

**Field Testing Residential Fan-Assisted Gas-Fired Furnaces:  
Effects of Altitude and Assessment of Current Derating Standards  
ASHRAE Research Project 1182**

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## Executive Summary

Results are presented for the project RP1182: a study designed to evaluate the effect of altitude on the performance of fan-assisted gas-fired residential furnaces. Output from standard furnace tests (ANSI Z21.47-2001•CSA 2.3-2001 American National Standards Institute / Canadian Standards Association, Standard for Gas-Fired Central Furnaces) performed on five different furnaces at three different altitudes (Sea Level, 2,250 ft (685 m), and 6,700 ft (2040 m)) are presented. The furnaces cover Venting Categories (I and IV), Direct and Non-Direct venting configurations, two ignition system types and steady-state thermal efficiencies between 75% and 97%. Both Natural Gas and Propane Gas were used as fuels. Each fuel was taken from a single source and transported to the test sites. This was done in order to minimize effects of fuel variability. In all tests the same instrumentation was used.

The results from the study indicate that the current derating scheme of 4% reduction in gas energy input rate per 1,000 ft (305 m) above Sea Level, for altitudes above 2,000 ft (610 m), is overly conservative for the furnaces tested. All the furnaces tested performed satisfactorily at all altitudes tested using the gas orifice drill sizes and the normal gas orifice manifold pressures settings (3.5 to 4 in. wc for Natural Gas and 10 in. wc for Propane Gas) as produced by the factories for Sea Level operation. The furnaces were able to perform satisfactorily because the mass flow through the pressure regulated fuel orifices decreases naturally by roughly 1.8% per 1,000 ft (305 m) increase in altitude. This was enough of a decrease to produce safe operation at all altitudes tested without orifice size adjustment and without manifold pressure adjustment.

ANSI Z21.47-2001•CSA 2.3-2001

Note that all the furnaces were tested at Sea Level and the higher altitudes with over fire and under fire gas input rates as per ANSI Z21.47-2001•CSA 2.3-2001, section **2.8.1**. This section prohibits CO-AF concentrations greater than 0.04% or 400 ppm when fired at 112% of

the rating plate gas input rate on Natural Gas and 109% on Propane Gas for altitudes up to 2,000 feet (610 m) above Sea level. These over fire percentages were applied to the furnace manufacturers' recommended high-altitude gas input rates and to the natural derate of 1.8% per 1,000 ft (305 m) increase in altitude during tests at altitudes above 2,000 feet (610 m).

The over fire rates used met the minimum percentage increases in all but two tests. These two occurred at Sea Level with two different furnaces. When the firing rate was set at or above the minimum over firing requirement, the CO-AF concentrations tended to rise above those obtained for firing at the Rating Plate Input or the manufacturers' recommended high-altitude gas input rates or the natural derate. With eight out of 46 tests in which the over firing was at or above the test requirements, the CO-AF concentrations were greater than 0.04% or 400 ppm.

Recommendations are made for revising ANSI Z21.47•CSA 2.3 for Gas-Fired Central Furnaces, ANSI Z223.1/NFPA 54 National Fuel Gas Code, and CSA B149.1 National Standard of Canada Natural Gas and Propane Installation Code for the amount of furnace gas input derating that is required at altitudes above 2,000 feet (610 m).

The applicability of Sea Level furnace testing to high-altitude furnace operation is discussed.

## Acknowledgements

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Special thanks goes to Mr. Stephen Paskaluk who spent countless hours working through the vagaries of Microsoft Word and Microsoft Excel, making tables, plotting graphs and successfully inserting them into the body of this report.

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## 1. Introduction

Current guidelines for the installation of gas fired residential furnaces at altitudes above 2,000 ft (610 m) require that gas input rate be reduced. Compared to standard sea level operation, the furnaces should fire 4% less energy for every 1,000 ft (305 m) above sea level. The input rates are primarily adjusted for the lower air density with altitude. Natural draft residential gas furnaces were designed to handle particular volumes of air. Thus at altitude, due to the reduced density, the mass of oxygen available for combustion in a given volume of air is reduced compared with sea level. Reducing the fuel flow rate was done to compensate for the reduced oxygen availability. Field experience showed that by reducing the gas input rate with altitude, safe operation could be obtained.

Installation codes such as ANSI Z223.1-2002/NFPA 54-2002 *National Fuel Gas Code* [1] in the U.S.A. and the CSA B149.1-00 *National Standard of Canada Natural Gas and Propane Installation Code* [2] in Canada recommend deratings for all appliances, subject to certification. Furnace fuel flow derate is controlled by installing smaller fuel orifices and/or decreasing the pressure in the fuel gas manifold. The derating standard was implemented before it became common to build furnaces with fan -assisted combustion systems to either draw or force products of combustion through the combustion chamber and/or heat exchanger. Since the majority of current furnace designs operate with fan assist, it is necessary to re-evaluate the traditional derating practice and determine what altitude derating is appropriate for fan-assisted furnaces.

The primary objective was to test gas fired furnaces of Categories I and IV at three altitudes: Sea Level, 2,250 ft (685 m) and 6,700 ft (2040 m) and to objectively determine if a new derating protocol with less derating than is currently required by installation codes for operating Natural Gas fired and Propane Gas fired furnaces with fan-assisted combustion

systems at high altitude might be acceptable. The test methods used came from ANSI Z21.47-2001•CSA 2.3-2001 *American National Standard/CSA Standard for Gas Fired Central Furnaces* [3]. The detailed tests used from these standards are listed in section 3 of this report, Objectives.

In addition, the applicability and validity of testing furnaces near sea level as outlined in National Standard of Canada CAN/CGA-2.17-M91, *Gas-Fired Appliances for Use at High Altitudes* [4] to demonstrate compliance with ANSI Z21.47•CSA 2.3 at altitudes up to 10,000 feet was to be investigated.

A third objective was to compare and recommend alternate near-sea-level testing and prediction methods which may be used to provide equivalent high altitude performance and validation without high-altitude field testing.

The plan for field evaluation of the furnaces was to install the furnaces in an industrial trailer, transport the trailer to the three different altitudes and perform tests according to ANSI Z21.47-2001•CSA 2.3-2001 *American National Standard/CSA Standard for Gas Fired Central Furnaces* at each location. Natural Gas and HD-5 Propane Gas fuels were used, each taken from one source and transported to the testing sites as needed. Using the same equipment and fuel sources improves the consistency of the tests by eliminating confounding factors that might arise due to differences in fuel composition and equipment at the different sites.

Note that in this report the words Propane Gas are used as a substitute for Liquefied Petroleum Gas. This was suggested by the Project Monitoring Subcommittee (PMS). The test fuel was HD-5 Propane Gas, not pure Propane Gas. The chemical composition of this test fuel was about 1.2% C<sub>2</sub>'s, 98.2% C<sub>3</sub>'s and 0.6% C<sub>4</sub>'s.

The trailer outfitting and preliminary system debugging was carried out in Edmonton, Alberta, Canada (53°N, 113°W), at the University of Alberta, which is at an altitude of 2,250 ft (685 m) above sea level. The trailer was then transported to Fortress Mountain, Alberta, Canada

(~51°N, 115°W) where the altitude is 6,700 ft (2040 m). Here extensive testing was carried out using recommended altitude derating schemes for the furnaces, production settings, and several settings in between. The trailer was then transported to Vancouver, British Columbia, Canada (49°N, 122°W), which is approximately at Sea Level, where baseline testing was performed. Finally the trailer was returned to Edmonton where more detailed testing at 2,250 ft (685 m) was conducted.

The report is laid out to first provide the reader with the theoretical background to the operation of venturi style burners now commonly used in gas fired furnaces and introduce the concept of natural derating with this style of burner. Next the objectives for the field testing portion of the study, as originally stated in the Scope of the “Invitation to Submit a Research Proposal on an ASHRAE Research Project”, are restated. Note that deviations to these Scope statements did occur. The next section is a description of the equipment used in the study, followed by details of the test methods and deviations which occurred from the Scope statements. The deviations which occurred do limit some of the conclusions that can be drawn. Next, results from the field testing are presented, followed by detailed discussions. Conclusions are presented next. These are drawn within the limitations of the field testing. Also included are observations made by the research team during the conduct of the study. The Appendices include full details of the equipment used, testing procedures, raw data, sample calculations, air supply and induced draft fan curves at two altitudes, estimates of the systematic error in the experiment and a discussion of potential methods to simulate high altitude operation at altitudes near sea level.

## 2. OPERATION OF VENTURI STYLE BURNERS

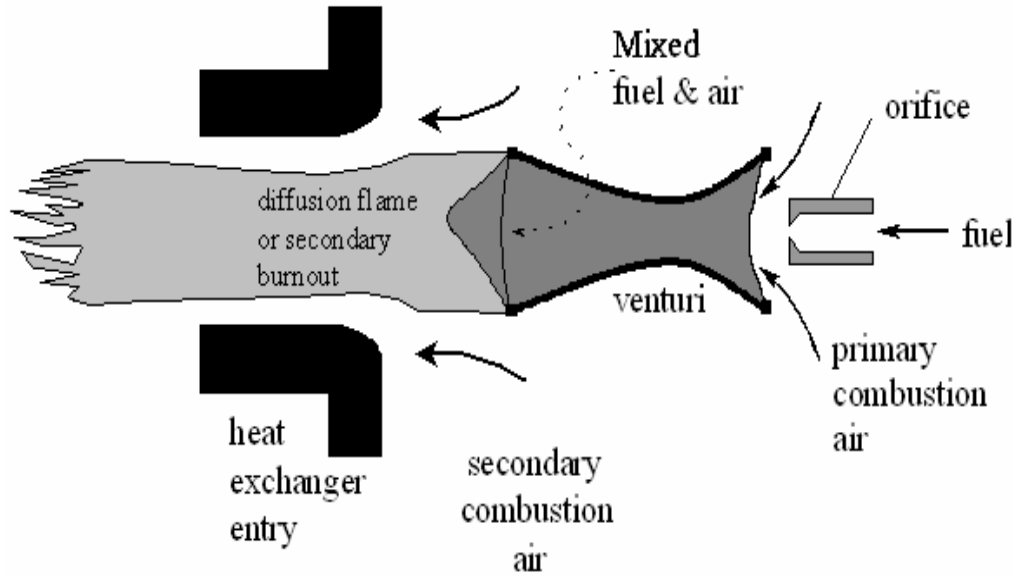
The furnaces tested in this research project used horizontally oriented in-shot venturi type burners. Figure 1 shows a schematic of a typical burner and location relative to the heat exchanger in a furnace. Fuel exiting from the fuel gas orifice enters one end of the venturi as a jet. This induces the primary combustion air into the venturi where turbulent mixing occurs. About 60% of the stoichiometric air required for complete combustion is drawn in by this process. The remaining secondary air for combustion is drawn into the flame zone at the other end of the venturi. The flame normally “sits” at this location. Because there are two mixing zones, the flame is characterized by an inner and outer cone, both of which stretch well into the heat exchanger due to the induced draft from the fan-assist and the buoyancy of the flue gasses.

The flow rate of the fuel is determined by the orifice size and the manifold pressure upstream from the orifice. With a fixed manifold pressure with respect to the atmospheric pressure, a decrease in atmospheric pressure automatically decreases the mass flow rate of fuel gas through the orifice because of the decrease in fuel gas density. The mass flow rate through a fuel gas orifice is given by

$$\dot{m} = \rho A C_d \sqrt{\frac{2\Delta P}{\rho}} \quad , \quad (1)$$

where  $\dot{m}$  is the mass flow rate,  $\rho$  is the gas density,  $A$  is the orifice area,  $C_d$  is the orifice discharge coefficient, and  $\Delta P$  is the manifold pressure drop. Assuming ideal gases, a constant fuel gas density and a constant orifice discharge coefficient, the ratio of mass flow rates for the same orifice at two slightly different manifold pressures is

$$\frac{\dot{m}_1}{\dot{m}_2} = \sqrt{\frac{P_1}{P_2}} \quad . \quad (2)$$



**Figure 1.** Schematic of the horizontal venturi-orifice burner firing into a draft induced heat exchanger (left) which draws both the flame and secondary air.

If the pressure ratio is close to one, the fractional change in mass flow rate is equal to roughly half the fractional decrease in pressure; therefore a 20% decrease in pressure gives about a 10% decrease in orifice mass flow rate. For this to hold true, according to the Ideal Gas Law, there must be an increase in jet velocity entering the venturi as the atmospheric pressure decreases.

The pressure profile in the troposphere is shown in Table 1. Starting at Sea Level the pressure decreases about 3.1% per 1,000 ft (305 m) increase in altitude up to 10,000 ft (3050 m), so that at 10,000 ft (3050 m), the pressure is 0.688 atmospheres [5]. This means that a furnace with a fixed orifice size and manifold pressure drop would fire roughly 1.8% less fuel per 1,000 ft (305 m) increase in altitude or 18% less fuel at 10,000 ft (3050 m) than it would at Sea Level. This fundamental result is hereafter referred to as the “natural derate”.

Table 1. Standard Atmospheric Data for Altitudes to 10 000 ft.  
2001 ASHRAE Fundamentals Handbook, page 6.1, Table 1.

Altitude (ft)	Pressure (psia)	Pressure* (in. Hg)	Pressure (Atm.)
-500	14.966	30.47	1.018
0	14.696	29.921	1.000
500	14.430	29.38	0.982
1,000	14.175	28.86	0.965
2,000	13.664	27.82	0.930
3,000	13.173	26.82	0.896
4,000	12.682	25.82	0.863
5,000	12.230	24.90	0.832
6,000	11.778	23.98	0.801
7,000	11.341	23.09	0.772
8,000	10.914	22.22	0.743
9,000	10.506	21.39	0.715
10,000	10.108	20.58	0.688

\* at 32°F (0°C)

The entry region of the fuel jet into the venturi effectuates a primary fuel-air mixture that is burned at the venturi exit. Apart from the very early stages of jet development, air density closely approximates the density of the fuel-air mix in the jet. With this assumption and using free jet theory where the nominal radius of the jet is proportional to the downstream distance and axial momentum is conserved, the mixture fraction in the jet is only dependent on the downstream distance from the fuel orifice. This is why the jet mixing system is so reliable for incompressible flow. The geometry creates a stable mix of fuel and oxidant for a given spacing between the orifice and venturi, irrespective of changes in jet inlet conditions resulting from atmospheric pressure changes.

The venturi outlet is directed at the inlet of a passage in the furnace heat exchanger. A negative pressure is generated in the furnace heat exchanger by the inducer fan and flue product buoyancy. The negative pressure draws in the flame and secondary air. The secondary air addition generally allows for complete combustion and gives excess air levels for most furnaces in the range of 25% to 125%.



The resulting system has a primary combustion zone with an additional secondary burnout. The effect of moderate pressure changes that result from changes in altitude will have minimal effect on the flame speeds in this type of flame (NACA 1957) [6]. Laminar flame speed directly affects turbulent flame speed, and the small relative changes in pressure cannot be expected to have a significant effect on the turbulent mixing structure of the fuel jets. It is therefore safe to say that changes in pressure will have very little effect on combustion zone flame speeds in residential furnaces. This means that the shape and location of the primary combustion zone flame for these burners are largely unaffected by altitude changes.

For the secondary burnout region of the flame entering the heat exchanger, the size of the combustion zone is dependent on the rate of turbulent mixing and the flow rates of unburned fuel and air. At the beginning of the secondary zone, the induced draft and flue gas buoyancy draw air and fuel gas into the heat exchanger. The suction produced by the induced draft fan approximates a set volumetric flow rate. The unchanged primary air and fuel gas velocity (at lower mass flow rate due to reduced pressure and density) from the venturi at higher altitude accounts for "natural derating" of energy input.

Differences in temperature in the heat exchanger will affect the system efficiency, buoyant flue gas draft, as well as the eventual burnout of carbon monoxide. The nature of the interaction of these effects is extremely difficult to predict and can vary greatly for different furnace models and heat exchanger designs. The flame zone temperature is affected by the amount of dilution due to the secondary air. This in turn affects the radiation heat transfer, reaction kinetics (CO oxidation to CO<sub>2</sub>) and convection heat transfer coefficients, all of which affect the heat exchanger temperature profile and thus system efficiency to some degree.

### 3. Objectives

Parts of the Scope in the original “Invitation to Submit a Research Proposal on an ASHRAE Project” that were germane to the field testing included the following statements:

1. To field test gas fired furnaces of Categories I and IV at three altitudes: Sea Level, 2,250 ft (685 m) and 6,700 ft (2040 m),
2. To objectively determine if a new derating protocol with less derating might be acceptable. The test methods used came from ANSI Z21.47-2001•CSA 2.3-2001 *American National Standard/CSA Standard for Gas Fired Central Furnaces* [3].

a) Category Determination (section **2.7**)

b) Combustion (section **2.8**)

Note: Contractor shall insure that 12% over fire for Natural Gas (9% over fire for Propane Gas) combustion margin is determined at all three altitudes, i.e., how much margin exists at these altitudes before combustion exceeds 400 ppm CO-AF. If clean combustion cannot be achieved within the requirements of section **2.8**, gas input and/or combustion air adjustments shall be determined to achieve clean combustion.

c) Burner Operating Characteristics (section **2.9**)

d) Pilot Burners and Safety Shutoff Devices (section **2.10**)

e) Direct Ignition Systems (section **2.11**)

f) Allowable Heating Element Temperature (section **2.16**)

Note: Contractor shall insure that test return air temperature is maintained between 60°F and 80°F.

g) Draft Test for Furnaces Not Equipped with Draft Hoods (section **2.22**)

h) Allowable Air Temperatures (section **2.24**)

Note: Record hottest heat exchanger temperatures.

i) Thermal Efficiency (section **2.38**)

For all tests listed above, the actual barometric pressure, relative humidity, gas inlet pressure, manifold pressure, air temperature rise, flue gas temperature, inlet voltage and the pressure at the pressure switch shall be recorded. Pressure-switch pressure data shall be frequently obtained from before cold startup through steady-state operation to analyze pressure-switch transient operation. Fuel gas constituents and concentrations shall be identified at each test location.

In addition, the applicability and validity of testing appliances near sea level to demonstrate robustness at high altitude as outlined in National Standard of Canada CAN/CGA-2.17-M91, *Gas-Fired Appliances for Use at High Altitudes* [4] shall be investigated.

3. To compare and recommend alternate testing and prediction methods which may be used to provide equivalent high altitude performance and validation without field testing.
4. To work with the Project Monitoring Subcommittee (PMS) to provide industry acceptable data and analytical tools for better understanding of high altitude furnace applications and steady state heating efficiency per ANSI Z21.47-2001•CSA 2.3-2001 section 2.38.

In carrying out the study both orifice sizes and manifold pressures were changed to produce over fire and under fire gas input rates. Tests labeled “Rating Plate Input” at altitudes other than sea level were performed using larger orifices and/or higher manifold pressures than would be used at sea level to give the same gas input rate (Btu/h) as specified on the rating plates for Sea Level. Using factory-installed orifices and factory-adjusted manifold pressures as

intended for Sea Level operation would amount to a “natural derate” of about 1.8% per 1,000 ft ( $\approx 1.8\%$  per 305 m).

A section titled Observations is included after the Conclusions. In it the research team has included notes and observations made during the study on the operation of the furnaces and the use of the ANSI Z21.47-2001•CSA 2.3-2001 Standard.

## 4. Equipment

### a) Furnaces and Trailer Installation

Five furnaces were purchased for use. Table 2 lists the furnace characteristics. Included are the venting Category, vent/air intake arrangement, rating-plate gas input rate (Btu/h), rated AFUE (Annual Fuel Utilization Efficiency), ignition system, number of stages, and the manufacturer's installation instructions recommended derating for high-altitude. Furnaces made by four different manufacturers were used. Four of the furnaces were equipped with hot surface igniter systems; the fifth had an intermittent pilot igniter. While five furnaces were purchased, one, Furnace E, experienced an operational problem and was severely damaged by fire. Thus results for only four furnaces will be presented.

**Table 2. Summary of the Five Test Furnaces**

<b>Furnace Code</b>	<b>Vent Category</b>	<b>Vent/Air Intake</b>	<b>Gas Input Rate (Btu/h)</b>	<b>Rated AFUE</b>	<b>Ignition System</b>	<b>No. of Stages</b>	<b>Manufacturer's Recommended Derate for Altitudes above 2,000 ft</b>
A	IV	Non-Direct	120,000	90%	Hot Surface	1	2% per 1,000 ft
B	IV	Direct	40,000	92%	Hot Surface	1	4% per 1,000 ft
C	I	Non-Direct	45,000	80+%	Hot Surface	1	4% per 1,000 ft
D	I (III in practice)	Non-Direct	120,000 75,000	80%	Hot Surface	2	4% per 1,000 ft
E	I	Non-Direct	50,000	78%	Pilot	1	4% per 1,000 ft

Vent Category is a measure of the relative vent gas pressure and temperature. Furnace D, for example, is rated as a Category I furnace, but it was found in practice to have a positive vent pressure at the standard location for Category determination (test described in section 2.7 of ANSI Z21.47-2001•CSA 2.3-2001), and is therefore a Category III furnace in practice. The Category Determination test was conducted at all three altitudes using both fuels at each altitude. The results for Furnace D were consistent in that a positive vent pressure was measured with each test. Values ranged from a low of +0.002574 in. wc (inches of water column) to a high of +0.02574 in. wc. The resolution of the pressure transducer used was 0.000122 in. wc.

Furnace A was a Non-Direct Vent high efficiency condensing furnace drawing its combustion air from within the trailer rather than from out doors. Furnace B, a Direct Vent high efficiency condensing furnace, drew its combustion air directly from outdoors. The remaining furnaces were mid efficiency, non-condensing, Non-Direct Vent furnaces, all of which drew their combustion air from within the trailer.

The 10 ft wide by 24 ft long by 7.5 ft high industrial trailer used for housing the furnaces is shown in Figure 2. At the time this photograph was taken the trailer was at the Fortress Mountain location. A schematic of the inside of the trailer showing the approximate layout of the furnaces and duct work, vents, etc. is shown in Figure 3. The location of each furnace is identified by its code letter. Duct work connecting the plenums of the furnaces was used to direct the heated air out of the trailer.

The “return” cold air was drawn directly from out doors and tempered with heated supply air as shown in Figure 4. Low leakage dampers were used to direct and mix the flows so as to maintain as constant as possible the return air temperature and a fixed pressure differential across the supply fan. Figure 5 is a photograph inside the trailer showing some of the ductwork details. As indicated in Figure 4, an open return was used to supply the tempered fresh air into the

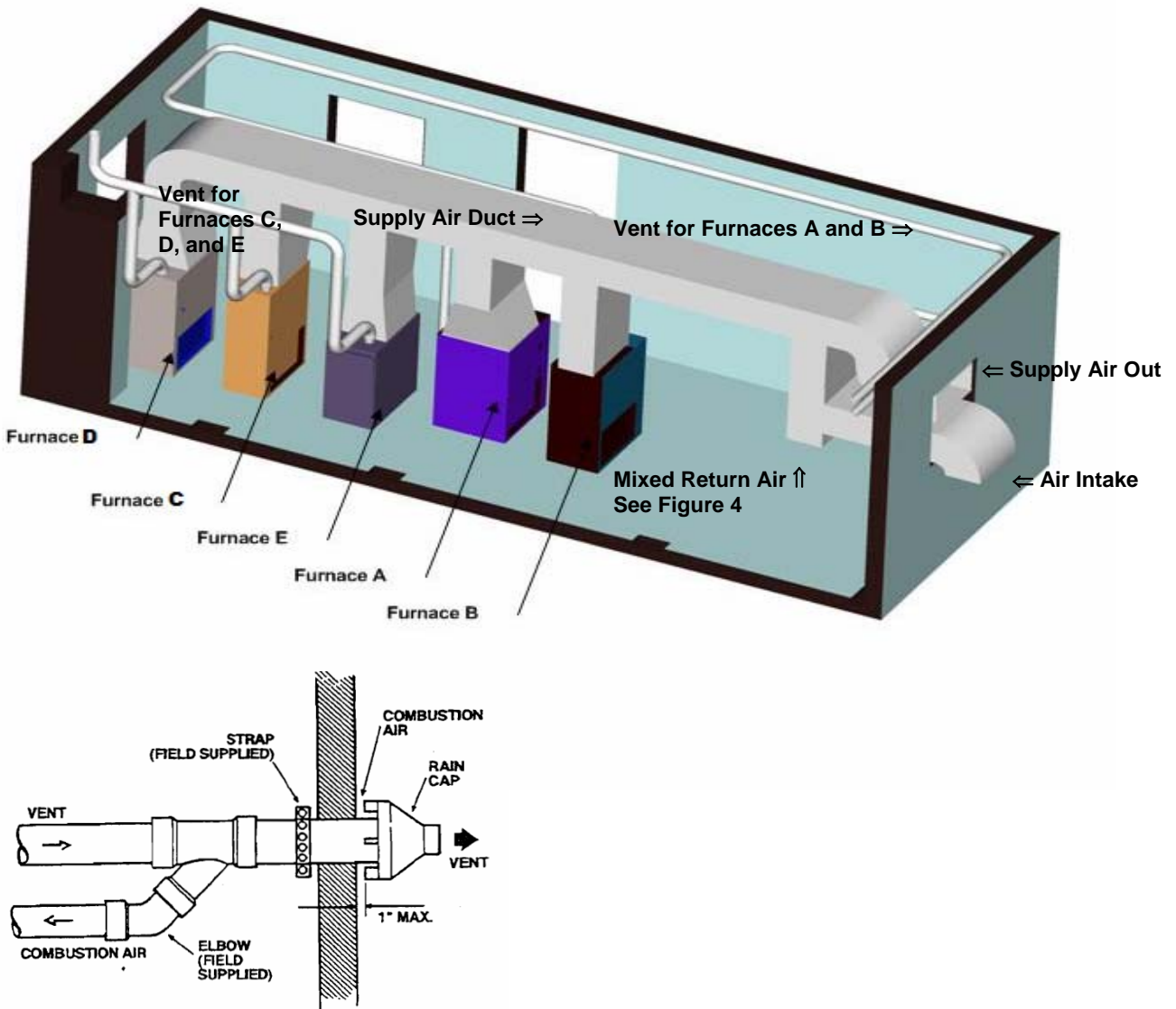
circulating fans of the furnaces. That is, as shown in Figure 3, there was no duct work directly connecting the “return” to the furnaces. As such the physical installation of the furnaces in the trailer did not meet the requirement in sections **1.24.2-a.7. and 1.24.7-a.** of ANSI Z21.47-2001•CSA 2.3-2001. The requirement is that “When a furnace is installed so that supply ducts carry air circulated by the furnace to areas outside the space containing the furnace, the return-air shall also be handled by duct(s) sealed to the furnace casing, and terminating outside the space containing the furnace”. By not having a full return air duct leading outside the trailer it is possible to impose pressures within the trailer that might affect the furnaces’ combustion air supply and vent system performance.

Each furnace had a Guillotine style damper installed in the return air inlet opening of the circulating fan furnace cabinet. These were used to isolate the furnaces not being tested. When a particular furnace was being tested, the damper was used to add flow resistance to the furnace circulating air fan in order to meet the external static pressure test requirements mentioned in section **2.6.4.** Air filters were installed on the room side of these dampers for all tests.

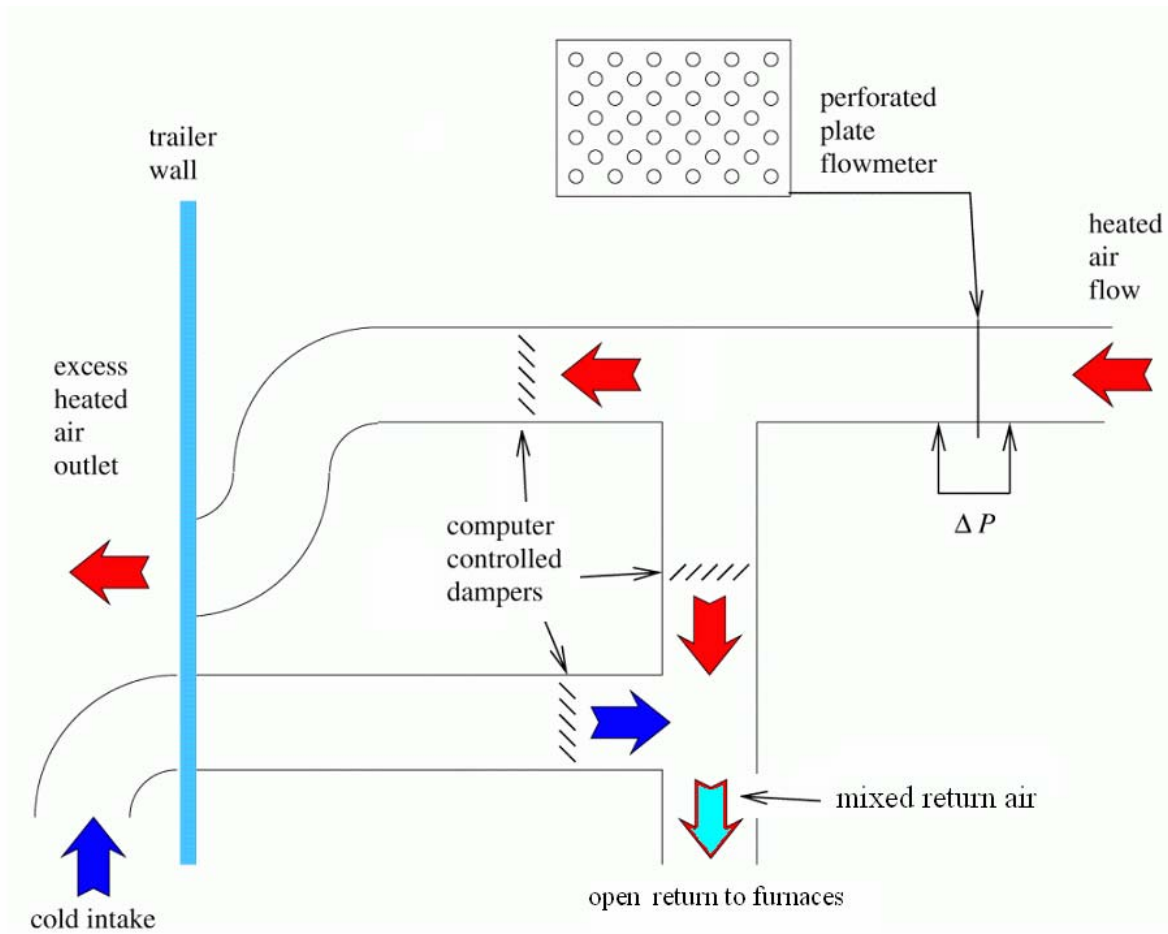


**Figure 2.** Photograph of trailer on site at Fortress Mountain. The trailer is 10 ft wide, 7.5 ft tall and 24 ft long.





**Figure 3.** Schematic of the layout of the furnaces in the trailer. The three mid efficiency furnaces are to the left (Furnaces C, D and E) while the two high efficiency furnaces are on the right (Furnaces A and B). Note the 50 ft long vent common to the two high efficiency furnaces on the far side of the trailer. This vent runs the length of the trailer and back to the furnaces beside the air supply duct. The Vent Termination used for the high efficiency furnaces (supplied with Furnace B) is shown in the lower left.



**Figure 4.** Schematic of supply and return air ducts layout in trailer.

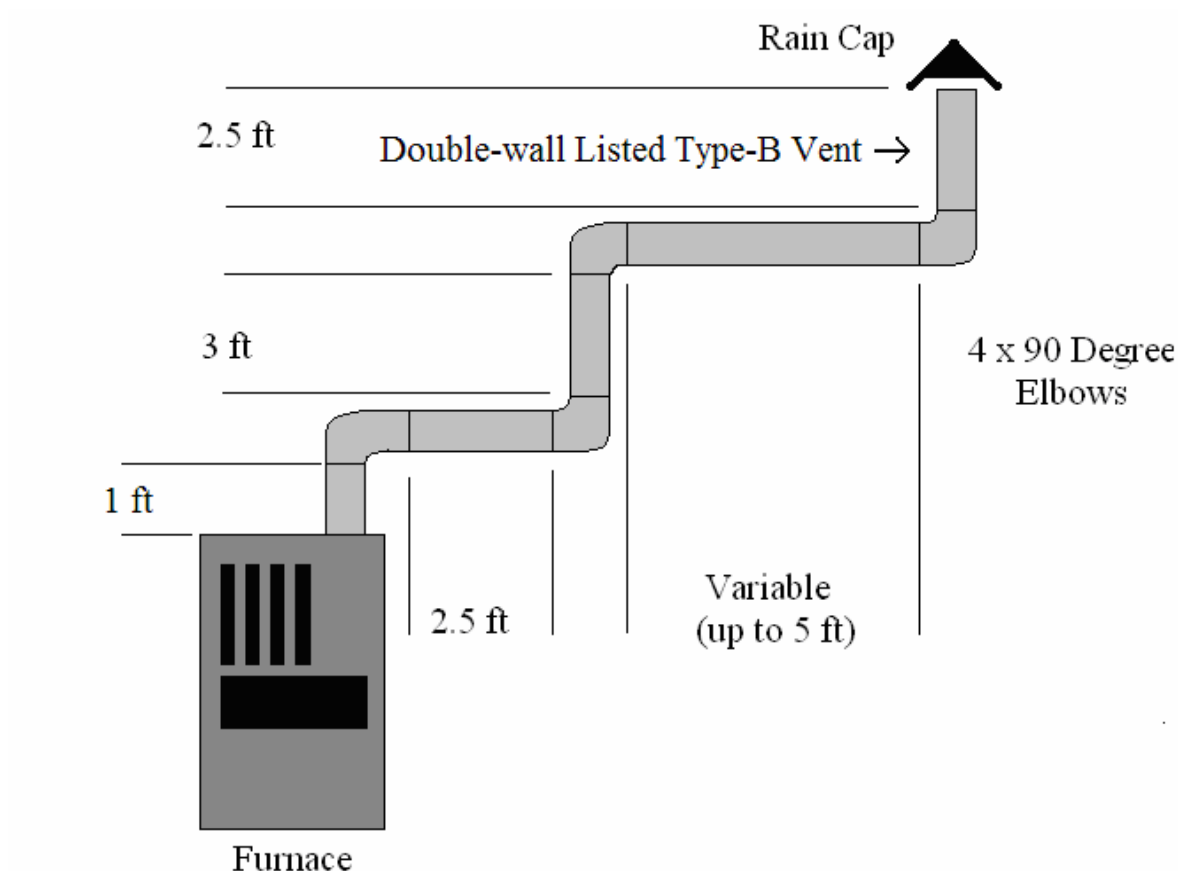


**Figure 5.** Photograph of supply and return air ducts in the trailer shown in Figure 4. One damper controller is visible as well as the pressure transducer for measuring the  $\Delta P$  across the perforated plate for determining the air supply volume flow rate.

In addition to using the Guillotine dampers on the return air side to isolate the furnaces and control the air flow, the computer controlled dampers installed in the hot air supply duct (Figures 4 and 5) were used to control the external static pressure imposed on the furnace circulating air fan in order to maintain the required test conditions. An attempt was also made to measure the fan operating characteristics using the perforated plate flow meter installed in the supply air duct (Figure 4). This unit did not work as well as had been planned. As such it was not possible to

measure the fan characteristics in situ. However measurement of the fan characteristics was done separately by removing fans from two of the furnaces and setting up a separate test bench. The fans were tested at 2,250 ft (685 m) and 6,700 ft (2040 m) altitude using ANSI/ASHRAE Standard 41.2-1987 (1987), “Standard Methods for Laboratory Airflow Measurement”[7]. Appendix E contains the fan curves for the two air supply fans and two induced draft fans (vent blowers) tested.

At the request of the Project Monitoring Subcommittee (PMS) the venting for the three mid-efficiency Non-Direct Vent furnaces was to be built to match a particular configuration in the ANSI Z223.1/NFPA 54 National Fuel Gas Code or CSA B149.1 National Standard of Canada Natural Gas and Propane Installation Code. The configurations used did not conform to the Category I vent requirements in the Codes in that it had two extra 90° elbows and for Furnace E a total horizontal run longer than recommended for the height of the vent. The horizontal runs for Furnaces C and D were in compliance with the Code. A schematic of the layout is shown in Figure 6. The vent layout for each of these furnaces had four 90° elbows, two vertical legs and two horizontal legs as shown. The three vents were joined to a header below the ceiling of the trailer. Figure 3 shows the general layout of Furnaces C, D, and E, while Figure 7 is a photograph showing the vertical legs of the actual venting inside the trailer. The header had a single vertical Type-B vent outlet through the ceiling as shown in Figures 3 and 6. This leg terminated about two feet above the roof of the trailer and was fitted with a rain cap as shown in Figure 2. Guillotine dampers were used to isolate the furnaces during testing. A full description is included in the title of Figure 6. Note that only one furnace was fired at any one time. Thus the sizing of the vent system was done on this basis. The Code requires increased vent sizes when multiple furnaces that can be fired simultaneously are connected to a single vertical vent or chimney.



**Figure 6.** Schematic of venting layout for Furnaces C, D and E. The vertical legs out of the furnaces were approximately 1 ft. in length. These legs were either a straight 4 in. diameter pipe (Furnace D) or as in the case of Furnaces C and E, a 3 in. to 4 in. diameter increaser. The remaining ductwork was 4 in. constant diameter single wall metal pipe up to the 4 in. diameter Type-B Vent. For clarity the other two furnaces are not shown. They were “Tee’d” into the horizontal section located just below the ceiling of the trailer as shown in Figure 3. Guillotine dampers (not shown) were used to isolate the furnaces from one another.



**Figure 7.** Photograph showing the venting arrangement for the mid-efficiency furnaces. See also Figures 2, 3 and 6.

The high efficiency furnaces (Furnaces A and B) used the vent termination supplied with Furnace B. As shown in Figure 3, the two furnaces used a common 50 ft (15.2 m), 3 in. diameter, PVC vent run that included four 90 degree elbows. Figure 8 is a photograph showing the vent and air intake mountings at the two furnaces. Guillotine dampers in the vent were used to isolate the furnaces during testing. Furnace B drew its combustion air through a pipe concentric to the vent at the trailer wall using the manufacturer's supplied kit, which also used a 3 in. PVC pipe. A schematic of the wall Vent Termination is included in Figure 3. Furnace A drew its combustion air directly from within the trailer.



**Figure 8.** Photograph showing the air intake and Direct Vent pipes for the two high efficiency furnaces. Furnace B is in the foreground, Furnace A is in the background. The common vent is seen at the very top of the photograph. The Guillotine dampers used to isolate each furnace from the Direct Vent can be seen at the top of the photograph near the top of the vent running to Furnace A.

## b) Instrumentation

The instruments used were common to all tests. They consisted of instruments for which output was recorded by a computer controlled data acquisition system (DAS) and instruments for which output was manually recorded. Appendix A lists the details of all the instruments used, the calibrations and the experimental error associated with each. Here only an overview of the instrumentation will be presented.

Temperatures in the ducts, heat exchangers and vents, were measured with thermocouples connected to an analogue to digital converter (A/D board). The air temperatures inside and outside the trailer were recorded with the same system. The unit contained specific calibrations for the type K and T thermocouples, including cold junction compensation. The layouts of the thermocouple grids used in the ducts, vents etc. are shown in Appendix A, Figures A1, A2 and A3. The return air supply temperature used a single thermocouple in the centre of the duct as shown in Figure A1. The supply air temperature for each furnace was measured using a nine thermocouple grid layout in the supply air duct for that furnace. Figure A2 shows the layout. It was based on the equal area method for averaging. Three thermocouples on one diameter were used to measure the flue gas temperature in the vents as shown in Figure A3. Operational problems occasionally reduced the number of functioning thermocouples in a grid. These installations match those required in ANSI Z21.47-2001•CSA 2.3-2001 section **2.3.2**.

The output from the A/D board was continuously monitored and recorded with a portable computer. The A/D system gathered signals at 2 Hz, averaging until recorded by the computer. When a particular test was ready for recording, the computer read each channel at 2 Hz for 30 seconds, giving 60 data points for averaging and calculating standard deviations.

Surface temperatures of the furnace casings were measured using a hand held surface thermocouple probe. A three by three grid was drawn on each face of the casing of each furnace.



The layout for the grid used is the same as that used for measuring the supply air temperature as shown in Figure A-2. This layout is different from that required by ANSI Z21.47-2001•CSA 2.3-2001 section **2.38**. The 36 points for a furnace were averaged to give the average jacket temperature. This information was manually entered into the data base. These temperatures were used to estimate the jacket losses in the calculation of steady state efficiency of the furnace as outlined in **EXHIBIT J** of ANSI Z21.47-2001•CSA 2.3-2001.

The manifold pressure was measured using an analogue bellows gauge. The gas line pressure was measured with a hand held electronic manometer. All the other pressures were measured using diaphragm pressure transducers read directly by the DAS. The same data acquisition rate and time averaging was used as with the temperature readings.

The fuel gas flow rate was measured using a standard temperature compensated residential dry gas bellows flow meter. The temperature compensation was to 60°F (15°C), the same temperature at which the energy content of the gaseous fuels is determined. The calibration of the meter was performed by the local outlet for the Canadian Meter Company. The meter read 0.3% fast. A copy of the calibration certificate is included in Appendix A as Figure A5. The equation used to calculate the energy input rate is given in Appendix A in the section titled Gas Input Rate.

The vent gas analysis was done by means of a portable gas analyzer that measured volumetric concentration of Oxygen ( $O_2$ ), Carbon Monoxide (CO) and Oxides of Nitrogen, as Nitric Oxide (NO) on a dry basis. Note that while the instrument contained only an NO sensor, the results are presented as NO<sub>x</sub>. The two fuels used did not contain any chemically bonded Nitrogen ( $N_2$ ). For these fuels the NO<sub>x</sub> produced essentially all NO. Carbon Dioxide ( $CO_2$ ) was not measured directly; rather it was calculated based on the composition of the fuel and the measured  $O_2$  concentration in the vent. The formulas used are listed with the fuel composition

tables in Appendix A. Purchased calibration gases were used for calibrating the CO and NO scales. Ambient air was used for the O<sub>2</sub>.

Other recorded variables included the relative humidity inside the trailer, the local atmospheric pressure, condensate flow rate for the condensing furnaces, the pressure in the vent downstream from the induced draft fan (static pressure in the vent) and the supply voltage to the furnace when running at reduced values as required in ANSI Z21.47-2001•CSA 2.3-2001. Unfortunately the instrument used to measure relative humidity turned out to be unreliable. Values were recorded but on some days the indicated values would change from the 15 % range to the 95% range. Weather data bases were examined for the cities in which tests were conducted for relative humidity data. Reliable day by day information could not be found.

### **c) Test Fuels**

The test fuels were commercial Natural Gas and HD-5 Propane Gas. The fuels were always taken from the same source in Edmonton, Alberta, Canada. The Natural Gas bottles were filled from a high pressure compressor station operated by the University of Alberta. The Natural Gas came through the ATCO GAS system. ATCO GAS is a regulated utility which serves large parts of the province of Alberta. The energy content of the Natural Gas varied a total of 5% over the testing period. The Propane Gas was taken from an “auto propane” filling system. This fuel is mandated to meet the HD-5 requirements for automobile and truck use; as such its composition and energy content are regulated and almost invariant. Typical compositions of the test fuels are listed in Appendix A.

It had been intended to collect samples of the fuels on a regular basis and have the compositions and energy contents measured. Unfortunately this was not done. As a fall back the month to month variation of the energy content of the Natural Gas was obtained from residential

bills. The energy content of the Propane Gas was calculated based on the composition of HD-5 published by the Propane Producers in Canada.

