LNG Research Study

Legacy Gravity Vented Wall Furnace

September 2005

Prepared By:

The Southern California Gas Company

Engineering Analysis Center – Applied Technologies

Jorge Gutierrez

Firas Hamze

Carol Mak

Juan R. Mora

Andre Saldivar

Acknowledgements

The authors express appreciation to the following associates whose efforts contributed much to the success of this project.

Monica Clemens
David Kalohi
Johnny Lozano
Larry Sasadeusz
Rod Schwedler
Kevin Shea
Dale Tomlinson
Robert Munoz

Disclaimer

LEGAL NOTICE

The Southern California Gas Company, its officers, employees, and contractors, make no warranty, expressed or implied, and assume no legal liability for accuracy of the information contained in this report; neither do they individually or collectively assume any liability with respect to the use of such information or report or for any damages which may result from the use of or reliance on any information, apparatus, methods, or process disclosed or described in or by this report.

No information contained in this report can be copied, reported, quoted, or cited in any way in publications, papers, brochures, advertising, or other publicly available documents without the prior written permission of the Southern California Gas Company.

Table of Contents

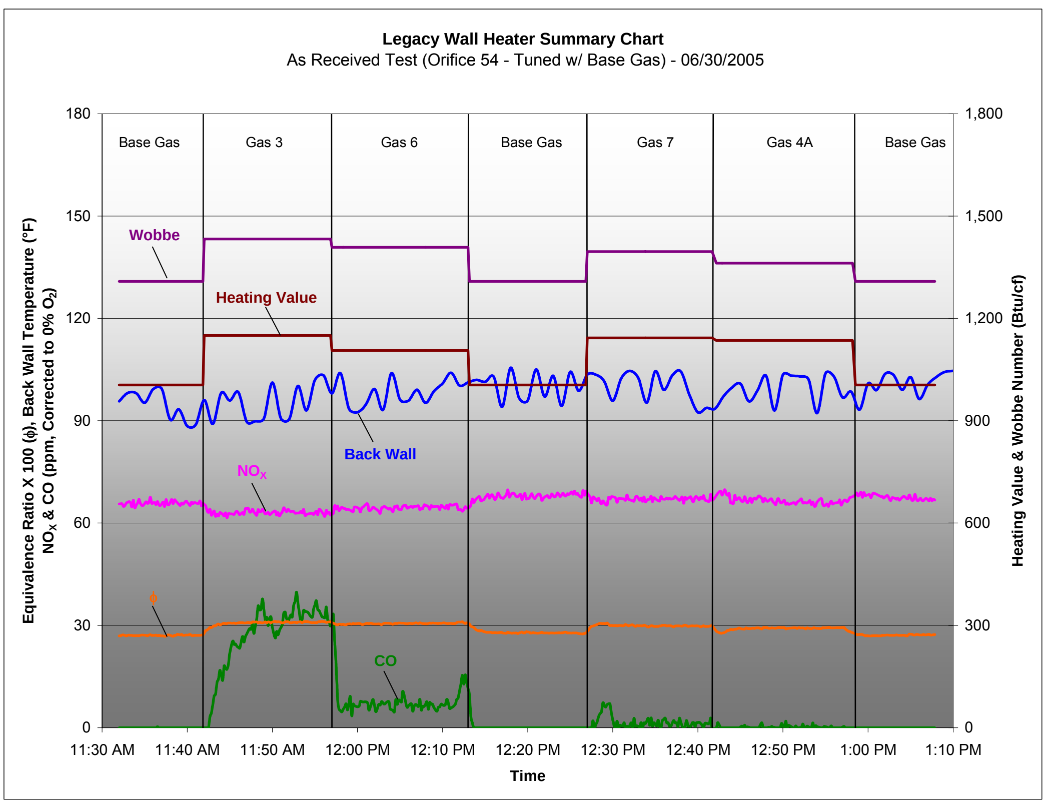
Results Summary

Results obtained from all tests conducted reveal that (a) there were no operational, ignition, flame stability, flame lifting, flashback, yellow tipping or safety problems with the different gases or during transitioning; (b) CO emissions at increased manifold pressure when tuned with either Base Gas or Gas 3 were above the ANSI Standard limit; (c) none of the temperatures monitored had critical changes and (d) unlike test results from other appliances, the flame temperature and NO_X emissions followed the opposite pattern as Wobbe Number when the unit was tuned with Base.

Results while appliance was tuned to rated input with Base Gas corroborate with results from testing conducted in October 1995 and November 2004.

As Received Test (Orifices #54 -Tuned w/ Base Gas)

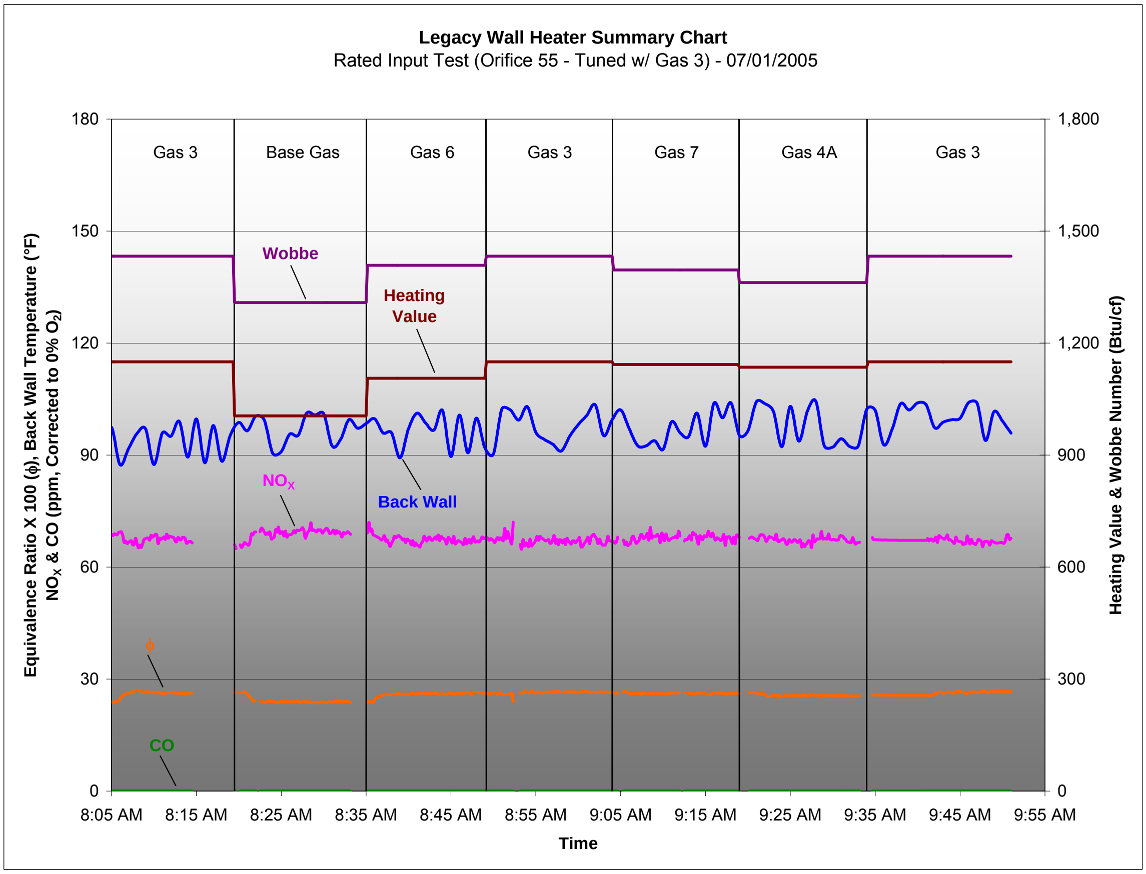
NO_X emissions (corrected to 0% O_2) were below 68 ppm for all gases tested. Base Gas NO_X emissions were highest at 67.1 ppm, but produced very low CO emissions (corrected to 0% O_2). Gas 3 had the lowest NO_X emissions at 63.0 ppm, but had the highest CO emission at 31.0 ppm. NO_X emissions and flame temperatures show an inverse pattern to the Wobbe number, while the equivalence ratio followed the same pattern as the Wobbe Number.



NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Rated Input Test (Four Orifices #55 - Tuned w/ Gas 3)

NO_X emissions (corrected to 0% O_2) and equivalence ratio were more stable than when the unit was tuned with Base Gas. NO_X emissions for Base Gas was 69.3 and 67.4 ± 0.4 ppm for all other gases. Equivalence ratio was 0.26 for all gases with the exception of Base Gas (0.24). CO emissions (corrected to 0% O_2) remained negligible throughout the course of the test.

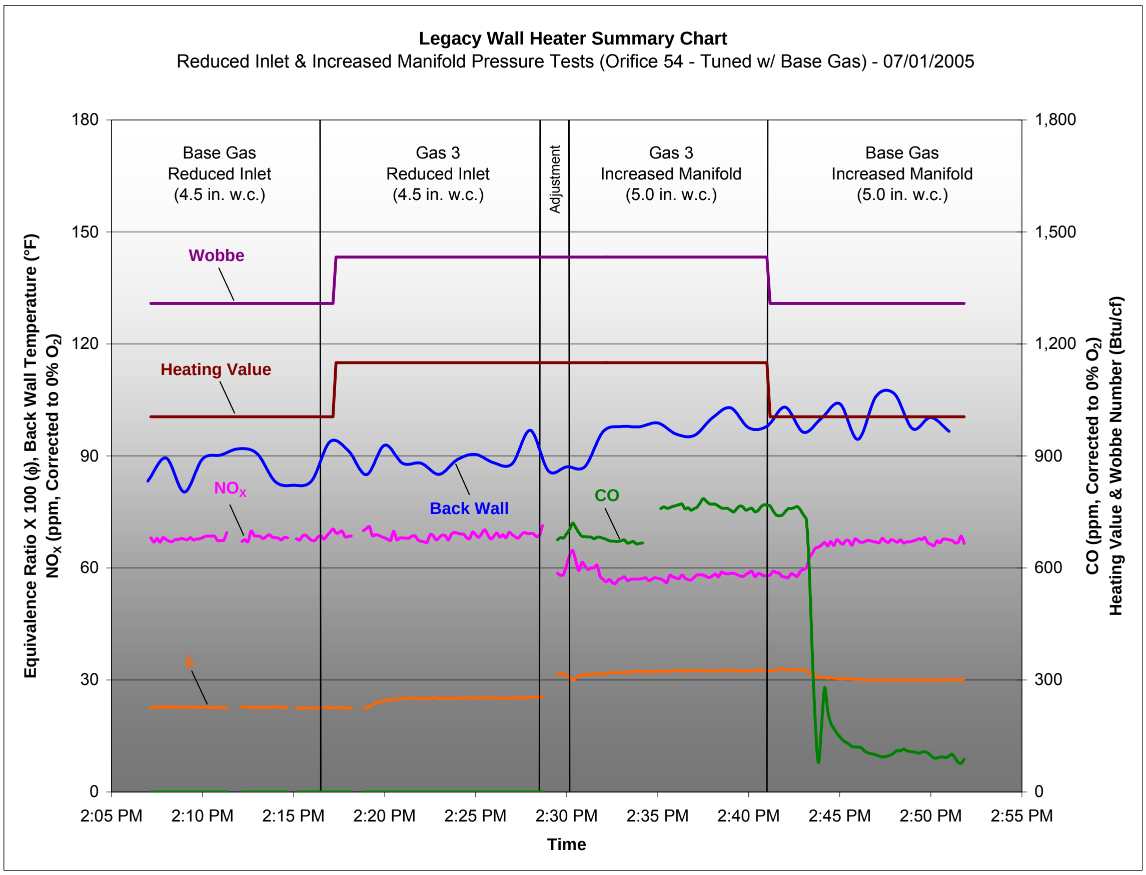


NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Reduced Inlet & Increased Manifold Pressure Tests (Orifices #54 - Tuned w/ Base Gas)

Results revealed that NO_X emissions (corrected to 0% O_2) for both Base Gas and Gas 3 decreased at increased manifold pressure. Base Gas went from 68.0 ppm at reduced inlet pressure to 66.7 ppm at increased manifold and Gas 3 went from 68.7 at reduced inlet pressure to 57.7 ppm at increased inlet pressure.

Conversely, CO emissions (corrected to 0% O_2) and equivalence ratio were highest at increased manifold pressure. CO emissions increased from 0 ppm (both gases) at reduced inlet pressure to 729.1 ppm (Gas 3) and 117.2 ppm (Base Gas). The equivalence ratio increased from 0.23 (Base Gas) and 0.25 (Gas 3) at reduced inlet pressure to 0.30 (Base Gas) and 0.32 (Gas 3).

