INTERIM PROJECT REPORT

Baseline Wall Furnace Laboratory Test Report - Improving the Performance of Wall Furnaces in California

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Executive Summary

This is an interim report for CEC-PIR-18-005, “Improving the Performance of Wall Furnaces in California”, a project designed to yield gas savings by replacing existing wall furnaces with more efficient retrofit models. This project gathers information about furnace performance, operation, emissions, and indoor air quality from laboratory testing and field monitoring of baseline and retrofit wall furnaces.

Background

It is estimated that there are 1.4 million wall furnaces in California. Wall furnaces were introduced in California as early as 1930 and gained prevalence in single-family homes and low-rise multifamily residential buildings as primary or auxiliary sources of heating. Not infrequently wall furnaces are as old as the buildings they occupy and may not have safety switches to prevent the furnaces from overheating. The oldest existing furnaces have rated thermal efficiencies of 50% while most standard replacement wall furnaces have rated thermal efficiencies of 70%.

More advanced wall furnaces achieve rated thermal efficiencies of 80% to 94% by eliminating pilot lights, using more efficient heat exchangers, and incorporating condensing or modulating technology. This means there is a substantial savings potential for a state-wide replacement program that promotes furnaces using these efficiency advancements.

This interim report documents test results for baseline wall furnaces that were removed from California homes for laboratory testing. Other interim reports for this project document field monitoring of these existing baseline furnaces, laboratory test results for more efficient retrofit furnaces, and field monitoring of retrofit furnaces that replaced the baseline furnaces.

Project Purpose and Approach

The goal of this research is to demonstrate cost-effective solutions for retrofitting existing wall furnaces in California multifamily and single-family residences. This interim report gives the results of baseline wall furnace laboratory testing to characterize the energy use, efficiency, and flue gas emissions of a sample of baseline wall furnaces. Other reports document results of retrofit wall furnace laboratory testing, and field monitoring results of baseline and retrofit wall furnaces.

The baseline wall furnaces studied in this project were existing furnaces that had been in service in California homes. The furnaces were initially monitored in the field over a heating season, then were removed and shipped to Des Plaines, IL facilities for testing in GTI Energy’s Residential and Commercial Equipment laboratory.

Ten baseline vented gravity wall furnaces were tested:

- Two from side-by-side apartments in Hayward (apartments 3 and 4)
- Four from a retirement apartment community in Los Angeles (apartments 104, 105, 106, and 107)
- One from a single-family home in Oakland (SFH)

- Three from multifamily apartments in Sacramento (apartments 4, 15, and 19)

These ten existing wall furnaces were all vented gravity non-condensing furnaces with standing pilots. These furnaces ranged in age from about 10 years to more than 40 years with rated input capacities between 25,000 and 50,000 Btu/hr and rated thermal efficiencies from 50% to 74%. The Oakland furnace was a double-sided unit serving two rooms, while all other furnaces were single-sided units. After field monitoring each of these furnaces over a winter heating season, they were removed from service and shipped to GTI Energy's Des Plaines facility for laboratory testing.

Laboratory testing included measurement of furnace natural gas flow, electricity use, operating temperatures, and concentrations of carbon monoxide (CO), nitrogen oxides (NOx), and total hydrocarbons (THC) in exhaust gases. The testing protocol covered furnace operation during standby, startup, steady state, and shutdown. Parameters derived from measurements include each furnace's input capacity and pilot gas use, efficiency, and pollutant emission rates.

Key Results

Table 1 lists the rated and measured natural gas flows of each wall furnace. All but one of the furnaces used less natural gas than their rated input, for an average 89% of rated input. Gas use of the standing pilot was either ~500/750/1000 Btu/hr and tended to be greater for furnaces with larger input capacity.

Table 1: Baseline Wall Furnace Natural Gas Input Rates

Wall Furnace Tested				Natural Gas Input			
Manufacturer	Model	Field Site	Age years	Rated Btu/hr	Tested Btu/hr	% Rated Input	Pilot Btu/hr
Perfection Products	PW8G25SEN #1	Hayward 3 Baseline	~40	25000	20280	81%	520
Perfection Products	PW8G25SEN #2	Hayward 4 Baseline	~40	25000	20210	81%	510
Williams	25GV-A1	LA 104 Baseline	~35	25000	25100	100%	750
Williams	35GV-C #1	LA 105 Baseline	~35	35000	31720	91%	520
Williams	35GV-C #2	LA 106 Baseline	~35	35000	31800	91%	570
Williams	RMG35-IN	LA 107 Baseline	~35	35000	31810	91%	500
Williams	5009622	Oakland SF Baseline	~15	50000	44500	89%	1090
Holly General	35S-D #1	Sacramento 4 Baseline	40+	35000	31530	90%	720
Holly General	35S-D #2	Sacramento 15 Baseline	40+	35000	29110	83%	710
Williams	3509622	Sacramento 19 Baseline	~10	35000	33800	97%	1050
		Average		**33500**	**30000**	**89%**	**690**

Table 2 lists the rated and test-derived thermal efficiency and AFUE for each unit. Rated AFUE values are only listed for the two furnaces manufactured after the minimum AFUE reporting requirement was put into place January 1, 1990. Six of the tested furnaces exceeded their thermal efficiency ratings while four did not. Six furnaces also exceeded the 70% minimum thermal efficiency required by the American National Standards Institute regulations (ANSI Z21.86 2016), and five met the 65% minimum AFUE required by the Code of Federal Regulations (CFR 430.32 2022).

Table 2: Baseline Wall Furnace Thermal Efficiency and AFUE

Wall Furnace Tested			Thermal Efficiency		AFUE	
Manufacturer	**Model**	**Field Site**	**Rated**	**Tested**	**Rated**	**Tested**
Perfection Products	PW8G25SEN #1	Hayward 3	70%	76.3%		70.5%
Perfection Products	PW8G25SEN #2	Hayward 4	70%	71.8%		66.1%
Williams	25GV-A1	LA 104	70%	70.5%		64.4%
Williams	35GV-C #1	LA 105	70%	62.8%		59.2%
Williams	35GV-C #2	LA 106	70%	73.6%		69.3%
Williams	RMG35-IN	LA 107	70%	75.1%		71.1%
Williams	5009622	Oakland SFH	76%	50.1%	74.0%	46.0%
Holly General	35S-D #1	Sacramento 4	50%	39.0%		35.7%
Holly General	35S-D #2	Sacramento 15	50%	60.8%		56.2%
Williams	3509622	Sacramento 19	74%	73.2%	72.0%	66.7%
		Average	**67.0%**	**65.3%**		**60.5%**

Table 3 lists the energy use and emissions for each wall furnace for a typical day of operation as found during field testing of these units, where the furnace cycles 1.5 times a day for 33 minutes per cycle and remains in standby with the pilot light on for the rest of the day. As expected, the largest capacity unit in this study, the 50,000 Btu/hr Oakland unit, would use the most natural gas. The 35,000 Btu/hr Sacramento 19 furnace used a lot of natural gas relative to its capacity due to its high pilot gas use while in standby.

Table 3: Baseline Wall Furnace Energy Use and Emission Rates for a Typical Day of Operation

Wall Furnace Tested			Average Energy Use & Emission Rates at Each Site			
Manufacturer	**Model**	**Field Site**	**Btu/Day**	**CO lbm/MMBtu**	**NOx lbm/MMBtu**	**THC lbm/MMBtu**
Perfection Products	PW8G25SEN #1	Hayward 3	28782	0.194	0.081	0.054
Perfection Products	PW8G25SEN #2	Hayward 4	28493	0.037	0.072	0.327
Williams	25GV-A1	LA 104	38089	0.116	0.063	0.255
Williams	35GV-C #1	LA 105	38220	0.086	0.075	0.006
Williams	35GV-C #2	LA 106	39445	0.039	0.059	0.000
Williams	RMG35-IN	LA 107	37831	0.061	0.071	0.147
Williams	5009622	Oakland SF	61973	0.333	0.077	0.006
Holly General	35S-D #1	Sacramento 4	42698	0.067	0.069	0.005
Holly General	35S-D #2	Sacramento 15	40470	0.596	0.019	0.029
Williams	3509622	Sacramento 19	52219	0.059	0.090	0.143
		Average	**40822**	**0.169**	**0.068**	**0.087**

There are no regulations for gravity wall furnace emissions, but two California air quality districts limit central furnace nitrogen oxides (NOx) emissions to 0.033 lbm/MMBtu, the South Coast Air Quality Management District's Rule 1111 (SCAQMD 2021) and the San Joaquin Valley

Air Pollution Control District's Rule 4905 (SJVAPCD 2020). Only one of the baseline wall furnaces would comply with this limit, the Holly General 35S-D unit from Sacramento 15, one of the two oldest furnaces tested in this project. On average, NOx emissions from these baseline wall furnaces were twice the regulated limit for central furnaces. NOx emissions from these furnaces were generated during active heating operation due to poor control of the fuel-air ratio.

Carbon monoxide and hydrocarbon emissions are not regulated for wall furnaces or central furnaces. Laboratory testing showed variation in these emissions between furnaces, with high CO emissions from three of the tested furnaces, and high hydrocarbon emissions from four furnaces. High CO and THC emissions are usually due to incomplete combustion during startup and shutdown, although the Holly General 35S-D #2 furnace produced high CO and THC emissions while actively heating.

Knowledge Transfer and Next Steps

The laboratory results documented in this study will be combined with results from the field monitoring of these baseline furnaces to determine energy use and emissions from typical baseline wall furnaces. Similar laboratory testing and field monitoring will be done to characterize the performance of more efficient retrofit furnaces. Baseline and retrofit data will then be used to estimate the energy savings and emission reduction potential of more efficient wall furnaces.

Introduction

This project's overall objective is to characterize the operation, energy, indoor air quality, and emissions of existing and retrofit wall furnaces. The goal of this research is to investigate and demonstrate efficient solutions for retrofitting existing wall furnaces in California multifamily and single-family residences.

A wall furnace is a compact device installed within a home's wall cavity and used to heat one or two rooms. Because they are less expensive, simpler to install, and take up less space than a central ducted furnace, they are used in multifamily apartment complexes and smaller single-family homes.

Wall furnaces are categorized by how they distribute heat (gravity or fan-type), where their combustion air comes from (from inside for top vent furnaces, from outside for direct vent furnaces), how they ignite the burner (standing pilot, intermittent pilot, or hot surface igniter), and whether they use condensing technology. Additionally, furnaces can be either single-sided to serve just one room, or double-sided to serve rooms on either side of the wall in which it is installed. These wall furnace technologies are described in more depth in Appendix A.

Many California low-rise multifamily buildings and smaller homes use wall furnaces for space heating. Most of these existing wall furnaces are non-condensing gravity vented furnaces that use a standing pilot to ignite the burner. Wall furnaces are usually replaced only when the original unit is irreparably broken. Anecdotal information from Williams, the predominant wall furnace manufacturer, indicates that many older furnaces are still in operation, some without safety switches and with rated thermal efficiencies as low as 50%.

Most replacement wall furnaces are non-condensing gravity vented furnaces that just meet current efficiency standards. ANSI Z21.86 for Vented Gas-Fired Space Heating Appliances (ANSI Z21.96 2016) is the federal regulating standard for wall furnaces, It currently requires gravity wall furnace thermal efficiency to be at least 70% and fan-type wall furnace efficiency to be at least 75%. In addition, Annual Fuel Utilization Efficiency (AFUE) for wall furnaces are mandated under the Code of Federal Regulations (CFR 430.32 (i) (1) 2022) and (CFR 430.32 (i) (2) 2022). AFUE must be at least 65% to 76%, depending on furnace capacity and whether it is a gravity or fan-type wall furnace. More information about wall furnace efficiency standards is included in Appendix A.

Minimum wall furnace AFUE levels are well below the 81% AFUE requirement for standard central ducted furnaces and even further below the >90% AFUE that condensing furnaces can deliver. However, wall furnaces have recently been developed with thermal efficiencies as high as 85% and AFUE up to 82%, achieved by improving burners and removing standing pilot lights. In addition, condensing wall furnaces with thermal efficiency up to 94% and AFUE as high as 93% have been developed.

As with all primary gas space heating equipment in the state of California, emissions from wall furnace combustion are required to be vented to the outside to prevent the accumulation of indoor pollutants. There are no federal or California limits for wall furnaces regarding flue gas emissions or indoor pollutants, although there are some limits on NOx emissions for natural gas-fired fan-type central furnaces in California's South Coast Air Quality Management District (SCAQMD) and the San Joaquin Valley Air Pollution Control District (SJVAPCD). See Appendix A for information about guidelines, standards, and regulations that pertain to indoor air quality and furnace emissions.

This project examines existing baseline and efficient retrofit wall furnaces in the laboratory and the field to assess their performance, ease of installation, operation, and reliability. Energy use, emissions, indoor air quality, and costs are assessed to help determine whether efficient retrofit wall furnace technologies should be promoted in California.

This interim report describes results from laboratory tests of ten baseline wall furnaces that were removed from homes and shipped to GTI's Des Plaines facility.

- Two from side-by-side apartments in Hayward (apartments 3 and 4)
- Four from a retirement apartment community in Los Angeles (apartments 104, 105, 106, and 107)
- One from a single-family home in Oakland (SFH)
- Three from multifamily apartments in Sacramento (apartments 4, 15, and 19)

Laboratory testing involved running the furnaces through a protocol that included standby, startup, steady state, and shutdown operation while measuring:

- Inlet, outlet, and exhaust temperatures of the wall furnaces
- Carbon monoxide, nitrogen oxide, and total hydrocarbon flue gas emissions
- Natural gas flow rates

In other project work, these test results will be applied to field monitoring data for these furnaces to estimate their energy use and emissions. Efficient retrofit furnaces will also be laboratory tested and field monitored as part of this project. Comparisons of baseline and retrofit energy use and emissions will be made to evaluate the savings that can be realized through the installation of more efficient retrofit furnaces.

Project Approach

Laboratory testing was conducted within the Residential and Commercial Equipment laboratory on the Des Plaines, IL GTI Energy campus. Wall furnace tests included measurement of intake, burner and exhaust temperatures, natural gas and electricity use, and exhaust gas emission levels.

Furnaces Tested

This project tested a total of ten baseline wall furnaces which had been in active use at various California sites. These furnaces were shipped to GTI Energy for laboratory testing after they were removed and replaced with more efficient retrofit furnaces. The characteristics of each baseline furnace are presented in Table 4.

Table 4: Laboratory Tested Baseline Wall Furnace Characteristics, Gravity Vented Non-Condensing Units with Standing Pilots

Field Site	Manufacturer	Model*	ANSI Z21 Std	Age years	Input Btu/hr	Thermal Efficiency	Rated AFUE
Hayward 3	Perfection Products	PW825SEN-B-4 #1	49a.1982	~40	25,000	50%	n/a
Hayward 4	Perfection Products	PW825SEN-B-4 #2	49a.1982	~40	25,000	50%	n/a
Los Angeles 104	Williams	25GV-A1	49.1986	~35	25,000	70%	n/a
Los Angeles 105	Williams	35GV-C #1	49.1986	~35	35,000	70%	n/a
Los Angeles 106	Williams	35GV-C #2	49.1986	~35	35,000	70%	n/a
Los Angeles 107	Williams	RMG35IN	49.1986	~35	35,000	70%	n/a
Oakland SFH	Williams	5009622 (Double-sided)	86a.2005	~15	50,000	76%	74%
Sacramento 4	Holly General	Narrowall 35S-D #1	none	40+	35,000	70%	n/a
Sacramento 15	Holly General	Narrowall 35S-D #2	none	40+	35,000	70%	n/a
Sacramento 19	Williams	3509622	86.2008	~10	35,000	74%	72%

* All models are single-sided except for the double-sided Williams model 5009622.

Input capacities range from 25,000 to 50,000 Btu/hr and thermal efficiencies, defined as the output capacity divided by the input capacity, are between 50% and 76%. AFUE ratings were only available for the two youngest furnaces, since they were not required to be determined for the older furnaces. The 50,000 Btu/hr furnace is a double-sided furnace that was installed

in the wall between the living and dining rooms of the Oakland single-family home. All other furnaces are single-sided.
The exact age of these furnaces could not be determined. An ANSI.Z21 standard and year is listed on most of the furnace nameplates, indicating that they range in age from about 10 to 40 years. The Holly-General furnaces installed in two Sacramento apartments have no ANSI standard included on their nameplate at all, so it is assumed they are more than 40 years old.

All the tested baseline furnaces were self-powered and used continuously fired standing pilots to light the main burner when heating was needed.

Figure 1, Figure 2, and Figure 3 show the existing baseline wall furnaces as they were installed in each California home.

Figure 1: Existing Baseline Wall Furnaces in Hayward 3 (left), Hayward 4 (middle), and Oakland SFH (right)

Figure 2: Existing Baseline Wall Furnaces in Los Angeles Apartments 104, 105, 106, and 107 (from left to right)

Figure 3: Existing Baseline Wall Furnaces in Sacramento Apartments 4 (left), 15 (middle), and 19 (right)

Measurements and Test Equipment

The following table details the measurement equipment used in the laboratory.

Table 5: Laboratory Test Equipment

Measurement	Description	Range, Accuracy
Flow-Field Temperatures	1/8″ J-type exposed bead thermocouple	32-1328ºF/0-750ºC, ±2.2ºC
Ambient Temperature	1/8″ J-type exposed bead thermocouple	32-1328ºF/0-750ºC, ±2.2ºC

Ambient Humidity	Omega OM-HL-SH-EX	0-100%RH, ±5%RH
Data Acquisition Modules	National Instruments Compact DAQ	-
Stack O_2	Horiba PG350	Span 25% O_2, ±1%
Stack CO_2	Horiba PG350	Span 25% CO_2, ±1%
Stack NO_x	Horiba PG350	Span 100 ppm, ±1%
Stack CO	Horiba PG350	Span 500 ppm, ±1%
Stack THC	Rosemount Analytical 400A	Span 1000 ppm, 0.5ppm
Gas Flow Rate	American Meter AC250	8 pulses/ft^3

While the furnaces were not installed into a wall assembly designed to mimic a typical internal wall cavity, GTI Energy's Des Plaines laboratory technicians followed all other ANSI Z21.86 test protocols for measurement of temperatures, exhaust gas emissions, and natural gas flow.

Inlet temperatures were measured using a thermocouple in the center of the furnace inlet grill at the bottom of each furnace.

Exhaust air temperatures were measured approximately three inches from the combustion air outlet using a probe inserted into the exhaust air duct, with three thermocouples to measure temperatures across the duct span.

Burner outlet temperature measurements were recorded using an array of nine equally spaced thermocouples, following the dimensions outlined in section 11.6.1 of ANSI Z21.86 (ANSI Z21.86 2016) to ensure an average reading in the case of a heterogeneous flow field. The burner thermocouple array was attached to the center of the burner outlet to measure temperatures of the heated air leaving the furnace.

A continuous measurement of exhaust constituents, including oxygen (O_2), carbon dioxide (CO_2) carbon monoxide (CO), nitrogen oxides (NO_X), and unburned total hydrocarbons (THC) were measured and reported on a dry basis. Emission measurements were made through a system of three 0.25-inch stainless steel inserts in a manifold arrangement in the stack downstream of the flue temperature and pressure measurements. The emission sample points were arranged to account for exhaust streams that are non-homogenous. Combustion products were drawn through a vacuum pump and passed through a series of desiccants to provide a dry sample to a bank of analyzers located within the laboratory. Each analyzer was calibrated before each test run against a "zero" gas of pure nitrogen and then against a span gas measured in an independent analyzer.

GTI's laboratory measures the composition of the natural gas used for testing every two weeks. Samples of the natural gas being used for combustion are analyzed through a calorimeter. Although variations in gas characteristics tend to be small, the latest available house gas data was used for analysis of each tested wall furnace.

Natural gas for all wall furnace tests was delivered at a pressure of 6.9 inches water column, at the high end of the recommended 5 to 7 inches water column range for each furnace.

Test Procedure

The following operating procedure was followed for wall furnace tests:

- Start up all test measurement equipment
- Calibrate all sensors following equipment manufacturer procedures
- Adjust gas supply pressure to 6.8 inches water column
- Begin recording measurements
- Light furnace pilot
- Leave furnace on standby with the pilot lit for 30 minutes to record any pilot and/or electrical energy use
- Cold start – start up furnace and allow it to run for 45 minutes (steady state operation from cold start is usually reached in less than 30 minutes)
- Turn off furnace and let it sit in standby with the pilot lit for 1.5 minutes
- Hot start – start up furnace again and let it run for 30 minutes (steady state operation from a hot start is usually reached in less than 20 minutes)
- Turn off furnace and leave on standby with pilot lit for 15 minutes
- End test

This entire procedure took about two hours and allowed for the measurement of the furnace in standby, startup, steady state, and shutdown operating modes. For retrofit furnaces without pilot lights, standby operating times at the beginning and end of the test were reduced since this time was not needed to measure pilot light natural gas use.

Data Corrections

The gas analyzer and burner data acquisition system are separate pieces of equipment operating on slightly different time stamps. In addition, the flow of exhaust gases to the analyzer added a time delay. Data from the gas analyzer was synchronized with burner temperatures by lining up changes in O_2 and CO_2 concentrations with exhaust temperature changes over time.

The following corrections were made to the collected data:

- O_2 concentration maximum was adjusted to 20.9%, down from as much as 21.3% within +/- 1% measurement accuracy
- CO_2 concentration was adjusted to match the corrected O2 concentration during combustion based on the house natural gas characteristics
- CO and NOx minimum concentrations were adjusted to 0.0% (up from -0.13 ppm which is within +/- 1% measurement accuracy)

CO, NOx, and THC concentrations are reported as absolute values, and not corrected to a standard O_2% concentration as is sometimes done with furnace and boiler emissions.

O_2% varied from 10% to 19% for the baseline furnaces due to their no longer being well-tuned. To report actual emissions from these furnaces in their existing condition, emission concentrations were not standardized.

Analysis of Test Data

The fuel input capacity of the pilot light and during active combustion is operating was calculated from the measured gas flow rate as follows:

Qin = Fuel input capacity Btu/hr = 60 x Active Gas Flow Rate x Heating Value/Timestep

Qp= Pilot Btu/hr = 60 x Standby Gas Flow Rate x Heating Value / Timestep

Active Gas Flow Rate, ft^3 = measured value during active combustion

Standby Gas Flow Rate, ft^3 = measured during standby conditions

Heating value, Btu/ft^3 = from house natural gas used during testing

Timestep = time between measurements in minutes

Emission mass flow rates are normalized to the gas input rate from their absolute measured concentrations as follows:

Equation 1. Converting Emission Concentration to Emission Rate

$$\text{Emission Rate, lbm/MMBtu} = \frac{\text{Concentration x Molecular Weight x Fd x 20.9}}{(20.9 - O_2\%) \text{ x Molar Volume}}$$

Concentration, ppm = absolute measured pollutant concentration

Molecular weight, lbm/lbmole = 28.0097 for CO, 46.0047 for NOx as NO2, and 16.04206 for Total Hydrocarbons (THC) as methane

Fd, lbm/MMBtu = 10^6 x (3.64 x %H + 1.53 x %C + 0.57 x %S + 0.14 x %N – 0.46 x %O)/HHV, using dry weight percentages of each element in the house natural gas used for testing

O_2% = adjusted oxygen percentage in exhaust stream

HHV, Btu/lbm = higher heating value of house natural gas used for testing

Molar Volume, dry ft^3/lbmole = 385.3 at 68°F and 1 atmosphere

Estimated test thermal efficiency and AFUE are calculated for steady state operation based on Title 10 of the Code of Federal Regulations, Appendix O, Subpart B, Part 430 (CFR 430.32 2022), using the following equations:

Test $\eta_{SS-WT}\ \mathrm{automatic} = 100 - \mathrm{Ls\ ss} - \mathrm{L\ la}$

Test η_{SS-WT} manual $= \eta_{SS-WT} - \mathrm{L\ i\ on}$

Overall Test η_{SS-WT} = (η_{SS-WT} automatic + η_{SS-WT} manual) / 2

Test $\mathrm{AFUE\ automatic} = [0.968 \times \eta_{SS-WT}] - 1.78D_f - 1.89D_s - 129P_f - 2.8L_J + 1.81$

Test AFUE manual = [2950 x $\eta_{ss\text{-}wt}$ x $\eta_{part\ load}$ x Qin] / [2950 x Qin + 2.083 x 4600 x $\eta_{part\ load}$ x Qp

Overall Test AFUE = (Test AFUE automatic + Test AFUE manual) / 2

η_{SS-WT} = weighted-average steady state efficiency $= 100 - L_{L,A} - L_{s,SS}$

$L_{L,A}$ = latent heat loss = 9.55 for natural gas fueled furnaces

$L_{S,SS}$ = sensible heat loss at steady state $= C(R_{T,S} + D)(T_{S,SS} - T_{RA})$
where $C = 0.0175,\ D = 0.171$

$R_{T,S}$ = actual to stoichiometric air mass flow rate = A + B/X_{co2}
where $A = 0.0919$, $B = 10.96$, and X_{co2} is the concentration of carbon dioxide present in dry stack gas

$T_{S,SS}$ =steady state flue gas temperature

T_{RA} = ambient room temperature

D_f = off-cycle flue gas factor $= 1$ for atmospheric burner type furnaces

D_s = off-cycle stack gas factor and is equal to zero for direct vent furnaces

P_f = pilot fraction = Q_p/Q_{in}

L_j = jacket loss for floor furnaces, which is zero in this study

$\eta_{part\ load}$ = part load utilization efficiency $= \eta_{SS-WT} - L_{I\ ON}$

$L_{i\ ON}$ = on cycle infiltration heat loss = (70-45) x (100 x Cp x S/F) x (1+ Rts x (A/F) / HHV

Cp = specific heat of air, 0.24 Btu/lbm R

S/F = stack/mass flow ratio = 1.0

A/F = stoichiometric air-fuel ratio = 14.45 for natural gas

Note that the test apparatus was not installed in a fabricated wall assembly as designated in ANSI Z21.86 2016, therefore this report's efficiencies are not official rating tests and are for informational and comparative purposes only.