#### **d) Test sites**

Three different altitudes were selected for performing the tests. One at Sea Level, one at 2,250 ft (685 m) and the other at 6,700 ft (2040 m) above sea level. The initial setting up of the furnaces in the trailer and preliminary tests were done at 2,250 ft (685 m). Once the system had been “proved”, the trailer was shipped first to the high altitude site, then to the Sea Level site and finally returning to the mid altitude location for final testing.

The fuel tanks were always filled at the one location mentioned above and transported to the trailer site as needed. The tanks used to transport the fuels were approved for that purpose. The amount of fuel used was quite modest. One 100 lb HD-5 Propane Gas tank would suffice for all the tests at one site, while two tanks for Natural Gas were required at each site. The volume of a Natural Gas tank was 3.32 ft<sup>3</sup> (94 L). The filling pressure was 2,500 psig (17 MPa).

The high altitude test site was chosen for its convenience to the test team, allowing road access during winter at the base of an alpine ski facility. The parking lot of the Fortress Mountain facility in Alberta, Canada is at 6,700 ft (2040 m) with vehicle access and electricity. The testing at this altitude was during the months of March and April 2002, during which time there was unusually high snowfalls and below average seasonal temperatures (usually well below 0°F or -18°C).

The Sea Level testing site was in Vancouver, Canada at an altitude of less than 200 ft (60 m). The testing was performed in June of 2002. In spite of summer conditions during testing, the inlet ambient air to the furnaces was maintained below 80°F (28°C) with the exception of two days when this was not possible. On those days the interior temperature of the trailer was just above 90°F (33°C); 90.4°F and 90.7°F were the recorded values. These occurred during steady

state efficiency measurements with two different furnaces. The effect on the measured efficiency is likely to be very small as the change in density of the air is less than 2% from the desired condition. A small reduction in the density of the flowing fluid can result in an equally small increase in volume flow rate of flowing fluid at a fixed head (see discussion in Appendix E concerning the effect of altitude on measured fan performance). Increasing the volume flow rate through either side of the heat exchange surfaces increases the convective heat transfer. Thus the efficiency of the furnace should increase due to the increased air temperature. With the 10°F or 5.6°C increase in temperature over the desired condition it is also possible to increase the jacket temperature and thus the jacket heat losses from the furnace offsetting any gains.

Having too high a return air temperature could potentially lead to operational problems with the limit control. Limit controls (maximum supply air temperature) are used to prevent the heat exchangers from attaining temperatures that may cause premature deterioration due to scaling and flaking of surface coatings or cracking due to extreme thermal cycling. The supply air temperature will increase in direct response to increases in the return air temperature.

The trailer was then transported back to Edmonton, Canada at an altitude of 2,250 ft (685 m) where the final tests were conducted. These took place in September and October 2002.

## 5. Methodology

All the Standard Tests (sections **2.7, 2.8.1, 2.8.3, 2.9, 2.10, 2.11, 2.16, 2.22.1, 2.24,** and **2.38**) as mentioned in the Objectives were performed on the five (four) furnaces. Depending on the altitude up to nine different orifice/manifold pressure combinations were used with each furnace. The detailed procedures used are listed in Appendix B.

All the recorded data from the field experiments are included in data tables recorded on a Compact Disk, which is included with this report. See Appendix C.

At Sea Level the manufacturer's recommended burner system was installed and the manifold pressure adjusted to give the Sea Level "Rating Plate Input",  $\pm 2\%$ , as outlined in section **2.5.4 Burner Adjustment**. A full set of Standard Tests were then performed. Variances from the procedures required for the Standard Tests occurred with two sections. With section **2.8.1 Combustion Operation** the tests were run at normal inlet gas line pressure and then at reduced inlet gas line pressure as outlined in section **2.5.1 Test Pressures and Burner Adjustments**. The next requirement was to adjust the manifold pressure regulator in order to raise the input rate to 12% above the Rating Plate Input for Natural Gas or 9% for Propane Gas, while at reduced inlet gas line pressure. It proved impossible to attain the required input with the reduced inlet test pressure so, as allowed, in section **2.8.1 Combustion Operation**, the inlet gas line pressure was raised to achieve the requirement. In some cases the over firing requirement was exceeded; in others it was not achieved. Thus some of the results for section **2.8.1 Combustion Operation** fall short of the required input rates during over firing.

The second variation in the testing occurred in section **2.22.1 Blocked Flue**. Here the tests were to be done only at normal gas line inlet test pressure. However, due to a miss understanding in reading ANSI Z21.47-2001•CSA 2.3-2001, additional tests following the procedure outlined in section **2.5.1 Test Pressures and Burner Adjustments** were performed.

Section **2.5.1 Test Pressures and Burner Adjustments** requires that tests be conducted with normal gas inlet test pressure, reduced gas inlet test pressure and increased gas inlet test pressure. The recommended values are given in Table **X** of ANSI Z21.47-2001•CSA 2.3-2001. For Natural Gas the inlet test pressure should be reduced by 50% from the normal gas inlet test pressure of 7.0 in. wc to 3.5 in. wc and then increased by 50% from the normal gas inlet test pressure to 10.5 in. wc. For Propane Gas the values are a 27% reduction from the normal gas inlet test pressure of 11.0 in. wc to 8.0 in. wc and an 18% increase from the normal gas inlet test pressure to 13.0 in. wc.

As mentioned section **2.22.1 Blocked Flue** requires that tests be done only at the normal gas inlet test pressure while those in section **2.8.1 Combustion Operation** requires normal, reduced and increased gas inlet test pressures. As the tests for sections **2.22.1** and **2.8.1** were run at the same time data was collected for both tests at all gas inlet test pressures even though some of it was not required by the test standard. All of this information is included in Tables 3 – 10 and Figures 9a – 9h.

At 2,250 ft (685 m) the above procedure was repeated, but with two different gas input settings, one for Sea Level, the other for the 2,250 ft (685 m) altitude. First the manufacturer's recommended burner system for Sea Level was installed, the line inlet test gas pressure set to normal and the gas manifold pressure adjusted to normal (3.5 in. wc for natural gas and 10 in. wc for propane gas) A full set of Standard Tests were then performed as described above. Following this, the manufacturer's recommended derated gas input for the 2,250 ft (685 m) altitude was set by changing the burner orifice sizes (if recommended) and adjusting the manifold pressure to produce the recommended gas input rate. The Standard Tests were then repeated. Thus six different combinations of manifold and gas inlet pressures and orifice sizes were tested at this altitude:

1. and 2. Reduced gas inlet test pressure with orifice for sea level and with the orifice for the altitude,
3. and 4. Normal gas inlet test pressure with orifice for sea level and with the orifice for the altitude, and
5. and 6. Increased gas inlet test pressure with orifice for sea level and with the orifice for the altitude.

One exception to this procedure occurred. When Furnace D was tested on Natural Gas at this altitude, the Sea Level orifices were not used. Note that the manufacturer of Furnace A does not recommend an orifice size change for this or the 6,700 ft (2040 m) altitude.

At 6,700 ft (2040 m) the process was repeated; first Sea Level inputs were used, then derated inputs for 2,250 ft (685 m) and finally the derated inputs for the 6,700 ft (2040 m) altitude. Again Standard Tests were run for each initial setting. Thus a total of nine runs using the different combinations of manifold and gas inlet pressures and orifice sizes were performed.

As shown in Table 1, all but one of the manufacturers recommended that the furnaces be derated 4% per 1000 ft (305 m) altitude if the furnace were installed at an altitude above 2,000 ft (610 m). Thus these furnaces would be derated 9.0% at the 2,250 ft (685 m) altitude and 26.8% at the 6,700 ft (2040 m) altitude. The manufacturer of Furnace A, however, recommends that the gas input only be derated at 2% per 1,000 ft (305 m) altitude if the furnace were installed at an altitude above 2,000 ft (610 m). Thus Furnace A was derated only 4.5% for the 2,250 ft (685 m) altitude and 13.4% at the 6,700 ft (2040 m) altitude.

Recall that the “natural derate” for the furnace tests is about 1.8%/1,000 ft. Thus a furnace that is moved from Sea Level to 6,700 ft (2040 m) without changing anything (orifice size, inlet test pressure and manifold pressure) would experience a 12.1% reduction in gas input

rate. With a recommended derating for Furnace A of 13.4% for this altitude it is expected that it will function nearly as well at this altitude as at Sea Level.

The original request for proposals for this project included a request to conduct tests according to the National Standard of Canada CAN/CGA-2.17-M91, *Gas-Fired Appliances for Use at High Altitudes*. In this standard the tests are to be conducted at 500 ft (152 m) altitude. The reason for this is that the Canadian Gas Association laboratory where the test was developed was located in Toronto where the altitude is approximately 500 ft (152 m). Testing at this specific altitude was not done. However, comments on the suitability of this test are presented in the Discussion. They are based on the tests done at Sea Level and compared with the results obtained for the higher altitudes.



## 6. Results

Tables 3 – 10 list measured and calculated results from tests conducted on the four furnaces using the two fuels. The vertical columns list the Test Number, the gas input rate for each test in Btu/h, the gas input rate as a percentage of the “Rating Plate Input”, the time averaged barometric pressure during the test in in. Hg (inches of mercury), the barometric pressure derived altitude in ft, the measured CO as ppm, the calculated CO-AF (Air Free) as ppm and the measured O<sub>2</sub> as a percentage from the Performance Tests – **2.8.1 Combustion Operation**, the same parameters from the blocked-flue portion of Performance Tests - **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**, the measured pressure in the furnace flue gas passageways to trip the safety shut off pressure switch during the blockage test in in. wc (inches of water column), the orifice size (drill size) used during the test, the fuel gas manifold pressure in in. wc, the gas line inlet test pressure in in. wc, the calculated steady state efficiency based on the Performance Test - **2.38 Thermal Efficiency** (accounting for jacket heat losses) and the emissions of NO, as ng/J of useful heat (nanograms per Joule) [lbs/10<sup>6</sup> Btu of useful heat (pounds of NO per million Btu)]. Note that the gas species concentrations are reported on a dry gas basis and that the NO is reported as NO<sub>x</sub>.

The Test Number code is straight forward: the first letter is the furnace code (A. B. C or D), the next letter is the location (FM – Fortress Mountain, ED – Edmonton, VA – Vancouver), the next letter identifies the fuel (N – Natural Gas, P – LPG or Propane Gas), next is orifice size and finally the run number with that orifice size. With one exception only three tests were done with one orifice at each location. The exception was Furnace A at Edmonton (Table 3) when running on Natural Gas. With the particular combination of manifold and gas line test pressures it turned out that only one orifice was required to meet the rest requirements.

The Test Numbers on the data sheets in Appendix C have a Performance Test section number appended to the basic number used in Tables 3 - 10. Thus a Test Number will appear for example as **A-FM-N-43-1-2.8.1** or **A-FM-43-1-2.38**, where the last numbers identify the Performance Test section in the ANSI Z21.47 Standard.

Each of the Tables 3 - 10 is divided into three parts. Each part represents one of the test sites as indicated. For reference the manufacturer's recommended high-altitude, gas input derating values (percents and Btu/h) and the over fire requirement (percents and Btu/h) from these derated values are given in the Headers of the Tables for each altitude.

Starting with the lower set of data for Vancouver, Sea Level, three gas input rates are listed. Starting from the top they are; the "Rating Plate Input", the reduced firing rate due to reduced gas inlet pressure, and finally the increased firing rate due to raising the manifold gas pressure to meet the over firing requirement. Note that in all cases the gas inlet test pressure was raised to produce the over firing requirement.

At Edmonton, 2,250 ft (685 m) above Sea Level, six gas input rates are listed. Starting at the top they are; the "Rating Plate Input" (Sea Level rate), the reduced firing rate due to reduced inlet test pressure, and the increased firing rate from Rating Plate Input. The next three gas input rates at this altitude are based on the derated gas input rate recommended by the manufacturer. The first is the manufacturer's recommended derated gas input. This is followed by the reduced inlet test pressure and then the increased gas input rate per ANSI Z21.47•CSA 2.3, section **2.8.1**

### **Combustion Operation.**

At Fortress Mountain, 6,700 ft (2040 m) above Sea Level, nine gas input rates are listed. Starting from the top they are; the "Rating Plate Input" (Sea Level rate), the reduced firing rate due to reduced inlet test pressure, and increased firing rates from Rating Plate Input. The next three gas input rates are approximately the same as the derated values for the 2,250 ft (685 m)

altitude for the same furnace. Finally the bottom three represent the derating testing requirements for the 6,700 ft (2040 m) altitude based on the manufacturer's recommendation. First is the manufacturer's recommended input rate, then the reduced gas input rate due to reduced inlet test pressure, and then the increased gas input rate per ANSI Z21.47•CSA 2.3, section **2.8.1 Combustion Operation**.

It proved difficult to match precisely the recommended gas input rates under all the required test conditions with the particular combinations of orifice sizes, gas inlet and manifold pressures. However, examination of the Tables shows that the gas input rate range covered at any altitude easily spans the recommended deratings and over firing values with the following two exceptions that occurred at Sea Level. Furnace C (Table 7) at Sea Level was only over fired by about 5% on Natural Gas rather than the recommended 12%. Similarly Furnace D (Tables 9 and 10) at Sea Level was only over fired by about 11% on Natural Gas and 6% on Propane Gas. The recommended values are 12% and 9% respectively. Section **2.5.4 Test Pressures and Burner Adjustments** recommends that the furnace be adjusted to within  $\pm 2\%$  of the manufacturer's specified hourly Btu input rating. Thus the settings for Furnace D at Sea Level were very close to this requirement, while the over fire gas input rate for Furnace C at Sea Level when operating on Natural Gas was not very close.

Table 3. Summary of Measured and Calculated Results for Furnace A on Natural Gas  
Rating Plate Gas Input Rate is 120,000 Btu/h.

Fortress Mountain – 6,700 ft (2040 m)																
Test Number	Manufacturer's recommended derate is 13.4%; 103,920 Btu/h. 12% increased input is 116,390 Btu/h.				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice Size	Manifold Pressure (in. wc)	Gas Line Inlet Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
A-FM-N-43-1	119 281	99.4	23.09	6997	223	310	5.9					43	3.9	7.0	92.0	21.3 (0.0496)
A-FM-N-43-2	84 277	70.2	23.09	6997	40	89	11.5					43	1.9	3.5		
A-FM-N-43-3	136 401	113.7	23.09	6997	1900	2205	2.9					43	5.0	9.0		
A-FM-N-44-1	110 496	92.1	23.10	6985	4	7	8.4					44	3.5	7.0	91.9	23.8 (0.0554)
A-FM-N-44-2	75 663	63.1	23.10	6985	118	315	13.1					44	1.9	3.5		
A-FM-N-44-3	130 521	108.8	23.10	6985	438	568	4.8					44	5.0	9.0		
A-FM-N-45-1	102 836	85.7	23.09	6997	6	11	9.6	14	23	8	1.6	45	3.3	7.0	91.9	23.4 (0.0543)
A-FM-N-45-2	70 232	58.5	23.09	6997	112	333	13.9	96	253	13	1.6	45	1.5	3.5		
A-FM-N-45-3	115 414	96.2	23.09	6997	12	20	8.1	126	175	5.9	1.6	45	4.3	9.0		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**.

Table 3 (continued). Summary of Measured and Calculated Results for Furnace A on Natural Gas  
Rating Plate Gas Input Rate is 120,000 Btu/h.

Edmonton – 2,250 ft (685 m)																
Test Number	Manufacturer's recommended derate is 4.5%; 114,600 Btu/h. 12% increased input is 128,352 Btu/h.				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice Size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
A-ED-N-45-1	117 432	97.9	27.82	2000	58	107	9.6	118	178	7.1	1.6	45	3.7	7.0	91.1	37.6 (0.0875)
A-ED-N-45-2	82 717	68.9	27.82	2000	198	653	14.6	106	290	13.3	1.6	45	1.5	3.5		
A-ED-N-45-3	133 933	111.6	27.82	2000	113	171	7.1	326	436	5.3	1.6	45	5.0	9.0		
A-ED-N-45-4	106 049	88.4	27.67	2147	59	125	11.1	65	109	8.4	1.6	45	3.1	7.0	89.9	31.5 (0.0731)
A-ED-N-45-5	71 149	59.3	27.67	2147	246	896	15.2	144	410	13.6	1.6	45	1.2	3.5		
A-ED-N-45-6	119 469	99.6	27.67	2147	60	110	9.5	136	203	6.9	1.6	45	4.0	9.0		
Vancouver – Sea Level																
Test Number	Manufacturer recommends no derate. 12 % increased input is 134 400 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice Size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
A-VA-N-45-1	122 555	102.1	29.98	-55	14	26	9.6	11	16	6.8	2.2	45	3.9	7.0	89.6	26.7 (0.0621)
A-VA-N-45-2	85 631	71.4	29.98	-55	195	541	13.4	73	162	11.5	2.2	45	1.8	3.5		
A-VA-N-45-3	138 650	115.5	29.98	-55	15	24	8	186	237	4.5	2.2	45	5.0	9.0		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by 2.8.1 Combustion Operation.

Table 4. Summary of Measured and Calculated Results for Furnace A on Propane Gas  
Rating Plate Gas Input Rate is 120,000 Btu/h.

Fortress Mountain – 6,700 ft (2040 m)																
Test Number	Manufacturer's recommended derate is 13.4%; 103,920 Btu/h. 9% increased input is 113273 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
A-FM-P-54-1	118 268	98.6	23.43	6611	41	57	5.9	416	494	3.3	1.6	54	9.6	11.0	93.3	29.1 (0.0676)
A-FM-P-54-2	102 728	85.6	23.43	6611	10	17	8.5					54	7.2	8.5		
A-FM-P-54-3	128 014	106.7	23.43	6611	302	375	4.1					54	11.9	13.5		
A-FM-P-55-1	104 548	87.1	23.42	6623	4	7	8.2	6	9	7	1.6	55	10.0	11.0	92.8	26.3 (0.0612)
A-FM-P-55-2	90 550	75.4	23.42	6623	7	14	10.3	5	9	9	1.6	55	7.5	8.5		
A-FM-P-55-3	117 613	98.0	23.42	6623	6	9	6.7	26	34	4.7	1.6	55	12.5	13.5		
A-FM-P-56-1	84 764	70.6	23.27	6792	11	23	11.1	4	7	9.1	1.8	56	9.5	11.0	93.1	23.5 (0.0546)
A-FM-P-56-2	73 375	61.1	23.27	6792	40	99	12.5	8	17	11	1.8	56	7.1	8.5		
A-FM-P-56-3	94 057	78.3	23.27	6792	6	11	9.9	4	6	7.8	1.8	56	11.6	13.5		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**.

Table 4 (continued). Summary of Measured and Calculated Results for Furnace A on Propane Gas  
Rating Plate Gas Input Rate is 120,000 Btu/h.

Edmonton – 2,250 ft (685 m)																
Test Number	Manufacturer's recommended derate is 4.5%; 114,600 Btu/h. 9% increased input is 124,914 Btu/h.				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [mg/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
A-ED-P-55-1	115 329	96.1	27.78	2039	52	99	10	77	126	8.1	1.6	55	9.5	11.0	91.5	39.0 (0.0907)
A-ED-P-55-2	101 855	84.9	27.78	2039	55	129	12	73	141	10.1	1.6	55	7.5	8.5		
A-ED-P-55-3	127 450	106.2	27.78	2039	62	103	8.3	109	151	5.8	1.6	55	12.0	13.5		
A-ED-P-56-1	97 913	81.6	27.79	2029	50	121	12.3	46	90	10.3	1.6	56	9.5	11.0	91.4	34.2 (0.0796)
A-ED-P-56-2	84 484	70.4	27.79	2029	83	247	13.9	50	116	11.9	1.6	56	7.5	8.5		
A-ED-P-56-3	106 620	88.9	27.79	2029	50	107	11.2	53	91	8.8	1.6	56	12.0	13.5		
Vancouver – Sea Level																
Test Number	Manufacturer recommends no derate. 9 % increased input is 130 800 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [mg/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
A-VA-P-55-1	119 999	100	30.00	-74	0	0	9.9	9	14	7.6	2.2	55	10.0	11.0	89.4	28.9 (0.0671)
A-VA-P-55-2	96 666	80.5	30.00	-74	15	33	11.4	16	30	9.8	2.2	55	7.5	8.5		
A-VA-P-55-3	131 319	109.4	30.00	-74	0	0	8.6	11	16	6.2	2.2	55	12.5	13.5		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by 2.8.1 Combustion Operation.

Table 5. Summary of Measured and Calculated Results for Furnace B on Natural Gas  
Rating Plate Gas Input Rate is 40,000 Btu/h.

Fortress Mountain – 6,700 ft (2040 m)																
Test Number	Manufacturer's recommended derate is 26.8%; 29 280 Btu/h. 12% increased input is 32 794 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%) ANSI Z21.47-2.38	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
B-FM-N-43-1	38 409	96.0	23.18	6895	14	23	8					43	4.3	7.0	95.1	17.8 (0.0414)
B-FM-N-43-2	24 762	61.9	23.18	6895	9	25	13.3					43	2.9	3.5		
B-FM-N-43-3	43 439	108.6	23.18	6895	1120	1569	6					43	6.0	9.0		
B-FM-N-45-1	33 509	83.8	23.18	6895	2	4	10.1	7	13	9.4	1.1	45	3.9	7.0	94.8	19.9 (0.0463)
B-FM-N-45-2	20 949	52.4	23.18	6895	12	38	14.3	13	33	12.8	1.1	45	1.9	3.5		
B-FM-N-45-3	38 288	95.7	23.18	6895	6	10	8.4	12	19	7.7	1.1	45	4.8	9.0		
B-FM-N-47-1	28 428	71.1	23.19	6883	6	15	12.8	4	8	10.5	1.1	47	3.9	7.0	94.6	19.7 (0.0459)
B-FM-N-47-2	18 207	45.5	23.19	6883	38	141	15.3	30	101	14.7	1.1	47	1.9	3.5		
B-FM-N-47-3	32 749	81.9	23.19	6883	5	10	10.7	5	9	9.5	1.1	47	5.0	9.0		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**.



Table 5 (continued). Summary of Measured and Calculated Results for Furnace B on Natural Gas  
Rating Plate Gas Input Rate is 40,000 Btu/h.

Edmonton – 2,250 ft (685 m)																
Test Number	Manufacturer's recommended derate is 9.0%; 36,400 Btu/h. 12% increased input is 40,768 Btu/h.				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NOx [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
B-ED-N-45-1	37 875	94.7	27.57	2246	38	99	12.9	48	110	11.8	1.6	45	3.9	7.0	95.0	33.1 (0.0770)
B-ED-N-45-2	22 990	57.5	27.57	2246	36	149	15.9	37	135	15.2	1.6	45	1.7	3.5		
B-ED-N-45-3	43 150	107.9	27.57	2246	73	169	11.9	322	639	10.4	1.6	45	5.0	9.0		
B-ED-N-46-1	34 312	85.8	27.73	2088	34	118	14.9	39	116	13.9	1.6	46	3.5	7.0	95.0	34.5 (0.0803)
B-ED-N-46-2	21 937	54.8	27.73	2088	43	247	17.3	43	207	16.6	1.6	46	1.5	3.5		
B-ED-N-46-3	37 195	93.0	27.73	2088	37	104	13.5	46	115	12.6	1.6	46	4.7	9.0		
Vancouver – Sea Level																
Test Number	Manufacturer recommends no derate. 12 % increased input is 44 800 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NOx [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
B-VA-N-45-1	41 388	103.5	29.97	-46	8	21	13.1	11	28	11.8	1.6	45	3.9	7.0	92.9	29.6 (0.0688)
B-VA-N-45-2	27 325	68.3	29.97	-46	9	39	16.1	6	21	14.9	1.6	45	1.9	3.5		
B-VA-N-45-3	46 897	117.2	29.97	-46	80	185	11.9	2100	3946	9.8	1.6	45	5.1	9.0		

Note: Only one value of steady state efficiency and NO are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**.

Table 6. Summary of Measured and Calculated Results for Furnace B on Propane Gas  
Rating Plate Gas Input Rate is 40,000 Btu/h.

Fortress Mountain – 6,700 ft (2040 m)																
Test Number	Manufacturer's recommended derate is 26.8%; 29 280 Btu/h. 9% increased input is 31 915 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
B-FM-P-54-1	38 389	96.0	23.18	6895	9	14	7.8					54	10.5	11.0	96.4	20.0 (0.0465)
B-FM-P-54-2	31 411	78.5	23.18	6895	4	8	9.9					54	7.6	8.5		
B-FM-P-54-3	42 281	105.7	23.18	6895	622	872	6					54	13.0	13.5		
B-FM-P-55-1	34 694	86.7	23.18	6895	3	5	9.2	3	5	7.7	1.1	55	10.5	11.0	94.3	20.9 (0.0487)
B-FM-P-55-2	28 417	71.0	23.18	6895	1	2	11.1	3	6	9.9	1.1	55	7.6	8.5		
B-FM-P-55-3	38 769	96.9	23.18	6895	3	5	7.5	10	14	5.7	1.1	55	13.0	13.5		
B-FM-P-56-1	28 168	70.4	23.16	6917	4	9	11.6	4	8	9.9	1.1	56	10.0	11.0	95.7	19.0 (0.0442)
B-FM-P-56-2	23 852	59.6	23.16	6917	7	19	13.1	5	11	11.4	1.1	56	7.5	8.5		
B-FM-P-56-3	32 438	81.1	23.16	6917	4	8	10.3	4	7	8.6	1.1	56	12.5	13.5		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**.

Table 6 (continued). Summary of Measured and Calculated Results for Furnace B on Propane Gas  
Rating Plate Gas Input Rate is 40,000 Btu/h.

Edmonton – 2,250 ft (685 m)																
Test Number	Manufacturer's recommended derate is 9.0%; 36,400 Btu/h. 9% increased input is 39,676 Btu/h.				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NOx [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
B-ED-P-55-1	40 518	101.3	27.75	2069	45	113	12.6	49	116	12.1	1.6	55	10.5	11.0	94.9	35.6 (0.0828)
B-ED-P-55-2	36 163	90.4	27.75	2069	43	128	13.9	48	131	13.3	1.6	55	8.0	8.5		
B-ED-P-55-3	45 026	112.6	27.75	2069	47	102	11.3	55	109	10.4	1.6	55	12.9	13.5		
	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A
	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			
	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			
Vancouver – Sea Level																
Test Number	Manufacturer recommends no derate. 9 % increased input is 43 600 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NOx [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
B-VA-P-55-1	40 549	101.4	29.93	-9	2	5	12.7	0	0	10.3	1.6	55	10.5	11.0	94.4	24.9 (0.0578)
B-VA-P-55-2	35 346	88.4	29.93	-9	2	6	13.8	6	14	11.8	1.6	55	7.5	8.5		
B-VA-P-55-3	44 714	111.8	29.93	-9	1	2	11.6	94	163	8.9	1.6	55	12.5	13.5		

Note: Only one value of steady state efficiency and NO are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by 2.8.1 Combustion Operation.

Table 7. Summary of Measured and Calculated Results for Furnace C on Natural Gas  
Rating Plate Gas Input Rate is 45,000 Btu/h.

Fortress Mountain – 6,700 ft (2040 m)																
Test Number	Manufacturer's recommended derate is 26.8%; 32 940 Btu/h. 12% increased input is 36 893 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
C-FM-N-43-1	43 909	97.6	23.12	6963	66	100	7.1					43	3.9	7.0	85.1	22.7 (0.0527)
C-FM-N-43-2	28 766	63.9	23.12	6963	18	46	12.7					43	1.9	3.5		
C-FM-N-43-3	50 073	111.3	23.12	6963	721	907	4.3					43	5.3	9.0		
C-FM-N-44-1	39 304	87.3	23.13	6951	21	38	9.4	45	72	7.9	0.4	44	3.6	7.0	85.4	26.4 (0.0616)
C-FM-N-44-2	25 767	57.3	23.13	6951	35	107	14.1	38	105	13.4	0.4	44	1.7	3.5		
C-FM-N-44-3	44 121	98.0	23.13	6951	57	89	7.6	253	337	5.2	0.4	44	4.5	9.0		
C-FM-N-47-1	31 121	69.2	23.13	6951	16	37	12	17	34	10.5	0.4	47	3.9	7.0	84.8	24.8 (0.0577)
C-FM-N-47-2	19 966	44.4	23.13	6951	58	245	16	54	181	14.7	0.4	47	1.9	3.5		
C-FM-N-47-3	35 788	79.5	23.13	6951	14	29	10.7	21	35	8.4	0.4	47	5.1	9.0		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**.

Table 7 (continued). Summary of Measured and Calculated Results for Furnace C on Natural Gas  
Rating Plate Gas Input Rate is 45,000 Btu/h.

Edmonton – 2,250 ft (685 m)																
Test Number	Manufacturer's recommended derate is 9.0%; 40,950 Btu/h. 12% increased input is 45,864 Btu/h.				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NOx [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
C-ED-N-44-1	41 390	92.0	27.92	1902	63	137	11.3	92	156	8.6	0.6	44	3.9	7.0	79.3	50.7 (0.1180)
C-ED-N-44-2	27 488	61.1	27.92	1902	88	351	15.7	79	235	13.9	0.6	44	1.9	3.5		
C-ED-N-44-3	45 983	102.2	27.92	1902	69	127	9.6	157	226	6.4	0.6	44	5.3	9.0		
C-ED-N-45-1	37 826	84.1	27.95	1873	48	116	12.3	53	102	10.1	0.6	45	3.6	7.0	79.2	41.5 (0.0965)
C-ED-N-45-2	24 171	53.7	27.95	1873	72	311	16.1	72	253	15	0.6	45	1.7	3.5		
C-ED-N-45-3	43 008	95.6	27.95	1873	46	94	10.7	68	113	8.3	0.6	45	4.5	9.0		
Vancouver – Sea Level																
Test Number	Manufacturer recommends no derate. 12 % increased input is 50 400 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NOx [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
C-VA-N-44-1	43 490	96.6	29.92	0	12	23	10.2	12	21	9	0.6	44	3.9	7.0	79.8	29.5 (0.0687)
C-VA-N-44-2	30 161	67.0	29.92	0	57	182	14.4	23	66	13.6	0.6	44	2.0	3.5		
C-VA-N-44-3	47 601	105.8	29.92	0	15	26	8.7	28	41	6.8	0.6	44	5.0	9.0		

Note: Only one value of steady state efficiency and NO are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**.

Table 8. Summary of Measured and Calculated Results for Furnace C on Propane Gas  
Rating Plate Gas Input Rate is 45,000 Btu/h.

Fortress Mountain – 6,700 ft (2040 m)																
Test Number	Manufacturer’s recommended derate is 26.8%; 32 940 Btu/h. 9% increased input is 35 905 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NOx [ng/J (lbs/10^6 Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O2 (%)	CO (PPM)	CO Air Free (PPM)	O2 (%)	Pressure Switch Pressure (in. wc)					
C-FM-P-52-1	43 475	96.6	23.15	6928	125	169	5.5	5005	5907	3.2	0.4	52	9.2	11.0	86.3	29.5 (0.0685)
C-FM-P-52-2	38 179	84.8	23.15	6928	35	57	8.1	112	153	5.6	0.4	52	7.1	8.5		
C-FM-P-52-3	47 846	106.3	23.15	6928	7020	8626	3.9	25535	28531	2.2	0.4	52	12.2	13.5		
C-FM-P-54-1	37 965	84.4	23.14	6940	32	53	8.4	98	140	6.3	0.4	54	10.1	11.0	85.9	31.2 (0.0726)
C-FM-P-54-2	33 200	73.8	23.14	6940	32	62	10.1	53	89	8.5	0.4	54	8.0	8.5		
C-FM-P-54-3	41 300	91.8	23.14	6940	78	112	6.4	214	263	3.9	0.4	54	12.5	13.5		
C-FM-P-56-1	31 093	69.0	23.14	6940	53	125	12.1	43	82	9.9	0.4	56	10.9	11.0	85.3	31.8 (0.0739)
C-FM-P-56-2	27 659	61.5	23.14	6940	99	275	13.4	32	71	11.5	0.4	56	8.4	8.5		
C-FM-P-56-3	34 353	76.3	23.14	6940	35	73	10.9	61	103	8.5	0.4	56	13.4	13.5		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**.

Table 8 (continued). Summary of Measured and Calculated Results for Furnace C on Propane Gas  
Rating Plate Gas Input Rate is 45,000 Btu/h.

Edmonton – 2,250 ft (685 m)																
Test Number	Manufacturer's recommended derate is 9.0%; 40,950 Btu/h. 9% increased input is 44,636 Btu/h.				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NOx [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
C-ED-P-54-1	45 071	100.1	27.62	2197	58	109	9.8	63	101	7.9	0.6	54	10.0	11.0	82.1	48.6 (0.1130)
C-ED-P-54-2	40 894	91.1	27.62	2197	64	140	11.4	67	133	10.4	0.6	54	7.8	8.5		
C-ED-P-54-3	52 555	116.8	27.62	2197	60	94	7.6	129	180	5.9	0.6	54	13.0	13.5		
C-ED-P-55-1	39 083	86.9	27.95	1873	89	216	12.3	84	170	10.6	0.6	55	9.5	11.0	81.9	34.4 (0.0801)
C-ED-P-55-2	37 034	82.3	27.95	1873	139	402	13.7	127	319	12.6	0.6	55	7.3	8.5		
C-ED-P-55-3	44 438	98.8	27.95	1873	73	148	10.6	78	144	9.6	0.6	55	12.4	13.5		
Vancouver – Sea Level																
Test Number	Manufacturer recommends no derate 9 % increased input is 49 050 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NOx [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
C-VA-P-54-1	46 031	102.3	29.91	9	8	14	8.8	16	26	8.1	0.6	54	10.0	11.0	81.6	41.2 (0.0958)
C-VA-P-54-2	36 649	81.4	29.91	9	12	25	10.7	17	32	9.8	0.6	54	7.5	8.5		
C-VA-P-54-3	50 594	112.4	29.91	9	10	15	7.2	40	71	9.1	0.6	54	12.5	13.5		

Note: Only one value of steady state efficiency and NO are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by 2.8.1 Combustion Operation.

Table 9. Summary of Measured and Calculated Results for Furnace D on Natural Gas  
Rating Plate Gas Input is Rate 120,000 Btu/h on High and 75,000 Btu/h on Low Fire.

Fortress Mountain – 6,700 ft (2040 m)																
Test Number	Manufacturer's recommended derate is 26.8%; 87 840 Btu/h. 12% increased input is 98 381 Btu/h.				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
D-FM-N-43-1	116 797	97.3	23.11	6974	142	196	5.8					43	3.9	7.0	83.3	26.2 (0.0610)
D-FM-N-43-2	74 725	62.3	23.11	6974	14	36	12.7					43	2.0	3.5		
D-FM-N-43-3	135 580	113.0	23.11	6974	1900	2057	1.6					43	6.0	10.5		
D-FM-N-45-1	101 169	84.3	23.11	6974	22	35	7.7	86	124	6.4	0.3	45	3.9	7.0	82.7	26.8 (0.0624)
D-FM-N-45-2	67 862	56.6	23.11	6974	17	49	13.7	14	29	10.9	0.3	45	2.0	3.5		
D-FM-N-45-3	117 768	98.1	23.11	6974	148	201	5.5	355	452	4.5	0.3	45	5.0	9.0		
D-FM-N-47-1	79 553	66.3	23.10	6986	5	12	11.9	6	12	10.5	0.3	47	3.9	7.0	80.7	28.3 (0.0658)
D-FM-N-47-2	53 166	44.3	23.10	6986	41	164	15.7	32	109	14.8	0.3	47	2.0	3.5		
D-FM-N-47-3	90 964	75.8	23.10	6986	4	8	10.4	8	14	8.9	0.3	47	5.2	9.0		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**. Due to an oversight, tests were not conducted with Furnace D operating at its low-gas or low-heat input rate. Thus results for the 2<sup>nd</sup> stage (low-heat) are not presented.



Table 9 (continued). Summary of Measured and Calculated Results for Furnace D on Natural Gas  
Rating Plate Gas Input is Rate 120,000 Btu/h on High and 75,000 Btu/h on Low Fire.

Edmonton – 2,250 ft (685 m)																
Test Number	Manufacturer's recommended derate is 9.0%; 109,200 Btu/h. 12% increased input is 122,304 Btu/h.				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
D-ED-N-44-1	114 967	95.8	27.69	2128	124	216	8.9	152	242	7.8	0.5	44	3.9	7.0	76.5	36.1 (0.0840)
D-ED-N-44-2	74 294	61.9	27.69	2128	63	234	15.3	71	231	14.5	0.5	44	1.5	3.5		
D-ED-N-44-3	130 831	109.0	27.69	2128	173	247	6.3	326	423	4.8	0.5	44	5.1	9.0		
D-ED-N-46-1	92 008	76.7	27.70	2118	74	193	12.9	97	215	11.5	0.5	46	3.6	7.0	74.5	48.6 (0.1130)
D-ED-N-46-2	59 979	50.0	27.70	2118	68	335	16.7	63	261	15.9	0.5	46	1.5	3.5		
D-ED-N-46-3	105 100	87.5	27.70	2118	83	170	10.7	111	205	9.6	0.5	46	4.8	9.0		
Vancouver – Sea Level																
Test Number	Manufacturer recommends no derate. 12 % increased input is 134 400 Btu/h.				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
D-VA-N-45-1	120 419	100.3	29.93	-9	3	5	8.5	24	37	7.3	0.5	45	3.9	7.0	77.0	38.0 (0.0884)
D-VA-N-45-2	74 191	61.8	29.93	-9	12	34	13.5	14	36	12.7	0.5	45	2.0	3.5		
D-VA-N-45-3	133 519	111.3	29.93	-9	22	32	6.7	86	115	5.3	0.5	45	5.0	9.0		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**. Due to an oversight, tests were not conducted with Furnace D operating at its low-gas or low-heat input rate. Thus results for the 2<sup>nd</sup> stage (low-heat) are not presented.

Table 10. Summary of Measured and Calculated Results for Furnace D on Propane Gas  
Rating Plate Gas Input Rate is 120,000 Btu/h on High and 75,000 Btu/h on Low Fire.

Test Number	Fortress Mountain – 6,700 ft (2040 m)															
	Manufacturer's recommended derate is 26.8%; 87 840 Btu/h. 9% increased input is 95 746 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
D-FM-P-54-1	113 852	94.9	23.13	6951	525	630	3.5					54	10.0	?	85.0	30.1 (0.0700)
	N/A				N/A											
	N/A				N/A											
D-FM-P-55-1	100 636	83.9	23.13	6951	42	61	6.5	148	194	5	0.3	55	10.5	11.0	84.5	34.2 (0.0795)
D-FM-P-55-2	88 705	73.9	23.13	6951	14	25	9.1	35	53	7.1	0.3	55	8.2	8.5		
D-FM-P-55-3	103 999	86.7	23.13	6951	68	94	5.8	233	293	4.3	0.3	55	11.5	13.5		
D-FM-P-56-1	81 321	67.8	23.00	7100	17	34	10.5	21	38	9.3	0.3	56	9.2	11.0	83.9	27.7 (0.0645)
D-FM-P-56-2	70 104	58.4	23.00	7100	23	55	12.2	19	40	11.1	0.3	56	7.2	8.5		
D-FM-P-56-3	87 850	73.2	23.00	7100	18	31	8.9	26	42	7.9	0.3	56	11.0	13.5		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**. Due to an oversight, tests were not conducted with Furnace D operating at its low-gas or low-heat input rate. Thus results for the 2<sup>nd</sup> stage (low-heat) are not presented.

Table 10 (continued). Summary of Measured and Calculated Results for Furnace D on Propane Gas  
Rating Plate Gas Input Rate is 120,000 Btu/h on High and 75,000 Btu/h on Low Fire.

Edmonton – 2,250 ft (685 m)																
Test Number	Manufacturer's recommended derate is 9.0%; 109,200 Btu/h. 9% increased input is 119,028 Btu/h.				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
D-ED-P-55-1	113 850	94.9	27.67	2147	64	107	8.4	114	170	6.9	0.5	55	10.0	11.0	80.3	47.7 (0.1110)
D-ED-P-55-2	97 930	81.6	27.67	2147	59	124	11	85	156	9.5	0.5	55	7.5	8.5		
D-ED-P-55-3	126 930	105.8	27.67	2147	96	139	6.5	203	270	5.2	0.5	55	12.0	13.5		
D-ED-P-56-1	97 558	81.2	27.69	2128	41	92	11.6	50	100	10.5	0.5	56	10.0	11.0	78.1	42.1 (0.0978)
D-ED-P-56-2	82 016	68.3	27.69	2128	43	118	13.3	47	115	12.4	0.5	56	7.5	8.5		
D-ED-P-56-3	106 236	88.5	27.69	2128	46	90	10.3	63	104	8.3	0.5	56	12.0	13.5		
Vancouver – Sea Level																
Test Number	Manufacturer recommends no derate. 9 % increased input is 130 800 Btu/h				Combustion Operation (ANSI Z21.47-2.8.1)			Blocked Flue (ANSI Z21.47-2.22.1)				Orifice size	Manifold Pressure (in. wc)	Gas Line Pressure (in. wc)	Steady State Efficiency (%)	NO <sub>x</sub> [ng/J (lbs/10 <sup>6</sup> Btu)]
	Gas Input Rate (Btu/h)	Percent of Rating Plate Input	Barometric Pressure (in. Hg)	Barometrically- Derived Altitude (ft)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	CO (PPM)	CO Air Free (PPM)	O <sub>2</sub> (%)	Pressure Switch Pressure (in. wc)					
D-VA-P-55-1	111 776	93.1	29.93	-9	20	35	9.1	21	33	7.7	0.5	55	10.5	11.0	79.4	40.3 (0.0937)
D-VA-P-55-2	90 831	75.7	29.93	-9	70	152	11.3	64	121	9.9	0.5	55	7.5	8.5		
D-VA-P-55-3	127 023	105.9	29.93	-9	16	26	8.3	37	56	7.0	0.5	55	12.5	13.5		

Note: Only one value of steady state efficiency and NO<sub>x</sub> are listed per test set. These values are the averages of the three tests performed with one orifice size at each elevation. Some over fire gas input rates exceeded the test requirements because gas manifold pressure was erroneously increased instead of gas inlet pressure as required by **2.8.1 Combustion Operation**. Due to an oversight, tests were not conducted with Furnace D operating at its low-gas or low-heat input rate. Thus results for the 2<sup>nd</sup> stage (low-heat) are not presented.

The recorded data for these results are listed in Appendix C. Appendix D contains spread sheets summaries of the calculations of steady state efficiency and emissions of NO. The introduction to Appendix D outlines the details of the calculations used in generating the spread sheets. The efficiency and NO values were calculated from data collected while conducting tests according to section **2.38 Thermal Efficiency**. As these were separate tests, the gas input rate and other measured parameters varied slightly from the tests conducted according to sections **2.8.1 Combustion Operation** and the blocked-flue portion of **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**. As requested by the PMS, the NO values shown in Appendix D are reported in Tables 3 – 10 as NO<sub>x</sub>.

The parameter of most interest is the CO concentration level (AF or air free) in flue gas with and without a blocked flue. High levels of CO concentration pose a safety hazard. The maximum allowed by ANSI Z21.47-2001•CSA 2.3-2001 Standard is 400 ppm CO-AF. The critical tests for CO include sections **2.8.1 Combustion Operation** and the blocked-flue portion of **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**.

In section **2.8.1 Combustion Operation** the furnace is tested at:

- a) normal firing rate,
- b) reduced firing rate achieved by reducing the gas inlet pressure by 50% for Natural Gas and 27% for Propane Gas,
- c) increased gas input rate (over fire) rate achieved by increasing the manifold pressure, blocking open the manifold pressure regulator or removing it, and/or increasing the gas inlet pressure to give a 12% over fire for Natural Gas and a 9% over fire for Propane Gas, and
- d) a reduced voltage supplied to the appliance.