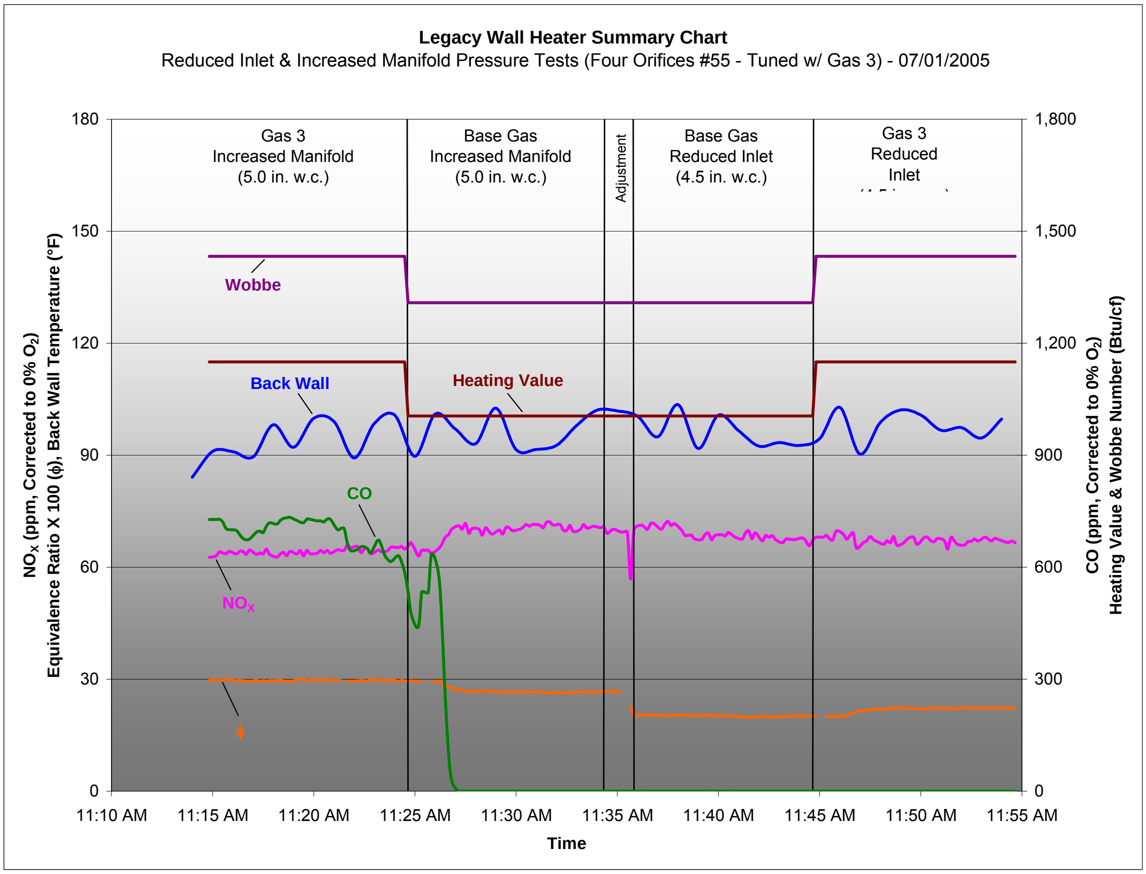


NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Reduced Inlet & Increased Manifold Pressure Tests (Four Orifices #55 - Tuned w/ Gas 3)

At increased manifold pressure, NO_X emissions (corrected to 0% O_2) for Gas 3 and Base Gas were 64.2 ppm and 69.4 ppm, respectively. At reduced inlet pressure, NO_X emissions decreased slightly for Base Gas (68.2 ppm) but increased for Gas 3 (67.3 ppm).

CO emissions (corrected to 0% O_2) were highest with Gas 3 at increased manifold pressure (689.2 ppm) and negligible for the remaining runs (0 ppm). The equivalence ratio decreased from 0.30 (Gas 3) and 0.27 (Base Gas) at increased manifold pressure to 0.22 (Gas 3) and 0.21 (Base Gas) at reduced inlet pressure.



NOTE: Emission test results are for information purposes, they were not the result of certified tests.

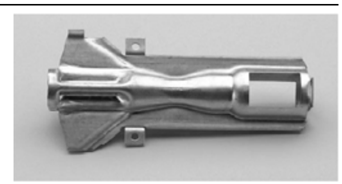
Equipment Selection Criteria

This type of (legacy) gravity vented wall furnace was selected for a third test to verify the results obtained in two previous tests (October 1995 and November 2004) and to evaluate how it will react to different test gases after tuning it with the highest Wobbe Number and highest heating value gas; Gas 3.

This wall heater is the same unit as the one tested in November 2004 but not the same as the one tested in October 1995. However, both units tested use similar controls, burners and heat exchangers.

Initially this gravity vented (legacy) wall furnace was selected because of the large number of these units in the Southern California Gas Company territory, their long life expectancy, and the potential for the heat exchangers to crack due to over firing.

Equipment Specification

Description	Gravity Vented (Legacy) Wall Furnace with a stamped steel heat exchanger vertically oriented with a draft diverter on top
Burner	4 in-shot atmospheric burners firing vertically into heat exchanger (see image on the right) 
Input rate	35,000 Btu/hr
Type of fuel	Natural Gas
Required gas supply pressure	4.5 - 10.5 in. w.c.

Standards

A detailed description of the protocol used to develop the test procedures is included in appendix A. Test protocol development was based on the following test standards.

CSA/ANSI Z21.86 - 2004	Vented Gas- Fired Space Heating Appliances
SCAQMD Method 100.1	Instrumental analyzer procedure for continuous gaseous emissions

Installation

Instrumentation was installed following the cited test standards and input from manufacturers and consultants. The gravity vented (legacy) wall furnace was installed in a wall stud space. Thermocouples were installed to measure flame, inlet air, heated air, stack, ambient, gas and wall temperatures. Also, pressure transducers were installed to measure manifold and gas delivery system pressures. A gas meter was used to measure the gas flow and an emissions probe was built and placed in the vent (Type B round) of the furnace.

Test Gases

The following gases have been specifically formulated to cover the range of gas compositions and calorific values of natural gases that could be delivered in the Southern California Gas Company territory by current natural gas suppliers and future LNG suppliers. Composition details are specified in Appendix C.

Gas	**Wobbe Number** (Btu/cf)	**Heating Value** (Btu/cf)
Base	1,330 (Low Wobbe)	1,002 (Low heat content)
3	1,436 (Highest Wobbe)	1,152 (Highest heat content)
4A	1,371 (Medium Wobbe)	1,148 (High heat content)
6	1,413 (High Wobbe)	1,107 (High heat content)
7	1,395 (High Wobbe)	1,142 (Highest heat content)

Test Procedure

Test procedures were developed based on the above test standards. However, due to differences between test standards, time limitations, and facility restrictions, the test procedures were simplified. Test procedure simplification was done with input from manufacturers and consultants in the context of developing and maintaining with input from the manufacturers and consultants that were directed to develop a sound test procedure.

Before every test the following steps were performed:

- All emissions analyzers were calibrated and checked for linearity.
- Data logger was enabled to verify temperature, pressure and gas flow readings.

During every test, the following steps were performed:

- Base and Test Gases were run continuously with switching between gases taking less than 14 seconds.
- Emissions, pressure and temperature data was observed before, during and after changeover.

After every test the following steps were performed:

- Test data was downloaded.
- Linearity and drift inspections were performed on all emissions analyzers.

As Received Test (Orifices #54 -Tuned w/ Base Gas)

Using Base Gas, an input rate of 35,000 Btu/hr ± 2 percent was achieved while inlet and manifold pressures were adjusted to 7 in. w.c. and 4 in. w.c. Once readings were stable, data collection began and the gases were run in the following order:

- Begin testing with Base Gas for 10 minutes
- Switch to Gas 3 for 15 minutes.
- Switch to Gas 6 for 15 minutes.
- Reestablish Base Gas for 15 minutes
- Switch to Gas 7 for 15 minutes.
- Switch Gas 4A for 15 minutes.
- Conclude testing with Base Gas for 10 minutes.

Rated Input Test (Orifices #55 - Tuned w/ Gas 3)

Prior to the start of the test, the #54 orifices were removed and #55 orifices were made to achieve the rated input. The size of the orifice was determined using an Orifice Drill Size Chart from Southern California Gas Company established procedures.

Using Gas 3, an input rate of 35,000 Btu/hr ± 2 percent was achieved while supply and manifold pressures were adjusted to 7 in. w.c. and 4 in. w.c. Once readings were stable, data collection began and the gases were run in the following order:

- Begin testing with Gas 3 for 15 minutes.
- Switch to Base Gas for 15 minutes.
- Switch to Gas 6 for 15 minutes.
- Reestablish Gas 3 for 15 minutes.
- Switch to Gas 7 for 15 minutes.
- Switch to Gas 4A for 15 minutes.
- Conclude testing with Gas 3 for 15 minutes.

Reduced Inlet & Increased Manifold Pressure Tests (Orifices #54 - Tuned w/ Base Gas)

For the Reduced Inlet Pressure Test, the inlet pressure was reduced to 4.5 in w.c and normal manifold pressure (4.0 in. w.c.) was maintained while operating the furnace with Base Gas. Once readings were stable, data collection began and the gases were run in the following order:

- Base Gas for 10 minutes at reduced inlet pressure.
- Gas 3 for 10 minutes at reduced inlet pressure.

After the Gas 3 run at reduced inlet pressure, the inlet pressure was adjusted back to normal pressure (7.0 in. w.c.) and the manifold pressure was increased to 5.0 in. w.c. for the Increased Manifold Pressure Test. Once steady-state conditions were achieved, testing continued in the following order:

- Gas 3 for 10 minutes at increased manifold pressure.
- Conclude testing with Base Gas for 10 minutes at increased manifold pressure.

Reduced Inlet & Increased Manifold Pressure Tests
(Four Orifices #55 - Tuned w/ Gas 3)

For the Increased Manifold Pressure Test, the manifold pressure was increased to 5.0 in. w.c. and normal inlet pressure (7.0 in. w.c.) was maintained while operating the furnace with Gas 3. Once readings were stable, data collection began and the gases were run in the following order:

- Gas 3 for 10 minutes at increased manifold pressure.
- Base Gas for 10 minutes at increased manifold pressure.

After the Base Gas run at increased manifold pressure, the manifold pressure was adjusted to normal manifold pressure (4.0 in. w.c.) and inlet pressure was decreased to 4.5 in. w.c. for the Reduced Inlet Pressure Test. Once steady-state conditions were achieved, testing continued in the following order:

- Base Gas for 10 minutes at reduced inlet pressure.
- Conclude testing with Gas 3 for 10 minutes at reduced inlet pressure.

Cold Ignition Test

The unit was tuned with each test gas. With appliance's components at ambient temperature, three ignition tests were conducted following the protocol detailed in Appendix A.

Hot Ignition Test

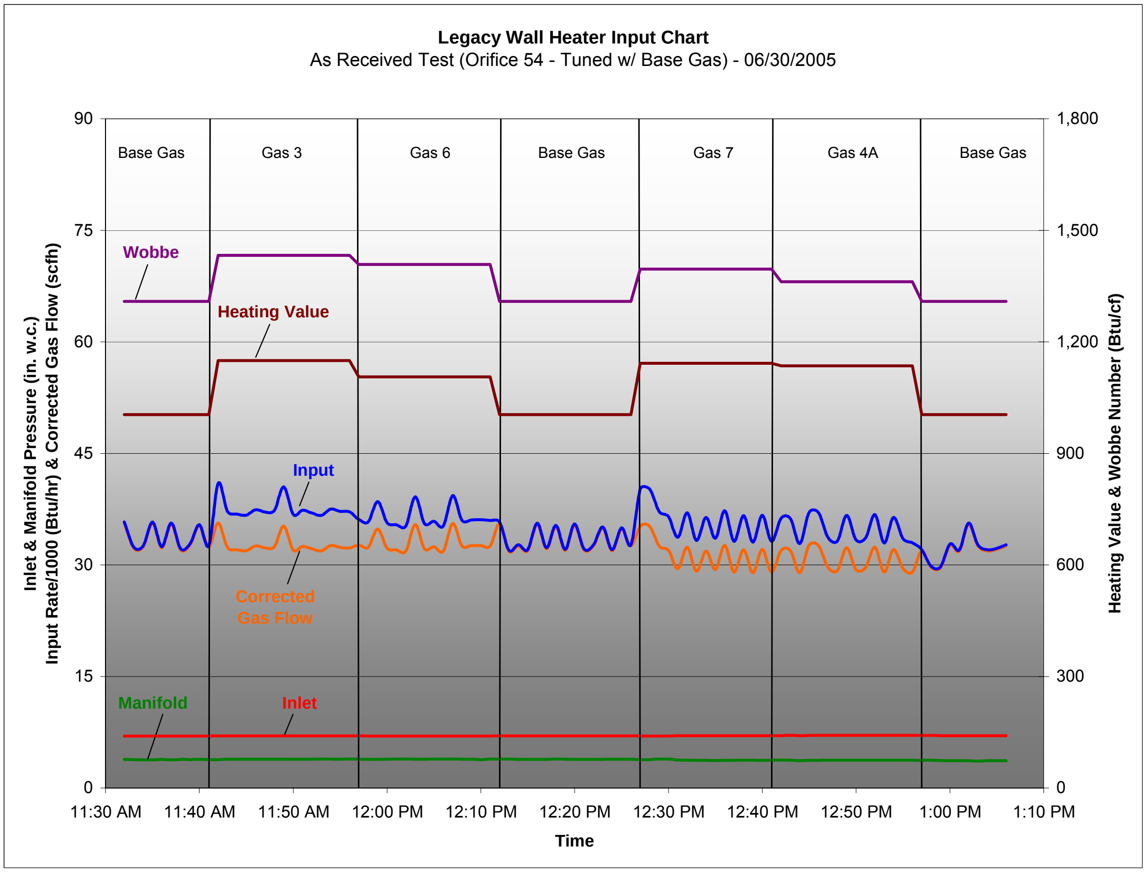
The unit was tuned with each test gas. After steady-state operating conditions were achieved, three ignition tests were conducted following the protocol detailed in Appendix A.

Results[1,2,3]

As Received Test (Tuned w/ Base Gas)

Input

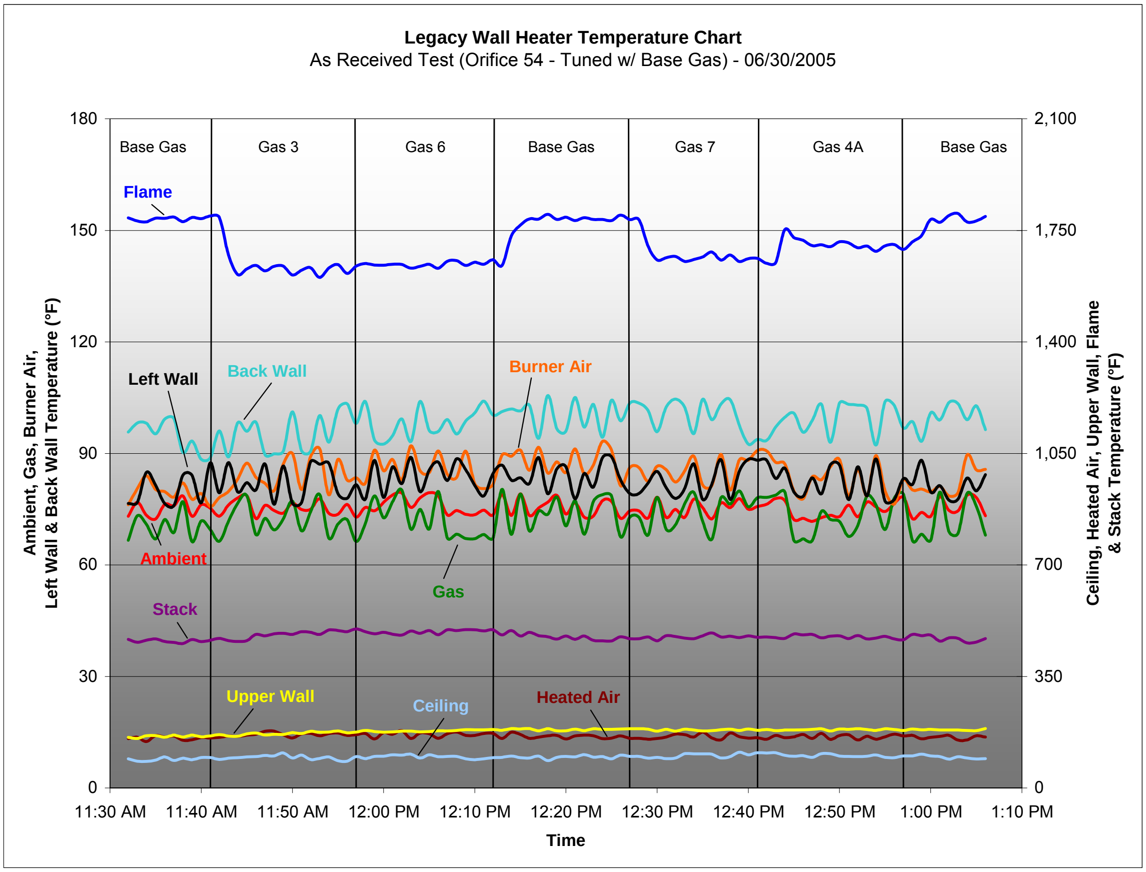
The input rate corresponded with the changes in Wobbe Number, with the minimum and maximum input rates being 33,250 Btu/hr (Base Gas) and 37,696 Btu/hr (Gas 3). The corrected gas flow ranged from 30.8 scfh (Gas 4A) to 32.8 scfh (Gas 3). Inlet and manifold pressures remained stable throughout the course of the test and within tolerances specified in the test protocol.



