac{Btu}{Hr}\right)}{100,000\ Btu/Hr}$$

Before starting the corrosion testing each furnace had its input and baseline CO₂ and CO air free values determined (see above). Of primary importance for sample 1 through 4 was the low fire input values. If a furnace was found to be outside the ±2% limit detailed in clause 2.5.4 of the ANSI Z21.47/CSA 2.3, the manifold pressure was adjusted to obtain the required BTU/Hr. input on the data plate. The low fire CO₂ values of samples 1, 2, 3, and 4 were needed in order to arrive at the proper spiking gas flow as detailed in Z21.47/CSA 2.3, section 2.15. Since sample 5 was not a two stage combustion system, only the full input data needed to be addressed.

Based upon the above data for minimum input for samples 1 through 4 and maximum input for sample 5 the following flow rates of spiking gas were determined for this evaluation.



FLOW RATES FOR SPIKING GAS					
Furnace Sample #	#1	#2	#3	#4	#5
Flow Rate (mL/min)	85	86	135	91	118

Table 5

150 mm glass flowmeters were used to determine the flow to each furnace and throughout the cycling the flow rates were monitored to confirm there was no drift in the control mechanism.

Furnace 1 was listed for and set up with 65' of PVC exhaust pipe and furnace 2 was listed for and setup with 200' of PVC exhaust pipe. Samples 3 – 5 were set up with vertical metallic pipe that then traversed vertically and horizontally to the central collector exhaust hood.

The rise and static pressure conditions were established with the appropriate duct work at a return air temperature of 70°F at full input. Again samples 1 through 4 needed the rise established while operating at low fire conditions and sample 5 only needed the high fire rise condition. The static pressure for samples 1-4 varied from that used at normal input.

Based upon the above heat exchanger temperatures, each furnace was also equipped with a removable panel that would allow visual inspection of the heat exchangers where it was expected that corrosion might occur. This would permit constant surveillance of the possible issues before the end on the cycling period.



TEST STRUCTURE FOR MAINTAINING RETURN AIR TEMPERATURE

Although Gas Consultants, Inc. has conducted numerous heat exchanger corrosion tests for many companies, the ambient air parameters for this project required a custom system to condition the air to 45°F. It was originally hoped that the testing could commence at the beginning of the cold weather in Cleveland, Ohio (around mid to late October), and finish while it was still cold outdoors. The goal was to utilize cold outdoor air as the main “feed” for the circulating air and combustion air systems. If the outdoor air was too cold it could be either heated or blended with indoor air to arrive at the desired or target temperature. Unfortunately, the furnaces to be tested arrived much later than requested/anticipated and the conditioned air needed to be both heated on some days and chilled on others. Four air conditioners were placed on the main trunk circulating air system and brought online as needed to maintain the blended air temperature. Two can be seen in Photo 1 (below) mounted above the main trunk feed and the remaining two were mounted outdoors and air ducted to the central circulating system as needed.

A 2D schematic of the air distribution system is shown below (Fig. 1) and for clarity only shows one furnace installed in the system. To conserve lab floor space the actual physical structure was “vertical” with the legs of the circulating trunk duct over and under each other and some of the A/C units mounted above the duct work. See the 3D schematic (Fig 2) and also the photos in the Appendix. Also photo 1 show’s a general setup of one of the furnaces before insulation was installed on the central distribution duct. Two of the air conditioning units can be seen being installed above the test system (no interconnection ductwork attached yet).

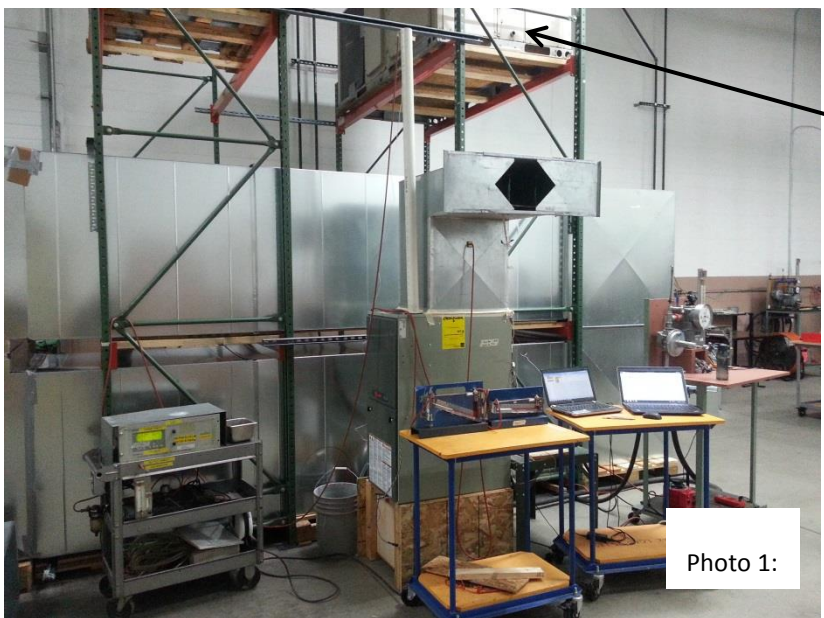


Photo 1:

A/C units being installed over central distribution duct.

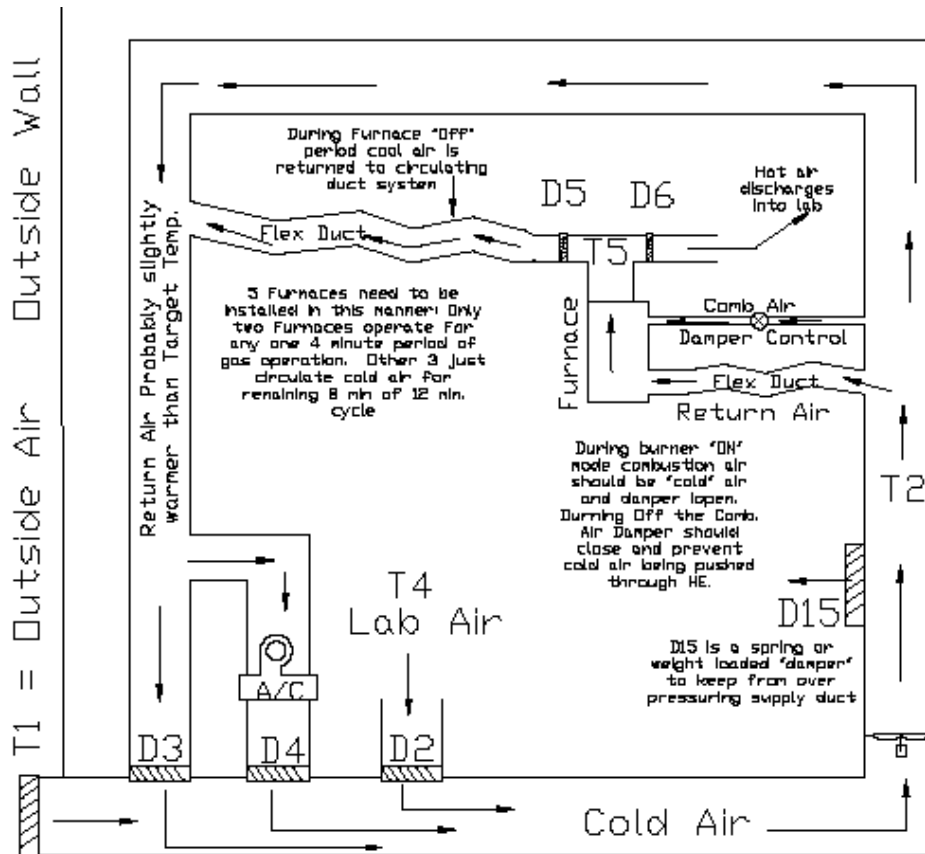
The inlet air of each furnace was attached to a 14" diameter flexible duct that in turn was attached to the central cold air supply duct Photo 2.

Inlet Flexible Duct between Supply System and
Furnace Inlet Air



The system was designed with thermostats that monitored outdoor air temperature, indoor air temperature and the air temperature within the ductwork. A series of dampers were used to modulate between outside and indoor air when the outdoor air was below the target temperature of 45°F. If the temperature rose above the target temperature, air conditioners were staged "on" to lower the circulating air temperature in the trunk duct. Unfortunately, by mid-March the outdoor temperatures were unseasonably warm.

See Appendix Photos A1 thru A11 for overview of the test apparatus.



D1 All dampers are open/close except D1 & D2 which are variable opening & D15 is pressure relief
Multiple A/C units can be ganged as needed depending on outdoor air temperature and system needs

D1 is 24" x 24" Damper with 2-10 VDC motor drive
D2 is 16" x 16" Damper with 2-10 VDC motor drive