In the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** a flue blockage test is performed by slowly restricting the flue gas flow area until the pressure switch used to detect flue blockage opens to stop fuel flow to the burners. The restriction would then be slightly reduced so continuous burner operation was achieved.

ANSI Z21.47-2.22.1 states that this test is to be done at normal inlet test pressure, implying Rating Plate Input at Sea Level and derated inputs at altitudes above 2,000 ft ( 610 m). In this study the flue blockage test was to be performed at natural derate gas input rates in addition to the normal gas input rates (Rating Plate Input) and the manufacturer-specified derate gas input rates. As shown in Tables 3 – 10, additional tests at reduced firing rate and increased gas input rate, as per section **2.8.1 Combustion Operation** parts b) and c) above, were also conducted while doing the Blocked Flue tests. While not required they were run as an extension of the section **2.8.1 Combustion Operation** tests using the same combinations of orifice size, manifold and line pressures. Thus the range of fuel input rates was broader than is required in ANSI Z21.47-2.22.1 and may have lead to premature foreclosing of some of the Blocked Flue tests as the indicated CO values may have been artificially high due to the incorrect operation of the burner.

For each gas input rate, the flue gas CO concentration was then measured and the CO-AF calculated. The furnace complies with section **2.22.1** if the CO-AF concentration in the flue gas does not exceed 400 ppm before the furnace shuts off or if the flue is 100% blocked without exceeding 400 ppm (CO-AF).

The tabular data (Tables 3 -10) are helpful for showing which tests caused non-compliance under different derating scenarios. In these tables the CO-AF values exceeding the 400 ppm limit are shaded for easy reference. Some of the CO values from the 6,700 ft (2040 m)

tests were not filled in. The reason for this is that it was obvious from the companion tests that the furnace would easily exceed the 400 ppm CO limit. Thus, further more stringent tests were not performed.

Figures 9a through 9h show the variation of CO-AF in the furnace flue gas as the gas input rate is varied from under fire to over fire conditions. Both sections **2.8.1 Combustion Operation** and the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** test results are plotted on each figure. The results for Natural Gas and Propane Gas for a particular furnace are shown on separate figures.

The O<sub>2</sub> concentration in the flue gases is an indicator of the amount of excess air used in the combustion process. When the flue gas O<sub>2</sub> level (dry basis) rises above 10%, the excess air is greater than 80%. This amount of excess air limits the flame temperature, reducing the rate of reaction within the flame, which can promote CO formation. This phenomenon happens even though large amounts of O<sub>2</sub> are present.

Other parameters of interest are the steady state efficiency of the furnaces on each fuel and how this varies with altitude, and the amount of NO<sub>x</sub> produced (mass per useful heat) and how it varies with altitude. Tables 3 - 10 list these values in the right hand columns. Only one value of efficiency and of NO<sub>x</sub> are listed per test set. The efficiency and NO<sub>x</sub> values were calculated from data collected while conducting tests according to section **2.38 Steady-State Thermal Efficiency**.

## 7. Discussion

### a) Meeting the 400 ppm Air Free CO requirement

Examination of the CO-AF concentrations listed in Tables 3 - 10 shows that in the **2.8.1 Combustion Operation** test column, only a few cases exceeded the 400 ppm CO-AF limit. Of the 139 tests listed in the Tables, only 12 exceeded the 400 ppm limit during this test. Of these 12 failures, 8 occurred at the highest altitude (6,700 ft, 2040 m), while the other 4 occurred at other altitudes. There was no pattern to the failures as they occurred with natural derating operation and under fired and over fired operation. However, most failures did occur with over firing.

The blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** tests show a higher percentage of tests exceeding the 400 ppm CO-AF limit. Many blank spaces exist in the tables because it seemed evident that the blocked flue test would show the CO-AF concentrations to be above the 400 ppm limit. Thus there seemed to be no purpose in running the tests. Nine of the reported test results have concentrations greater than 400 ppm CO-AF. If the blank spaces are included as failures, the total failures would be 31, about two and one-half times the concentration for the **2.8.1 Combustion Operation** test. Most of the failures occurred at the highest altitude. Many of these “failures” are from measurements made when operating the furnaces under conditions not required by ANSI Z21.47-2001•CSA 2.3-2001.

Recall that when the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** were run, additional tests at reduced gas input rate and increased gas input rate were included. These additional tests are not required by ANSI Z21.47-2001•CSA 2.3- section **2.22**. Counting any of these additional tests which exceed the 400 ppm CO-AF limit as failures is not appropriate. They were performed in error. This was not

realized during the field testing. Thus these erroneous failures gave misleading results and foreclosed running other tests that may not have failed.

Detailed examination of the **2.22.1** blocked flue CO-AF results listed in Tables 3 – 10 suggests that with Rating Plate Input at Sea Level and manufacturers' recommended derates and natural derates at the other altitudes, all the furnaces tested always complied with the 400 ppm CO-AF limit on both fuels. Thus based on the specific furnaces tested, the results show that the current derating scheme may be conservative for Category I and Category IV furnaces. The results suggest that all of the four furnaces, with either fuel, will operate below the 400 ppm CO-AF limit under "natural" derating under most conditions. That is, the Sea Level burners fitted with the recommended orifice sizes for Sea Level operation operated satisfactorily at all the altitudes tested when at the manufacturer's recommended manifold and gas inlet test pressures. It was only when these burners were over fired or under fired that the CO-AF limit was exceeded. See the discussions below for the exceptions.

In examining the results and drawing conclusions it is important to remember that specific rates of over firing and under firing are included in the criteria for compliance with ANSI Z21.47•CSA 2.3-2001. The over firing and under firing rates were not always achieved in the field tests and as such firm conclusions on compliance with ANSI Z21.47•CSA 2.3 sections 2.8 and 2.22.1 can not be drawn for the test furnaces for some field-installed conditions.

Figures 9a through 9h are plots of the calculated flue gas CO-AF concentrations at all three altitudes for the two different test procedures (**2.8.1** and **2.22.1**) for each furnace on each fuel. The calculated CO-AF is based on the measured CO and O<sub>2</sub> concentrations. The 400 ppm CO-AF concentration is marked on each figure as a horizontal dashed line.

The general behavior (see Figure 9a) is one of decreasing CO-AF concentrations as the gas input (Btu/h) increases from an under fired condition to derated gas input rates and up to the



Rating Plate Input value. With firing rates above Rating Plate Input the general trend is for the CO-AF concentrations to rise. Testing was terminated when it seemed evident that the 400 ppm limit would be exceeded or the furnace was being fired safely above the Rating Plate Input using increased gas inlet test pressures as stipulated in the ANSI Z21.47-2001•CSA 2.3-2001 Standard. Some of the failures occurred during the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** tests in which gas input rates were set outside the test requirements due to adjustments made to the manifold pressure and/or inlet test pressure. All these figures show a reasonably large safe operating range especially with reduced input rate from the Rating Plate Input. The results are inconclusive and indeterminate for natural derating for some over firing conditions that occurred with some of the field installed furnaces.

Detailed results for each furnace are presented below.

**Furnace A** complies with **2.8.1 Combustion Operation** and the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** as shown in the following analysis.

Furnace A provides data for a Category IV Non-Direct-vent furnace. The CO-AF test results for Natural Gas and Propane Gas firing are listed in Tables 3 and 4 and are shown in Figures 9a and 9b respectively. For this furnace, the manufacturer has already moved to a derating of 2% per 1000 ft (305 m) above Sea Level. This is a slight increase over “natural derating” of 1.8% per 1000 ft (305 m). The test results plotted in the Figures 9a and 9b for the derating of 13.4% to 103,920 Btu/h at 6,700 ft (2040 m) and 4.5% to 114,600 Btu/h at 2,250 ft (685 m) show that this derating scheme is applicable for this furnace.

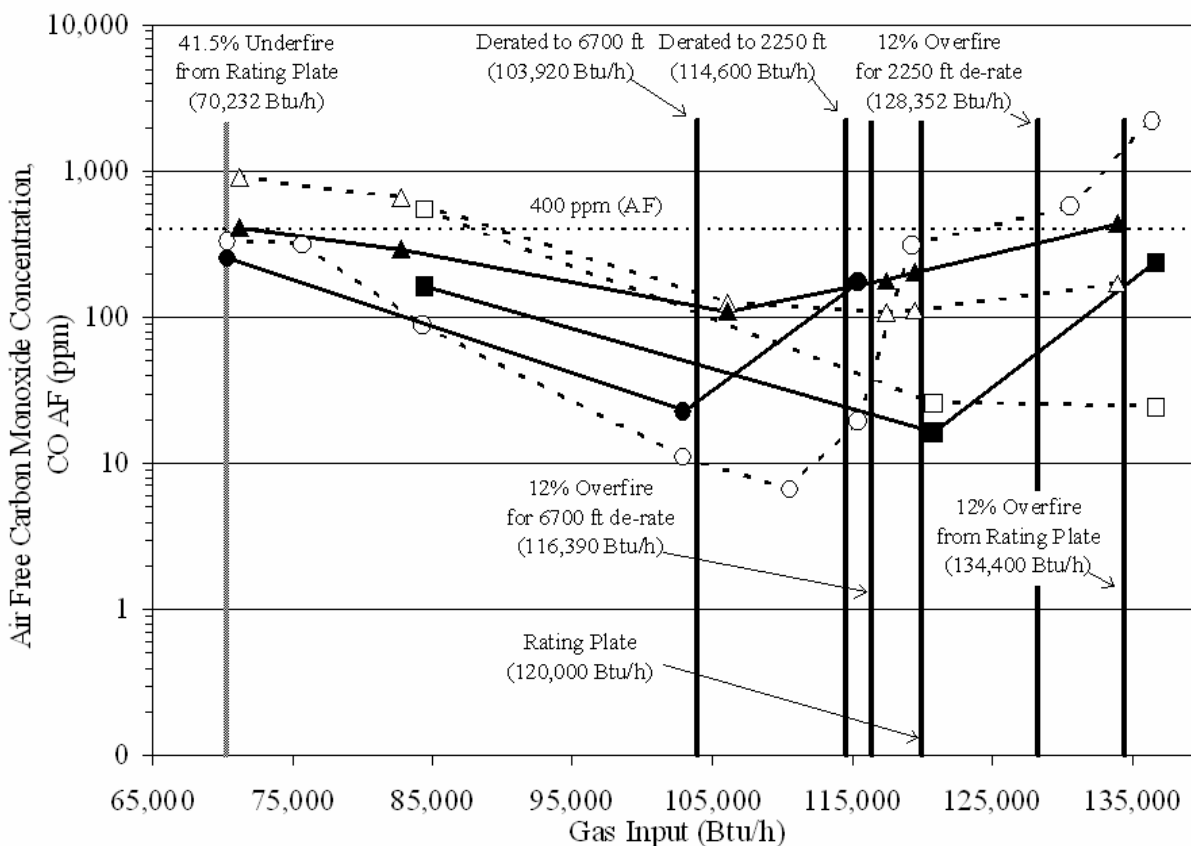
Dealing specifically with the **2.8.1 Combustion Operation** test results for Furnace A using Natural Gas, at 6,700 ft (2040 m) and the 13.4% manufacturer-recommended derate (103,920 Btu/h) (Table 3), the highest CO-AF concentration, 333 ppm, was found when the

furnace was operated at an under fire condition from this derating where the gas input rate was 70,232 Btu/h (58.5% of Rating Plate gas input), Test Number **A-FM-N-45-2**. This characteristic was also found at the other two test altitudes. When the furnace was tested at the manufacturer-recommended derating at 2,250 ft (685 m) and Sea Level, with the 45 orifice size at 71,149 Btu/h and 85,631 Btu/h, respectively (59.3% and 71.4% of Rating Plate gas input), (Test Numbers **A-ED-N-45-5** and **A-VA-N-45-2**) the calculated CO-AF levels were 896 ppm and 541 ppm respectively. With these three high CO-AF results the furnace was operating with a reduced gas line inlet test pressure of 3.5 in. wc and the resulting reduced manifold pressure of 1.2 to 1.8 in. wc. But when run at the derated gas input rates of 102,836 Btu/h, 117,432 Btu/h and 122,555 Btu/h for 6,700 ft (2040 m), 2,250 ft (685 m), and Sea Level (Test Numbers **A-FM-N-45-1**, **A-ED-N-45-1** and **A-VA-N-45-1**) with normal manifold pressures of 3.3 to 3.9 in. wc and 7.0 in. wc gas line inlet test pressure (near manufacturer-recommended altitude deratings of 103,920 Btu/h, 114,600 Btu/h and 120,000 Btu/h; and natural deratings of 105,528 Btu/h, 115,140 Btu/h and 120,000 Btu/h), the calculated CO-AF levels were about 11 ppm, 107 ppm and 26 ppm respectively. Note as well that for the operating points with high CO-AF levels, the O<sub>2</sub> levels were higher than the other test points. As mentioned above, high O<sub>2</sub> levels (actually high air to fuel ratios) can be detrimental to controlling the level of CO.

The other high values of CO-AF shown in Table 3 occur with gas input rates of 136,401 Btu/h at 6,997 ft and 130,521 Btu/h at 6,985 ft (Test Numbers **A-FM-N-43-3** and **A-FM-N-44-3**). These tests were over fired beyond the requirements of ANSI Z21.47•CSA 2.3-2001, **2.8.1 Combustion Operation**, which required gas input over fire rates of 116,390 Btu/h and 118,191 Btu/h for Furnace A manufacturer-recommended and natural derates at 6,700 ft (2040 m). The Natural Gas test at 119,281 Btu/h and 6,997 ft with 310 ppm CO-AF in (Test Number **A-FM-N-43-1**) demonstrates that Furnace A complies with the **2.8.1 Combustion Operation** over fire test

at 116,390 Btu/h and 118,191 Btu/h for 6,700 ft (2040 m). Although Furnace A was significantly over fired at 133,933 Btu/h on Natural Gas for 2,000 ft (Test Number **A-ED-N-45-3**), its calculated CO-AF of 171 ppm shows compliance with **2.8.1 Combustion Operation** for required over fire of 128,352 Btu/h for the manufacturer-recommended derate of 114,600 Btu/h and over fire of 128,957 Btu/h for natural derate of 115,140 Btu/h at 2,250 ft (685 m).

The results for Furnace A plotted in Figures 9a and 9b do show that the calculated CO-AF values do exceed the 400 ppm limit at low and high values of gas input rate as discussed above. The excursions are more frequent with Natural Gas firing than with Propane Gas firing and are a result of the particular procedures used in conducting the experiments.



**Figure 9a. Furnace A operating on Natural Gas:** Measured carbon monoxide concentration in the flue gases on an air free dry basis for three different altitudes with Furnace A operating on Natural Gas. Squares  $\square$  for Sea Level, triangles  $\Delta$  for 2,250 ft (685 m) and circles  $\circ$  for 6,700 ft (2040 m); filled symbols are for blocked flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**. The Rating Plate Input is 120,000 Btu/h. The manufacturer's recommended derating is 114,600 Btu/h at 2,250 ft (685 m) and 103,920 Btu/h at 6,700 ft (2040 m). Test data is for approximate altitudes of Sea Level, 2,250 ft (685 m) and 6,700 ft (2040 m). See Table 3 for exact barometrically-derived test altitudes and the individual data point values.

Consider now the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** test results for Furnace A when operating on Natural Gas. The only test condition that is required by ANSI Z21.47-2001•CSA 2.3-2001 Standard is to fire the furnace at the rating plate gas input rate at Sea Level and manufacturer-recommended derate at altitudes over 2,000 ft (610 m).

At the Fortress Mountain location the manufacturer-recommended and natural derates for this furnace are 103,920 Btu/h and 105,528 Btu/h respectively. Tests **A-FM-N-45-1** and **A-FM-N-45-3** bracket these inputs. The calculated CO-AF values are 23 ppm and 175 ppm respectively, both well below the 400 ppm limit. Examination of the other test results for this location under **2.8.1 Combustion Operation** suggest that only when this furnace was over fired by at least 25% from the derated values did the calculated CO-AF values exceed the 400 ppm limit (Test Numbers **A-FM-N-43-3** and **A-FM-N-44-3**). Thus is likely that Test **A-FM-N-44-1** would have complied with the 400 ppm requirement had the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** test been conducted, but not necessarily so for Test **A-FM-N-43-1** where the Gas Input Rate was 119,281 Btu/h.

At the Edmonton location, 2,250 feet (685 m) altitude, the manufacturer-recommended and natural derates are 114,600 Btu/h and 115,140 Btu/h respectively. Tests **A-ED-N-45-4** and **A-ED-N-45-1** bracket these requirements. The calculated CO-AF values for the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** tests for these two cases are 109 ppm and 178 ppm respectively. Both are well below the 400 ppm limit. It was only when the furnace was over fired or under fired that the calculated CO-AF values exceeded the 400 ppm limit. These latter test points are not required by the ANSI Z21.47-2001•CSA 2.3-2001 Standard, so they are not to be considered failures.

The results for Furnace A operating on Propane Gas are found in Table 4. For the **2.8.1 Combustion Operation** tests at any altitude the worst case for CO emissions was Test Number **A-FM-P-54-3**. Here the furnace was operating at 6.7% over fire from its Sea Level “Rating Plate Input” (128,014 Btu/h). The calculated CO-AF level was 375 ppm. This input is well above the required test point of derated value plus 9%. The manufacturer-recommended derate and natural derate gas inputs are 103,920 Btu/h and 105,528 Btu/h respectively for the 6,700 ft

(2040 m) altitude. Examination of Test Numbers **A-FM-P-54-1** and **A-FM-P-55-3** show that Furnace A easily complies with the 400 ppm limit when the input rate is above that required for the **2.8.1 Combustion Operation** tests at this altitude.

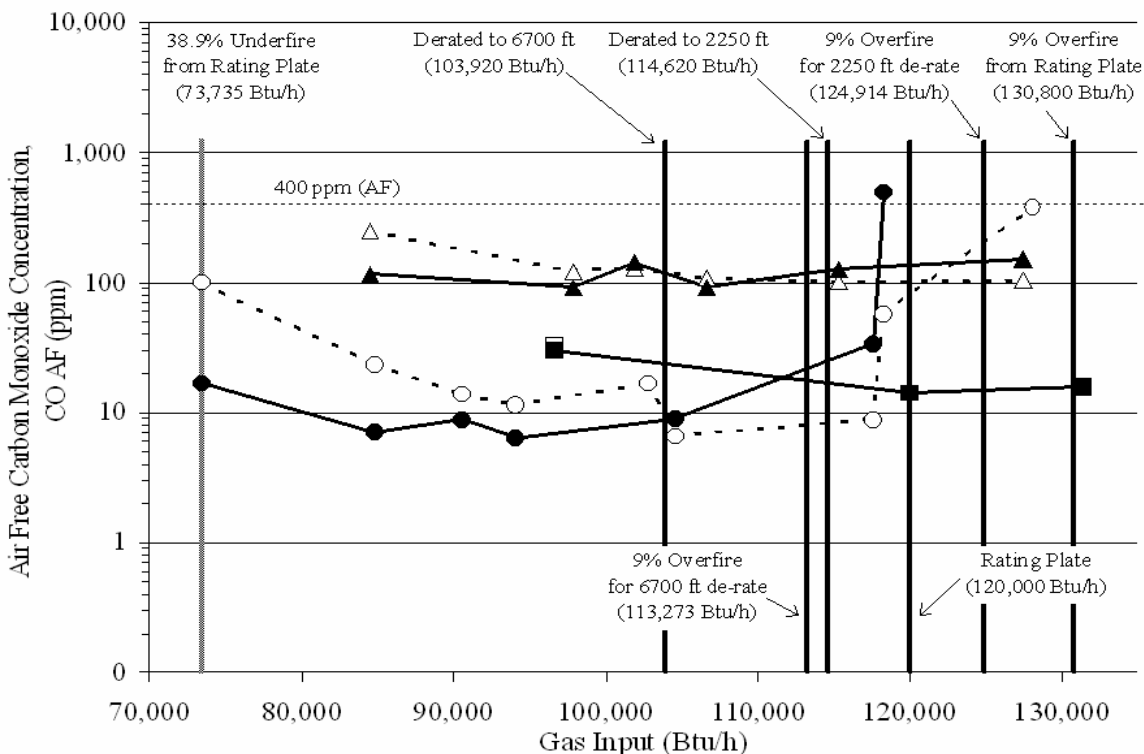
The manufacturer-recommended and natural derates at 2,250 ft (685 m) are 114,600 Btu/h and 115,140 Btu/h respectively for which the **2.8.1 Combustion Operation** increased inputs are 124,914 Btu/h and 125,503 Btu/h. Test Number **A-ED-P-55-3** was fired at 127,450 Btu/h, well above the required rate. The calculated CO-AF was 103 ppm, which is well below the 400 ppm limit showing compliance.

This furnace easily met the **2.8.1 Combustion Operation** requirement at Sea Level when operating on Propane Gas.

Examination of the results for the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** tests show that only one test point exceeded the 400 ppm limit. This test (**A-FM-P-54-1**) had an input rate of 118,268 Btu/h, at least 12% above the manufacturer-recommended and natural derates of 103,920 Btu/h and 105,528 Btu/h respectively. Test **A-FM-P-55-3** had a slightly lower input rate and easily complied with the 400 ppm limit requirement, as did all the other reported test results at this altitude. Thus it is logical to conclude that Furnace A was in compliance at this altitude under manufacture-recommended and natural derates when fired with Propane Gas, if drill size 55 orifices instead of 54 orifices are used.

At the other two test altitudes the calculated CO-AF values for the required input rates for the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** tests, Test Numbers **A-ED-P-55-1** and **A-VA-P-55-1**, produced CO-AF concentrations of 126 ppm and 14 ppm respectively. Both well below the 400 ppm limit.

Figure 9b shows the variation of flue gas CO-AF concentration with Gas Input Rate (Btu/h) variation for Furnace A when firing with Propane Gas. It was only when the input rate was well above the test requirements for the blocked flue test at 6,700 ft (2040 m), the filled circles, that this furnace exceeded the 400 ppm CO-AF limit. The general trend shown in the results are similar to those shown in Figure 9a for Furnace A when fired with Natural Gas.



**Figure 9b. Furnace A operating on Propane Gas:** Measured Carbon Monoxide concentration in the flue gases on an air free dry basis for three different altitudes with Furnace A operating on Propane Gas. Squares  $\square$  for Sea Level, triangles  $\Delta$  for 2,250 ft (685 m) and circles  $\circ$  for 6,700 ft (2040 m); filled symbols are for blocked flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**. The Rating Plate Input is 120,000 Btu/h. The manufacturer's derating is 114,600 Btu/h at 2,250 ft (685 m) and 103,920 Btu/h at 6,700 ft (2040 m). Test data is for approximate altitudes of sea level; 2,250 ft (685 m); and 6,700 ft (2040 m). See Table 4 for exact barometrically-derived test altitudes and the individual data point values.

**Furnace B:** Compliance with 2.8.1 Combustion Operation is uncertain, but probable on Natural Gas at natural-derate, at 6,700 ft (2040 m). Compliance with the blocked-flue portion of section

**2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** is uncertain, but probable on Natural Gas at natural derate, at 2,250 ft (685 m).

Furnace B, a Direct Vent, Category IV furnace, showed the same general behavior as Furnace A. The results are listed in Tables 5 and 6 for Natural Gas and Propane Gas respectively. Considering only the **2.8.1 Combustion Operation results**, it was only at 6,700 ft (2040 m) when over fired by 8.6% and 5.7% of the 40,000 Btu/h Sea Level “Rating Plate Input” on Natural Gas (Test Number **B-FM-N-43-3**) at 43,439 Btu/h and Propane Gas (Test Number **B-FM-P-54-3**) at 42,281 Btu/h, that the furnace produced calculated CO-AF concentrations of 1,569 ppm and 872 ppm respectively, which exceed the 400 ppm limit. Based on manufacturer-recommended and natural derates respectively, the **2.8.1 Combustion Operation** test requires over fire gas input rates of 32,794 Btu/h and 39,397 Btu/h at 6,700 ft (2040 m) and 40,768 Btu/h and 42,986 Btu/h at 2,250 ft (685 m) on Natural Gas; and 31,915 Btu/h and 38,342 Btu/h at 6,700 ft (2040 m) and 39,676 Btu/h and 41,834 Btu/h at 2,250 ft (685 m) on Propane Gas. The test results clearly show compliance with the 400 ppm limit in all cases except the Fortress Mountain tests with Natural Gas. Here the furnace was fired at 38,409 Btu/h input (Test Number **B-FM-N-43-1**) and 43,439 Btu/h input (Test Number **B-FM-N-43-3**). The former gas input rate exceeded the over fire input from the manufacturer-recommended derating with a calculated CO-AF of 23 ppm, but did not exceed the over fire input from the natural derating. The latter input, 43,439 Btu/h, did exceed the natural derate over fire input, but it produced a calculated CO-AF of 1,569 ppm which is greater than the 400 ppm limit. As shown in Figure 9c, Furnace B might have complied if the gas input rate had been closer to the 39,397 Btu/h test requirement and not 13% above.

Examination of the test results for the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** tests reported in Tables 5 and 6 show

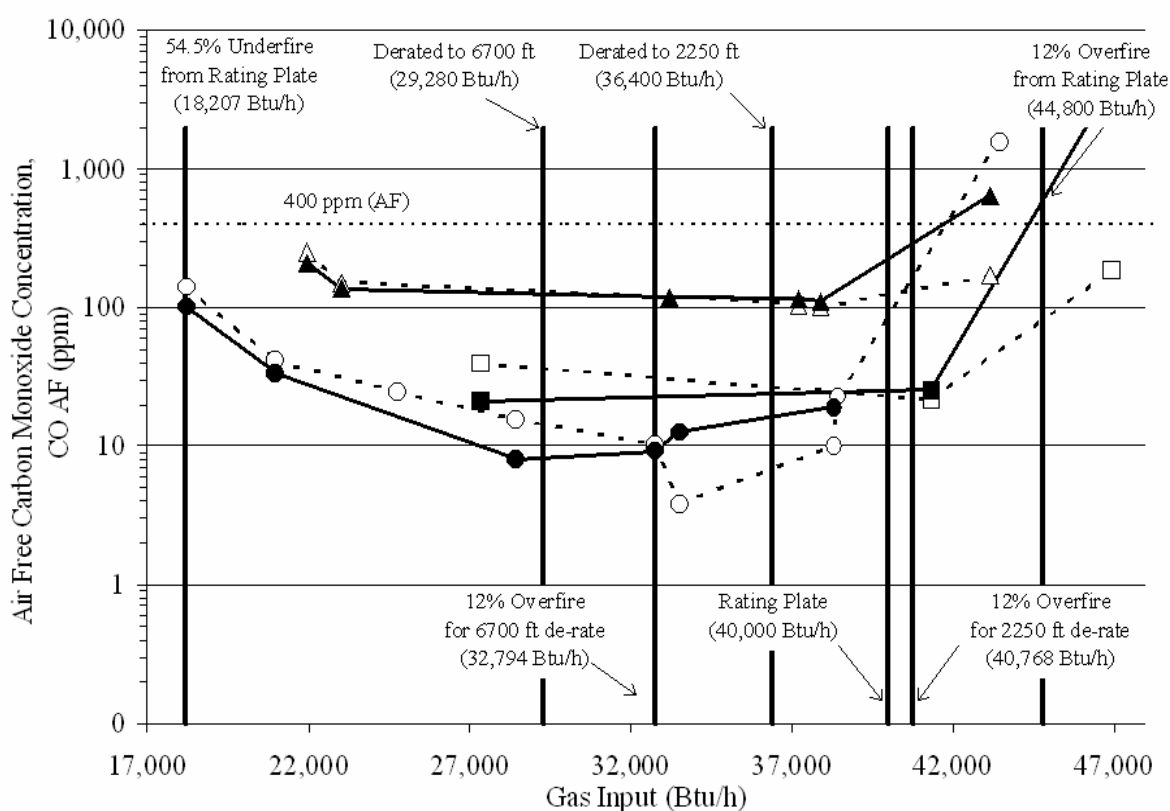


that two cases exceeded the CO-AF 400 ppm limit. As seen in Table 5, both occurred when using Natural Gas during over firing, one at Sea Level, the other at 2,250 ft (685 m). None of the Propane Gas tests failed to comply with the 400 ppm limit. Recall that for the **2.22.1** test, the gas input rate requirement is the Rating Plate Input at Sea Level and manufacturer-recommended and natural derates at altitudes above 2,000 ft (610 m). Thus Test Numbers **B-VA-N-45-1** and **B-Ed-N-45-1** are the ones which match the rating plate and manufacturer-recommended derated gas input rates, respectively. The manufacturer's Sea Level Rating Plate Input is 40,000 Btu/h, while the recommended derated input for 2,250 ft (685 m) is 36,400 Btu/h and the natural derating is 38,400 Btu/h. The gas input rate in Test Number **B-VA-N-45-1** exceeds the requirement, while that for **B-ED-N-45-1** is within 2% of the requirement. The calculated CO-AF concentrations for these two test points were 28 ppm and 110 ppm respectively, both well below the 400 ppm limit.

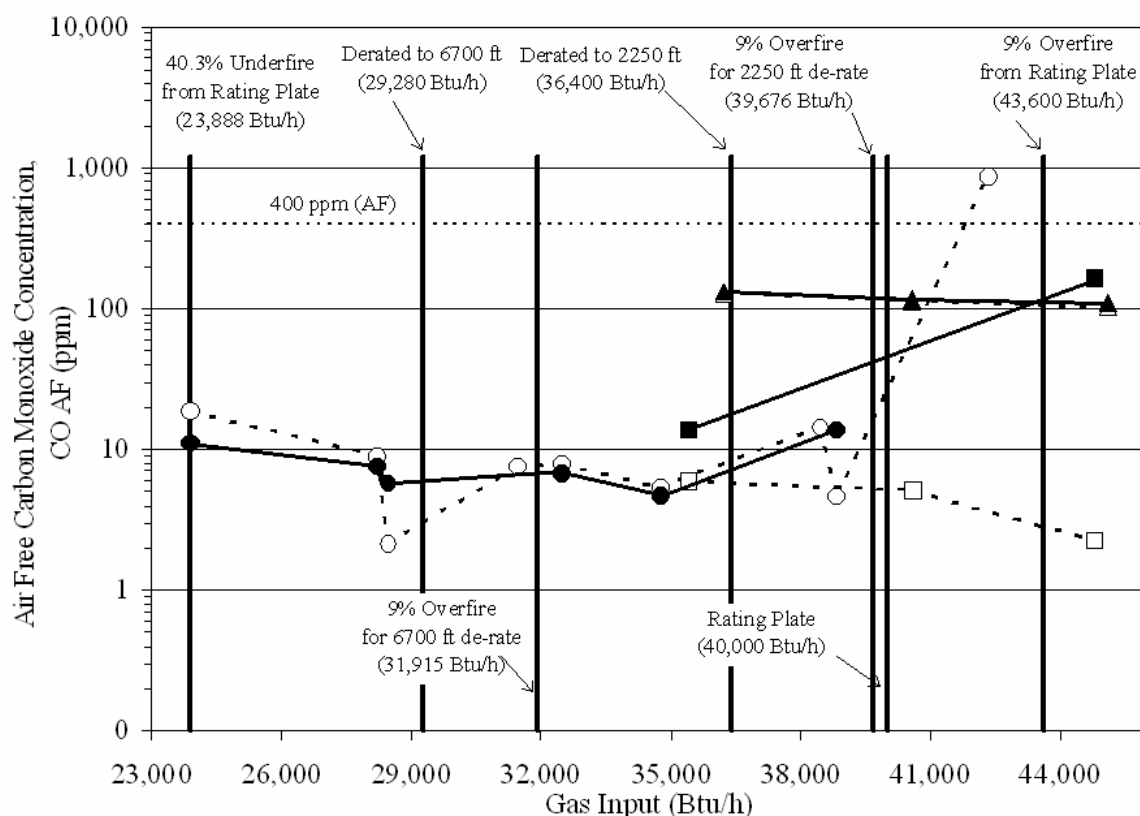
Due to an oversight, Furnace B was not fired on Propane Gas at the 9% derated condition at 2,250 ft (685 m) with a normal gas line inlet test pressure of 11.0 in. wc. It was fired below the manufacturer-recommended derate of 36,400 Btu/h as shown in Test Number **B-ED-P-55-2**, where the rate was 36,163 Btu/h. However, this was done with a reduced gas line inlet test pressure of 8.5 in. wc. The calculated CO-AF concentration for this operating point was only 131 ppm, well below the 400 ppm limit.

The CO-AF concentration results for Furnace B when operating on Natural Gas and Propane Gas are shown in Figures 9c and 9d respectively. For this furnace, the manufacturer recommends the historical derating of 4% per 1000 ft (305 m). This is over twice the 1.8% per 1,000 ft "natural" derating. The test results plotted in Figures 9c and 9d for manufacturer-recommended derating of 9.0% at 2,250 ft (685 m) of 36,400 Btu/h and of 26.8% at 6,700 ft (2040 m) of 29,280 Btu/h show that Furnace B easily complies with the 400 ppm CO-AF limit

with altitude adjusted input and zero over fire. The natural deratings of 1.8% per 1,000 feet at 2,250 ft (685 m) and 6,700 ft (2040 m) for this furnace are 38,380 Btu/h and 35,176 Btu/h respectively. The over fire tests for natural derating would be at 42,986 Btu/h and 39,397 Btu/h respectively on Natural Gas and 41,834 Btu/h and 38,342 Btu/h on Propane Gas. Examination of the trend lines in Figures 9c and 9d show that the CO-AF concentrations are under the 400 ppm for all these firing rates. This suggests that Furnace B could operate safely at all altitudes using the sea level orifices and manifold pressure.



**Figure 9c. Furnace B on Natural Gas:** Measured carbon monoxide concentration in the flue gases on an air free dry basis for three different altitudes with Furnace B operating on Natural Gas. Squares □ for Sea Level, triangles Δ for 2,250 ft (685 m) and circles ○ for 6,700 ft (2040 m); filled symbols are for blocked flue portion of section 2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods. The Rating Plate Input is 40,000 Btu/h. The manufacturer's recommended deratings are 36,400 Btu/h at 2,250 ft (685 m) and 29,280 Btu/h at 6,700 ft (2040 m). Test data is for approximate altitudes of sea level; 2,250 ft (685 m); and 6,700 ft (2040 m). See Table 5 for exact barometrically-derived test altitudes and the individual data point values.



**Figure 9d. Furnace B on Propane Gas:** Measured carbon monoxide concentration in the flue gases on an air free dry basis for three different altitudes with Furnace B operating on Propane Gas. Squares  $\square$  for Sea Level, triangles  $\Delta$  for 2,250 ft (685 m) and circles  $\circ$  for 6,700 ft (2040 m); filled symbols are for blocked flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**. The Rating Plate Input is 40,000 Btu/h. The manufacturer's recommended deratings are 36,400 Btu/h at 2,250 ft (685 m) and 29,280 Btu/h at 6,700 ft (2040 m). Test data is for approximate altitudes of sea level; 2,250 ft (685 m); and 6,700 ft (2040 m). See Table 6 for exact barometrically-derived test altitudes and the individual data point values.

**Furnace C** compliance with **2.8.1 Combustion Operation** is uncertain, but probable. Compliance with the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** is uncertain, but probable. On Propane Gas at 6,700 ft (2040 m) **Furnace C** might barely comply with **2.22.1**.

Furnace C is a Non-Direct vent, Category I furnace. The results for Natural Gas and Propane Gas are found in Tables 7 and 8 respectively. Figures 9e and 9f show the CO-AF concentrations as a function of gas input rate.

Dealing first with the **2.8.1 Combustion Operation** calculated CO-AF results for Natural Gas, Table 7 and Figure 9e, only one test point, Test Number **C-FM-N-43-3**, failed to comply with the 400 ppm limit. It produced 907 ppm CO-AF while being over fired by 11.3% to 50,073 Btu/h at 6,700 ft (2040 m) from the Sea Level Rating Plate Input of 45,000 Btu/h. Note that this input is 52% above the manufacturer's recommended derated gas input rate of 32,940 Btu/h and 35.7% above the applicable **2.8.1 Combustion Operation** 12% over fire rate of 36,893 Btu/h for Natural Gas at 6,700 ft (2040 m). For this altitude the natural derate is 39,573 Btu/h, so the 12% over fire input would be 44,322 Btu/h. The actual firing rate was obviously well above that required. Test Numbers **C-FM-N-43-1**, **C-FM-N-44-1** and **C-FM-N-44-3** all have input rates above the required inputs, yet have calculated CO-AF concentrations well below the 400 ppm limit. Thus it seems likely that Furnace C would be in compliance with the **2.8.1 Combustion Operation** test requirement had it been fired correctly.

Examination of the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** test results for Natural Gas in Table 7 shows Furnace C to always be in compliance with the 400 ppm CO-AF limit with the exception of the natural derated result Test Number **C-FM-N-43-1** where no CO-AF concentrations are reported. Since Test Numbers **C-FM-N-44-1** and **C-FM-N-44-3** bracket the natural derate input rate of 39,573 Btu/h and have calculated CO-AF concentrations less than 400 ppm it is very likely that Test Number **C-FM-N-43-1** would also have complied with the requirement.

The results for this furnace when fired on Propane Gas are shown in Table 8 and Figure 9f. Dealing first with the **2.8.1 Combustion Operation** calculated CO-AF results, two test

points, Test Numbers **C-FM-P-52-3** and **C-ED-P-55-2**, failed to comply with the 400 ppm CO-AF limit. They produced 8,626 ppm and 402 ppm CO-AF respectively.

The 8,626 ppm was produced while being fired at 6.3% above the Sea Level Rating Plate gas input rate of 45,000 Btu/h while at 6,700 ft (2040 m). Note that this input is 45.3% above the manufacturer's recommended derated gas input rate of 32,940 Btu/h and 33.3% above the applicable **2.8.1 Combustion Operation** 9% over fire rate of 35,905 Btu/h for Propane Gas at 6,700 ft (2040 m). For this altitude the natural derate is 39,573 Btu/h, so the 9% over fire input would be 43,135 Btu/h. Test Numbers **C-FM-P-52-1** and **C-FM-P-52-3** both have gas input rates above the required inputs, the former producing an acceptable result, the latter not. Considering the gross over firing that was occurring with the latter test, this was not unexpected. Because Test Number **C-FM-P-52-1** had an input greater than that required and a CO-AF concentration below the 400 ppm limit, one can conclude that Furnace C complies with this test requirement at this altitude.

The 402 ppm CO-AF result occurred at the 2,250 ft (685 m) altitude while being 17.7% under fired, Test Number **C-ED-P-55-2**, with a gas input rate of 37,034 Btu/h. The gas manifold pressure was very low compared to the manufacturer-recommended gas manifold pressure of 10 in. wc, which would reduce the amount of primary air aspirated by the orifice gas jet and could reduce gas-air mixing to account for the poor combustion operation. Other tests had lower input rates, Test Numbers **C-FM-P-54-2** at 33,200 Btu/h, **C-FM-P-56-1**, **C-FM-P-56-2** and **C-FM-P-56-3** at 27,659 Btu/h to 34,353 Btu/h, and **C-VA-P-54-2** at 36,649 Btu/h, so it is uncertain as to why Test Number **C-ED-P-55-2** exceeded the 400 ppm limit. It is important to note that the measured 13.7% O<sub>2</sub> in the flue gas was higher for Test Number **C-ED-P-55-2** than any of the other tests mentioned which have a lower input rate. High O<sub>2</sub> in the flue gas indicates excess air in the combustion system that can lead to cool flame temperatures which may produce high CO

concentrations due to lowering of reaction rates for the oxidation of CO to CO<sub>2</sub>. Note as well that Furnace B when operating on Propane Gas (Table 6) showed even higher O<sub>2</sub> values in Test Numbers **B-ED-P-55-2** and **B-VA-P-55-2**, yet the CO-AF concentrations are very low, only a few ppm! Whether these results are due to physical differences in the furnace or errors made during the testing is unknown.

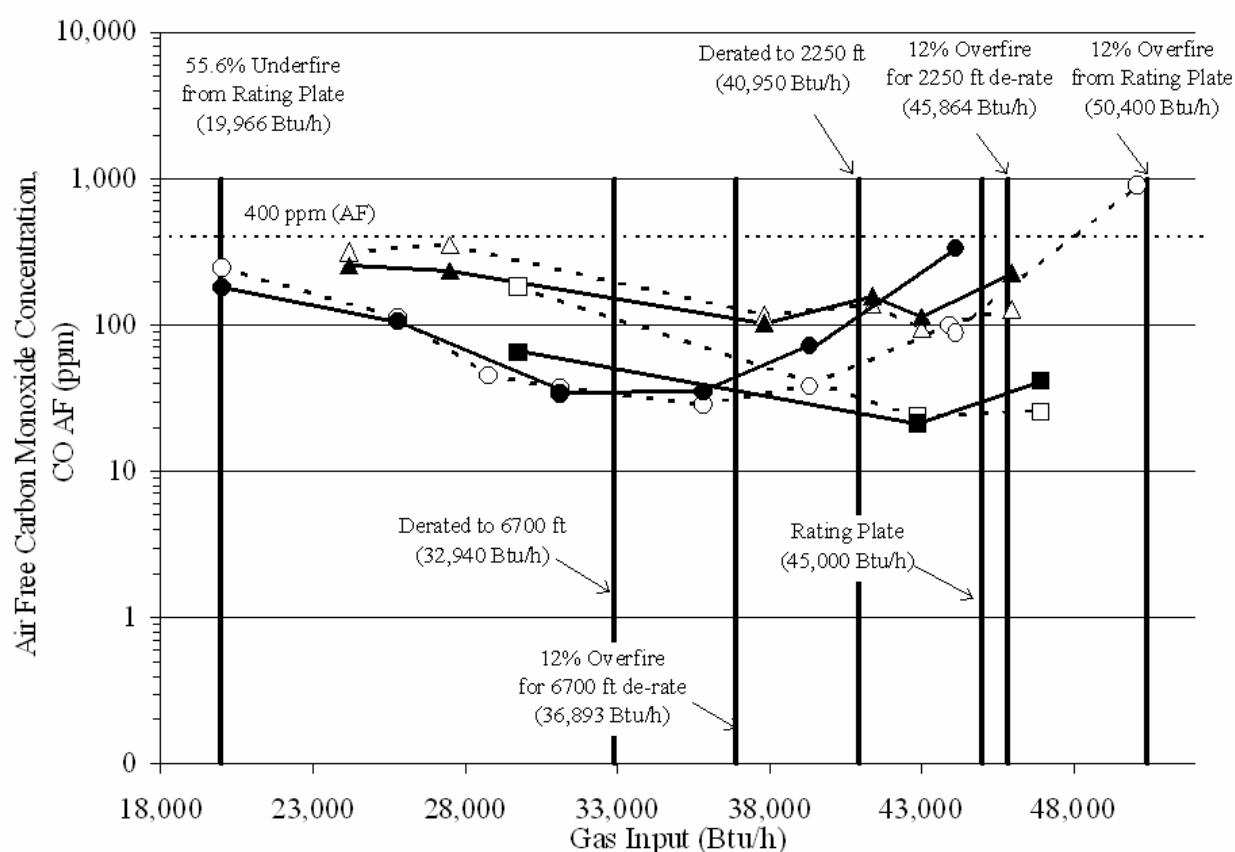
Examination of the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** test results for Propane Gas in Table 8 shows Furnace C to exceed the 400 ppm CO-AF limit in two tests, Test Numbers **C-FM-P-52-1** and **C-FM-P-52-3**. The gas input rates for the **2.22.1** tests at this altitude are 32,940 Btu/h for the manufacturer-recommended derating and 39,573 Btu/h for the natural derating. Thus the input rates where the calculated CO-AF concentration exceeded the 400 ppm limit are a minimum of 10% above the highest input rate required and are not appropriate test points.