Unlike central furnaces which are most often allowed to cycle automatically to meet a thermostat setting, wall furnaces are much more likely to be turned on and off manually when occupants want heating. To reflect this operation, thermal efficiency and AFUE were found as the average of the efficiency for heaters that are automatically controlled and the efficiency for heaters with manual controls.

Results

Laboratory test results are presented here for each baseline wall furnace. Data for each furnace is presented in standardized plots that show their operation during testing. Two pages of test result plots are shown for each of the ten baseline furnaces:

- Cold start operation including five minutes of standby operation beforehand
- Hot start operation plus a summary of steady state conditions

Each page of test results includes the following information:

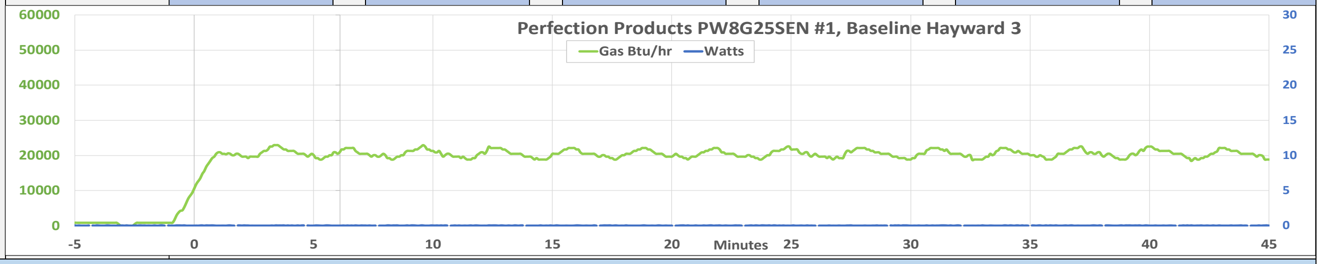
- Time to reach steady state and measured values at time intervals of 0%, 20%, 40%, 60%, 80% and 100% of steady state for the cold start, and values at time intervals of 0%, 33%, 67%, and 100% of steady state time for the hot start
- Fuel use, including both natural gas use and electrical power draw
- Exhaust, burner, inlet, and room temperatures
- Exhaust gas concentrations including O2%, CO2%, and CO, NOx, and THC concentrations in parts per million
- Note that vertical scales vary on emissions plots to show their values more clearly

Figure 4: Hayward 3, Perfection Products PW8G25SEN #1, Cold Start

Perfection Products PW8G25SEN #1, Baseline Hayward 3, Rated Input 25000 Btu/hr, Thermal Efficiency 70%

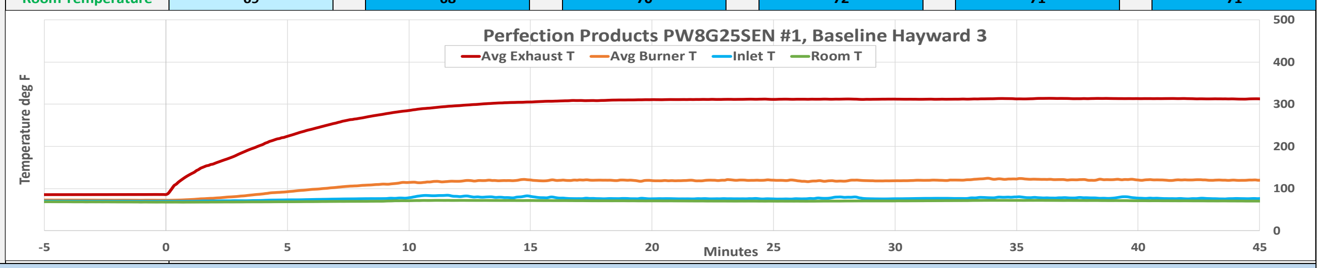
COLD START

		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	4.9	9.8	14.6	19.5	24.4
FUELS	Gas Input Btu/hr	520	20610	20610	20320	20930	19990
FUELS	Watts	0.0	0.0	0.0	0.0	0.0	0.0



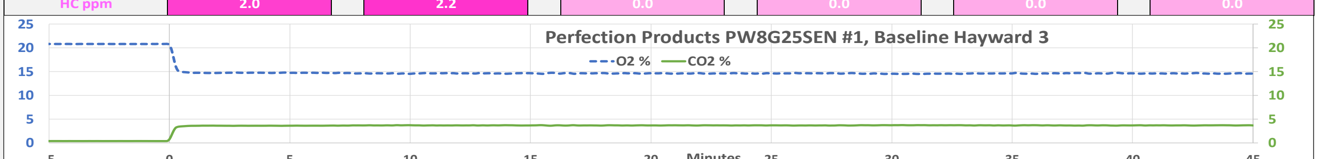
COLD START

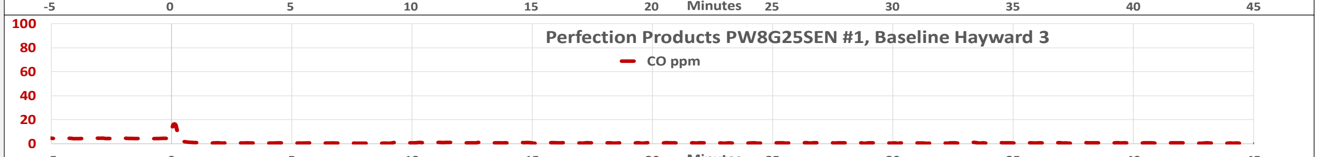
		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	4.9	9.8	14.6	19.5	24.4
TEMPERATURES	Exhaust Temperature	83 84 85 85 85	159 165 170 169 168	248 256 264 262 260	288 295 302 300 299	301 307 312 311 311	304 309 315 314 314
TEMPERATURES	Burner Temperatures	73 73 73 73 73	80 80 81 81 81	103 103 104 105 101	118 117 118 119 120	122 119 120 121 120	123 119 119 119 117
		73 73 73 73 73	80 80 80 82 81	103 104 103 111 104	117 117 116 121 119	119 117 119 122 120	119 116 119 123 119
		73 72 72 73 73	80 79 79 80 80	104 102 95 101 104	117 114 110 114 117	119 118 119 117 119	119 118 116 116 118
		73 72 72 73 73	80 79 79 78 80	105 107 100 97 103	117 116 113 111 116	119 118 116 111 118	120 120 115 110 118
		73 73 73 73 73	82 80 80 80 83	105 104 104 103 112	120 116 116 116 124	123 119 118 118 127	122 119 118 118 128
TEMPERATURES	Avg Burner Temperature	73	92	115	121	118	120
TEMPERATURES	Inlet Temperature	70	71	75	81	77	76
TEMPERATURES	Room Temperature	69	68	70	72	71	71

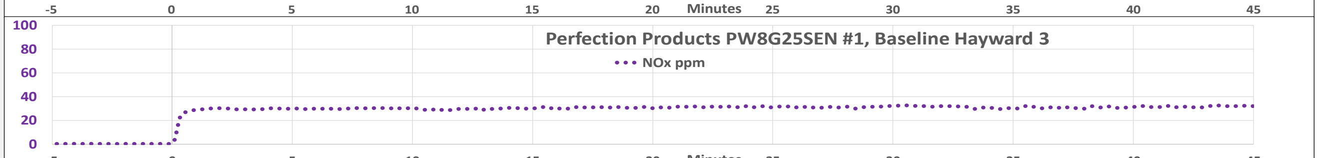


COLD START

		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	4.9	9.8	14.6	19.5	24.4
EMISSIONS	O2 %	20.8	15.0	14.7	14.6	14.6	14.6
EMISSIONS	CO2 %	0.4	3.6	3.7	3.7	3.7	3.7
EMISSIONS	CO ppm	4.3	1.6	0.5	0.8	0.6	0.6
EMISSIONS	NOx ppm	0.3	27.8	30.1	29.7	30.7	31.4
EMISSIONS	HC ppm	2.0	2.2	0.0	0.0	0.0	0.0







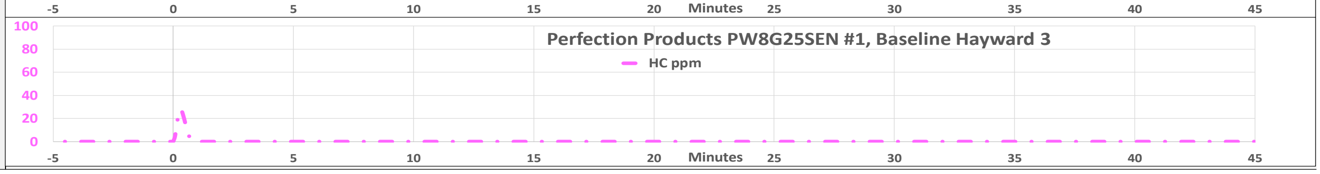
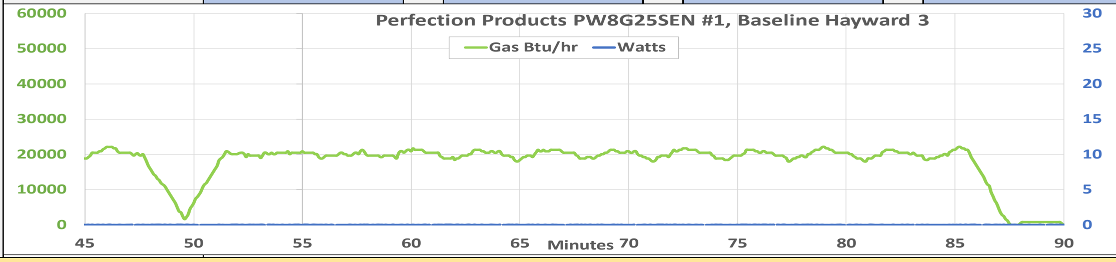


Figure 5: Hayward 3, Perfection Products PW8G25SEN #1, Hot Start & Steady state

Perfection Products PW8G25SEN #1, Baseline Hayward 3, Rated Input 25000 Btu/hr, Thermal Efficiency 70%

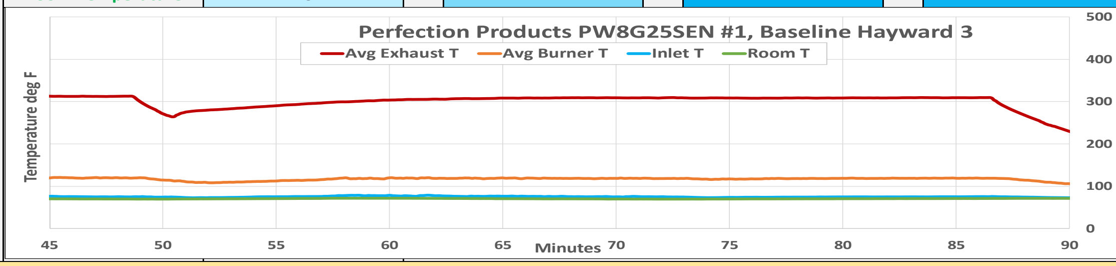
		HOT START				Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
TIME	Minutes On	0.0 (50.4)	4.7 (55.1)	9.6 (60)	14.3 (64.7)	
FUELS	Gas Input Btu/hr	520	20010	19820	20370	20280
FUELS	Watts	0.0	0.0	0.0	0.0	0.0



Pilot Light
520 Btu/hr

Standby Power
0 W

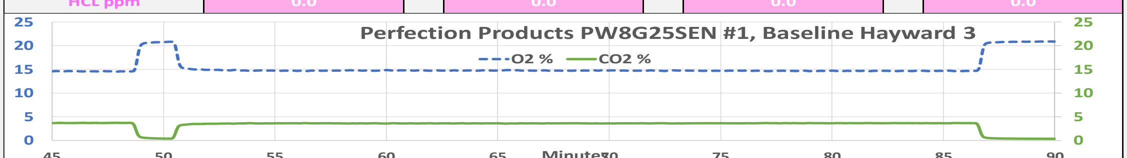
		HOT START (0%)					HOT START (33%)					HOT START (67%)					HOT START (100%)					Steady-State
TIME	% of Steady State	0%					33%					67%					100%					
TIME	Minutes On	0.0 (50.4)					4.7 (55.1)					9.6 (60)					14.3 (64.7)					
TEMPERATURES	Exhaust Temperature	262	264	265	266	266	276	280	284	284	284	291	296	302	301	300	300	304	309	309	308	310
TEMPERATURES	Burner Temperatures	120	115	114	113	111	115	110	110	109	108	118	116	116	117	116	121	118	119	120	119	120
		114	112	113	116	113	111	108	107	113	108	116	114	115	121	116	118	116	119	121	119	
		114	112	112	112	113	112	108	100	105	109	118	116	109	112	115	119	118	119	117	118	
		113	112	111	108	114	113	117	106	102	110	119	124	113	106	115	119	118	116	110	118	
		115	113	113	114	122	113	112	111	110	121	119	118	117	115	126	123	119	118	118	127	
TEMPERATURES	Avg Burner Temperature	114					111					117					119					
TEMPERATURES	Inlet Temperature	74					74					77					77					76
TEMPERATURES	Room Temperature	70					71					72					72					71

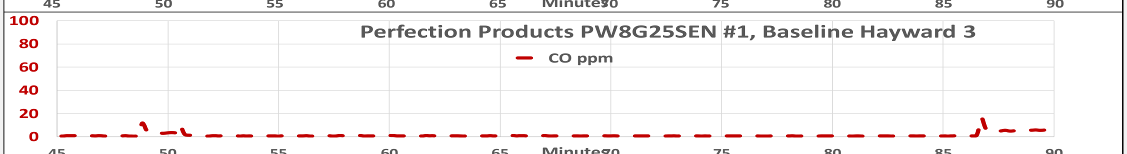


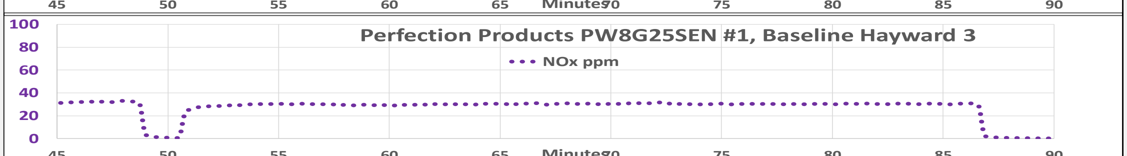
Test Thermal Efficiency
76.3%

Test AFUE
70.5%

		HOT START				Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
TIME	Minutes On	0.0 (50.4)	4.7 (55.1)	9.6 (60)	14.3 (64.7)	
EMISSIONS	O2 %	20.8	15.2	14.7	14.7	14.7
EMISSIONS	CO2 %	0.4	3.4	3.6	3.6	3.7
EMISSIONS	CO ppm	3.3	1.0	0.5	0.6	0.5
EMISSIONS	NOx ppm	0.6	27.2	29.7	29.9	30.8
EMISSIONS	HCL ppm	0.0	0.0	0.0	0.0	0.0







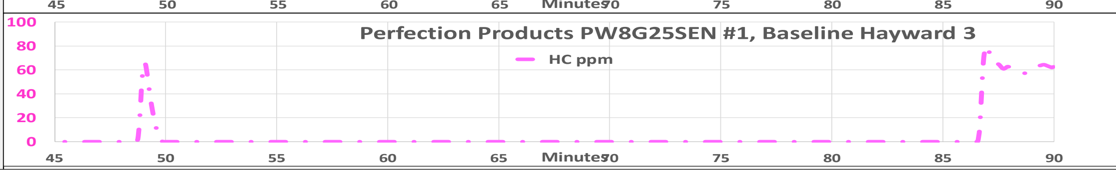
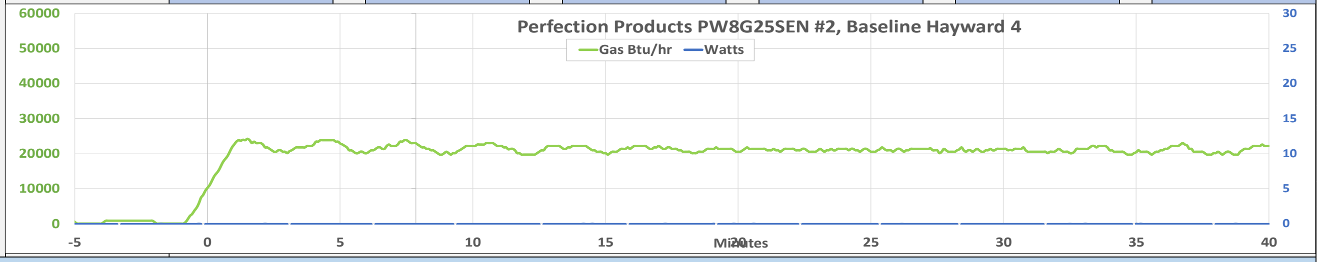


Figure 6: Hayward 4, Perfection Products PW8G25SEN #2, Cold Start

Perfection Products PW8G25SEN #2, Baseline Hayward 4, Rated Input 25000 Btu/hr, Thermal Efficiency 70%

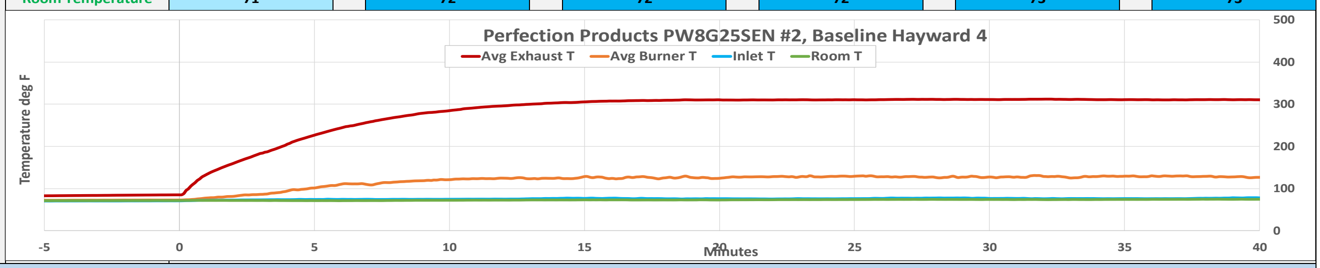
COLD START

		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	3.7	7.5	11.2	15	18.7
FUELS	Gas Input Btu/hr	510	21160	22550	21860	20910	21000
FUELS	Watts	0.0	0.0	0.0	0.0	0.0	0.0



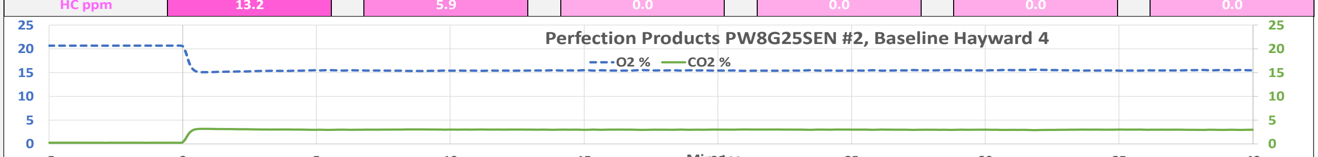
COLD START

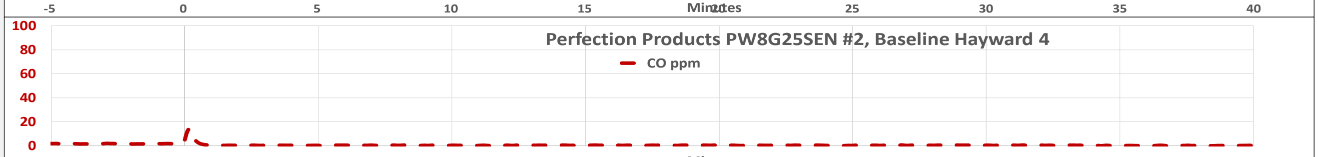
		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	3.7	7.5	11.2	15	18.7
TEMPERATURES	Exhaust Temperature	81 82 83 82 82	143 150 156 154 153	223 233 244 241 239	265 278 290 287 284	286 297 309 306 304	294 305 317 315 313
TEMPERATURES	Burner Temperatures	72 72 72 72 73	76 79 81 83 87	88 99 105 112 118	104 115 121 127 124	105 119 126 133 134	104 118 128 138 145
		72 72 72 73 72	78 80 80 83 83	97 105 104 113 110	114 120 123 133 125	117 124 127 140 131	116 124 126 142 136
		72 72 72 72 72	80 79 78 79 81	101 99 95 100 105	117 118 116 117 120	122 122 116 120 125	122 119 111 120 127
		72 72 72 72 72	81 77 77 77 80	105 97 94 92 100	121 119 112 101 114	127 126 116 105 118	127 122 114 108 118
		73 72 72 72 73	87 80 80 80 85	119 104 102 100 115	126 119 117 114 130	132 125 121 118 134	140 125 122 118 133
	Avg Burner Temperature	72	90	113	123	128	129
	Inlet Temperature	70	73	74	75	76	77
	Room Temperature	71	72	72	72	73	73

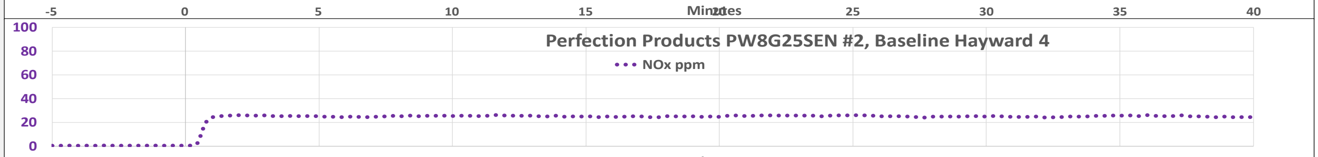


COLD START

		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	3.7	7.5	11.2	15	18.7
EMISSIONS	O2 %	20.6	15.6	15.4	15.4	15.4	15.4
EMISSIONS	CO2 %	0.2	3.0	2.9	3.0	2.9	2.9
EMISSIONS	CO ppm	1.7	1.6	0.4	0.4	0.4	0.5
EMISSIONS	NOx ppm	0.3	20.9	25.0	25.5	25.4	24.8
EMISSIONS	HC ppm	13.2	5.9	0.0	0.0	0.0	0.0







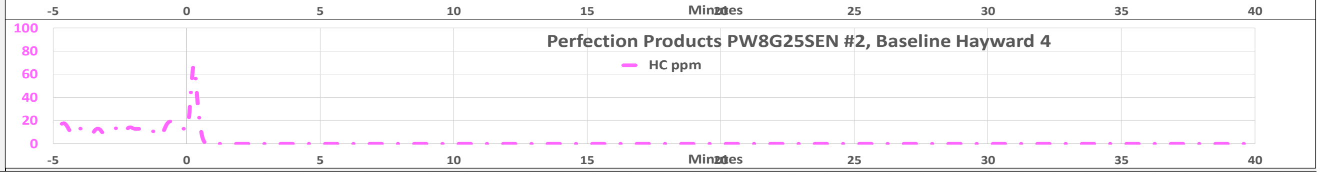
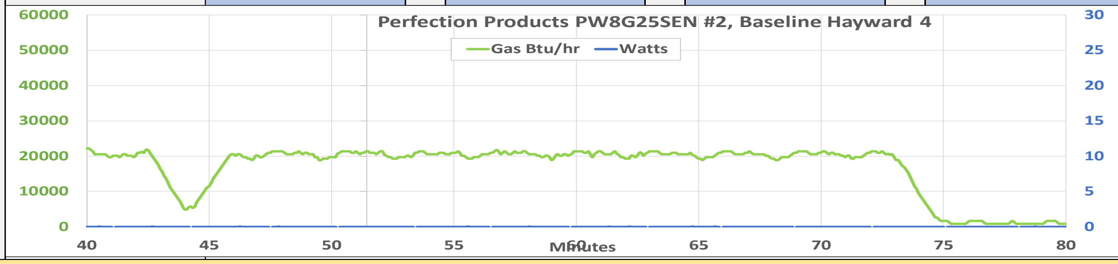