D3 & D4 are 24" x 24" Damper with On/Off damper motors

Fig 1 2D Schematic of cold air system

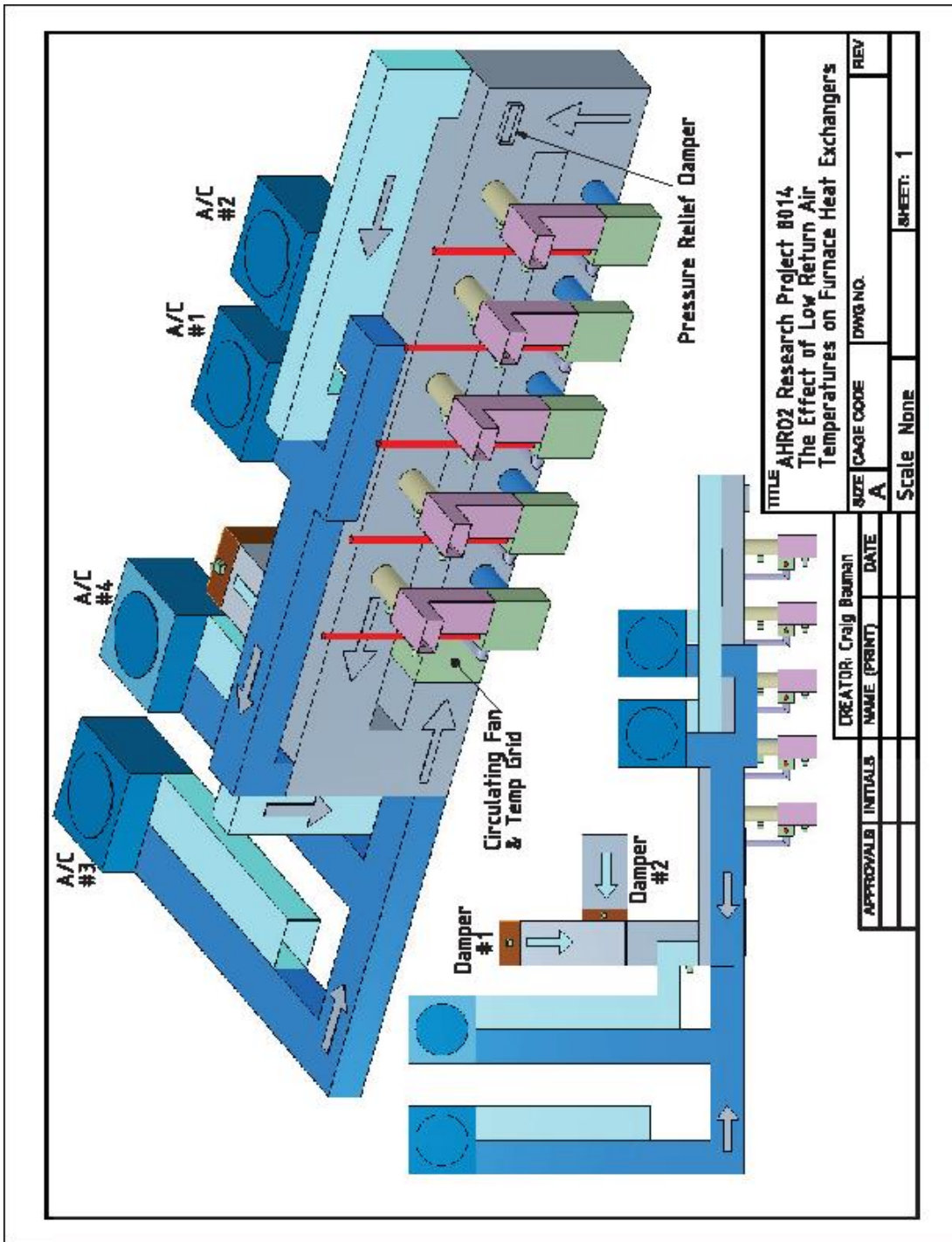


Fig 2 3D Schematic of cold air system



Referring to the schematic above, each furnace was equipped with two dampers in the warm air discharge plenum. While in the heating mode the “hot” air was diverted into the lab space with damper D6 open and damper D5 closed. During the furnace off cycle and once the furnace discharge air temperature dropped to the temperature of the main cold feed system (nominally 45°F), damper D6 closed and damper D5 opened such that the “cold” air would be returned to the cold air delivery system and not wasted or dumped into the lab space.

The design of the system was such that two furnaces were on for 4 minutes while three furnaces were in the cool down mode. Then when the first two started their cool down period, two more furnaces started their 4 minute operational cycle. When those two furnaces completed 4 minutes of burn time, the burners turned off and they started into their cool down period. At that point the fifth furnace came on for its four minute cycle. When the fifth furnace completed its four minute “on” cycle, the process started over, i.e., furnaces 1 and 2 started back up. The total corrosion test cycle is to be 4 minutes “on” and 8 minutes “off” for a total of 12,000 cycles or 800 hours of burner on time.



Those furnaces with outdoor combustion inlet air connections were connected to the central cold duct directly. For those furnaces designed for indoor air, a “plenum” or box was built on the front of the furnace and a 6” vent pipe was connected between that plenum box and the central cold distribution duct (Photo 3).

The same was done for the rooftop unit plus the rooftop unit required a “collector hood” placed over the combustion discharge that was fan equipped to exhaust the products into the primary collector hood for the project. The collector hood was decoupled from the rooftop exhaust (much like a kitchen range exhaust) such that no abnormal operation of the combustion system would take place.

Each combustion air pipe between the furnace and the central duct utilized an electric damper that opened on a call for heat and closed when the combustion blower shut off. Therefore, cold air was not continuously forced through the inside of the furnace heat exchangers during the “off” or cool down cycles.



The maximum vent length exhaust pipes of units 1 through 4 were plumbed into a collection hood at the ceiling and the exhaust products were drafted to the outdoors. See Appendix Photo A2.

The test gas used for spiking was 30,000 ppm (3%) of methyl chloride, 10,000 ppm (1%) methyl fluoride in nitrogen. The gases used were all analyzed by an ISO 17025 lab and were within $\pm 2\%$ (actual- 1.7%) of the required constituent's concentration. See Appendix Photos A7 thru A9.

The cycling apparatus for the actual corrosion testing was the same as that detailed in clause 2.15 of Z21.47/CSA 2.3 appendix G. Thus each furnace had a dedicated corrosion cycling system consisting of valves, flow meter, gas meter, leak checker bottle, etc. A common timing system was used due to the required sequencing of the five furnaces. Also a central spiking gas supply system was used to feed the spiking gas to the individual furnace spiking gas systems.

If the central cold air supply temperature went outside of the temperature limitation of $45^{\circ}\text{F} \pm 5^{\circ}\text{F}$, the system allow the current (in process) cycle to be completed but then stopped the cycling apparatus and held the system in a "hold" mode until the inlet air temperature was back within specifications. To prevent possible rapid on and off operation due to return air temperature fluctuations, a minimum down time was specified of 30 minutes before cycling could be reinstated.

The total down time due to temperature excursions outside of the limits was 24 days for Furnace 1, 2, 3 and 5 with a total down time for any one event was no more than 2 days. Because Furnace 4 experienced issues with CO levels, its total down time was 30 days with an single off period of 6 days. Although clause 2.15 calls for no more than 20 days of "down" time it was not possible to stay within these confined conditions due to some abnormally warm temperatures that occurred. It was felt that more incidents of down time would be a more adverse situation and visual and intermediate tests indicated that no issues were being experienced by the higher than permitted "down" days.

Through the use of dataloggers, the temperature of the plenum air temperature was tracked once per minute over the course of the whole testing and the average air temperature during run cycles was 46.1°F .



POST CORROSION CYCLING RESULTS

The cycling program was begun on Feb. 25, 2015. Although there were two air conditioning units installed in the system with approx. 7 tons of air conditioning, later in the program, as the weather became substantially warmer, the system was shut down while two more air conditioning systems (approx. 7 additional tons) were installed in the air duct system.

The data, photographs, examination for failure points and dismantling all took place within 10 days after cycling was completed.

The data recorded during the cycling testing is shown below for each furnace.

It should be noted that all intermediate checks of emissions during the cycling program were conducted with the maximum exhaust pipe vent length for Furnaces 1 through 4. Therefore, correlation of pre-cycling CO₂ and CO data and that obtained during cycling are not identical due to vent length differences and temperature conditions that varied for the combustion air supply..

FURNACE 1				
Date (m/d/y)	3/17/15	4/6/15	5/21/15	6/30/15
Hours of On Time	166.8	332.9	571.8	813.4
Cycle Count	2525	5036	8902	12,723
Input (Btu/Hr)	54,100	55,500	55,900	54,500
CO₂ (%)	5.6	5.65	5.67	5.65
CO (ppm)	32	20	26	29
Flue Temp (°F)	70.1	74.8	70.9	82.3
Inlet Air Temp (°F)	45.2	51.4	47.3	56
Outlet Air Temp (°F)	91.2	99.9	94.3	99
Rise (°F)	46	48.5	47	43



FURNACE 2				
Date (m/d/y)	3/17/15	4/7/15	5/21/15	6/30/15
Hours of On Time	166.7	331.4	569.4	808.3
Cycle Count	2534	5058	8996	13079
Input (Btu/Hr)	57,100	58,300	58,100	57,100
CO2 (%)	6.31	6.32	6.07	5.80
CO (ppm)	7	7	4	1
Flue Temp (°F)	85.5	102.6	85.6	105
Inlet Air Temp (°F)	46.9	53.4	46.3	55
Outlet Air Temp (°F)	95.6	102.6	198.1	103
Rise (°F)	48.7	49.2	51.8	55

FURNACE 3				
Date (m/d/y)	3/17/15	4/6/15	5/21/15	6/30/15
Hours of On Time	167.2	329.4	566.5	800.3
Cycle Count	252.2	329.4	8797	12651
Input (Btu/Hr)	57,600	58,300	59,100	58,400
CO2 (%)	4.21	4.31	4.36	4.19
CO (ppm)	7	6	11	1
Flue Temp (°F)	244.9	240.3	220.0	220.0
Inlet Air Temp (°F)	43.5	50.3	43.6	52
Outlet Air Temp (°F)	88.2	98.9	95.2	97
Rise (°F)	44.7	48.6	51.6	45



FURNACE 4					
Date (m/d/y)	3/17/15	4/7/15	5/21/15	5/26/15	7/13/15
Hours of On Time	166.8	314.4	545.8	After Correction	800.3
Cycle Count	2524	4913	8902		12,601
Input (Btu/Hr)	65,000	64,500	62,700	62,700	64,400
CO₂ (%)	9.14	8.42	9.37	7.04	5.85
CO (ppm)	157	88	1000+*	25	13
Flue Temp (°F)	215.1	220.5	211.6		262
Inlet Air Temp (°F)	43.3	46.9	43.6		77
Outlet Air Temp (°F)	95.8	94.7	92.6		121
Rise (°F)	52.5	47.8	49.0		44

*This furnace was taken out of the cycling system for a period of time to determine why the CO levels were elevated. It was found that condensate and pipe corrosion had found their way back into the blower housing. Additionally, a damaged blower gasket was also found. The vent pipe was replaced and pitched properly, the debris was removed, and the gasket replaced. The system was checked out for proper operation and placed back into the cycling process, but in the meantime a number of days was lost and delayed the completion of this sample.

FURNACE 5				
Date (m/d/y)	3/17/15	4/6/15	5/21/15	6/30/15
Hours of On Time	168.3	331.6	575.9	807.4
Cycle Count	2528	4970	8797	Counter Failure
Input (Btu/Hr)	56,700	57,400	57,400	55,500
CO₂ (%)	5.87	5.03	6.05	5.38
CO (ppm)	12	12	17	12
Flue Temp (°F)	260.1	258.5	266.1	207.0
Inlet Air Temp (°F)	46.5	47.6	45.7	51
Outlet Air Temp (°F)	93.3	96.0	91.3	96
Rise (°F)	46.8	48.4	45.6	45

A visual examination* of the furnaces for integrity of the heat exchangers and flue passageway systems revealed the following:



*If one finds any signs of corrosion on the circulating air side of the metal parts it is an almost positive indicator that corrosion from the interior has eaten a hole through to the exterior surface. That surface will become an eventual pathway if penetrating dyes or other leak checkers are used.

Furnace 1 (Condensing): Appendix Photos A12 – A21

- There was no sign of corrosion on any metallic surfaces in the circulating air side of the furnace.
- The primary heat exchanger was in excellent shape both on the exterior and interior portions with no signs of pinholes or rust penetration.
- The secondary heat exchanger baffles were examined and found to be in good condition.

Furnace 2 (Condensing): Appendix Photos A22 – A31

- There were no signs of corrosion any metallic surfaces in the circulating air side of the furnace.
- The primary heat exchanger was in excellent shape both on the exterior and interior portions with no signs of pinholes or rust penetration.
- The distribution box between the primary and secondary heat exchanger was examined and although it contained some corrosion there was no severe attack of the metal.
- The secondary heat exchanger baffles were examined and found to be in good condition.

Furnace 3 (Non-Condensing): Appendix Photos A32 – A42

- There were no signs of corrosion any metallic surfaces on of the heat exchanger tubes on the circulating air side of the furnace.
- The interior surfaces of the heat exchanger tubes showed some signs of corrosion on the discharge (exit) portion of the heat exchanger tubes but no penetrations had occurred
- The collector box showed signs of corrosion on the interior bur no exterior corrosion. Thus indicating that the collector box kept its integrity. This is probably because the drawn box was on the control compartment side and not penetrating into the circulating air flow side.
- The header plate which separates the control compartment from the circulating air side did show signs of corrosion on the circulating air side. An examination of the flue gas side showed extensive damage with a large “flake” of “rust” covering



numerous holes. When the “flake” was touched, it fell off and the holes were readily visible.