At Sea Level Furnace C used a 54 drill size orifice. The natural derating tests are to be done with the same orifice size as Sea Level so Test Numbers **C-FM-P-54-1**, **C-FM-P-54-2** and **C-FM-P-54-3**, which bracket the natural derating input are the appropriate tests to examine, not the two tests that failed to comply with the 400 ppm limit due to over firing. Test Numbers **C-FM-P-56-1**, **C-FM-P-56-2** and **C-FM-P-56-3** bracket the manufacturer's recommended derating input. In all cases the calculated CO-AF concentrations were less than the 400 ppm limit, showing that this furnace is in compliance with the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** test requirement when operating on Propane Gas.

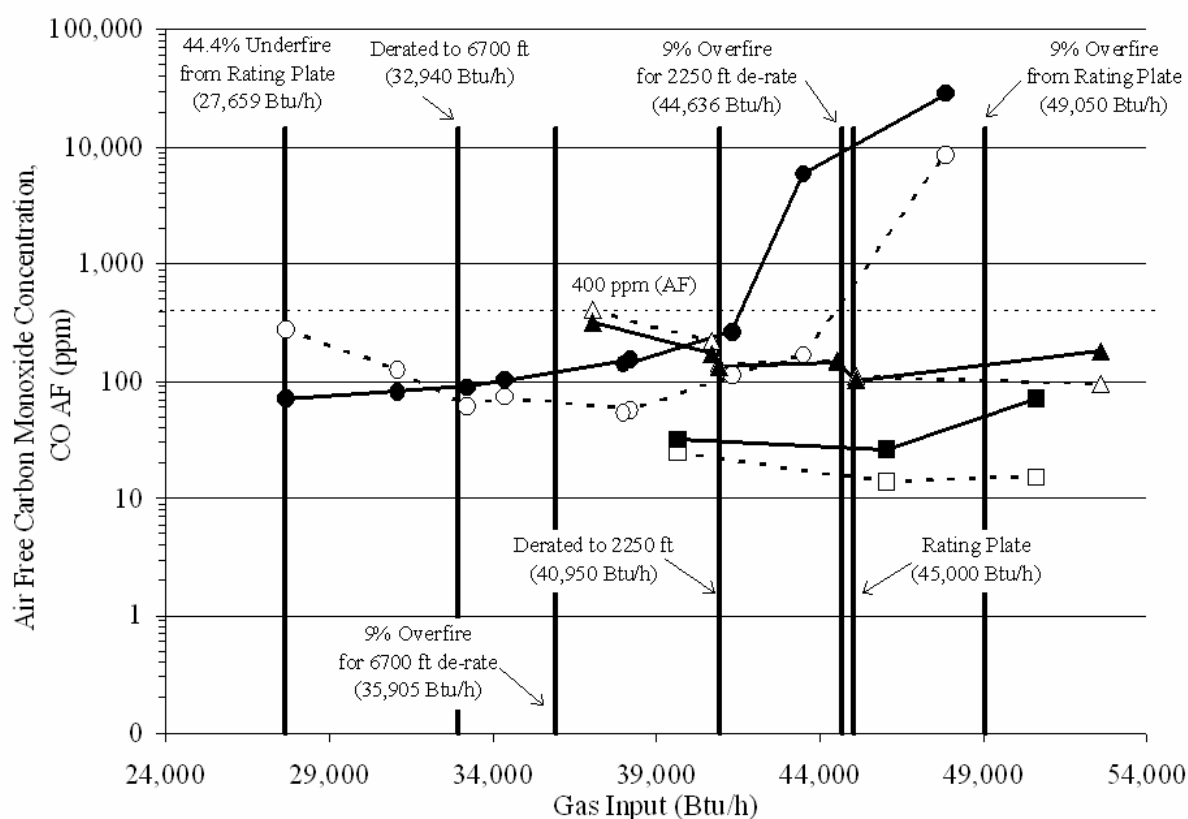
Figures 9e and 9f show the same behavior as for the other furnaces. The extreme over firing at 6,700 ft (2040 m) caused the furnace to exceed the 400 ppm CO-AF limit, as did the under firing (low manifold pressure) at 2,250 ft (685 m) when the furnace was derated according

to the manufacturer's recommendations. A rise in CO is seen at all altitudes when the manifold pressure is reduced from the normal value.

The natural derating for Furnace C is 43,178 Btu/h at 2,250 ft (685 m) and 39,573 Btu/h at 6,700 ft (2040 m). The 12% over fire for Natural Gas from these rates are 48,359 Btu/h and 44,322 Btu/h respectively. The 9% over fire for Propane Gas from the natural derates are 47,063 Btu/h and 43,135 Btu/h for 2,250 ft (685 m) and 6,700 ft (2040 m), respectively. Examination of Figures 9e and 9f suggests that Furnace C would operate safely under these firing conditions.



**Figure 9e. Furnace C on Natural Gas:** Measured carbon monoxide concentration in the flue gases on an air free dry basis for three different altitudes with Furnace C operating on Natural Gas. Squares  $\square$  for Sea Level, triangles  $\Delta$  for 2,250 ft (685 m) and circles  $\circ$  for 6,700 ft (2040 m); filled symbols are for blocked flue portion of section 2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods. The Rating Plate Input is 45,000 Btu/h. The manufacturer's recommended derates are 40,950 Btu/h at 2,250 ft (685 m) and 32,940 Btu/h at 6,700 ft (2040 m). Test data is for approximate altitudes of sea level; 2,250 ft (685 m); and 6,700 ft (2040m). See Table 7 for exact barometrically-derived test altitudes and the individual data point values.



**Figure 9f. Furnace C on Propane Gas:** Measured carbon monoxide concentration in the flue gases on an air free dry basis for three different altitudes with Furnace C operating on Propane Gas. Squares  $\square$  for Sea Level, triangles  $\Delta$  for 2,250 ft (685 m) and circles  $\circ$  for 6,700 ft (2040 m); filled symbols are for blocked flue portion of section 2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods. The Rating Plate Input is 45,000 Btu/h. The manufacturer's recommended derates are 40,950 Btu/h at 2,250 ft (685 m) and 32,940 Btu/h at 6,700 ft (2040 m). Test data is for approximate altitudes of sea level; 2,250 ft (685 m); and 6,700 ft (2040 m). See Table 8 for exact barometrically-derived test altitudes and the individual data point values.

**Furnace D:** Furnace D might barely exceed 2.8.1 Combustion Operation 400 ppm on Natural Gas, natural-derate at 6,700 ft (2040 m).

Furnace D could be categorized as either a Category I or a Category III furnace when operating on high gas input rate. Measurement of the vent pressure produced a positive value for every test. That coupled with the Net Vent Gas Temperatures indicated the furnace operated in Category III mode at 1<sup>st</sup>-stage (high) gas input rate. Unfortunately the Category Determination



at the 2<sup>nd</sup>-stage (low) gas input rate was not conducted, nor were any tests conducted with Furnace D operating at its low firing or low heat input. This was an error on the part of the operator. Thus only results for the 1<sup>st</sup> – stage (high-heat) are presented. These appear in Tables 9 and 10 and Figures 9g and 9h.

Another error occurred when running on Natural Gas only. Orifice size 45 was used at Sea Level as recommended by the manufacturer. Thus for the natural derating tests this size orifice should have been used at the other two altitudes. Unfortunately it was not used at the 2,250 ft (685 m) altitude. The input range tested at this altitude covers that expected for natural derating, only the orifice size is not the correct one. This is the only test point for all the test furnaces where the Sea Level burner configuration (orifice size and gas manifold pressure) was not tested for natural derating.

The **2.8.1 Combustion Operation** test results will be discussed first. They show that calculated CO-AF concentrations remained under the 400 ppm limit at both Sea Level and 2,250 ft (685 m) on both fuels, and only when over fired at 6,700 ft (2040 m) on Natural Gas did it exceed the 400 ppm CO-AF limit. Unfortunately the test data for Test Number **D-FM-P-54-1**, when operating on Propane Gas at this altitude, were not properly recorded so no conclusions can be drawn for this **2.8.1 Combustion Operation** test. No data was recorded for most of the runs for 2.8.1, and no data was recorded for 2.8.3, 2.9, 2.22 and 2.24. The only complete data is for 2.7 and 2.38. The other tests with Propane Gas at 6,700 ft (2040 m) do however cover the natural and manufacturer-recommended deratings, all of which met the 400 ppm limit without over fire. Note that the Sea Level orifice size (55) was used at all test altitudes with Propane Gas.

For the 120,000 Btu/h high input setting at 6,700 ft (2040 m) the manufacturer recommended derate is 87,840 Btu/h and the natural derate is 105,528 Btu/h. The **2.8.1**

**Combustion Operation** over fire inputs for manufacturer-recommended and natural deratings on Natural Gas are 98,381 Btu/h and 118,191 Btu/h respectively. Test Numbers **D-FM-N-43-1** and **D-FM-N-45-3** had inputs of 116,797 Btu/h and 117,768 Btu/h respectively. Both had calculated CO-AF concentrations well below the 400 ppm limit at 196 ppm and 201 ppm respectively. Both these firing rates are within 2% of the natural derated over fire requirement suggesting that Furnace D was in compliance with this test requirement on Natural Gas.

At 6,700 ft (2040 m) operating on Propane Gas the over fire requirements for **2.8.1 Combustion Operation** are 95,746 Btu/h and 115,026 Btu/h for the manufacturer derating and natural derating respectively. Examination of Table 10 shows that the former test requirement was met (Test Numbers **D-FM-P-55-1** and **D-FM-P-55-3**), but not the latter. The one test with a higher input (Test Number **D-FM-P-54-1**) was not properly recorded so no conclusions can be drawn on whether or not Furnace D meets the 400 ppm limit with natural derating on Propane Gas. It certainly does with the manufacturer's derating.

Six tests of the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** are reported in Table 9 for Natural Gas firing at 6,700 ft (2040 m). Of these all but one complied with the 400 ppm limit. The one exception, Test Number **D-FM-N-45-3**, had a firing rate of 117,768 Btu/h, well in excess of the required test inputs of 87,840 Btu/h for manufacturer recommended derate and 105,528 Btu/h for natural derate. This is not considered a failure because of the excess firing rate.

At 2,250 ft (685 m) altitude, when firing on Natural Gas, one test, Test Number **D-ED-N-44-3**, had a calculated CO-AF concentration higher than 400 ppm during the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods test**. The concentration was 423 ppm. For this altitude the manufacturer-recommended and natural derates for this furnace on high firing on Natural Gas are 109,200 Btu/h and 115,140

Btu/h respectively. Thus the firing rate during this particular test at 130,831 Btu/h is well above that required for either the manufacturer-recommended or natural derating. Test Number **D-ED-N-44-1** at 114,967 Btu/h input is very close to the natural derate requirement. Its calculated CO-AF concentration is only 242 ppm, complying with the test requirement. Thus Furnace D complies with these test requirements at this altitude on Natural Gas.

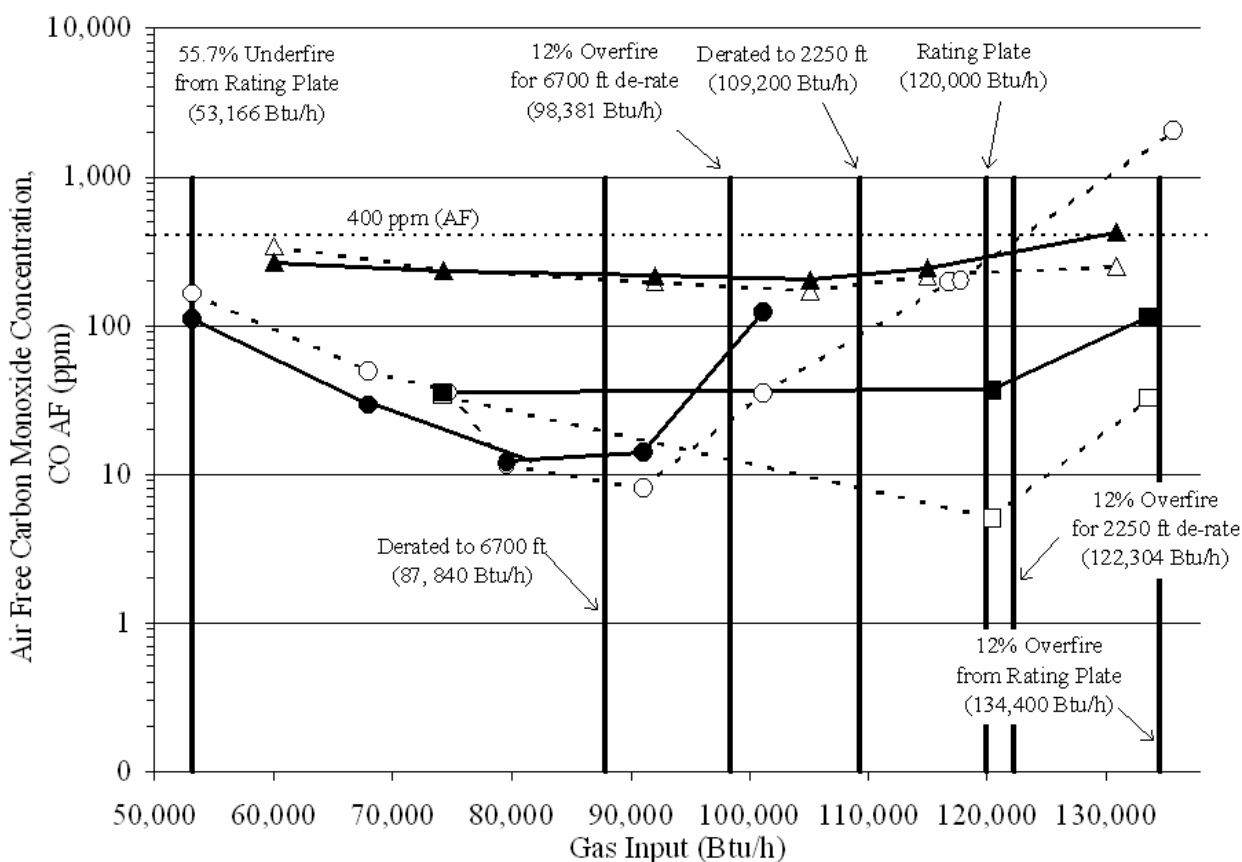
At Sea Level, Furnace D had a calculated CO-AF concentration of 37 ppm at 120,419 Btu/h (Test Number **D-VA-N-45-1**), easily complying with the 400 ppm limit for the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**.

None of the six tests of the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** reported in Table 10 for Propane Gas conducted at 6,700 ft (2040 m) failed. Note that while the input rate exceeded the 87,840 Btu/h for manufacturer-recommended derate, no test inputs were above 105,528 Btu/h for the natural derate requirement. Test Number **D-FM-P-55-3**, with an input of 103,999 Btu/h, was within 2% of the required value. The calculated CO-AF concentration was 293 ppm, complying with the 400 ppm limit, but not really comfortably. Had the Test Number **D-FM-P-54-1**, with an input of 113,852 Btu/h, been completed it most likely would have exceeded the 400 ppm CO-AF limit before the furnace safely shut down. Furnace D on propane gas at natural-derate for 6,700 feet might have exceeded the 2.22.1 Blocked Flue test 400 ppm CO-AF limit before the furnace safely shut down, if test had been run.

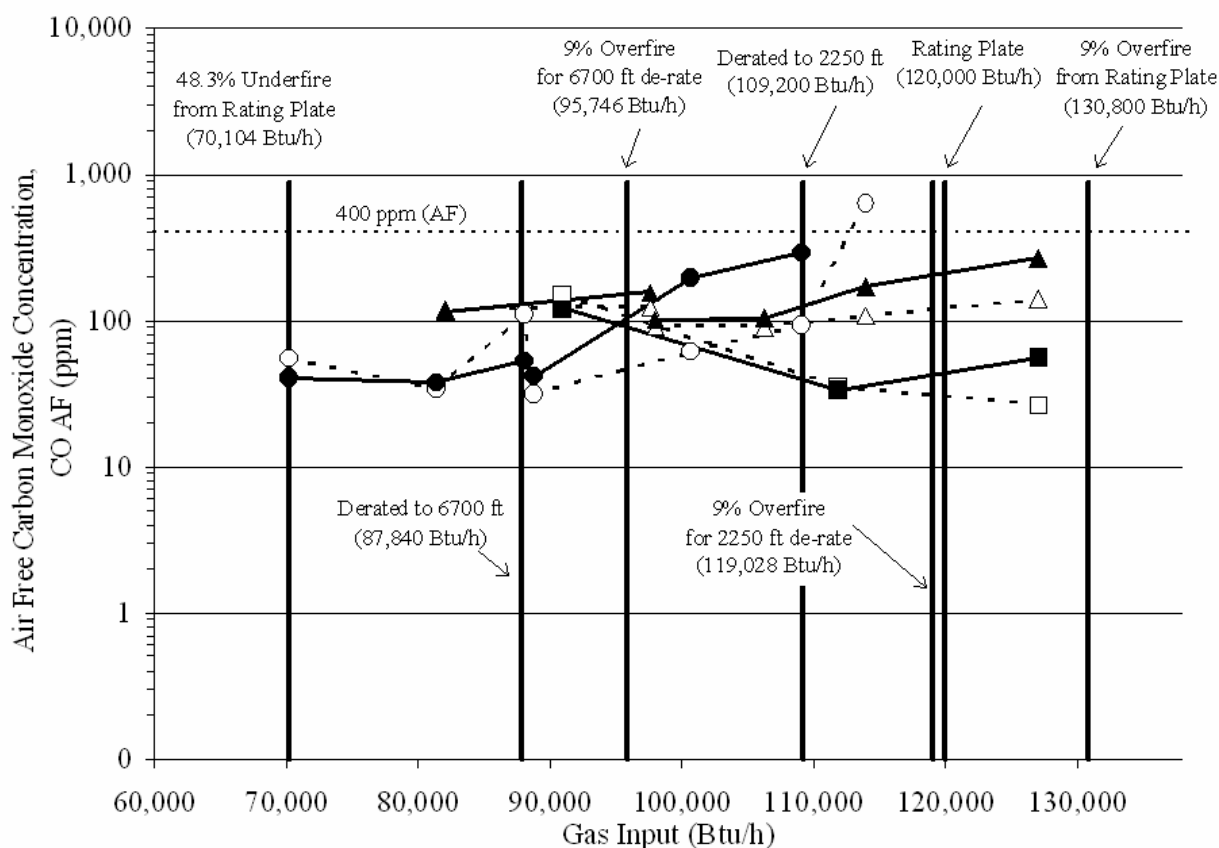
None of the six tests of the blocked-flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** reported in Table 10 for 2,250 ft (685 m) failed even though the 126,930 Btu/h test well exceeded the required test inputs of 109,220 Btu/h for

manufacturer recommended derate and 115,140 Btu/h for natural derate. The same conclusion can be drawn for the tests conducted at Sea Level.

Figures 9g and 9h show the CO-AF level as a function of the Gas Input Rate. The trends are very similar to those of the other three test furnaces.



**Figure 9g. Furnace D on Natural Gas:** Measured carbon monoxide concentration in the flue gases on an air free dry basis for three different altitudes with Furnace D operating on Natural Gas. Squares  $\square$  for Sea Level, triangles  $\Delta$  for 2,250 ft (685 m) and circles  $\circ$  for 6,700 ft (2040 m); filled symbols are for blocked flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**. The Rating Plate Input is 120,000 Btu/h. The manufacturer's recommended de-rate is 109,200 Btu/h at 2,250 ft (685 m) and 87,840 Btu/h at 6,700 ft (2040 m.). Test data is for approximate altitudes of sea level; 2,250 ft (685 m); and 6,700 ft (2040 m). See Table 9 for exact barometrically-derived test altitudes and the individual data point values.



**Figure 9h. Furnace D on Propane Gas:** Measured carbon monoxide concentration in the flue gases on an air free dry basis for three different altitudes with Furnace D operating on Propane Gas. Squares  $\square$  for Sea Level, triangles  $\Delta$  for 2,250 ft (685 m) and circles  $\circ$  for 6,700 ft (2040 m); filled symbols are for blocked flue portion of section 2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods. The Rating Plate Input is 120,000 Btu/h. The manufacturer's recommended de-rate is 109,200 Btu/h at 2,250 ft (685 m) and 87,840 Btu/h at 6,700 ft (2040 m). Test data is for approximate altitudes of sea level; 2,250 ft (685 m); and 6,700 ft (2040 m). See Table 10 for exact barometrically-derived test altitudes and the individual data point values.

These results demonstrate that both Categories of furnaces tested can be operated safely at manufacturer specified high altitude deratings and some of the furnaces can be operated safely under natural derating as summarized below.

#### Furnace A:

This furnace complied with **2.8.1 Combustion Operation** and the blocked flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** on Natural

Gas and Propane Gas, manufacturer recommended and natural derates, at 2,250 ft (685 m) and 6,700 ft(2040 m) when operated with normal gas line input and gas manifold pressures.

**Furnace B:**

1. Complied with **2.8.1 Combustion Operation** at all altitudes and both test fuels with one exception. The exception occurred with gross over firing on Natural Gas, at 6,700 ft (2040 m). Had the input rate been closer to the required value for natural derating, it may have met the test requirement.
2. Complied with the blocked flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** at all altitudes and both test fuels.
3. Errors in setting the test input rates greater than the procedure requires led to conducting unnecessary tests which produced CO-AF concentrations greater than 400 ppm. These tests are not considered failures.

**Furnace C:**

1. Compliance with **2.8.1 Combustion Operation** is uncertain, but probable. Failures occurred at 6,700 ft (2040 m) on both fuels and at 2,250 ft (685 m) on Propane Gas. Had the input rates been closer to the required input rates, compliance may have occurred.
2. Compliance with the blocked flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** occurred with both test fuels except when over fired above the natural derate input at 6,700 ft (2040 m) on Propane Gas. These excessive over fire tests are not considered failures.

**Furnace D:**

1. Complied with the **2.8.1 Combustion Operation** 400 ppm CO-AF limit on Natural Gas with one exception. This exception (Test Number **D-FM-N-43-3**) occurred when the

furnace was fired at 135,580 Btu/h (15% above the required over fire gas input rate of 118,191 Btu/h for natural derating) at 6,700 ft (2040 m), and is not considered a failure.

2. When fired with at 113,852 Btu/h on Propane Gas at 6,700 ft (2040 m) (test **D-FM-P-54-1**) near the 9% over fire for natural derating (115,026 Btu/h) Furnace D produced 630 ppm CO-AF and did not comply with **2.8.1 Combustion Operation**. All other tests with Propane Gas were in compliance.
3. Complied with the blocked flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** with limitations as noted below:
  - a. Manufacturer recommended derate requirement of 87,840 Btu/h at 6,700 ft (2040 m) and 109,200 Btu/h at 2,250 ft (685 m) on:
    - I. Natural Gas at:
      - i. Complied at gas input rate of 101,169 Btu/h at 6,974 feet with 124 ppm CO-AF (Test Number **D-FM-N-45-1**),
      - ii. Complied at gas input rate of 114,697 Btu/h at 2,128 feet with 242 ppm CO-AF (Test Number **D-ED-N-44-1**) and
    - II. Propane Gas at:
      - i. Complied at gas input rate of 100,636 Btu/h at 6,951 feet with 194 ppm CO-AF (Test Number **D-FM-P-55-1**),
      - ii. Complied at gas input rate of 113,850 Btu/h at 2,147 feet with 170 ppm CO-AF (Test Number **D-ED-P-55-1**),
  - b. Natural derate requirement of 105,528 Btu/h at 6,700 ft (2040 m) and 115,140 Btu/h at 2,250 ft (685 m) on:

I. Natural Gas at:

- i. With a gas input rate of 101,169 Btu/h, which is 4.1% lower than natural derate at 6,974 ft, the CO-AF was 124 ppm (Test Number **D-FM-N-45-1**). However, if the gas input rate had been nearer the required natural derate of 105,528 Btu/h, Furnace D may not have complied with the 400 ppm limit using the sea level orifice (drill size 45).
- ii. Complied at gas input rate of 114,967 Btu/h (within  $\pm 2\%$  of 115,140 Btu/h) at 2,128 ft with 242 ppm CO-AF (Test Number **D-ED-N-44-1**),

II. Propane Gas at:

- i. Complied at gas input rate of 103,999 Btu/h (within  $\pm 2\%$  of 105,528 Btu/h) at 6951 ft with 293 ppm CO-AF (Test Number **D-FM-P-55-3**),
- ii. Complied at gas input rate of 126,930 Btu/h at 2,147 ft with 270 ppm CO-AF (Test Number **D-ED-P-55-3**).

4. Might have exceeded the 400 ppm CO-AF limit for the blocked flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** before the furnace safely shut down on 113,852 Btu/h Propane Gas (Test Number **D-FM-P-54-1**) when over fired above the natural derate of 105,528 Btu/h for 6,700 ft (2040 m), if test had been properly run and documented. Note that in Test Number **D-FM-P-55-3**, the 103,999 Btu/h gas input rate is within 2% of the required natural derate gas input rate and is in compliance.

With this in mind it may be feasible to move the derating scheme for fan-assisted furnaces to a level of 1.8% per 1000 ft (rationale presented in Section 3 above), which amounts



to making no changes to some of the fan-assisted furnaces regardless of altitude. Although one of the four furnaces exhibited unsatisfactory performance on natural derate, that may have resulted from test conditions that did not conform to ANSI Z21.47•CSA 2.3 requirements as described above. These tests suggest that some furnaces as currently designed and constructed can be installed and operated safely and acceptably at some high altitudes with no modifications to the sea-level gas orifices, gas manifold pressure, etc. as currently needed with the 4% per 1,000 feet altitude derating requirements. Furnaces should be tested for high-altitude compliance with furnace safety standard requirements so that installation codes can safely permit installation and operation of such tested furnaces at high altitude.

The ANSI Z21.47•CSA 2.3 Gas-Fired Central Furnace standard could be revised to require verification tests by nationally-recognized testing agencies for listing at manufacturer-selected altitudes. The tests would verify furnace compliance with selected ANSI Z21.47•CSA 2.3 requirements at a specific high-altitude derate such as 1.8% per 1,000 ft (305 m) above sea level (natural derate) without modification of the furnace (gas orifice size, manifold pressure, etc.) at altitudes above 2,000 ft (610 m). The ANSI Z223.1/NFPA 54 National Fuel Gas Code could be revised to permit installation of furnaces that include designations on their rating plates signifying compliance with such ANSI Z21.47•CSA 2.3 requirements in order to be installed without modification of the furnace (gas orifice size, manifold pressure, etc.) at high altitude.

Additional research tests should be done to provide supporting rationale for altitudes higher than the 6,700 ft (2040 m) tests in this project, if natural derating is to be applied at altitudes higher than 6,700 ft (2040 m) altitude.

Figures 9a through 9h are included to give a qualitative impression of how CO levels vary for operation at different altitudes when the gas input rate to the furnace varies. Carbon monoxide levels are used as an indicator of system performance and to determine compliance

with safety standards. Thus it is important to see how it is affected by changing the gas input rate. The results show that for the four furnaces tested there appears to be an optimum excess air level that results in the lowest generation of CO. Generally this occurs at measured O<sub>2</sub> concentrations of between 8% and 12%, corresponding to roughly 70% to 150% excess air. Slight increases in CO are measured when greater excess air is added, which would be evidence of too low a combustion temperature. More significant increases in flue gas CO concentration are witnessed for air/fuel mixture fractions nearer stoichiometric. In this latter case, the higher concentrations of CO with the richer flames are most likely due to inadequate mixing and more dissociation of CO<sub>2</sub> to CO and O<sub>2</sub> at the higher flame temperatures. In all cases it is nearly impossible to eliminate CO production altogether, since the flames come in contact with the relatively cool walls of the heat exchanger where combustion is quenched, leaving products of incomplete combustion.

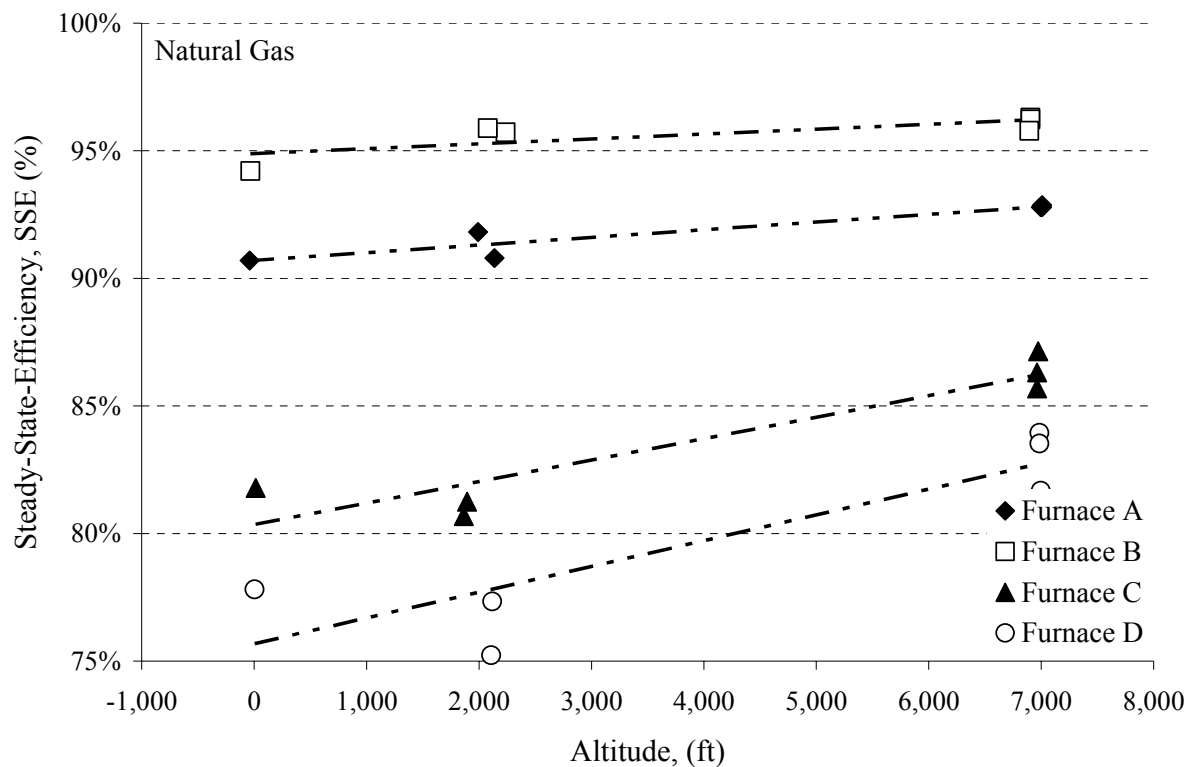
## **b) Steady State Efficiencies**

The steady state efficiency and NO values were calculated from data collected while conducting tests according to section **2.38 [Steady-State] Thermal Efficiency**. As these were separate tests, the gas input rate and other measured parameters varied slightly from the other tests conducted according to section **2.8.1 Combustion Operation** and the blocked flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**. The details of these calculations, including an illustrative sample, and summary spread sheets are in Appendix D.

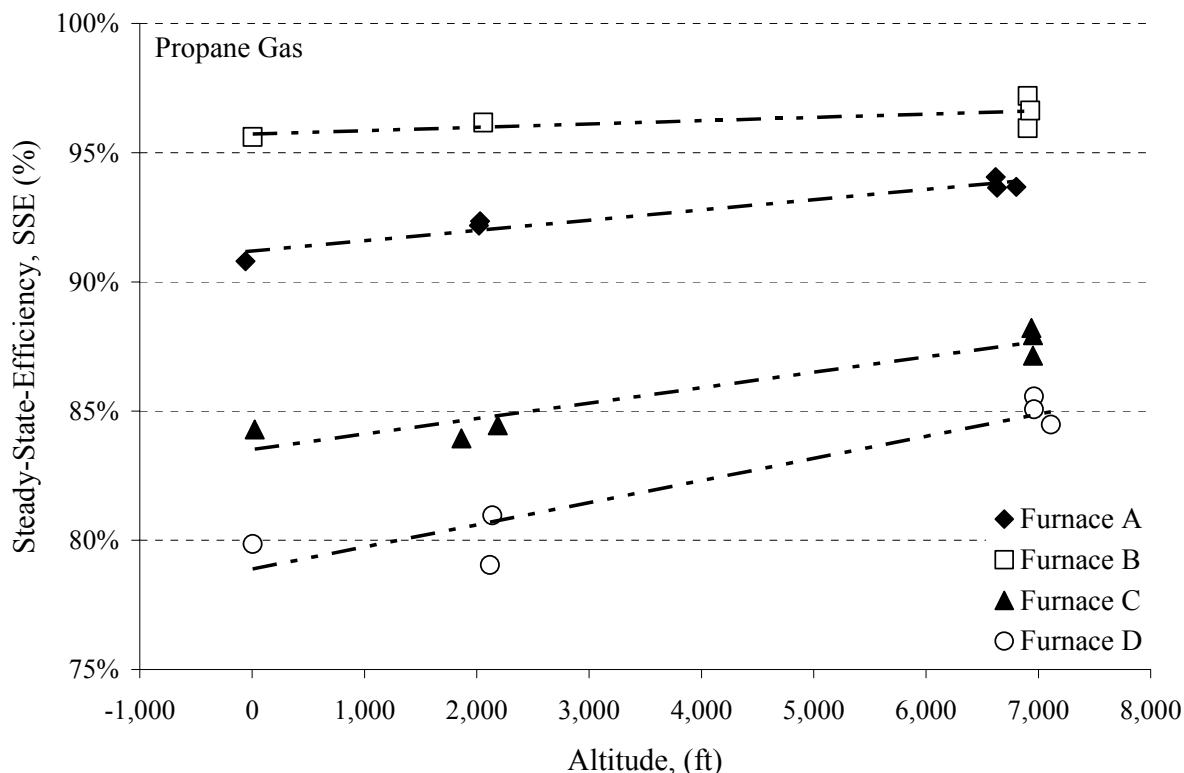
The calculations were done for each separate test group at normal manifold and gas inlet test pressures for the test fuel. Thus at sea level there is only one calculated value, while at 2,250 ft (685 m) there are two calculated values and at 6,700 ft (2040 m), three calculated values.

The steady state efficiency was calculated by subtracting the “losses” from the measured energy input. The losses considered were the latent and sensible heat in the flue gases and the “jacket” losses. With the condensing furnaces the energy recovered due to condensing the moisture in the flue gases (latent heat recovery) was included in the calculations. The recovered energy is based on the measured condensation rate for those furnaces.

The calculated results for the steady state efficiencies are plotted as a function of altitude in Figures 10a and 10b. Here each data point plotted represents the value for a given orifice size with the manifold and gas line inlet test pressures near normal values (3.5 to 4.0 in.wc and 7 in. wc for Natural Gas respectively, and 10 in.wc and 11 in.wc for Propane Gas respectively) at each altitude. The general trend shown is that the efficiency increases with increasing altitude. Appendix E contains a discussion as to possible reasons for this trend. Note that operation on Propane Gas produces a higher efficiency than operation on Natural Gas. This latter result is expected as less moisture is formed with the combustion of Propane Gas than with Natural Gas (principally methane). Thus the flue losses due to moisture being formed during combustion are less with Propane Gas than Natural Gas.



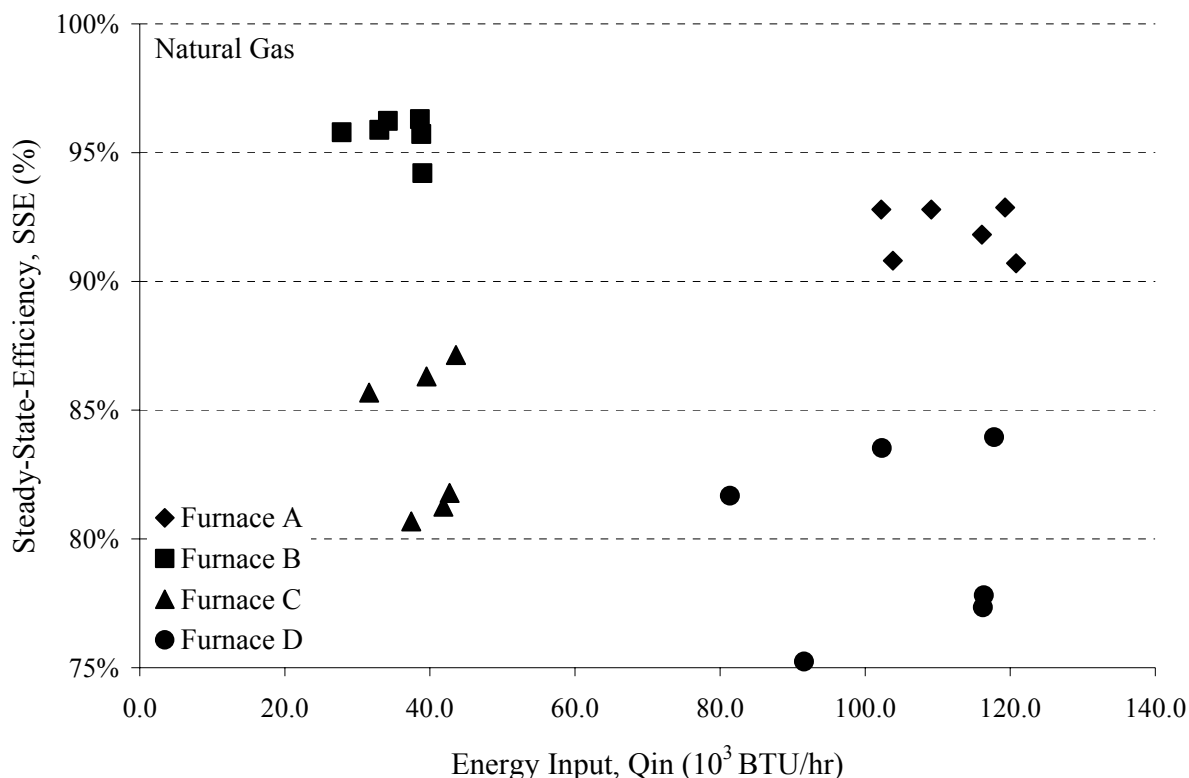
**Figure 10a.** Effect of altitude on the measured steady state efficiency of four Natural Gas fired residential furnaces. Two furnaces were high efficiency furnaces while two were mid efficiency furnaces, all induced draft.



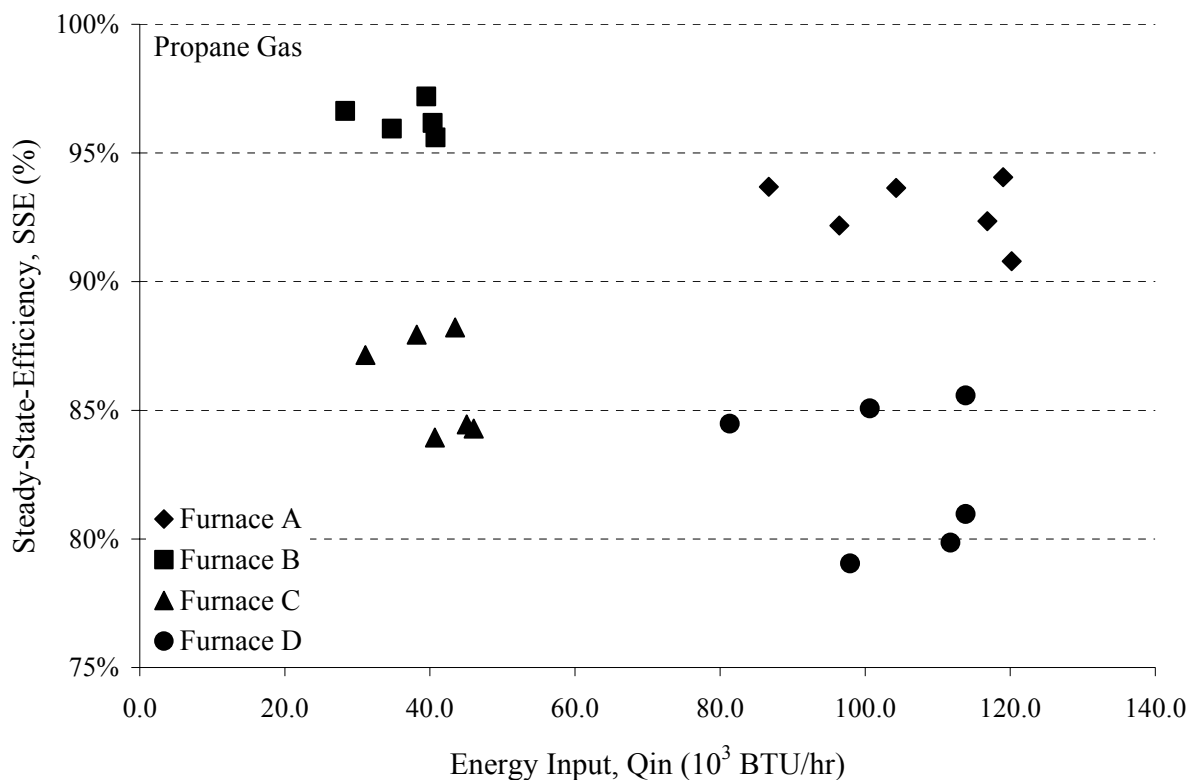
**Figure 10b.** Effect of altitude on the measured steady state efficiency of four Propane Gas fired residential furnaces. Two furnaces were high efficiency furnaces while two were mid efficiency furnaces, all induced draft.

Figures 11a and 11b show the variation in measured efficiencies for each furnace as a function of the gas input rate and altitude for the two fuels. No trend lines are shown because the air to fuel ratio for the tests were not held constant. Thus two important parameters were changing during these tests; the gas input rate and the air to fuel ratio, both of which may affect the measured efficiency. While no trend lines are shown, the results plotted in Figures 11a and 11b suggest that the steady state efficiencies of the high efficiency (condensing) furnaces (Furnaces A and B) are essentially independent of firing rate, while for the mid efficiency furnaces (Furnaces C and D) there is an increase in steady state efficiency with increasing gas input rate and an increase with increasing altitude. In Figures 11a and 11b, the upper three data

points for Furnaces C and D are for the 6,700 ft (2040 m) altitude, while the next two highest data points are for the 2,250 ft (685 m) altitude and the lowest data points for Sea Level. Note however, increasing the gas input rate tends to decrease the air to fuel ratio for the furnaces. This in turn reduces the mass flow in the flue gas which can lead to reduced losses if the temperature of the flue gases does not increase in proportion.