Figure 7: Hayward 4, Perfection Products PW8G25SEN #2, Hot Start & SteadyState

Perfection Products PW8G25SEN #2, Baseline Hayward 4, Rated Input 25000 Btu/hr, Thermal Efficiency 70%

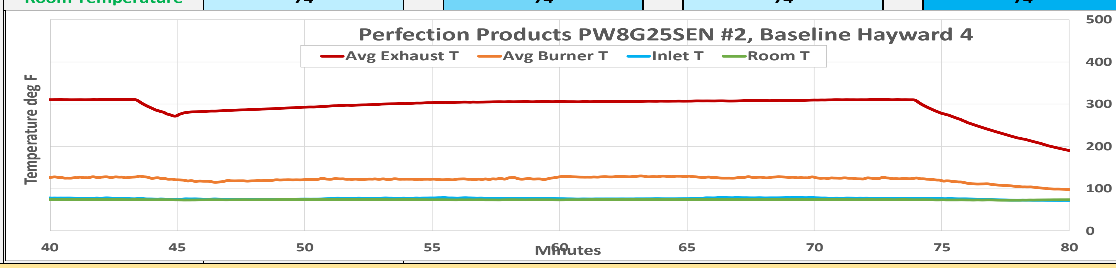
	HOT START				Steady-State
TIME % of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (44.8)	8.2 (53)	16.7 (61.5)	24.9 (69.7)	
FUELS Gas Input Btu/hr	510	20290	20430	20400	*18750*
Watts	0.0	0.0	0.0	0.0	*0.0*



Pilot Light 510 Btu/hr

Standby Power 0 W

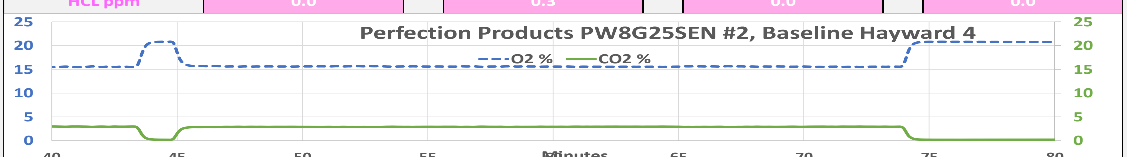
	HOT START				Steady-State
TIME % of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (44.8)	8.2 (53)	16.7 (61.5)	24.9 (69.7)	
TEMPERATURES Exhaust Temperature	263 272 281 279 277	278 287 297 295 293	291 302 313 311 309	295 305 315 313 311	*308*
Burner Temperatures	103 114 124 134 142	105 116 123 129 128	107 119 126 133 136	113 124 130 136 134	*126*
	112 118 121 140 133	114 121 123 136 127	117 125 126 139 131	122 129 131 144 134	
	117 114 105 117 124	117 117 112 117 121	120 119 113 119 124	124 124 122 125 128	
	123 118 110 108 115	121 118 111 103 115	123 119 113 106 118	127 122 117 109 121	
	137 122 118 115 128	127 119 117 115 130	132 121 119 118 134	134 124 123 121 138	
Avg Burner Temperature	122	120	123	127	
Inlet Temperature	75	76	77	78	*77*
Room Temperature	74	74	74	74	*74*

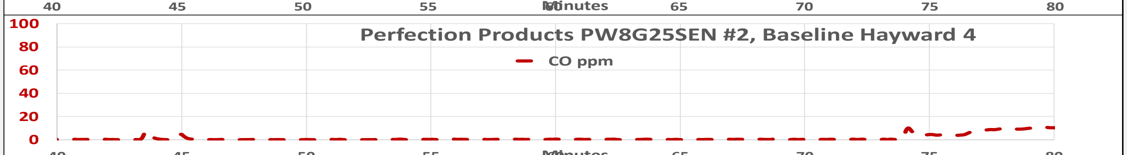


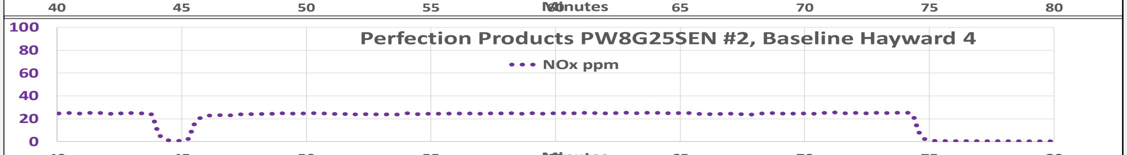
Test Thermal Efficiency 71.8%

Test AFUE 66.1%

	HOT START				Steady-State
TIME % of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (44.8)	8.2 (53)	16.7 (61.5)	24.9 (69.7)	
EMISSIONS O2 %	20.8	15.8	15.6	15.6	*15.9*
CO2 %	0.2	2.8	2.9	2.9	*2.7*
CO ppm	0.3	0.2	0.2	0.2	*0.8*
NOx ppm	0.7	21.9	24.4	24.5	*23.9*
HCL ppm	0.0	0.3	0.0	0.0	*19.6*







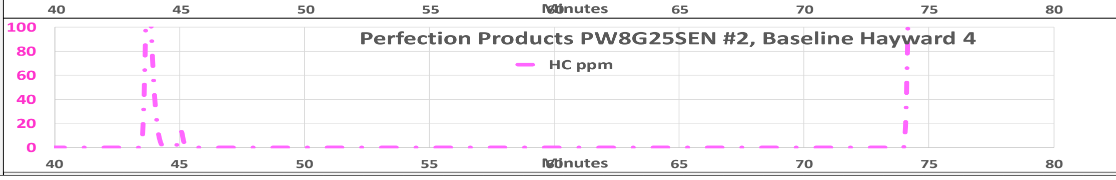
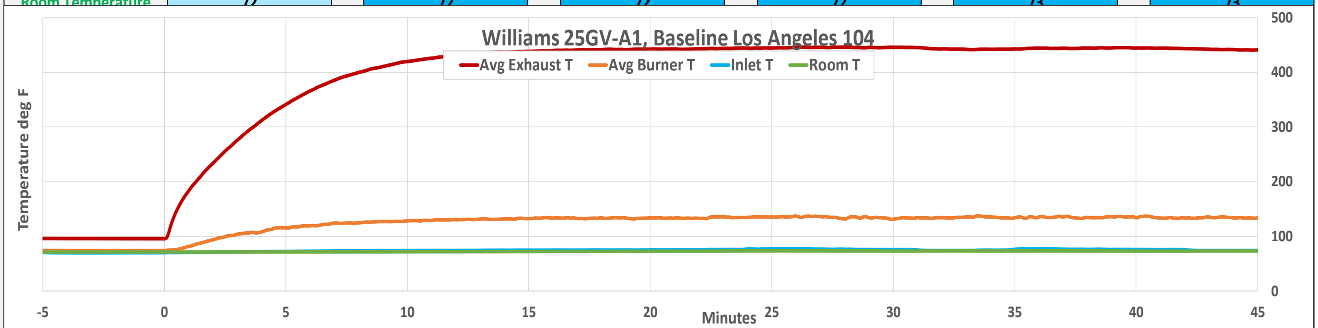


Figure 8: Los Angeles 104, Williams 25-GV-A1, Cold Start

COLD START

TIME / TEMPERATURES

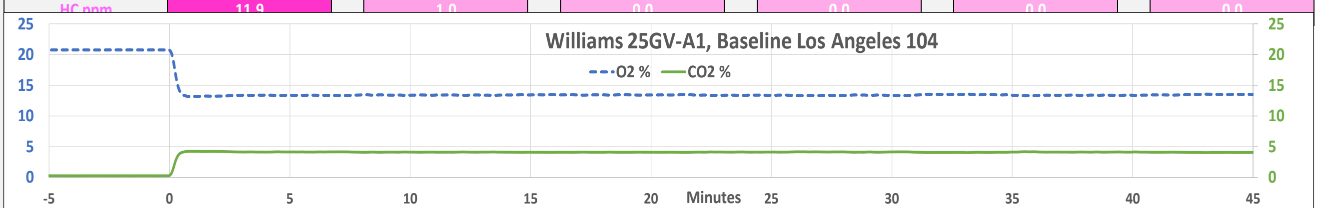
	PILOT	20%	40%	60%	80%	100%
% of Steady State	PILOT	20%	40%	60%	80%	100%
Minutes On	0.0	4.7	9.4	14.1	18.8	23.5
Exhaust Temperature	98 98 98 95 93	264 261 259 227 195	418 411 404 365 325	465 456 446 411 376	475 466 456 423 390	478 468 458 426 393
Burner Temperatures	74 74 75 75 75	81 91 100 109 94	113 120 132 145 121	128 128 137 147 126	132 131 140 149 129	131 131 139 147 131
	74 75 75 76 75	86 89 105 129 109	113 111 136 178 144	124 116 140 173 146	127 118 142 174 148	129 121 142 168 146
	74 74 73 74 75	88 90 97 105 102	116 116 118 133 129	128 129 132 138 134	131 132 135 141 137	132 135 137 140 137
	74 73 73 74 74	90 84 90 89 94	118 120 114 104 114	131 141 127 109 122	134 144 131 115 126	136 147 133 115 127
	75 74 74 74 75	95 90 92 94 103	119 117 116 114 123	122 130 126 122 129	124 133 130 126 132	125 135 131 127 134
Avg Burner Temperature	74	116	128	133	135	135
Inlet Temperature	71	71	73	75	75	76
Room Temperature	72	72	72	72	73	73

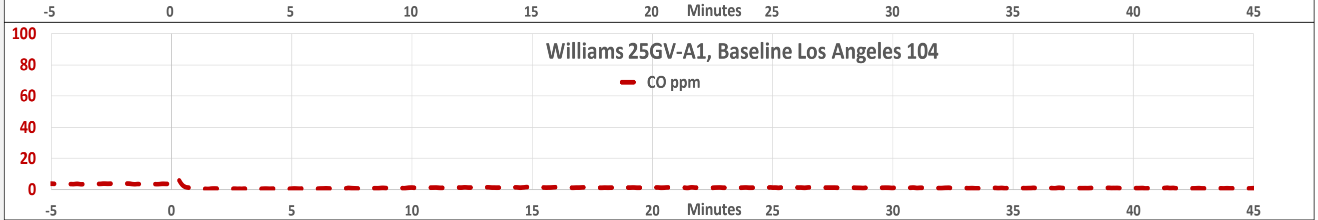


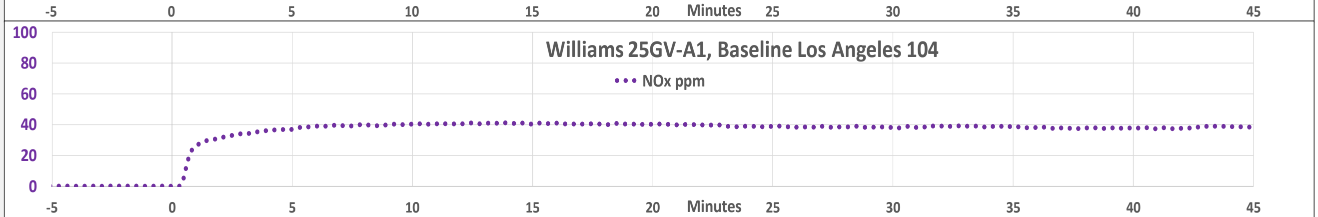
COLD START

TIME / EMISSIONS

	PILOT	20%	40%	60%	80%	100%
% of Steady State	PILOT	20%	40%	60%	80%	100%
Minutes On	0.0	4.7	9.4	14.1	18.8	23.5
O2 %	20.7	13.8	13.4	13.4	13.4	13.4
CO2 %	0.3	4.1	4.1	4.1	4.1	4.1
CO ppm	3.4	1.0	0.6	1.1	1.2	1.1
NOx ppm	0.1	28.0	39.0	40.5	40.5	39.8
HC ppm	11.9	1.0	0.0	0.0	0.0	0.0







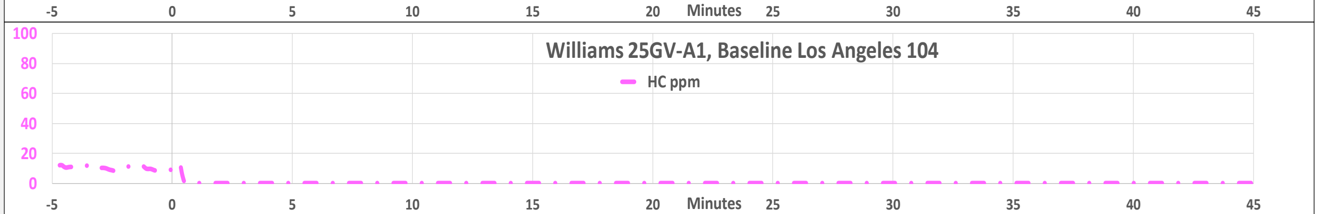
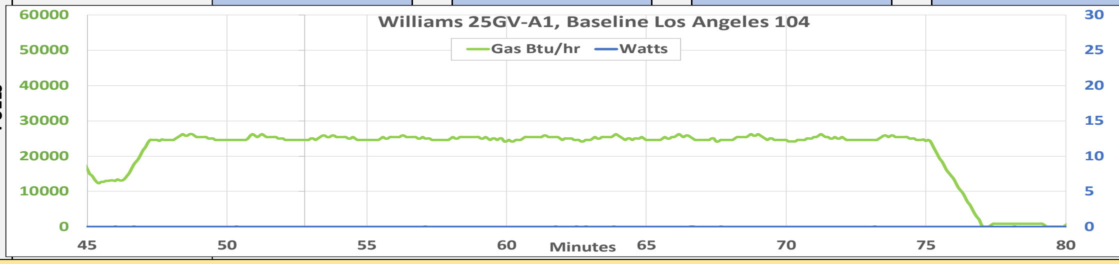


Figure 9: Los Angeles 104, Williams 25-GV-A1, Hot Start & Steady State

Williams 25GV-A1, Baseline Los Angeles 104, Rated Input 25000 Btu/hr, Thermal Efficiency 70%

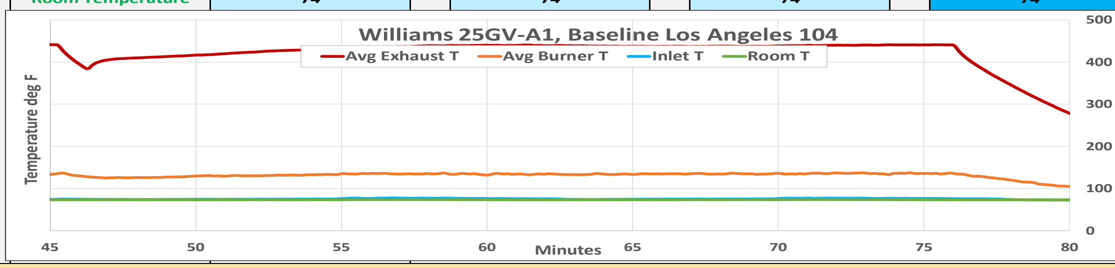
FUELS	HOT START				Steady-State
% of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (46.2)	4.1 (50.3)	8.4 (54.6)	12.5 (58.7)	
Gas Input Btu/hr	750	24440	25380	25010	25010
Watts	0.0	0.0	0.0	0.0	0.0



Pilot Light
750 Btu/hr

Standby Power
0 W

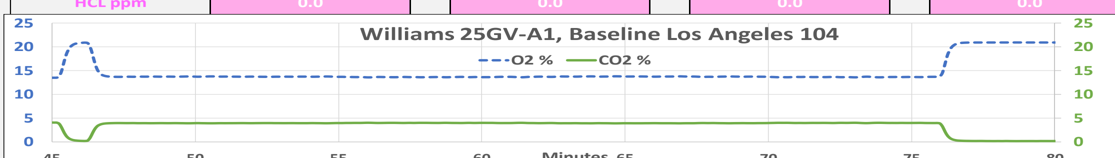
TEMPERATURES	HOT START																				Steady-State
% of Steady State	0%					33%					67%					100%					
Minutes On	0.0 (46.2)					4.1 (50.3)					8.4 (54.6)					12.5 (58.7)					
Exhaust Temperature	407	403	399	381	362	440	432	423	394	364	461	452	442	407	372	472	463	454	418	382	442
Burner Temperatures	135	129	135	141	125	129	127	133	140	125	133	131	139	147	128	134	133	139	146	135	135
	126	116	136	163	141	124	117	134	162	139	127	120	141	172	146	131	122	141	162	145	
	127	127	128	135	132	125	125	124	132	130	129	129	130	138	134	134	136	140	139	137	
	128	136	126	114	123	126	133	123	111	120	130	139	127	112	122	137	148	135	117	128	
	121	128	125	123	129	120	125	122	120	126	123	129	126	122	129	128	137	133	128	134	
Avg Burner Temperature	130					127					132					135					
Inlet Temperature	75					74					75					77					76
Room Temperature	74					74					74					74					74

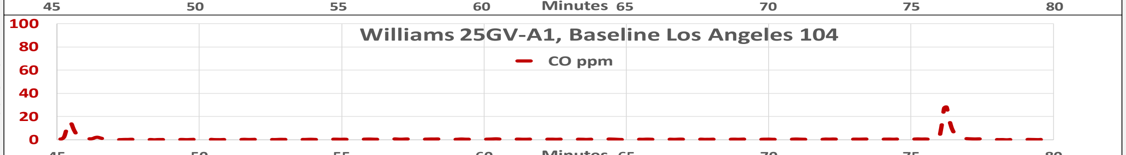


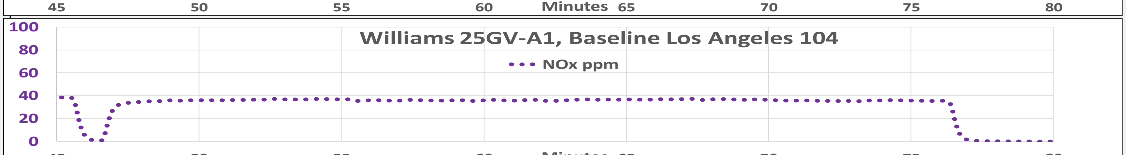
Test Thermal Efficiency 70.5%

Test AFUE 64.4%

EMISSIONS	HOT START				Steady-State
% of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (46.2)	4.1 (50.3)	8.4 (54.6)	12.5 (58.7)	
O2 %	20.8	14.2	13.7	13.6	13.5
CO2 %	0.2	3.7	3.9	4.0	4.0
CO ppm	0.9	0.4	0.3	0.5	0.7
NOx ppm	2.4	29.9	36.6	36.1	37.3
HCL ppm	0.0	0.0	0.0	0.0	0.0







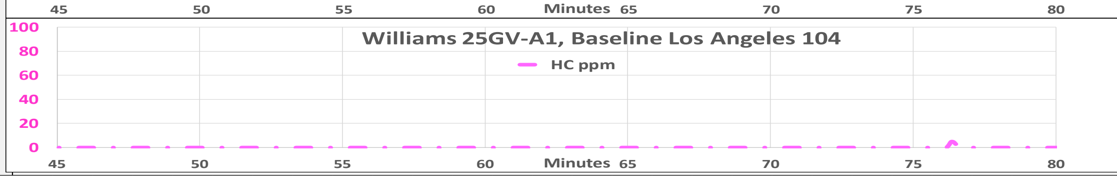
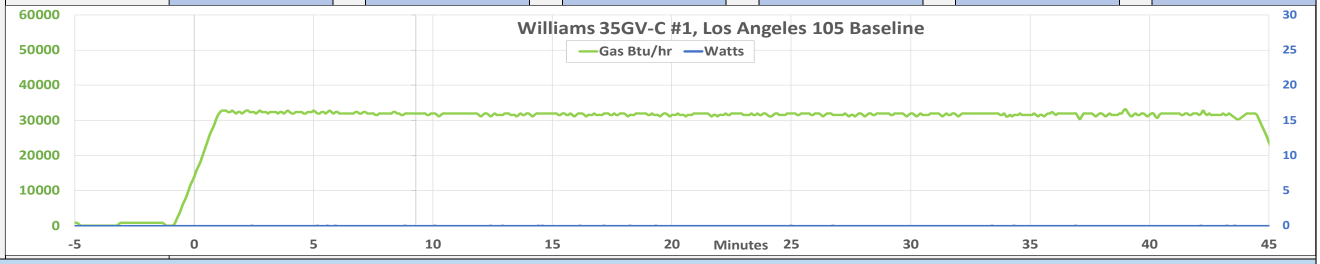


Figure 10: Los Angeles 105, Williams 35GV-C #1, Cold Start

Williams 35GV-C #1, Los Angeles 105 Baseline, Rated Input 35000 Btu/hr, Thermal Efficiency 70%

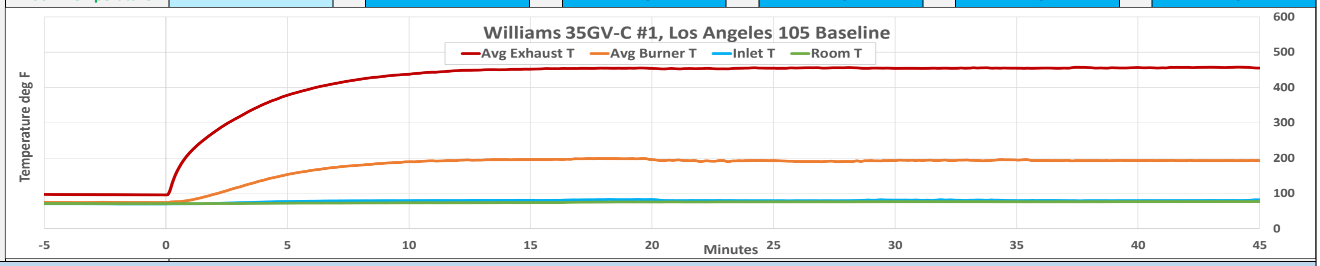
COLD START

TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
	Minutes On	0.0	4.8	9.7	14.5	19.4	24.2
FUELS	Gas Input Btu/hr	520	31210	32280	31540	32020	31370
	Watts	0.0	0.0	0.0	0.0	0.0	0.0



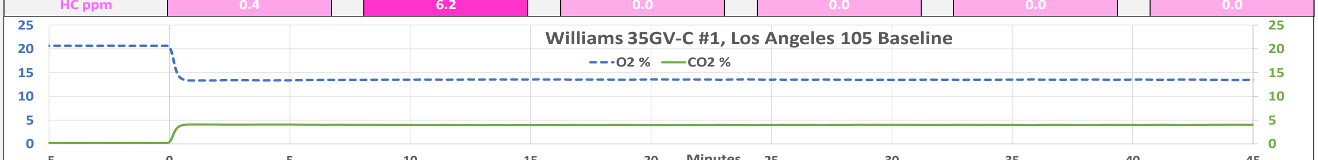
COLD START

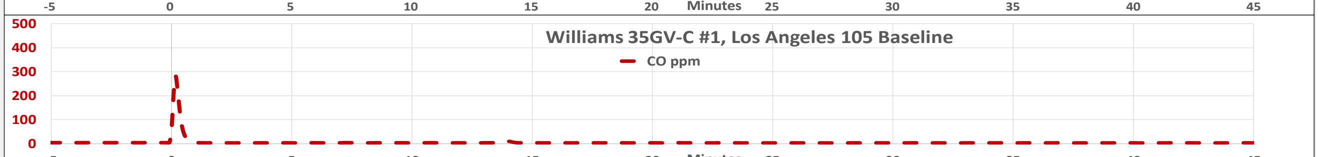
TIME	% of Steady State	PILOT					20%					40%					60%					80%					100%				
	Minutes On	0.0					4.8					9.7					14.5					19.4					24.2				
TEMPERATURES	Exhaust Temperature	97	97	98	99	100	255	268	282	286	290	390	400	409	423	436	427	433	439	456	473	434	441	447	464	480	432	441	450	465	479
	Burner Temperatures	75	75	76	76	76	89	110	112	115	111	136	173	183	192	177	155	192	203	213	194	166	197	207	217	198	153	189	199	209	192
		75	76	75	76	76	107	126	114	119	111	167	196	189	212	185	185	210	210	236	207	190	212	213	240	211	184	210	206	229	203
		75	75	74	75	75	107	105	97	102	106	169	169	160	168	173	189	190	184	190	193	192	193	188	194	197	190	191	179	189	194
		75	74	74	74	75	107	93	93	89	101	172	151	148	133	161	193	178	170	149	179	195	178	174	155	183	195	184	174	160	184
		76	75	75	75	77	122	102	102	101	121	195	165	163	161	201	211	186	183	179	219	214	189	186	183	222	212	190	187	184	218
	Avg Burner Temperature	75					151					188					195					197					193				
	Inlet Temperature	71					73					78					80					81					80				
	Room Temperature	71					71					73					73					75					76				