- The point where the heat exchanger tubes are swaged onto the header plate showed extensive rust on the flue gas side but none was found on the circulating air side. It is expected that if the system sat for 12 months in this condition and was not used, the rust condition would eventually penetrate at the swage point.

Furnace 4 (Non-Condensing): Appendix Photos A43 – A53

- There was a spot where corrosion occurred on one heat exchanger tube approximately 4” from where the tube screwed onto the header plate.
- The interior surfaces of the heat exchanger tubes showed signs of corrosion on the discharge (exit) portion of the heat exchanger tubes with the one penetration noted above.
- The collector box which is a formed (drawn) portion of the header plate showed signs of extensive corrosion on the interior but no exterior corrosion. Thus indicating that the collector box kept its integrity.

When Furnace 4 was further examined approximately 60 days after the corrosion cycling was finished, it was found that what appeared to be a slight spot of corrosion (metallic colored) with two pin holes (less than 1/8” each in diameter) had grown to a substantial spot of red/orange colored corrosion. When touched with a slight pressure, the “rust” spot the metal gave way and left a hole in the heat exchanger about a 1/2” in diameter. See Appendix Photos A52 and A53.

It should be noted that all furnaces were kept in a heated storage area under shrink wrap.



Furnace 5 (Non-Condensing): Appendix Photos A54– A68

- There were no signs of corrosion any metallic surfaces on of the heat exchanger tubes on the circulating air side of the furnace.
- The cover plate over the drawn collector box was examined and there was no corrosion on the exterior surface and moderate on the flue gas side of the plate.
- The drawn flue gas collector box had extensive corrosion on the interior of the box.
- The exterior of the flue gas collector box had numerous points that exhibited corrosion and these points did indicate penetration had occurred.

The collector box of Furnace 5 was re-examined after approximately 60 days and the small penetrations noted above had grown into large voids in the metal. See comparison photographs A67 and A68 for the substantial difference in penetration size.

As can be seen from the above, for non-condensing rated furnaces, the results of the evaluation indicate that when such a furnaces is subjected to 45°F return air and tested under the conditions of this evaluation will lead to penetrations of the sheet metal surface that form the boundary between the combustion gas side of the furnaces and the circulating air side of the furnace. For condensing rated furnaces when tested under the same method of test do not exhibit any adverse issues of deterioration of the sheet metal components of the flue gas system.



TEST EQUIPMENT AND LABATORY PROCEDURES

Gas Consultants, Inc. laboratory operates under an ISO 17025 laboratory accreditation from LAB, an ILAC member. The Gas Consultants, Inc. quality control manual covers all aspects of necessary operation, staff training, and, equipment calibration requirements to maintain an EPA accreditation for Energy Star testing of gas along with the necessary surveillance by UL, CSA and ETL to permit data generation for those three listing agencies including conducting Z21.47 /CSA 2.3 Corrosion Testing of Heat Exchangers.

All calibration records of specific equipment used in this program are maintained in Gas Consultants, Inc.'s database in Cleveland, Ohio.



Gas
Consultants,
Inc.

