Webpage Abstract

This is the final 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 gathered information about baseline and retrofit wall furnace performance, operation, emissions, and indoor air quality from laboratory testing and field monitoring.

Ten existing baseline vented gracity furnaces were monitored over a heating season:

- Two single-sided furnaces in side-by-side apartments in Hayward
- Four single-sided furnaces in retirement apartments in Los Angeles
- One double-sided furnace in a single-family home in Oakland
- Three single-sided furnaces in multifamily apartments in Sacramento

After monitoiring was complete, these furnaces were replaced with highly efficient retrofit wall furnaces and monitored over a second heating season:

- Two Williams 1753012 direct vent condensing furnaces in Hayward apartments
- Four Williams AC2030TN vented fan-type furnaces in Los Angeles apartments
- One Williams AC3040TN vented fan-type double-sided furnace Oakland home
- Three Williams TG2030TN vented fan-type self-powered furnaces in Sacramento

Field monitoring included measuring wall furnace operating time, indoor temperature and humidity, and indoor concentrations of carbon monoxide, nitrogen oxides, and particulate matter (PM2.5 and PM10). Information derived from analysis of monitoring data include each furnace’s pattern of operation and its effect on indoor air quality.

All ten baseline furnaces and four different retrofit furnace models were also tested at GTI Energy’s laboratory in Des Plaines, IL. Laboratory testing included measuring natural gas flow, electricity use, operating temperatures, and concentrations of carbon monoxide, nitrogen oxides, and total hydrocarbons 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, electrical energy use, efficiency, and flue gas emission rates.

This report presents an overview of the field monitoring and laboratory test results for baseline and retrofit wall furnace, including their operating patterns, energy use, efficiency measurements, emissions, and effects on indoor air quality. Advanced retrofit wall furnaces were found to use 66% less energy, reduce emissions of carbon monoxide by 88%, nitrogen oxides by 89%, and total hydrobcarbons by 92%. However, costs of the retrofit wall furnaces are high, with payback periods averaging 21 years, and the furnaces could use some adjustments to improve their operability.

CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

FINAL PROJECT REPORT

Improving the Performance of Wall Furnaces in California – Final Project Report

Agreement Number: PIR-18-005

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Executive Summary

This is the final 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

There are an estimated 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. The oldest existing furnaces have thermal efficiencies of 50% while today’s standard replacement wall furnaces have thermal efficiencies of 70%.

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

This interim report documents field monitoring results from the evaluation of nine retrofit wall furnaces in California homes. Other interim reports for this project document laboratory testing of these retrofit furnaces, and field monitoring and laboratory testing for existing 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 final report gives an overview of the field monitoring and laboratory testing that were done on existing baseline wall furnaces and advanced retrofit wall furnaces.

The baseline wall furnaces studied in this project were existing wall furnaces that were in service in California homes. Ten baseline vented gravity wall furnaces were tested:

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

These furnaces were 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 retrofit wall furnaces studied in this project were installed in California homes in place of the baseline furnaces, then monitored over a second heating season:.

- Two 1753012 direct vent condensing furnaces side-by-side apartments in Hayward (apartments 3 and 4)
- Four AC2030TN vented fan-type furnaces in a retirement apartment community in Los Angeles (104, 105, 106, and 107)
- One AC3040TN vented fan-type double-sided furnace in a single-family home in Oakland (SFH)
- Three TG2030TN vented fan-type self-powered furnaces in multifamily apartments in Sacramento (4, 15, and 19), with apartment 19's furnace operated by two different tenants

The field monitoring performed by the research team included:

- Heating season measurement of furnace operation
- Heating season measurement of indoor temperature and humidity
- Heating season measurement of indoor air quality (IAQ) in terms of concentrations of carbon monoxide, nitrogen oxides, and particulate matter (PM2.5 and PM10)

Laboratory testing of the ten baseline furnaces and four different retrofit furnace models included measurements of the following parameters:

- Furnace natural gas flow during operation and standby (i.e. pilot gas use, if any)
- Electricity use, if any
- Operating ambient, inlet, outlet, and exhaust temperatures
- Exhaust gas concentrations of carbon monoxide, nitrogen oxides, and total hydrocarbons

Field and laboratory data are used to estimate energy savings, emissions reduction, and indoor air quality improvements of retrofit wall furnaces compared to baseline furnaces. Utility costs, wall furnace pricing, and installation costs are analyzed to determine the cost effectiveness of advanced retrofit wall furnaces compared to baseline furnaces. Problems with the installation and operation of these wall furnaces are assessed and recommendations for improvements are made.