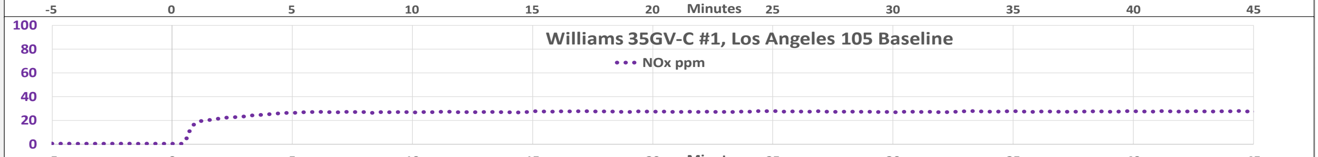


COLD START

TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
	Minutes On	0.0	4.8	9.7	14.5	19.4	24.2
EMISSIONS	O2 %	20.6	13.7	13.4	13.5	13.5	13.5
	CO2 %	0.2	4.1	4.0	4.0	4.0	3.9
	CO ppm	4.0	21.6	3.4	3.7	3.1	3.1
	NOx ppm	0.5	19.4	26.8	26.9	27.4	27.2
	HC ppm	0.4	6.2	0.0	0.0	0.0	0.0







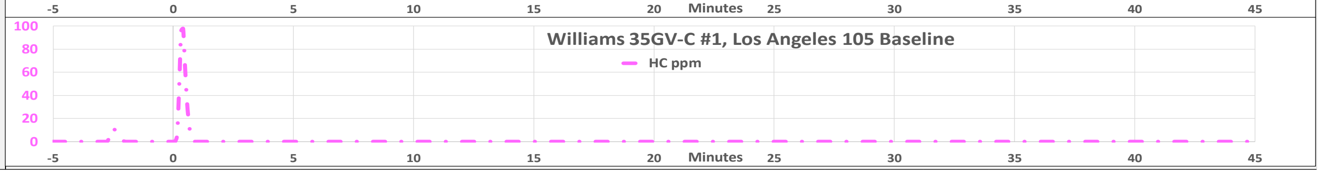
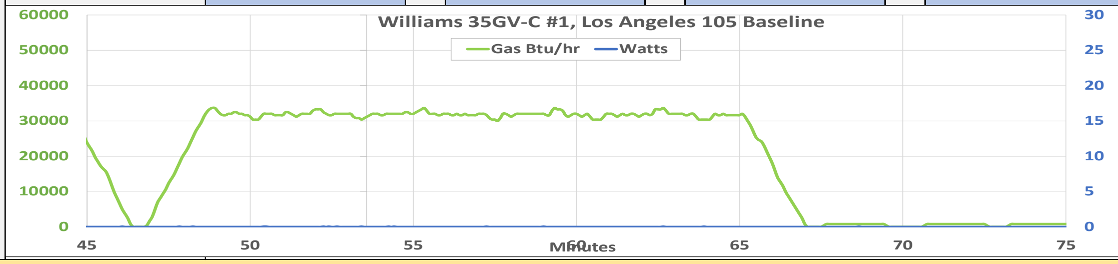


Figure 11: Los Angeles 105, Williams 35GV-C #1, Hot Start & Steady State

Williams 35GV-C #1, Los Angeles 105 Baseline, Rated Input 35000 Btu/hr, Thermal Efficiency 70%

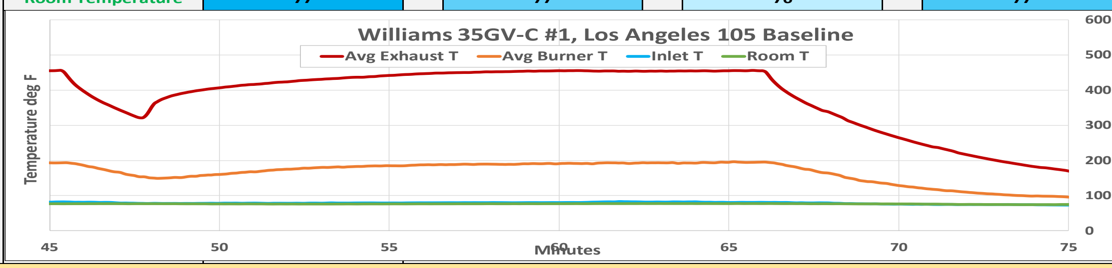
	HOT START					Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (47.7)	3.8 (51.5)	7.6 (55.3)	11.4 (59.1)	
FUELS	Gas Input Btu/hr	520	32180	31850	31770	31550
	Watts	0.0	0.0	0.0	0.0	0.0



Pilot Light
520 Btu/hr

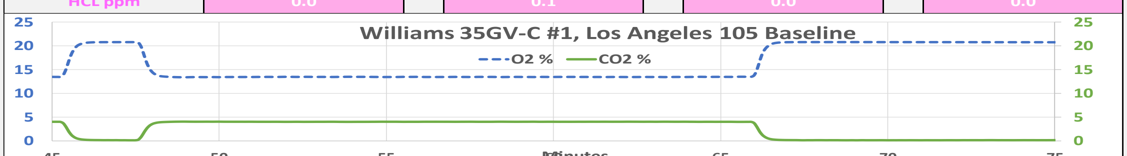
Standby Power
0 W

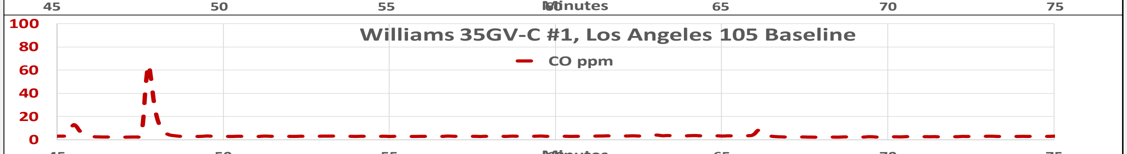
	HOT START					Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (47.7)	3.8 (51.5)	7.6 (55.3)	11.4 (59.1)	
TEMPERATURES	Exhaust Temperature	308 314 321 329 338	372 385 398 407 415	409 421 433 445 457	425 437 450 462 475	455
	Burner Temperatures	133 150 156 162 151	133 157 162 168 158	139 177 186 194 181	141 182 193 205 193	192
		148 157 159 174 160	154 171 167 180 165	172 200 192 210 189	177 205 200 221 200	
		152 153 147 154 156	157 157 149 156 159	177 178 166 176 181	183 185 173 185 191	
		157 156 148 141 152	160 152 146 138 153	182 168 162 152 173	190 177 170 161 182	
		160 155 153 152 166	172 157 155 153 175	201 177 175 173 205	208 185 183 182 214	
	Avg Burner Temperature	154	159	180	188	
	Inlet Temperature	78	78	79	80	80
	Room Temperature	77	77	76	77	76

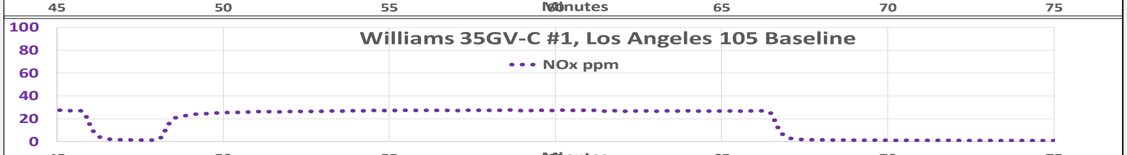


Test Thermal Efficiency
62.8%
Test Thermal AFUE
59.2%

	HOT START					Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (47.7)	3.8 (51.5)	7.6 (55.3)	11.4 (59.1)	
EMISSIONS	O2 %	20.2	13.6	13.4	13.4	15.5
	CO2 %	0.6	3.9	4.0	4.0	2.9
	CO ppm	30.4	6.8	2.9	2.9	3.0
	NOx ppm	1.2	21.1	26.8	27.4	20.4
	HCL ppm	0.0	0.1	0.0	0.0	0.8







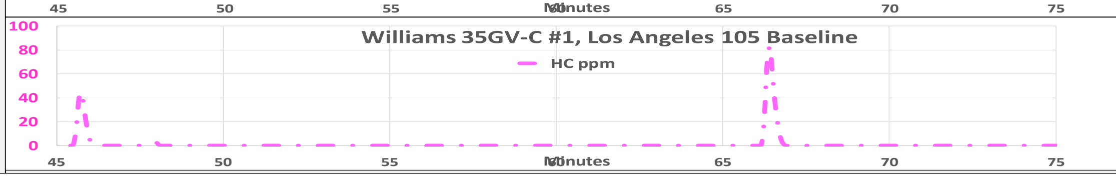
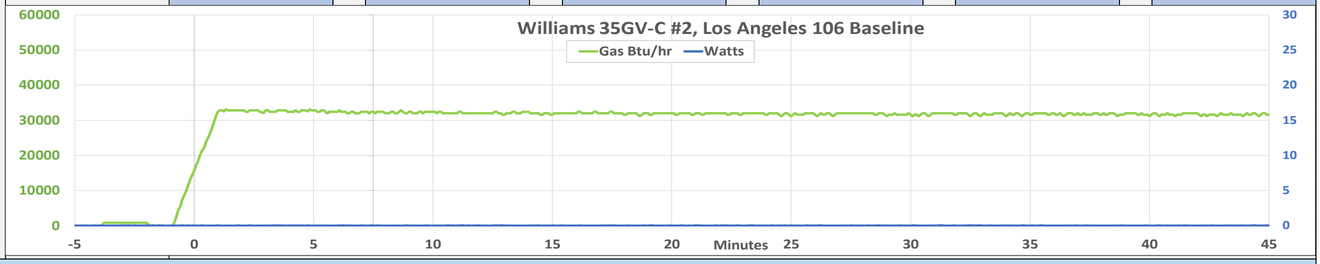


Figure 12: Los Angeles 106, Williams 35GV-C #2, Cold Start

Williams 35GV-C #2, Los Angeles 106 Baseline, Rated Input 35000 Btu/hr, Thermal Efficiency 70%

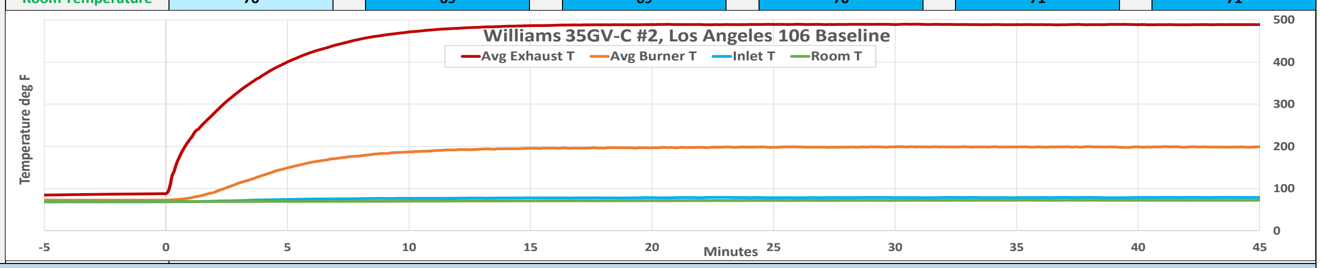
COLD START

TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
	Minutes On	0.0	3.3	6.7	10.0	13.4	16.7
FUELS	Gas Input Btu/hr	570	31590	32880	32290	31590	32290
	Watts	0.0	0.0	0.0	0.0	0.0	0.0



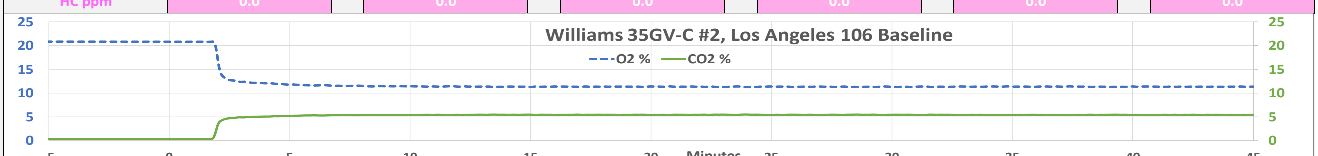
COLD START

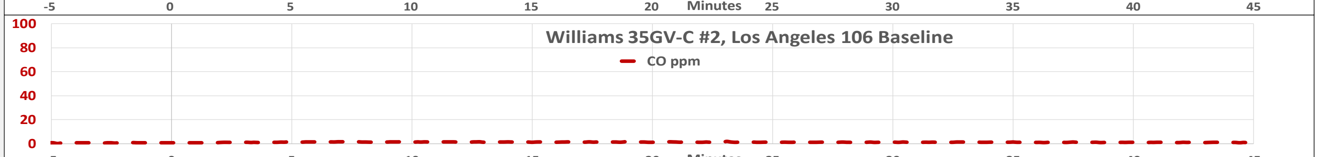
TIME	% of Steady State	PILOT					20%					40%					60%					80%					100%				
	Minutes On	0.0					3.3					6.7					10.0					13.4					16.7				
TEMPERATURES	Exhaust Temperature	82	84	85	84	84	222	242	262	257	252	367	390	414	411	408	428	450	471	470	469	451	471	492	492	492	459	479	499	499	499
	Burner Temperatures	72	72	72	72	73	88	92	90	89	95	142	155	150	146	151	179	190	183	176	177	191	201	194	187	188	195	205	198	191	191
		72	73	72	71	72	91	99	88	85	87	153	175	147	140	140	189	211	180	171	169	201	220	192	182	180	205	223	197	186	184
		72	72	71	71	72	90	87	81	82	87	150	142	125	130	140	185	178	157	159	170	197	192	174	172	182	202	197	183	177	186
		72	71	71	71	72	88	81	81	81	86	146	127	126	124	141	180	165	157	150	172	193	181	171	159	183	198	187	177	162	187
		73	72	72	72	73	97	86	86	86	97	168	140	140	141	172	199	174	173	172	208	208	187	185	183	218	211	191	189	187	221
	Avg Burner Temperature	72					119					169					187					194					196				
	Inlet Temperature	69					70					74					76					77					78				
	Room Temperature	70					69					69					70					71					71				

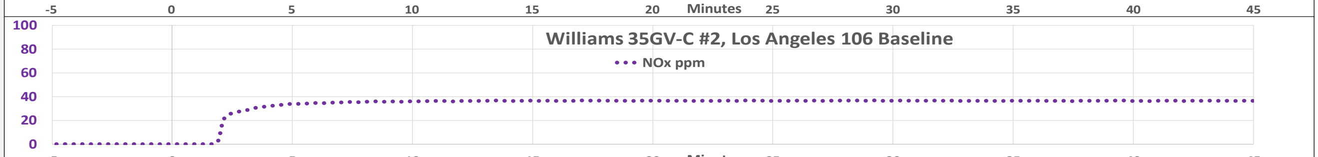


COLD START

TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
	Minutes On	0.0	3.3	6.7	10.0	13.4	16.7
EMISSIONS	O2 %	20.8	17.7	11.8	11.4	11.3	11.3
	CO2 %	0.3	5.0	5.3	5.4	5.5	5.5
	CO ppm	0.6	0.8	1.2	1.3	1.3	1.2
	NOx ppm	0.1	10.2	33.1	35.5	36.1	36.4
	HC ppm	0.0	0.0	0.0	0.0	0.0	0.0







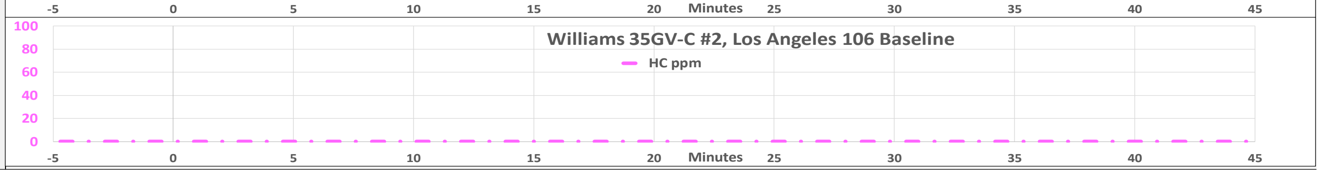
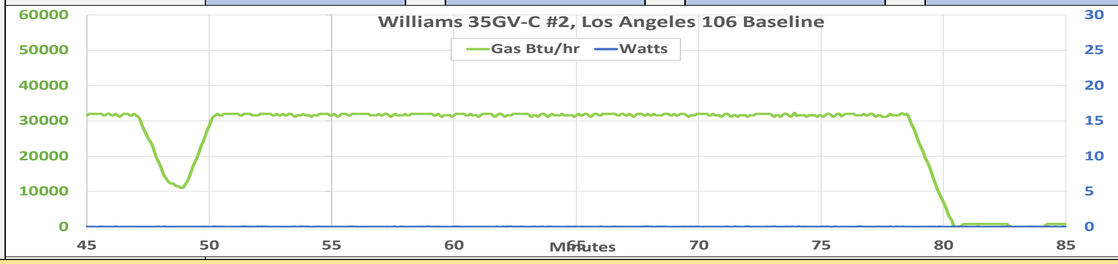


Figure 13: Los Angeles 106, Williams 35GV-C #2, Hot Start & Steady State

Williams 35GV-C #2, Los Angeles 106 Baseline, Rated Input 35000 Btu/hr, Thermal Efficiency 70%

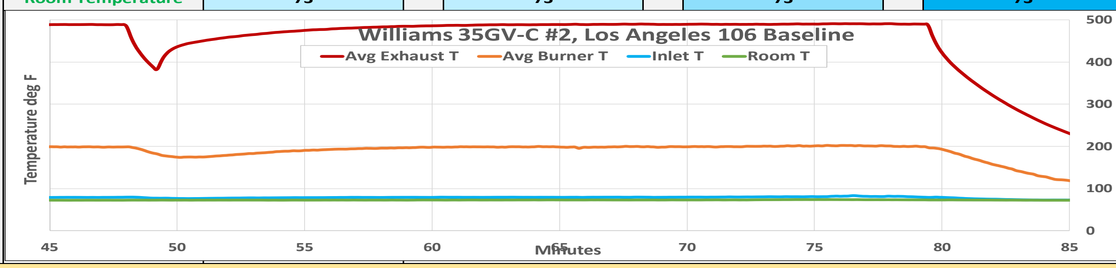
		HOT START				Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (49.1)	5.3 (54.4)	10.9 (60)	16.2 (65.3)	
FUELS	Gas Input Btu/hr	570	30980	31750	31730	*31790*
	Watts	0.0	0.0	0.0	0.0	*0.0*



Pilot Light
570 Btu/hr

Standby Power
0 W

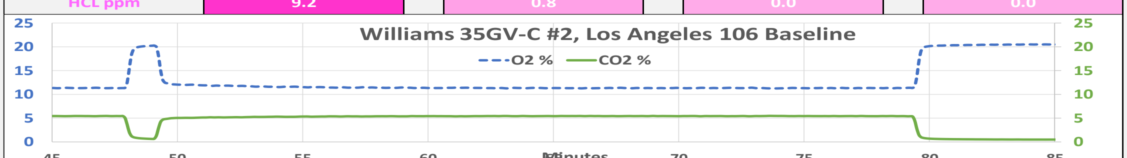
		HOT START				Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (49.1)	5.3 (54.4)	10.9 (60)	16.2 (65.3)	
TEMPERATURES	Exhaust Temperature	376 383 390 395 400	427 444 462 463 463	454 474 494 494 494	461 481 501 501 501	*489*
	Burner Temperatures	187 193 187 180 175	180 188 182 176 175	193 204 197 191 191	197 208 202 195 195	*199*
		194 208 186 179 174	189 203 182 172 170	204 221 197 185 184	208 226 202 189 188	
		191 188 172 169 176	186 183 171 164 171	201 197 184 176 185	205 202 190 181 189	
		189 185 171 156 177	184 176 166 150 172	198 186 177 160 185	203 191 181 164 190	
		192 183 180 177 205	193 178 175 172 201	211 191 188 185 220	215 196 193 190 224	
	Avg Burner Temperature	184	180	194	199	
	Inlet Temperature	78	78	79	80	*79*
	Room Temperature	73	73	73	73	*73*

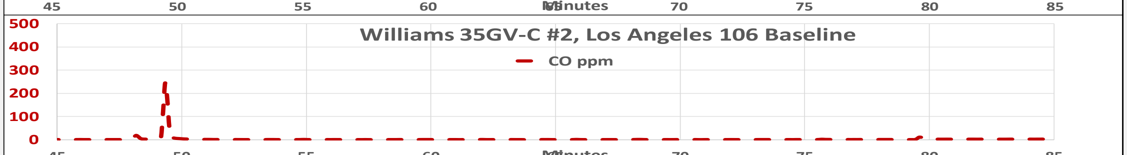


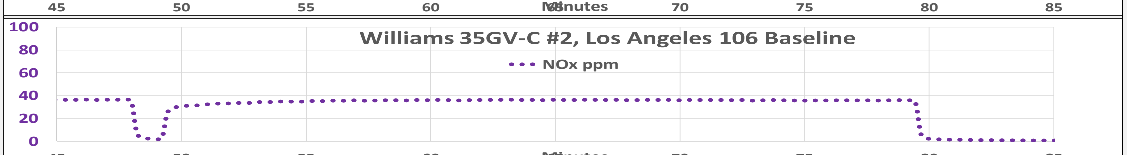
Test Thermal Efficiency
73.6%

Test AFUE
69.3%

		HOT START				Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (49.1)	5.3 (54.4)	10.9 (60)	16.2 (65.3)	
EMISSIONS	O2 %	20.2	12.1	11.4	11.3	*11.3*
	CO2 %	0.6	5.0	5.4	5.4	*5.5*
	CO ppm	2.7	11.4	0.9	0.9	*1.0*
	NOx ppm	1.7	31.4	35.5	36.1	*36.2*
	HCL ppm	9.2	0.8	0.0	0.0	*0.0*







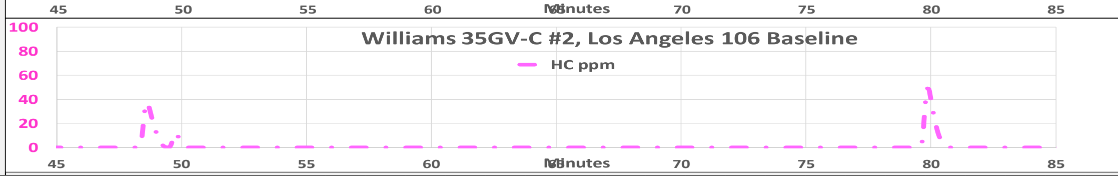
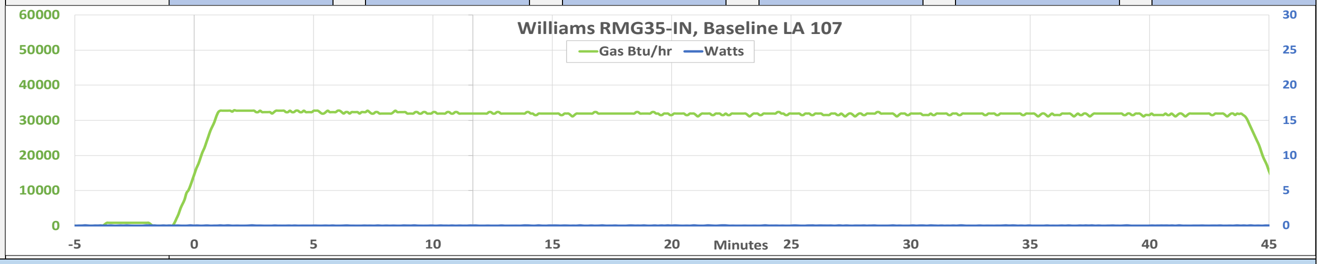


Figure 14: Los Angeles 107, Williams RMG35-IN, Cold Start

Williams RMG35-IN, Baseline LA 107, Rated Input 35000 Btu/hr, Thermal Efficiency 70%

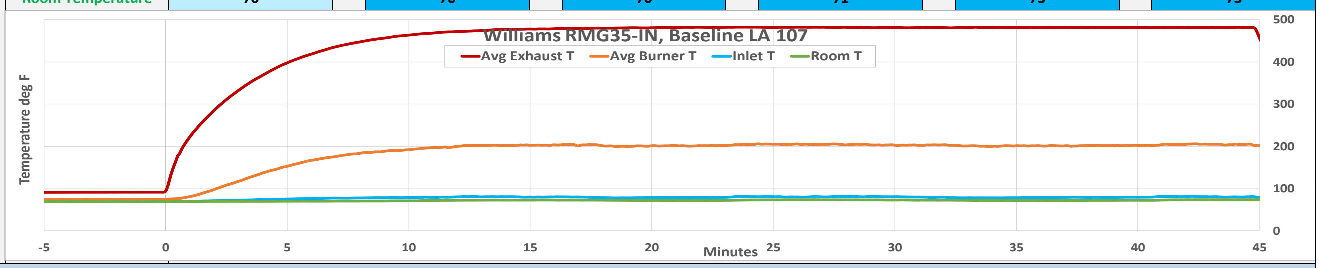
COLD START

		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	3.7	7.5	11.2	15.0	18.7
FUELS	Gas Input Btu/hr	500	31850	32380	32140	31970	31710
FUELS	Watts	0.0	0.0	0.0	0.0	0.0	0.0