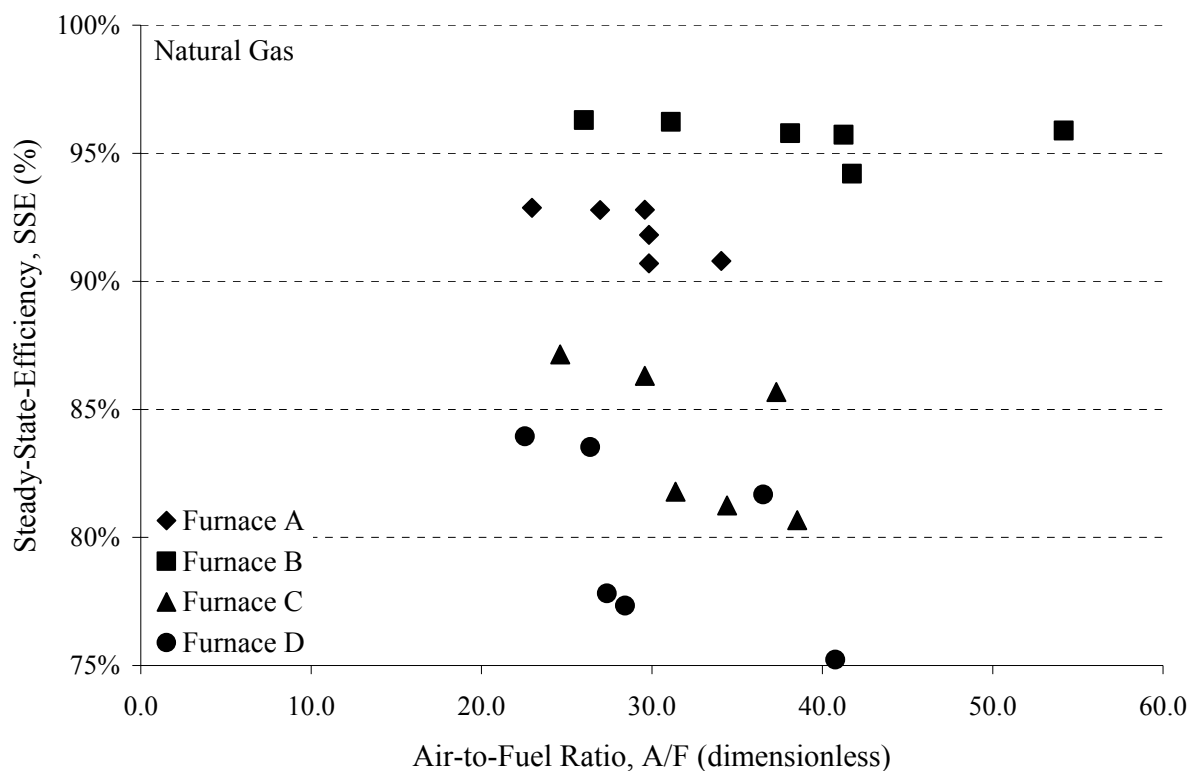


**Figure 11a.** Effect of gas input rate variations on the measured steady state efficiency of four Natural Gas fired residential furnaces. Two furnaces were high efficiency furnaces while two were mid efficiency furnaces, all induced draft. The furnaces were tested at Sea Level and altitudes of 2,250 ft (685 m) and 6,700 ft (2040 m).



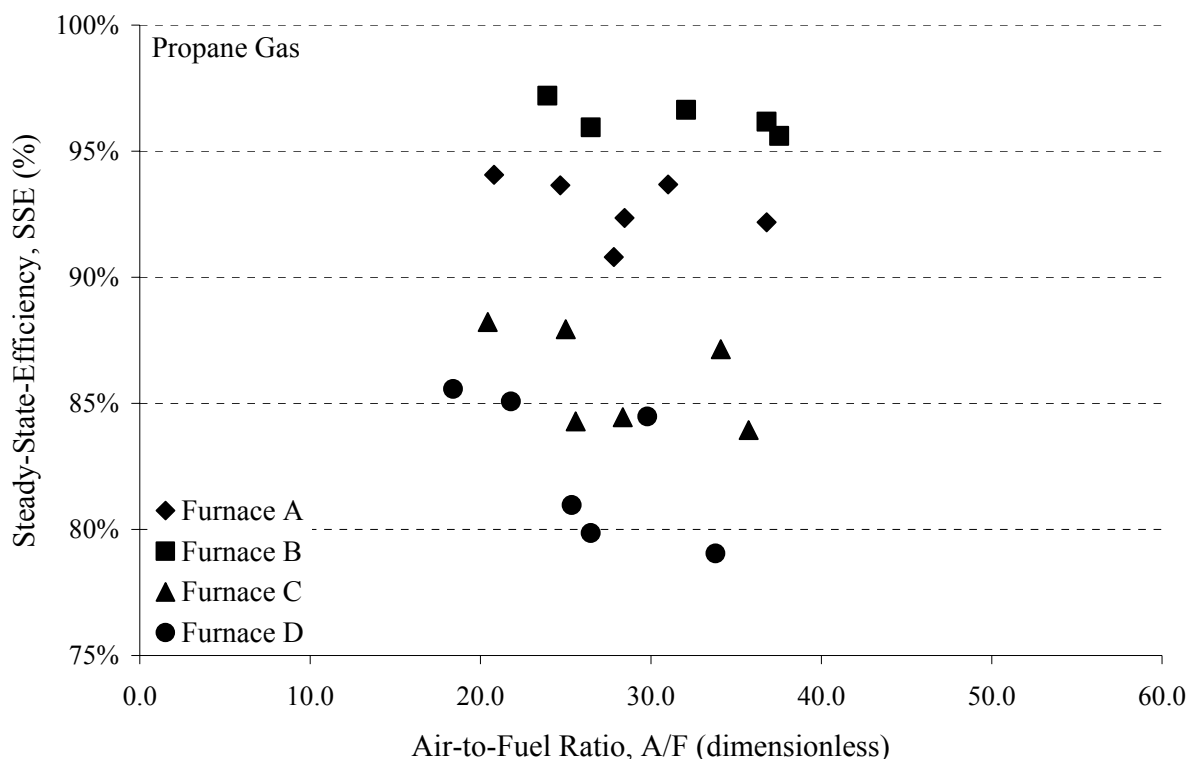
**Figure 11b.** Effect of rate of gas input on the measured steady state efficiency of four Propane Gas fired residential furnaces. Two furnaces were high efficiency furnaces while two were mid efficiency furnaces, all induced draft. The furnaces were tested at Sea Level and altitudes of 2,250 ft (685 m) and 6,700 ft (2040 m).

The steady state efficiencies for these furnaces are plotted as a function of air to fuel ratio in Figures 12a and 12b. This information shows a clear tendency for the efficiency of all the furnaces to increase as the air to fuel ratio decreases. This is an expected result as the losses from a fuel fired furnace are directly related to the mass flow rate of the flue gases. As noted above for Furnaces C and D the increase in steady state efficiency with altitude is still evident in these figures.



**Figure 12a.** Effect of air to fuel ratio, mass basis, on the measured steady state efficiency of four Natural Gas fired residential furnaces. Two furnaces were high efficiency furnaces while two were mid efficiency furnaces, all induced draft. The furnaces were tested at Sea Level and altitudes of 2,250 ft (685 m) and 6,700 ft (2040 m).





**Figure 12b.** Effect of air to fuel ratio, mass basis, on the measured steady state efficiency on four Propane Gas fired residential furnaces. Two furnaces were high efficiency furnaces while two were mid efficiency furnaces, all induced draft. The furnaces were tested at Sea Level and altitudes of 2,250 ft (685 m) and 6,700 ft (2040 m).

The jacket losses were calculated using the method outlined in **Exhibit K**. A sample calculation is included in Appendix D. The results for each test are included in Table D-1 for Natural Gas and Table D-2 for Propane Gas. Examination of the jacket loss columns in these tables shows 10 out of 47 values to be at or above the maximum of 1.5% allowed in **section 2.38**. Of these 10 high values, 9 occurred with Furnace C. For Furnace C, the average for all altitudes was 1.6% when fired with Natural Gas and 2.1% when fired with Propane Gas. Examination of the calculated jacket heat losses for all the furnaces shows that there is no obvious dependency on fuel or altitude.

### c) NO Measurements

The gas analyzer used in this research project had the capability of measuring oxides of nitrogen as nitric oxide (NO). Using the recorded information, the mass of NO formed per unit

of useful heat produced by the furnaces was calculated. The details of the calculations are included with the spread sheet analysis used for calculating the steady state efficiencies in Appendix D. The results of these calculations expressed in mass of  $\text{NO}_x$  per unit of useful heat energy output ( $\text{lbs NO}_x/10^6 \text{ Btu}$ ) are included in Tables 3 - 10. The test data used was that gathered while performing the steady state efficiency tests (section **2.38 Thermal Efficiency**). As such, the gas input rates listed in Appendix D are not identical to those listed in Tables 3-10.

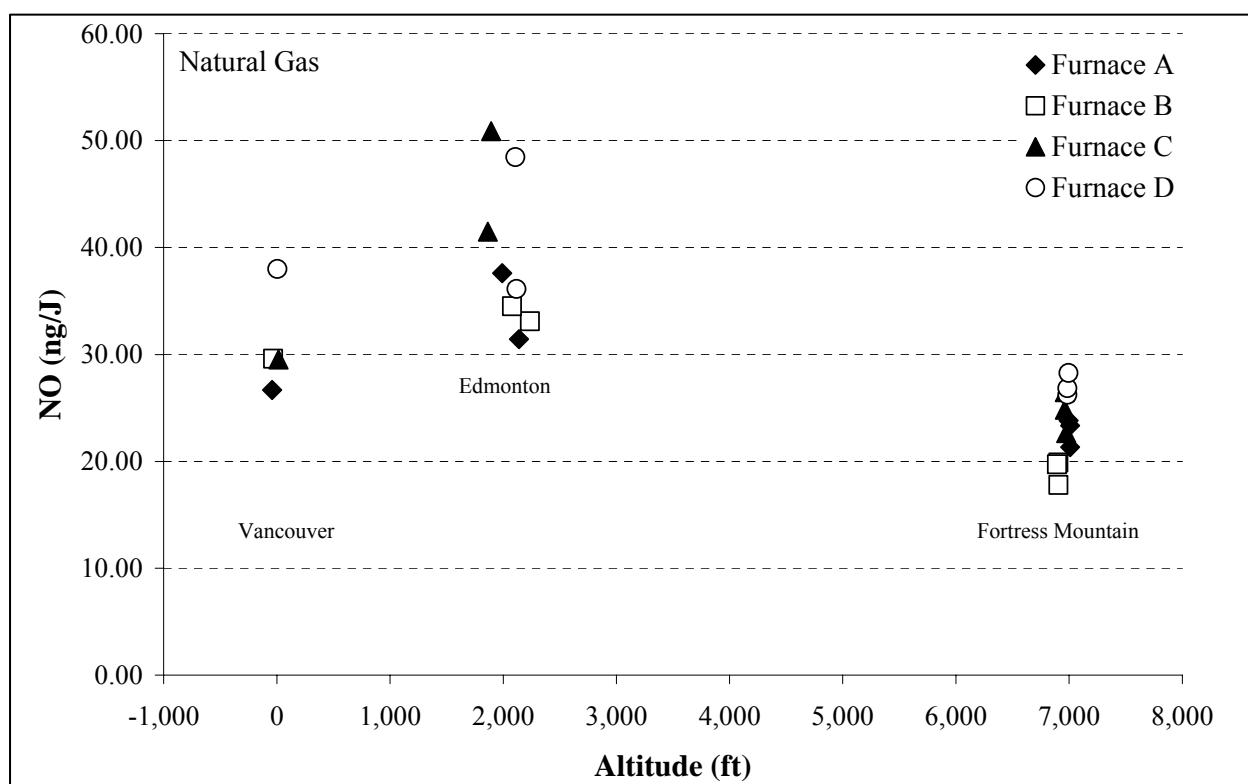
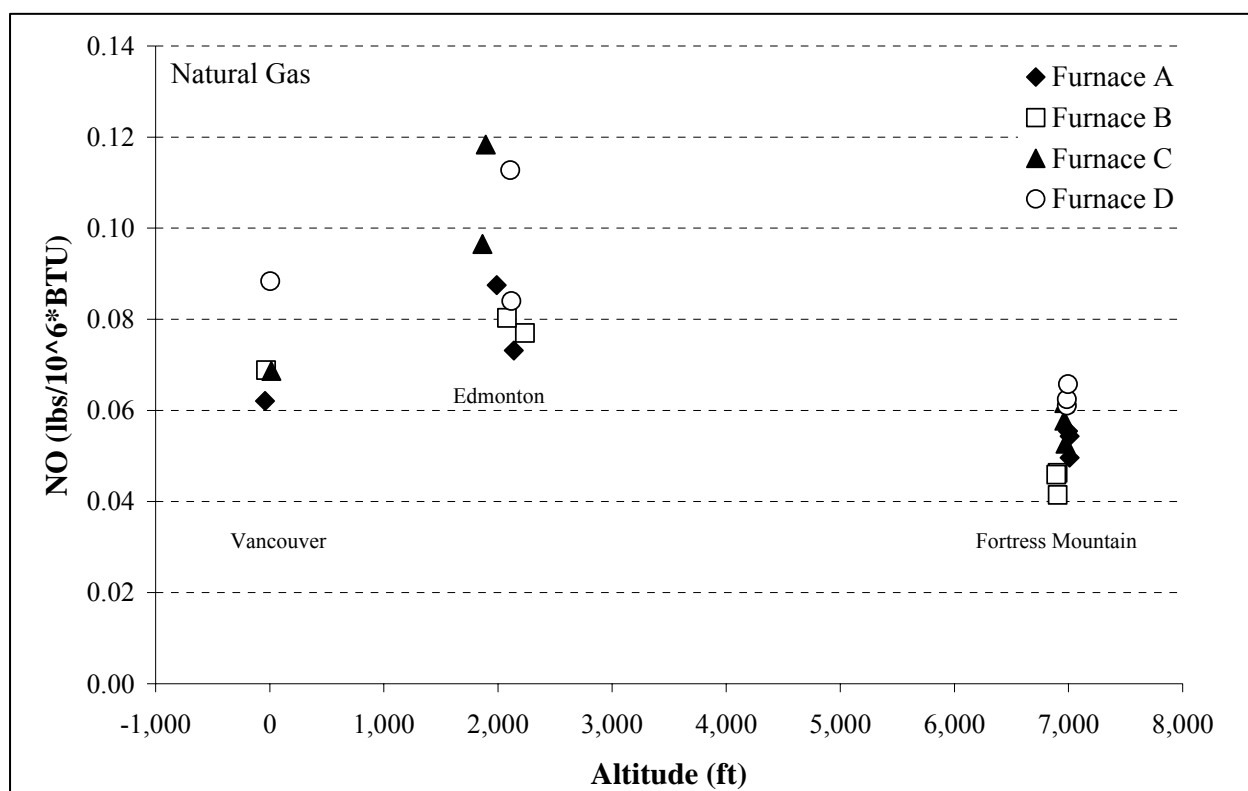
Figures 13a and 13b show the variation of the calculated emissions of  $\text{NO}_x$  as a function of altitude. Examination of the Figures shows a parabolic trend with altitude for both fuels with the highest values tending to be at the 2,250 ft (685 m) altitude. The burners used in the test furnaces essentially premix the reactants. With these flames the formation of  $\text{NO}_x$  is dominated by thermal fixation (reaction of nitrogen and oxygen at high combustion temperatures). Thus the amount of  $\text{NO}_x$  formed is dependent on the availability of the reactants ( $\text{N}_2$  and  $\text{O}_2$ ) and their temperature history; the higher the flame temperatures the more  $\text{NO}_x$  is likely to be produced. The amount of moisture in the air participating in the combustion reaction also affects the production of  $\text{NO}_x$  [8]. Higher moisture levels produce lower  $\text{NO}_x$  levels. The instrument used to measure relative humidity turned out to be unreliable. Values were recorded but on some days the indicated values would change from the 15% range to the 95% range. Weather data bases were examined for daily variations in relative humidity for the locations where the tests were conducted, but reliable day by day information could not be found, only monthly average values. These showed the relative humidity for the sites to be almost the same. Thus any corrections would not change the relative positions of these results.

With the test furnaces the air to fuel ratio tended to reduce with increasing altitude. This would raise flame temperatures, resulting in more  $\text{NO}_x$  being produced. The measured volume concentrations of  $\text{NO}$ , as reported in Tables D-1 and D-2 of Appendix D, do show a slight trend

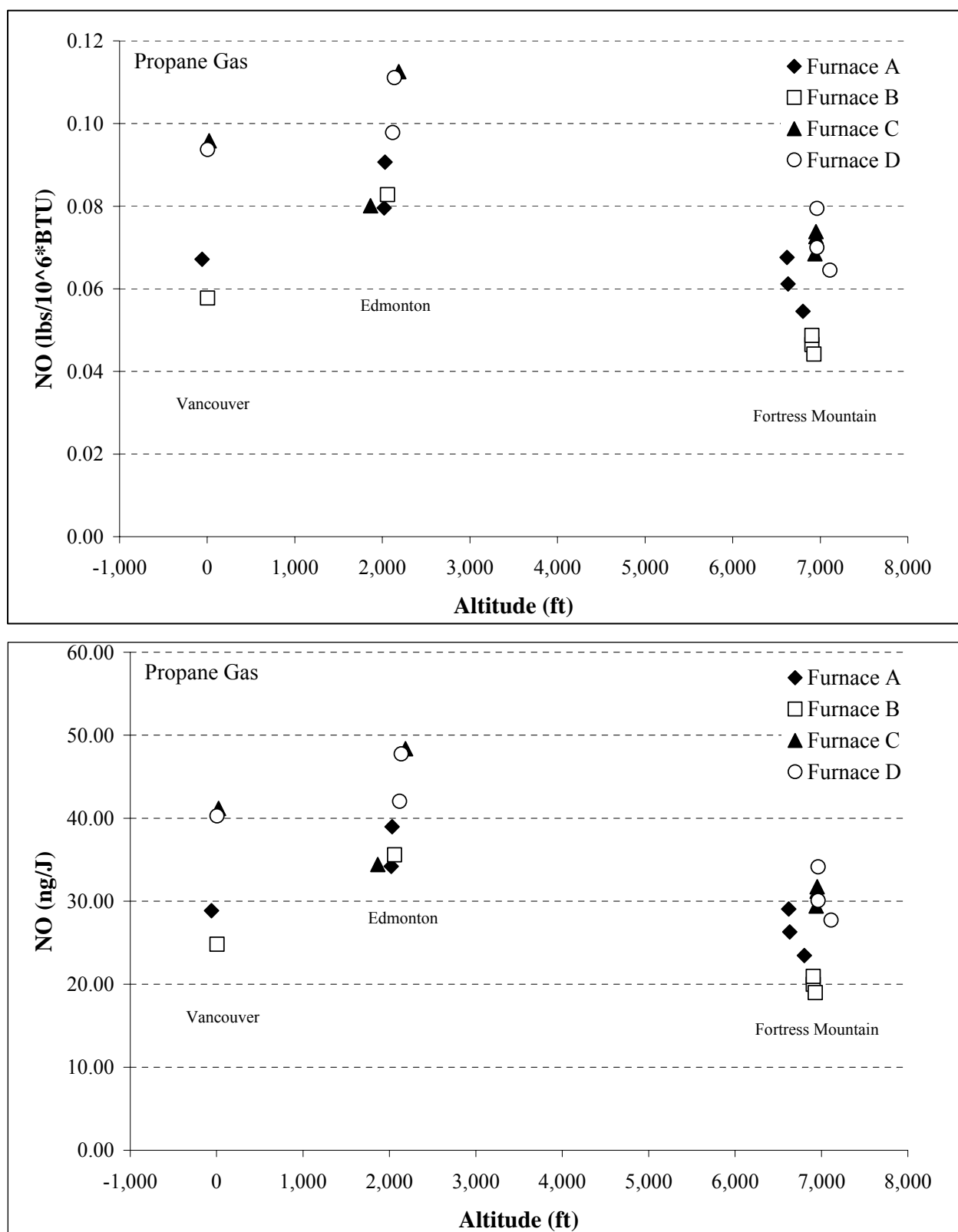
of increasing value with altitude. However the measurements reported in these tables also show that for the same gas input rate, the total mass flow of combustion products at 6,700 ft (2040 m) is typically 50% to 65% of that at Sea Level due to changing air to fuel ratios. Thus there are offsetting parameters present when the  $\text{NO}_x$  is calculated as the mass produced per unit of useful heat energy output. The overall air to fuel ratios measured tend to be well above the values where peak values of  $\text{NO}_x$  are formed. Peak values would occur with air to fuel ratios (mass basis) around 19/1 for Natural Gas and 17/1 for Propane Gas.

The  $\text{NO}_x$  values in  $\text{lbs}/10^6 \text{ Btu}$  of useful heat energy output plotted in Figures 13a and 13b show that the values at 6,700 ft (2040 m) tend to be lower than the values obtained at Sea Level and at 2,250 ft (685 m). This implies that for the particular furnaces tested the reduced  $\text{NO}_x$  values measured for these furnaces are primarily due to the reduced mass flow rate of fuel and air through the furnaces at altitude. Note as well that in many cases the highest total mass flow through the furnaces occurred at the 2,250 ft (685 m) altitude. This would contribute to having higher values of  $\text{NO}_x$  at this altitude as seen in Figures 13.

The values obtained for the test furnaces show that most of the values are below 0.093  $\text{lbs NO}_x/10^6 \text{ Btu}$  of useful heat output ( $40 \text{ ng NO}_x/\text{J}$ ) with the exception of  $\text{NO}_x$  emissions at 2,250 ft (685 m). The 0.093  $\text{lbs NO}_x/10^6 \text{ Btu}$  of useful heat output ( $40 \text{ ng NO}_x/\text{J}$ ) is typical of emission levels required by California's Air Quality Management Districts for the South Coast (Los Angeles) and the San Francisco Bay Area for Natural Gas fired residential heating appliances [9].



**Figure 13a. (charts for SI and IP units)** NO<sub>x</sub> emissions of four Natural Gas fired residential furnaces as a function of altitude. Two furnaces were high efficiency furnaces while two were mid efficiency furnaces, all induced draft. The furnaces were tested at Sea Level and altitudes of 2,250 ft (685 m) and 6,700 ft (2040 m).



**Figure 13b. (charts for SI and IP units)** NO<sub>x</sub> emissions of four Propane Gas fired residential furnaces as a function of altitude. Two furnaces were high efficiency furnaces while two were mid efficiency furnaces, all induced draft. The furnaces were tested at Sea Level and altitudes of 2,250 ft (685 m) and 6,700 ft (2040 m).

#### **d) Ignition systems**

Ignition tests were carried out according to ANSI Z21.47•CSA 2.3-2001, **2.10 Pilot Burners and Safety Shutoff Devices** and **2.11 Direct Ignition Systems**. The details of this procedure are summarized in Appendix B.

Tests were performed at both 2,250 ft (685 m) and 6,700 ft (2040 m) with all five furnaces. The tests at 2,250 ft (685 m) were done during the “proving” period before sending the trailer to the high altitude location. Between these altitudes no significant differences in performance were observed.

Unfortunately the Furnace E, the furnace with the standing pilot light ignition system, was damaged at the Sea Level location and further comparisons could not be made.

#### **e) Heat exchanger effects**

Visual inspection was made of all the heat exchanger inlets during and after some of the tests. The observations indicated that at no time did any of the furnace heat exchangers experience undue thermal stress or overheating during the high altitude tests.

Photographs of the heat exchangers in Furnace B and Furnace C are shown in Figures 14 and 15 respectively. The visual observations indicated that these two furnaces showed the most discoloration in the flame zone area. Hand held surface thermocouple probes were used in a few cases to measure heat exchanger temperatures for comparison. They were found to vary as much from test to test as they did between the altitudes. The measured air to fuel ratios show a general decrease with increasing altitude. This would result in higher flame temperatures with altitude and by implication higher localized heat exchanger temperatures. However, identifying specific locations of higher temperatures proved difficult with the instrumentation used. Tables D-1 and

D-2 contain a column listing heat exchanger temperatures. The values listed are based on the best judgment of the observer as to where the maximum temperatures were occurring in the heat exchangers.

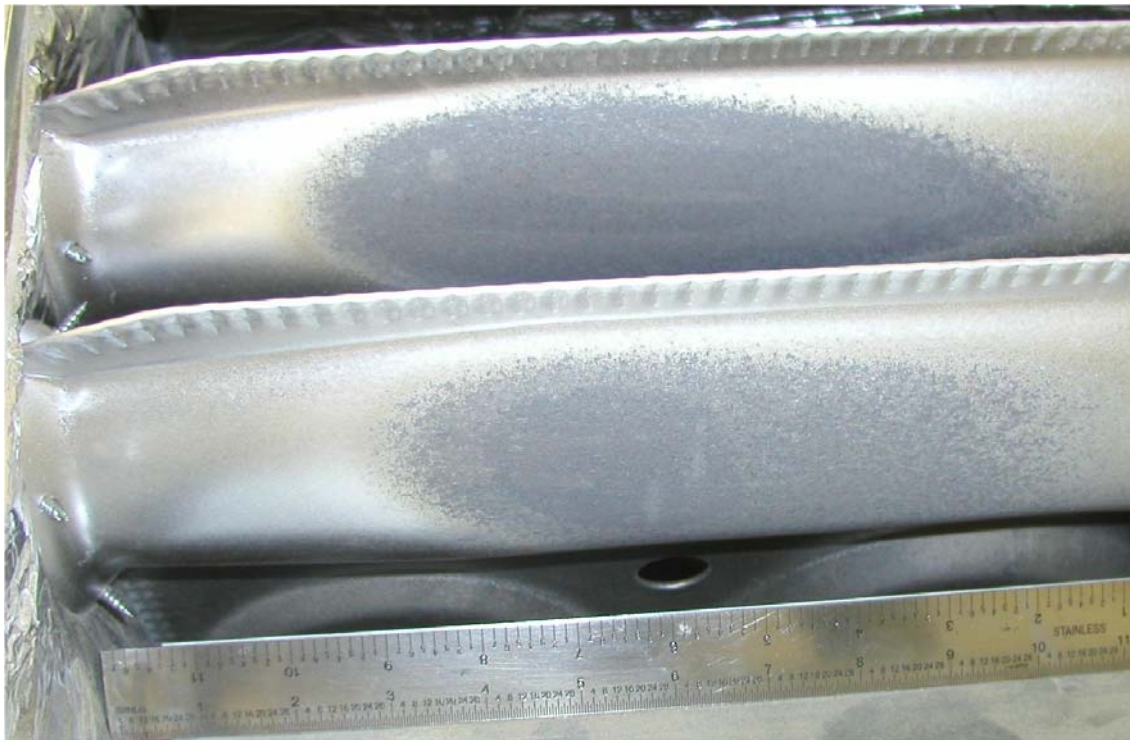


Figure 14. Close up photograph showing the heat affected zone of heat exchanger tubes in Furnace B. The zone begins roughly 3" downstream from the inlet.

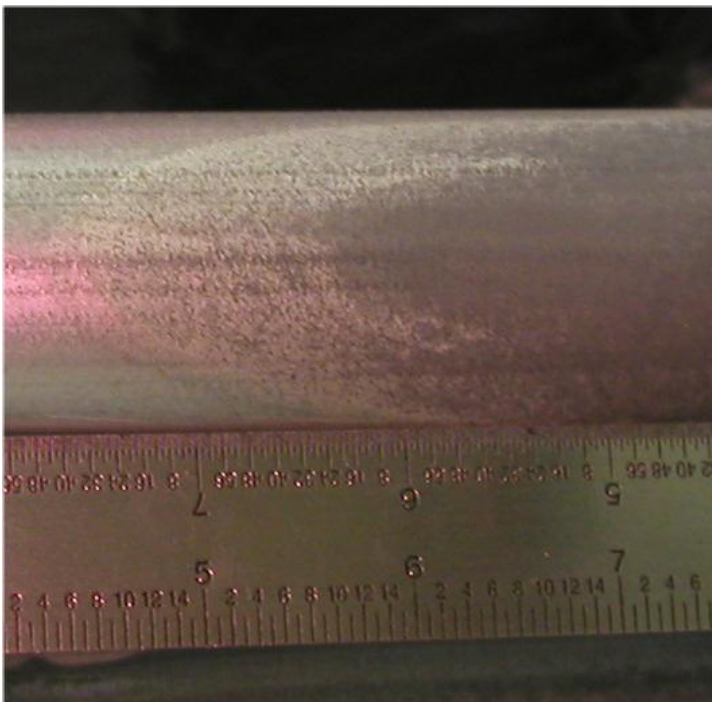
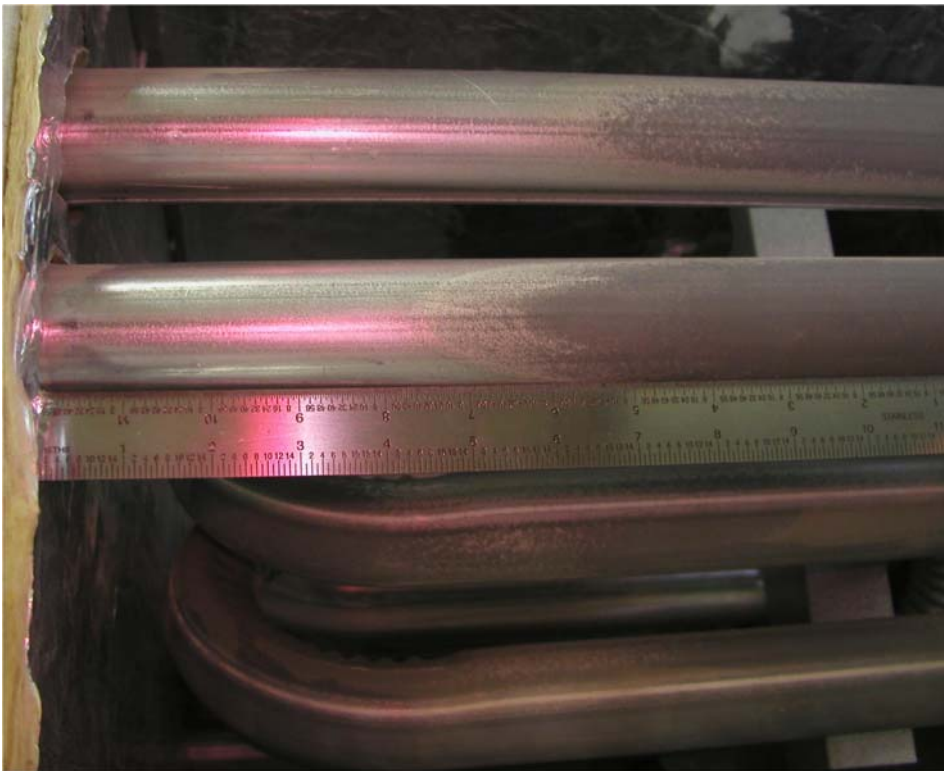


Figure 15. Photographs showing the heat affected zones in Furnace C. The upper photograph is a general view of the heat exchanger. The lower photograph is a close up of a heat affected zone of one of the flame tubes. The zone begins roughly 5" downstream from the inlet.



**f) Allowable Air Temperature, section 2.24**

At each elevation a measurement of the temperature at which the limit control shuts off the gas to the main burner(s) according to section **2.24** was conducted for each fuel and orifice size combination. The results are shown in Table 11.

Table 11. Measured Outlet Air Temperatures Required to Activate the Limit Control

Furnace Code	A		B		C		D	
Manufacturer's Maximum Outlet Air Temperature* (°F)	180		160		175		160	
Fuel	NG	PG	NG	PG	NG	PG	NG	PG
Measured Temperatures (°F) at Different Altitudes								
FM	—	—	—	—	—	180	—	—
FM	—	166	158	161	180	185	144	165
FM	163	166	159	159	180	183	134	138
ED	196	197	—	—	176	181	166	170
ED	196	191	150	159	183	172	162	160
V	184	180	158	161	190	185	147	166

The results indicate that only Furnace B met the requirements in section **2.24**. The temperature measurements with the other furnaces suggest that outlet air temperatures in excess of the manufacturer's rating plate values were necessary to trip the limit control. The differences ranged from 10°F to 17°F. It is important to note that the nature of this type of temperature measurement would incur a large variability.

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\* Per 1.27.10-c. of ANSI Z21.47•CSA 2.3-2001 for Gas-Fired Central Furnaces

**g) Applicability of CAN/CGA-2.17-M91**

In the original Request for Proposals it was asked that the procedure outlined in the National Standard of Canada CAN/CGA-2.17-M91, *Gas-Fired Appliances for Use at High Altitudes* be conducted and investigated to determine its applicability and validity as an alternate method to field testing furnaces at a variety of different altitudes. These tests were not specifically conducted. Notwithstanding, it is possible to predict what would have been the outcome had the test actually been conducted. The CAN/CGA 2.17-M91 procedure applies to altitudes up to 4,500 ft (1370 m). In it the furnace is operated at a low altitude (500 ft or 105 m above sea level) with a gas input rate at 5% or 11% above the manufacturer's recommended high altitude gas input rate. The lower percentage is for direct vent appliances while the higher percentage is for non-direct vent appliances. The same Standard Tests that were conducted in the present study (**2.8 Combustion, 2.9 Burner operating Characteristics, 2.10 Pilot Burners and Safety Shutoff Devices, and 2.22 Draft Test For Furnaces Not Equipped With Draft Hoods**) would then be performed on the test furnace. For example from the data collected on Furnace A at Sea Level:

The manufacturer of Furnace A recommends that the Natural Gas input rate for 4,500 ft (1370 m) was 109,200 Btu/h. The test input rate for a test at 500 ft altitude according to CAN/CGA 2.17-M91 (for up to 4,500 ft) is calculated using:

$$R_t = (1.05) * (P_H) * (R_{ha}) / 29.38 ,$$

Where:

$P_H$  is the actual barometric pressure at test site: i.e., Sea Level at 29.92 in. Hg, and

$R_{ha}$  is the manufacturer's recommended derated gas input rate for the altitude above Sea Level (Btu/h).

29.38 is the standard barometric pressure for 500 ft altitude in inches of mercury. The CGA test laboratory was near that altitude.

For the 4,500 ft (1370 m) altitude then

$$R_t = (1.05) * (29.92) * (103,920) / 29.38$$

or  $R_t = 116,767$  Btu/h, test gas input rate for 4,500 ft (1370 m) when tested at Sea Level altitude.

All tests for CAN/CGA 2.17-M91 would be run at 116,767 Btu/h at Sea Level, except for

**2.8.1 Combustion Operation** at 12% increased input for Natural Gas, which would be  $116,767 \text{ Btu/h} \times 112\% = 130,779 \text{ Btu/h}$ .

Tables 12 and 13 list the required gas input rates for each furnace, both normal and over fire, calculated according to the procedure in CAN/CGA-2.17-M91 for Natural Gas and Propane Gas, respectively. There are two options to look at for expanding the applicability of the CAN/CGA 2.17-M91 to altitudes above the current limit of 4,500 ft.

1. If a manufacturer recommends that their furnace is designed for use up to 4,500 ft, use the manufacturer's recommended gas input rate for  $R_{ha}$  in the calculation. The gas input rates obtained above appear in the 4,500 ft (1,372 m) columns of Table 12. If they recommend that the furnace is designed for use up to 6,700 ft, use the manufacturer's recommended gas input rate for  $R_{ha}$  in the calculation. The gas input rates obtained for 6,700 ft appear in the 6,700 ft (2040 m) columns of Table 12. The gas input rates for 6,700 ft are lower than for 4,500 ft, which makes the tests easier to pass.
2. Use the gas input rates calculated for 4,500 ft for altitudes higher than 4,500 ft, which maintains the same difficulty of passing the tests as for 4,500 ft (more difficult than for option 1 above). This option assumes that either natural derating due to altitude or intentional derating as recommended by furnace manufacturers sufficiently reduces gas input rates at the same rate as available oxygen in the air is reduced to yield complete combustion without excessive production of CO.

Table 12. Test Points for CAN/CGA 2.17-M91 When Operating on Natural Gas

Furnace Code	Vent Category	Rating Plate Input, Btu/h	blocked flue portion of section <b>2.22.1</b> <b>Flue Draft Tests For Furnaces Not Equipped With Draft Hoods</b> Required Input at Sea Level to Simulate Altitude, Based on Manufacturer's Derating, Btu/h			<b>2.8.1</b> <b>Combustion Operation</b> 12% Over Fire Input at Sea Level to Simulate Altitude Btu/h		
			2,250 ft	4,500 ft	6,700 ft*	2,250 ft	4,500 ft	6,700 ft*
A	IV	120,000	122,542	116,767	111,122	137,246	130,779	124,456
B	IV	40,000	38,923	35,073	31,309	43,593	39,282	35,066
C	I	45,000	46,290	41,712	37,235	51,845	46,717	41,704
D	I(III)	120,000	123,440	111,232	99,294	138,253	124,579	111,210

\* CGA 2.17-M91 does not cover applications above 4,500 ft.

Table 13. Test Points for CAN/CGA 2.17-M91 When Operating on Propane Gas

Furnace Code	Vent Category	Rating Plate Input, Btu/h	blocked flue portion of section <b>2.22.1</b> <b>Flue Draft Tests For Furnaces Not Equipped With Draft Hoods</b> Required Input at Sea Level to Simulate Altitude, Based on Manufacturer's Derating, Btu/h			<b>2.8.1</b> <b>Combustion Operation</b> 9% Over Fire Input at Sea Level to Simulate Altitude Btu/h		
			2,250 ft	4,500 ft	6,700 ft*	2,250 ft	4,500 ft	6,700 ft*
A	IV	120,000	122,542	116,767	111,122	133,570	127,276	121,123
B	IV	40,000	38,923	35,073	31,309	42,426	38,230	34,127
C	I	45,000	46,290	41,712	37,235	50,456	45,466	40,587
D	I (III)	120,000	123,440	111,232	99,294	134,549	121,242	108,231

\* CGA 2.17-M91 does not cover applications above 4,500 ft.

CGA 2.17-M91 is recommended for altitudes up to 4,500 ft (1370 m). The data from 2,250 ft (685 m) falls into this range, while that for 6,700 ft (2040 m) does not. To check on the suitability of CGA 2.17-M91 as a predictor of performance one needs to examine the test results for several cases.

First consider Furnace A operating on Natural Gas at Sea level and 2,250 ft (685 m) altitude. For option 1, Table 12 recommends that the Furnace A be tested at 122,542 Btu/h, 116,767 Btu/h or 111,122 Btu/h gas input rate at Sea Level to simulate the normal derate condition at 2,250 ft (685 m), 4,500 ft (1370 m), or 6,700 ft (2040 m), respectively and be tested at 137,246 Btu/h, 130,779 Btu/h or 124,456 Btu/h input rate at Sea Level to simulate the over fire condition at 2,250 ft (685 m), 4,500 ft (1370 m) or 6,700 ft (2,040 m), respectively.

For the 2,250 ft, 4,500 ft and 6,700 ft (685 m, 1370 m and 2040 m, respectively) altitudes then;

$$R_{t-2250} = (1.05) * (29.92) * (114,600) / 29.38 = 122,542 \text{ Btu/h, for 2,250 ft (685 m),}$$

$$R_{t-4500} = (1.05) * (29.92) * (109,200) / 29.38 = 116,767 \text{ Btu/h, for 4,500 ft (1370 m),}$$

and.

$$R_{t-6700} = (1.05) * (29.92) * (103,920) / 29.38 = 111,122 \text{ Btu/h, for 6,700 ft (2040 m).}$$

The 12% increased input would be, respectively;

$$R_{2250} = 122,542 \text{ Btu/h} \times 112\% = 137,246 \text{ Btu/h,}$$

$$R_{4500} = 116,767 \text{ Btu/h} \times 112\% = 130,779 \text{ Btu/h, and}$$

$$R_{6700} = 111,122 \text{ Btu/h} \times 112\% = 124,456 \text{ Btu/h.}$$

The Sea Level results in Table 3 show test gas input rates of 138,650 Btu/h and 122,555 Btu/h. The **2.8.1 Combustion Operation** test at 138,650 Btu/h (Test Number **A-VA-N-45-3**) and the blocked flue portion of section **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** test at 122,555 Btu/h (Test Number **A-VA-N-45-1**) produced CO-AF concentrations of 24 ppm and 16 ppm, respectively. For this furnace at 2,250 ft, 4,500 ft and 6,700 ft (685 m, 1372 m and 2040 m) the manufacturer's recommended derate is an input rate of 114,600 Btu/h, 109,200 Btu/h and 103,920 Btu/h; the 12 % over fire condition being 128,352

Btu/h, 122,304 Btu/h and 116,390 Btu/h. When the furnace was fired at 133,393 Btu/h (Test Number **A-ED-N-45-3**) and 117,432 Btu/h (test A-ED-N-45-1) at 2,250 ft (685 m) altitude and at 119,281 Btu/h (Test Number **A-FM-N-43-1**) and 115,414 Btu/h (Test Number **A-FM-N-45-3**) at 6,700 ft(2040 m) altitude the **2.8.1 Combustion Operation** and the blocked flue portion of section **2.22.1 Draft Test For Furnaces Not Equipped With Draft Hoods** CO-AF concentrations were 171 ppm, 178 ppm, 310 ppm, and 175 ppm, respectively. The gas input rates at 2,250 ft (685 m) are about 2½% and 4%, respectively, above the ANSI Z21.47-2001•CSA 2.3-2001 requirement for tests at 2,250 ft (685 m). The gas input rates at 6,700 ft (2040 m) are about 2½% and 11%, respectively, above the ANSI Z21.47-2001•CSA 2.3-2001 requirement for test at 6,700 ft (2040 m). Examination of Figure 9a suggests that at a gas input rate of 128,352 Btu/h (open and closed triangles for 2,250 ft (685 m)) and of 116,390 Btu/h (open and closed circles for 6,700 ft (2040 m)) the CO-AF concentrations are below the required 400 ppm limit. The Sea Level tests at the normal and overfire gas input rates of 122,555 Btu/h (Test Number **A-VA-N-45-1**) and 138,650 Btu/h (Test Number **A-VA-N-45-3**) comply with the required gas input rates for 2,250 ft (685 m), 4,500 ft (1370 m) and 6,700 ft (2040 m) in Table 12 (122,542 Btu/h and 137,246 Btu/h; 116,767 Btu/h and 130,779 Btu/h; and 111,122 Btu/h and 124,456 Btu/hr, respectively) as required by Option 1. This suggests that CAN/CGA 2.17-M91 gives a proper indication of performance. Examination of the test results when Furnace A is fired on Propane Gas (Table 13, Table 4, and Figure 9b) for the same altitudes (Sea Level, 2,250 ft (685 m) and 6,700 ft (2040 m)) suggests the same conclusion, except that the highest tested gas input rate at Sea Level, 131,319 Btu/h (Test Number **A-VA-P-55-3**), was 1.7% (2,251 Btu/h) short of the **2.8.1** input requirement of 133,570 Btu/h in Table 13.

Now, consider Option 2. If the gas input rates in Tables 12 and 13 for 6,700 ft (2040 m) altitude are used, the tests become easier to pass because 6,700 ft (2040 m) altitude requires

lower gas input rates than for 4,500 ft (1370 m) altitude (or for any other altitude lower 6,700 ft (2040 m)). There is no reason for furnaces for use at an altitude higher than 4,500 ft (2040 m) to be Sea Level-tested at lower gas input rates than furnaces for use at 4,500 ft (1370 m) are tested. In addition, furnaces that are designed for use at altitudes higher than 4,500 ft (1370 m) are normally intended to be used at all lower altitudes, including 4,500 ft (1370 m). Furnaces for use at altitudes higher than 4,500 ft (1370 m), should have at least the same difficulty of passing the tests as for furnaces for use at 4,500 ft (1370 m) (more difficult than for option 1 above where higher altitudes require lower gas input rates for tests than do lower altitudes).

Option 1 does not provide the same high level of safety for high altitude furnace applications as does Option 2. Option 2 is the option of choice and supports the use of CAN/CGA 2.17-M91.

Consideration of the same test conditions for Furnace B suggests that the same conclusion is also appropriate. Unfortunately the experimental results for Furnace C and Furnace D do not include high enough gas input rates at Sea Level to be able to draw any conclusions about the use of CGA 2.17-M91 to predict performance at 2,250 ft (685 m) for the two Vent Category I furnaces.

Another way of examining the applicability of CGA 2.17-M91 is to examine how the furnaces performed when over fired from naturally derated gas input rates at the 2,250 ft (685 m) altitude. Tables 14 and 15 list the “Natural Derated” values for the four test furnaces at the two test altitudes. Included are the over fire values for the respective fuels.