Appendix



Insulation
Board
Over Air
Ductwork

Photo A1

Layout of the Air Cooling System for Low Inlet Air
Temperature Study

2 of 4 Air Conditioning Systems Mounted
Above Air Duct Chambers

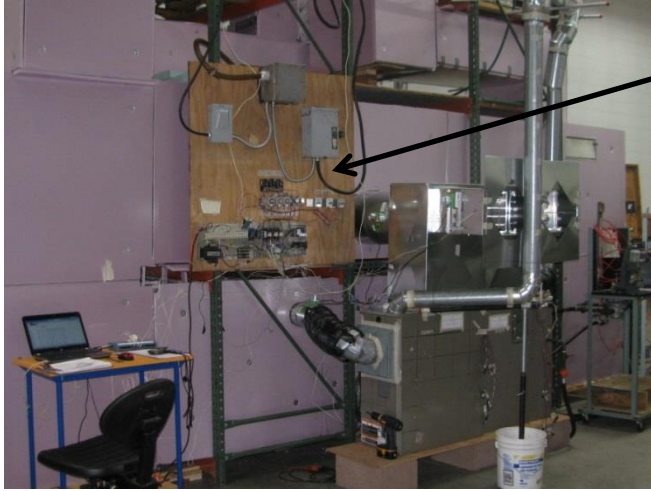


Photo A2



Photo A3

Duct To Outdoor Air Supply



**Control Panel For Air
Temperature Control**

Photo A4



Photo A5

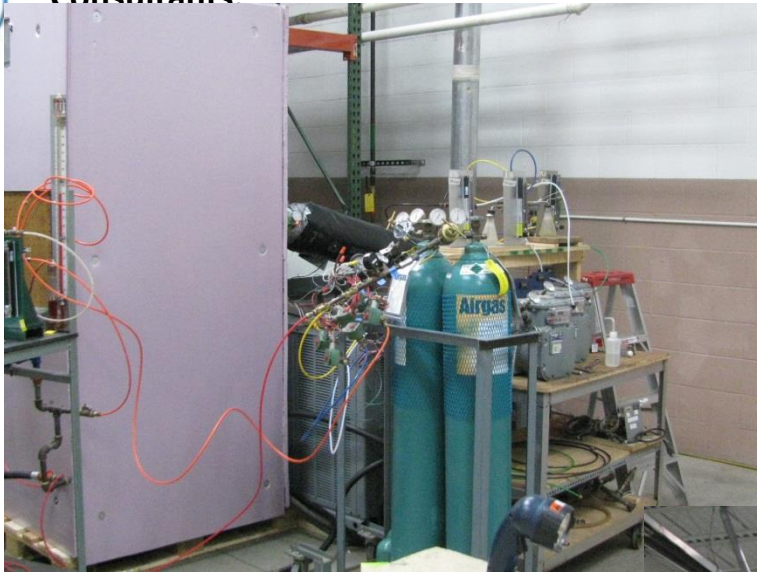
**Insulated
Combustion Air**

**Furnaces
III and IV**



**Gas Meters Used To
Check Flows and
Operational Times**

Photo A6

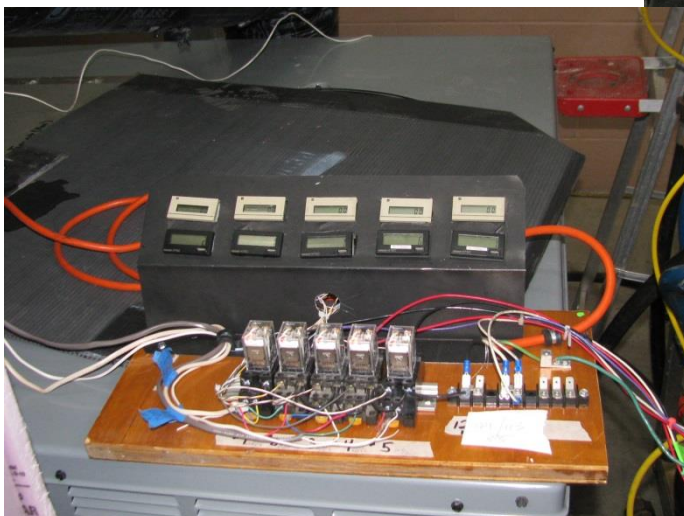


**Spiking Gas Cylinders
and Control**

Photo A7

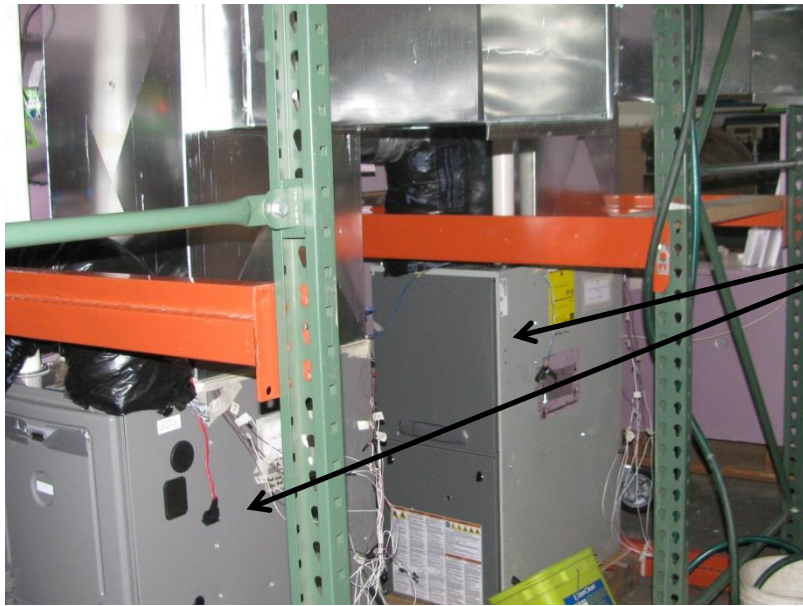


Photo A8



**Cycle and Hour Counters and
Cycle Timers for Furnace**

Photo A9



**Furnaces I
and II**

Photo A10



**Roof Top
Packaged
Furnace**

Photo A11



Furnace I (Condensing): Post Cycling



Photo A12



Photo A13



Photo A14



Furnace I (Condensing): Post Cycling

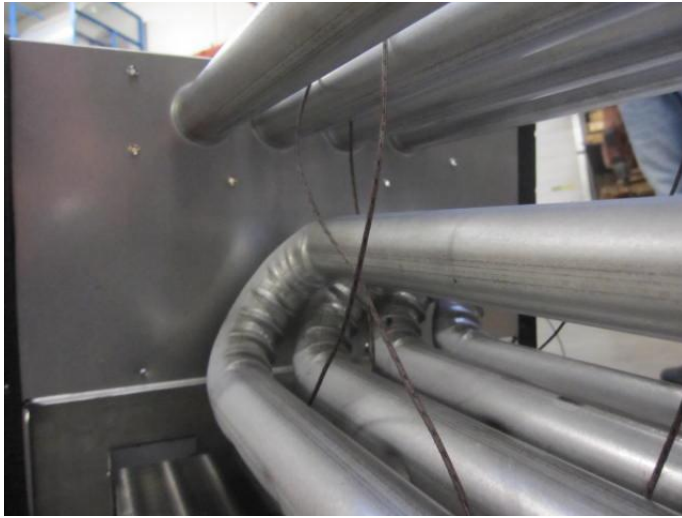


Photo A15



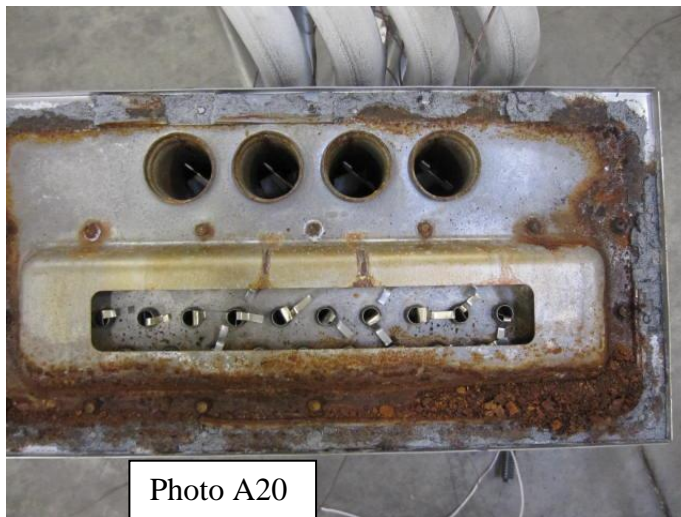
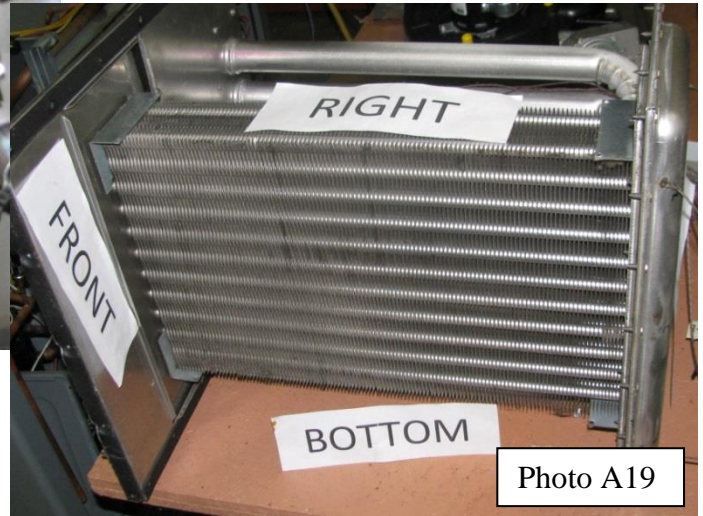
Photo A16