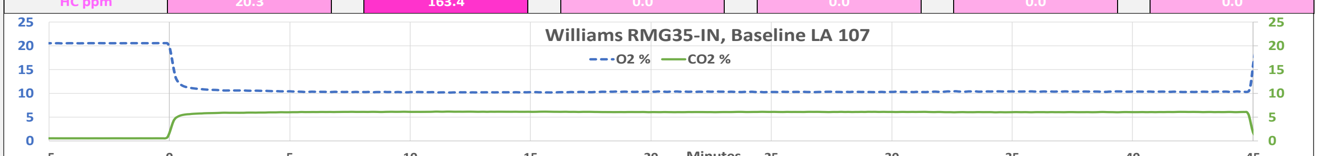
COLD START

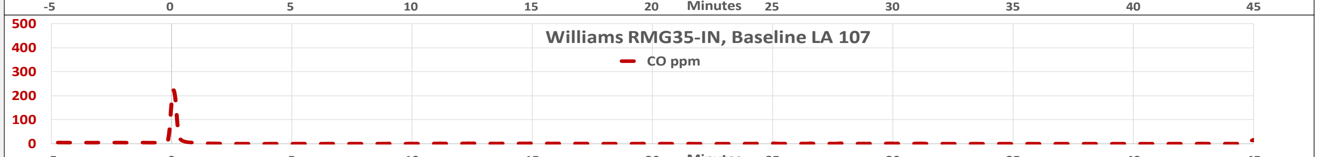
TEMPERATURES	PILOT					20%					40%					60%					80%					100%				
Minutes On	0.0					3.7					7.5					11.2					15.0					18.7				
Exhaust Temperature	91	91	91	91	92	251	258	265	269	272	391	400	410	417	425	442	450	457	467	477	457	465	473	483	494	461	470	479	489	499
Burner Temperatures	75	75	75	74	75	96	102	100	97	104	160	172	165	157	168	193	203	194	186	198	206	215	206	196	209	207	216	207	198	209
	75	77	74	73	74	102	114	98	90	94	171	198	159	142	149	203	227	189	170	177	215	237	202	178	188	216	237	205	180	189
	75	74	73	73	74	99	96	89	88	94	165	156	138	136	149	197	188	170	163	177	209	203	193	176	188	210	205	197	179	190
	74	73	73	73	74	97	85	86	85	93	159	133	133	127	149	191	167	162	149	177	203	179	176	158	188	203	179	179	160	190
	76	74	74	74	76	111	94	93	93	108	189	151	150	149	188	217	182	179	177	220	227	194	191	188	230	227	195	192	190	231
Avg Burner Temperature	75					131					181					198					203					201				
Inlet Temperature	70					72					77					79					81					80				
Room Temperature	70					70					70					71					73					73				

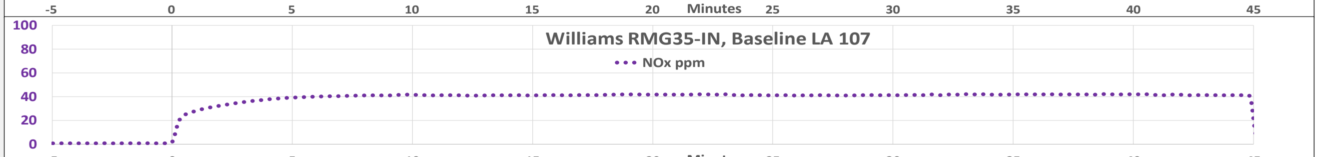


COLD START

		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	3.7	7.5	11.2	15.0	18.7
EMISSIONS	O2 %	20.5	11.4	10.4	10.3	10.2	10.3
EMISSIONS	CO2 %	0.5	5.9	6.1	6.1	6.1	6.0
EMISSIONS	CO ppm	5.3	17.2	0.6	1.0	1.5	1.2
EMISSIONS	NOx ppm	0.8	29.7	39.6	41.3	41.2	41.5
EMISSIONS	HC ppm	20.3	163.4	0.0	0.0	0.0	0.0







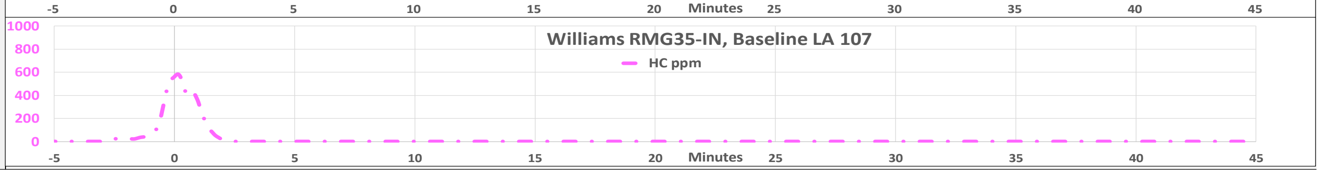
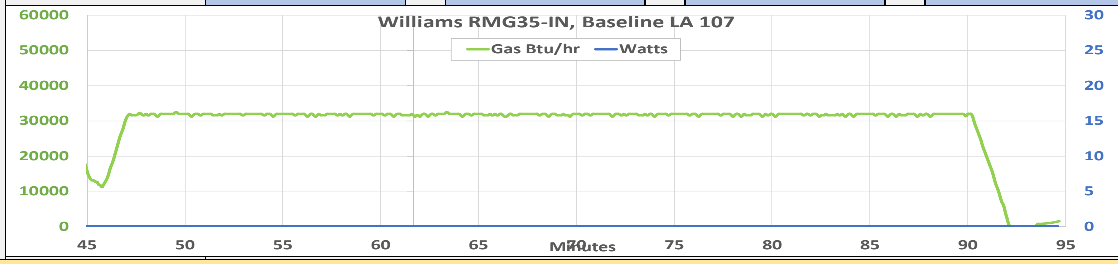


Figure 15: Los Angeles 107, Williams RMG35-IN, Hot Start & Steady State

Williams RMG35-IN, Baseline LA 107, Rated Input 35000 Btu/hr, Thermal Efficiency 70%

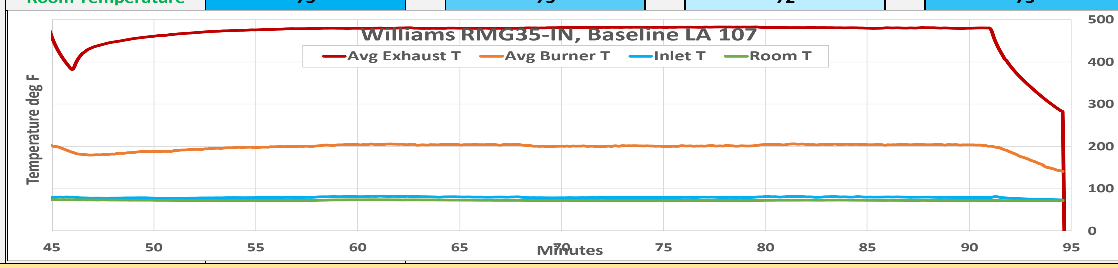
	HOT START				Steady-State
TIME – % of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (46)	5.5 (51.5)	11.1 (57.1)	16.6 (62.6)	
FUELS – Gas Input Btu/hr	500	31430	31660	31710	31820
Watts	0.0	0.0	0.0	0.0	0.0



Pilot Light
500 Btu/hr

Standby Power
0 W

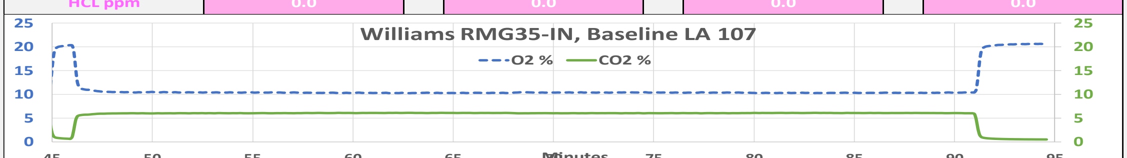
	HOT START																				Steady-State
TIME – % of Steady State	0%					33%					67%					100%					
Minutes On	0.0 (46)					5.5 (51.5)					11.1 (57.1)					16.6 (62.6)					
TEMPERATURES – Exhaust Temperature	367	376	385	392	400	431	440	448	457	466	457	465	474	484	494	461	470	479	489	500	482
Burner Temperatures	193	196	189	181	189	188	196	188	180	188	200	209	201	192	200	209	216	207	198	209	203
	197	208	188	167	175	197	214	188	166	173	210	230	197	178	183	217	236	205	182	190	
	193	191	190	169	176	192	189	183	165	173	205	199	183	172	184	212	206	196	179	190	
	189	175	172	151	177	187	169	166	146	174	201	183	173	154	184	206	186	180	159	190	
	201	183	180	177	209	204	180	177	174	209	220	192	188	184	225	227	198	194	190	231	
Avg Burner Temperature	187					185					197					204					
Inlet Temperature	80					78					79					81					80
Room Temperature	73					73					72					73					72

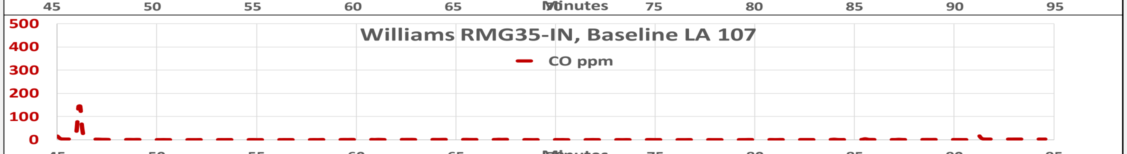


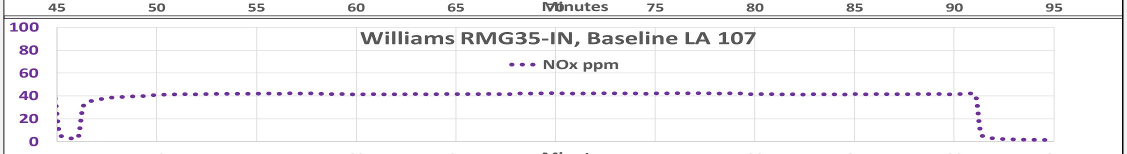
Test Thermal Efficiency
75.1%

Test AFUE
71.1%

	HOT START				Steady-State
TIME – % of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (46)	5.5 (51.5)	11.1 (57.1)	16.6 (62.6)	
EMISSIONS – O2 %	20.3	10.8	10.4	10.3	10.4
CO2 %	0.8	5.8	6.0	6.0	6.0
CO ppm	26.4	6.6	0.4	0.8	0.7
NOx ppm	2.3	38.0	41.8	41.6	41.8
HCL ppm	0.0	0.0	0.0	0.0	0.1







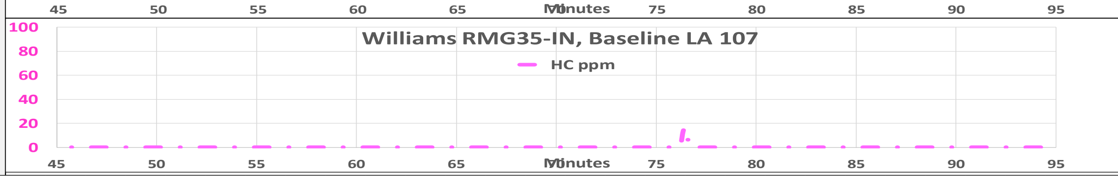
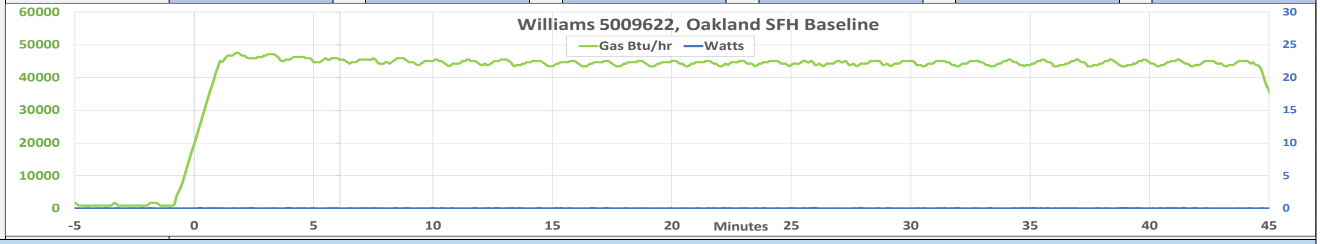


Figure 16: Oakland Single-Family, Williams 5009622, Cold Start

Williams 5009622, Oakland SFH Baseline, Rated Input 50000 Btu/hr, Thermal Efficiency 76%

COLD START

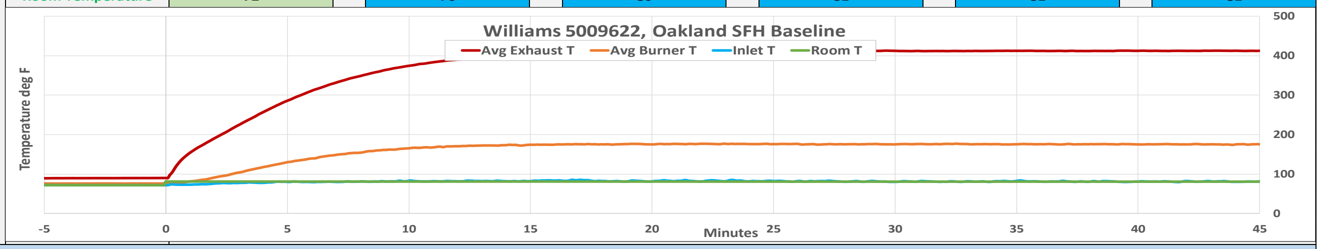
		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	4.2	8.4	12.7	16.9	21.1
FUELS	Gas Input Btu/hr	1090	44550	45260	44780	44500	44370
FUELS	Watts	0.0	0.0	0.0	0.0	0.0	0.0



COLD START

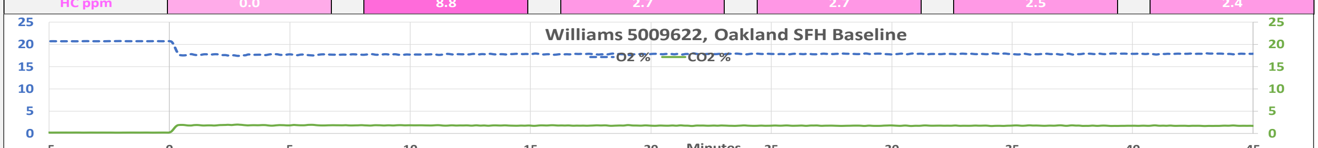
TEMPERATURES	PILOT					20%					40%				
% of Steady State	PILOT					20%					40%				
Minutes On	0.0					4.2					8.4				
Exhaust Temperature	85	86	87	85	83	194	207	219	186	153	323	342	361	310	260
Burner Temperatures Front Side	77	75	75	75	76	102	92	91	90	101	158	133	130	126	149
	75	75	74	74	75	91	89	85	84	89	132	126	116	112	123
	75	74	74	74	74	89	84	82	82	88	126	113	111	110	123
	74	73	73	74	74	86	80	81	82	86	119	102	106	106	122
	76	74	74	74	76	95	86	86	86	95	142	117	119	122	153
Burner Temperatures Back Side	78	76	76	76	79	119	100	99	99	124	202	161	158	154	210
	76	76	75	75	76	100	95	87	86	98	162	154	128	124	150
	76	74	73	74	75	94	87	79	83	95	149	129	105	115	145
	75	74	74	74	75	89	87	83	84	92	137	128	116	115	139
	77	75	75	75	77	92	87	90	92	109	153	132	136	139	188
Avg Burner Temperature	75					119					158				
Inlet Temperature	72					77					81				
Room Temperature	72					76					80				

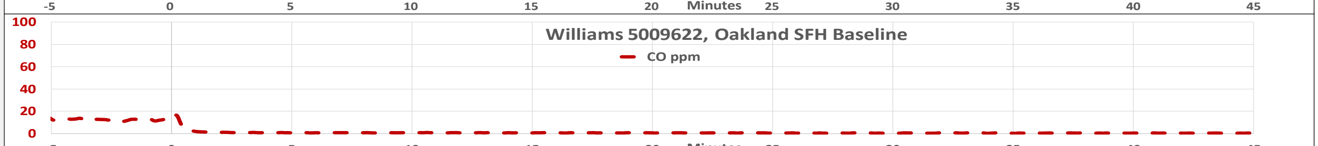
TEMPERATURES	60%					80%					100%				
% of Steady State	60%					80%					100%				
Minutes On	12.7					16.9					21.1				
Exhaust Temperature	385	404	424	374	325	408	426	445	398	351	415	433	451	406	360
Burner Temperatures Front Side	179	155	151	147	172	183	162	158	154	180	181	163	160	157	181
	154	149	139	130	144	161	156	147	135	151	162	158	150	140	153
	147	135	137	129	143	154	143	150	137	150	158	148	152	138	150
	140	118	125	121	142	148	124	133	126	149	154	136	137	122	147
	168	137	140	142	180	177	145	147	149	187	178	150	148	147	182
Burner Temperatures Back Side	235	192	187	182	245	243	200	195	189	254	246	203	197	192	255
	193	189	153	147	175	201	198	160	153	182	204	200	164	156	185
	180	155	122	133	169	189	163	129	139	176	191	167	136	143	179
	167	154	136	131	163	176	163	143	135	170	178	165	146	139	173
	191	160	162	163	223	203	169	169	170	231	202	171	172	173	234
Avg Burner Temperature	172					176					176				
Inlet Temperature	81					82					83				
Room Temperature	81					81					81				

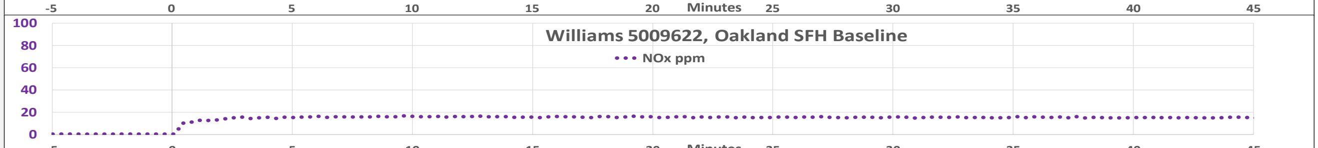


COLD START

		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	4.2	8.4	12.7	16.9	21.1
EMISSIONS	O2 %	20.7	17.8	17.7	17.7	17.8	17.8
EMISSIONS	CO2 %	0.2	1.7	1.7	1.7	1.7	1.7
EMISSIONS	CO ppm	14.1	2.7	0.8	0.8	0.7	0.7
EMISSIONS	NOx ppm	0.4	12.4	15.5	15.9	15.5	15.5
EMISSIONS	HC ppm	0.0	8.8	2.7	2.7	2.5	2.4







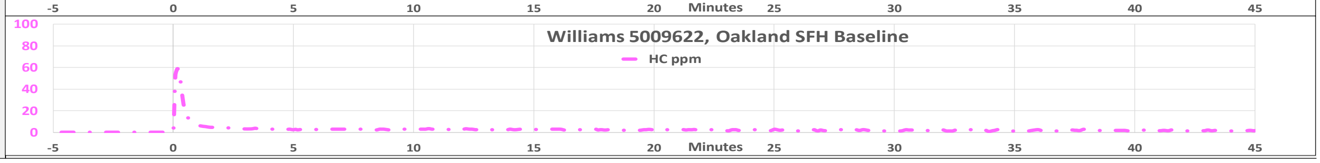
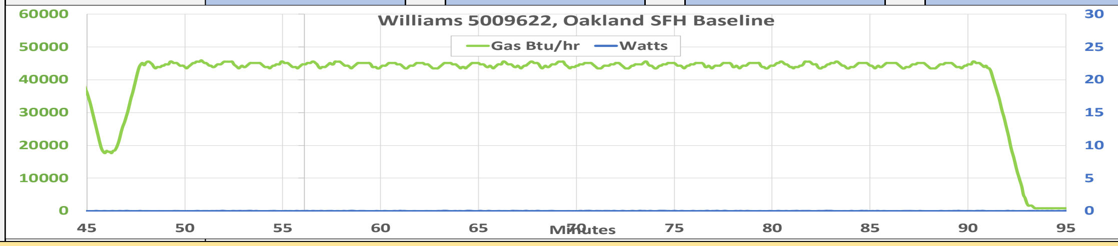


Figure 17: Oakland Single-Family, Williams 5009622, Hot Start & Steady State

Williams 5009622, Oakland SFH Baseline, Rated Input 50000 Btu/hr, Thermal Efficiency 76%

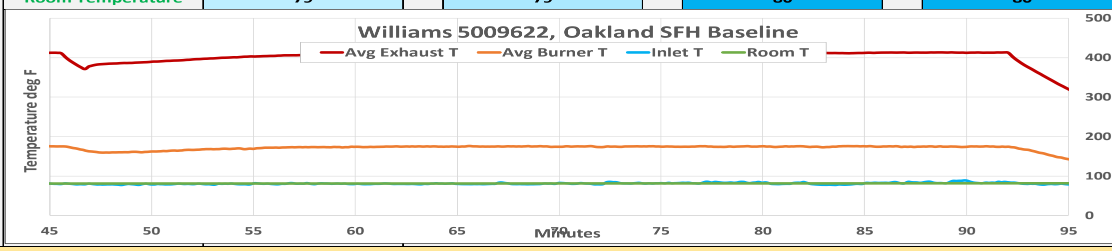
		HOT START				Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (46.6)	5.9 (52.5)	12.1 (58.7)	18.0 (64.6)	
FUELS	Gas Input Btu/hr	1090	43820	44850	44350	44450
	Watts	0.0	0.0	0.0	0.0	0.0



Pilot Light
1090 Btu/hr

Standby Power
0 W

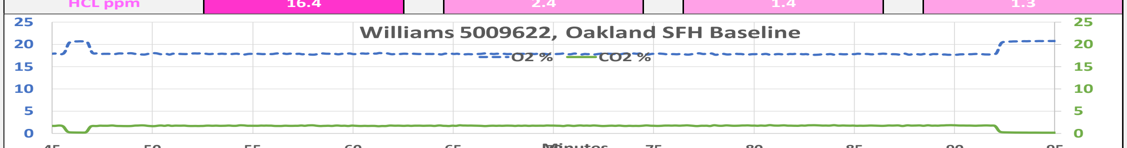
		HOT START				Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (46.6)	5.9 (52.5)	12.1 (58.7)	18.0 (64.6)	
TEMPERATURES	Exhaust Temperature	379 391 402 373 345	394 410 427 386 344	410 428 446 401 356	417 434 452 408 363	413
	Burner Temperatures Front Side	171 154 149 144 159	168 151 147 143 163	177 158 154 150 172	182 161 156 152 172	175
		155 149 142 132 140	151 146 139 129 140	158 152 144 135 146	162 155 146 136 147	
		154 145 145 130 140	148 139 141 128 138	155 145 145 132 144	158 147 146 134 146	
		152 143 134 115 140	145 131 129 114 137	151 136 133 117 143	155 141 135 118 145	
		169 149 145 140 173	164 141 139 137 168	173 147 145 143 178	176 151 148 145 182	
	Burner Temperatures Back Side	229 193 188 182 237	225 187 182 177 233	241 198 193 187 250	245 203 197 191 254	
		194 192 158 151 176	188 184 153 146 171	199 195 160 153 181	204 200 163 157 184	
		183 160 132 139 171	177 155 128 135 166	187 162 131 140 175	191 166 134 143 178	
		172 157 141 135 165	166 153 137 130 160	174 162 143 135 169	178 164 145 137 172	
		198 166 165 165 219	189 160 160 160 213	198 167 168 169 228	203 171 171 172 233	
	Avg Burner Temperature	167	163	171	174	
	Inlet Temperature	79	80	81	81	81
	Room Temperature	79	79	80	80	81

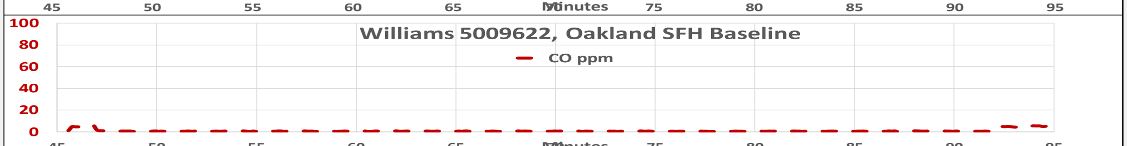


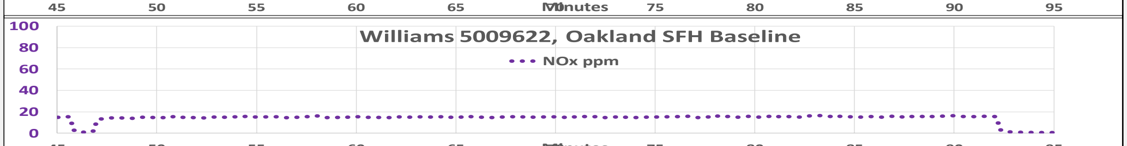
Test Thermal Efficiency
50.1%

Test AFUE
46.0%

		HOT START				Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (46.6)	5.9 (52.5)	12.1 (58.7)	18.0 (64.6)	
EMISSIONS	O2 %	20.7	18.0	17.9	17.9	17.8
	CO2 %	0.2	1.6	1.7	1.7	1.7
	CO ppm	4.6	0.7	0.4	0.4	0.4
	NOx ppm	0.8	13.8	15.1	15.0	15.2
	HCL ppm	16.4	2.4	1.4	1.3	1.5