Table 14. Naturally Derated and Over Fire Gas Input Rates for Test Furnaces on Natural Gas

Furnace Code	Vent Category	Rating Plate Input, Btu/h	blocked flue portion of section <b>2.22.1</b> <b>Flue Draft Tests For Furnaces Not Equipped With Draft Hoods</b> Derated Input Using 1.8% per 1000 ft (305 m) Btu/h		<b>2.8.1</b> <b>Combustion Operation</b> 12% Over Fire Input Btu/h		
			2,250 ft	6,700 ft	2,250 ft	6,700 ft	
A	IV	120 000	115 140	105 528	128 957	118 191	
B	IV	40 000	38 380	35 176	42 986	39 397	
C	I	45 000	43 178	39 573	48 359	44 322	
D	I (III)	120 000	115 140	105 528	128 957	118 191	

Table 15. Naturally Derated and Over Fire Gas Input Rates for Test Furnaces on Propane Gas

Furnace Code	Vent Category	Rating Plate Input, Btu/h	blocked flue portion of section <b>2.22.1</b> <b>Flue Draft Tests For Furnaces Not Equipped With Draft Hoods</b> Derated Input Using 1.8% per 1000 ft (305 m) Btu/h		<b>2.8.1</b> <b>Combustion Operation</b> 9% Over Fire Input Btu/h		
			2,250 ft	6,700 ft	2,250 ft	6,700 ft	
A	IV	120 000	115 140	105 528	125 503	115 026	
B	IV	40 000	38 380	35 176	41 834	38 342	
C	I	45 000	43 178	39 573	47 063	43 135	
D	I (III)	120 000	115 140	105 528	125 503	115 026	

The over fire gas input rates in the 2,250 ft (685 m) columns in Tables 14 and 15 do not match specific tests points given in Tables 8 and 9. By examining Figures 9a through 9h, one can see if these gas input rates produce safe operation at 2,250 ft (685 m) (open and closed triangles).

Tables 16 and 17 show the CO characteristics for the blocked flue portion of **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods** for each furnace for the two test altitudes above Sea Level. Looking specifically at the results for 2,250 ft (685 m), the results for

Natural Gas are mixed, while those for Propane Gas are all satisfactory. For 6,700 ft (2040 m), the results for Natural Gas are all satisfactory, while those for Propane Gas are mixed.

Table 16. Natural Derated CO Performance on Natural Gas - blocked flue portion of  
**2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**

Furnace Code	Vent Category	Rating Plate Input, Btu/h	Naturally Derated (1.8% per 1,000 ft (305 m)) With 12% Over Fire, Btu/h			
			2,250 ft	TEST NO. Satisfactory Operation	6,700 ft	TEST NO. Satisfactory Operation
A	IV	120 000	128 957	A-ED-N-45-3 Y	118 191	A-FM-N-43-1 Y
B	IV	40 000	42 986	B-ED-N-45-3 N	39 397	B-FM-N-43-1 Y
C	I	45 000	48 359	C-ED-N-44-3 ?	44 322	C-FM-N-43-1 and C-FM-N-44-3 Y
D	I (III)	120 000	128 957	D-ED-N-44-3 Y	118 191	D-FM-N-45-3 Y

Table 17. Natural Derated CO Performance on Propane Gas - blocked flue portion of  
**2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**

Furnace Code	Vent Category	Rating Plate Input, Btu/h	Naturally Derated (1.8% per 1,000 ft (305 m)) With 9% Over Fire Btu/h			
			2,250 ft	TEST NO. Satisfactory Operation	6,700 ft	TEST NO. Satisfactory Operation
A	IV	120 000	125 503	A-ED-P-55-3 Y	115 026	A-FM-P-55-3 Y
B	IV	40 000	41 834	B-ED-P-55-3 Y	38 342	B-FM-P-55-3 Y
C	I	45 000	47 063	C-ED-P-54-3 Y	43 135	C-FM-P-52-1 Y
D	I (III)	120 000	125 503	D-ED-P-55-3 Y	115 026	D-FM-P-54-1 N

The gas input rates for 4,500 ft (1370 m), calculated from CAN/CGA 2.17-M91, were included in Tables 12 and 13 so as to gauge what may happen when tested for the upper altitude limit stated in the test method. All the test furnaces were fired at Sea Level at gas input rates above the calculated values listed for the over fire conditions at 4,500 ft (1370 m) altitude. All easily met the 400 ppm requirement. Unfortunately there is not any field data for the test furnaces at this altitude for direct comparison. However, one can use Figures 9a through 9h to predict what the out come may be by examining if the CO concentrations for all test altitudes are below 400 ppm CO-AF at the prescribed gas input rates in the tests for **2.8.1 Combustion Operation** and the blocked flue portion of **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**. Furnace A does not exceed the 400 ppm CO-AF limit at 6,700 ft (2040 m), 2,250 ft (685 m), and Sea Level on Natural Gas and Propane Gas. Furnace B is under the limit at both altitudes. The data for Furnace C does not cover the required gas input rate range. Furnace D is below the limit at both altitudes when fired with Natural Gas but the Propane Gas data does not cover the required gas input range on Propane Gas. These results are inconclusive even though the Sea Level tests were very good. This suggests that additional field testing is necessary before any final conclusions as to the suitability of CAN/CGA 2.17-M91 can be made.

To gauge the appropriateness of using CAN/CGA 2.17-M91 to predict performance at 6,700 ft (2040 m), which is beyond its stated range of up to 4,500 ft (1370 m), consider again the test results for Furnace A on Natural Gas. These are listed in Table 3. When tested at Sea Level at a gas input rate of 138,650 Btu/h, which is higher than the test gas input rate of 124,456 Btu/h listed for 6,700 ft in Table 12 as required by CAN/CGA 2.17-M91, the CO-AF Combustion and Blocked Flue results were 24 ppm and 237 ppm respectively. When tested at 122,555 Btu/h at

Sea Level, slightly below the required value from CAN/CGA 2.17-M91, the CO-AF Combustion and Blocked Flue results were 26 ppm and 16 ppm respectively.

The manufacturer of Furnace A recommends a gas input rate of 103,920 Btu/h for the 6,700 ft (2040 m) altitude. This is well less than the required gas input rate to simulate the 6,700 ft (2040 m) altitude using CAN/CGA 2.17-M91. As shown in Table 3, at the 6,700 ft (2040 m) altitude, when operating at a gas input rate of 115,414 Btu/h, the **2.8.1 Combustion Operation** and the blocked flue portion of section **2.22.1 Draft Test For Furnaces Not Equipped With Draft Hoods** CO-AF results were 20 ppm and 175 ppm respectively. The value of 115,414 Btu/h is very close to the manufacturer's recommended derated gas input rate plus 12% over fire for this furnace at this altitude. The required gas input rate is 116,390 Btu/h, which is less than 1% above the actual test value. Examination of the other test points at 6,700 ft (2040 m) altitude in Table 3 shows that raising the gas input rate above 115,414 Btu/h results in the CO-AF concentration rising above the 400 ppm CO-AF limit. These results suggest that for this Vent Category IV furnace and manufacturer's recommended derating that CAN/CGA 2.17-M91 is a reasonable predictor of performance at 6,700 ft (2040 m) altitude. Note however that a 3% increase in gas input rate to 119,281 Btu/h produced a nearly unacceptable concentration of CO-AF. Thus it seems that Furnace A when fired on Natural Gas is operating near a critical point concerning CO production with this derating at this altitude. Examination of the test results for Furnace A when operating on Propane Gas draws a different conclusion. That is, it is not near a critical operating point at 6,700 ft (2040 m) when using a gas input rate 9% above the recommended derating and that operation at Sea Level using the recommended gas input rates from CAN/CGA 2.17-M91 are a good predictor of performance at this altitude.

Examination of the Furnace B test results at Sea level and 6,700 ft (2040 m) shows that with the manufacturer's recommended derating the furnace could be grossly over fired (> 15%)

at both Sea Level and 6,700 ft (2040 m) and still not exceed the 400 ppm CO-AF limit. Operating at the gas input rates well above those recommended by CAN/CGA 2.17-M91 (Table 12 and Table 13) at Sea Level produced very little CO except when fired at 46,897 Btu/h (Test Number **B-VA-N-45-3**, about 35% above the 12% over fire gas input rate of 35,066 Btu/h listed in Table 12). For this furnace using CAN/CGA 2.17-M91 calculated gas input rates at Sea Level suggested safe operation at 6,700 ft (2040 m), which was found in practice with both test fuels.

Examination of the results for Furnace C, a Vent Category I furnace, shows that at Sea Level it could be fired with either test fuel at well over the gas input rates calculated using CAN/CGA 2.17-M91 for the 6,700 ft (2040 m) without exceeding the CO-AF 400 ppm limit. The results for the tests conducted at 6,700 ft (2040 m) show the same trend. The furnace could be fired at 43,909 Btu/h (about 5% above 41,740 Btu/h, the 12% over fire on Natural Gas) and at 43,475 Btu/h (about 7% above 40,587 Btu/h, the 9% over fire on Propane Gas without exceeding the 400 ppm CO-AF limit. Thus CAN/CGA 2.17-M91 would seem to be a good predictor of performance at altitude for this furnace.

The results for Furnace D, a Vent Category I furnace, are similar to those for Furnace C. That is, the furnace could be easily operated at 111,210 Btu/h, the gas input rate suggested by CAN/CGA 2.17-M91 at Sea Level, without exceeding the 400 ppm CO-AF limit. At 6,700 ft (2040 m) the test results show that the furnace could be fired well above the over fire conditions based on the manufacturer's derating. With Natural Gas the gas input rate could be raised about 15% above the over fire condition at altitude, while with Propane Gas the value was about 8% above the over fire condition. CAN/CGA 2.17-M91 would seem to be a good predictor of performance at altitude for this furnace as well.

Tables 16 and 17 include results for achieving acceptable CO-AF concentrations when over fired from "Natural Derated" inputs at 6,700 ft (2040 m). Here one needs to examine the

open and closed circles on Figures 9a through 9h. As with the results for 2,250 ft (685 m) the outcomes are mixed in their predictions.

Based on the limited number of furnaces used in this study it would seem that using CAN/CGA 2.17-M91 as a predictor of performance at altitudes up to 6,700 ft (2040 m) works well for furnaces using the historical derating of 4% per 1000 ft (305 m) increase in altitude above 2,000 ft (610 m), its application is marginally acceptable as evidenced by the results for Furnace A which uses a 2% derating, which is very close to the natural derating of all the furnaces tested. Before any final recommendations can be made on possible revisions to CAN/CGA 2.17-M91, tests should be run at 12% increased input at several different altitudes up to 10,000 ft (3050 m) to determine the gas input rates at which 400 ppm CO-AF is reached in the 2.8.1 Combustion Operation test.

Appendix F contains a discussion of other possible methods of testing furnaces at low altitudes for use at higher altitudes.

## 8. Conclusions

Based on the tests conducted in this study on the performance of fan-assisted gas-fired residential furnaces at three altitudes, the following conclusions are drawn.

1. The burner design used in all the furnaces provided a natural derating of 1.8% per 1,000 ft (305 m) increase in altitude.
2. The natural derating permitted all the furnaces to safely operate (CO- AF<400 ppm) at all test altitudes when using the orifices and manifold pressures for Sea Level operation.
3. Over firing by the required amounts from the naturally derated gas input rates resulted in the CO-AF concentration exceeding 400 ppm in only one test.
4. With minor exceptions, the test furnaces could be fired at the Rating Plate Input at all test altitudes without exceeding the CO-AF 400 ppm limit provided normal gas line and manifold pressures were used. The exceptions all occurred at the highest test altitude, 6,700 ft (2040 m), mostly with Propane Gas and the blocked flue portion of **2.22.1 Flue Draft Tests For Furnaces Not Equipped With Draft Hoods**
5. All test furnaces complied with **2.8.1 Combustion Operation** when over fired by the required amounts at the two test altitudes above Sea Level when derated according to the manufacturer's recommendation.

6. The measured CO and calculated CO-AF values showed the same general trends with increasing altitude for both test fuels.
7. The steady state efficiencies were found to increase with altitude for all furnaces.
8. The steady state efficiency for all furnaces was higher when operating on Propane Gas compared with Natural Gas.
9. The steady state efficiencies of the two Vent Category IV furnaces were found to be almost independent of firing rate and air to fuel ratio (mass basis).
10. The steady state efficiencies of the two Vent Category I furnaces were found to have more dependence on firing rate and air to fuel ratio (mass basis) than the two Vent Category IV furnaces.
11. The NO<sub>x</sub> levels generally fell below 0.093 lbs/10<sup>6</sup> Btu (40 ng/J) of useful heat output. Similar results were obtained for both test fuels.
12. No clear statement can be made as to the effects of altitude on NO<sub>x</sub> levels because of changing air to fuel ratios and total mass of air and fuel through the furnace with changes in altitudes.
13. No effects of altitude on the performance of the ignition systems (hot surface igniters) were observed.



14. More altitude testing is required before the suitability of CAN/CGA 2.17-M91 as a predictor of performance can be determined.
15. Temperature measurements of the outlet air showed that only one of the four test furnaces did not exceed the maximum outlet air temperature marked on its furnace rating plate.

## 9. References

1. ANSI Z223.1-2002/NFPA 54-2002 National Fuel Gas Code
2. CSA B149.1-00 National Standard of Canada, Natural Gas and Propane Installation Code
3. ANSI Z21.47-2001•CSA 2.3-2001 American National Standard/CSA Standard for Gas Fired Central Furnaces
4. CAN/CGA-2.17-M91 National Standard of Canada, Gas-Fired Appliances for Use at High Altitudes
5. ASHRAE. 2001 Handbook of Fundamentals, page 6.1, Table 1 Standard Atmospheric Data for Altitudes to 60,000 ft, and page 18.3, Altitude Compensation
6. NACA 1957, Basic considerations in the combustion of hydrocarbon fuels with air (National Advisory Committee for Aeronautics Report 1300), Edited by Henry C. Barnett and Robert R. Hibbard, January 1957, p339.
7. ANSI/ASHRAE Standard 41.2-1987 (1987), “Standard Methods for Laboratory Airflow Measurement”.
8. Schuler, O., Gass, J., and Goettling, D., How to correct NO<sub>x</sub>-Emissions of burners in boilers and furnaces to exclude the influence of humidity, temperature, and pressure in the combustion air. - A proposal for a standardized correction factor, Trans. 4th European Conference on Industrial Furnaces and Boilers, Portugal, 1998.
9. ASHRAE 1997, *ASHRAE Handbook – Fundamentals*, Chapter 17
10. Colburn, A. P. *Trans. AIChE*, **29**, 174, 1933.
11. Eiseman, John H.; Francis A. Smith; Cecil J. Merritt; U.S. Bureau of Standards, Research Paper No. 553, The Effect of Altitude on the Limits of Safe Operation of Gas Appliances, May, 1933.

## **10. Bibliography**

Kam, Vera. P.; Ni, Li; Borgenson, Robert A.; Sheridan, Roger; and Partridge, John; “High Altitude Installation of Natural Gas-Fired Appliances with Fan-Assisted Combustion Systems”, Gas Research Institute Topical Report GRI-95/0014, American Gas Association Laboratories, Cleveland, Ohio, USA, January 18, 1995.

Sheridan, Roger D.; White Paper – The Effect of Altitude on the Operation of Gas Appliances; American Gas Association Laboratories for Gas Research Institute contract no. 5086-241-1220 Gas Appliance Technology Center, Cleveland, Ohio, USA, December, 1988.

## 11. Observations

It was not the purpose of this study to call into question the appropriateness of the ANSI Z21.47•CSA 2.3-2001 Standard for Gas-Fired Central Furnaces; in this work the Standard Tests were not evaluated. It is however important to note that the most difficult test to pass for these systems was the blocked flue portion of section **2.22.1 Draft Test For Furnaces Not Equipped With Draft Hoods** test, which also is a test of the sensitivity of the flue gas, pressure-activated shutoff switch. This begs the question as to whether more sensitive pressure switches should be employed in modern residential furnaces.

One of the purposes of this research project was to determine, if by testing a limited number of fan-assisted furnaces, whether there is clear evidence to indicate that current derating practices are overly conservative. Although it is impossible to perform field tests on every possible furnace currently available or in use in the market, there is an undeniable trend evident in the testing that was performed here. From the Furnace A results presented here, it is clear that a 2% derate per 1000 ft (305 m) of altitude may be more than adequate to provide safe operation of fan-assisted residential gas furnaces up to 6,700 ft (2040 m). In fact, given more strict codes for the sensitivity of pressure switches, it is tempting to postulate that no derating scheme is needed at all for most systems given the “natural derate” they all experience. Unfortunately, there are enough exceptions to the rule that proposing the abolition of altitude de-rating cannot be made out of hand. One must bear in mind that for many times, the design goal is to bring to market a furnace that meets safety standards with minimal overshoot. With that in mind and knowing manufacturers will perform their own tests as they bring products to market, one would expect ethical self-regulated furnace manufacturers to restrict use of models that were not likely to pass the standard tests at altitude regardless of what derating scheme or standard is adopted

unless high-altitude kits are viable and safe. As was mentioned previously, one of the systems used in this study came with a de-rating scheme of 2%/1000 ft (305 m) suggested by the manufacturer. In other words, the manufacturer has already done their own version of this testing to ship the furnace with its own customized derating protocol. This practice seems sound and might be a suggested protocol for systems made by other companies. While precise gas input rates were not matched, the results presented here suggest that Furnace A can be over fired from its naturally derated gas input rate at all the test altitudes on either fuel without exceeding the 400 ppm CO-AF limit. Note however that not all the test furnaces met the 400 ppm CO-AF limit under similar test conditions at all altitudes.

The furnaces that did fail the blocked flue portion of section **2.22 Draft Test For Furnaces Not Equipped With Draft Hoods** test were ones that continued to operate with almost entirely blocked flues; this was more likely in systems with leaky enough vent systems that blocking the flue did not generate significant pressure rise since flue gas could escape elsewhere. The failures occurred when the furnace was either over fired or under fired from the required test point. As such these are not failures according to the test procedure as they should not have been recorded.

The research team had difficulty understanding the wording in ANSI Z21.47•CSA 2.3-2001, especially in section **2.8.1 Combustion Operation**, which refers to earlier information in **2.3.2 Test Ducts and Plenums**, **2.5.1 Test Pressures and Burner Adjustments**, **2.5.4 Test Pressure and Burner Adjustments** and **2.6.1 Static Pressure and Air Flow Adjustments**. First note that it requires the outlet end of the supply air duct to be “symmetrically restricted”. The supply air duct is normally rectangular as suggested in section **2.3.2**. With the equipment used and space limitations in the trailer used in this study, the “symmetrical restriction” was impossible to implement.

ANSI Z21.47•CSA 2.3-2001 is not clear on how the over firing should be determined at altitudes other than Sea Level. In sections **2.8.1** and **2.5.3** it states that when increased input rates are specified, the gas appliance pressure regulator (meaning manifold pressure) shall then be adjusted to provide an increase in input rate specified by the manufacturer of twelve percent .....

These statements override section **2.5.1** which requires the inlet gas pressure (not the manifold pressure) be raised to values specified in Table **X**. There are no explicit statements as what to do when testing is being done at altitudes where derating would normally be employed. For example does one select for Natural Gas an input rate 12% above the Rating Plate Input or the derated value? Also it was observed that sometimes the settings from Table **X** produced input rates higher than those required for the over firing stated in **2.8.1**, sometime less.

The test furnaces were purchased from Canadian vendors where the line voltage is 120 V. The rating plates of the furnaces were marked accordingly. Thus when doing the reduced voltage test, the 85 % value is 102 V and not 94 V or 98 V as would be expected when the line voltage is 110 V or 115 V. Whether this difference has an effect on the performance of the appliance gas pressure regulator, igniter or fan operation is not known.

The student conducting the field work stated that he wore out the screw threads in several appliance gas pressure regulators while making all the adjustments. He also experienced difficulty with the threads on the manifolds into which the orifices were screwed. The manifolds tend to be constructed of light material and are not really designed for the frequent orifice replacement as was required in this study.

## **APPENDIX A: Details of Equipment and Procedures**

### Data Acquisition System (DAS)

The data acquisition system consisted of two analogue to digital (A/D) data acquisition boards and a two channel analog output board. An Omega PCI-DAS-TC (S.N. AM29F010) 16 channel thermocouple board was used to record the temperature measurements taken with the DAS. The temperature channels were cold junction compensated. The other A/D board was an Omega DAS-8PGA(S/N 085376) 8 channel board used with the pressure transducers. An Omega CIO-DAC02 card was used for the analog outputs. The analog outputs were used to remotely control the position of dampers in the supply and return air ducts. The position of the damper in the supply air duct was changed to maintain the external static pressure in the air supply duct as required by the test method. The damper in the return duct was always open during testing, while the cross over damper used to control mixing was usually shut. The location of the dampers was shown in Figures 4 and 5.

The three boards were controlled with Omega DasWiz software. The software links the data acquisition boards to Microsoft Excel which allowed for programming and control through Visual Basic.

The output from the A/D board was continuously monitored and recorded with a portable computer. The A/D system gathered signals at 200 Hz, averaging until recorded by the computer. When a particular test was ready for recording, the computer read each channel at 2 Hz for 30 seconds, giving 60 data points for averaging and calculating standard deviations.

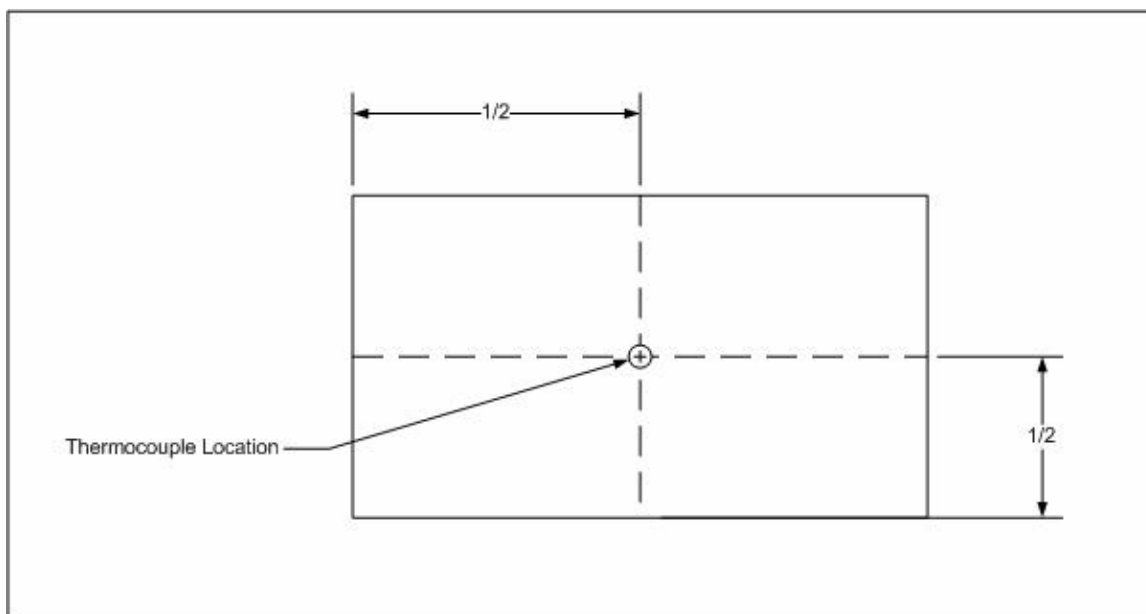
### DAS Temperature Measurements

#### Outdoor Air Temperature

A single type K thermocouple was used to record outdoor air temperature.

## Return and Room Air Temperature

A single type T thermocouple was used to measure the circulating return air temperature at the inlet of the active furnace. Figure A1. shows the location used for all the furnaces. The open return method used ensured good mixing of the air streams before entering the furnace fan cabinet. This temperature was also used as the Room Temperature.



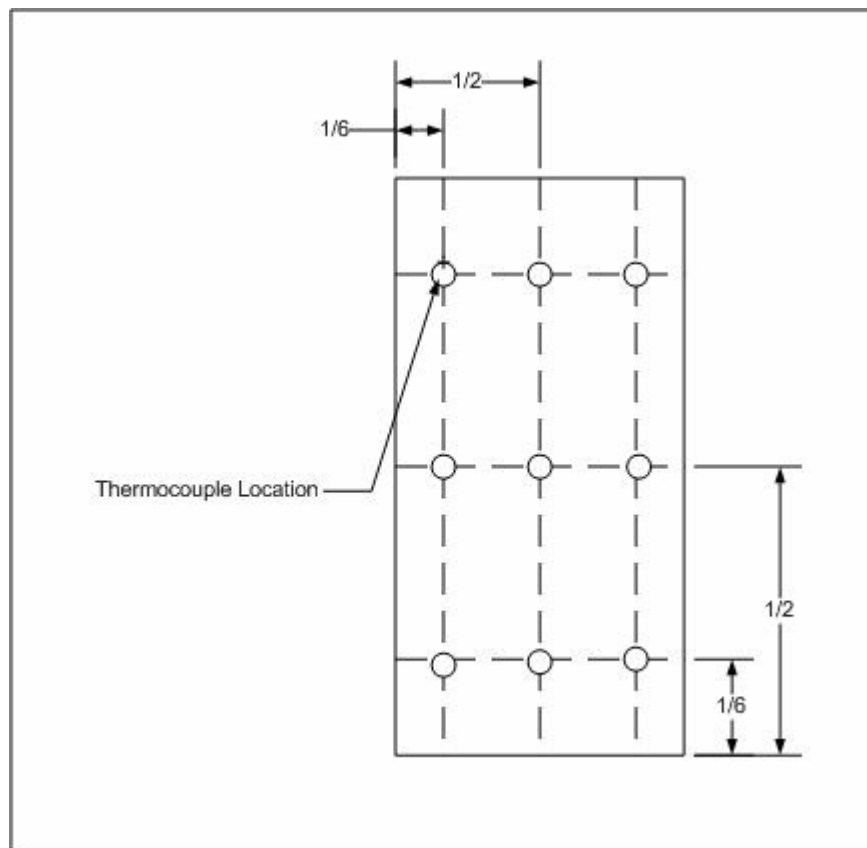
**Figure A1.** Return air temperature measurement location. The dimensions shown are fractions of the height and width of the passage.



### Supply Air Temperature

A grid of nine area weighted type T thermocouples was used to measure the circulating supply air temperature at the outlet of the plenum of the active furnace.

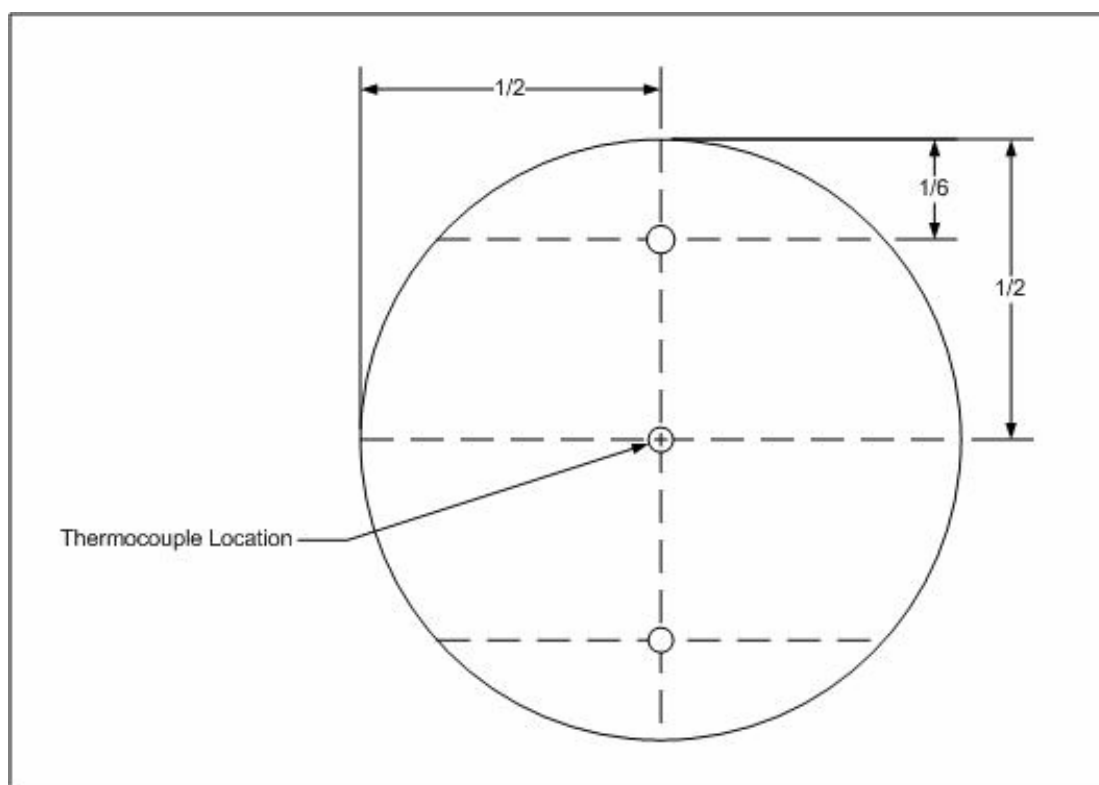
Figure A2 is a schematic of the thermocouple grid.



**Figure A2.** Supply air temperature locations. The dimensions shown are fractions of the height and width of the passage.

## Vent Gas Temperature

A line of three averaged type T thermocouples placed through the centerline of the duct was used to measure the vent temperature of the active furnace. Figure A3 is a schematic of the set up. Operational difficulties at times reduced the number of active thermocouples in this system.



**Figure A3.** Flue gas temperature measuring grid. The dimensions shown are fractions of the diameter of the passage.

## Other DAS Measurements

### Relative Humidity

A 0-1 V (0-100%) relative humidity sensor was used to record the relative humidity inside the trailer. The unit was manufactured in house and used a purchased humidity sensor that varied its capacitance with relative humidity. The unit has a linear output over the range of 0 – 1 V corresponding to 0% to 100% relative humidity. Unfortunately this instrument turned out to be unreliable. Values were recorded but on some days the indicated values would change from the 15% range to the 95% range without any noticeable change in the environmental conditions.

### Barometric Pressure

An Omega PX2760-600A5V barometric pressure sensor was used. The device had a manufacturer calibrated linear output of 0.1 V-5.1 V for a 600-1100 mbar range. The factory information gave 600 mbar = 450 mm of Hg @ 0 °C

### Furnace Supply Air External Static Pressure

A Setra 264 (S/N 1399119) was used to record the external static pressure inside the hot air supply duct of the active furnace. The device had a linear range of 0-5 VDC corresponding to 0-0.5" WC. With the 12 bit A/D DAS the resolution of the system was 0.000122" WC.

### Vent Static Pressure

A Setra 264 (S/N 1399117) was used to record the pressure inside the vent of the active furnace. The device had a linear range of 0-5 VDC corresponding to 0-0.5 in. wc. With the 12 bit A/D DAS the resolution of the system was 0.000122 in. wc.

## Manual Measurements

### Flue Gas Analysis

Flue gas measurements were manually recorded by reading the output from a DEDESCO, Model CEA-9201 combustion/emissions analyzer. The analyzer provided output of CO, NO<sub>x</sub> (as NO), and O<sub>2</sub>. A calculation based output of CO<sub>2</sub> was also provided by the analyzer. The analyzer was calibrated for Oxygen using room air. For CO, calibrations were performed using a 97 ppm bottle of CO mixture prepared by Praxair and checked for zero with a 100% nitrogen bottle prepared by Praxair in addition to checking zero with ambient air between tests. For all calibrations the analyzer was never out more than 3 ppm for CO.

The calculation based output for CO<sub>2</sub> with this analyzer was limited to pure methane (CH<sub>4</sub>) or pure propane (C<sub>3</sub>H<sub>8</sub>). These values were not used. Rather an algorithm was written to more closely approximate the CO<sub>2</sub> produced based on the O<sub>2</sub> content in flue gas when Natural Gas and Propane Gas (HD-5) are burned with excess air.

The operating characteristics (range, sensitivity and accuracy) of the gas analyzer are listed in the table below. The calibration history of the unit for CO is shown in the next table. The manufacturer states that the sensing elements have a linear response over the ranges listed.

Operating Characteristics of the DEDESCO, Model CEA-9201  
Combustion/Emissions Analyzer

MEASUREMENT	RANGE	RESOLUTION	ACCURACY
O <sub>2</sub>	0-25%	0.1%	+/-0.25%
CO	0-2000 ppm	1 ppm	+/-1%FS
NO <sub>x</sub>	0-2000 ppm	1 ppm	+/-1% FS

Calibrations of the CO Output of the DEDESCO,  
Model CEA-9201 Combustion/Emissions Analyzer

Calibration Date	Nitrogen Zero (ppm)	CO (ppm) with 97 ppm Calibration Gas
02/13/02	1	98
02/15/02	0	95
02/20/02	0	96
02/27/02	0	99
03/05/02	1	97
03/10/02	1	98
03/16/02	0	98
03/25/02	0	100
04/02/02	1	98
04/10/02	0	97
04/18/02	0	98
06/18/02	0	98
06/20/02	0	96
06/22/02	0	96
08/15/02	0	99
08/21/02	0	97

#### Casing Temperatures

This measurement was taken using an Omega HH508 (S/N 98000080) thermocouple reader and a type K thermocouple surface probe. Thirty six measurements were taken (9 per face) and averaged to determine the average jacket temperature for the furnace. The pattern used is shown in Figure A2.

## Manifold Pressure

Each furnace was equipped with a Magnehelic 0-15 in. wc gauge to record the manifold pressure. The high side of the pressure gauge was tapped into the manifold pressure tap on the furnace regulator and the low side was left vented to atmosphere. The resolution is 0.5 in. wc.

## Gas Supply (Line) Pressure

The gas supply pressure was measured between the dry gas meter and the manifold pressure regulator (furnace gas control valve). The dry gas meter being located down stream of the gas line pressure regulator. This pressure was recorded with a UEI EM100A Electronic Manometer, range – 20 to + 20 in. wc (resolution 0.1 in. wc, accuracy  $\pm 0.4$  in. wc).

## Gas Input Rate

A standard bellows dry gas meter, Canadian Meter Company Inc. Model AC 250 (serial # 00-793591) was used along with a stop watch to determine the gas input rate. Corrections to the indicated rate from the gas meter reading were made for inlet and barometric pressure. The gas meter was temperature compensated to 60°F (15°C) via a bi-metal strip internal to the meter. The meter calibration test sheet is shown in Figure A4. The meter read 0.3% fast.

Gas Input Rate Calculation:

$$H_{in} = (V/t) * 3600 * [(P_{atm} + P_{supply}) / (P_{standard})] * H_{HHV} * 0.997$$

t – Time for measured Volume (s)

V – Measured volume read from meter dial gauge (ft<sup>3</sup>)

P<sub>atm</sub> – Measured barometric pressure (in. Hg at 59°F / 15°C)

P<sub>supply</sub> – Measured gas supply pressure (in. Hg at 59°F / 15°C)

$P_{\text{standard}}$  – Standard Atmospheric Pressure (30.00 in. Hg at 59°F / 15°C)



$H_{\text{HHV}}$  – Higher Heating Value of Fuel Gas at Standard Atmospheric Pressure  
and 59°F / 15°C (Btu/ft<sup>3</sup>)

$H_{\text{in}}$  – Input Rate (Btu/h)

0.997 - Flow Correction Factor

The composition and energy content of Natural Gas and Propane Gas used in the greater Edmonton area are shown in Figures A5 and A6. Note these are approximate. Due to an oversight the composition of the actual gases used was not determined. The sample bags were never sent for analysis. By the time this was realized, the sample bags had been discarded and could not be recovered.

Based on the range of compositions, the volume percent of CO<sub>2</sub>, dry basis, expected for a measured volume concentration of O<sub>2</sub> was calculated. The values used are listed below.

	<b>NORTH AMERICAN SERVICES GROUP</b>		FILE: UOFA 040805
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**OUTGOING CUSTOMER CALIBRATION RECORD - NASG - EDMONTON, ALBERTA**

CUSTOMER: University of Alberta ADDRESS: CITY, PROV: POSTAL CODE: METER TYPE: AC-250 TC	QUANTITY: 1 SALES ORDER: UOFA 040805 COMP. DATE: 08-APR-2005 ORDER DATE: 07-APR-2005 NASG TARGET (%PROOF): 100.0
---	--

OPEN Corr Fx: 0.0	CHECK Corr Fx: 0.0
-------------------	--------------------

NOTES:  
Proof runs for meter.

<u><b>FIRST OPEN</b></u> X-BAR 99.70 SIGMA	<u><b>FIRST CHECK</b></u> X-BAR 99.70 SIGMA	<u><b>LAST OPEN</b></u> X-BAR 99.70 SIGMA	<u><b>LAST CHECK</b></u> X-BAR 99.70 SIGMA 0.00000
--	---	---	--

	<u><b>FIRST RUN</b></u>	<u><b>LAST RUN</b></u>						
<u>No.</u>	<u>BARCODE</u>	<u>CUSTOMER</u> <u>SERIAL#</u>	<u>MFG</u> <u>SERIAL#</u>	<u>INDEX</u> <u>READING</u>	<u>%PROOF</u> <u>OPEN</u>	<u>%PROOF</u> <u>CHECK</u>	<u>%PROOF</u> <u>OPEN</u>	<u>%PROOF</u> <u>CHECK</u>
1	01527290	#####	00-793591	0000	99.7	99.7	99.7	99.7

Figure A4. Gas Meter Calibration Certificate



Atco Natural Gas Composition	
Gas	Percentage
Methane	92.8661
Ethane	4.0664
Propane	0.5329
Isobutane	0.0598
Butane	0.0791
Isopentane	0.0160
C <sub>5</sub> <sup>+</sup>	0.0000
Carbon Dioxide	0.8567
Nitrogen	1.5320
Specific gravity (AGA) HV	0.596 38.47 MJ/m <sup>3</sup>

Figure A5. Natural Gas composition used in the tests (typical)

Note: The energy content in Natural Gas in Edmonton (ATCO) is by law measured at the standard conditions of 60°F (15°C) and 14.696 psia. (101 325 Pa). The energy content does change during the year because it is drawn from a variety of fields and storage caverns. During the time of the investigations reported here the energy content was:

Fortress Mountain	1056 Btu/ft <sup>3</sup>
Vancouver	1058 Btu/ft <sup>3</sup>
Edmonton	1022 Btu/ft <sup>3</sup>

Note that the energy content varied by less than 4% over the testing period.


The composition shown in Figure A5 shows that the Natural Gas used contains two inerts. Otherwise the fuel is composed of simple structures of the form C<sub>n</sub>H<sub>2n+2</sub>. The presence of the inerts causes a shift in the volume concentration of CO<sub>2</sub> present in the combustion products compared with combustion products for pure Methane (CH<sub>4</sub>). The formula used was:

$$\% \text{CO}_2 = -0.5654 (\% \text{O}_2) + 11.88$$

For comparison purposes, if the fuel were pure Methane ( $\text{CH}_4$ ), as assumed by the formula built into the gas analyzer, the formula would be.

$$\% \text{CO}_2 = -0.5553 (\% \text{O}_2) + 11.73$$

Comparing these two relationships shows that for a given Oxygen concentration the latter formula predicts about a 2% (relative) lower value of %  $\text{CO}_2$ .



**NORWEST  
LABS**

7217 Roper Road NW, Edmonton, AB. T6B 3J4  
Phone (780) 438-5522

**Gas Analysis**

Lot Number: 376256  
Report Number: 686630  
NWL Sample ID: 1456033

Page: 1 of 1

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University of Alberta

Operator

Sample Fuel 01

Well Name

Mark Ackerman

Tedlar

Container Identity

---

Location

Field/Area

Pool / Zone

Sampler

KB Elev. m

GR Elev. m

---

Test Type ☐ No

Multiple Recovery ☐ No

Test Interval, m

Perforations, m

Test Recovery:

Propane Tank

Sample Point

Meter # / Sample ID

Type of Production: Pumping ☐ Flowing ☐ Gas Lift ☐ Swab ☐

Production Rates: Water  m<sup>3</sup>/d Oil  m<sup>3</sup>/d Gas  10<sup>3</sup> m<sup>3</sup>/d

Gauge Pressure, kPa  0

Temperature, °C  20

Source  Sampled  Received

Date On  Date Off

---

2005-04-19

Date Sampled (Y-M-D)

Time Sampled

2005-04-19

Date Received (Y-M-D)

2005-04-25

Date Reported (Y-M-D)

Sample Fuel 01

Other Information

---

Comp.	Mole Fraction (Air Free)		Petroleum Liquid Content mL/m <sup>3</sup>
	As Received	Acid Gas Free	
H2	0.0000	0.0000	
He	0.0002	0.0002	
N2	0.0000	0.0000	
CO2	0.0000	0.0000	
H2S	0.0000	0.0000	
C1	0.0000	0.0000	
C2	0.0120	0.0120	42.6
C3	0.9816	0.9816	3605.9
iC4	0.0058	0.0058	25.3
nC4	0.0004	0.0004	1.7
iC5	Trace	Trace	0.0
nC5	Trace	Trace	0.0
C6	Trace	Trace	0.0
C7+	0.0000	0.0000	0.0
Total	1.0000	1.0000	3675.5

**Gross Heating Value - Moisture Free**  
MJ/m<sup>3</sup> @15°C, 101.325 kPa

AGA #5	AGA #5	GPA 2172	Pseudocritical Properties	
As Received	Acid Gas Free	As Received	Pressure, kPa	Temperature, K
94.85	94.85	95.46	4247	369.2

**Density - Moisture Free, As Sampled**

Ideal Gas (AGA #5)		Real Gas (GPA 2172)	
Absolute, kg/m <sup>3</sup>	Relative	Absolute, kg/m <sup>3</sup>	Relative
1.861	1.519	1.894	1.546

**Relative Molecular Mass**

Total Gas	C7+	Hydrogen Sulphide g/m <sup>3</sup>	Vapour Pressure Pentanes Plus, kPa
44.01		0.00	0

Figure A6. Typical composition of HD -5 Propane Gas used in the tests.

Note: The energy content of the Propane Gas at the standard conditions of 60°F (15°C) and 14.696 psia. (101 325 Pa) was taken to be 2518 Btu/ft<sup>3</sup>.

The composition shown in Figure A6 shows the HD-5 LPG used contains no inerts. It is seen that the fuel is composed entirely of Carbon and Hydrogen atoms, in simple structures of the form  $C_nH_{2n+2}$  which is identical to the structure of  $C_3H_8$ . Thus the percent  $CO_2$  calculation based on the percent  $O_2$  in the vent sample is literally identical to that calculated by the analyzer using its “propane” fuel setting. The formula is

$$\% CO_2 = -0.6597 (\% O_2) + 13.80$$

#### Condensate Flow Rate

The condensate was collected with a 200 ml graduated cylinder and the collection time was measured with a stop watch.

#### Pressure at Pressure Switch used to Indicate Vent Blockage

The pressure to the switch was recorded with a 0-5 in. wc Magnehelic pressure gauge (resolution 0.1 in. wc). With the non-condensing furnaces only a single tubing line is fitted between the Vent tap and the switch. In this case the Vent pressure was accessed by Teeing into this line and connecting to the Magnehelic gauge.

The condensing furnaces, however, had two lines running into the pressure switch. One line went to the outlet of the induced draft blower (Vent static pressure) and the other went to the burner enclosure box. Both lines were “Teed” into. The line going to the induced draft blower inlet was put onto the low side of the 0-5 in. wc Magnehelic pressure gauge. The line to the burner enclosure box was then fitted to the high side of the gauge.

## Supply Voltage

The supply voltage to the furnaces was controlled with a Variac, model W5MT3A. The Variac had an analog needle gauge to allow for the reading and control of the supply voltage to the furnace.