[1] All emissions, temperature and input values mentioned throughout the results section are average values.
[2] Emissions values are corrected to 0% O_2.
[3] When either Base Gas or Gas 3 is used as the set-up gas, the values reported for the set-up gas are the average values of all runs for that gas during each test.

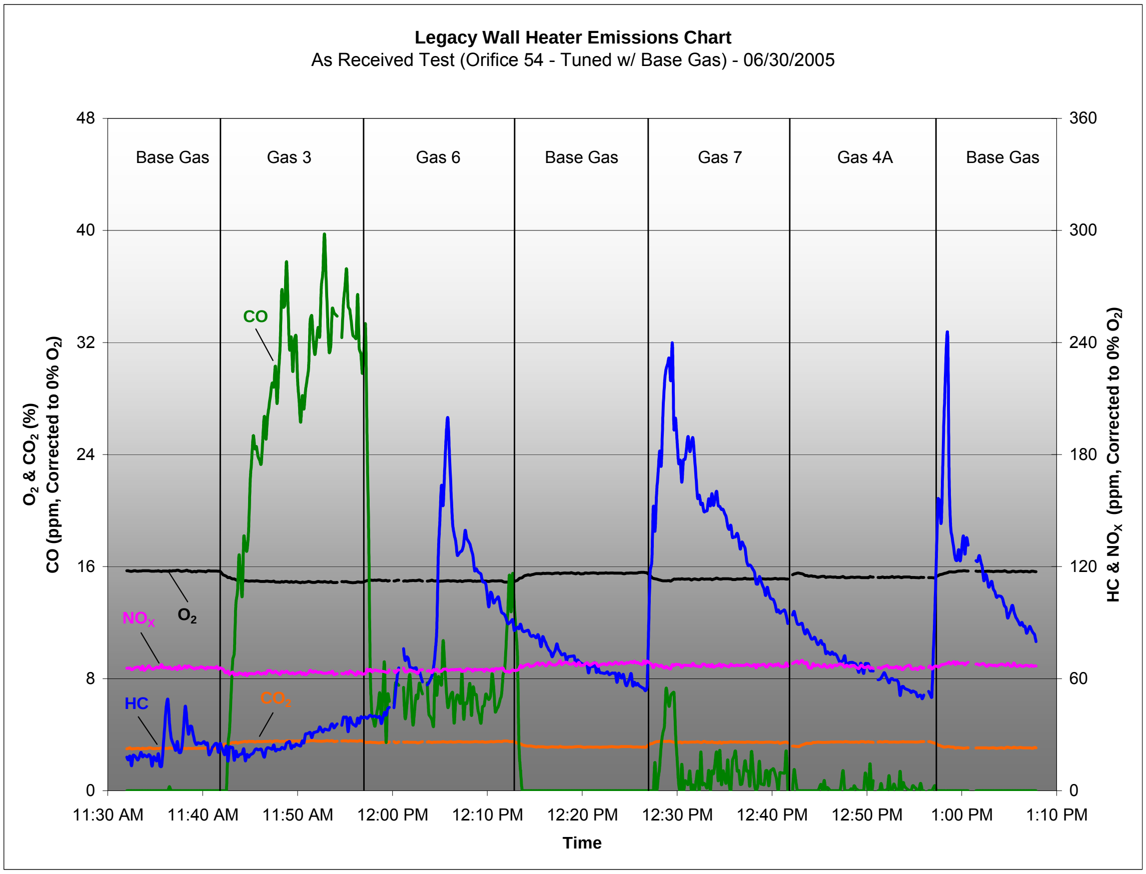
Temperatures

Results revealed flame temperatures to be highest with Base Gas at 1,772°F. The remaining gases all tested flame temperatures below 1,702°F. The back wall temperatures ranged from 95°F to 100°F. The left wall temperatures ranged from 82°F to 84°F and the upper wall temperatures ranged from 171°F to 183°F. Stack temperatures ranged from 468°F (Base Gas) to 490°F (Gas 6). Burner air, heated air and ceiling temperatures fluctuated slightly. Ambient temperature (75.0 ± 1.0°F) and gas temperature (73.0 ± 1.0°F) were steady throughout the course of the test.



Emissions

The NO_X emissions experienced small changes with the different gases tested, ranging from 63.0 ppm (Gas 3) to 67.1 ppm (Base Gas). Inversely, CO emissions were highest with Gas 3 (31 ppm) and lowest with Base Gas (0 ppm). The cause of the HC emissions spikes is unknown.

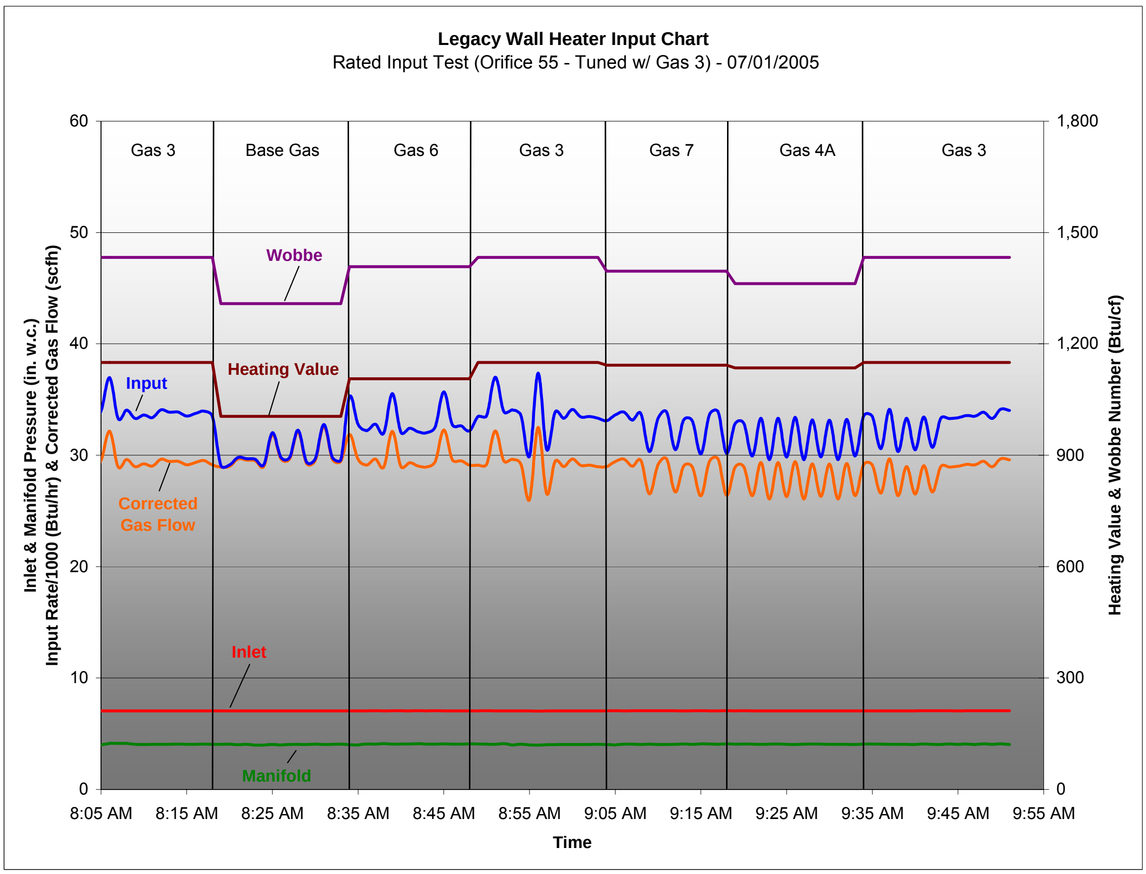


NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Rated Input Test (Tuned w/ Gas 3)

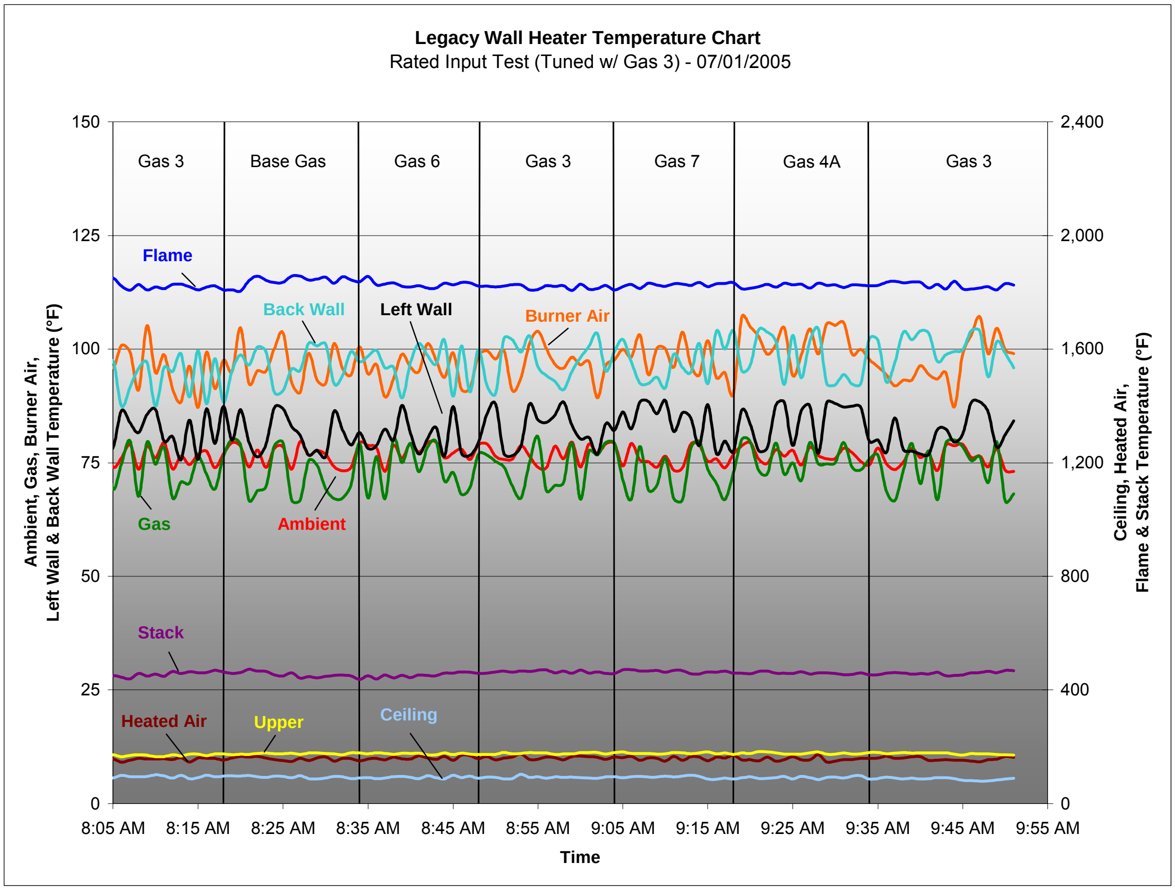
Input

The highest input rate was observed with Gas 3 (33,603 Btu/hr) and lowest with Base Gas (30,205 Btu/hr). Corrected gas flow rates had little variance. Base Gas (30.1 scfh) had the highest corrected gas flow rate and the lowest gas flow rate was with Gas 7 (28.7 scfh). Inlet and manifold pressures remained stable throughout the course of the test and within tolerances specified in the test protocol.