Key Results

Table 1 lists the average energy characteristics of the ten baseline and ten retrofit wall furnaces tested during this project. This shows the difference between rated and tested values of these furnaces, resulting in a 31% higher tested output capacity on average for the retrofit furnaces than the baseline furnaces.

Table 1: Wall Furnace Energy Characteristics

	Natural Gas Input Capacity			Thermal Efficiency		Natural Gas Output Capacity		AC Power
	Rated Input Btu/hr	Tested Input Btu/hr	Pilot Btu/hr	Rated TE	Tested TE	Rated Output Btu/hr	Tested Output Btu/hr	Active W
Baseline Average	33500	29990	690	67.0%	65.3%	22490	19190	0
Retrofit Average	28500	30830	0	85.7%	82.0%	24190	25050	26.3
Difference	5000	-840	690	-18.7%	-16.6%	-1700	-5860	-26.3
Percent Difference	15%	-3%	100%			-8%	-31%	

Table 2 shows annual operation, energy use, and energy costs of baseline and retrofit wall furnaces. These projections are based on laboratory tests and field monitoring, and estimated for a Typical Meteorological Year at each wall furnace location. The retrofit furnaces operated for 37% fewer hours, in part because they have higher capacity than the baseline furnaces, and in part because the fan-type furnaces distribute heat differently. Fewer operating hours, plus the removal of the standing pilot, resulted in retrofit wall furnaces using 66% less natural gas on average. Some of the furnaces also used a small amount of electricity. Average annual utility bills were reduced by $144 or 65%.

Table 2: Wall Furnace Annual Operation, Energy Use, and Energy Costs

	Operating hrs/year	Cycles/year	Avg Cycle Minutes	MMBtu/year	kWh/year	Utility Cost
Baseline Average	178.3	410	26.1	11.602	0.0	$220
Retrofit Average	112.1	188	31.0	4.003	2.3	$77
Savings Average	66.2	222.0	-4.9	7.600	-2.3	$144
Percent Savings	37%			66%		65%

Table 3 lists average annual emissions from the baseline and retrofit wall furnaces tested in this project. Using the same operating characteristics and Typical Meteorological Year as in Table 2, annual emissions of carbon monoxide, nitrogen oxides, and total hydrocarbons are projected to be 89%, 88%, and 92% lower, respectively. The bulk of the CO and THC emission reductions are due to the removal of the standing pilot, while NOx emission reductions are also due to combustion improvements specifically made to reduce NOx formation.

Table 3: Wall Furnace Annual Emissions

	Operating hrs/year	Cycles/year	Avg Cycle Minutes	CO lbm/year	NOx lbm/year	THC lbm/year
Baseline Average	178.3	410	26.1	2.61	0.74	1.18
Retrofit Average	112.1	188	31.0	0.28	0.09	0.09
Savings Average	66.2	222.0	-4.9	2.33	0.65	1.09
Percent Savings	37%			89%	88%	92%

Table 4 lists the average and maximum indoor pollutant concentrations for the baseline and retrofit furnaces. The retrofit furnaces have mixed effects on indoor air quality. Drops in indoor pollution levels when furnaces were ON (average CO and NOx, maximum NOx, PM2.5, PM10) indicate that some furnace exhaust gases do make their way into the indoor spaces, and the lower emitting retrofit furnaces reduce indoor pollutant levels. However, indoor pollutant concentrations should have dropped dramatically after the retrofit furnaces were installed if wall furnaces were the largest source of indoor air pollution. Indoor pollution is likely also being generated by natural gas ranges and water heaters.

When the furnaces were OFF, indoor pollutant concentrations were surprisingly lower for baseline furnaces than retrofit furnaces. A beneficial effect of wall furnace operation on indoor air quality is also confirmed by drops in maximum pollutant concentrations when furnaces are ON. It is theorized that wall furnaces draw air from the space for combustion when they operate, even when only the pilot light is burning, and actually help to reduce indoor pollutant concentrations.