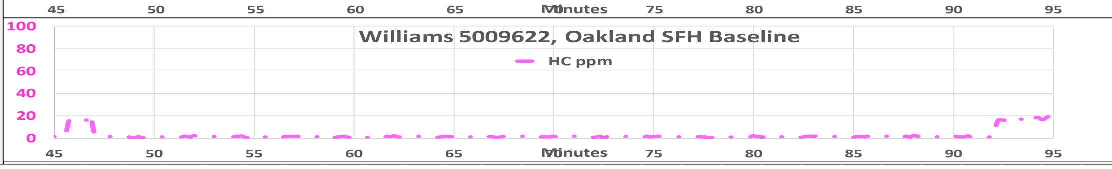
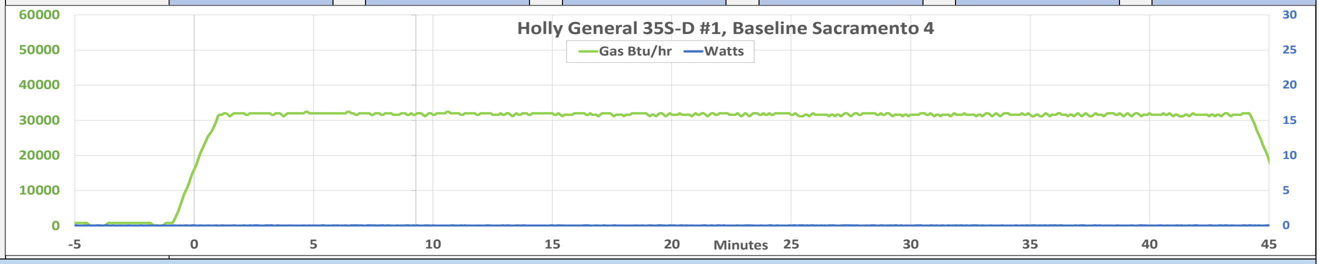


Figure 18: Sacramento 4, Holly General 35S-D #1, Cold Start

Holly General 35S-D #1, Baseline Sacramento 4, Rated Input 35000 Btu/hr, Thermal Efficiency 50%

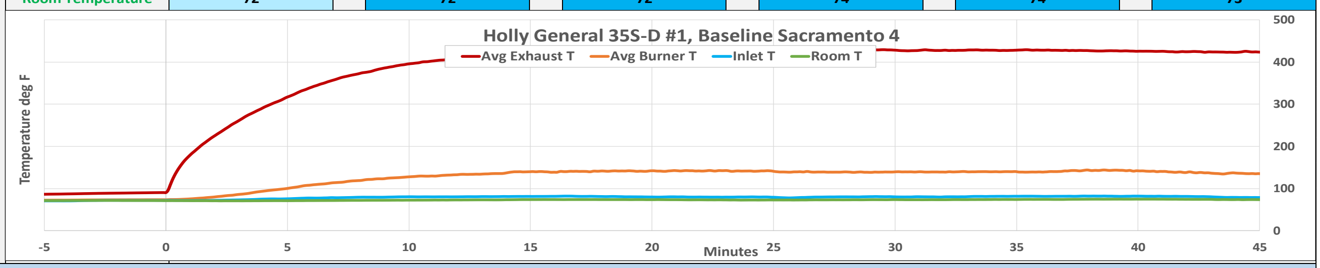
COLD START

		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
	Minutes On	0.0	5.3	10.6	15.9	21.2	26.5
FUELS	Gas Input Btu/hr	720	31380	31670	31730	31820	31820
	Watts	0.0	0.0	0.0	0.0	0.0	0.0



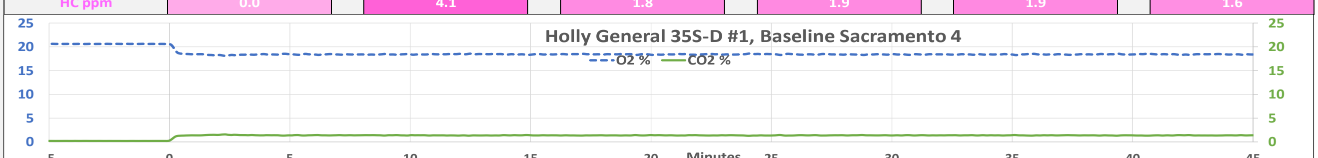
COLD START

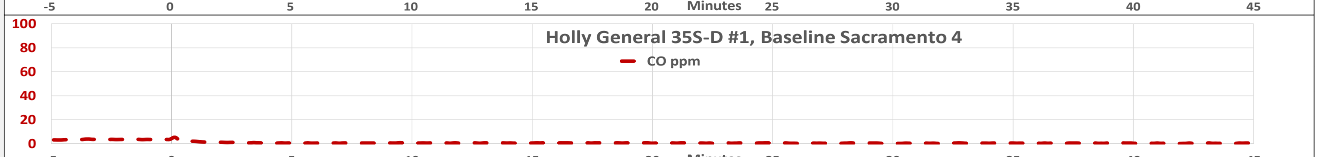
		PILOT					20%					40%					60%					80%					100%				
TIME	Minutes On	0.0					5.3					10.6					15.9					21.2					26.5				
TEMPERATURES	Exhaust Temperature	84	85	86	83	80	234	275	317	239	161	370	421	472	369	266	413	464	514	412	311	422	472	523	422	322	424	475	525	424	324
	Burner Temperatures	73	73	73	72	73	88	85	85	85	89	117	117	118	118	123	130	134	134	134	135	138	142	141	140	139	137	142	141	140	140
		73	73	72	72	72	85	85	83	82	84	118	122	114	117	116	136	141	132	136	131	142	148	142	140	138	142	149	140	139	137
		73	72	72	72	72	85	83	81	81	84	121	115	102	107	115	140	136	120	124	131	144	142	137	134	138	144	142	134	133	137
		72	72	72	72	73	85	82	81	80	85	124	123	109	103	114	144	147	128	116	130	145	140	134	125	138	146	142	134	126	138
		73	72	72	73	73	91	84	84	85	92	133	122	118	114	130	150	142	136	130	147	153	142	140	138	154	155	144	141	138	153
	Avg Burner Temperature	73					104					130					139					142					139				
	Inlet Temperature	71					73					79					81					81					80				
	Room Temperature	72					72					72					74					74					73				

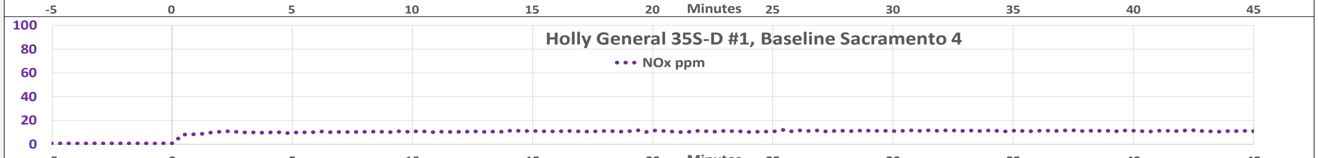


COLD START

		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
	Minutes On	0.0	5.3	10.6	15.9	21.2	26.5
EMISSIONS	O2 %	20.6	18.5	18.4	18.4	18.4	18.4
	CO2 %	0.2	1.4	1.4	1.4	1.3	1.4
	CO ppm	3.6	1.2	0.5	0.5	0.5	0.5
	NOx ppm	0.5	9.1	10.4	10.7	10.8	10.9
	HC ppm	0.0	4.1	1.8	1.9	1.9	1.6







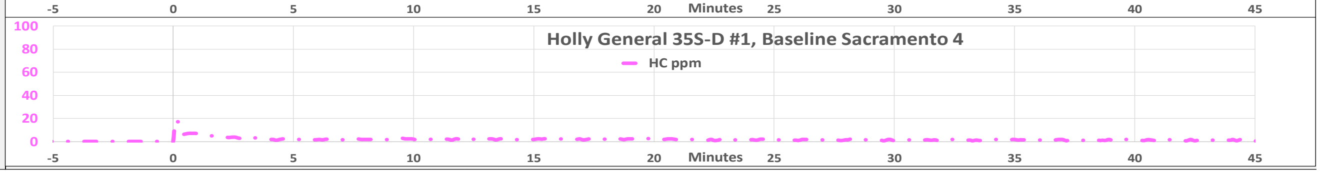
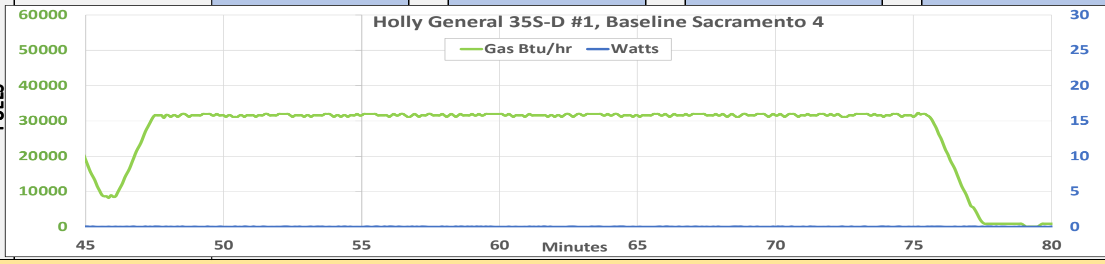


Figure 19: Sacramento 4, Holly General 35S-D #1, Hot Start & Steady State

Holly General 35S-D #1, Baseline Sacramento 4, Rated Input 35000 Btu/hr, Thermal Efficiency 50%

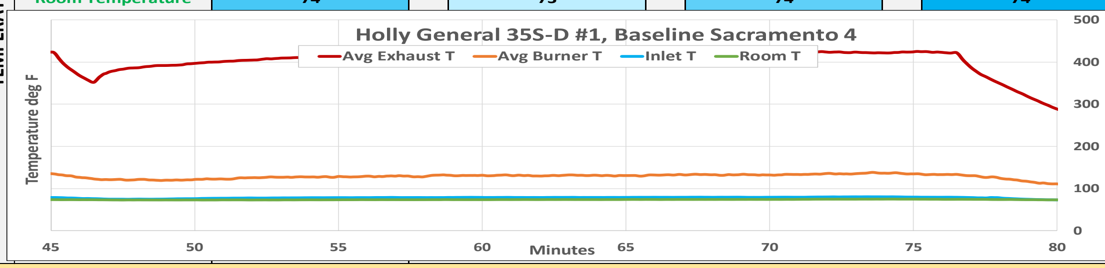
	HOT START				Steady-State
TIME % of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (46.4)	6.0 (52.4)	12.2 (58.6)	18.2 (64.6)	
FUELS Gas Input Btu/hr	720	30900	31430	31690	*31570*
Watts	0.0	0.0	0.0	0.0	*0.0*



Pilot Light
720 Btu/hr

Standby Power
0 W

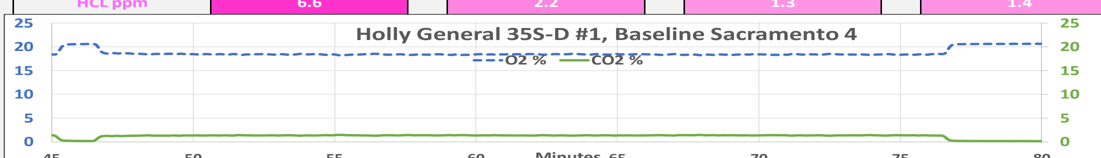
	HOT START				Steady-State
TIME % of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (46.4)	6.0 (52.4)	12.2 (58.6)	18.2 (64.6)	
TEMPERATURES Exhaust Temperature	354 385 415 356 296	392 437 483 391 298	417 466 515 413 311	426 474 523 420 318	*426*
Burner Temperatures	125 126 123 120 129	123 122 120 118 130	128 127 126 125 137	130 130 129 127 139	*137*
	128 135 117 114 117	123 129 114 110 116	128 133 120 117 122	132 137 123 120 125	
	130 123 103 109 119	126 119 104 107 117	132 124 109 113 123	135 128 113 115 125	
	132 131 115 111 120	128 124 112 107 117	135 130 117 112 124	138 135 120 113 126	
	140 129 124 120 135	140 125 121 117 133	149 132 128 124 142	152 136 131 126 144	
Avg Burner Temperature	125	122	129	131	
Inlet Temperature	76	76	78	79	*80*
Room Temperature	74	73	74	74	*75*

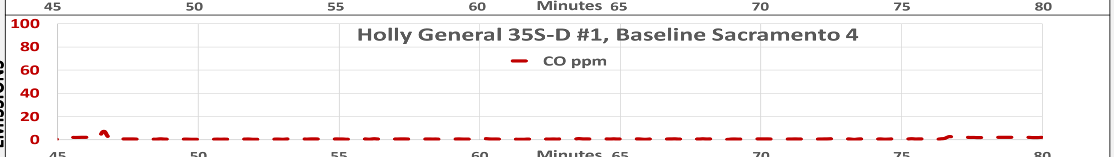


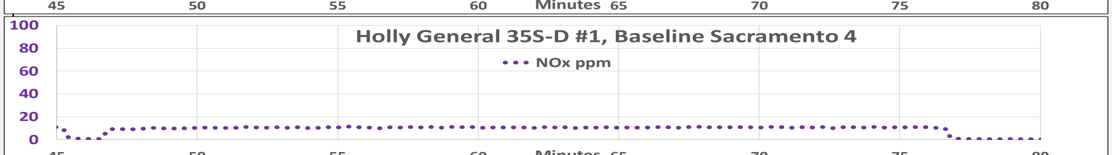
Test Thermal Efficiency
39.0%

Test AFUE
35.7%

	HOT START				Steady-State
TIME % of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (46.4)	6.0 (52.4)	12.2 (58.6)	18.2 (64.6)	
EMISSIONS O2 %	20.6	18.6	18.4	18.4	*18.4*
CO2 %	0.2	1.3	1.4	1.4	*1.4*
CO ppm	1.9	0.6	0.4	0.4	*0.4*
NOx ppm	0.5	9.5	10.7	10.7	*11.0*
HCL ppm	6.6	2.2	1.3	1.4	*1.4*







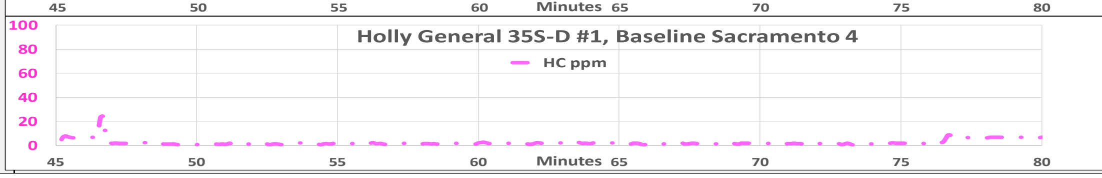
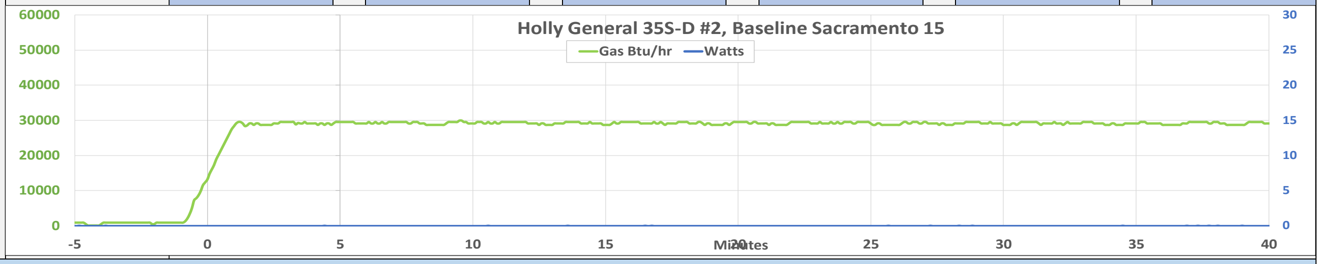


Figure 20: Sacramento 15, Holly General 35S-D #2, Cold Start

Holly General 35S-D #2, Baseline Sacramento 15, Rated Input 35000 Btu/hr, Thermal Efficiency 50%

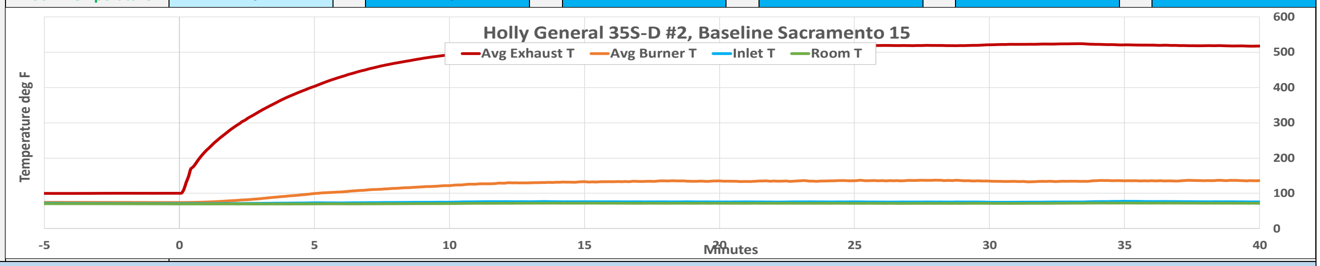
COLD START

		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	6.1	12.3	18.4	24.6	30.7
FUELS	Gas Input Btu/hr	710	28670	29300	29190	29040	29060
FUELS	Watts	0.0	0.0	0.0	0.0	0.0	0.0



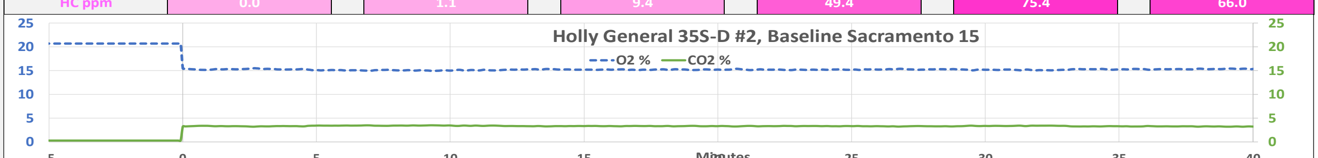
COLD START

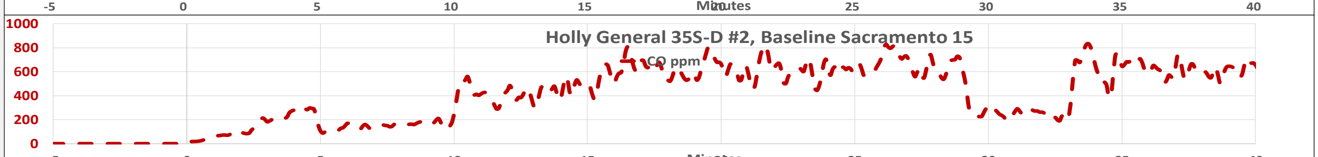
		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	6.1	12.3	18.4	24.6	30.7
TEMPERATURES	Exhaust Temperature	102 101 100 98 97	390 341 292 279 267	553 503 452 443 433	583 533 483 476 469	589 539 489 483 477	590 540 491 485 479
TEMPERATURES	Burner Temperatures	73 74 74 74 74	80 85 87 90 88	107 120 121 122 113	123 136 136 135 122	125 138 139 139 125	127 140 140 139 124
		73 74 74 74 74	84 88 88 93 89	118 129 123 130 119	134 145 139 146 132	137 149 141 149 135	138 150 143 151 136
		73 73 73 73 74	85 85 83 85 87	119 119 112 115 117	133 133 124 129 131	136 136 126 130 132	137 137 127 132 134
		73 73 73 73 73	86 83 82 81 86	120 117 111 102 115	132 130 124 118 129	135 132 124 115 129	136 134 127 119 131
		74 73 73 73 74	90 85 85 86 94	123 117 116 115 131	134 129 129 129 144	138 131 130 129 148	137 133 132 131 148
	Avg Burner Temperature	74	104	129	135	136	133
	Inlet Temperature	71	72	75	76	76	75
	Room Temperature	70	70	71	72	72	72

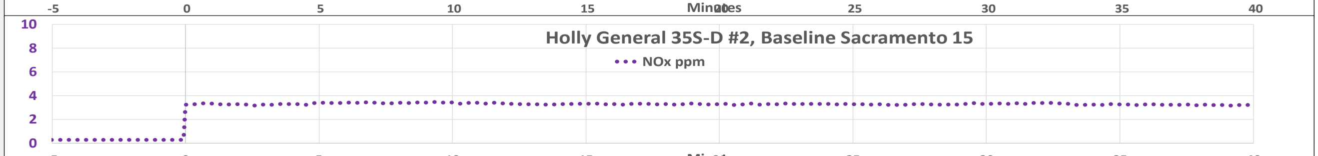


COLD START

		PILOT	20%	40%	60%	80%	100%
TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	6.1	12.3	18.4	24.6	30.7
EMISSIONS	O2 %	20.7	15.3	15.1	15.2	15.2	15.2
EMISSIONS	CO2 %	0.3	3.4	3.3	3.2	3.2	3.3
EMISSIONS	CO ppm	0.0	139.7	253.3	527.8	616.1	556.7
EMISSIONS	NOx ppm	0.3	3.3	3.4	3.3	3.3	3.3
EMISSIONS	HC ppm	0.0	1.1	9.4	49.4	75.4	66.0







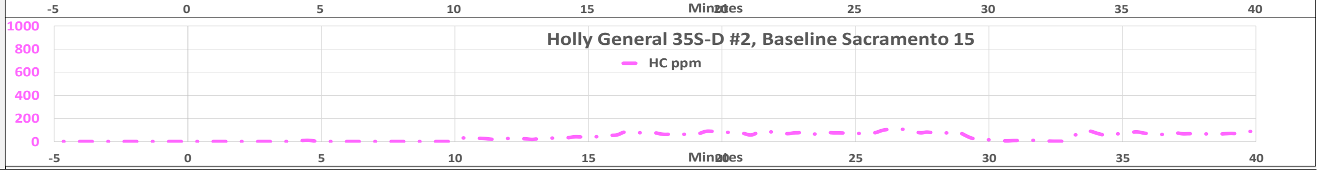
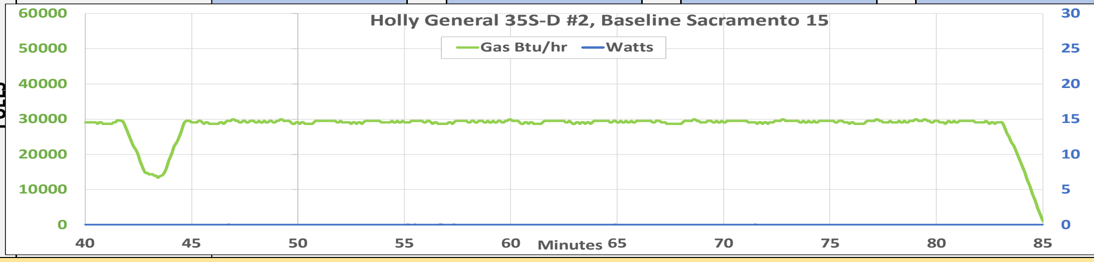


Figure 21: Sacramento 15, Holly General 35S-D #2, Hot Start & Steady State

Holly General 35S-D #2, Baseline Sacramento 15, Rated Input 35000 Btu/hr, Thermal Efficiency 50%

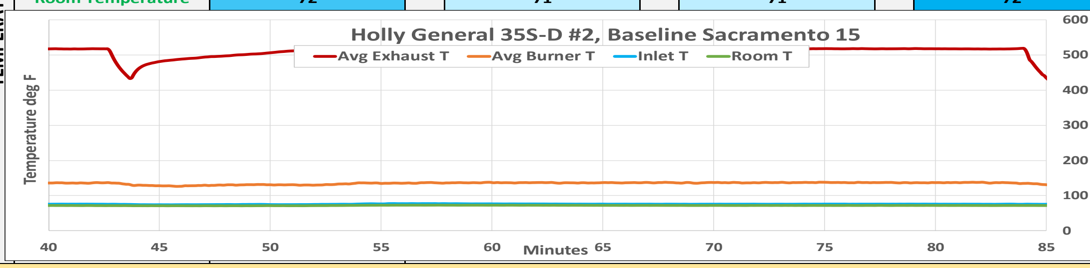
		HOT START				Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (43.7)	3.1 (46.8)	6.2 (49.9)	9.3 (53)	
FUELS	Gas Input Btu/hr	710	28540	29560	29030	29250
	Watts	0.0	0.0	0.0	0.0	0.0