## **Appendix B: Detailed Test Procedure**

### Fuel Gas Source and Gas Input Rate Test Setups

In order to obtain data that is unaffected by differing Natural Gas and Propane Gas mixtures, a subset of test data shall be obtained with a controlled fuel gas source, such as a single tank of Natural Gas supply trucked to every test location. In the interest of minimizing the amount of tank gas required, the appliances shall be operated on local gas until data is to be taken. Then the tank gas shall be swapped on the run (without interruption of appliance operation) with the local gas for only as long as required to establish a new equilibrium and take data. Data should also be taken with the local source gas for comparative analysis. Wobbe numbers shall be obtained on all gases.

Since barometric pressure can vary over time, the actual barometric pressure shall be recorded for all tests listed. This is to provide the corresponding test altitude if found to be different from the designated test location altitude for purposes of setting rate (or derate) and analyzing results. The composition of the inlet air supply (i.e., % oxygen and water in the air by weight) shall be measured during each test. Each furnace model shall be tested at the following conditions:

- a) At sea level with factory-installed orifice(s) and factory-set manifold pressure.
- b) At natural derate with no change in orifice size or manifold pressure setting, except for the following:
  - 1. If any change to orifice size or manifold pressure is required to satisfy CAN/CGA-2.17 or ANSI Z21.47-2001•CSA-2.3-2001, they must be recorded. If the manufacturer(s) of the tested furnace(s) recommends a different derating method(s), then that method(s) shall also be tested.

2. If there is a difference in Wobbe number between sea level gas and the gas used at altitude that would affect the amount of derate observed, it must be recorded.
- c) At 4% per 1,000 ft (305 m) above sea level derate when installed above 2,000 ft (610 m). (These tests shall be conducted with adjustable orifice sizes and constant manifold pressure and with adjustable manifold pressure and constant orifice size.)
- d) Depending on the test results for conditions b) and c), at derate necessary to produce the same CO<sub>2</sub> percent at altitude as was obtained at sea level.
- e) Repeat d) to produce clean combustion per ANSI Z21.47-2001•CSA-2.3-2001, section 2.8.

#### Test Procedures – Chronological Order

#### **2.7 Category Determination and 2.38 Thermal Efficiency (ANSI Z21.47•CSA 2.3, 2.7 and 2.38)**

These two tests were run at the same time. The furnace is started with the external static pressure in the supply air duct set as close to ANSI Z21.47 requirements as possible for the test. The furnace is run until a steady state condition is achieved and then run for another 10 minutes. During this 10 minute period the gas input rate is recorded and if the furnace is condensing, the condensate flow rate is recorded as well. The DAS is run at 2 Hz during the whole test and the last 60 data points are averaged to determine the DAS collected values. Spot measurements are taken for the manifold pressure, gas inlet pressure, jacket loss temperatures, vent gas temperature, vent gas pressure and vent gas O<sub>2</sub> and CO concentrations.

Note that these two tests require different vent configurations. Vent configurations were essentially the same, but section **2.38** was used. The vent gas temperature and pressure data for **2.7 Category Determination** are listed in with the data recorded for test **2.38 Thermal Efficiency**. For a Category I furnace the vent configuration is not the same as required in **2.38**

**Thermal Efficiency**, for a Category IV furnace the configuration is slightly different. ANSI Z21.47•CSA 2.3-2001 for Gas-Fired Central Furnaces, section **2.7 Categorization** says vent pipe is 5'-0" high, insulated, with thermocouples 12" below the vent pipe outlet and a piezo ring pressure tap as shown in Figure 3. Section **2.38 Thermal Efficiency** says vent pipe is 5'-6" high and uninsulated with thermocouples 6" below the vent pipe outlet and no piezo ring. The vent configurations may not have conformed with these requirements.

### **Heat Exchanger Temperatures (ANSI Z21.47•CSA 2.16)**

Following the Category and Efficiency test a surface thermocouple was used to probe the heat exchanger hot spots to determine the maximum heat exchanger temperature. This method of temperature measurement is different from the requirements in **2.16 Allowable Heating Element Temperatures**. The recommended method is to securely fix at least five thermocouples to the area deemed to be the hottest.

### **Combustion Test I (ANSI Z21.47•CSA 2.3, 2.8.1)**

The furnace is run for 5 minutes at standard operation conditions, and the flue gas CO concentration is recorded off the gas analyzer. Following this the gas inlet pressure (the pressure in the gas meter) is adjusted to the reduced inlet pressure as per ANSI Z21.47•CSA 2.3-2001 sections **2.8.1** and **2.5.1**. The furnace is run for another five minutes at reduced inlet pressure and the flue gas concentrations are again recorded. The furnace's gas inlet pressure is then adjusted in accordance with ANSI Z21.47•CSA 2.3-2001 section **2.8.1** to give 12% over fire for Natural Gas or 9% over fire for Propane Gas and run for another 5 minutes. The flue gas concentrations are recorded. The last part of this test is to adjust the gas inlet pressure back to



the standard input value and reduce the line voltage to 85% of the line voltage ( $85\% \times 120 \text{ V} = 101 \text{ V}$ ). The furnace is operated for 15 minutes at these conditions, and the flue gas concentrations are read from the gas analyzer. The flue gas CO-AF concentration shall not exceed 0.04%.

#### **Blocked Flue Test - ANSI Z21.47•CSA 2.3-2001, 2.22.1 Draft Tests for Furnaces Not Equipped With Draft Hoods**

This is a trial and error procedure in which the flue for the active furnace is choked using a restriction to simulate a blockage. The furnace control (e.g., a flue gas pressure switch) will then cut off the fuel supply when the back pressure reaches its factory setting. Once the amount of restriction that a particular furnace could sustain is determined, the pressure at the flue switch is read off the pressure gauge that is connected to the furnace control (e.g., pressure switch) circuit. The furnace flue gas CO-AF concentration is then measured using the exact same procedure used for Combustion Test I. The values obtained are included in Tables 3 – 10.

#### **Allowable Air Temperature ANSI Z21.47•CSA 2.3-2001, 2.24**

The furnace is placed into operation and a symmetric restriction plate is placed over the circulating return air inlet of the furnace. The furnace inlet is gradually restricted until the limit switch shuts off the furnace. The room temperature and supply air temperature are recorded off the DAS to determine the maximum supply air temperature at which the limit switch shuts down the furnace. The outlet air temperature shall not exceed the maximum outlet air temperature marked on the rating plate.

**Ignition Test - ANSI Z21.47•CSA 2.3-2001, 2.10 Pilot Burners and Safety Shutoff Devices and 2.11 Direct Ignition Systems**

The furnaces were tested for ignition. Furnaces are cycled ten times for each tested gas input rate at: normal gas inlet pressure, increased gas inlet pressure, decreased gas inlet pressure, and reduced voltage. The test is done to ensure that the furnaces would reliably ignite without any abnormalities in each condition. The test result information is listed on the data sheets. Compliance was 100% at all altitudes.

## **Appendix C: Recorded Data**

A large amount of data was recorded during this field study. If printed out there would be about 200 pages of information. A compact disk located in the jacket pocket at the rear of this report contains this information.

The compact disk has instructions written on it on how to open the files. Included is a legend file giving an explanation of how to relate the titles of the files to locate a particular set of test data. The compact disk uses the master file title of:

ASHRAE RP 1182

## **Appendix D: Sample Calculation of Furnace Steady State**

### **Efficiencies and Summary Sheets**

The calculation of Steady State Efficiency (SSE) for each of the furnaces considered in ASHRAE RP 1182 was a central consideration. The following sample calculation details the steps that were taken to determine SSE for a single furnace, at one test location (Furnace A at the Fortress Mountain test site, using orifice #54 and Propane Gas). The calculations are completed in SI units and the pertinent results converted to English Engineering IP units. Tables D-1 and D-2 at the end of this section summarize the calculation results for the four test furnaces and two test fuels. The numerical values given in Tables D-1 and D-2 are English Engineering IP and metric SI units. The emissions of NO<sub>x</sub> on a mass per useful energy output basis is expressed in ng/J in order to match units used by regulatory agencies such as the California Air Resources Board [9].

Two efficiency calculations are presented. The first will be referred to as the “Combustion Efficiency” (CE) which is based on the input energy and the flue sensible and latent losses. The second will be referred to as the “Steady State Efficiency” (SSE) and it will include the jacket losses in addition to the sensible and latent losses.

### 1) Experimental Variables and Known Constants

The following list identifies each variable that was needed for the SSE calculation. This is not an exhaustive list of all the data that was recorded.

$L$  = Barometrically Derived Altitude (m or ft)

$P_{\text{atm}}$  = Atmospheric Barometer Pressure (Pa or “Hg)

$P_{\text{man}}$  = Gas Manifold Pressure (Pa or “H<sub>2</sub>O)

$T_{\text{out}}$  = Outdoor Temperature (°C or °F)

$T_{\text{room}}$  = Return Air and Room Temperature inside the Trailer were identical because of the open return used in the trailer (°C or °F)

$T_{\text{supply}}$  = Supply Air Temperature (°C or °F)

$T_{\text{flue}}$  = Flue Gas Temperature (°C or °F)

$T_{\text{hex}}$  = Heat Exchanger Temperature (°C or °F)

$T_{\text{jack}}$  = Furnace Jacket Temperature (°C or °F)

$O_2$  = Volume Concentration of O<sub>2</sub> in Flue Gas (dry basis) (%)

$CO_2$  = Calculated Volume Concentration of CO<sub>2</sub> in Flue Gas (dry basis) (%)

$CO$  = Volume Concentration of CO in Flue Gas (dry basis) (ppm)

$NO$  = Volume Concentration of NO in Flue Gas (dry basis) (ppm)

$P_{\text{flue}}$  = Flue Gas Pressure (Pa or “H<sub>2</sub>O)

$m_{\text{cond}}$  = Mass Flowrate of Condensate (kg/s or lb/hr)

There are also a number of known constants that will be used regularly throughout these calculations. For example, the molar masses of the combustion components. A brief list of constants and known values is provided in the following list.

### **Molar Masses**

M of C	12.011 kg/kmol
M of H	1.008 kg/kmol
M of AIR	28.966 kg/kmol (based on dry volume composition of 79% N <sub>2</sub> and 21% O <sub>2</sub> )
M of O <sub>2</sub>	31.999 kg/kmol
M of N <sub>2</sub>	28.013 kg/kmol
M of NO	30.006 kg/kmol
M of H <sub>2</sub> O	18.0155 kg/kmol
M of CO	28.0105 kg/kmol
M of CO <sub>2</sub>	44.01 kg/kmol
M of C <sub>3</sub> H <sub>8</sub>	44.10 kg/kmol
M of C <sub>3</sub> H <sub>6</sub>	42.08 kg/kmol
M of C <sub>4</sub> H <sub>10</sub>	58.12 kg/kmol
M of CH <sub>4</sub>	16.04 kg/kmol
M of C <sub>2</sub> H <sub>6</sub>	30.07 kg/kmol

The volume composition of Propane Gas used in this project is 92.5% C<sub>3</sub>H<sub>8</sub>, 5.0% C<sub>3</sub>H<sub>6</sub>, and 2.5% C<sub>4</sub>H<sub>10</sub>. Thus, after summing the appropriate mass fractions, the molecular weight of Propane Gas was found to be 44.347 kg/kmol. In a similar manner, the standard volume composition of Natural Gas (NG) in this project is 93% CH<sub>4</sub>, 4.5% C<sub>2</sub>H<sub>6</sub>, 1.0% CO<sub>2</sub> and 1.5%

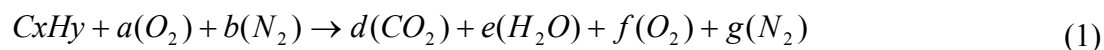
N<sub>2</sub>. Thus, after considering the mass fractions, the molecular weight of Natural Gas was found to be 17.133 kg/kmol.

## 2) Stoichiometric Calculations, Air Free CO, Air/Fuel Ratio and Equivalency Ratio

The first step in the calculation of **SSE** was the determination of the various stoichiometric quantities from the standard combustion equation. Using the measured flue gas O<sub>2</sub> concentration, the volume concentration of CO<sub>2</sub> in the combustion products was first calculated assuming excess air combustion and ignoring the small amounts of CO and NO present. Several realistic fuel compositions were tested in this calculation. It was found that the predicted concentration of CO<sub>2</sub> was almost invariant. The equations used are listed in the Manual Measurements section of Appendix A.

Recall that the calculations below follow the results for Furnace A, at the Fortress Mountain site, using orifice 54 and Propane Gas.

The standard combustion reaction is provided below in (1).



In this equation, f is known from measurements and d is calculated as above. For the case under consideration d = 10.1 and f = 5.7. Solving (1) for the unknowns gives:

$$x = d = 10.1$$

$$g = 100 - d - f = 100 - 10.1 - 5.7 = 84.2$$

$$b = g = 84.2$$

$$a = b/3.76 = 84.2/3.76 = 22.4$$

$$e = 2(a) - 2(d) - 2(f) = 2 \cdot (22.4) - 2 \cdot (10.1) - 2 \cdot (5.7) = 13.2$$

$$y = 2(e) = 2 \cdot (13.2) = 26.4$$

This also allows for the determination of the standard x/y ratio (for 100% pure  $C_3H_8$  the ratio should be equal to  $3/8 = 0.375$ ) and in this case,  $x/y = 10.1/26.4 = 0.383$ .

The Air – Free CO calculation assumes an inverse linear dependency of CO on  $O_2$  as shown in equation (2), where the volume concentration of  $O_2$  in atmospheric air is assumed to be 20.9%. Using the measured CO concentration of 60 ppm gives:

$$CO(PPM, airfree) = \frac{20.9}{20.9 - O_2} \times CO = \frac{20.9}{20.9 - 5.7} \times 60 = 83 \text{ ppm} \quad (2)$$

Next, the Air to Fuel (A/F) ratios were calculated, which includes both the stoichiometric (A/Fs) and the actual (A/F) ratios as shown below in (3) and (4). Using the results from balancing equation (1) and the molecular weights of the various combustion components produces:

$$A / F_s = \frac{4.76 \left( x + \frac{y}{4} \right) M_{AIR}}{xM_C + yM_H} = 15.56 \quad (3)$$

$$A / F = \frac{a(M_{O_2}) + b(M_{N_2})}{xM_C + yM_H} = 20.79 \quad (4)$$

Using the A/F ratios, one can calculate the Equivalence Ratio as shown in (5).

$$\phi = \frac{A / F_s}{A / F} = \frac{15.56}{20.79} = 0.75 \quad (5)$$

The Equivalence Ratio has no direct input into the **SSE** calculation except as an easy method of checking whether the combustion reaction is fuel lean ( $\phi < 1$ ) or fuel rich ( $\phi > 1$ ).

### 3) Mass Flow Rates of Fuel, Air, and Flue Gases (moist and dry components)

The Volume flow rate of fuel ( $Q_{fuel}$ ) was measured using a calibrated dry gas meter. The meter was located out side the trailer. Thus the density of the fuel in the meter varied with

atmospheric conditions. The meter was temperature compensated to 60°F or 15.6°C, so the indicated volumes were at this temperature. The meter was calibrated and found to read fast by 0.3% (See Figure A4 in Appendix A for Calibration Certificate). The indicated rates were adjusted accordingly.

The fuel density in the gas meter was determined using the Ideal Gas law and measured pressures and temperatures as in (6).

$$\rho_{FUEL} = \frac{P_{atm} + P_{line}}{T_{out} \left( 8314 J / kmol / K / MW_{ofFuel} \right)} = \frac{82.5 kPa}{270.6 K \left( 8314 J / kmol / K / 44.347 kg / kmol \right)} = 1.626 kg / m^3 \quad (6)$$

where: the outdoor temperature ( $T_{out}$ ), the atmospheric pressure ( $P_{atm}$ ), gas line pressure upstream of the meter ( $P_{line}$ ) and the molecular weight (MW) of the fuel are known. The fuel density was calculated for each individual test as there were daily variations due to local pressure and temperature changes.

The mass flow rate of fuel ( $m_{fuel}$ ) is then simply calculated by multiplying the measured volume flow rate of fuel ( $Q_{fuel}$ ) from Table D-2, converted into S I units, times the calculated fuel density from (6) as shown in (7).

$$Q_{fuel} = 0.013 \text{ ft}^3 / s \times 0.02832 \text{ m}^3 / \text{ft}^3 = 0.00037 \text{ m}^3 / s$$

$$m_{fuel} = \rho_{fuel} (Q_{fuel}) = 1.626 kg / m^3 (0.00037 \text{ m}^3 / s) = 0.00060 kg / s \quad (7)$$

In a similar manner, the mass flow rate of the air ( $m_{air}$ ) can be calculated using  $m_{fuel}$  and the A/F ratio that was determined using equation (4). The  $m_{air}$  is calculated using (8).

$$m_{air} = m_{fuel} \times A / F = 0.00060 kg / s \times 20.79 = 0.0125 kg / s \quad (8)$$



The mass flow rate of the flue gases ( $m_{FLUE}$ ) is simply the sum of the fuel and air flow rates that were determined from (7) and (8), as shown below in (9).

$$m_{FLUE} = m_{air} + m_{fuel} = 0.00060 \text{ kg/s} + 0.0125 \text{ kg/s} = 0.0131 \text{ kg/s} \quad (9)$$

The amount of moisture in the flue gas was determined by multiplying the mass flow rate of the flue gas by the mass fraction of water (in the flue), as shown below in (10).

$$\begin{aligned} m_{H_2O} &= \frac{m_{FLUE} \times \left(\frac{e}{113.2}\right) M_{H_2O}}{\left(\frac{d}{113.2}\right) M_{CO_2} + \left(\frac{e}{113.2}\right) M_{H_2O} + \left(\frac{f}{113.2}\right) M_{O_2} + \left(\frac{g}{113.2}\right) M_{N_2}} \dots \\ &= \frac{0.0131 \times \left(\frac{13.2}{113.2}\right) 18.0155}{\left(\frac{10.1}{113.2}\right) 44.01 + \left(\frac{13.2}{113.2}\right) 18.0155 + \left(\frac{5.7}{113.2}\right) 31.999 + \left(\frac{84.2}{113.2}\right) 28.013} \\ &= 0.000953 \text{ kg/s} \end{aligned} \quad (10)$$

This does not correspond to the amount of water that was condensed out of the high efficiency furnaces; that flow rate was experimentally monitored in a separate process. This is a measure of the total moisture in the combustion products due to the conversion of H in the fuel to  $H_2O$  during the combustion process. It will later be used to calculate energy losses. In a similar manner, the mass flow rate of the dry components of the flue gases ( $m_{DRY}$ ) can simply be calculated as shown in (11).

$$m_{DRY} = m_{FLUE} - m_{H_2O} = 0.0131 \text{ kg/s} - 0.000953 \text{ kg/s} = 0.012147 \text{ kg/s} \quad (11)$$

#### 4) Energy Losses (dry and moist flue gas components) and Energy Gain (condensing only)

The determination of the energy losses for each furnace and the energy gain that occurs in the high-efficiency condensing furnaces provides the remaining variables needed to solve for the combustion efficiency, **CE**. To begin, it is necessary to calculate the energy loss associated

with the dry flue gases. This is found using the energy equation which is common to each furnace. The first step is to recall the combustion equation, (1), and use it to determine the mass fraction of CO<sub>2</sub>, O<sub>2</sub> and N<sub>2</sub> in the flue gases when all of the water is neglected. This is accomplished by considering the ratio of the d, f and g components from (1) to their sum, resulting in the following mass fractions:

$$mf_{CO_2} = \frac{101,000}{1,000,000} M_{CO_2} \quad mf_{O_2} = \frac{57,000}{1,000,000} M_{O_2} \quad mf_{N_2} = \frac{842,000}{1,000,000} M_{N_2}$$

The specific heats of CO<sub>2</sub>, O<sub>2</sub> and N<sub>2</sub> were calculated using 3<sup>rd</sup> order polynomial equations from standard references. For example for N<sub>2</sub> the variation of Cp with temperature is given by:

$$Cp_{N_2} = 28.90 - 0.1571 \times 10^{-2} (T) + 0.8081 \times 10^{-5} (T)^2 - 2.873 \times 10^{-9} (T)^3 \quad (12)$$

where the T is in K. For the specific example being considered the flue temperature is 319.15 K, thus the Cp of N<sub>2</sub> is:

$$Cp_{N_2} = 28.90 - 0.1571 \times 10^{-2} (319.15) + 0.8081 \times 10^{-5} (319.15)^2 \dots$$

$$\dots - 2.873 \times 10^{-9} (319.15)^3 = 1.040 \text{ kJ / kgK}$$

In a similar manner the Cp of the other dry flue gas components (O<sub>2</sub> and CO<sub>2</sub>) were solved. The total Cp of the dry flue gas components was then determined using the various specific heat values and the appropriate mass fractions.

$$Cp_{DRY} = Cp_{N_2} (mf_{N_2}) + Cp_{CO_2} (mf_{CO_2}) + Cp_{O_2} (mf_{O_2}) \dots \quad (13)$$

$$Cp_{DRY} = 1.040 \text{ kJ / kgK} \left( \frac{842,000}{1,000,000} \right) + 0.864 \text{ kJ / kgK} \left( \frac{101,000}{1,000,000} \right) + \dots$$

$$\dots 0.926 \text{ kJ / kgK} \left( \frac{57,000}{1,000,000} \right) = 1.0156 \text{ kJ / kgK}$$

The sensible energy loss of the dry components of the flue gas can then be determined using (14), as shown below.

$$\begin{aligned} Q_{DRY} &= m_{DRY} (Cp_{DRY T_f} x T_{flue} - Cp_{DRY T_r} x T_{room}) \\ &= 0.0122 \text{ kg/s} (1.0156 \text{ kJ/kgK} \times 319.5 \text{ K} - 1.01 \text{ kJ/kgK} \times 293.82 \text{ K}) = 0.32 \text{ kW} \end{aligned} \quad (14)$$

The next step is to calculate the total energy loss (sensible and latent now) associated with the moisture in the flue gases. In carrying out this calculation it is necessary to determine the enthalpies of steam and water at the test conditions, especially when at high altitudes. The appropriate values were obtained by interpolating points in standard steam tables. The  $h_{fg}$ , and  $Cp$  of  $H_2O$  at  $T_{flue}$  and local atmospheric pressure ( $P_{atm}$ ) and the saturation temperature of water ( $T_{sat}$ ) at local atmospheric pressure ( $P_{atm}$ ) were determined in this manner. It was then possible to calculate the energy losses of the wet components using these properties and the calculated mass flow rate of  $H_2O$  in the flue gas, as is shown in (15).

$$\begin{aligned} Q_{WET} &= m_{H_2O} \left[ Cp_{H_2O} \Big|_{T_{flue}} \times T_{flue} - Cp_{H_2O} \Big|_{T_{sat}} \times T_{sat} + h_{fg} + 4.186(T_{sat} - T_{room}) \right] \\ Q_{WET} &= 0.000953 \text{ kg/s} \left[ 1.877 \text{ kJ/kgK} \times 319.15 \text{ K} - 1.897 \text{ kJ/kgK} \times 366.3 \text{ K} \dots \right. \\ &\quad \left. + 2275.4 \text{ kJ/kgK} + 4.186 \text{ kJ/kgK}^2 (366.3 \text{ K} - 293.82 \text{ K}) \right] \dots \\ &\quad \dots = 2.36 \text{ kW} \end{aligned} \quad (15)$$

The final variable needed to calculate **CE** is the energy gain that occurs from condensing some of the moisture out of the flue gas; note this only occurs in the high – efficiency condensing Furnaces A and B. To complete the calculation of  $Q_{GAIN}$  one needs to consider the amount of condensate that occurred. Recall that the mass flow rate of condensate ( $m_{cond}$ ) was experimentally measured. Thus the energy gain can be calculated from (16), as

$$Q_{GAIN} = m_{cond} \times h_{fg} = 0.00029 \text{ kg/s} \times 2275.4 \text{ kJ/kg} = 0.66 \text{ kW} \quad (16)$$

where 2275.4 kJ/kg is the latent heat of evaporation of water at 11.5 psia (the local atmospheric pressure during the test).

### 5) Combustion Efficiency

At this point all the energy losses from the furnace to the out doors have been evaluated, as well as the gains from the condensation of part of the moisture in the flue gases. The **CE** for each of the furnaces at each test condition is obtained using (17).

$$CE = \frac{Q_{in} - Q_{DRY} - Q_{WET} + Q_{GAIN}}{Q_{in}} = \dots \quad (17)$$

$$\dots \frac{34.88kW - 0.31kW - 2.36kW + 0.66kW}{34.88kW} = 94.24\%$$

Thus, the Combustion Efficiency in this case (Furnace A, Propane Gas, Orifice 54, tested at Fortress Mountain) is 94.24%. Note in Table D-2 (end), first line, the Combustion Efficiency listed is listed as 94.1%. The slight difference in the values is due to round off errors and approximated values used in the hand calculation here versus the spread sheet. Similar calculations were completed for each of the four furnaces at all the test sites.

### 6) Steady State Efficiency

The Steady State Efficiency (**SSE**) is simply the Combustion Efficiency (**CE**) minus the heat losses from the jacket of the furnace to the surroundings, expressed as a percentage of the energy input rate. Following the procedure outlined in **Exhibit K** of **ANSI Z21.47•CSA 2.3-2001**, the jacket losses are evaluated using (18)

$$Hs = [hc + hrs] \times As \times [T_{jack} - T_{room}] \quad (18)$$

where:

$H_s$  = heat loss, W (Btu/hr),

$h_c$  = coefficient of convection for the surface,  $W/m^2 \cdot ^\circ C$  (Btu/hr $\cdot$ sq.ft $\cdot$  $^\circ F$ ),

$h_r$  = coefficient of radiation for the surface,  $W/m^2 \cdot ^\circ C$  (Btu/hr $\cdot$ sq.ft $\cdot$  $^\circ F$ ),

$A_s$  = area of group,  $m^2$  (sq.ft),

$T_{jack}$  = averaged temperature of the surfaces in the group,  $^\circ C$  ( $^\circ F$ ), and

$T_{room}$  = temperature of room,  $^\circ C$  ( $^\circ F$ ).

The values of  $h_c$  and  $h_r$  are obtained for Figure K1 and Figure K2 respectively. The latter is for an ideal radiator (black body). To correct this value to be more representative of a painted engineering surface **Exhibit K** recommends using an emissivity value of 0.87. To find the representative values of  $h_c$  and  $h_r$  from the Figures one needs the average surface or jacket temperature and the surrounding air or room temperature. For the test furnace and operating conditions being analyzed in this example the average jacket temperature was found to be  $36^\circ C$  ( $96.8^\circ F$ ) while the room air temperature was measured as  $23^\circ C$  ( $73.4^\circ F$ ). With these temperatures the values of  $h_c$  and  $h_r$  were found to be  $3.4 W/m^2 \cdot ^\circ C$  and  $5.6 W/m^2 \cdot ^\circ C$  respectively. The latter value has been corrected using the suggested value of emissivity.

For Furnace A the jacket surface area was estimated to be  $2.7 m^2$  ( $28.6 ft^2$ ). The open areas in the walls of the furnace where the return and supply air ducts connect are not included in the area estimate.

Substituting the values into equation (18) produces an estimated jacket loss of 292 W. For the test conditions, from equation (14),  $Q_{in} = 34.88$  kW. Thus the jacket losses represent 0.84% of the input energy. Subtracting 0.84% from the Combustion Efficiency (94.24%) gives the Steady State Efficiency as 93.40%.

## 7) **Flue Loss Calculations Using Exhibit J**

Exhibit J lists formulas for calculating the flue loss as a percent of heat input rate in both IP and SI units. No background information is provided as to the assumptions made in deriving these equations or their origin. Nomographs are provided for use in lieu of the equations for two different fuels; Natural Gas and Propane HD-5. Limitations on the use of the nomographs are given. In particular the Heating value (gross), Specific gravity and Ultimate carbon dioxide must fall within the ranges stated for the two fuels.

While not specifically mentioned it is apparent that the nomographs are not applicable to condensing furnaces. Thus one can not use them to check on the SSE calculation illustrated here. To illustrate, one needs the carbon dioxide concentration in the flue gases as a percent and the difference between the flue gas temperature and the room temperature. For the Furnace A calculation the oxygen content of the flue gases was measured to be 5.7% while the temperature difference between the flue gas and the room was 46°F. This latter temperature difference is not available on the line given in Figure J2 for Propane HD-5. Thus no intersection with the flue loss line is possible.

The nomographs do work well for the mid efficiency, non-condensing furnaces, such as Furnaces C and D. Consider Furnace C on Natural Gas at Sea Level (Vancouver). From Table D-1 the oxygen content in the flue gases was measured to be 10.2% and the temperature

difference was found to be 215°F. Using the equation for Natural Gas in Appendix A, the carbon dioxide content is calculated to be 6.1%. From Figure J1, the flue loss is about 17.5%, giving a CE of 82.5%. The Combustion Efficiency arrived at using the detailed calculation procedure for this furnace is 81.8% in Table D-1. These efficiencies are within 1% of each other. Checks using Propane Gas, Furnace D and other altitudes showed the same level of agreement for the mid efficiency furnaces.

### 8) **Estimated Systematic Error in Steady State Efficiency**

An estimate of the uncertainty in the evaluation of steady state efficiency can be made by rewriting the equation in straight forward terms as shown in (18).

$$SSE = \frac{Q_{in} - Losses}{Q_{in}} \quad (18)$$

Where Losses represents the latent and sensible energies in the flue gases relative to ambient conditions. Note that this analysis ignores the jacket losses.

The uncertainties in evaluating the **SSE** include:

- a) the energy content of the fuel (volume basis)
- b) the volume flow rate of fuel
- c) the mass flow rate of individual flue gases
- d) the specific heat of constituent flue gases and the enthalpy of the phase change of moisture

e) the temperature of the flue gases relative to room

In this study, parts a), b) and e) are subject to the largest uncertainty. The first being the energy content of the fuel on a particular test day ( $\pm 2\%$ ), the second the manual timing of the gas meter (1 part in 150) and the last being the allowance in thermocouple wire calibration ( $\pm 1^\circ\text{F}$ ).

Assuming that the uncertainties in the independent variables are all given with the same odds, then the total uncertainty in the measurement is found by taking the derivative of (18), squaring the terms, adding them and taking the square root of the sum. Taking the derivative of (18) produces:

$$d(\text{SSE}) = (-1/Q_{\text{in}}) \cdot (dL) + (L/Q_{\text{in}}^2) \cdot dQ_{\text{in}} \quad (19)$$

Squaring the individual terms, adding them and taking the square root of the sum produces:

$$d(\text{SSE}) = [((-1/Q_{\text{in}}) \cdot (dL))^2 + (L/Q_{\text{in}}^2 \cdot dQ_{\text{in}})^2]^{1/2} \quad (20)$$

where;

$d(\text{SSE})$  = derivative of **SSE**

$Q_{\text{in}}$  = energy input rate = energy content per volume X volume flow rate

$dL$  = error in measurement of Losses (uncertainty in temperature difference between flue temperature and room temperature X magnitude of the losses)

$L$  = latent and sensible losses

$dQ_{\text{in}}$  = error in measurement of energy input rate

Dividing (20) by (18) produces



$$\frac{d(SSE)}{SSE} = \left[ \left[ \frac{-dL}{Q_{in} - L} \right]^2 + \left[ \frac{LdQ_{in}}{Q_{in}(Q_{in} - L)} \right]^2 \right]^{1/2} \quad (21)$$

where;

$$\frac{d(SSE)}{SSE} = \text{total uncertainty in the measurement}$$

For a typical case (high efficiency furnace with  $SSE \approx 93\%$ ),  $Q_{in} = 120\,000$  Btu/h. The uncertainty in the Higher Heating Value of Natural Gas or Propane Gas is about 4%, while the error in timing the gas meter is only 0.7%. Thus  $dQ_{in} \approx (120\,000 \text{ Btu/h} \times 0.041) = 4920$  Btu/h.  $L = 8400$  Btu/h,  $dL = (2^\circ\text{F} / 45^\circ\text{F}) \cdot (8400 \text{ Btu/h}) = 373$  Btu/h. Substituting values into (21) gives

$$\frac{d(SSE)}{SSE} = \left[ \left[ \frac{-373}{111,600} \right]^2 + \left[ \frac{8400(4920)}{120,000(111,600)} \right]^2 \right]^{1/2} = 4.6 \times 10^{-3} = 0.46\% \quad (22)$$

This value is quite low. It illustrates that for the high efficiency furnace example selected, large errors in measurement of the losses have small effects on the overall uncertainty due to the fact that the losses are a small fraction of the total energy input.

Table D-1. Measured and Calculated Results for the Four Test Furnaces When Operated on Natural Gas

**Natural Gas**

		Barometric Altitude (ft)	Fuel Energy Input (15C base) (BTU/HR)	Orifice (size)	Atmospheric Pressure ("Hg)	Manifold Pressure ("H2O)	Room Temp. (F)	Supply Temp. (F)	Flue Temp. (F)	Temp. Rise (F)	Delta Flue (F)	Heat Exch. Temp. (F)	Jacket Temp. (F)	O2 (%)	CO (PPM)
Furnace A	Fortress	7,008	119,286	43	23.09	3.8	73	154	119	81	46	435	96	5.9	215
	Fortress	6,996	109,111	44	23.09	3.5	73	146	115	72	42	425	95	8.3	6
	Fortress	7,008	102,230	45	23.09	3.3	68	136	111	68	42	371	88	9.5	7
	Edmonton	1,990	116,093	45	27.22	3.7	72	140	112	69	40	425	95	9.6	58
	Edmonton	2,138	103,827	45	27.81	3.1	73	135	112	62	40	422	87	11.1	52
	Vancouver	-41	120,821	45	29.99	3.6	84	149	124	65	40	437	113	9.6	14
Furnace B	Fortress	6,905	38,629	43	23.18	4.3	73	126	96	53	23	456	84	7.8	26
	Fortress	6,905	34,213	45	23.18	3.9	78	123	99	44	21	442	83	10.1	2
	Fortress	6,894	27,850	47	23.18	3.9	76	112	96	37	20	408	84	12.2	5
	Edmonton	2,236	38,795	44	27.57	3.9	81	120	98	39	17	430	88	12.9	38
	Edmonton	2,079	33,034	46	27.72	3.5	63	96	79	33	16	408	72	14.9	36
	Vancouver	-32	38,971	45	29.94	3.9	91	130	108	39	17	439	103	13.0	3
Furnace C	Fortress	6,973	43,588	43	23.12	3.9	76	140	261	65	186	752	93	7.0	69
	Fortress	6,962	39,546	44	23.12	3.6	74	130	260	56	182	757	83	9.5	24
	Fortress	6,962	31,616	47	23.13	3.9	75	120	243	45	168	728	79	12.0	15
	Edmonton	1,893	41,872	44	27.91	3.9	74	128	275	54	201	730	96	11.2	64
	Edmonton	1,864	37,406	45	27.94	3.5	75	123	268	48	194	721	92	12.3	46
	Vancouver	14	42,698	44	29.94	3.9	78	142	294	63	215	744	110	10.2	12
Furnace D	Fortress	6,985	117,794	43	23.11	3.9	64	146	411	81	347	495	101	5.6	167
	Fortress	6,985	102,307	45	23.10	3.9	69	145	394	76	325	452	87	8.0	19
	Fortress	6,996	81,366	47	23.10	3.9	67	128	346	61	279	436	88	11.8	5
	Edmonton	2,118	116,243	44	27.69	3.8	68	131	421	63	353	576	91	9.0	111
	Edmonton	2,108	91,593	46	27.70	3.6	68	118	365	51	297	559	87	12.8	72
	Vancouver	5	116,356	45	29.95	3.9	79	146	430	67	351	622	101	8.5	3

Table D-1. Continued

## Natural Gas

		NO (PPM)	Flue Pressure ("H <sub>2</sub> O)	Condensate Flowrate (H <sub>2</sub> O) (ml/s)	Air Free CO (PPM)	Air to Fuel Ratio (ratio)	Fuel Flowrate (ft <sup>3</sup> /s)	Fuel Density (lbs/ft <sup>3</sup> )	Fuel Mass Flowrate (lbs/s)	Air Mass Flowrate (lbs/s)	Flue Gas Mass Flowrate (lbs/s)	Outdoor Temp. (F)	Dry Flue Gas Mass Flowrate (lbs/sec)
Furnace A	Fortress	55	0.194	0.32	300	23.0	0.031	0.037	0.0012	0.0269	0.0281	34	0.0255
	Fortress	52	0.193	0.29	10	27.0	0.029	0.037	0.0011	0.0290	0.0301	33	0.0277
	Fortress	46	0.197	0.30	84	29.6	0.027	0.038	0.0010	0.0301	0.0311	29	0.0288
	Edmonton	62	0.237	0.43	107	29.8	0.032	0.043	0.0014	0.0404	0.0417	46	0.0387
	Edmonton	43	0.225	0.33	111	34.1	0.028	0.045	0.0013	0.0429	0.0442	37	0.0414
	Vancouver	42	0.229	0.32	26	29.8	0.032	0.045	0.0015	0.0434	0.0449	67	0.0417
Furnace B	Fortress	43	0.018	0.24	41	26.0	0.010	0.036	0.0004	0.0096	0.0100	49	0.0092
	Fortress	40	0.022	0.21	4	31.1	0.009	0.036	0.0003	0.0102	0.0105	49	0.0098
	Fortress	32	0.027	0.16	77	38.1	0.007	0.037	0.0003	0.0102	0.0105	47	0.0099
	Edmonton	40	0.049	0.32	99	41.2	0.011	0.044	0.0005	0.0191	0.0195	41	0.0185
	Edmonton	31	0.040	0.30	125	54.2	0.009	0.045	0.0004	0.0218	0.0222	33	0.0213
	Vancouver	35	0.043	0.24	8	41.7	0.010	0.044	0.0005	0.0193	0.0197	76	0.0187
Furnace C	Fortress	51	-0.008		104	24.6	0.011	0.037	0.0004	0.0106	0.0110	34	0.0101
	Fortress	49	-0.012		44	29.6	0.010	0.037	0.0004	0.0115	0.0119	34	0.0110
	Fortress	36	-0.008		35	37.3	0.008	0.037	0.0003	0.0116	0.0119	34	0.0112
	Edmonton	61	-0.010		138	34.4	0.011	0.045	0.0005	0.0177	0.0182	33	0.0170
	Edmonton	44	-0.009		112	38.5	0.010	0.045	0.0005	0.0177	0.0181	33	0.0171
	Vancouver	40	-0.002		78	31.4	0.011	0.045	0.0005	0.0161	0.0166	69	0.0155
Furnace D	Fortress	64	0.008		228	22.5	0.031	0.036	0.0011	0.0254	0.0266	48	0.0241
	Fortress	56	0.011		91	26.4	0.027	0.036	0.0010	0.0256	0.0266	52	0.0244
	Fortress	40	0.018		11	36.5	0.021	0.037	0.0008	0.0292	0.0300	35	0.0282
	Edmonton	51	0.008		195	28.4	0.032	0.044	0.0014	0.0398	0.0412	39	0.0381
	Edmonton	46	0.003		186	40.8	0.025	0.044	0.0011	0.0451	0.0462	37	0.0438
	Vancouver	56	0.025		5	27.4	0.031	0.045	0.0014	0.0384	0.0398	66	0.0367

Table D-1. Continued. (End)

	Sens. Heat Loss of DRYcomp. (BTU/hr)	hfg (BTU/lb)	H2O Mass Flowrate (lbs/s)	Sens. and Lat. Heat Loss of WET comp. (BTU/hr)	H2O Mass (meas.) Flowrate lb/s	Sens. And Lat. Heat Recovery (BTU/hr)	Energy Input (BTU/hr)	Combustion Efficiency (%)	NO concentration (lbs/10 <sup>6</sup> *BTU)	Jacket Heat Loss (%)	Steady State Efficiency (%)
Fortress	1,086	1090	0.0026	9,898	7.04E-04	2,479	119,225	92.9%	4.96E-02	0.9	92.0%
Fortress	1,061	1090	0.0024	9,050	6.38E-04	2,247	109,055	92.8%	5.54E-02	0.9	91.9%
Fortress	1,118	1090	0.0022	8,571	6.60E-04	2,324	102,178	92.8%	5.43E-02	0.9	91.9%
Edmonton	1,431	1085	0.0030	11,382	9.46E-04	3,316	116,033	91.8%	8.75E-02	0.7	91.1%
Edmonton	1,505	1084	0.0028	10,586	7.26E-04	2,543	103,774	90.8%	7.31E-02	0.9	89.9%
Vancouver	1,522	1082	0.0032	12,169	7.04E-04	2,460	120,759	90.7%	6.21E-02	1.1	89.6%
Fortress	196	1090	0.0008	3,093	5.28E-04	1,859	38,609	96.3%	4.14E-02	1.2	95.1%
Fortress	188	1090	0.0007	2,728	4.62E-04	1,627	34,195	96.2%	4.63E-02	1.4	94.8%
Fortress	182	1090	0.0006	2,231	3.52E-04	1,240	27,835	95.8%	4.59E-02	1.2	94.6%
Edmonton	293	1085	0.0010	3,833	7.04E-04	2,467	38,775	95.7%	7.70E-02	0.7	95.0%
Edmonton	309	1084	0.0009	3,362	6.60E-04	2,312	33,017	95.9%	8.03E-02	0.9	95.0%
Vancouver	297	1082	0.0010	3,806	5.28E-04	1,845	38,951	94.2%	6.88E-02	1.3	92.9%
Fortress	1,751	1090	0.0009	3,848			43,566	87.1%	5.27E-02	1.4	85.7%
Fortress	1,919	1090	0.0009	3,491			39,526	86.3%	6.16E-02	0.9	85.4%
Fortress	1,754	1090	0.0007	2,770			31,600	85.7%	5.77E-02	0.9	84.8%
Edmonton	3,210	1084	0.0011	4,636			41,851	81.3%	1.18E-01	2	79.3%
Edmonton	3,094	1084	0.0010	4,129			37,387	80.7%	9.65E-02	1.5	79.2%
Vancouver	3,128	1082	0.0011	4,644			42,676	81.8%	6.87E-02	2.6	79.2%
Fortress	7,989	1090	0.0025	10,908			117,733	83.9%	6.10E-02	0.6	83.3%
Fortress	7,563	1090	0.0021	9,282			102,255	83.5%	6.24E-02	0.8	82.7%
Fortress	7,407	1090	0.0018	7,494			81,324	81.7%	6.58E-02	1	80.7%
Edmonton	12,797	1084	0.0031	13,530			116,183	77.3%	8.40E-02	0.8	76.5%
Edmonton	12,234	1084	0.0024	10,438			91,546	75.2%	1.13E-01	0.7	74.5%
Vancouver	12,302	1082	0.0031	13,500			116,297	77.8%	8.84E-02	0.8	77.0%

Table D-2. Measured and Calculated Results for the Four Test Furnaces When Operated on Propane Gas

## Propane Gas

		Barometric Altitude (ft)	Fuel Energy Input (15C base) (BTU/HR)	Orifice (size)	Atmospheric Pressure ("Hg)	Manifold Pressure ("H2O)	Room Temp. (F)	Supply Temp. (F)	Flue Temp. (F)	Temp. Rise (F)	Delta Flue (F)	Heat Exch. Temp. (F)	Jacket Temp. (F)	O2 (%)	CO (PPM)
Furnace A	Fortress	6,621	119,016	54	23.42	9.6	69	153	115	83	46	363	89	5.7	60
	Fortress	6,632	104,283	55	23.42	10	74	149	114	75	40	425	91	8.2	4
	Fortress	6,803	86,726	56	23.28	9.5	72	131	107	59	34	363	85	10.9	10
	Edmonton	2,030	116,845	55	27.77	9.5	78	150	118	72	40	436	96	9.9	52
	Edmonton	2,020	96,444	56	27.79	9.5	71	131	109	60	38	416	88	12.5	50
	Vancouver	-59	120,217	55	29.99	10	78	151	121	73	43	443	112	9.7	2
Furnace B	Fortress	6,905	39,491	54	23.18	10.5	75	136	101	61	26	445	84	7.8	9
	Fortress	6,905	34,744	55	23.18	10.5	78	134	100	56	22	434	91	9.1	1
	Fortress	6,928	28,320	56	23.16	10	72	113	94	41	22	419	79	11.3	4
	Edmonton														
	Edmonton	2,059	40,389	55	27.75	10.5	70	145	86	45	17	389	82	12.5	42
	Vancouver	5	40,785	55	29.92	10	78	123	98	45	20	455	90	12.7	2
Furnace C	Fortress	6,939	43,475	52	23.15	9.2	72	154	292	81	220	714	95	5.4	115
	Fortress	6,951	38,179	54	23.14	10.1	71	144	269	72	198	688	92	8.4	32
	Fortress	6,951	31,093	56	23.14	10.9	74	125	246	51	172	676	90	11.9	53
	Edmonton	2,187	45,071	54	27.62	10	75	130	274	56	200	713	102	9.8	53
	Edmonton	1,864	40,688	55	27.69	9.5	71	120	251	50	181	695	93	12.3	79
	Vancouver	23	46,037	54	29.91	10	78	152	301	74	223	739	110	8.7	8
Furnace D	Fortress	6,962	113,863	54	23.13	10	71	155	431	83	359	733	90	3.5	525
	Fortress	6,962	100,636	55	23.13	10.5	75	149	405	74	330	630	90	6.4	45
	Fortress	7,111	81,321	56	22.95	9.2	69	121	347	52	278	569	83	10.5	17
	Edmonton	2,138	113,850	55	27.66	10	78	145	410	67	332	723	97	8.4	64
	Edmonton	2,118	97,930	56	27.69	10	79	138	381	59	302	705	100	11.7	36
	Vancouver	5	111,776	55	29.99	10.5	90	161	436	70	346	640	102	9.1	20

Table D-2. Continued.