Table 4: Wall Furnaces and Indoor Air Quality

Average IAQ Concentrations	CO Off ppmx10	CO On ppmx10	NOx Off ppb/10	NOx On ppb/10	PM2.5 Off ug/m3	PM2.5 On ug/m3	PM10 Off ug/m3	PM10 On ug/m3
Baseline Average	15.7	18.9	17.4	19.0	15.2	15.5	16.5	18.5
Retrofit Average	15.9	13.6	24.7	18.8	21.6	20.4	24.2	22.4
Reduction	-0.3	5.2	-7.3	0.2	-6.4	-4.9	-7.7	-3.9
% Reduction	-2%	28%	-42%	1%	-42%	-31%	-47%	-21%
Comparative Limit	50-150 ppmx10 inside properly adjusted (US EPA)		3.0 ppb/10 24 hour outside (CAAQS)		35 ug/m3 24 hour outside (NAAQS)		50 ug/m3 24 hour outside (CAAQS)	
Maximum IAQ Concentrations	**CO Off ppmx10**	**CO On ppmx10**	**NOx Off ppb/10**	**NOx On ppb/10**	**PM2.5 Off ug/m3**	**PM2.5 On ug/m3**	**PM10 Off ug/m3**	**PM10 On ug/m3**
Baseline Average	45.6	24.5	54.9	26.5	134.2	35.9	152.9	39.4
Retrofit Average	70.7	29.5	58.8	22.4	185.4	34.5	211.8	37.3
Reduction	-25.2	-5.0	-4.0	4.1	-51.2	1.3	-58.9	2.2
% Reduction	-55%	-20%	-7%	16%	-38%	4%	-38%	5%
Comparative Limit	50-150 ppmx10 inside properly adjusted (US EPA)		18 ppb/10 1 hour outside (CAAQS)		35 ug/m3 24 hour outside (NAAQS)		50 ug/m3 24 hour outside (CAAQS)	

The incremental costs of advanced retrofit furnaces over standard baseline furnaces range from $2100 to $2940. This led to high simple payback periods for retrofit furnaces compared to standard efficiency furnaces with standing pilots that operate all year, ranging from 6.5 to 43.8 years, and averaging 21.7 years. Utility incentives for these furnaces can help make them more economically feasible, but advanced furnace prices must be reduced in order to gain substantial market share in the future.

There were also some operating issues that need to be improved in the retrofit furnaces.

- Noise levels from these fan-type retrofit furnaces was sometimes unacceptably high, and it is recommended they adhere to levels mandated for intermittent indoor fans
- Self-charging batteries on one of the retrofit models are a promising advance, but need to be more reliable and come with clearer operating instructions
- Wall furnace controls need to be improved to respond instantly to thermostat settings changes and to adjust more quickly to space temperatures, and the use of wireless thermostats and temperature sensors should be investigated by manufacturers as a way to improve occupant comfort and control

Knowledge Transfer and Next Steps

Information from this study is being disseminated to manufacturers, utilities, HVAC contractors, affordable housing advocates, and other interested parties. Future work on wall furnaces should concentrate on 1) verifying the savings results found in this project, 2) studying effects on indoor air quality in more depth, and 3) testing future iterations of these furnace products with improved batteries, reduced noise levels, and better controls, and 4) reinvestigating wall furnace costs after these advanced furnaces have been on the market for a couple of years.

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 which is 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. 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 field monitoring of nine retrofit wall furnaces in California homes:

- Two 1753012 direct vent condensing furnaces side-by-side apartments in Hayward
- Four AC2030TN vented fan-type furnaces in retirement apartments in Los Angeles
- One AC3040TN vented fan-type double-sided furnace in an Oakland single-family home
- Two TG2030TN vented fan-type self-powered furnaces in Sacramento apartments, with one of these furnaces operated by two different tenants

Field monitoring results will be combined with laboratory test data for each of these furnaces to estimate their field energy use, emissions and effects on idoor air quality. More efficient retrofit furnaces will also be laboratory tested and field monitored as part of this project. Comparisons of baseline and retrofit wall furnace energy use, emissions, and indoor air quality will be made to evaluate the benefits that can be realized through the installation of more efficient retrofit furnaces. Both initial purchase and installation costs and long term utility costs are assessed to estimate cost effectiveness. Furnace operability and reliability issues are also addressed.