Photo A17



Furnace I (Condensing): Post Cycling





Furnace II (Condensing): Post Cycling

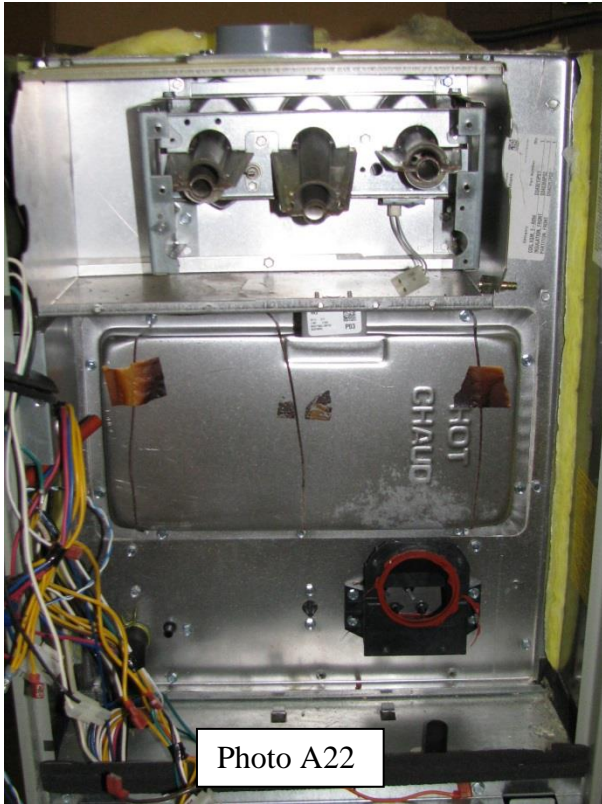


Photo A22



Photo A23

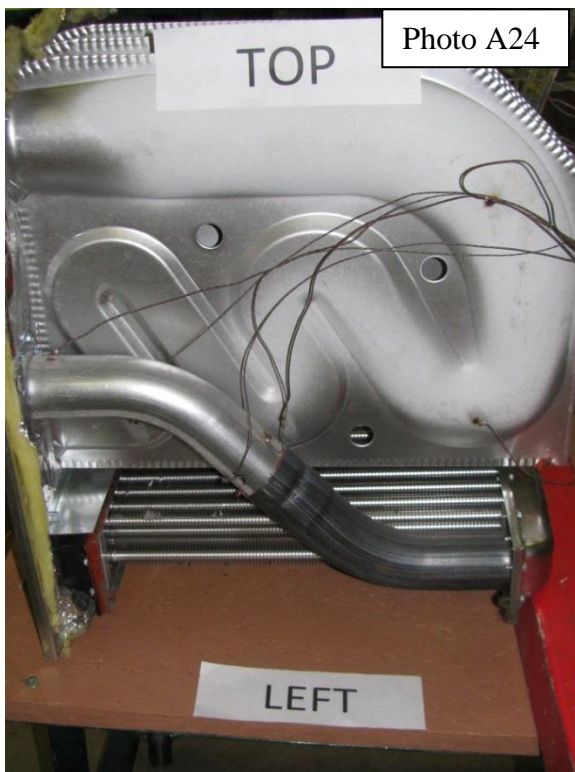


Photo A24



Photo A25



Furnace II (Condensing): Post Cycling



Photo A26

Photo A27



Photo A28



Furnace II (Condensing): Post Cycling

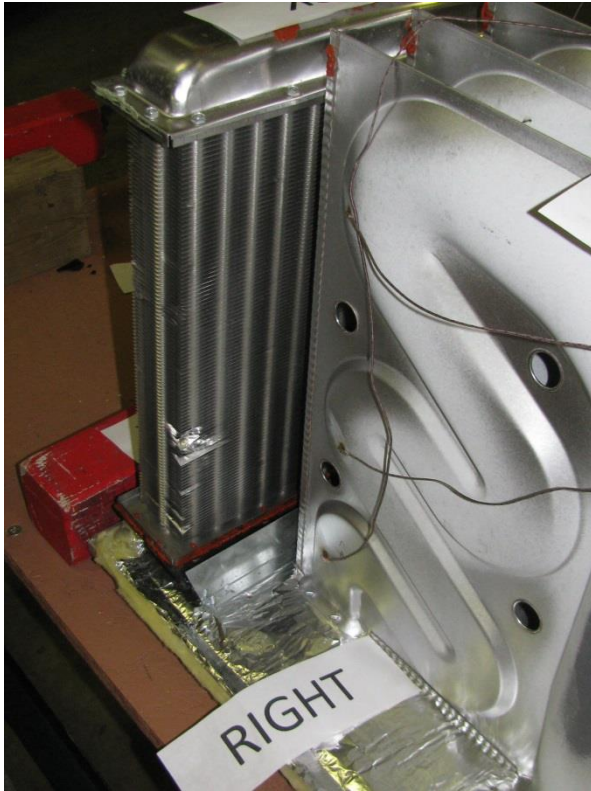


Photo A29



Photo A30



Photo A31



Furnace III (Non-Condensing): Post Cycling



Photo A32

**Inlet to Combustion
Bower Assembly**

**View Through Collector
Box Cover Into Collector
Box**



Photo A33



Furnace III (Non-Condensing): Post Cycling



**Inside of Collector Box
Cover**

Photo A34

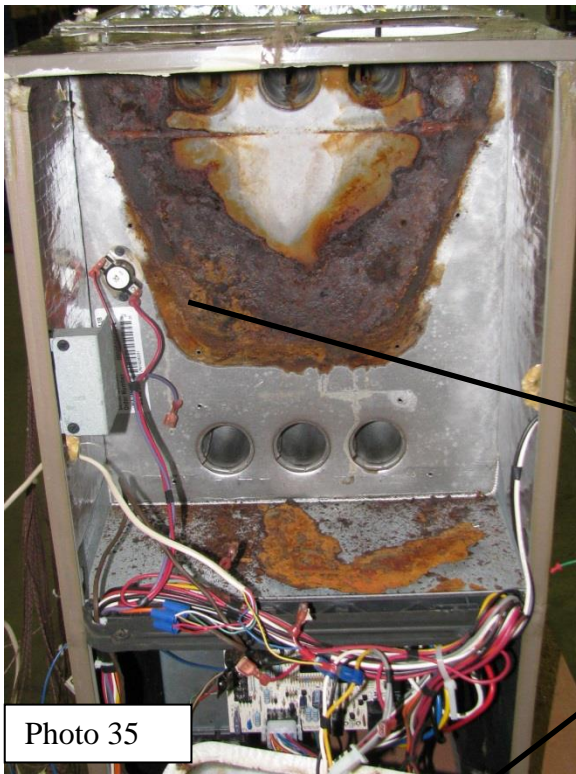


Photo 35

**Collector Box Removed
Showing Vestibule Panel
Behind Collector Box**

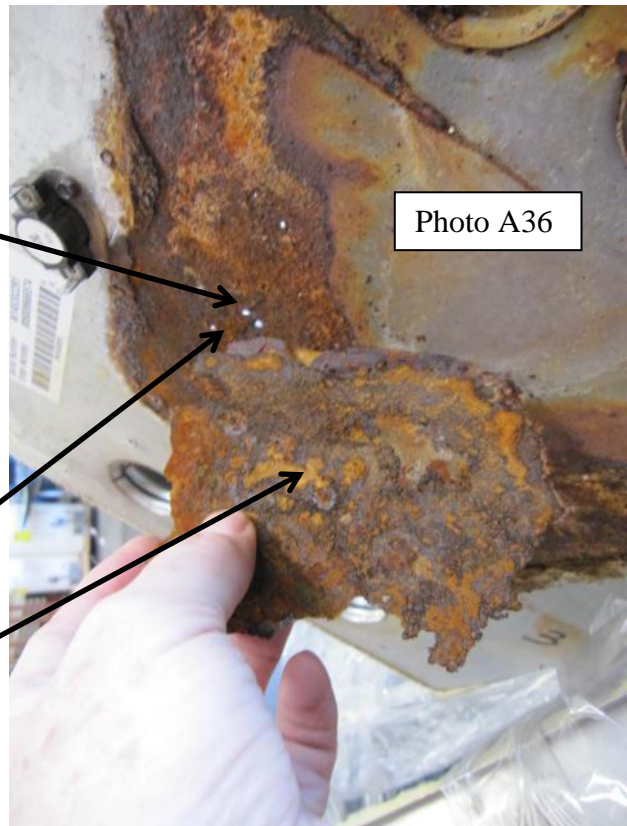


Photo A36

**Perforations Behind
Metal Scale on Vestibule
Panel. Scale Fell Off
Panel When Touch**



Furnace III (Non-Condensing): Post Cycling

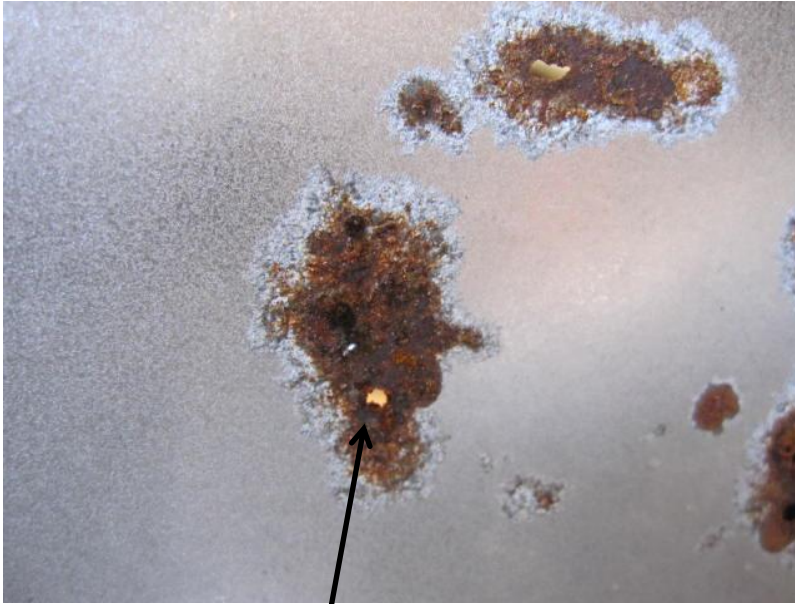


Photo A37

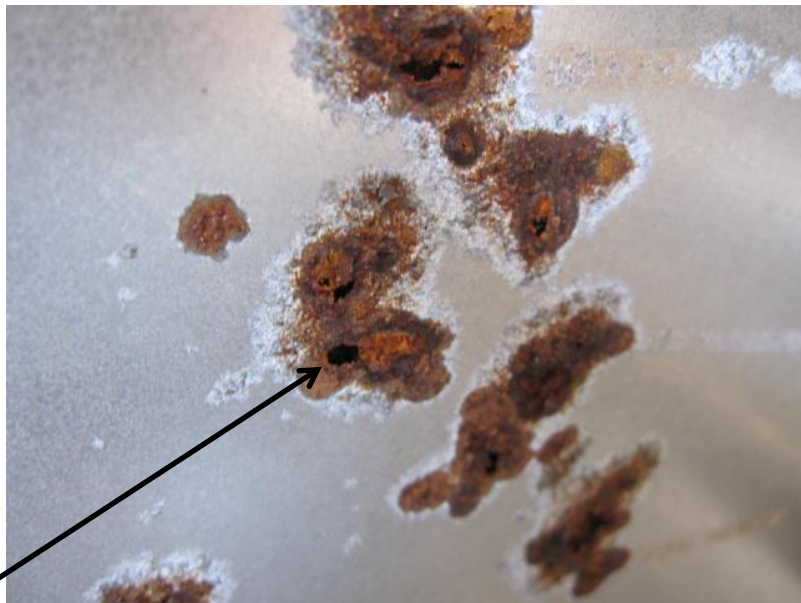


Photo A38

**Perforation (Previous Page) Viewed
From The Circulating Air Side of
Vestibule or Header Panel**



Furnace III (Non-Condensing): Post Cycling

Photo A39



Photo A40



Extensive Corrosion Around Where Heat Exchanger Swaged to Header / Vestibule Plate, but No Loss of Integrity of Connection/Seal



Photo A41



Furnace III (Non-Condensing): Post Cycling



Photo A42



Furnace IV (Non-Condensing): Post Cycling



Photo A43

**Rust Found on Right, Inside
of Body Panel Caused by
Dripping Vent Pipe**

Photo A44

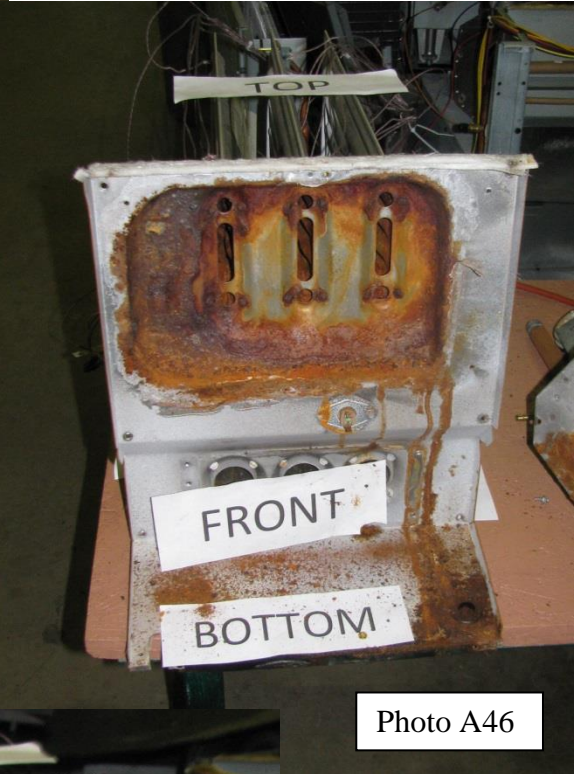




Furnace IV (Non-Condensing): Post Cycling



**Collector Cover Panel and
Combustion Blower Removed
From Flue Collector Box**





Furnace IV (Non-Condensing): Post Cycling



Photo A48

**Combustion Blower/Flue
Box Cover Plate**

Photo A49

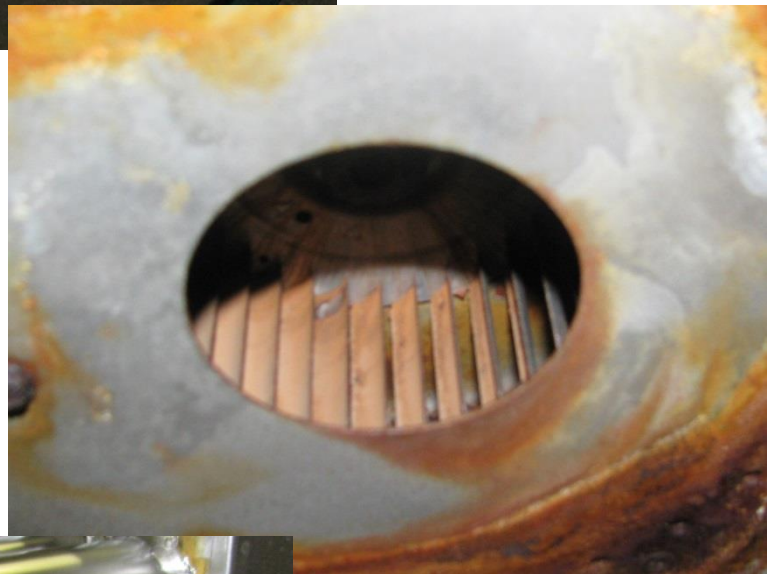


Photo A50



Furnace IV (Non-Condensing): Post Cycling



Photo A51



Photo A52



Furnace IV (Non-Condensing): Post Cycling (60 Days After Cycling Completed)

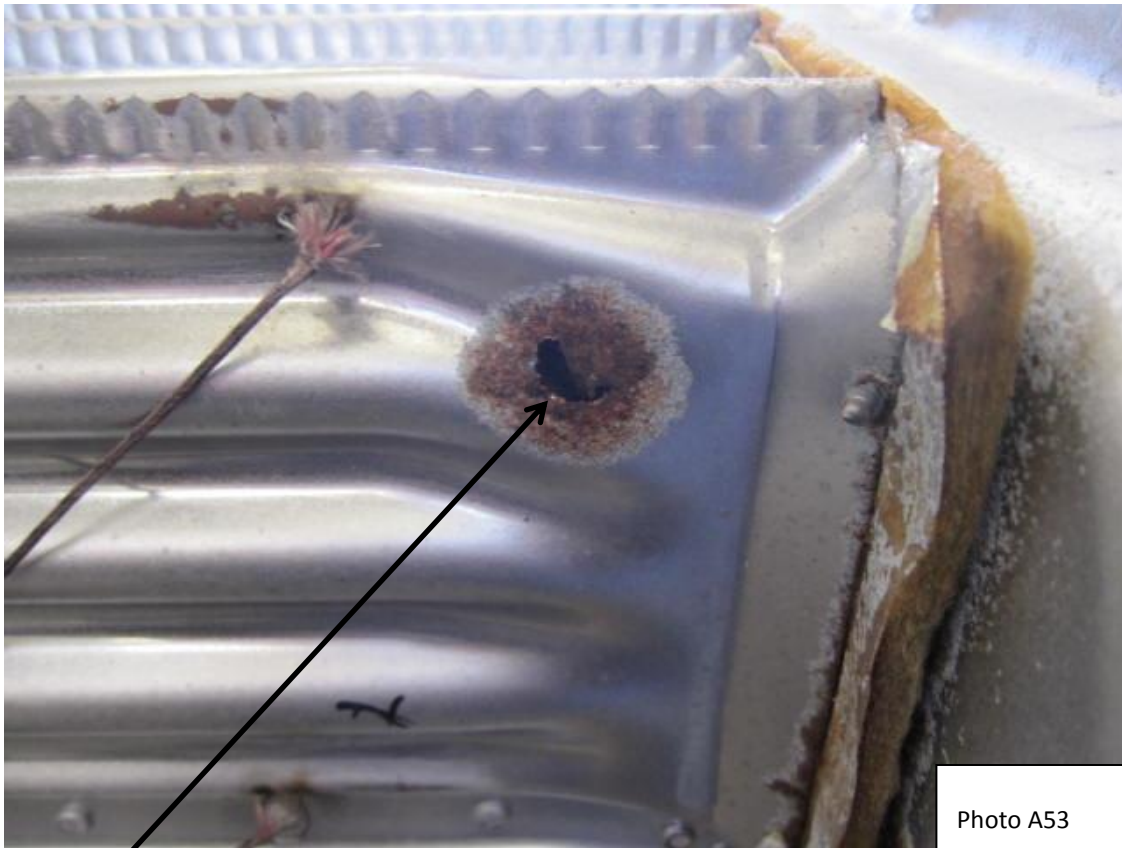


Photo A53

Approx. 60 Days After the Previous Photo Was Taken, the Corrosion Spot On the Heat Exchanger Was Found Substantially Enlarged and a Slight Pressure Caused the Above Hole To Be Created



Furnace V (Non-Condensing): Post Cycling



Photo A54

Artificial Collector Box Placed Around Standard Vent Discharge to Capture Flue Products and Discharge Outdoors