## Propane Gas

		NO (PPM)	Flue Pressure ("H <sub>2</sub> O)	Condensate Flowrate (H <sub>2</sub> O) (ml/s)	Air Free CO (PPM)	Air to Fuel Ratio	Fuel Flowrate (ft <sup>3</sup> /s)	Fuel Density (lbs/ft <sup>3</sup> )	Fuel Mass Flowrate (lbs/s)	Air Mass Flowrate (lbs/s)	Flue Gas Mass Flowrate (lbs/s)	Outdoor Temp. (F)	Dry Flue Gas Mass Flowrate (lbs/sec)
Furnace A	Fortress	69	0.209	0.29	83	20.8	0.013	0.101	0.0013	0.0276	0.0289	27	0.0268
	Fortress	53	0.214	0.21	87	24.7	0.012	0.101	0.0012	0.0286	0.0297	29	0.0279
	Fortress	39	0.221	0.17	21	31.0	0.010	0.098	0.0009	0.0291	0.0301	38	0.0285
	Edmonton	59	0.228	0.27	99	28.4	0.013	0.115	0.0015	0.0423	0.0438	43	0.0413
	Edmonton	41	0.020	0.23	124	36.8	0.011	0.114	0.0012	0.0444	0.0457	51	0.0436
	Vancouver	43	0.234	0.05	4	27.8	0.013	0.118	0.0016	0.0435	0.0450	71	0.0425
Furnace B	Fortress	45	0.027	0.22	72	23.9	0.004	0.096	0.0004	0.0100	0.0105	45	0.0098
	Fortress	42	0.016	0.14	2	26.5	0.004	0.097	0.0004	0.0098	0.0102	43	0.0096
	Fortress	32	0.015	0.14	9	32.1	0.003	0.097	0.0003	0.0097	0.0100	43	0.0095
	Edmonton												
	Edmonton	43	0.044	0.27	105	36.8	0.004	0.118	0.0005	0.0193	0.0198	33	0.0189
	Vancouver	29	0.049	0.25	5	37.5	0.004	0.119	0.0005	0.0200	0.0206	66	0.0197
Furnace C	Fortress	68	-0.009		155	20.4	0.005	0.099	0.0005	0.0097	0.0102	31	0.0094
	Fortress	60	-0.009		54	25.0	0.004	0.098	0.0004	0.0103	0.0107	37	0.0101
	Fortress	45	-0.009		123	34.1	0.003	0.098	0.0003	0.0114	0.0118	37	0.0112
	Edmonton	67	-0.008		100	28.3	0.005	0.116	0.0006	0.0163	0.0169	39	0.0159
	Edmonton	38	-0.008		192	35.7	0.004	0.116	0.0005	0.0185	0.0191	40	0.0182
	Vancouver	61	-0.009		14	25.6	0.005	0.119	0.0006	0.0155	0.0161	63	0.0151
Furnace D	Fortress	75	0.002		631	18.4	0.013	0.098	0.0012	0.0227	0.0239	35	0.0219
	Fortress	72	0.001		65	21.8	0.011	0.098	0.0011	0.0238	0.0249	34	0.0231
	Fortress	44	0.022		88	29.8	0.009	0.096	0.0009	0.0258	0.0266	40	0.0252
	Edmonton	72	0.023		107	25.4	0.013	0.113	0.0014	0.0360	0.0375	51	0.0350
	Edmonton	47	0.015		82	33.8	0.011	0.113	0.0012	0.0414	0.0426	51	0.0405
	Vancouver	56	0.003		35	26.5	0.012	0.116	0.0014	0.0380	0.0394	77	0.0371

Table D-2. Continued. (End)

## Propane Gas

		Sens. Heat Loss of DRYcomp. (BTU/hr)	hfg (BTU/lb)	H2O Mass Flowrate (lbs/s)	Sens. and Lat. Heat Loss of WET comp. (BTU/hr)	H2O Mass (meas.) Flowrate lb/s	Sens. And Lat. Heat Recovery (BTU/hr)	Energy Input (BTU/hr)	Combustion Efficiency (%)	NO concentration (lbs/10 <sup>6</sup> *BTU)	Jacket Heat Loss (%)	Steady State Efficiency (%)
Furnace A	Fortress	1,128	1089	0.0021	8,185	6.38E-04	2,246	118,955	94.1%	6.76E-02	0.8	93.3%
	Fortress	1,035	1089	0.0019	7,215	4.62E-04	1,626	104,230	93.6%	6.12E-02	0.8	92.8%
	Fortress	895	1090	0.0015	5,899	3.74E-04	1,317	86,681	93.7%	5.46E-02	0.6	93.1%
	Edmonton	1,521	1084	0.0025	9,496	5.94E-04	2,081	116,785	92.3%	9.07E-02	0.8	91.5%
	Edmonton	1,527	1084	0.0020	7,785	5.06E-04	1,772	96,394	92.2%	7.96E-02	0.8	91.4%
	Vancouver	1,679	1081	0.0026	9,764	1.10E-04	384	120,155	90.8%	6.71E-02	1.4	89.4%
Furnace B	Fortress	238	1090	0.0007	2,573	4.84E-04	1,704	39,471	97.2%	4.65E-02	0.8	96.4%
	Fortress	195	1090	0.0006	2,298	3.08E-04	1,084	34,726	95.9%	4.87E-02	1.6	94.3%
	Fortress	190	1090	0.0005	1,848	3.08E-04	1,085	28,306	96.6%	4.42E-02	0.9	95.7%
	Edmonton											
	Edmonton	285	1084	0.0009	3,343	5.94E-04	2,081	40,368	96.2%	8.28E-02	1.3	94.9%
	Vancouver	359	1082	0.0009	3,355	5.50E-04	1,922	40,764	95.6%	5.78E-02	1.2	94.4%
Furnace C	Fortress	1,955	1090	0.0008	3,163			43,453	88.2%	6.85E-02	1.9	86.3%
	Fortress	1,866	1090	0.0007	2,737			38,160	87.9%	7.26E-02	2	85.9%
	Fortress	1,801	1090	0.0005	2,193			31,077	87.1%	7.39E-02	1.8	85.3%
	Edmonton	2,973	1084	0.0010	4,031			45,047	84.5%	1.13E-01	2.4	82.1%
	Edmonton	3,067	1084	0.0008	3,463			40,667	83.9%	8.01E-02	2	81.9%
	Vancouver	3,179	1082	0.0010	4,050			46,013	84.3%	9.58E-02	2.7	81.6%
Furnace D	Fortress	7,592	1090	0.0020	8,826			113,804	85.6%	7.00E-02	0.6	85.0%
	Fortress	7,309	1090	0.0018	7,704			100,584	85.1%	7.95E-02	0.6	84.5%
	Fortress	6,629	1090	0.0014	5,986			81,279	84.5%	6.45E-02	0.6	83.9%
	Edmonton	11,106	1084	0.0024	10,552			113,791	81.0%	1.11E-01	0.7	80.3%
	Edmonton	11,612	1084	0.0021	8,898			97,879	79.0%	9.78E-02	0.9	78.1%
	Vancouver	12,304	1081	0.0023	10,199			111,719	79.9%	9.37E-02	0.5	79.4%

## APPENDIX E: Altitude Effects on Heat Exchanger Performance

### - Increasing Efficiency with Altitude

The heat exchangers in the furnaces tested consist of an “S” shaped hot side duct for combustion products flowing from each burner with cold circulating air flowing over the other side of the heat exchanger. The general configuration is a hybrid between conventional parallel flow (flow of both hot and cold fluid in the same direction), counter flow (the two fluids flow in opposite directions to one another) and cross flow styles (the two fluids flow at 90 degrees to one another).

The overall heat transfer in a heat exchanger is given by

$$q = U A \Delta T_{LMTD}$$

where  $U$  is the overall heat transfer coefficient,  $A$  is the surface area (for thin walled heat exchangers this area is effectively equal on either side) and  $\Delta T_{LMTD}$  is the log-mean temperature difference corrected for the counter/cross/parallel flow configuration.

Since the purpose of a residential furnace is to use hot combustion products to heat supply air, its performance can be quantified by the total amount of energy transferred ( $q$ ) to the circulating supply air for a given amount of chemical energy released by the combustion process. The effect of altitude, and thus fluid density, on the performance of the heat exchanger may be evaluated by studying the simple heat exchanger equation above.

Since for a given appliance the heat exchanger area is fixed, the overall heat transfer coefficient and the temperature differences will determine the performance. Neglecting system fouling (which is independent of altitude) and using the thin walled assumption, the overall heat transfer coefficient is given by,



$$U = \left( \frac{1}{h_i} + \frac{1}{h_o} \right)^{-1}$$

where  $h_i$  and  $h_o$  are the internal and external heat transfer coefficients respectively.

The internal flow is the hot flow of combustion products through the ‘S’ shaped duct. The most general equation predicting the heat transfer coefficient for an internal flow (Colburn [10]) predicts

$$h = 0.023 \text{ Re}^{0.8} \text{ Pr}^{1/3} k D^{-1}$$

where Re is the Reynolds number, Pr is the Prandtl number,  $k$  is the thermal conductivity and  $D$  is the duct diameter.

$$\text{Re} = V \cdot D / \nu$$

where  $V$  is the fluid velocity,  $D$  is the duct diameter and  $\nu$  is the kinematic viscosity.

$$\text{Pr} = \nu / \alpha$$

where  $\alpha$  is the thermal diffusivity of the fluid.

For gases in a residential furnace, Pr is essentially constant, as is the duct diameter,  $D$ . Thus the only parameters likely to be affected by the change of altitude in the above heat transfer coefficient equation are the velocity ( $V$ ) and the kinematic viscosity ( $\nu$ ) in the Reynolds number. The thermal conductivity  $k$  is temperature dependent only.

It is seen from this equation that

$$h \propto \left( \frac{V}{\nu} \right)^{0.8}$$

where  $V$  is the velocity in the duct and  $\nu$  is the kinematic viscosity. The velocity will only change if the change in altitude results in a significant change in the volume flow rate. On the

other hand kinematic viscosity is inversely proportional to the density of the fluid. Thus the reduction in the density that occurs with increasing altitude will result in an increase in  $\nu$ .

In order to gauge what happens to the fluid velocities inside the furnace two of the supply fans and two of the vent fans were flow tested at the Edmonton location (2,250 ft or 685 m altitude) and the Fortress Mountain location (6,600 ft or 2040 m altitude). The tests were conducted according to ANSI/ASHRAE Standard 41.2-1987 (1987), “Standard Methods for Laboratory Airflow Measurement”[6]. The resulting fan curves are shown in Figures E1 through E6. Note that the ordinate is Static Head in meters of air at local conditions.

Resistance to the moving fluid is due to both major and minor losses created by the heat exchanger geometry. Because the fluid density changes with altitude it is best to examine the fan characteristics in terms of static head of flowing fluid, not in pressure rise created by the fan. Comparing the fan curves for each fan at the two different altitudes shows that as the altitude is increased the volume flow rate of air increased for the same static head and rotational speed. Thus one would expect that the flow velocities of the gases traveling through the furnaces on the two sides of the heat exchanger to increase, resulting in higher convective heat transfer rates, improving the transfer of energy from the hot (combustion) side to the air circulation side. This will increase the steady state efficiency with increasing altitude.

To estimate the overall effect of these off setting parameters consider the following. Bernoulli’s equation for a vertical stack of uniform diameter with a hot flue gas gives

$$\rho_{atm} g h = \rho_{flue} g h + K \rho_{flue} \frac{V^2}{2}$$

where  $K$  is the combined friction and local loss coefficients combined and  $h$  is the stack height. Using the ideal gas law and assuming the flue gas and surrounding gases have essentially the same properties, the above equation can be rewritten as

$$\left( \frac{T_{flue}}{T_{atm}} - 1 \right) gh = K \frac{V^2}{2}$$

This shows that the flue velocity is very sensitive to slight changes in temperature for when the flue gas is close to ambient temperatures (high efficiency furnaces), which is, of course why fans are installed to assist when buoyancy forces are expected to be weak.

Taking into account the added pressure rise of a vent fan, which operates as an incompressible flow, volumetric flow device, the velocity will be constant for low vent temperatures (high efficiency furnaces). For furnaces of lower efficiency, there would have to be very significant changes (compared to the absolute temperatures in the above form of the Bernoulli equation) in the vent temperature as a result in altitude change for there to be a noticeable effect.

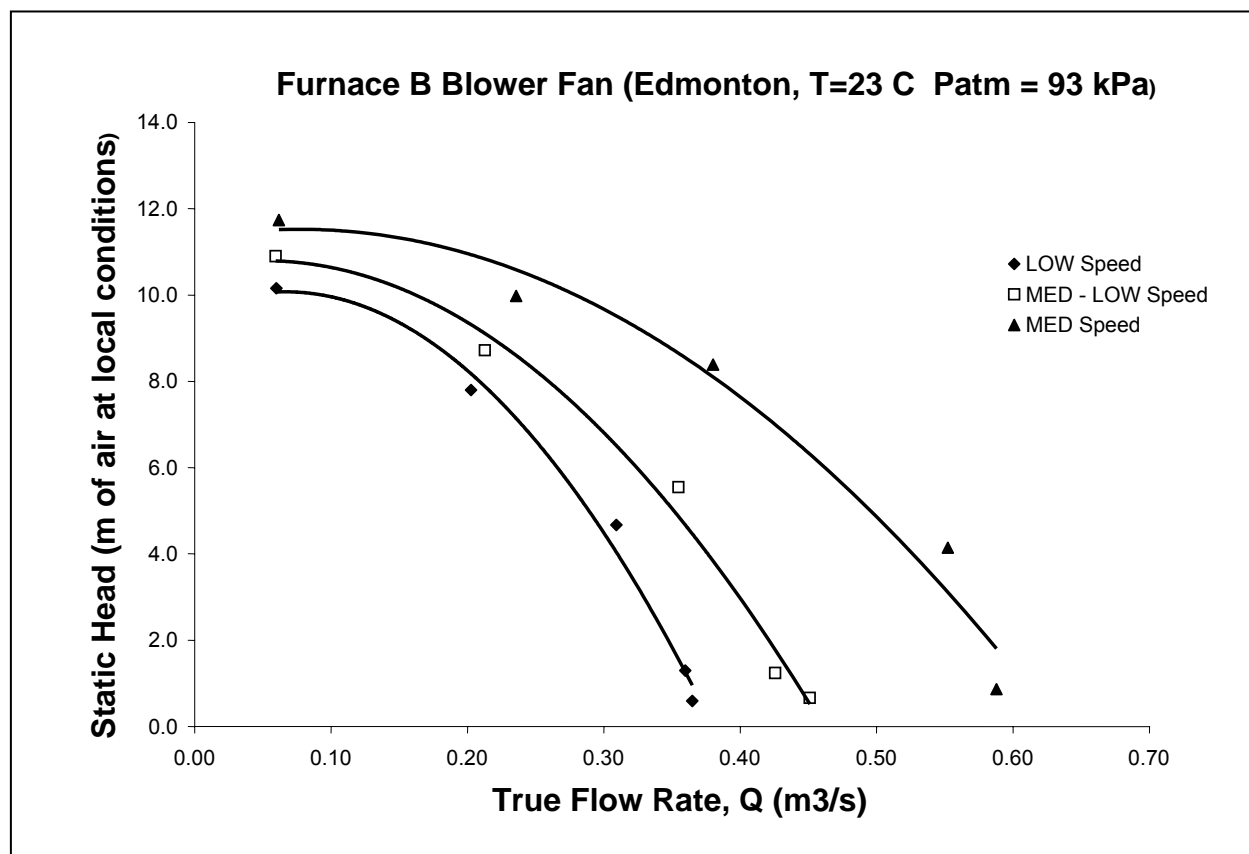


Figure E1. Flow Characteristics of Supply Air Fan for Furnace B at 2,250 ft (685 m) altitude

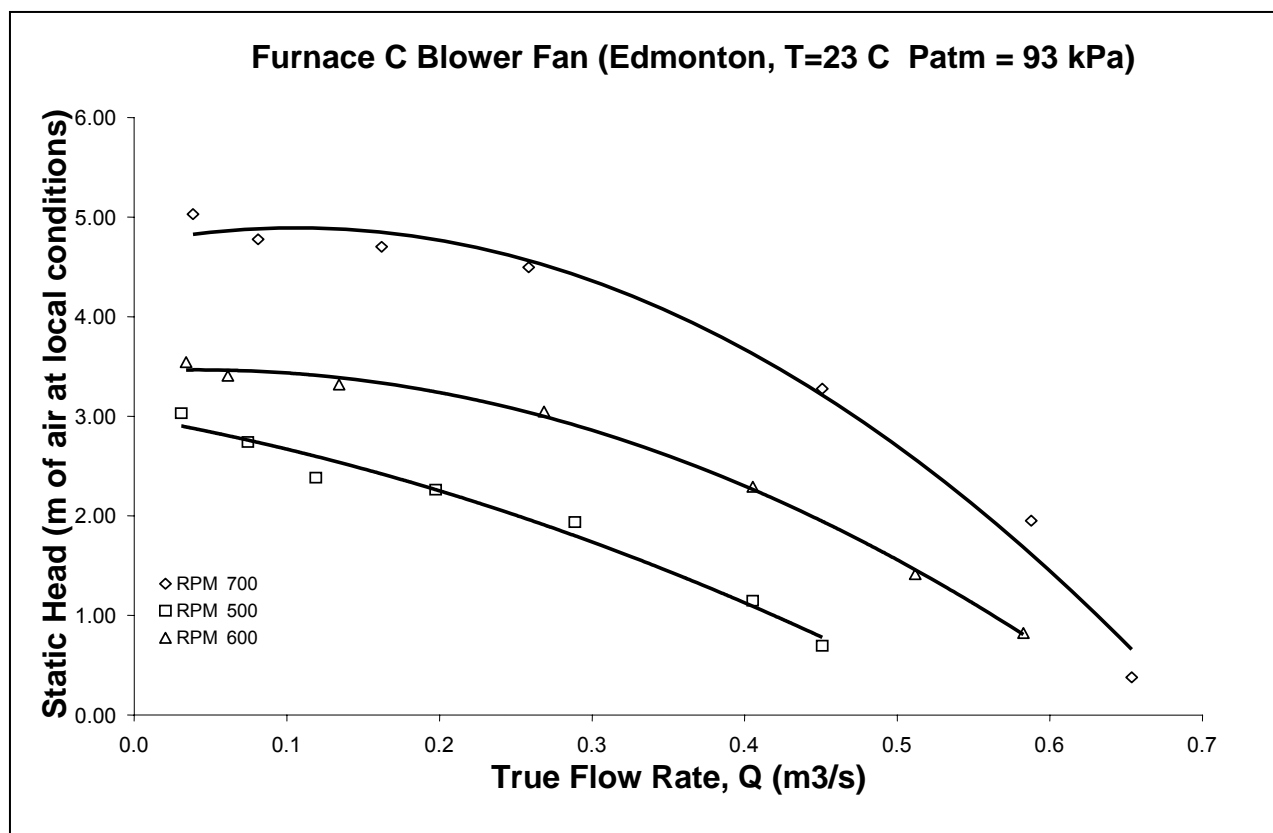


Figure E2. Flow Characteristics of Supply Air Fan for Furnace C at 2,250 ft (685 m) altitude

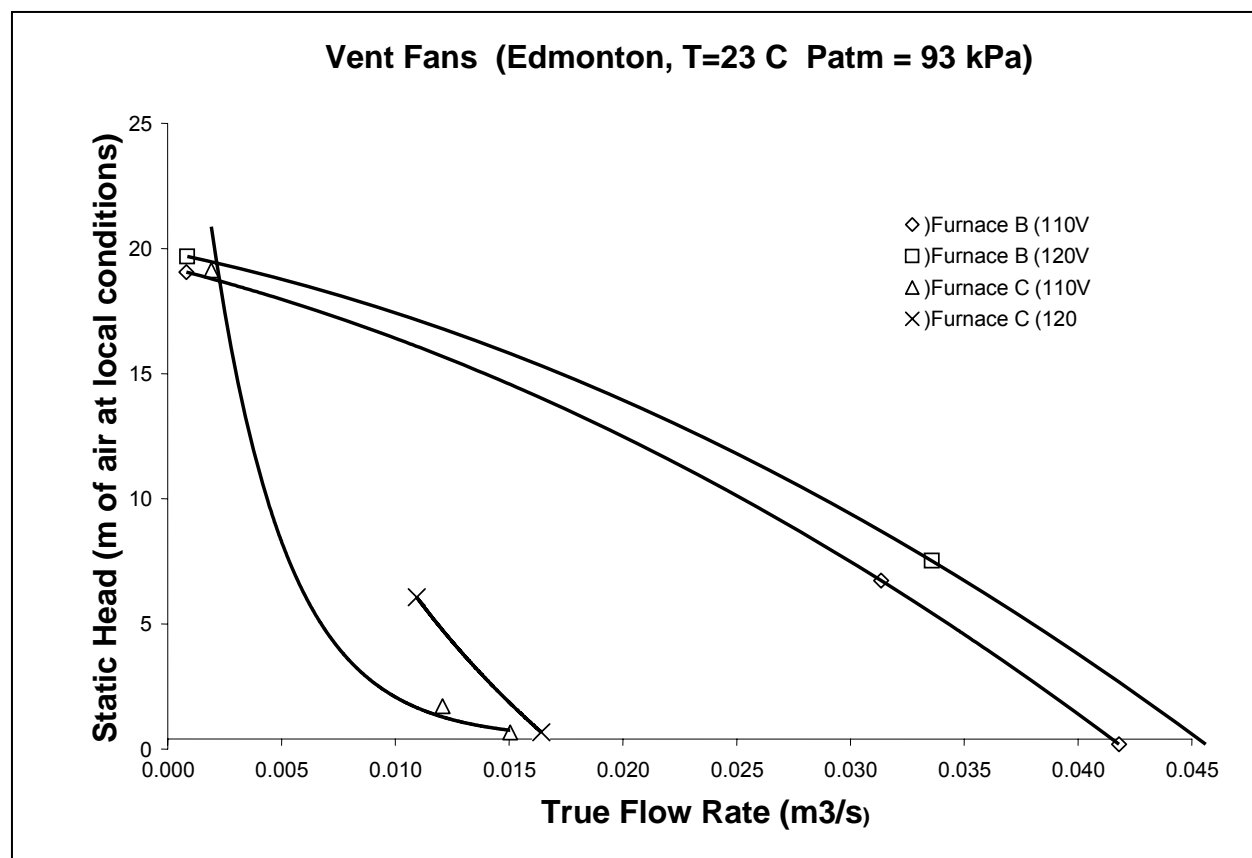


Figure E3. Flow Characteristics of two vent fans at two different supply voltages at  
2,250 ft (685 m)

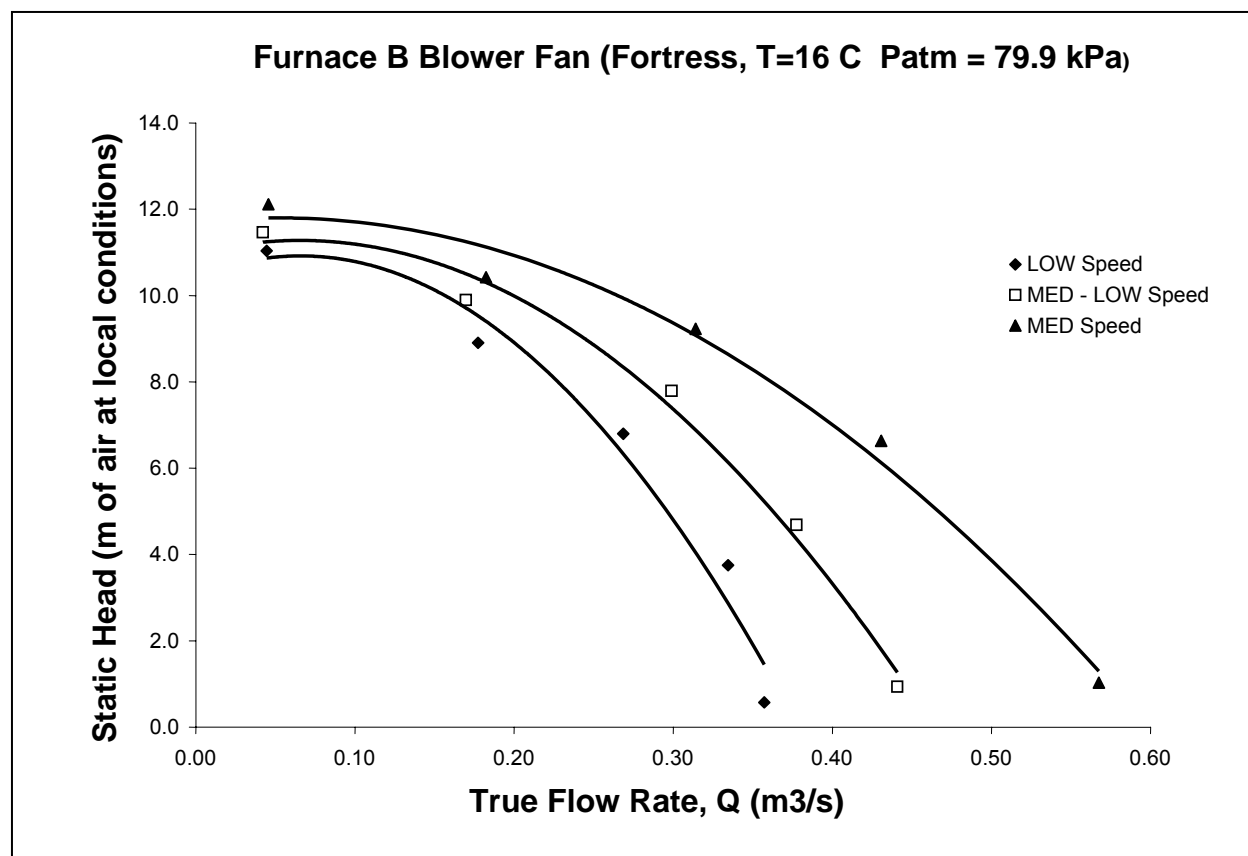


Figure E4. Flow Characteristics of Supply Air Fan for Furnace B at 6,700 ft (2040 m) altitude

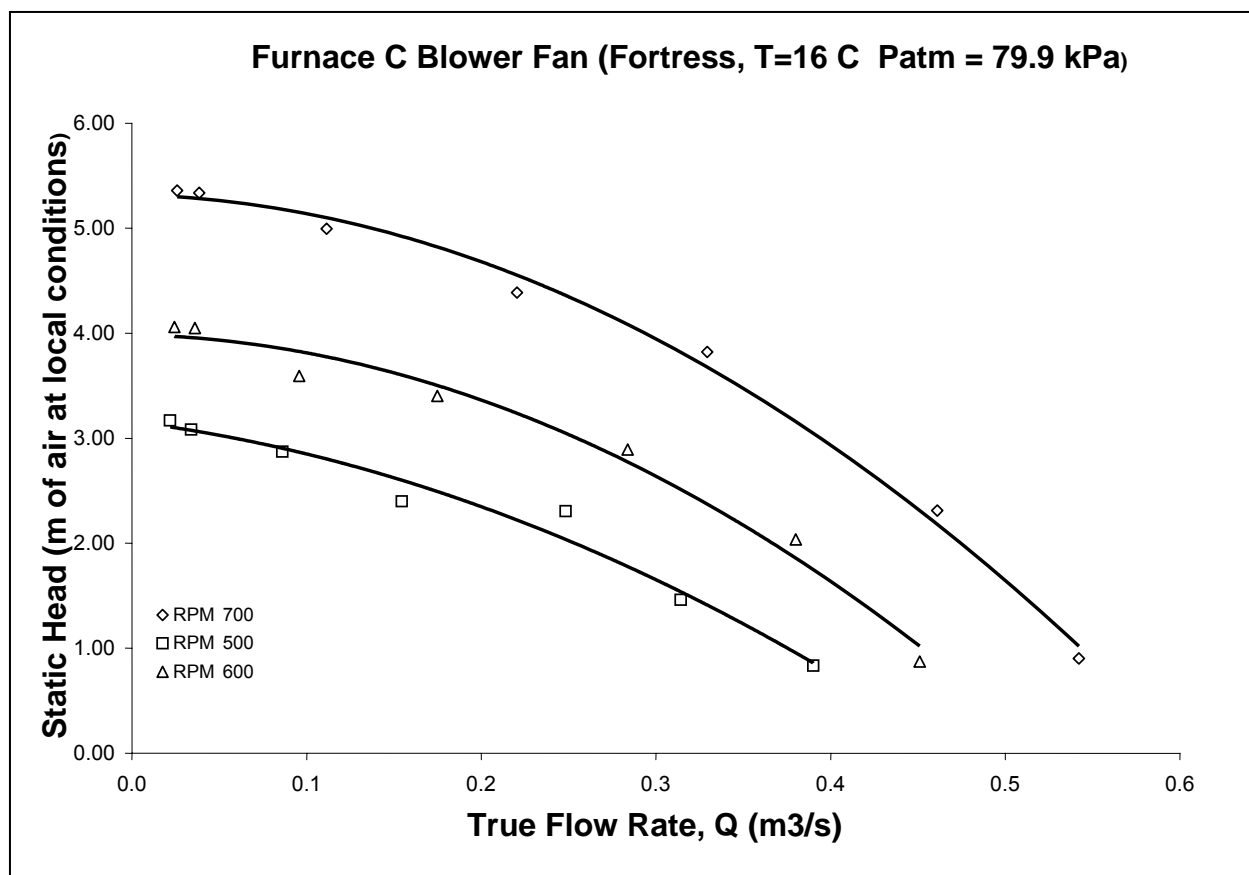


Figure E5. Flow Characteristics of Supply Air Fan for Furnace C at 6,700 ft (2040 m) altitude



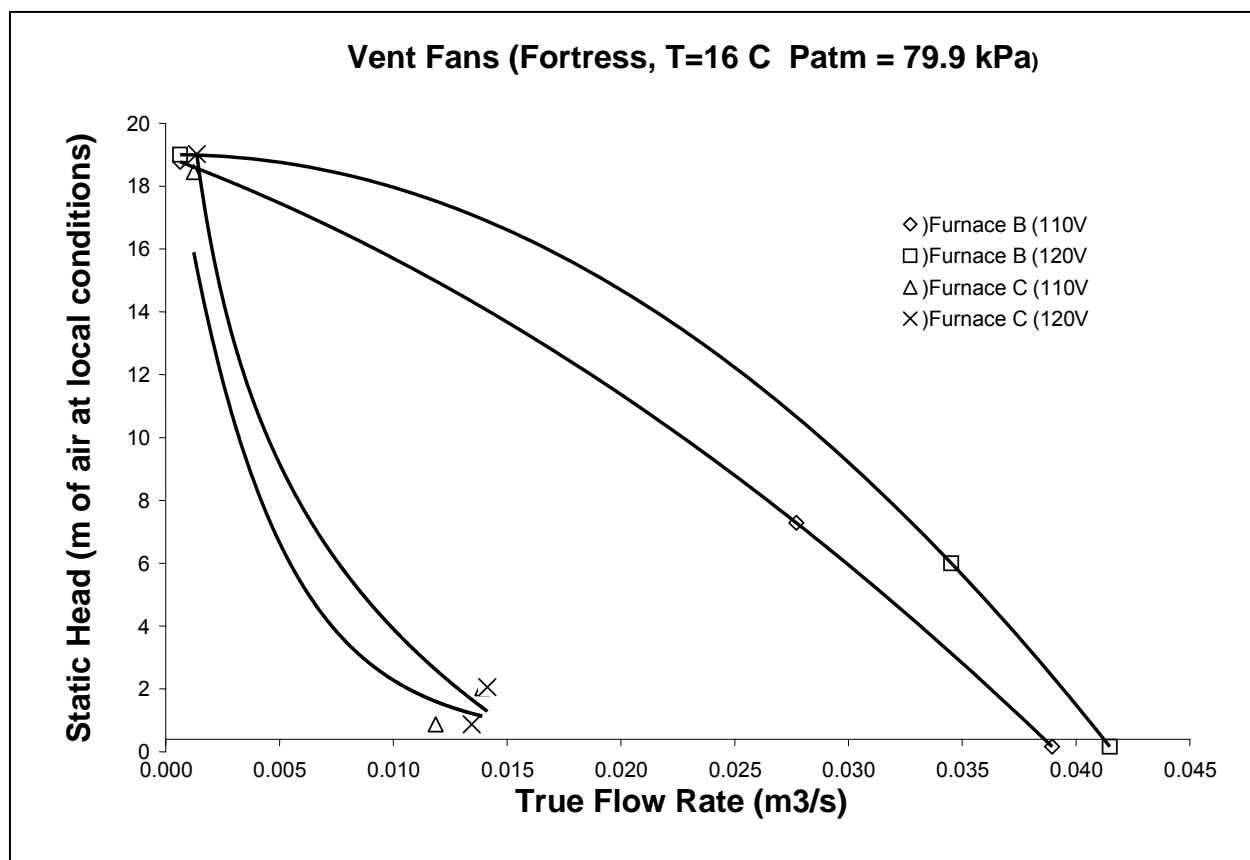


Figure E6. Flow Characteristics of two vent fans at two different supply voltages at 6,700 ft (2040 m).

If a furnace operating at higher altitude were to run with an air to fuel mixture closer to stoichiometric (compared to Sea Level operation), it will have hotter combustion gases in the heat exchanger. At an atmospheric pressure of 0.8 atmospheres (6,000 ft or 2000 m), it has been shown that a non-derated furnace with production settings will fire roughly 90% of its sea level fuel mass flow. If the system is normally run at 50% excess air, a worst case scenario (where all the air flow is dominated by the stack buoyancy and fan, and not the fuel jet entrainment) would have the high altitude system running with only 33% excess air ( $1.5 \times 0.8/0.9$ ). Based on a very simple analysis using an adiabatic flame temperature for methane, one could expect the inlet temperature to the heat exchanger to increase by 150°C due to the altitude change. This would result in roughly a 15% increase in the inlet kinematic viscosity. Based on the above analysis, this would result in a 10% decrease in the inlet hot side heat transfer coefficient.

On the cold side, the heat transfer coefficient is again dependent on Reynolds number and Prandtl number, but since the supply fan is again a volumetric flow device and the room and heated supply air temperatures are only very slightly different at different altitudes, the heat transfer coefficient on the cold side would be effectively independent of altitude.

The overall heat transfer coefficient is most affected by the lower of the outer and inner heat transfer coefficients. In a well-designed heat exchanger using the same fluid (air) on both sides, these heat transfer coefficients are of similar value. This means the 10% decrease in  $h_i$  at the inlet results in roughly a 5% decrease in  $U$  at the inlet. At the outlet, the difference would be considerably lower as the expected relative effect on the viscosity of the outlet flue gas would diminish. Thus, for the whole heat exchanger, the 20% decrease in atmospheric pressure would decrease the overall heat transfer coefficient on the order of a few percent.

Although  $U$  might decrease, the log mean temperature difference would increase. This factor is strongly dependent on the inlet temperature difference and only weakly affected by the outlet temperature difference. Using a range of example data from the experimental testing and the above assumed excess air values, the example 20% decrease in atmospheric pressure results in increased log mean temperature difference on the order of 10% or less.

Combining the rough estimates for the change in overall heat transfer coefficient and the log mean temperature difference, one can estimate a small (<5%) increase in the total heat transferred, due to a 20% decrease in atmospheric pressure.

On top of this is the additional effect of lower mass flow rates on both sides of the heat exchanger. Even if the increase in heat transferred is very small, the lower mass flow for both sides of the heat exchangers will result in high temperature changes of the flows. On the supply air side, since the temperature changes are relatively small due to the higher mass flow rate, the increased temperature rise will be nearly linear. This effect can therefore easily be estimated directly based on conservation of energy; thus the supply air will be likely to experience a temperature rise similar to the fractional decrease in density. Thus decreasing density 20% means a 20% increase in the temperature rise in the supply air.

## **APPENDIX F: Possible methods for simulating high altitudes for testing**

Because it is inconvenient to perform testing of heating appliances in laboratories at different altitudes, it would ideally be advantageous to devise a method for simulating the effect of high altitude at a sea level and other altitudes. Simply by looking at the ideal gas law, it is clear that changing the atmospheric density can be done only by changing its pressure, temperature, or molecular weight.

### **Low pressure chamber (Representing pressure simulation from ideal gas law)**

The most obvious solution that comes to mind is to construct a low pressure chamber in which to operate the furnaces as reported in Bureau of Standards Research Paper No. 553 [11]. The Canadian Gas Association had such a chamber up into the 1990's. This poses several daunting problems if an accurate simulation of high altitude performance is desired.

1. Structural requirements of the chamber
2. Cost of air decompression
3. Disruption of small combustion air and vent pressure regimes (0.005 in. wc to 2.0 in. wc) while circulating cool return air and hot supply air into and out of the chamber across a 70 in. wc differential pressure.
4. Human factors

If one considers that the highest altitudes for residential furnaces in North America at 10,000 feet (10.108 psia or 20.6 in. Hg) result in pressures on the order of 31% lower than sea level pressure, it seems logical to target design performance of a test chamber for 0.69 atmospheres. On a single 10 ft (3 m) square wall the static load due to a 0.31 atmosphere pressure difference would be 33 tons(294 kN); this is roughly equivalent to having 127 inches or 10.6 ft (3.2 m) of water loaded on every surface of the chamber. This is not impossible to overcome but would

require significant design measures to accommodate. The chamber would most likely be a domed or barrel vault shape constructed of steel or reinforced concrete. The National Aeronautics and Space Administration Wind Tunnels of Glenn Research Center in the U. S. A. (described at <http://www.nasa.gov/centers/glenn/about/fs05grc.html>) might offer ideas for such a test chamber.

The next problem arises from the need for continuous decompression of the chamber. Similar low pressure chambers in other engineering applications (such as low pressure cavitation towing tanks for naval design) are not faced with the additional problem posed by the requirements of human occupants to oversee and operate the furnace, circulation of both heated supply air and cool return air, combustion air supply, and venting of combustion products. The hot supply air side could be handled by refrigeration within the chamber to cool the heated air or simply by using large enough blowers to move the required air into and out of the chamber all the while maintaining the desired constant low chamber pressure.

The last problem arises from the fact that heating, ventilating and air conditioning (HVAC) systems are driven by particularly low pressure differentials, especially flue and vent flows driven or assisted by buoyancy. The furnace performance, and certainly its defined Category, are dependent on pressures which are minute compared to the chamber differential of 0.31 atmosphere. To overcome this, the furnace flue outlet would have to be fitted with a powerful fan with an extremely sensitive control that could push the combustion gases across the pressure differential (in excess of 127 in. wc), all the while simulating the correct buoyancy dominated flow sensitive to pressures well below a single inch of water column.

Finally, it would be difficult for an operator to work in this depressurized chamber due to altitude sickness and the need for emergency access in or out of the chamber.

**Dilution with lighter gas (Representing molecular weight simulation from ideal gas law)**

Another way to reduce the air density in an experimental chamber would be to dilute the room air with a lighter inert gas, namely helium. Helium is inert and could be added to reduce the density of gases in an enclosed chamber around the furnace. The helium would have to be provided in a mix of 79% helium and 21% oxygen so as to maintain the oxidizing potential of the atmosphere in the chamber; thus in effect one would be replacing just the nitrogen in the atmosphere. To reduce the atmospheric density by 20%, the aforementioned mix would have to make up about 30% of the gas in the chamber giving a mix roughly 24% He, 21% O<sub>2</sub> and 55% N<sub>2</sub>.

To avoid cycling very large quantities of potentially expensive gases into and out of the chamber, the supply air could be circulated through a refrigeration system within the chamber and remain within the chamber. Thus the volumetric consumption of the bottled (expensive) gas would only be about one third the vent stack flow rate.

The unfortunate problem arises with this system that the fuel gas supply would still be delivered to the laboratory at up to 13 or more in.wc above sea level atmospheric pressure (15.17 psia total pressure). To control gas inlet test pressure, a service regulator would reduce the gas pressure from 15.17 psia to as low as 10.23 psia (4.94 psi differential) gas inlet test pressure in the pipe passing into the chamber at simulated 10,000 feet altitude for 3.5 in.wc gas inlet test pressure (relative to chamber pressure) to the furnace gas control valve.

Finally, some adjustments might have to be made to the stack height or flow resistance to compensate for the fact that the hydrostatic pressure stratification outside the stack (outside the chamber) would not correspond to the helium lightened gas mixture. The lighter stack gas would

have a much greater “draw” which would have to be compensated for by a flow restriction or shorter stack.

**Increasing ambient temperature. (Representing temperature simulation from ideal gas law)**

Since the cheapest way to decrease the gas density is to heat it, some considerable thought was put to how a furnace might be operated at a higher temperature. Unfortunately, this was found to be unfeasible both because of the confounding influence it would have on heating the supply air, as well as the potential problems posed to equipment that is not designed to operate close to the boiling point of water (the atmosphere would have to be heated to near this temperature to get the 20% decrease in density). Since all of the air side components need to handle 200°F air and the lowest temperature component on the flue side is the wire present for ignition and flame sensing, this seems like something to try. Other wires could be replaced by high-temperature wire for the test. The motor, gas valve, etc. might last long enough to complete the tests. If this scheme works, it is cheaper and more convenient than on-sight high-altitude testing, or constructing and using a high-altitude chamber.

**Summary**

A simple investigation into possible methods for simulating high altitude operation at a Sea Level experimental location shows that any solution may be costly or impractical. It seems probable that the most practical solution might be to perform tests at a convenient high altitude location (perhaps Denver or Leadville, Colorado). It is the only way to ensure the altitude effects are perfectly “simulated”.

Barring this, the construction of a low pressure chamber is a significant undertaking and balancing the flue outlet pressure could prove to be extremely problematic, if not impossible.

Using helium as a diluent is sure to incur operational cost penalties that would make simple testing at a real high altitude location very tempting.