Project Approach

This project combined field monitoring and laboratory testing of wall furnaces. Existing baseline furnaces were first field monitored over a heating season, then removed and sent for testing in GTI Energy's Des Plaines, IL laboratory. Advanced efficient retrofit furnaces were installed at each field site and monitored for another heating season. Additional retrofit furnace units were also shipped to Des Plaines for laboratory testing.

Field monitoring and laboratory testing procedures are briefly described below. Descriptions of the baseline and retrofit wall furnaces are also given. More detailed information including equipment, site characteristics, and analysis equations can be found in these project reports:

- Baseline Wall Furnace Laboratory Test Report
- Retrofit Wall Furnace Laboratory Test Report
- Baseline Wall Furnace Field Monitoring Report
- Retrofit Wall Furnace Field Monitoring Report

Field Monitoring Procedures

The objective of the field monitoring portion of this project was to characterize the operation of wall furnaces and their effects on indoor air quality. Field monitoring included measuring furnace run time, indoor temperature, and relative humidity. Levels of indoor carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM2.5 and PM10) were also monitored in each dwelling to quantify the effects of wall furnace operation on indoor comfort and air quality.

A single monitoring package from Senseware was used for this research. The Senseware package included visually unobtrusive sensors that measured furnace operation, indoor conditions, and indoor air quality. During the monitoring period, data was collected every minute from each sensor and sent to the wireless node, then relayed to the cloud through the gateway at least twice a day. Each furnace was monitored over a winter heating season.

Field monitoring data from each site was supplemented with regional weather data and air quality data. Hourly weather data including outdoor temperature, humidity, and wind speed was collected from the National Oceanic and Atmospheric Administration's Climate Data Online Tool for Local Climatological Data (NOAA 2022), an archive of historical weather data collected by the National Climate Data Center. Hourly air quality data, including levels of carbon monoxide, nitrogen oxides, and particulate matter PM2.5, was collected from the California Air Resources Board Air Quality Data Query Tool (CARB 2022).

Key results from field monitoring include:

- Wall furnace operating hours based on gas solenoid valve signals
- Indoor air quality measurements (CO, NOx, PM2.5, PM10)
- Indoor temperature and relative humidity
- Correlations with outdoor temperatures from local weather stations

Laboratory Testing Procedures

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.

Gas flow was measured using a pulse meter, and electricity use measured via current transducers. Single thermocouples were used to measure ambient room temperature and inlet temperature, a set of three thermocouples measured exahsut gas temperature, and an array of nine thermocouples measured heated outlet temperatures around the furnace face. A Horiba PG350 gas analyzer was used to measure nitrogen oxides and carbon monoxide, and it was supplemented by a Rosemount Analytical 400 A gas analyzer to measure total hydrocarbon emissions. The furnaces were not installed into a wall assembly designed to mimic a typical internal wall cavity, but GTI Energy's Des Plaines laboratory technicians followed all other ANSI Z21.86 requirements. .

The test protocol covered furnace operation during standby, startup, steady state, and shutdown. The test procedure included the following steps:

- 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)

Data from all equipment was synchronized and corrected to an ambient oxygen percentage of 20.9%, and minimum emission concentrations were adjusted to 0%. Test data was analyzed to determine gas flow rates during standby and active operation. Emission concentrations were converted to emission rates in lbm per MMBtu of natural gas energy used. Wall furnace thermal efficiency and AFUE (annual fuel utilization efficiency) were 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) 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.
Key parameters derived from laboratory measurements included each furnace's:

- input capacity
- pilot gas use
- thermal efficiency and AFUE
- emission rate of carbon monoxide, nitrogen oxides, and total hydrocarbons during standby, startup, steady-state, and shutdown operations

Baseline Wall Furnaces

Baseline furnaces from ten sites were field monitored and laboratory tested during this project:

- four apartments (104, 105, 106, and 107) in Los Angeles
- a single-family home in Oakland
- two apartments (3 and 4) in Hayward
- three apartments (4, 15, and 19) in Sacramento

A summary of the characteristics of each baseline furnace is presented in Table 5. All the monitored baseline furnaces are gravity, top vent, non-condensing furnaces with standing pilots. See Appendix A for a description of each of these furnace technologies.