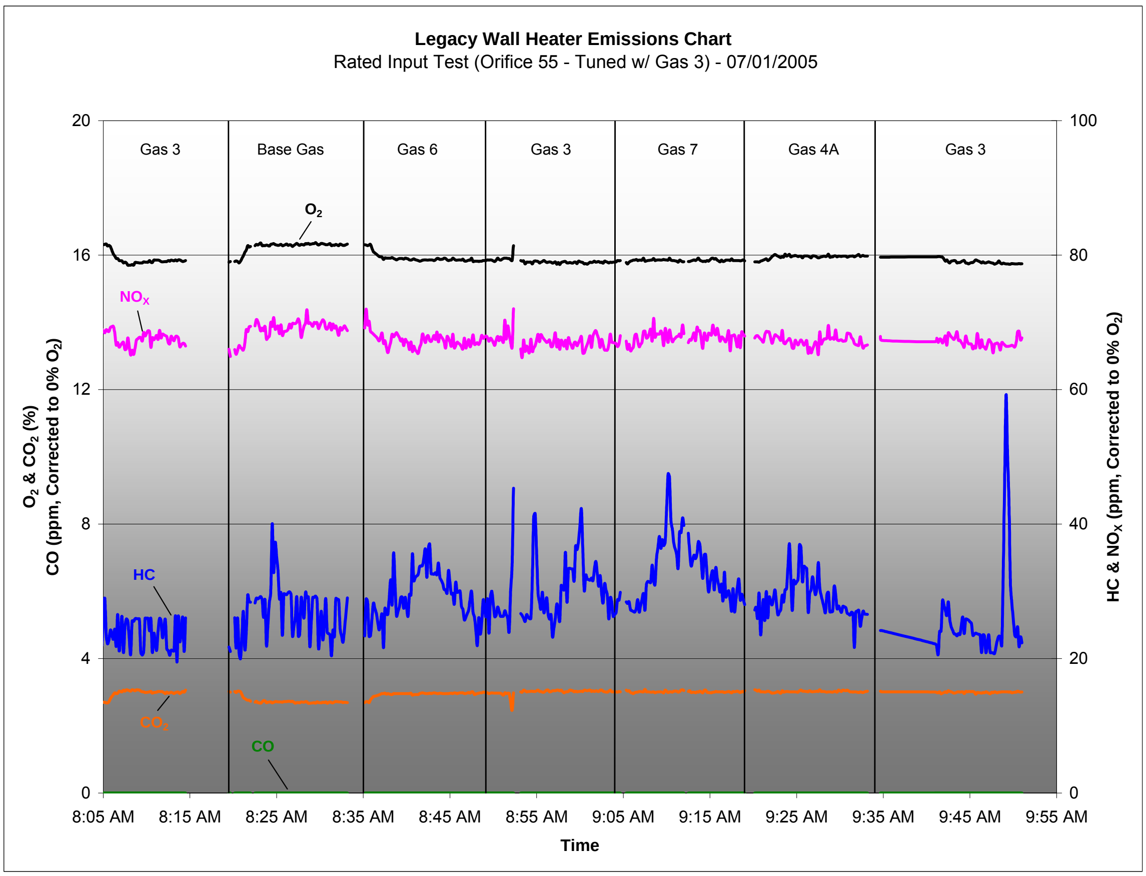
Temperatures

The highest flame temperature was observed with Base Gas (1,846°F), whereas Gas 3 (1,821°F) had the lowest flame temperature. Stack temperature was highest with Gas 7 (464.7°F) while the lowest was observed with Gas 6 (451.5°F). Temperatures from the back wall, left wall, upper wall, and ceiling, behaved similarly with all gases. Burner air was highest with Gas 4A (102.1°F) and 96.8°F ± 1.0°F with the remaining gases. Heated air ranged between 155°F and 162°F. Ambient temperature (77.0 ± 1.0°F) and gas temperature (74.0 ± 2.0°F) were steady throughout the course of the test.



Emissions

NO_X emissions for all gases (68.3 ± 1.0 ppm) were more stable than when the unit was tuned with Base Gas. HC emissions were sporadic, with the lowest range of values from the first Gas 3 run (19.5 - 29.0 ppm), and the highest range from the last Gas 3 run (20.6 - 59.2 ppm). O_2 percentage was 16.0 ± 0.3 percent for all gases and CO emissions remained negligible throughout the course of the test.

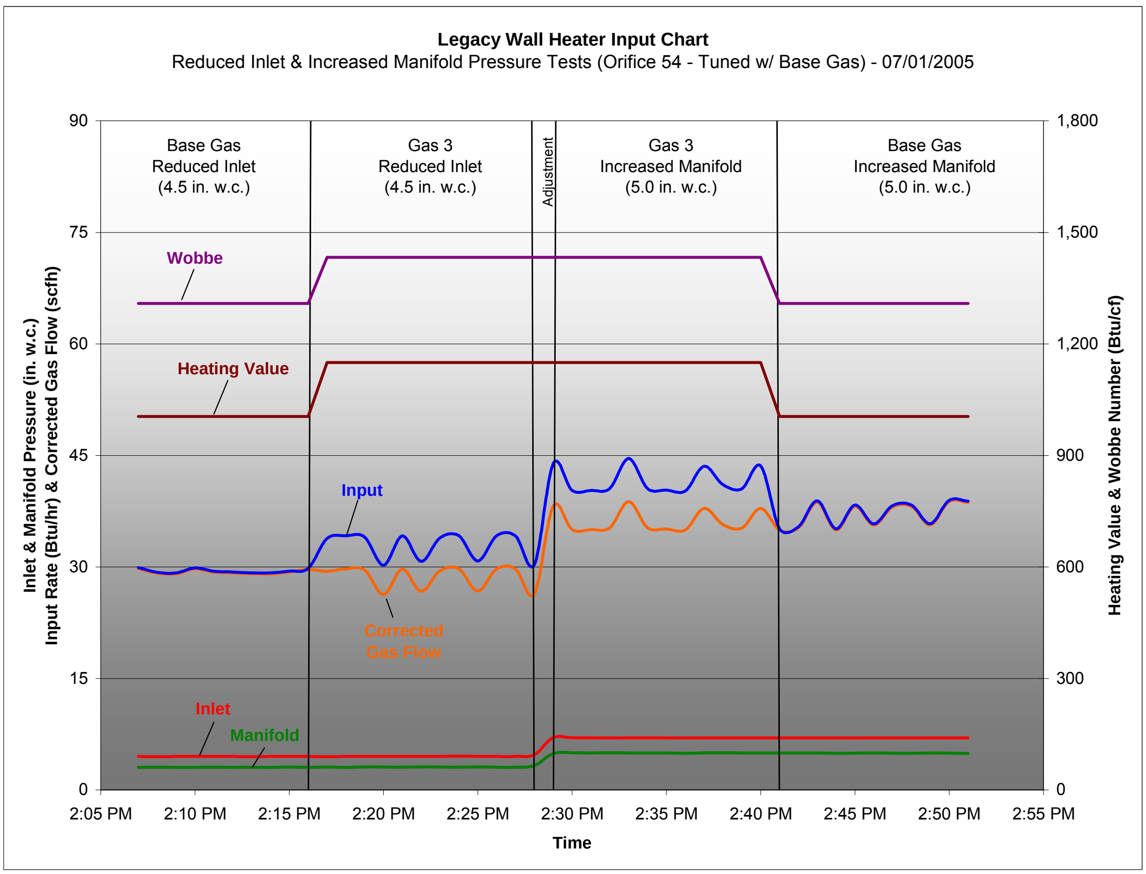


NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Reduced Inlet & Increased Manifold Pressure Tests
(Orifice 54 - Tuned w/ Base Gas)

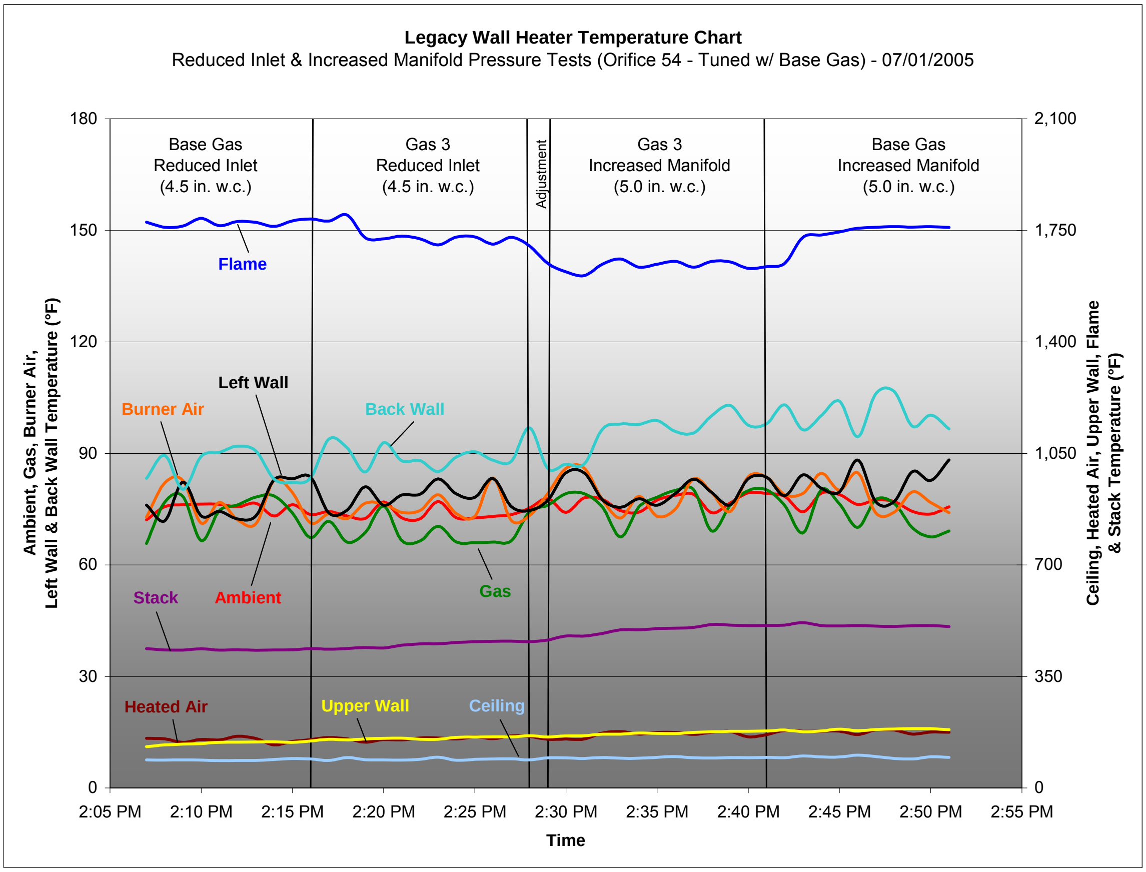
Input

The highest input and gas flow rates for both Base Gas (36,993 Btu/hr, 36.8 scfh) and Gas 3 (41,220 Btu/hr, 35.8 scfh) were observed at increased manifold pressure. The lowest input and gas flow rates for both Base Gas (29,344 Btu/hr, 29.2 scfh) and Gas 3 (33,006 Btu/hr, 28.7 scfh) were observed at reduced inlet pressure. Inlet and manifold pressures remained stable throughout the course of the test and within tolerances specified in the test protocol.



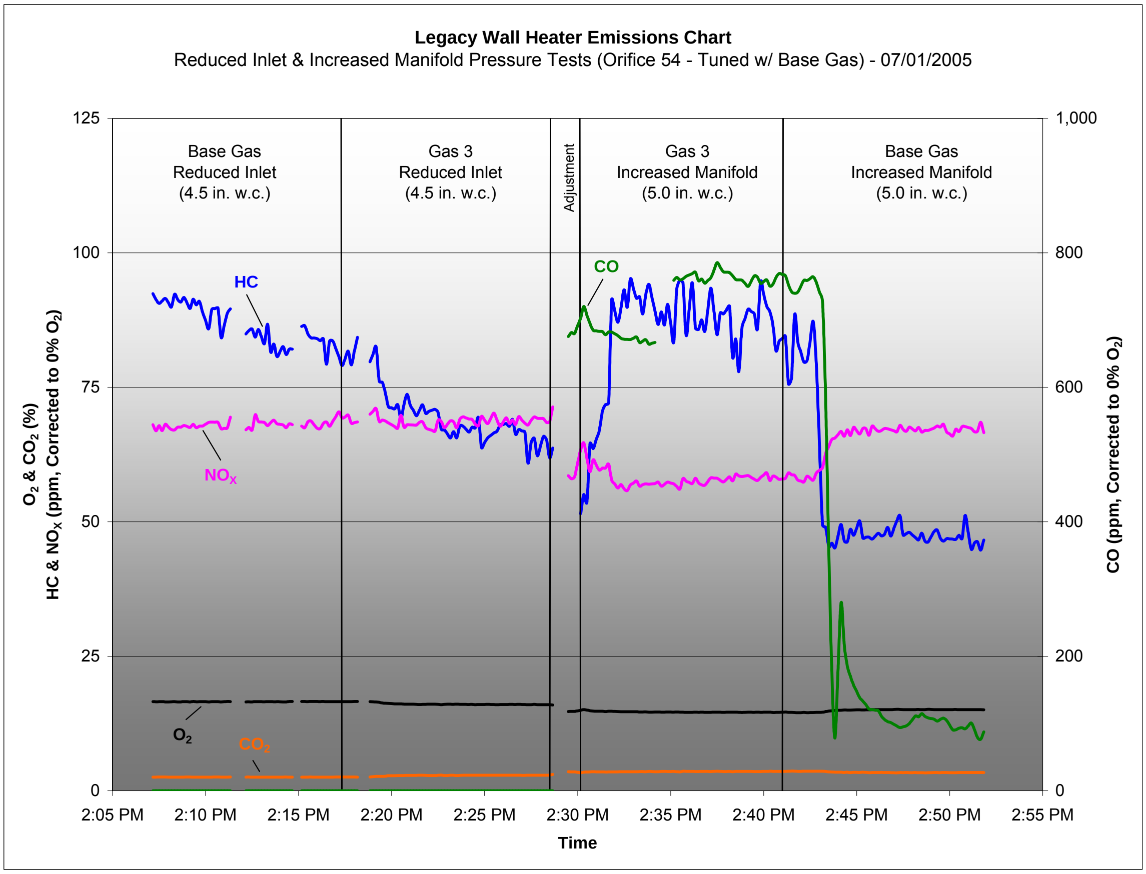
Temperatures

Flame temperature values for both Base Gas and Gas 3 decreased at increased manifold pressure, the lowest observed with Gas 3 (1,639°F). Conversely, the stack temperature rose at increased manifold pressure; the highest with Base Gas (508.3°F). The burner air and heated air temperatures also rose at increased manifold pressure. Ambient temperatures ranged from 74°F to 77°F and gas temperatures ranged from 68°F to 76°F. The highest wall temperatures and ceiling temperature was observed at increased manifold pressure.



Emissions

At reduced inlet pressure, NO_X emissions for Base Gas and Gas 3 were 68.0 ppm and 68.7 ppm. At increased manifold pressure, NO_X emissions decreased to 57.7 ppm for Gas 3 and 66.7 ppm for Base Gas. CO and HC emissions were negligible for both gases at reduced inlet pressure but increased to 117 ppm with Base Gas and 729 ppm with Gas 3 at increased manifold pressure.