Photo A55

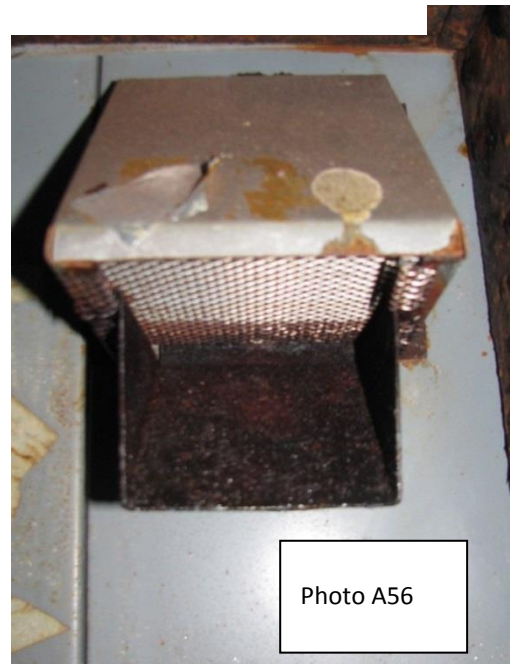


Photo A56



Furnace V (Non-Condensing): Post Cycling

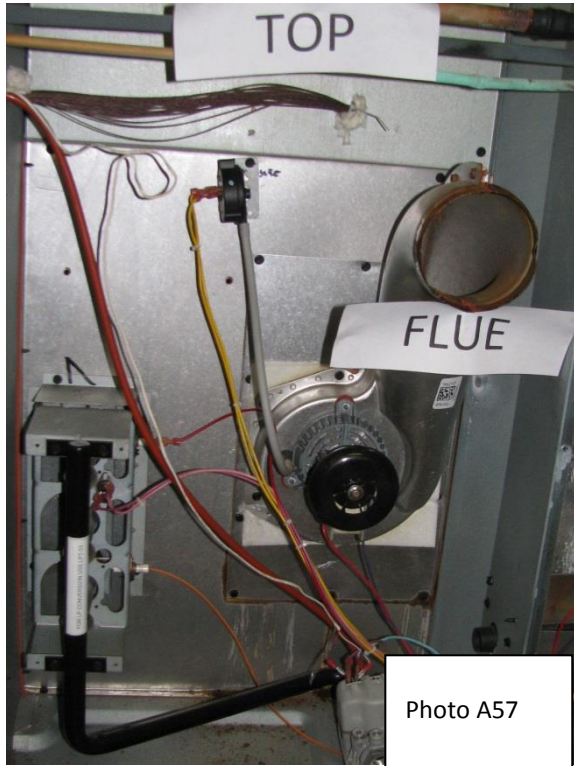


Photo A57

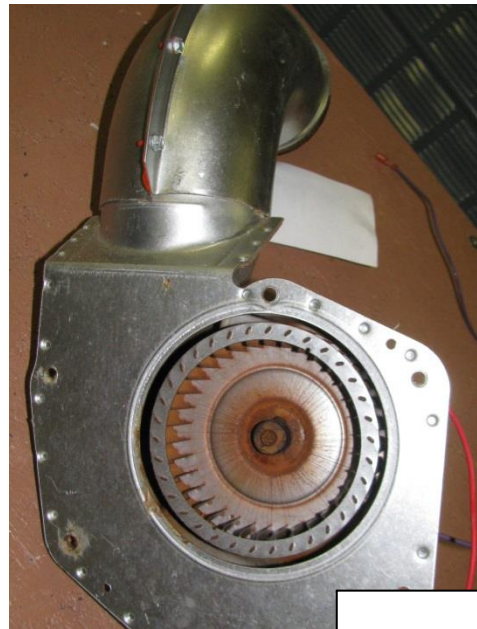


Photo A58

Flue Collector Box Cover

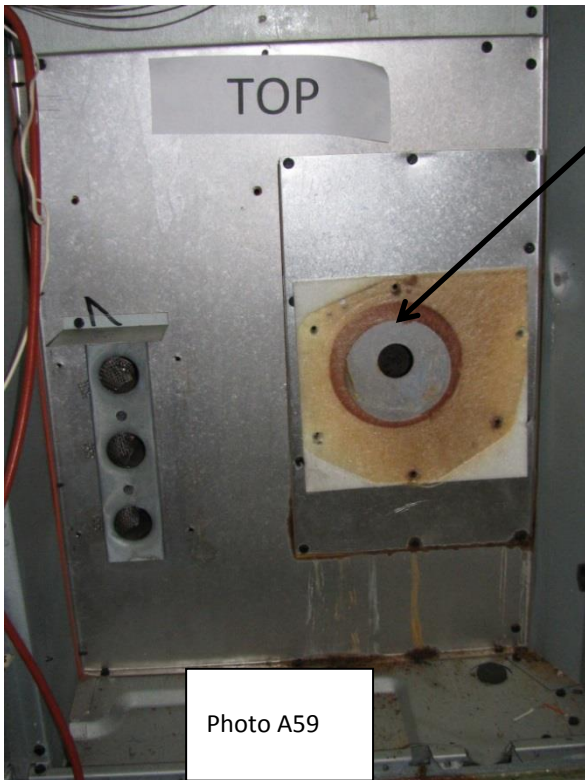


Photo A59

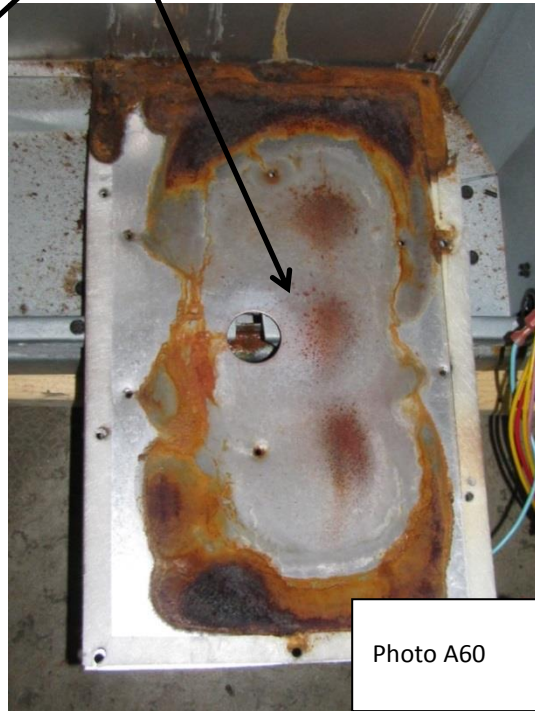


Photo A60



Furnace V (Non-Condensing): Post Cycling



Photo A61

**Actual Heat Exchanger Tubes
Show No Signs Of
Perforations**

Photo A62





Furnace V (Non-Condensing): Post Cycling



Photo A63

Flue Collector Box Cover



Photo A64

Flue Collector Box



Furnace V (Non-Condensing): Post Cycling

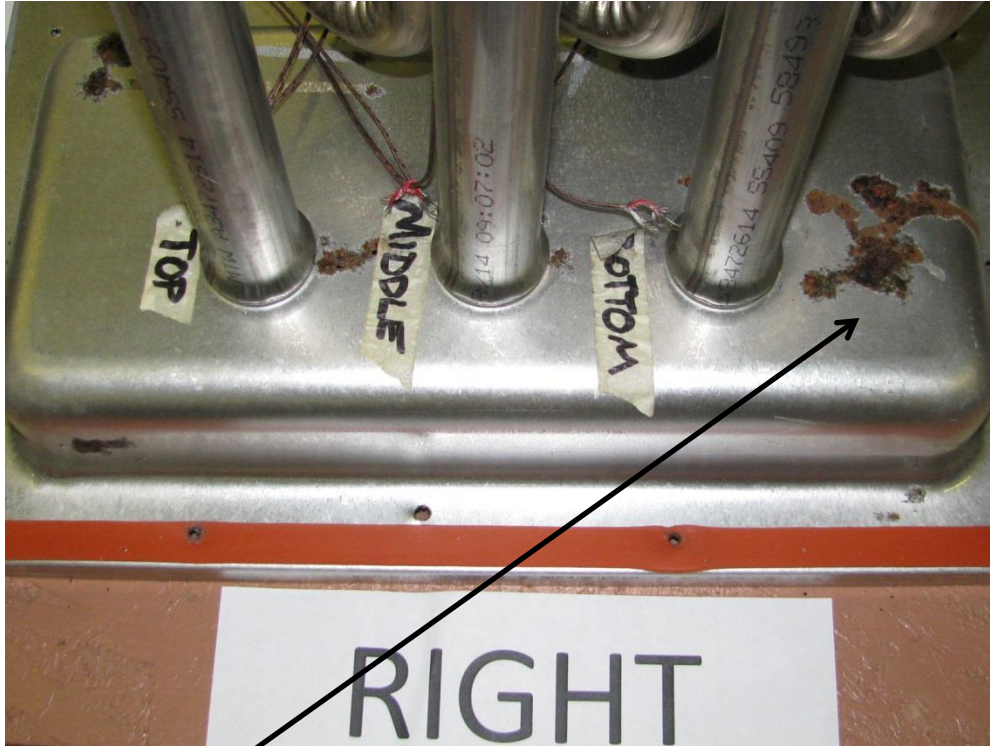


Photo A65

Any Area Where Rust Has Formed On Outside of Collector Box Is Indication of A Perforation from Flue Side to Circulating Air Side of Furnace.

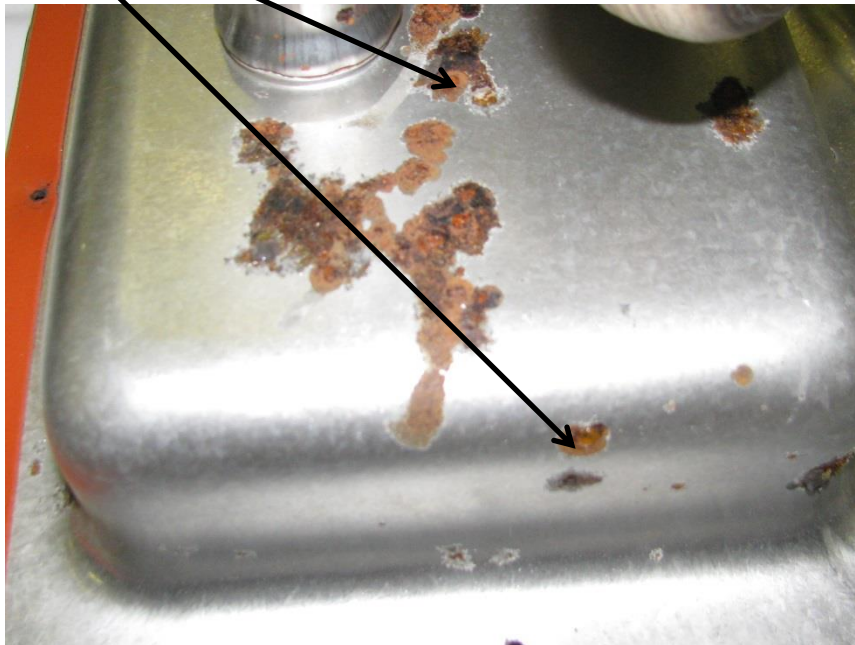


Photo A66



Furnace V (Non-Condensing): Post Cycling



The Photo Above Was Taken 8 Days After Cycling Was Finished. Very Small Holes Present.

The Photo Below Was Taken of Same Spot After 60 Days in Storage After Cycling Was Completed.





AHRI 8014: Heat Exchanger Cold Spots Identification



Gas Consultants, Inc.
7590 Independence Drive
Walton Hills, OH 44146

Furnace Design Types

- I. 2-Stage, Condensing, Upflow, Tubular
(AFUE = 96%)
- II. 2-Stage, Condensing, Upflow, Clam Shell
(AFUE = 97%)
- III. 2-Stage, Non-Condensing, Upflow, Tubular
(AFUE = 80%)
- IV. 2-Stage, Non-Condensing, Upflow, Clam Shell
(AFUE = 80%)
- V. Weatherized, Non-Condensing, Upflow, Tubular
(AFUE = 81%)



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Furnace I: Heat Exchanger Thermocouples Cont.