Pilot Light
710 Btu/hr

Standby Power
0 W

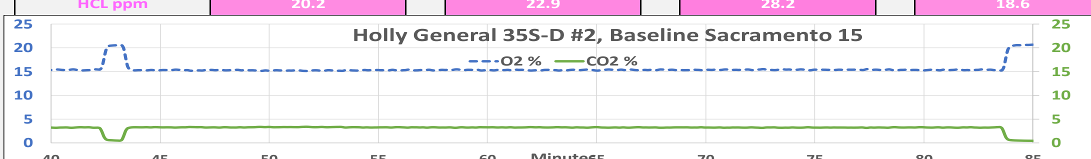
		HOT START				Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (43.7)	3.1 (46.8)	6.2 (49.9)	9.3 (53)	
TEMPERATURES	Exhaust Temperature	462 442 421 423 424	541 498 455 448 442	569 520 472 465 458	581 534 487 479 471	519
	Burner Temperatures	124 137 136 136 122	121 133 133 132 121	121 134 134 135 122	121 135 135 134 123	135
		135 147 140 146 132	131 142 135 142 129	132 144 137 145 131	133 146 137 143 130	
		133 134 127 128 129	129 129 121 124 125	131 131 124 127 128	132 132 122 125 127	
		132 128 122 111 125	128 123 118 109 122	130 126 121 112 125	131 127 120 110 124	
		134 128 127 125 142	131 124 123 122 139	133 127 126 125 142	135 127 126 124 144	
	Avg Burner Temperature	131	128	130	130	
	Inlet Temperature	75	74	75	75	76
	Room Temperature	72	71	71	72	72

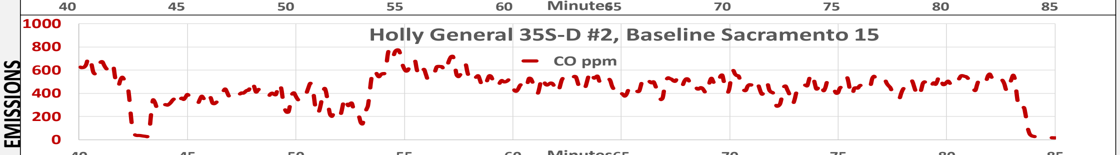


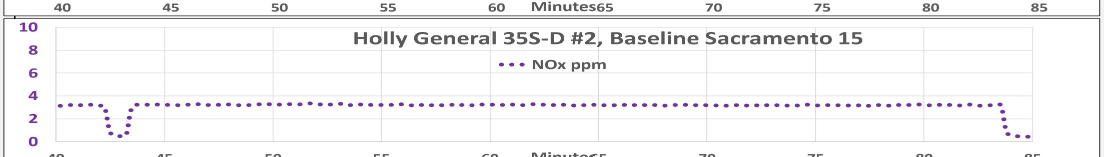
Test Thermal Efficiency
60.8%

Test AFUE
56.2%

		HOT START				Steady-State
TIME	% of Steady State	0%	33%	67%	100%	
	Minutes On	0.0 (43.7)	3.1 (46.8)	6.2 (49.9)	9.3 (53)	
EMISSIONS	O2 %	15.5	15.3	15.3	15.2	15.3
	CO2 %	3.2	3.2	3.2	3.3	3.2
	CO ppm	269.0	343.6	395.1	307.4	513.5
	NOx ppm	3.2	3.2	3.2	3.3	3.2
	HCL ppm	20.2	22.9	28.2	18.6	46.5







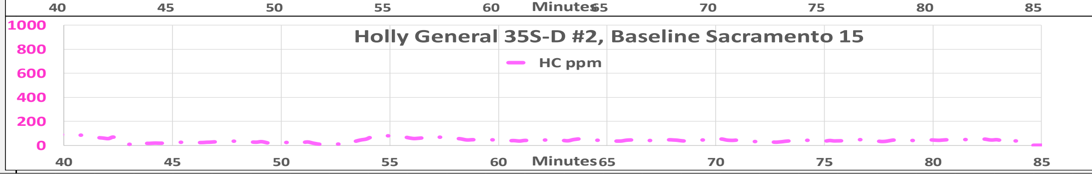
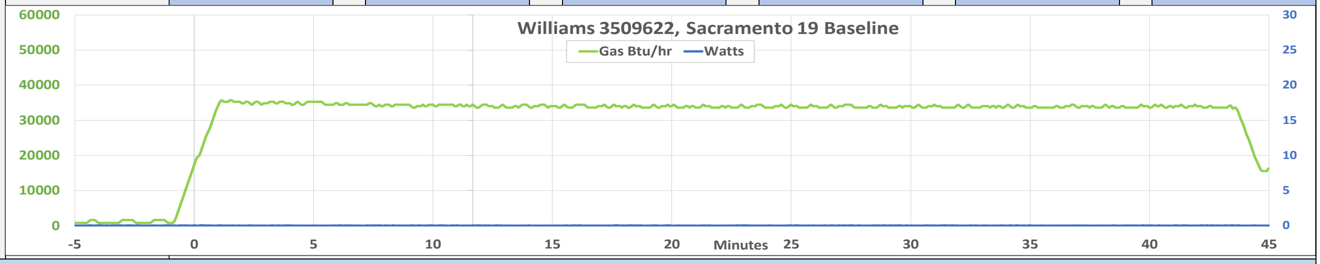


Figure 22: Sacramento 19, Williams 3509622, Cold Start

Williams 3509622, Sacramento 19 Baseline, Rated Input 35000 Btu/hr, Thermal Efficiency 74%

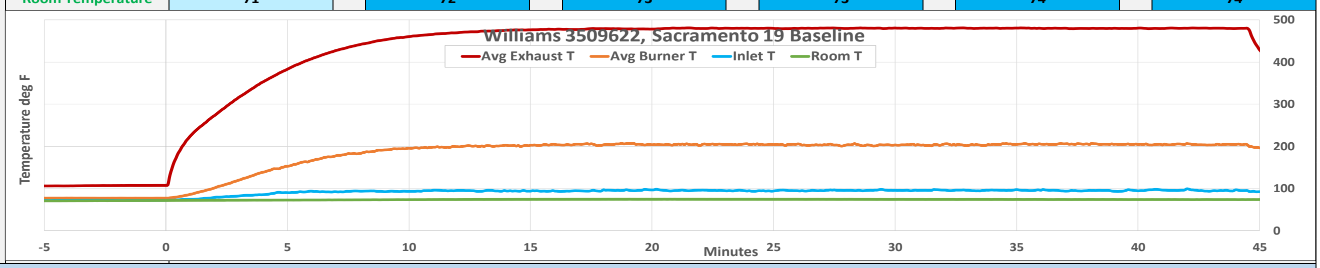
COLD START

TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	3.5	7.0	10.4	13.9	17.4
FUELS	Gas Input Btu/hr	1050	33770	34570	34650	34350	33900
FUELS	Watts	0.0	0.0	0.0	0.0	0.0	0.0



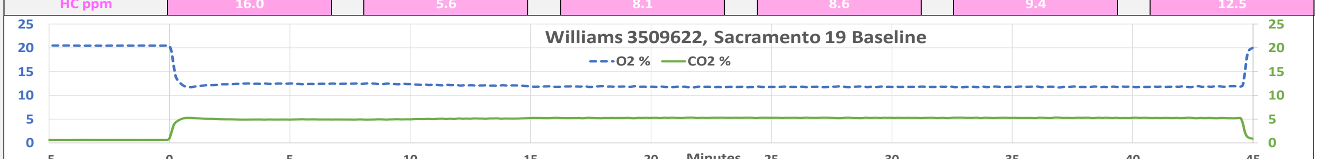
COLD START

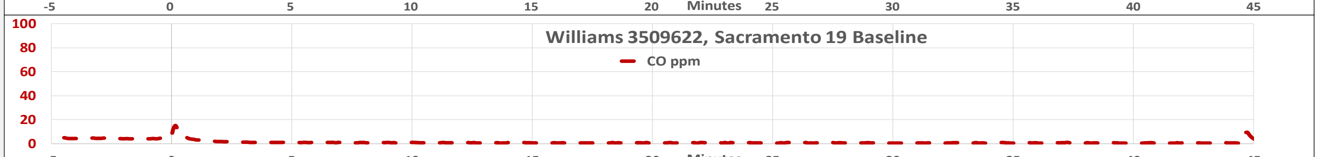
TIME	% of Steady State	PILOT					20%					40%					60%					80%					100%				
TIME	Minutes On	0.0					3.5					7.0					10.4					13.9					17.4				
TEMPERATURES	Exhaust Temperature	102	104	105	102	99	253	265	276	250	224	389	407	424	387	350	446	466	485	449	413	467	486	506	471	436	474	493	512	478	444
TEMPERATURES	Burner Temperatures	79	77	77	76	78	115	102	102	101	113	189	164	160	156	175	219	196	191	186	202	227	206	200	194	209	229	210	204	199	212
		77	77	76	75	76	102	98	94	95	99	164	157	147	147	152	197	189	181	175	181	207	199	193	180	190	211	203	199	186	194
		76	75	74	75	76	99	93	89	90	97	157	145	139	136	148	192	182	179	167	179	202	196	201	180	189	207	202	209	185	193
		76	75	75	75	76	96	92	89	87	94	150	141	134	122	145	186	179	168	147	176	198	187	182	158	189	203	193	187	159	192
		78	76	76	76	78	103	95	94	94	106	165	146	146	145	179	199	182	179	176	215	210	193	191	189	225	213	198	195	192	229
	Avg Burner Temperature	77					130					178					197					203					206				
	Inlet Temperature	72					78					90					93					95					94				
	Room Temperature	71					72					73					73					74					74				

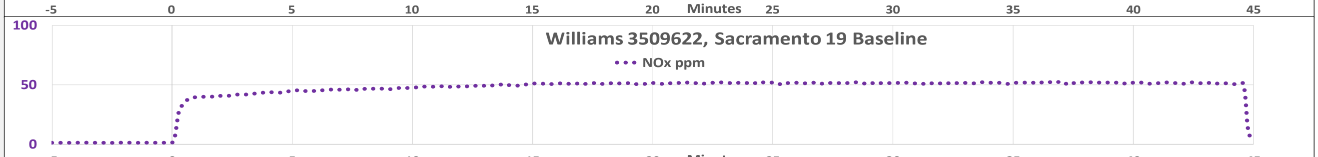


COLD START

TIME	% of Steady State	PILOT	20%	40%	60%	80%	100%
TIME	Minutes On	0.0	3.5	7.0	10.4	13.9	17.4
EMISSIONS	O2 %	20.4	12.8	12.5	12.4	12.2	11.9
EMISSIONS	CO2 %	0.6	4.9	4.9	5.0	5.1	5.2
EMISSIONS	CO ppm	4.3	3.5	0.9	0.7	0.6	0.6
EMISSIONS	NOx ppm	1.2	37.1	44.5	46.5	48.8	50.4
EMISSIONS	HC ppm	16.0	5.6	8.1	8.6	9.4	12.5







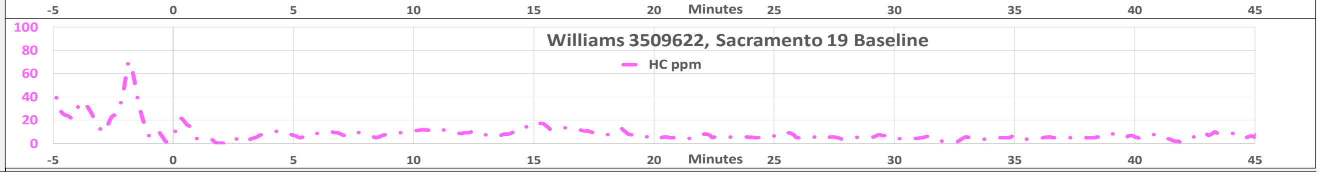
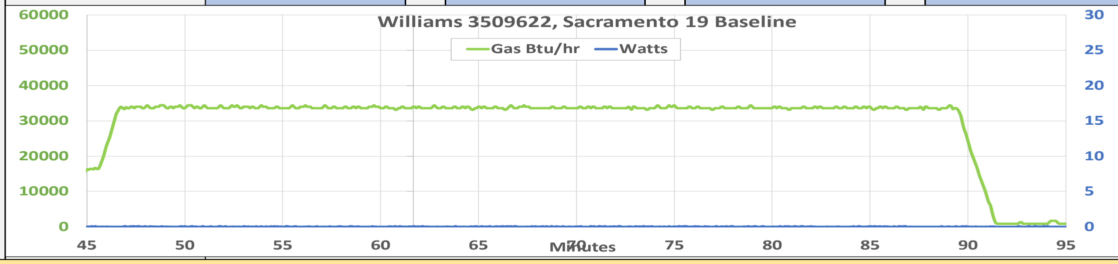


Figure 23: Sacramento 19, Williams 3509622, Hot Start & Steady State

Williams 3509622, Sacramento 19 Baseline, Rated Input 35000 Btu/hr, Thermal Efficiency 74%

FUELS

	HOT START				Steady-State
TIME – % of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (45.5)	4.5 (50)	9.1 (54.6)	13.6 (59.1)	
Gas Input Btu/hr	1050	33170	33600	34220	33510
Watts	0.0	0.0	0.0	0.0	0.0

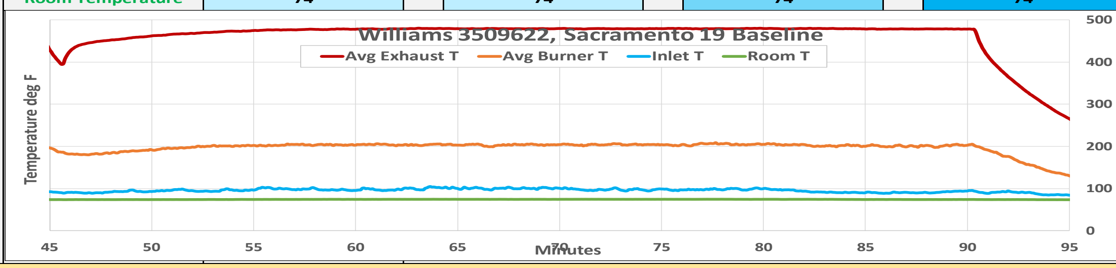


Pilot Light
1050 Btu/hr

Standby Power
0 W

TEMPERATURES

	HOT START																				Steady-State
TIME – % of Steady State	0%					33%					67%					100%					
Minutes On	0.0 (45.5)					4.5 (50)					9.1 (54.6)					13.6 (59.1)					
Exhaust Temperature	396	410	423	402	381	443	461	479	448	416	466	485	503	470	436	474	492	511	477	444	479
Burner Temperatures	208	192	187	182	196	205	190	186	181	195	220	203	199	194	209	226	208	204	200	213	204
	193	187	180	172	178	191	185	181	168	177	205	196	193	180	190	210	201	198	189	195	
	191	183	181	168	178	188	184	190	169	176	202	198	203	180	188	209	204	204	182	192	
	188	182	171	150	177	186	178	172	147	175	200	194	184	156	187	208	207	188	154	189	
	199	184	180	177	208	195	182	178	175	205	209	195	191	187	220	213	202	196	189	225	
Avg Burner Temperature	187					185					199					203					
Inlet Temperature	91					92					95					99					96
Room Temperature	74					74					74					74					74

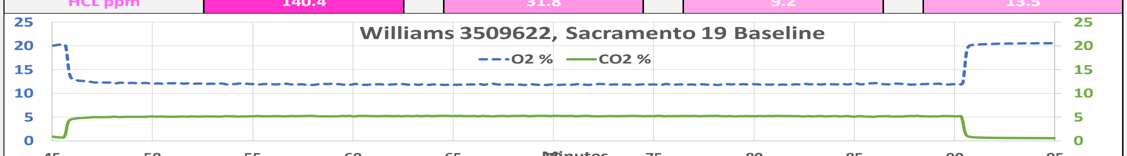


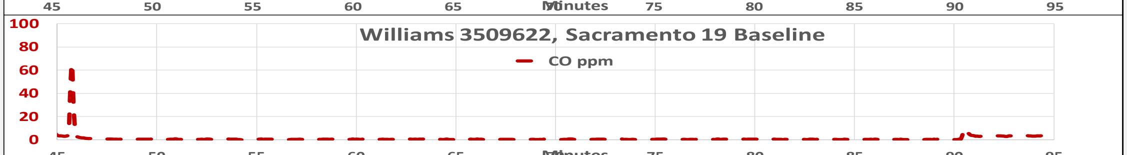
Test Thermal Efficiency
73.2%

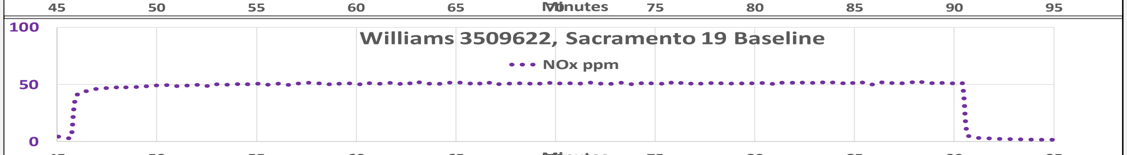
Test AFUE
66.7%

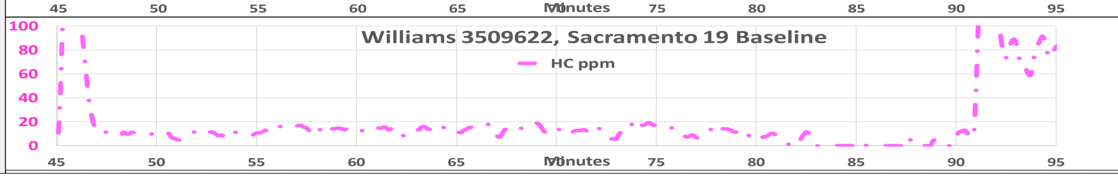
EMISSIONS

	HOT START				Steady-State
TIME – % of Steady State	0%	33%	67%	100%	
Minutes On	0.0 (45.5)	4.5 (50)	9.1 (54.6)	13.6 (59.1)	
O2 %	20.3	12.8	12.1	11.9	11.9
CO2 %	0.7	4.7	5.1	5.2	5.2
CO ppm	3.2	3.4	0.5	0.5	0.5
NOx ppm	3.0	43.8	49.4	50.4	50.9
HCL ppm	140.4	31.8	9.2	13.5	7.7









Conclusion

Below laboratory test results are compared for all ten baseline wall furnaces, including their fuel use, combustion and thermal characteristics, efficiency, and emissions.

Baseline Wall Furnace Fuel Use

Table 6 lists the measured fuel input for all tested wall furnaces, including both natural gas use during active firing and during pilot-only standby conditions as well as the rated input capacity. Note that a gas pressure of 6.8 inches water column was used during all testing, at the high end of the recommended 5 to 7 inches water column range for each furnace.

Table 6: Baseline Wall Furnace Natural Gas Input Rates

Wall Furnace Tested				Natural Gas Input			
Manufacturer	Model	Field Site	Age years	Rated Btu/hr	Tested Btu/hr	% Rated Input	Pilot Btu/hr
Perfection Products	PW8G25SEN #1	Hayward 3 Baseline	~40	25000	20280	81%	520
Perfection Products	PW8G25SEN #2	Hayward 4 Baseline	~40	25000	20210	81%	510
Williams	25GV-A1	LA 104 Baseline	~35	25000	25100	100%	750
Williams	35GV-C #1	LA 105 Baseline	~35	35000	31720	91%	520
Williams	35GV-C #2	LA 106 Baseline	~35	35000	31800	91%	570
Williams	RMG35-IN	LA 107 Baseline	~35	35000	31810	91%	500
Williams	5009622	Oakland SF Baseline	~15	50000	44500	89%	1090
Holly General	35S-D #1	Sacramento 4 Baseline	40+	35000	31530	90%	720
Holly General	35S-D #2	Sacramento 15 Baseline	40+	35000	29110	83%	710
Williams	3509622	Sacramento 19 Baseline	~10	35000	33800	97%	1050
		Average		**33500**	**30000**	**89%**	**690**

All baseline furnaces except the Williams 25GV-A1 furnace used less natural gas than their rated value, with the oldest furnaces using as little as 81% of their rated input. This indicates that over time the furnace gas valves were clogged or can no longer open fully, and therefore tend to restrict the amount of gas flow.

All baseline units used pilot lights to ignite the burner, drawing between 500 and 1090 Btu/hr. Pilot use seems to settle into ~500, ~700, and ~1,000 Btu/hr pilot use classifications corresponding to 25,000, 35,000 and 50,000 Btu/hr capacity furnaces. But there are three exceptions, with Williams 25GV-A1 falling into the 700 Btu/hr class, Williams RMG35-IN into the 500 Btu/hr class, and Williams 3509622 into the 1,000 Btu/hr class.

Baseline Wall Furnace Combustion and Thermal Characteristics

Table 7 lists the percentages of oxygen and carbon dioxide found in the exhaust gases of each wall furnace, which is an indicator of combustion efficiency. Oxygen levels around 13.5% and carbon dioxide around 4% indicate that the fuel-air ratio is neither too rich nor too lean for good combustion. While on average the baseline furnaces have adequate combustion, four operated above 15% O2 and below 3.5% CO2, and three operated below 12.5% O2 and above 5% CO_2. This means that seven of ten furnaces were not operating with proper fuel-air ratios.

Table 7: Combustion Exhaust Gas Oxygen and Carbon Dioxide Percentages

Wall Furnace Tested			Combustion	
Manufacturer	**Model**	**Field Site**	**% O2**	**% CO2**
Perfection Products	PW8G25SEN #1	Hayward 3 Baseline	14.8	3.6
Perfection Products	PW8G25SEN #2	Hayward 4 Baseline	15.6	2.8
Williams	25GV-A1	LA 104 Baseline	13.6	4.0
Williams	35GV-C #1	LA 105 Baseline	14.2	3.6
Williams	35GV-C #2	LA 106 Baseline	11.9	5.2
Williams	RMG35-IN	LA 107 Baseline	10.5	5.9
Williams	5009622	Oakland SF Baseline	17.8	1.7
Holly General	35S-D #1	Sacramento 4 Baseline	18.4	1.4
Holly General	35S-D #2	Sacramento 15 Baseline	15.3	3.3
Williams	3509622	Sacramento 19 Baseline	12.2	5.1
		Average	**14.4**	**3.7**

Table 8 lists the time to reach steady state conditions during cold and hot starts for each tested furnace. Steady state conditions were assumed to be reached when the average exhaust temperature first rose to within 3°F of the maximum temperature achieved during each respective cold or hot start.

Table 8: Baseline Wall Furnace Steady State Conditions, deg F

Wall Furnace Tested			Minutes to Steady-State		Steady State Conditions			
Manufacturer	**Model**	**Field Site**	**Cold Start**	**Hot Start**	**Exhaust °F**	**Burner °F**	**Inlet °F**	**Room °F**
Perfection Products	PW8G25SEN #1	Hayward 3 Baseline	24.4	14.3	310.3	119.5	76.0	70.7
Perfection Products	PW8G25SEN #2	Hayward 4 Baseline	18.7	24.9	308.3	125.7	77.1	73.8
Williams	25GV-A1	LA 104 Baseline	23.5	12.5	441.9	135.3	76.1	73.6
Williams	35GV-C #1	LA 105 Baseline	24.2	11.4	454.9	192.3	80.4	76.4
Williams	35GV-C #2	LA 106 Baseline	16.7	16.2	488.8	198.9	79.3	72.8
Williams	RMG35-IN	LA 107 Baseline	18.7	16.6	481.7	202.7	80.0	72.4
Williams	5009622	Oakland SF Baseline	21.1	18.0	412.5	175.3	81.4	80.9
Holly General	35S-D #1	Sacramento 4 Baseline	26.5	18.2	425.7	137.2	80.4	74.6
Holly General	35S-D #2	Sacramento 15 Baseline	30.7	9.3	519.2	135.3	75.9	72.4
Williams	3509622	Sacramento 19 Baseline	17.4	13.6	479.0	204.1	95.9	74.0
		Average	**22.2**	**15.5**	**432.2**	**162.6**	**80.3**	**74.2**

Steady state was reached within 16 to 31 minutes during cold starts, and within 9 to 25 minutes during hot starts. In all but one furnace, the cold start took longer to reach steady state than the hot start. The exception is Perfection Products PW8G25SEN #2, where it took about six more minutes to reach steady state during the hot start than during the cold start.

Table 8 also lists the average cold start and hot start steady state exhaust, burner, inlet, and room temperatures reached for each furnace. Room temperatures varied since the test facility was not isolated in a climate-controlled room. Inlet temperatures to each furnace tended to be higher than the room temperature, indicating that the furnaces entrain some of the heat they produce directly back into the unit. This entrainment may have been affected by a lack of conditioning and air circulation in the test facility. Average exhaust temperatures vary by more than 200°F, from 308°F to 519°F, and burner temperatures vary from 120°F to 204°F.