Table 5: Baseline Wall Furnace Characteristics, Gravity Top Vent 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.

Figure 1, Figure 2, and Figure 3 show the existing baseline wall furnaces described in Table 5 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)

Retrofit Wall Furnaces

Retrofit furnaces were installed at ten sites for monitoring during this project. These sites were:

- two apartments (3 and 4) in Hayward
- four apartments (104, 105, 106, and 107) in Los Angeles
- one single-family home in Oakland
- three apartments (4, 15, and 19) in Sacramento.

Retrofit field monitoring could not be completed at the Sacramento apartment 15 site because the replacement furnace would not operate and had to be removed.

A summary of the characteristics of each installed retrofit furnace is presented in Table 6, and photographs of each furnace are shown in Figure 4.

Table 6: Retrofit Wall Furnace Characteristics

Field Sites	Manufacturer	Model	Input Btu/hr	Thermal Efficiency	Rated AFUE	Features
Hayward 3 & 4	Williams	1753012	17,500	94%	93%	• Direct Vent • Condensing • Hot Surface Igniter • 2 Stage Heat Exchanger • Fan-Type w/AC Power
Los Angeles 104-107	Williams	AC2030TN #1 & #2	30,000	85%	82%	• Top Vent • Intermittent Pilot • Fan-Type w/AC Power • Low NOx emissions • Single-Sided • Traditional Form Factor
Oakland SFH	Williams	AC3040TN	40,000	83%	80%	• Top Vent • Intermittent Pilot • Fan-Type w/AC Power • Low NOx emissions • Double-Sided • Traditional Form Factor
Sacra-mento 4, 15 & 19	Williams	TG2030TN	30,000	82%	80%	• Top Vent • Intermittent Pilot • Fan-Type w/Battery • Low NOx emissions • Traditional Form Factor

The Williams AC2030TN, AC3040TN, and TG2030TN furnaces described in **Error! Reference source not found.** and shown in Figure 4 are all top vent furnaces with traditional form factors. The Williams 1753012 furnace is a direct vent condensing furnace, with a different form factor, and usually installed on an outside wall for easy access to outside air. In this study, the 1753012 furnaces were installed on an inside wall using extra ducting through which to draw in outside air.

Figure 4: High Efficiency Williams Wall Furnaces Tested in this Project from left to right: 1753012, AC2030TN, AC3040TN, TG2030TN

Annual Operation, Energy Use, Cost, and Emissions Calculations

The wall furnaces were field monitored over different time periods with varying weather conditions. Regression equations were developed from the monitoring data, and then used determine how these furnaces would have operated during a normalized year of weather. The procedures used for calculating normalized annual operating hours, furnace on-off cycles, energy use, and emissions are described below.

First, regression equations were developed from field monitoring data to describe daily hours hours of operation versus average daily outdoor temperature, as well as the average daily cycle length versus average daily outdoor temperature. These equations are listed in **Error! Reference source not found.** of the Results section of this report

Average daily outdoor temperatures for a typical meteorological year were derived from TMY3 files compiled from the National Solar Radiation Database (NSRDB 2022) for years 1998 to 2020 at location 131637 for Sacramento, 122886 for Oakland/Hayward, and 83557 for Los Angeles. Hourly temperatures were then averaged for each day of the TMY3 data set to get the average daily outdoor temperature (ADOT) at each location.

These ADOT values were used in the regression equations to calcuate operating time and cycle length for each day of the typical meteorological year. Daily operating time was set to zero if the regression returned a negative number for any day. Daily cycle length was set to the operating time if this length was lower than the daily operating time. Cycles per day were calculated by dividing operating hours by cycle length.

Annual operating time and the number of cycles were then summed for all days of the typical meteorological year. An average annual cycle length was found by dividing annual operating time by the total number of cycles. Total annual operating time and the number of cycles were customized to each site by multiplying them by a ratio of each site's monitored value divided by the averaged monitored value for all sites at that location.