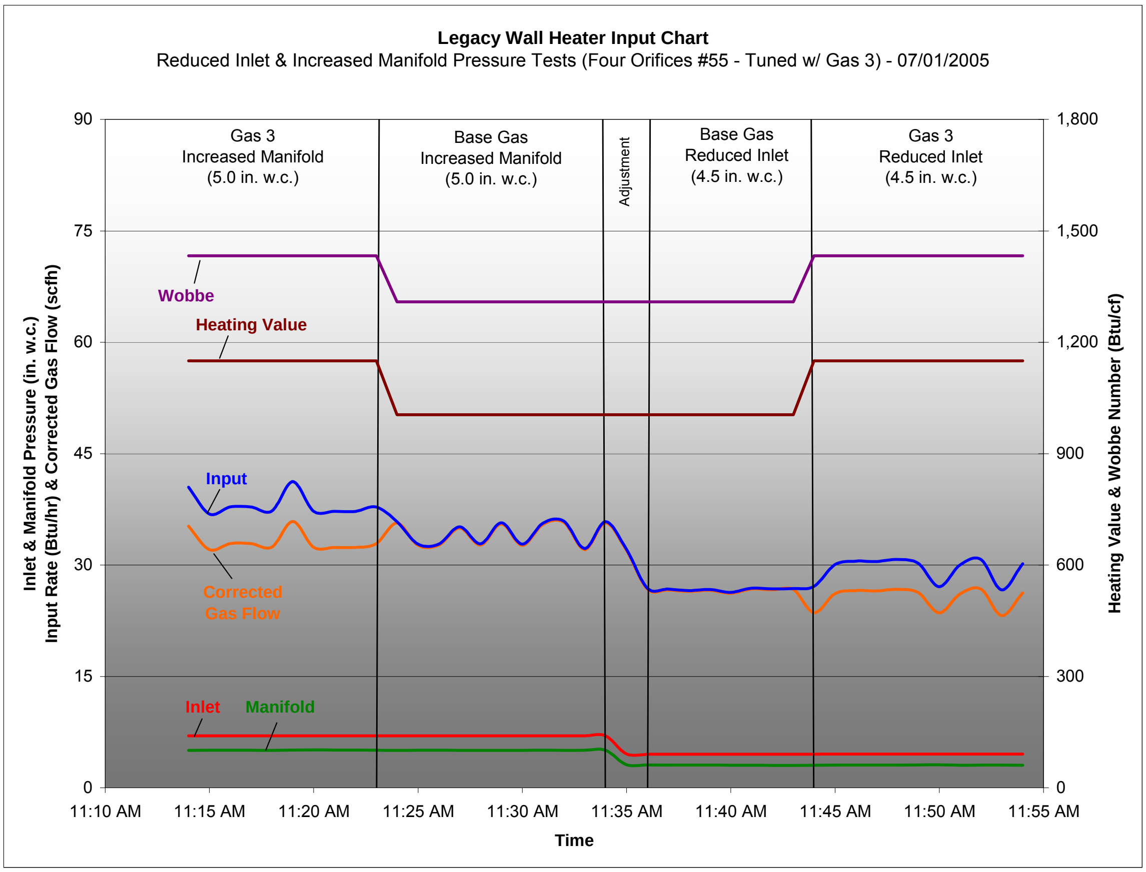


NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Reduced Inlet & Increased Manifold Pressure Test
(Four Orifices #55 – Tuned w/ Gas 3)

Input

At reduced inlet pressure, lower input rates were observed for Base Gas (26,600 Btu/hr) and Gas 3 (29,341 Btu/hr) compared to values observed at increased manifold pressure (Base Gas: 34,176 Btu/hr, Gas 3: 37,942 Btu/hr). Corrected gas flow was 33.5 ± 0.5 scfh at increased manifold pressure and 26.0 ± 0.5 scfh at reduced inlet pressure. Inlet and manifold pressures remained stable throughout the course of the test and within tolerances specified in the test protocol.

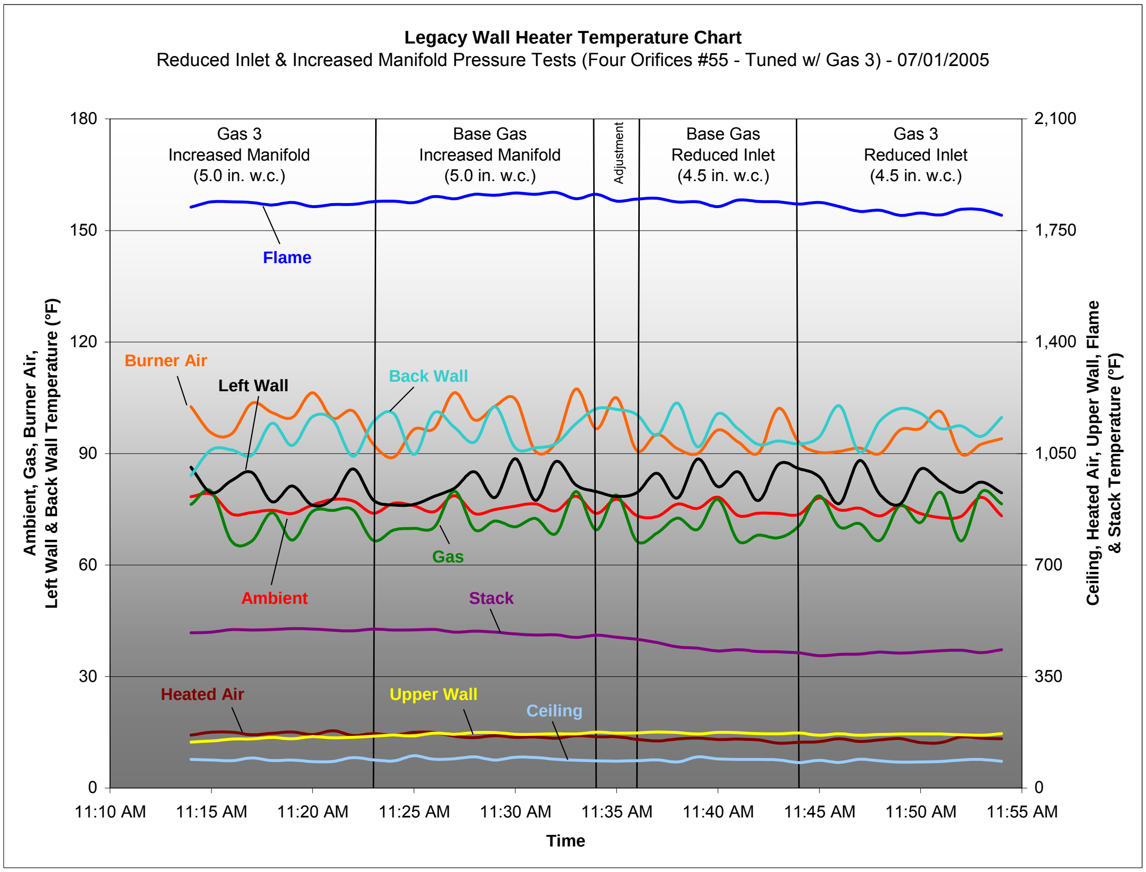


Temperatures

The highest stack, flame, burner air, heated air and ceiling temperatures were observed at increased manifold pressure whereas the highest wall temperatures were seen at reduced inlet pressure.

At increased manifold pressure, the highest stack burner air and heated air temperatures were observed with Gas 3 (495.4°F, 99.7°F and 171.4°F). The highest flame and ceiling temperatures were observed with Base Gas (1,860°F and 92.3°F).

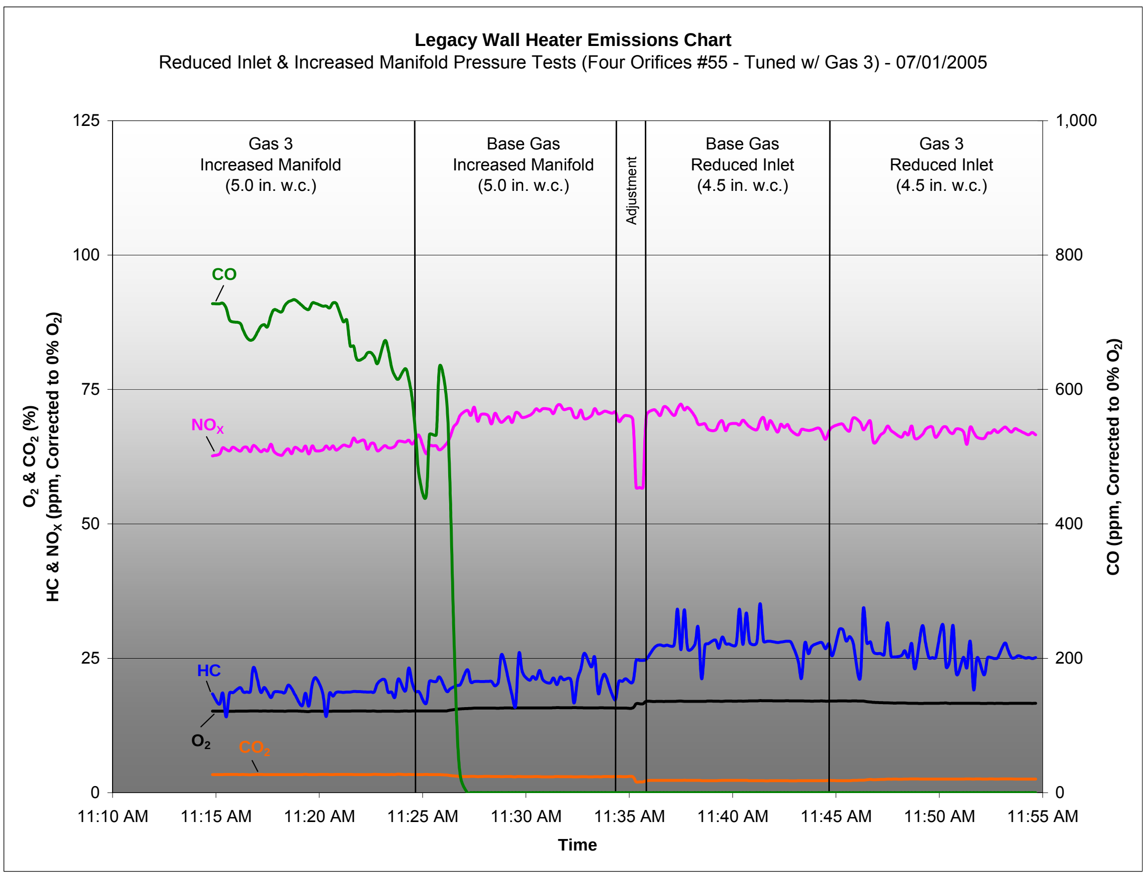
At reduced inlet pressure, back, left and upper wall temperatures were higher for Base Gas and Gas 3 compared to temperatures at increased manifold. Ambient and gas temperatures remained stable throughout the course of the test and complied with the specifications in the test protocol.



Emissions

Base Gas NO_X emissions at each pressure setting were higher than values observed with Gas 3. NO_X emissions for Base Gas at increased manifold pressure were highest at 69.4 ppm and decreased slightly to 68.2 ppm at reduced inlet pressure. NO_X emissions for Gas 3 at increased manifold and reduced inlet pressure were 64.2 ppm and 67.3 ppm, respectively.

CO emissions values were highest for Gas 3 (689.2 ppm) at increased manifold pressure but were negligible for the remaining runs (0 ppm). HC emissions values were highest at reduced inlet pressure for both gases (Base Gas - 27.2 ppm and Gas 3 - 26.2 ppm) compared to values observed at increased manifold pressure (Base Gas - 20.8 ppm and Gas 3 - 18.8 ppm).



NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Cold Ignition Test

For each set-up gas (Base Gas and Gas 3), the appliance was turned “on” without any problems during all the ignition tests. After ignition, flames were stable and there was no flame lifting, flashback or yellow tipping.

Rated Input Test (Tuned w/ Base Gas)		
Gas	Start-Up #	Comment & Observation
Base	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
Rated Input Test (Tuned w/ Gas 3)		
Gas	Start-Up #	Comment & Observation
Base	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays

Hot Ignition Test

For each set-up gas (Base Gas and Gas 3), the appliance turned “on” without any problems during all ignition tests. After ignition, flames were stable and there was no flame lifting, flashback or yellow tipping.

Rated Input Test (Tuned w/ Base Gas)		
Gas	Start-Up #	Comment & Observation
Base	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
Rated Input Test (Tuned w/ Gas 3)		
Gas	Start-Up #	Comment & Observation
Base	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays

Appendix A: Test Protocol

1. Standards

CSA/ANSI Z21.86 - 2004	Vented Gas- Fired Space Heating Appliances
SCAQMD Method 100.1	Instrumental analyzer procedure for continuous gaseous emissions

2. Wall Furnace Description

Description	Gravity Vented Wall Furnace (Legacy)
Burner	4 in-shot atmospheric burners firing vertically into heat exchanger
Maximum rated input	35,000 Btu/hr
Type of fuel	Natural Gas
Required gas supply pressure	4.5 – 10.5 in. w.c.

3. Test Arrangement

Basic Setup
The gravity vented (legacy) wall furnace shall be connected to a vent extending to a height 12 feet above the test floor. The furnace shall be installed with the minimum clearances specified by the manufacturer and in a test structure as shown in Figure 7 of ANZI Z21.86 - 2004 for vented wall furnaces (installation between studs 16 inches or less on center).

The portions of the appliance normally located in a wall shall be enclosed on top, bottom and sides by wood framing of 2 inches nominal thickness and a width appropriate for the wall thickness specified for installation by the manufacturer. When the manufacturer specifies nominal 2 x 4 stud walls, the width of the studs in the test wall shall be 3 ½ inches. The studs at the sides of the appliance shall extend to a height of 8 feet, including the floor and ceiling plates.

In the case of appliances having top vertical flue outlets, such top framing shall be omitted from the stud spacing enclosing the flue outlet when the manufacturer's instructions do not specify such framing. Additional studs of appropriate width and extending from the floor plate to the ceiling plate shall be placed at 16 inches on center outside the studs framing the space in which the appliance is installed.

The ceiling plate adjacent to the vent shall maintain the specified clearance from the vent pipe, and a flat sheet metal collar of suitable shape to fit closely about the periphery of the vent shall be placed over this clearance space and secured to the ceiling plate, or if a plate spacer is supplied by the manufacturer, that spacer will be used. Both sides of this frame shall be enclosed with nominal ¾ inch plywood panels with both sides painted dull black. A side wall and ceiling shall be provided as shown in Figure 7.

Draft Diverter
Draft hoods shall be in place during all performance tests.

4. Test Gases
All test gases will adhere to the Southern California Gas Company's Gas Quality Specification (Rule 30), which is approved by the California Public Utilities Commission (CPUC).