Baseline Wall Furnace Efficiency

Table 9 lists the rated and tested thermal efficiency and Annual Fuel Utilization Efficiency (AFUE) of each wall furnace. Note that these are not official rated values since the furnaces were not installed into a fabricated wall cavity assembly as specified by the ANSI Z21.86 2016 test standard. Values in red are below the current minimum listed in Table 14 and Table 15 of Appendix A for thermal efficiency (70% for gravity furnaces) and AFUE (65% to 67%).

Table 9: Baseline Wall Furnace Tested Thermal Efficiency and AFUE

Wall Furnace Tested			Thermal Efficiency		AFUE	
Manufacturer	**Model**	**Field Site**	**Rated**	**Tested**	**Rated**	**Tested**
Perfection Products	PW8G25SEN #1	Hayward 3	70%	76.3%		70.5%
Perfection Products	PW8G25SEN #2	Hayward 4	70%	71.8%		66.1%
Williams	25GV-A1	LA 104	70%	70.5%		**64.4%**
Williams	35GV-C #1	LA 105	70%	**62.8%**		**59.2%**
Williams	35GV-C #2	LA 106	70%	73.6%		69.3%
Williams	RMG35-IN	LA 107	70%	75.1%		71.1%
Williams	5009622	Oakland SFH	76%	**50.1%**	74.0%	**46.0%**
Holly General	35S-D #1	Sacramento 4	**50%**	**39.0%**		**35.7%**
Holly General	35S-D #2	Sacramento 15	**50%**	**60.8%**		**56.2%**
Williams	3509622	Sacramento 19	74%	73.2%	72.0%	66.7%
		Average	**67.0%**	**65.3%**		**60.5%**

Findings regarding wall furnace efficiency include:

- Tested thermal efficiency was within 2% of rated thermal efficiency on three units, Perfection Products PW8G25SEN #2, Williams 25GV-A1, and Williams 3509622
- Thermal efficiency was more than 2% higher than the rated thermal efficiency on four units, Perfection Products PW8G25SEN #1, Williams 35GV-C #2, Williams RMG35-IN, and Holly General 35S-D #2
- Tested thermal efficiency was well below rated thermal efficiency on three units, Williams 35GV-C #1, Williams 5009622, and Holly General 35S-D #1
- Six of the ten baseline units meet the 70% thermal efficiency standard for wall furnaces from the ANSI Z21.86 (Table 4)

Individual furnaces in identical furnace pairs fared quite differently from each other in terms of tested efficiency, as seen when comparing the pairs of Perfection Products PW8G25SEN, Williams 35GV-C, and Holly General 35S-D models. Their performance differences are likely due to the varying history of each furnace in terms of how much it was used and how well it was maintained.

The average tested thermal efficiency of all ten units was 65.3% compared to the 67% rated average, so efficiency did not fare too badly from a collective standpoint. However, individual units performed as much as 26% lower and 6% higher than their rated thermal efficiency.

According to ANSI Z21.86-2016 as listed in Table 14 in Appendix A, the minimum thermal efficiency for these gravity furnaces should be 70% and four of these ten furnaces tested below 70%. It was not expected that the two Holly General 35S-D furnaces would meet this standard, since they were manufactured before it was in effect. The Williams 35GV-C #1 and the Williams 5009622 double-sided furnace were ~7% and ~20% short of this standard.

AFUE ratings were not available for most of the baseline furnaces since these were not required before January 1, 1990, when these units were manufactured. Calculated AFUE from test data are included for informational purposes only. These calculated AFUE values were 3% to 6% lower than tested thermal efficiencies.

As listed in Table 15 in Appendix A, the minimum AFUE from the Code of Federal Regulations is 65% for the 25,000 Btu/hr furnaces, 66% for the 35,000 Btu/hr furnaces, and 67% for the 50,000 Btu/hr furnace. AFUE minimums were not reached for the same four furnaces that did not attain minimum thermal efficiency: Holly General 35S-D #1, Holly General 35S-D #2, Williams 35GV-C #1, and Williams 5009622. AFUE for the Williams 25GV-A1 furnace, at 64.4%, was just short of the required 65%.

Baseline Wall Furnace Emissions

Emission concentrations for each wall furnace were measured using a gas analyzer probe inserted in the exhaust stream. Emissions during the test procedure were then averaged over four operating conditions:

- Pilot – while in standby with only the pilot light burning natural gas
- Startup – from the start of combustion until the average exhaust temperature reaches steady state as defined by heating up to within 2°F of the maximum temperature achieved during that test
- Steady State – after the exhaust temperature reaches steady state and before the burner shuts off
- Shutdown – for 1.5 minutes after gas flow to the burner is turned off and only the pilot light burning natural gas

Exhaust stream concentrations in parts per million are converted to emission mass flow rates in lbm per MMBtu using Equation 1. Note that this conversion uses the percentage of oxygen in the exhaust flow to account for the fuel input, not the measured natural gas flow itself. There are often brief high concentrations and mass flow rates of pollutants in the exhaust stream at startup and shutdown. These spikes get ameliorated because startup emissions get folded into the entire startup time to steady state, and because shutdown emissions are assumed to occur at the much lower pilot gas rate.

Table 10, Table 11, and Table 12 on the following page list the carbon monoxide, nitrogen oxides, and total hydrocarbon emission rates found during testing of each wall furnace.

As was seen in the plots of emission concentrations over time during each wall furnace test, carbon monoxide and total hydrocarbon emissions tend to be higher during startup and especially shutdown, when combustion is not complete. Nitrogen oxide emissions tend to be higher while heating is actively operating due to poor fuel-air ratios.

Table 10: Baseline Wall Furnace Carbon Monoxide Emissions

Wall Furnace Tested			Carbon Monoxide, lbm/MMBtu			
Manufacturer	**Model**	**Field Site**	**Standby**	**Startup**	**Steady State**	**Shutdown**
Perfection Prod	PW8G25SEN #1	Hayward 3 Baseline	0.459	0.005	0.001	0.314
Perfection Prod	PW8G25SEN #2	Hayward 4 Baseline	0.078	0.002	0.019	0.178
Williams	25GV-A1	LA 104 Baseline	0.253	0.002	0.001	0.271
Williams	35GV-C #1	LA 105 Baseline	0.190	0.018	0.063	0.175
Williams	35GV-C #2	LA 106 Baseline	0.105	0.010	0.001	0.057
Williams	RMG35-IN	LA 107 Baseline	0.183	0.012	0.001	0.059
Williams	5009622	Oakland SF Baseline	0.809	0.008	0.002	0.261
Holly General	35S-D #1	Sacramento 4 Baseline	0.166	0.004	0.002	0.072
Holly General	35S-D #2	Sacramento 15 Baseline	0.000	0.880	1.194	1.065
Williams	3509622	Sacramento 19 Baseline	0.122	0.006	0.001	0.064
		Average	**0.237**	**0.095**	**0.128**	**0.251**

Table 11: Baseline Wall Furnace Nitrogen Oxides Emissions

Wall Furnace Tested			Nitrogen Oxides, lbm/MMBtu			
Manufacturer	**Model**	**Field Site**	**Standby**	**Startup**	**Steady State**	**Shutdown**
Perfection Prod	PW8G25SEN #1	Hayward 3 Baseline	0.049	0.102	0.105	0.125
Perfection Prod	PW8G25SEN #2	Hayward 4 Baseline	0.021	0.095	0.133	0.309
Williams	25GV-A1	LA 104 Baseline	0.009	0.105	0.108	0.890
Williams	35GV-C #1	LA 105 Baseline	0.038	0.073	0.113	0.414
Williams	35GV-C #2	LA 106 Baseline	0.032	0.076	0.071	0.061
Williams	RMG35-IN	LA 107 Baseline	0.045	0.081	0.084	0.091
Williams	5009622	Oakland SF Baseline	0.037	0.103	0.106	0.077
Holly General	35S-D #1	Sacramento 4 Baseline	0.036	0.088	0.093	0.045
Holly General	35S-D #2	Sacramento 15 Baseline	0.028	0.012	0.012	0.031
Williams	3509622	Sacramento 19 Baseline	0.058	0.115	0.121	0.107
		Average	**0.035**	**0.085**	**0.095**	**0.215**

Table 12: Baseline Wall Furnaces Total Hydrocarbon Emissions

Wall Furnace Tested			Total Hydrocarbons, lbm/MMBtu			
Manufacturer	**Model**	**Field Site**	**Standby**	**Startup**	**Steady State**	**Shutdown**
Perfection Prod	PW8G25SEN #1	Hayward 3 Baseline	0.126	0.001	0.000	1.889
Perfection Prod	PW8G25SEN #2	Hayward 4 Baseline	0.383	0.002	0.642	6.767
Williams	25GV-A1	LA 104 Baseline	0.558	0.001	0.000	0.003
Williams	35GV-C #1	LA 105 Baseline	0.012	0.001	0.009	0.097
Williams	35GV-C #2	LA 106 Baseline	0.000	0.000	0.000	0.140
Williams	RMG35-IN	LA 107 Baseline	0.448	0.025	0.000	0.000
Williams	5009622	Oakland SF Baseline	0.000	0.014	0.004	0.586
Holly General	35S-D #1	Sacramento 4 Baseline	0.000	0.009	0.004	0.161
Holly General	35S-D #2	Sacramento 15 Baseline	0.000	0.047	0.075	0.140
Williams	3509622	Sacramento 19 Baseline	0.287	0.023	0.007	0.939
		Average	**0.181**	**0.012**	**0.074**	**1.072**

There are some clear outlying furnaces with higher emission rates:

- Holly General 35S-D #2 had high CO emissions throughout its entire test
- Williams 5009622 had large CO emissions during standby pilot-only operation
- Williams 25GV-A1 had high NOx emissions at shutdown
- Perfection Products PW8G25SEN #2's high HC emissions indicate a gas leak
- Perfection Products PW8G25SEN #1, an older model, and Williams 3509622, a newer model, also had high HC emissions

As was seen with comparisons of tested efficiencies, emissions from individual furnaces in identical furnace pairs (Perfection Products PW8G25SEN, Williams 35GV-C, and Holly General 35S-D models) were quite different from each other. Performance differences are likely due to the varying history of each furnace in terms of hours of use and maintenance.

There are no standards for emissions from wall furnaces. However, as detailed in Appendix A, the South Coast Air Quality Management District and the San Joaquin Valley Air Pollution Control District require central furnaces nitrogen oxide emissions below 0.033 lbm/MMBtu.

From Table 11, only the Holly General 35S-D #2 furnace kept below the 0.033 lbm/MMBtu NOx limit during pilot, startup, steady state, and shutdown operations. This is surprising since it is one of the oldest and least efficient furnaces in this study, and it also had high CO emissions. All the other furnaces exceed the 0.033 lbm/MMBtu NOx limit in all or most of their operating modes.

Wall Furnace Energy Use and Emissions during Typical Operation

To investigate energy use and emissions further, Table 13 lists fuel use and emission rates over a typical day of operation for each baseline furnace. Field testing showed that the average baseline furnace was operated for 1.5 on-off cycles every day for 33 minutes per cycle. Natural gas use and flue gas emissions were summed up during pilot, startup, standby, and shutdown operations for this typical day.

Table 13: Energy Use and Emission Rates for a Typical Day of Operation

Wall Furnace Tested			Average Energy Use & Emission Rates at Each Site			
Manufacturer	Model	Field Site	Btu/Day	CO lbm/MMBtu	NOx lbm/MMBtu	THC lbm/MMBtu
Perfection Products	PW8G25SEN #1	Hayward 3	28782	0.194	0.081	0.054
Perfection Products	PW8G25SEN #2	Hayward 4	28493	0.037	0.072	0.327
Williams	25GV-A1	LA 104	38089	0.116	0.063	0.255
Williams	35GV-C #1	LA 105	38220	0.086	0.075	0.006
Williams	35GV-C #2	LA 106	39445	0.039	0.059	0.000
Williams	RMG35-IN	LA 107	37831	0.061	0.071	0.147
Williams	5009622	Oakland SF	61973	0.333	0.077	0.006
Holly General	35S-D #1	Sacramento 4	42698	0.067	0.069	0.005
Holly General	35S-D #2	Sacramento 15	40470	0.596	0.019	0.029
Williams	3509622	Sacramento 19	52219	0.059	0.090	0.143
		Average	**40822**	**0.169**	**0.068**	**0.087**

Not surprisingly, the largest capacity Williams 5009622 furnace would use the most natural gas and have the highest NOx emissions. But the furnace using the least amount of natural gas, Perfection Products PW8GSEN25 #2, had the most hydrocarbon emissions. The furnace with the lowest NOx and THC emissions, Holly General 35S-D #2, had the highest CO emissions.

Only the Holly General 35S-D #2 meets the 0.033 lbm/MMBtu limit for NOx emissions. All other furnaces emit about twice the limit. It is important to remember that this limit only applies to central furnaces, not wall furnaces, but it is a useful guideline to consider when evaluating wall furnace environmental sustainability.

Summary and Next Steps

These laboratory test results show how complicated it is to estimate baseline wall furnace energy use, performance, and emissions.

Collectively, baseline furnaces input capacity is 89% of their rated capacity, average pilot gas use is 690 Btu/hr, and average thermal efficiency was about 2% below rated efficiency. However, capacity, pilot gas use, and efficiency vary from unit to unit with respect to their ratings.

Emissions are also quite complicated to predict, as they are not just dependent upon how much natural gas is burned. Emissions also depend on how often furnaces start up and shut down, and whether their operating cycles last long enough to reach steady state conditions.

In next steps associated with the project, the laboratory results documented in this study are used together with analysis of field monitoring results to perform additional estimates of energy use and emissions from this sample of baseline wall furnaces. Comparisons will be made with retrofit wall furnace laboratory testing and field monitoring to estimate energy savings, emissions reductions, and indoor air quality improvements of more efficient wall furnaces.

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Project Deliverables

The following project deliverables, including interim project reports, are available upon request by submitting an email to ERDDpubs@energy.ca.gov:

- Baseline Wall Furnace Laboratory Test Report – Improving the Performance of Wall Furnaces in California
- Retrofit Wall Furnace Laboratory Test Report – Improving the Performance of Wall Furnaces in California
- Baseline Wall Furnace Field Monitoring Report – Improving the Performance of Wall Furnaces in California
- Retrofit Wall Furnace Field Monitoring Report – Improving the Performance of Wall Furnaces in California
- Wall Furnace Technology Transfer Report – Improving the Performance of Wall Furnaces in California
- Final Wall Furnace Report – Improving the Performance of Wall Furnaces in California

Appendix A: Related Efficiency, Emissions, and Indoor Air Quality Information

Wall Furnace Characteristics

A wall furnace is a compact device used to heat one or two rooms. Because they are less expensive, simpler to install, and take up less space than a central ducted furnace, they are used in multifamily apartment complexes and smaller single-family homes.
Wall furnaces are typically installed within the stud cavity of an interior wall. They exhaust combustion gases through a flue stack running vertically up to a roof penetration. They use continuously operating pilot lights to fire the main burner when there is a call for heating, and usually do not even need an electrical connection.

Wall furnaces are categorized by how they distribute heat, where their combustion air comes from, how they ignite the burner, and whether they use condensing technology.
Heated air from wall furnaces can be distributed in two ways. **Gravity** furnaces heat the air around the furnace, causing it to rise and distribute itself throughout a space naturally. This gravity-induced air flow can be supplemented by a booster fan, with the fan separately connected to AC power. **Fan-type** wall furnaces integrate a fan directly into the wall furnace unit to distribute heated air. The energy used by these fans can vary from 0.8 to 5 amps of single-phase AC current at 120 V depending on the capacity of the wall furnace and the efficiency of the fan.

Wall furnace combustion air is also handled in two ways. A **vented** or **top vent furnace** draws combustion air from inside the house, then exhausts combustion gases directly to the outside. This furnace is located between the studs of an interior wall, and exhaust gases are sent through a flue of six or eight inches in diameter that travels vertically through the wall cavity to the roof. In contrast, **direct vent** furnaces draw combustion air from outside. They are placed in an outside wall to keep their intake ducts short, although they can be installed in an inside wall by using the proper duct extensions. Exhaust gases can also be sent outside horizontally through the wall or vertically through the wall cavity to the roof.

Three different technologies exist to ignite wall furnaces. The oldest and least efficient ignition technology is a standing pilot. This device uses a small burner that stays lit continually, ready to ignite the main burner whenever there is a call for heating. The standing pilot stays on by heating a thermopile which sends current to keep the pilot gas valve open. If the pilot goes out the thermopile cools off and stops sending current, and the pilot gas will stop flowing. An intermittent **pilot**, developed after the oil crisis of the 1970s, is lit only when a call for heating is made. The intermittent pilot uses an electronic spark to first light a pilot flame and then the pilot flame lights the main burner. Use of an intermittent pilot is said to reduce furnace energy use by about 5% on average. A hot surface igniter also uses electricity to light the furnace, but it lights the burner directly by heating a silicon nitride ceramic probe to 2000-2500°F. While heating up, the hot surface igniter draws 2 to 4 amps of current at 120 V.

Thermal efficiency and AFUE are both measures of a furnace's efficiency, but they represent different furnace operations. Thermal efficiency represents the full-load performance of a system, while AFUE represents the performance over a typical range of operating conditions. Many of the baseline furnaces in this study were manufactured before AFUE ratings were required. While all rated and tested AFUE values are reported, furnace efficiency comparisons rely mostly on thermal efficiency values.

Wall Furnace Efficiency Standards

From 1982 through 1995, wall furnaces were regulated under ANSI Z21.49 for Gas-Fired Gravity and Fan Type Vented Wall Furnaces (ANSI Z21.49 1995). In 1996, ANSI Z21.49 was made inactive and ANSI Z21.86 for Vented Gas-Fired Space Heating Appliances (ANSI Z21.86 2016) became the regulating standard for wall furnaces. This standard was most recently updated in 2016.

Both the Z21.49 and Z21.86 standards mandated that wall furnace nameplates list their input and output capacity based on standard test methods. The latest Z21.86 standard mandates for thermal efficiency (output capacity divided by input capacity) are listed in Table 14. The date when these minimum thermal efficiency standards were first introduced was unable to be confirmed, but they were probably part of the ANZI Z21.49-1986 update.

Table 14: Minimum Wall Furnace Thermal Efficiency Requirement from ANSI Z21.86-2016

	Gravity Wall Furnaces	Fan-Type Wall Furnaces
Minimum Thermal Efficiency	70%	75%

In addition, minimum Annual Fuel Utilization Efficiency (AFUE) levels for wall furnaces are mandated under the Code of Federal Regulations for furnaces manufactured after 1990 (CFR 430.32 (i) (1) 2022) and furnaces manufactured after 2013 (CFR 430.32 (i) (2) 2022). Table 15 lists the current minimum AFUE requirements for new wall furnaces. AFUE minimums were raised by at least 2% for furnaces manufactured after 2013.

Table 15: Minimum AFUE Requirements for Wall Furnaces manufactured after January 1, 1990 and April 16, 2013

<table>
<tr><th>Furnace Type</th><th>Input Capacity</th><th>AFUE 1990</th><th>AFUE 2013</th></tr>
<tr><td>Gas Wall Gravity</td><td>up to 10,000 Btu/hr</td><td>59%</td><td rowspan="5">65%</td></tr>
<tr><td>Gas Wall Gravity</td><td>over 10,000 up to 12,000 Btu/hr</td><td>60%</td></tr>
<tr><td>Gas Wall Gravity</td><td>over 12,000 up to 15,000 Btu/hr</td><td>61%</td></tr>
<tr><td>Gas Wall Gravity</td><td>over 15,000 up to 19,000 Btu/hr</td><td>62%</td></tr>
<tr><td>Gas Wall Gravity</td><td>over 19,000 up to 27,000 Btu/hr</td><td>63%</td></tr>
<tr><td>Gas Wall Gravity</td><td>over 27,000 up to 46,000 Btu/hr</td><td>64%</td><td>66%</td></tr>
<tr><td>Gas Wall Gravity</td><td>over 46,000 Btu/hr</td><td>65%</td><td>67%</td></tr>
<tr><td>Gas Wall Fan-Type</td><td>up to 42,000 Btu/hr</td><td>73%</td><td>75%</td></tr>
<tr><td>Gas Wall Fan-Type</td><td>over 42,000 Btu/hr</td><td>74%</td><td>76%</td></tr>
</table>

While thermal efficiency represents the full-load, steady-state performance of furnaces, AFUE is supposed to reflect furnace performance over a range of operating conditions. Many of the baseline furnaces in this study were manufactured before AFUE ratings were required. While all rated and tested AFUE values are reported, furnace efficiency comparisons rely mostly on thermal efficiency values.

Wall furnaces are located inside the building envelope, and all top vent furnaces use indoor air for combustion. This means that their performance tends to stay relatively constant under different weather conditions as compared to furnaces that sit in unconditioned or semi-conditioned spaces. It also means that laboratory-measured efficiencies should be fairly good job of predicting actual efficiency of wall furnaces as they operate in the field.

Related Emissions and Indoor Air Quality Guidelines

Like all gas burning equipment, even properly operating wall furnaces produce low levels of CO, NOx, and particulate matter emissions. As with all primary gas space heating equipment in the state of California, emissions must be vented to the outside to prevent the accumulation of indoor pollutants.

There are no federal or California limits on flue gas emissions or indoor pollutants generated by wall furnaces. However, the Code of Federal Regulations limits particulate matter emissions from wood-burning residential forced-air furnaces. Residential forced-air furnaces are defined for this standard as fuel burning devices designed to burn wood or wood pellet fuel that warms a space other than the space where the furnace is located. Wall furnaces do not meet this definition because they burn natural gas, and because heat the space where they are installed.

For reference, forced-air furnaces manufactured after May 16, 2015 were required to emit no more than 0.93 lbm/MMBtu of particulate matter (CFR 60.5474 (b) (4) 2022), defined as the total of PM2.5 and PM10 particles. This limit was lowered to 0.15 lbm/MMBtu in total particulate matter for forced-air furnaces manufactured after May 15, 2020 (CFR 60.5474 (b) (6) 2022).

In California, the South Coast Air Quality Management District (SCAQMD) and the San Joaquin Valley Air Pollution Control District (SJVAPCD) limit NOx emissions from natural gas-fired fan-type central furnaces distributed or sold in their territories. These standards do not specifically define a central furnace. It is typically a furnace that heats air in one place and circulates it through ducts to other places, so these rules do not apply to wall furnaces. For reference, both the SCAQMD Rule 1111 (SCAQMD 2021) and SJVAPCD Rule 4905 (SJVAPCD 2020) require furnaces to keep NOx emissions, on a basis of NO2, below 14 ng/Joule (0.033 lbm/MMBtu).

The US Environmental Protection Agency does not regulate indoor air quality, but they have characterized typical levels of carbon monoxide found in homes (US EPA CO 2022). They have not agreed upon standards for nitrogen oxides (US EPA NOx 2022) or particulate matter (US EPA PM 2022) within homes but have laid out acceptable levels for these pollutants in outside air over different time periods.

The US Environmental Protection Agency has developed guidelines for outdoor air quality, the National Ambient Air Quality Standards (US EPA NAAQS 2022), with acceptable limits of outdoor air pollutants in terms of averages over different time periods. The California Air Resources Board has also developed standards for outdoor air quality that are sometimes more stringent than federal standards, the California Ambient Air Quality Standards (CARB CO 2022, CARB NOx 2022, CARB PM 2022).

Table 16 summarizes the regulations, standards, and guidelines for residential furnaces and indoor air quality, as well as some outdoor air pollution standards. Although none of these standards applies to wall furnaces, they serve as reference values for this project's emissions and indoor air quality analyses. Note that no regulations, standards, or guidelines were identified that help characterize hydrocarbon emissions.

Table 16: Emissions and Indoor Air Quality Regulations, Standards and Guidelines

Rule	Equipment	CO	NOx	PM2.5 & PM10
Code of Federal Regulation	Residential forced-air furnaces, wood-burning	n/a	n/a	0.93 lbm/MMBtu, 2015 0.15 lbm/MMBtu, 2020
SCAQMD Rule 1111 & SJVAPCD Rule 4905	Central furnaces	n/a	0.033 lbm/MMBtu (14 nanograms/Joule)	n/a
US EPA reference levels of typical indoor air pollutants	Indoor air quality in homes	0 - 5 ppm normal 5 - 15 ppm near properly adjusted gas stove 30 ppm or more near improperly adjusted gas stoves	n/a	n/a
National Ambient Air Quality Standards	Outside air	9 ppm 8 hours 35 ppm 1 hour	100 ppb 1 hour 53 ppb 24 hours	PM2.5 35 ug/m^3 24 hours PM10 150 ug/m^3 24 hours
California Ambient Air Quality Standards	Outside air	9 ppm 8 hours 20 ppm 1 hour	180 ppb I hour 30 ppb 24 hours	PM2.5 none 24 hours PM10 50 ug/m3 24 hours