Annual energy use were calculated using the equations 1, 2 and 3:

1) Annual Natural Gas Use, Btu = Tested Btu/hr x Operating Hours/year + Pilot Btu/hr x Standby Hours/year
2) Standby Hours/year = Total Hours/year – Operating Hours/year
3) Annual Electricity Use, kWh = Operating Hours/year x Active W

Rates of energy use found during laboratory tested are listed in the Results section of this report in Table 9 for baseline wall furnace and in Table 10 for retrofit wall furnaces. Two AC2030TN retrofit furnaces were tested, and average values from those tests were used in equations 1, 2, and 3 for the Los Angeles furnaces.

Residential utility costs of $19.00 per MMBtu of natural gas and $0.25 per kWh of electricity. These costs are based on average California utility rates collected by the US Energy Information Administration for October 2021 through September 2022 (US EIA #1 2023, US EIA #2 2023, US EIA #3 2023).

Total flue gas emissions were found from the sum of emissions during standby, startup, steady state, and shutdown operations, using equations 4 through 8:

4) Standby Emissions lbm/day = [Standby hrs/day x Pilot Btu/hr x Standby Emission lbm/MMBtu] / (1000 x 1000)
5) Startup Emissions lbm/day = [Cycles/day x minimum (Cycle minutes/60 or Avg Startup minutes/60) x Tested Btu/hr x Startup Emission lbm/MMBtu] / (1000 x 1000)
6) Steady state Emissions lbm/day = [Cycles/day x maximum (Cycle min/60 - Avg Startup min/60) x Tested Btu/hr x Steady state Emission lbm/MMBtu] / (1000 x 1000)
7) Shutdown Emissions lbm/day = [Cycles/day x (1.5 minutes/60 x Pilot Btu/hr + 2 seconds/3600 x Tested Btu/hr) x Shutdown Emission lbm/MMBtu] / (1000 x 1000)
8) Total Emissions, lbm/day = Standby Emissions + Startup Emissions + Steady state Emissions + Shutdown Emissions

Note that equations 1 through 8 assume that any standing pilots stay lit all year, burning natural gas and creating emissions outside the heating season when the furnace would be actively heating. It is likely that some fraction of wall furnaces are completely shut down with the standing pilot off outside of the heating season, but it was outside the scope of this research to establish that fraction.

Laboratory tested flue gas emissions during standby, startup, steady state, and shutdown modes of operation are listed in the Results section of this report in

Table 14, Table 15, and Table 16 for baseline furnaces and in

Table 17, Table 18, and Table 19 for retrofit furnaces. Average values of emissions from the two AC2030TN furnaces are used to calculate overall emissions for the Los Angeles wall furnaces.

Results

The following report section presents and compares the results from laboratory testing and field monitoring of baseline and retrofit wall furnaces, including:

- Performance characteristics from laboratory testing
- Flue gas emissions from laboratory testing
- Operating characteristics from field monitoring
- Indoor air quality levels from field monitoring

These results were used to estimate annual wall furnace energy use and emissions during a typical meteorological year.

First, we summarize nameplate information from the baseline and retrofit wall furnaces that were studied in this project in Table 7 and Table 8.

Table 7: Baseline Wall Furnace Nameplate Information

Manufacturer	Model	Description	Field Sites	Age years	Rated Input Btu/hr	% Rated Input	Rated Output Btu/hr
Perfection Products	PW8G25SEN #1	1-sided, top vent, gravity	Hayward 3	~40	25000	81%	17500
Perfection Products	PW8G25SEN #2	1-sided, top vent, gravity	Hayward 4	~40	25000	81%	17500
Williams	25GV-A1	1-sided, top vent, gravity	LA 104	~35	25000	100%	24500
Williams	35GV-C #1	1-sided, top vent, gravity	LA 105	~35	35000	91%	24500
Williams	35GV-C #2	1-sided, top vent, gravity	LA 106	~35	35000	91%	24500
Williams	RMG35-IN	1-sided, top vent, gravity	LA 107	~35	35000	91%	35000
Williams	5009622	2-sided, top vent, gravity	Oak SF	~15	50000	89%	26600
Holly General	35S-D #1	1-sided, top vent, gravity	Sacto 4	40+	35000	90%	17500
Holly General	35S-D #2	1-sided, top vent, gravity	Sacto 15	40+	35000	83%	17500
Williams	3509622	1-sided, top vent, gravity	Sacto 19	~10	35000	97%	24790
			Average	**32**	**33500**	**89%**	**22990**