The following gases have been specifically formulated to cover the range of gas compositions and calorific values of natural gases that could be delivered in the Southern California Gas Company territory by current natural gas suppliers and future LNG suppliers. Composition details are specified in Appendix C.

Gas	**Wobbe Number** (Btu/cf)	**Heating Value** (Btu/cf)
Base	1,330 (Low Wobbe)	1,002 (Low heat content)
3	1,436 (Highest Wobbe)	1,152 (Highest heat content)
4A	1,371 (Medium Wobbe)	1,148 (High heat content)
6	1,413 (High Wobbe)	1,107 (High heat content)
7	1,395 (High Wobbe)	1,142 (Highest heat content)

5. Basic Operating Condition
Unless required otherwise by specific test requirements, the following are to apply:

Room temperature
Room temperature shall be maintained between 65 – 85°F. The temperature shall be determined by means of 4 J-type thermocouples, the junctions of which are shielded from radiation. These thermocouple junctions shall be located so room air temperature can be measured at points approximately 24 inches away from the approximate midpoints of each of the 4 sides of the appliance or test structure. The thermocouple leads shall be connected to a data logger, and room temperature shall be the average of the four individual temperature readings.

Test Pressures and Burner Adjustments
Unless stated otherwise, all tests will be conducted at normal inlet test pressure and normal input rate. When operated for 15 minutes, starting with all parts of the appliance at room temperature, the burner input rating shall be within ± 2 percent of the manufacturer's specified hourly Btu input rating. Primary air shall be set to give a good flame at this adjustment and neither burner ratings nor primary air adjustments shall be changed during a series of tests with any one test gas. Any adjustments resulting in an appreciable deposit of carbon during any of the tests specified shall not be acceptable.

Burner Operating Characteristics
The gas from the main burners and ignition devices shall be effectively ignited without delayed ignition or flashback when turned on and off at normal input rate and inlet test pressure, either manually or by a thermostatically actuated control device. When ignition is made, the flames shall not flash outside the appliance. Burners shall ignite, operate and extinguish without any undue noise.

Pilot Burners and Safety Shutoff Devices
The pilot(s) shall not deposit appreciable carbon during any test specified when adjusted according to the manufacturer's instructions. The pilot(s) shall also effect ignition of gas at the main burner(s) port(s) and, except for designed turn-off of intermittent or interrupted pilots, shall not become extinguished and remain extinguished when the gas to the main burner(s) is turned off and on in a normal manner. The test shall be conducted for each type of gas using the following method of test.

Gas shall be admitted to the main burner(s) by turning on fully in a continuous movement any manual means provided for controlling main burner gas flow. At least 3 successive ignition tests shall be conducted with the main burner gas flow maintained for 30 seconds and interrupted for 30 seconds for each cycle. Failure to effect ignition immediately after gas reaches the main burner port(s) in any one instance, or continued extinction of the pilot, shall be considered as noncompliance with this provision (Note: Test the unit with Base Gas and Gas 3 first. If it failed, retest with Gases 4A, 7 and 6).

Any type of pilot equipped with an automatic igniter shall not cause excessive flame flash out or damage to the appliance.

Wall, Floor and Ceiling Temperatures
The temperatures on the surface of any exterior portion of the test wall in contact with the wall furnace shall not be more than 117°F in excess of room temperature when the appliance is operated as required in the following method of test. The temperatures within the stud space enclosing any portion of the appliance and the test vent, and on the floor under the appliance and for a distance of 18 inches in front of and to the sides of the appliance shall not be more than 90°F in excess of room temperature when the appliance is operated as required in the following method of test.

Flue Gas Temperature
Under normal operating conditions, the average temperature of the flue gases of a wall furnace shall not exceed 380°F above room temperature. The flue gas temperature shall be determined by a grid of parallel-connected No. 24 AWG thermocouples, located in a horizontal plane 3 ½ feet above the plane of the flue outlet and connected to an indicating or recording potentiometer.

Flame Temperature
Due to the difficulties and cost involved in accurately measuring flame temperature continuously during each test, a simplistic method for measuring flame temperature will be used. This method requires the installation of a thermocouple tip inside the outer mantel of the flame such that it is fixed throughout the length of the test. Due to measurement method and changes in both flame shape and flame length, readings simply indicate temperature treads in the flame zone.

Temperature at Discharge Air Opening and Surface Temperature
This test shall be conducted as specified in section 8.7.1 of ANSI Z21.86 2004.

Draft Diverter
Flue gases shall not expel from the relief openings of a draft hood when the wall furnace is connected to a vent terminating 12 feet above the floor.

6. Testing

Rated Input — Tuned with Base Gas
Operate the wall furnace at normal input rate and normal inlet test pressure with Base Gas. Start collecting temperature, pressure and emissions data while verifying proper operation of all equipment and instrumentation.

Continue steady furnace operation with Base Gas for a specified duration and conduct a high-speed switch to the first test gas. Record data before, during and after changeover and observe transient phenomena. Possible phenomena include flame flashback, yellow tipping, noise, instability or outage, etc. (**NOTE:** the furnace firing rate is not to be adjusted).

After the specified duration of the test on the first test gas, conduct a high-speed switch to the second test gas and record observations and data. After the specified duration of the test on the second test gas, conduct a high-speed switch to Base Gas and record observations and data as indicated above. Continue testing by reestablishing steady state conditions with the Base Gas after two or three runs with test gases.

When testing has been conducted with all gases, shut down the furnace and examine flue collector and vent connection area for presence of soot by means of the swab technique. If soot is found, clean surfaces and repeat testing with suspect gas blend(s), selected on the basis of earlier yellow tipping observations, to establish which gas(es) deposited soot in the appliance.

Reduced Inlet and Increased Manifold Pressure Test — Tuned with Base Gas
Based on the information from manufacturers, consultants and the requirements of the test standards, adjust the appliance to operate under and over the rated input. For this furnace, the under rate input should be achieved by reducing the inlet pressure to 4.5 in. w.c. The over rate input should be achieved by increasing the manifold pressure to 5 in. w.c. Due to time limitations only the most critical test will be performed.

From a cold start, record input and combustion data (O_2, NO_X, CO, CO_2 and HC) and verify that the firing rates are under and over the rated input after 15 minutes. If the burner modulates, automatically continue the test at operating input.

During testing, observe flames and note yellow tipping and flame lifting or flashback phenomena or lack of the same. Record these observations. If significant yellow tipping was observed, inspect flue collector and vent connection area and swab with a white cloth to determine if soot has been deposited. If soot is found, clean surfaces and repeat testing with suspect gas blend(s), selected on the basis of earlier yellow tipping observations, to establish which gas(es) deposited soot in the appliance.

Rated Input — Tuned with Gas 3
Tune the appliance with Gas 3 to achieve the same input rate and similar performance (including emissions, temperatures, etc.) as with Base Gas. Follow the same procedures as specified in §6.1.

Reduced Inlet and Increased Manifold Pressure Test — Tuned with Gas 3
Tune the appliance with Gas 3 to achieve the same input rate and similar performance (including emissions, temperatures, etc.) as with Base Gas. Follow the same procedures as specified in §6.2.

7. **Ignition Tests**
   Shortly after and during ignition, observe flames and note yellow tipping, flame lifting, or flashback phenomena or lack of same.

   Cold Ignition Test (Tuned w/ Base Gas)
   With the appliance at room temperature and at the maximum allowable input rate achieved during initial tuning with Base Gas, purge the gas delivery system with Base Gas. Using Base Gas, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Allow the appliance to cool down to room temperature then repeat this procedure 2 more times.

   Purge the gas delivery system with Gas 3. Using Gas 3, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Allow the appliance to cool down to room temperature then repeat this procedure 2 more times.

   Cold Ignition Test (Tuned w/ Gas 3)
   Follow the same procedure as Cold Ignition Test (Tuned w/ Base Gas) but substitute Base Gas with Gas 3.

   Hot Ignition Test (Tuned w/ Base Gas)
   With the appliance at steady state temperatures and at the maximum allowable input rate achieved during initial tuning with Base Gas, purge the gas delivery system with Base Gas. Using Base Gas, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Repeat this procedure 2 more times without allowing the appliance to cold down.

   Purge the gas delivery system with Gas 3. Using Gas 3, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Repeat this procedure 2 more times without allowing the appliance to cool down.

   Hot Ignition Test (Tuned w/ Gas 3)
   Follow the same procedure as Cold Ignition Test (Tuned w/ Base Gas) but substitute Base Gas with Gas 3.

8. **Special tests**
   Special tests may be conducted to investigate phenomena of concern to the furnace manufacturer. The decision of whether or not to test and the design of appropriate tests will be discussed with the manufacturer.

9. **Additional Testing**
   Conduct additional testing and/or testing with other gas blends, per the Phase II protocol, when test results or observations indicate it is necessary.

   If indicated additional testing is outside of the project scope, include appropriate comment in the test report.

Appendix B: Tables of Averages

As Received Test (Tuned w/ Base Gas)

Table of Averages Legacy Wall Heater As Received Test (Orifice 54 - Tuned w/ Base Gas) June 30, 2005							
Gases	**Base**	**3**	**6**	**Base**	**7**	**4A**	**Base**
HHV (Btu/cf)	1,005	1,150	1,106	1,005	1,143	1,100	1,005
Wobbe (Btu/cf)	1,309	1,433	1,408	1,309	1,396	1,362	1,309
Input Rate (Btu/hr)	33,854	37,696	36,503	33,628	35,986	34,954	32,268
Corrected Gas Flow (scfh)	32.4	32.8	33.0	33.5	31.5	30.8	32.1
Emissions (not from certified tests)							
O_2 (%)	15.7	14.9	15.0	15.5	15.1	15.2	15.7
CO_2 (%)	3.0	3.5	3.5	3.1	3.5	3.5	3.1
CO (ppm @ 3% O_2)	0.0	31.0	6.7	0.0	1.0	0.2	0.0
HC Range (ppm @ 3% O_2)	13.1 - 48.9	15.8 - 39.5	36.0 - 199.7	53.6 - 89.2	89.5 - 239.3	49.3 - 95.73	79.9 - 245.0
NO_X (ppm @ 3% O_2)	65.8	63.0	64.5	67.9	67.0	66.4	67.5
Ultimate CO_2 (%)	12.2	12.3	12.2	12.3	12.6	12.5	12.2
Equivalence Ratio (Φ)	0.28	0.31	0.30	0.29	0.29	0.28	0.27
Temperatures (°F)							
Ambient	75.1	75.4	75.9	75.5	75.1	74.6	75.5
Gas	70.3	72.4	71.8	73.9	74.3	73.0	72.0
Stack	461.1	480.2	490.0	475.6	473.2	474.1	468.5
Flame	1,786	1,640	1,642	1,764	1,681	1,701	1,765
Burner Air	79.3	84.1	85.8	87.6	85.6	83.5	82.3
Heated Air	156.0	167.1	167.4	162.0	160.2	160.3	159.0
Back Wall	94.7	95.2	97.9	100.2	100.3	99.5	99.4
Left Wall	80.4	82.1	83.5	84.3	82.6	82.5	81.6
Upper Wall	161.4	170.5	178.4	183.1	182.1	182.8	182.1
Ceiling	90.1	95.2	97.5	96.6	101.1	101.5	96.9
Pressures (in. w.c.)							
Inlet	7.0	7.0	7.0	7.0	7.0	7.1	7.1
Manifold	3.8	3.9	3.9	3.9	3.8	3.7	3.7

Rated Input Test (Tuned w/ Gas 3)

Table of Averages Legacy Wall Heater Rated Input Test (Orifice 55 -Tuned w/ Gas 3) July 1, 2005							
Gases	**3**	**Base**	**6**	**3**	**7**	**4A**	**3**
HHV (Btu/cf)	1,150	1,005	1,106	1,150	1,143	1,135	1,150
Wobbe (Btu/cf)	1,433	1,309	1,408	1,433	1,396	1,362	1,433
Input Rate (Btu/hr)	34,008	30,205	33,106	33,778	32,754	31,692	33,023
Corrected Gas Flow (scfh)	29.6	30.1	29.9	29.4	28.7	27.9	28.7
Emissions (not from certified tests)							
O_2 (%)	15.8	16.3	15.9	15.8	15.8	16.0	15.8
CO_2 (%)	3.0	2.7	3.0	3.0	3.0	3.0	3.0
CO (ppm @ 3% O_2)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HC Range (ppm @ 3% O_2)	19.5 - 29.0	20.0 - 40.0	21.6 - 37.0	23.2 - 45.3	26.8 - 47.5	26.0 - 37.1	20.6 - 59.2
NO_X (ppm @ 3% O_2)	67.7	69.3	67.2	67.1	67.8	67.3	67.1
Ultimate CO_2 (%)	12.4	12.3	12.3	12.3	12.5	12.8	12.2
Equivalence Ratio (Φ)	0.26	0.24	0.26	0.26	0.26	0.26	0.26
Temperatures (°F)							
Ambient	76.4	76.4	77.7	76.9	76.1	76.9	76.0
Gas	73.8	72.0	74.3	73.9	72.5	75.6	73.9
Stack	456.1	454.5	451.5	464.1	464.7	459.2	458.8
Flame	1,818	1,846	1,828	1,819	1,826	1,823	1,825
Burner Air	95.8	96.4	95.8	97.1	97.7	102.1	96.9
Heated Air	155.6	158.3	160.0	161.7	160.5	155.8	157.7
Back Wall	93.6	96.8	96.9	97.0	97.4	97.4	100.1
Left Wall	82.6	81.2	80.5	82.7	83.7	84.7	81.3
Upper Wall	170.2	175.7	175.5	176.7	177.5	177.0	176.1
Ceiling	95.1	93.3	92.1	92.1	92.7	91.8	86.5
Pressures (in. w.c.)							
Inlet	7.0	7.0	7.1	7.0	7.1	7.0	7.1
Manifold	4.1	4.0	4.1	4.0	4.0	4.1	4.1

Reduced Inlet & Increased Manifold Pressure Tests
(Orifice 54 - Tuned w/ Base Gas)