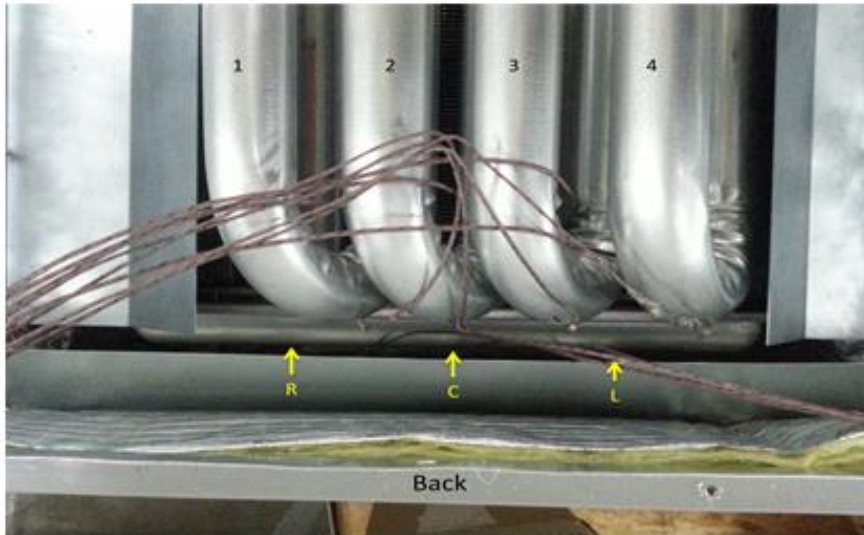


Furnace I: Heat Exchanger Thermocouples





Furnace I: Heat Exchanger Thermocouples Cont.



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Furnace I Cold Spots

Heat Exchanger Cold Spots

Inlet Air	40 °F	45 °F	50 °F	55 °F
High Fire	1.4/273°F	1.4/273°F	1.4/280°F	1.4/280°F
Low Fire	1.4/209°F	1.4/212°F	1.4/217°F	1.4/221°F

Collection Box Cold Spots

Inlet Air	40 °F	45 °F	50 °F	55 °F
High Fire	R/101°F	R/98°F	R/109°F	R/115°F
Low Fire	R/82°F	R/85°F	R/90°F	R/99°F

Rise:

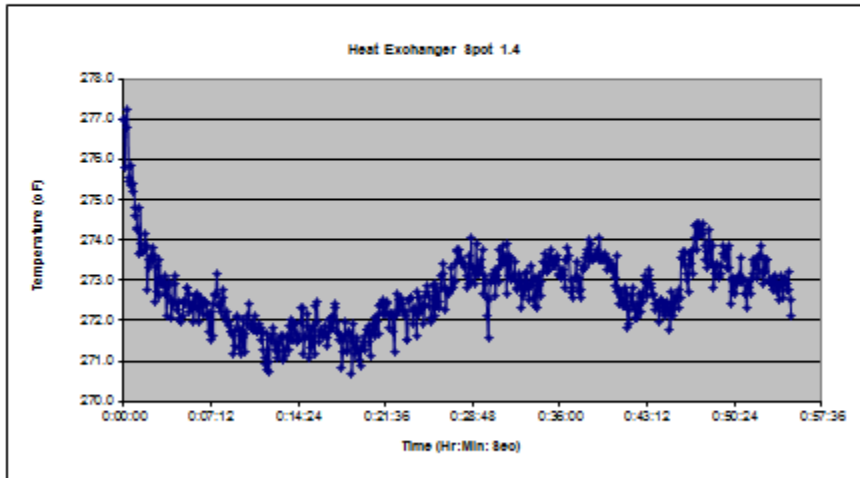
- High: 30-60°F (Mid-point: 45°F)
- Low: 20-50 °F (Mid-point: 35°F)



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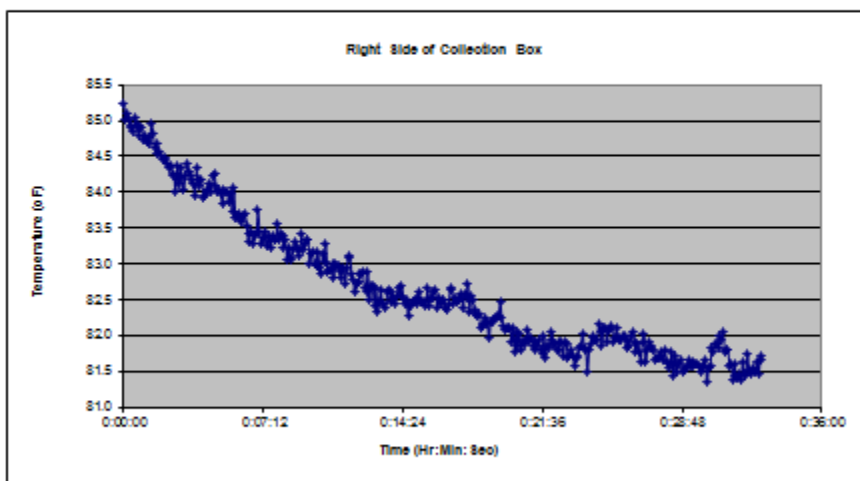


Furnace I Cold Spot Profile: 40 °F Inlet Air on High Fire



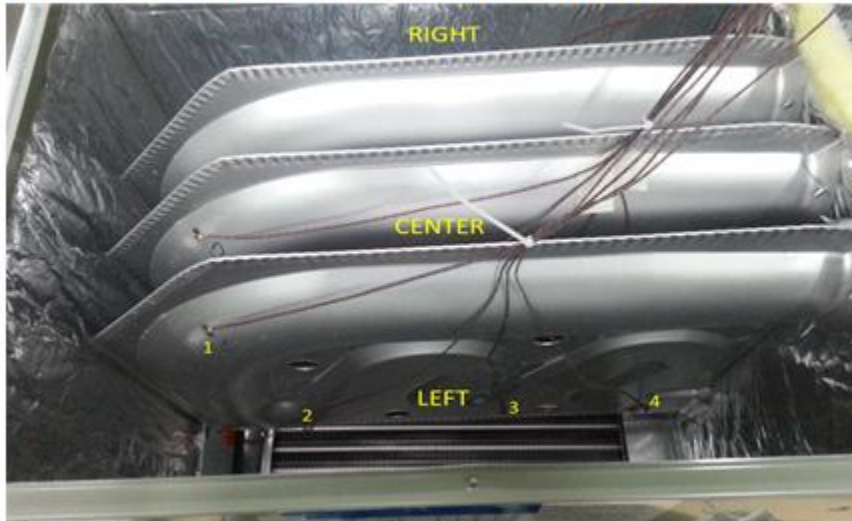
Gas Consultants, Inc.

Furnace I Cold Spot Profile: 40 °F Inlet Air on Low Fire Cont.

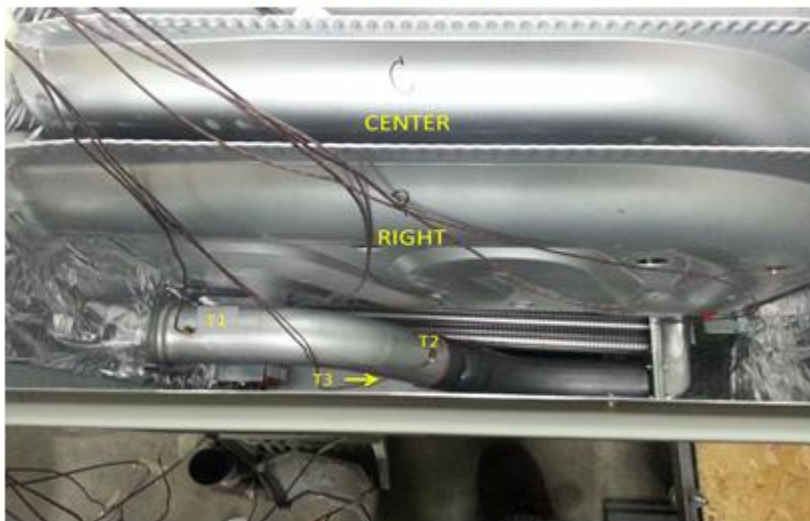


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Furnace II: Heat Exchanger Thermocouples



Furnace II: Heat Exchanger Thermocouples Cont.





Furnace II: Heat Exchanger Thermocouples Cont.



Gas Consultants, Inc.

Furnace II Cold Spots

Heat Exchanger Cold Spots

Inlet Air	40 °F	45 °F	50 °F	55 °F
High Fire	R4/265°F	R4/265°F	R4/269°F	R4/275°F
Low Fire	R3/193°F	R4/223°F	R4/229°F	R4/232°F

Transfer Tube Cold Spots

Inlet Air	40 °F	45 °F	50 °F	55 °F
High Fire	T3/187°F	T3/188°F	T3/192°F	T3/197°F
Low Fire	T3/152°F	T3/159°F	T3/164°F	T3/167°F

Rise:

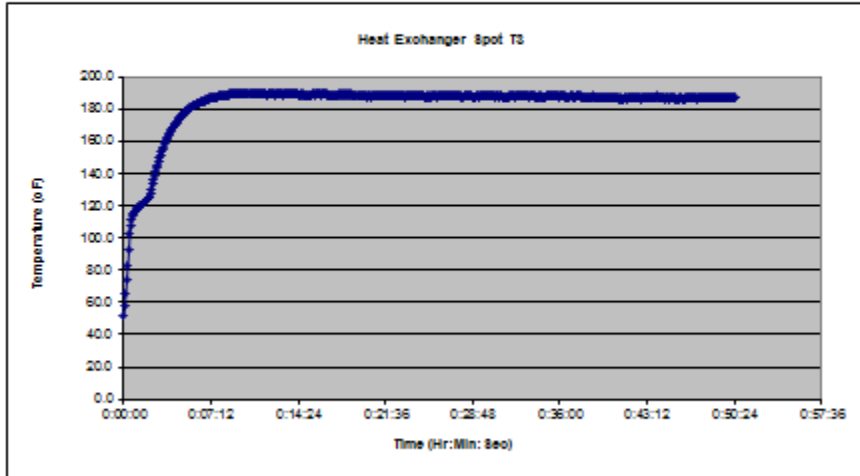
- High: 35-65 °F (Mid-point: 50 °F)
- Low: 35-65 °F (Mid-point: 50 °F)



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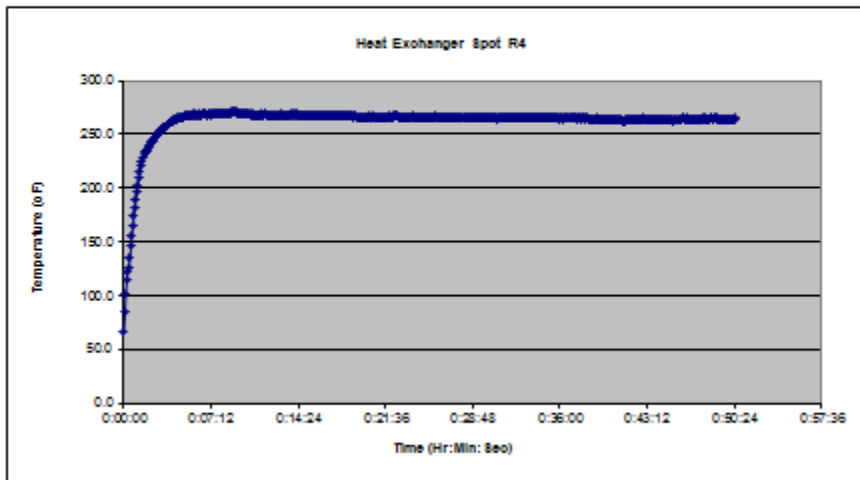


Furnace II Cold Spot Profile: 40 °F Inlet Air on High Fire Cont.