Table of Averages Legacy Wall Heater Reduced Inlet & Increased Manifold Pressure Tests Orifice #54 - Tuned w/ Base Gas July 1, 2005				
Pressure Test	**Reduced Inlet**		**Increased Manifold**	
Gases	**Base**	**3**	**3**	**Base**
HHV (Btu/cf)	1,005	1,150	1,150	1,005
Wobbe (Btu/cf)	1,309	1,433	1,433	1,309
Input Rate (Btu/hr)	29,344	33,006	41,220	36,993
Corrected Gas Flow (scfh)	29.2	28.7	35.8	36.8
Emissions (not from certified tests)				
O_2 (%)	16.6	16.1	14.6	15.1
CO_2 (%)	2.5	2.9	3.6	3.4
CO (ppm @ 3% O_2)	0.0	0.0	729.1	117.2
HC Range (ppm @ 3% O_2)	79.3 - 92.4	60.9 - 84.3	51.5 - 94.9	44.7 - 88.5
NO_X (ppm @ 3% O_2)	68.0	68.7	57.7	66.7
Ultimate CO_2 (%)	12.2	12.4	11.9	12.2
Equivalence Ratio (Φ)	0.23	0.25	0.32	0.30
Temperatures (°F)				
Ambient	75.2	73.7	76.7	76.8
Gas	73.6	68.2	76.4	73.8
Stack	434.0	449.1	497.2	508.3
Flame	1,773	1,723	1,639	1,732
Burner Air	76.2	75.4	77.5	79.1
Heated Air	150.4	154.7	168.5	175.6
Back Wall	86.4	89.1	96.1	100.3
Left Wall	77.3	78.4	79.8	82.3
Upper Wall	141.9	155.8	172.9	181.9
Ceiling	88.1	89.9	94.6	96.6
Pressures (in. w.c.)				
Inlet	4.5	4.5	7.0	7.0
Manifold	3.0	3.1	5.0	4.9

Reduced Inlet & Increased Manifold Pressure Tests
(Four Orifices #55 - Tuned w/ Gas 3)

Table of Averages Legacy Wall Heater Reduced Inlet & Increased Manifold Pressure Tests Four Orifices #55 - Tuned w/ Gas 3 July 1, 2005				
Pressure Test	**Increased Manifold**		**Reduced Inlet**	
Gases	**3**	**Base**	**Base**	**3**
HHV (Btu/cf)	1,150	1,005	1,005	1,150
Wobbe (Btu/cf)	1,433	1,309	1,309	1,433
Input Rate (Btu/hr)	37,942	34,176	26,600	29,341
Corrected Gas Flow (scfh)	33.0	34.0	26.5	25.5
Emissions (not from certified tests)				
O_2 (%)	15.2	15.6	16.9	16.7
CO_2 (%)	3.4	3.1	2.3	2.5
CO (ppm @ 3% O_2)	689.2	0.0	0.0	0.0
HC (ppm @ 3% O_2)	18.8	20.8	27.2	26.2
NO_X (ppm @ 3% O_2)	64.2	69.4	68.2	67.3
Ultimate CO_2 (%)	12.3	12.2	12.2	12.4
Equivalence Ratio (Φ)	0.30	0.27	0.21	0.22
Temperatures (°F)				
Ambient	75.9	76.0	74.9	74.7
Gas	72.0	72.1	70.0	73.3
Stack	495.4	487.6	436.9	425.2
Flame	1,834	1,860	1,840	1,814
Burner Air	99.7	98.6	94.3	93.3
Heated Air	171.4	163.8	150.8	150.0
Back Wall	93.3	95.8	96.2	97.3
Left Wall	80.9	81.0	83.1	81.7
Upper Wall	156.4	169.6	171.6	168.4
Ceiling	88.1	92.3	89.4	84.4
Pressures (in. w.c.)				
Inlet	7.0	7.0	4.5	4.5
Manifold	5.1	5.0	3.0	3.1

Appendix C: Test Gases

Gas Analysis	Gas BASELINE	Gas 3	Gas 4A	Gas 6	Gas 7
SAMPLE DATE	7/1/05	7/1/05	7/15/05	7/1/05	6/20/05
COMPONENTS	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**
C6 + 57/28/14	0.0213	0.0002	0.0142	0.0001	0.0232
NITROGEN	1.7436	0.1280	1.1174	0.2737	3.0250
METHANE	94.6797	86.5492	85.1030	91.1679	86.4659
CARBON DIOXIDE	1.2664	0.0345	3.0792	0.0032	0.0344
ETHANE	1.6701	9.4799	0.0000	5.7474	0.3119
PROPANE	0.3421	2.7246	10.5884	1.7268	9.9457
i-BUTANE	0.0581	1.0339	0.0442	0.5340	0.0940
n-BUTANE	0.0578	0.0000	0.0247	0.5312	0.0614
NEOPENTANE	0.0000	0.0000	0.0000	0.0000	0.0000
i-PENTANE	0.0172	0.0000	0.0044	0.0000	0.0192
n-PENTANE	0.0115	0.0003	0.0040	0.0000	0.0156
OXYGEN	0.1322	0.0494	0.0205	0.0156	0.0038
TOTAL	**100.0000**	**100.0000**	**100.0000**	**100.0000**	**100.0000**
Compressibility Factor	0.998	0.9972	0.9970	0.9975	0.9971
HHV (Btu/real cubic foot)	**1004.8**	**1150.00**	**1135.30**	**1106.00**	**1142.00**
LHV (Btu/real cubic foot)	905.4	1039.90	1027.50	998.90	1033.40
Specific Gravity	0.5895	0.6442	0.6946	0.6167	0.6697
WOBBE Index	**1308.67**	**1432.81**	**1362.21**	**1408.37**	**1395.49**

Appendix D: Zero, Span and Linearity Tables

As Received Test (Tuned w/ Base Gas)

	Zero, Span & Linearity Data Legacy Wall Heater As Received Test (Tuned w/ Base Gas) June 30, 2004	**O_2 (%)**	**CO_2 (%)**	**CO (ppm)**	**HC (ppm)**	**NO_x (ppm)**
	Analyzer Emission Ranges	**0 - 25**	**0 - 20**	**0 - 200**	**0 - 1000**	**0 - 100**
Zero	**Zero Calibration Gas (Low-Range Values)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	Allowable Zero Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Zero Calibration - 7:40:11 AM	0.09	0.06	0.74	0.33	0.07
	Zero Drift Check - 1:23:36 PM	0.08	0.08	1.02	-0.04	-0.01
	Total Drift Over Test Period	**0.01**	**0.02**	**0.28**	**0.37**	**0.08**
	Was the Zero Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.10**	**12.07**	**182.40**	**443.00**	**85.20**
	Allowable Span Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Span Calibration - 7:56:39 AM	20.10	12.14	183.22	442.16	85.40
	Span Drift Check - 1:30:39 PM	20.03	12.13	183.34	443.31	86.96
	Total Drift Over Test Period	**0.07**	**0.01**	**0.12**	**1.15**	**1.56**
	Was the Span Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**8.00**	**78.20**	**443.00**	**18.30**
	Allowable Linearity Drift (Less Than ±1% of Range)	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
	Linearity Check - 8:02:34 AM	9.08	8.04	75.02	441.85	17.95
	Difference From Mid-Range Values	**0.11**	**0.04**	**3.18**	**1.15**	**0.35**
	Was the Linearity Within Allowable Deviation?	**Yes**	**Yes**	**No**	**Yes**	**Yes**
	Linearity Check - 1:56:13 PM	9.10	8.03	75.00	443.75	17.78
	Difference From Mid-Range Values	**0.13**	**0.03**	**3.20**	**0.75**	**0.52**
	Was the Linearity Within Allowable Deviation?	**Yes**	**Yes**	**No**	**Yes**	**Yes**

Rated Input Test (Tuned w/ Gas 3)

	Zero, Span & Linearity Data Legacy Wall Heater Rated Input Test (Tuned w/ Gas 3) July 1, 2004	O_2 (%)	CO_2 (%)	CO (ppm)	HC (ppm)	NO_x (ppm)
	Analyzer Emission Ranges	**0 - 25**	**0 - 20**	**0 - 200**	**0 - 1000**	**0 - 100**
Zero	**Zero Calibration Gas (Low-Range Values)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	Allowable Zero Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Zero Calibration - 7:38:10 AM	0.07	0.06	0.00	0.00	0.00
	Zero Drift Check - 10:07:44 AM	0.08	0.01	0.00	-1.31	0.29
	Total Drift Over Test Period	**0.01**	**0.05**	**0.00**	**1.31**	**0.29**
	Was the Zero Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.10**	**12.07**	**182.40**	**443.00**	**85.20**
	Allowable Span Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Span Calibration - 7:49:47 AM	20.11	12.14	181.66	444.24	85.22
	Span Drift Check - 10:02:52 AM	20.10	12.01	181.50	448.38	84.91
	Total Drift Over Test Period	**0.01**	**0.13**	**0.16**	**4.14**	**0.31**
	Was the Span Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**8.00**	**78.20**	**443.00**	**18.30**
	Allowable Linearity Drift (Less Than ±1% of Range)	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
	Linearity Check - 10:11:50 AM	9.06	7.94	74.09	443.66	17.52
	Difference From Mid-Range Values	**0.09**	**0.06**	**4.11**	**0.66**	**0.78**
	Was the Linearity Within Allowable Deviation?	**Yes**	**Yes**	**No**	**Yes**	**Yes**
	Linearity Check - 10:47:01 AM	9.06	8.02	74.43	443.13	17.95
	Difference From Mid-Range Values	**0.09**	**0.02**	**3.77**	**0.13**	**0.35**
	Was the Linearity Within Allowable Deviation?	**Yes**	**Yes**	**No**	**Yes**	**Yes**

Reduced Inlet & Increased Manifold Pressure Tests
(Orifice 54 - Tuned w/ Base Gas)

	Zero, Span & Linearity Data Legacy Wall Heater Reduced Inlet & Increased Manifold Pressure Tests Orifice #54 - Tuned w/ Base Gas July 1, 2005	O_2 (%)	CO_2 (%)	CO (ppm)	HC (ppm)	NO_x (ppm)
	Analyzer Emission Ranges	**0 - 25**	**0 - 20**	**0 - 200**	**0 - 1000**	**0 - 100**
Zero	**Zero Calibration Gas (Low-Range Values)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	Allowable Zero Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Zero Calibration - 12:03:27 PM	0.09	0.07	0.35	0.00	0.10
	Zero Drift Check - 3:13:42 PM	0.09	0.09	0.46	0.20	0.03
	Total Drift Over Test Period	**0.00**	**0.02**	**0.11**	**0.20**	**0.07**
	Was the Zero Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.10**	**12.07**	**182.40**	**443.00**	**85.20**
	Allowable Span Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Span Calibration -12:00:16 PM	20.07	12.13	182.73	443.71	85.52
	Span Drift Check - 3:01:24 PM	20.02	12.11	182.81	443.94	86.40
	Total Drift Over Test Period	**0.05**	**0.02**	**0.08**	**0.23**	**0.88**
	Was the Span Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**8.00**	**78.20**	**443.00**	**18.30**
	Allowable Linearity Drift (Less Than ±1% of Range)	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
	Linearity Check - 10:47:01 AM	9.06	8.02	74.43	443.13	17.95
	Difference From Mid-Range Values	**0.09**	**0.02**	**3.77**	**0.13**	**0.35**
	Was the Linearity Within Allowable Deviation?	**Yes**	**Yes**	**No**	**Yes**	**Yes**
	Linearity Check - 3:10:40 PM	9.06	8.04	74.90	441.27	18.06
	Difference From Mid-Range Values	**0.09**	**0.04**	**3.30**	**1.73**	**0.24**
	Was the Linearity Within Allowable Deviation?	**Yes**	**Yes**	**No**	**Yes**	**Yes**

Reduced Inlet & Increased Manifold Pressure Tests
(Four Orifices #55 - Tuned w/ Gas 3)

	Zero, Span & Linearity Data Legacy Wall Heater Reduced Inlet & Increased Manifold Pressure Tests Four Orifices #55 - Tuned w/ Gas 3 July 1, 2005	O_2 (%)	CO_2 (%)	CO (ppm)	HC (ppm)	NO_x (ppm)
	Analyzer Emission Ranges	**0 - 25**	**0 - 20**	**0 - 200**	**0 - 1000**	**0 - 100**
Zero	**Zero Calibration Gas (Low-Range Values)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Zero	**Allowable Zero Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Zero	Zero Calibration - 10:42:49 AM	0.09	0.05	0.48	-0.13	0.07
Zero	Zero Drift Check - 12:03:27 PM	0.09	0.07	0.35	-0.50	0.10
Zero	**Total Drift Over Test Period**	**0.00**	**0.02**	**0.13**	**0.37**	**0.03**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.10**	**12.07**	**182.40**	**443.00**	**85.20**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration -10:38:19 AM	20.12	12.06	182.78	443.62	85.34
Span	Span Drift Check - 12:00:16 PM	20.07	12.13	182.73	443.71	85.52
Span	**Total Drift Over Test Period**	**0.05**	**0.07**	**0.05**	**0.09**	**0.18**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**8.00**	**78.20**	**443.00**	**18.30**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
Linearity	Linearity Check - 10:42:01 AM	9.06	8.02	74.43	443.13	17.95
Linearity	**Difference From Mid-Range Values**	**0.09**	**0.02**	**3.77**	**0.13**	**0.35**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**No**	**Yes**	**Yes**
Linearity	Linearity Check - 3:10:40 PM	9.06	8.04	74.90	441.27	18.06
Linearity	**Difference From Mid-Range Values**	**0.09**	**0.04**	**3.30**	**1.73**	**0.24**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**No**	**Yes**	**Yes**

Appendix E: Calculations

Emission Concentrations

Corrected to O_2 Standard (3 percent O_2)

$$\text{CO, HC \& NO}_x \text{ Concentrations (corrected to 3\% O}_2) = \text{Raw Concentrations (ppm)} \times \left[\frac{20.9-3}{20.9-\%\,O_2}\right]$$

Where

Raw Concentration = Measured CO, HC & NO_x concentrations, by volume (ppm)

% O_2 = Measured O_2 Concentration

Ultimate CO_2

$$\text{Ultimate } CO_2(\%) = \text{Raw } CO_2 \times \left[\frac{20.9}{20.9-\text{Raw } O_2}\right]$$

Where

Raw CO_2 = Measured CO_2 Concentration (%)

Raw O_2 = Measured O_2 Concentration (%)

% Excess Air

To determine the percent Excess Air, the theoretical air and theoretical flue gas values for each gas tested must be calculated. The table above lists the constituents found in natural gas, the balanced chemical equations for each constituent and their respective theoretical air and theoretical flue gas values (expressed in moles).