Gas Consultants, Inc.

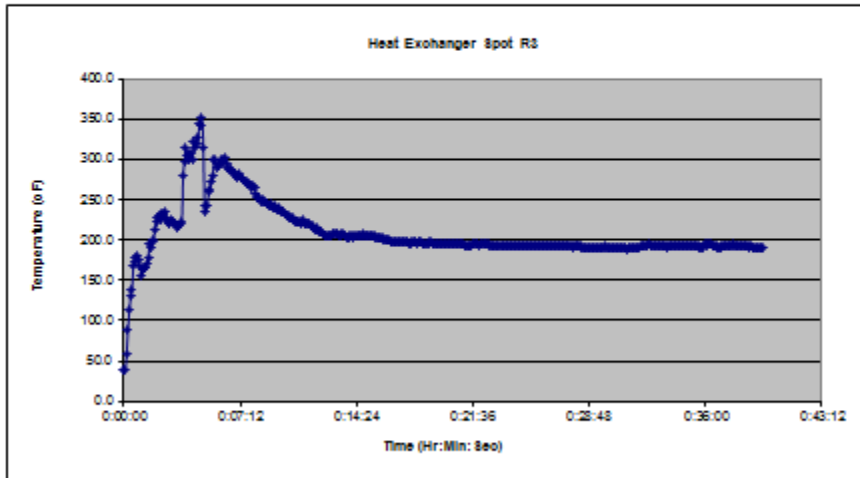
Furnace II Cold Spot Profile: 40 °F Inlet Air on High Fire



Gas Consultants, Inc.

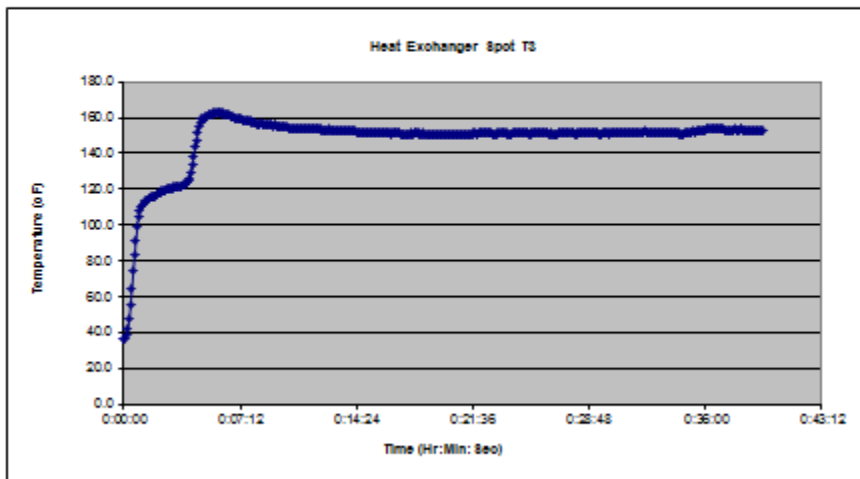


Furnace II Cold Spot Profile: 40 °F Inlet Air on Low Fire



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Furnace II Cold Spot Profile: 40 °F Inlet Air on Low Fire Cont.



Gas Consultants, Inc.



Furnace III: Heat Exchanger Thermocouples



Gas Consultants, Inc.

Furnace III Cold Spots

Heat Exchanger Cold Spots

Inlet Air	40 °F	45 °F	50 °F	55 °F
High Fire	L7/250°F	L7/255°F	L7/260°F	L7/266°F
Low Fire	L7/185°F	L7/189°F	L6/207°F	L6/210°F

Rise:

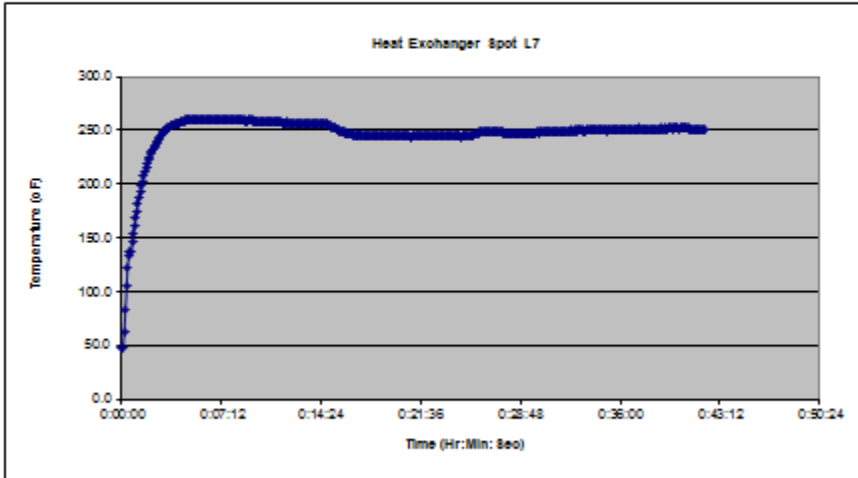
- High: 30-60°F (Mid-point: 45°F)
- Low: 20-50 °F (Mid-point: 35°F)



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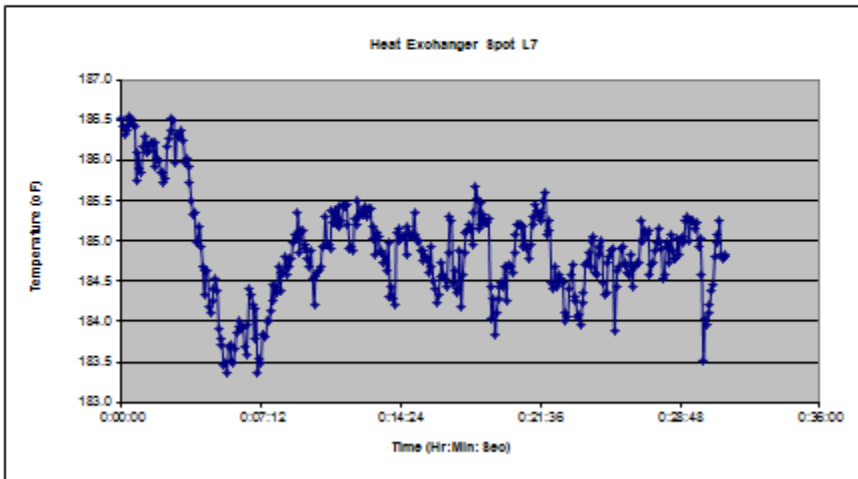


Furnace III Cold Spot Profile: 40 °F Inlet Air on High Fire



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Furnace III Cold Spot Profile: 40 °F Inlet Air on Low Fire



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Furnace IV: Heat Exchanger Thermocouples



Gas Consultants, Inc.

Furnace IV Cold Spots

Heat Exchanger Cold Spots

Inlet Air	40 °F	45 °F	50 °F	55 °F
High Fire	C6/171°F	C6/175°F	C6/178°F	C6/182°F
Low Fire	L6/145°F	L6/155°F	L6/160°F	L6/165°F

Rise:

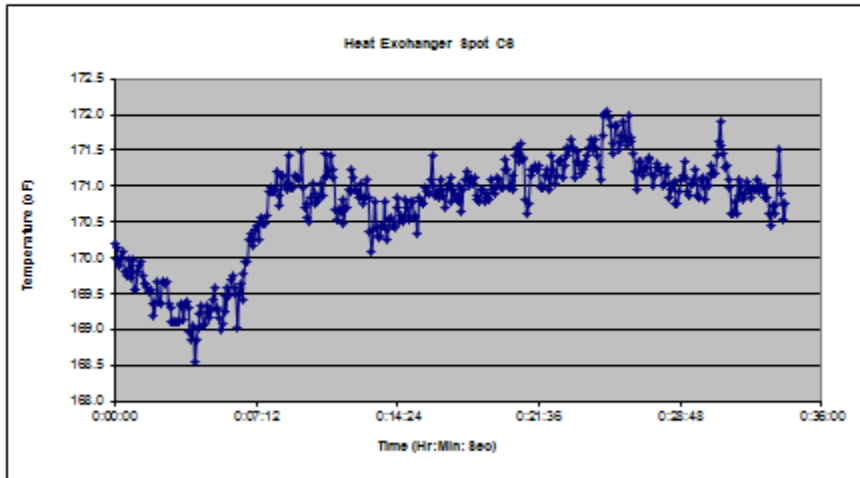
- High: 30-60 °F (Mid-point: 45 °F)
- Low: 30-60 °F (Mid-point: 45 °F)



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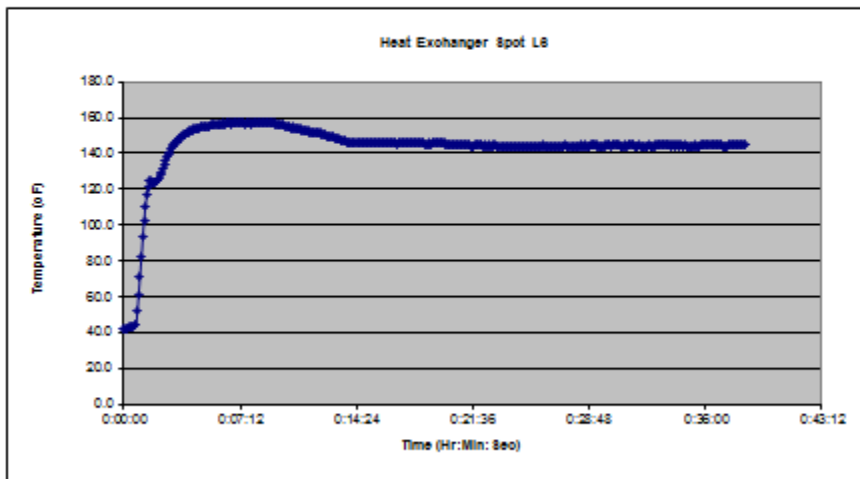


Furnace IV Cold Spot Profile: 40 °F Inlet Air on High Fire



Gas Consultants, Inc.

Furnace IV Cold Spot Profile: 40 °F Inlet Air on Low Fire



Gas Consultants, Inc.



Furnace V: Heat Exchanger Thermocouples



Furnace V Cold Spots

Heat Exchanger Cold Spots

Inlet Air	40 °F	45 °F	50 °F	55 °F
High Fire	B8/156°F	B8/161°F	B8/167°F	B8/171°F

Rise:

- High: 30-60°F (Mid-point: 45°F)
- Low: N/A





Furnace V Cold Spot Profile: 40 °F Inlet Air on High Fire