Constituent	Balanced Chemical Composition	Theo. Air	Theo. Flue Gas
Methane (CH_4)	$CH_4 + 2O_2 + 2(3.78)N_2 \Longrightarrow 1CO_2 + 2H_2O + 2(3.78)N_2$	9.56	8.56
Ethane (C_2H_6)	$C_2H_6 + 3.5O_2 + 3.5(3.78)N_2 \Longrightarrow 2CO_2 + 3H_2O + 3.5(3.78)N_2$	16.73	15.23
Propane (C_3H_8)	$C_3H_8 + 5O_2 + 5(3.78)N_2 \Longrightarrow 3CO_2 + 4H_2O + 5(3.78)N_2$	23.90	21.90
i-Butane (C_4H_{10})	$C_4H_{10} + 6.5O_2 + 6.5(3.78)N_2 \Longrightarrow 4CO_2 + 5H_2O + 6.5(3.78)N_2$	31.07	28.57
n-Butane (C_4H_{10})	$C_4H_{10} + 6.5O_2 + 6.5(3.78)N_2 \Longrightarrow 4CO_2 + 5H_2O + 6.5(3.78)N_2$	31.07	28.57
i-Pentane (C_5H_{12})	$C_5H_{12} + 8O_2 + 8(3.78)N_2 \Longrightarrow 5CO_2 + 6H_2O + 8(3.78)N_2$	38.24	35.24
n-Pentane (C_5H_{12})	$C_5H_{12} + 8O_2 + 8(3.78)N_2 \Longrightarrow 5CO_2 + 6H_2O + 8(3.78)N_2$	38.24	35.24
Hexanes (C_6H_{14})	$C_6H_{14} + 9.5O_2 + 9.5(3.78)N_2 \Longrightarrow 6CO_2 + 7H_2O + 9.5(3.78)N_2$	45.41	41.91

The theoretical air value for each constituent is the sum of moles for both O_2 and N_2 on the reactants side of the balanced chemical equation (ex: For Methane, 2 moles of O_2 plus 7.56 moles of N_2 = 9.56 moles of Theoretical Air). The theoretical flue value for each constituent is the sum of moles for both CO_2 and N_2 on the product side of the balanced chemical equation (ex: For Methane, 1 mole of CO_2 plus 7.56 moles of N_2 = 8.56 moles of Theoretical Flue Gas).

Once the test gases have been analyzed (via gas chromatography), the percent composition of each gas is used to determine the theoretical air and theoretical flue gas values for each gas tested. Thus,

$$\text{Theoretical Air} = \sum C_1P + C_2P + \ldots + C_nP$$

$$\text{Theoretical Flue} = \sum D_1P + D_2P + \ldots + D_nP$$

Where *C* is the theoretical air value for each constituent, *D* is the theoretical flue gas value for each constituent and *P* is the percent composition for each constituent (expressed as a decimal, not a percentage). Therefore, the percent Excess Air is calculated as follows:

$$\%\,\text{Excess Air} = \left[\text{Theoretical Flue Value} \times \frac{\text{Ultimate } CO_2 - \text{Raw } CO_2}{\text{Theoretical Air Value} \times \text{Raw } CO_2}\right] \times 100$$

Air/Fuel Ratio

$$\text{Air/Fuel Ratio} = \text{Theoretical Air Value} + \frac{\text{Theoretical Air Value} \times \%\,\text{Excess Air}}{100}$$

Equivalence Ratio (ϕ)

$$\text{Equivalence Ratio}\ (\phi) = \frac{100}{100 + \%\,\text{Excess Air}}$$

Gas Meter Accuracy Table

The gas meter used during testing was compared to a certified bell prover to determine its accuracy (error percentage) at various flow rates.

The gas meter accuracy table (below) shows the prover flow rates that the meter was tested, error percentage for each accuracy test and an average meter error.

Also included on the table is a gas meter flow rate. The gas meter flow rate is the meter's reading at each prover flow rate when the average meter error is factored in. This flow rate was calculated using the meter accuracy equation:

$$\%\,\text{Error} = \left(\frac{\text{Gas Meter Flow - Prover Flow}}{\text{Prover Flow}}\right) \times 100$$

Through algebraic manipulation, the gas meter flow is determined using the following equation:

$$\text{Gas Meter Flow} = \text{Prover Flow} \times \left(1 + \frac{\%\,\text{Error}}{100}\right)$$

A negative error percentage indicates the gas meter flow rate was below the prover flow rate whereas a positive error percentage indicates the gas meter flow rate was above the prover flow rate.

2 CU. FT. BELL NO. 4087 CPUC CERTIFICATE OF BELL PROVER ACCURACY # 1004							
Model Number: DTM-200A **Meter Number:** U258696				**Date:** August 1, 2004 **Prepared By:** Joe Garcia			
Prover Flow Rate cfh	**Gas Meter Error Percentage** Test #1	Test #2	Test #3	Test #4	Test #5	**Average Meter Error**	**Gas Meter Flow Rate** cfh
50	0.78%	0.67%	0.48%	0.58%	0.53%	**0.61%**	**50.30**
100	0.57%	0.58%	0.66%	0.72%	0.66%	**0.64%**	**100.64**
150	0.85%	0.84%	0.95%	1.18%	1.11%	**0.99%**	**151.48**
200	0.78%	1.03%	0.90%	0.87%	0.88%	**0.89%**	**201.78**

Actual Gas Flow with Meter Correction (acfh)

To correct the actual gas flow that was measured during testing, a gas meter flow rate range is selected from the meter accuracy table. The gas meter flow rates and the average meter error (divided by 100) will be used to calculate the meter correction factor at any given gas flow rate.

Setting y = average meter error (divided by 100) and x = gas meter flow rate, the error can be calculated using the following equation:

$$\frac{y - y_0}{y_1 - y_0} = \frac{x - x_0}{x_1 - x_0}$$

Manipulating the right side of the equation algebraically:

$$\alpha = \frac{x - x_0}{x_1 - x_0}$$

The equation would then simplify into:

$$y = \frac{y_1 - y_0}{x_1 - x_0}(x - x_0) + y_0$$

If the appliance has an actual gas flow rate (F_A) of 110.0 actual cubic feet per hour (acfh), the gas meter flow rate range would be 100.64 to 151.48 acfh and the average meter error range (divided by 100) would be 0.0064 to 0.0099. Using this information, the meter error (y) is:

$$y = \frac{0.0099 - 0.0064}{151.48\ \text{acfh} - 100.64\ \text{acfh}}(110.0\ \text{acfh} - 100.64\ \text{acfh}) + 0.0064 = 0.007021$$

Once the meter error is known, the actual gas flow rate with meter correction ($F_{meter.}$) can be calculated using the following equation:

$$F_{meter} = \frac{F_A}{(1 + y)}$$

$$F_{meter} = \frac{110.0\ \text{acfh}}{(1 + 0.007021)} = 109.2331\ \text{acfh}$$

Corrected Gas Flow (scfh)

$$F_{corrected} = F_{meter} \times \left[\frac{P_{Fuel}\,(psig) + P_1\,(psia)}{P_{standard}}\right] \times \left[\frac{T_{standard}}{T_{Fuel}\,(^\circ F) + 459.67}\right]$$

Where

$F_{corrected}$ = Gas flow corrected to standard temperature and pressure (scfh)

F_{meter} = Actual gas flow with meter correction (acfh)

P_{Fuel} = Natural gas inlet pressure (psig)

P_1 = Average pressure in Pico Rivera at an average elevation of 161 ft (psia)

$P_{standard}$ = Standard atmospheric pressure (14.735 psia @ 60°F)

$T_{standard}$ = Standard atmospheric temperature (519.67 R @ 1 atm)

T_{Fuel} = Fuel temperature (°F)

Input Rate (Btu/cf)

$$\text{Input Rate} = \text{Corrected Gas Flow} \times \text{HHV}$$

Where

HHV = Higher Heating Value (Btu/cf)

Wobbe Number (Btu/cf)

$$W_0 = \frac{HHV}{\sqrt{G}}$$

Where

W_0 = Wobbe Number (Btu/cf)

HHV = Higher Heating Value (Btu/cf)

G = Specific gravity of gas sample

Appendix F: Test Equipment

Emissions analyzers (meet CARB and SCAQMD standards), Analyzer Calibration Gases, and Instrumentation.

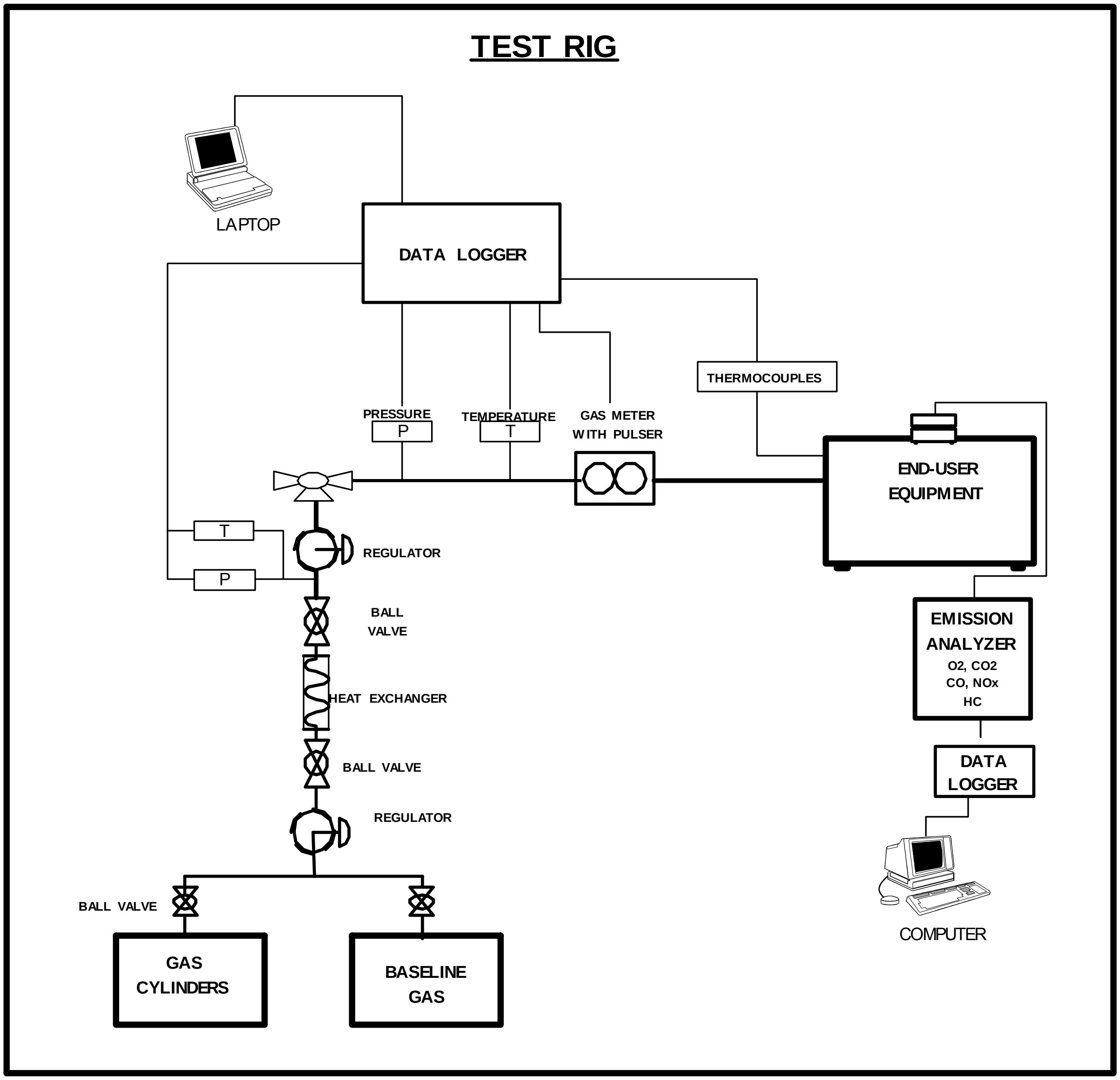
Emissions Analyzer				
Analyzer	Manufacturer	Model	Type	Accuracy
NO/NO_X	Thermo Environmental Instruments Inc.	10AR	Chemiluminescent	± 1% of full scale
CO	Thermo Environmental Instruments Inc.	48	Nondispersive infrared (NDIR) gas analyzer	± 1% of full scale
CO_2	Fuji	ZRH	Nondispersive infrared (NDIR) gas analyzer	± 1% of full scale
HC	California Analytical Instruments, Inc.	300 HFID	Flame ionization detector (FID)	± 1% of full scale
O_2	Teledyne	326RA	Electrochemical cell	± 1% of full scale

Calibration & Span Gases			
Gas	Manufacturer	Type	Accuracy
Calibration	Scott Specialty Gases	Certified Master Class - 0 %	± 2%
NO/NO_X	Scott Specialty Gases	Certified Master Class - 18.95 ppm	± 2%
CO	Scott Specialty Gases	Certified Master Class - 79.3 ppm	± 2%
CO_2	Scott Specialty Gases	Certified Master Class -12.1 %	± 2%
HC	Scott Specialty Gases	Certified Master Class - 0.5 ppm	± 2%
O_2	Scott Specialty Gases	Certified Master Class - 9.1 %	± 2%

Test Equipment			
Equipment	Manufacturer	Model	Accuracy
Datalogger	Delphin	D51515	n/a
Gas Chromatograph	Agilent	6890	± 0.5 BTU/scf
K	Omega Engineering Co.	KMQSS	2.2°C or 0.75%
J	Omega Engineering Co.	JMQSS	2.2°C or 0.75%
T	Omega Engineering Co.	TMQSS	2.2°C or 0.75%
Dry Test Gas Meter 200 cf/h max	American Meter Company	DTM-200A	@ 200 cf/h – 100.1 % @60 cf/h – 99.9 %
Gas Meter Pulser 2 pulses per 1/10 cf	Rio Tronics	4008468	n/a
Gas Pressure Regulator	Fisher	299H	± 1.0 %
Differential Pressure Transmitter	Dwyer	607-4	±0.25 -0.50%
Pressure Transducer	Omega	PX205-100GI	±0.25% of full scale

Appendix G: Test Set-Up/Schematic

Equipment utilized for testing adheres to industry standards for testing laboratories that certify such equipment. The test rig is transportable and includes a data logger, emissions cart, gas meter, thermocouples and pressure transducers; plus, a gas regulation system that can take natural gas from 3,000 psig and deliver up to 2,000 cubic feet per hour (cfh) at low pressure (approx. 8 in w.c.). The test rig is illustrated below.



Appendix H: Gravity Vented Wall Furnace Setup