Table 8: Retrofit Furnace Nameplate Information

Manufacturer	Model	Description	Field Sites	Age years	Rated Input Btu/hr	% Rated Input	Rated Output Btu/hr
Williams	1753012	direct vent, condensing	Hayward 3	0	17500	113%	16450
Williams	1753012	direct vent, condensing	Hayward 4	0	17500	113%	28200
Williams	AC2030TN	1-sided, top vent, fan-type, AC power	LA 104	0	30000	111%	25500
Williams	AC2030TN	1-sided, top vent, fan-type, AC power	LA 105	0	30000	111%	25500
Williams	AC2030TN	1-sided, top vent, fan-type, AC power	LA 106	0	30000	111%	25500
Williams	AC2030TN	1-sided, top vent, fan-type, AC power	LA 107	0	30000	111%	34000
Williams	AC3040TN	2-sided, top vent, fan-type, AC power	Oakland SFH	0	40000	104%	24900
Williams	TG2030TN	1-sided, top vent, fan-type, self power	Sacto 4	0	30000	105%	24600
Williams	TG2030TN	1-sided, top vent, fan-type, self power	Sacto 19 T2	0	30000	105%	24600
Williams	TG2030TN	1-sided, top vent, fan-type, self power	Sacto 19	0	30000	105%	23370
			Average	**0**	**28500**	**109%**	**25260**

Wall Furnace Performance Characteristics

Table 9 and Table 10 list performance characteristics of the baseline and retrofit wall furnaces as measured during laboratory testing. Natural gas Remember that none of the baseline furnaces used electricity, and none of the retrofit furnaces pilot lights. These values were used in equations 1, 2 and 3 to calculate annual energy use during a typical meteorological year, and equations 4 through 8 to calculate annual emissions.

Table 9: Baseline Furnace Energy Performance Characteristics

BASELINE Wall Furnace		Natural Gas Input Capacity				Thermal Efficiency		Natural Gas Output Capacity			AC Power
Model	Field Sites	Rated Input Btu/hr	Tested Input Btu/hr	% Rated Input	Pilot Btu/hr	Rated TE	Tested TE	Rated Output Btu/hr	Tested Output Btu/hr	% Rated Output	Active W
PW8G25SEN	Hayward 3	25000	20280	81%	520	70.0%	76.3%	17500	15470	88%	0
PW8G25SEN	Hayward 4	25000	20210	81%	510	70.0%	71.8%	17500	14510	83%	0
25GV-A1	LA 104	25000	25100	100%	750	70.0%	70.5%	17500	17700	101%	0
35GV-C #1	LA 105	35000	31720	91%	520	70.0%	62.8%	24500	19920	81%	0
35GV-C #2	LA 106	35000	31800	91%	570	70.0%	73.6%	24500	23400	96%	0
RMG35-IN	LA 107	35000	31810	91%	500	70.0%	75.1%	24500	23890	98%	0
5009622	Oak SF	50000	44500	89%	1090	76.0%	50.1%	38000	22290	59%	0
35S-D #1	Sacto 4	35000	31530	90%	720	50.0%	39.0%	17500	12300	70%	0
35S-D #2	Sacto 15	35000	29110	83%	710	50.0%	60.8%	17500	17700	101%	0
3509622	Sacto 19	35000	33800	97%	1050	74.0%	73.2%	25900	24740	96%	0
	Average	**33500**	**29990**	**89%**	**690**	**67.0%**	**65.3%**	**22490**	**19190**	**87%**	**0**

Table 10: Retrofit Furnace Energy Performance Characteristics

RETROFIT Wall Furnace		Natural Gas Input Capacity				Thermal Efficiency		Natural Gas Output Capacity			AC Power
Model	Field Sites	Rated Input Btu/hr	Tested Input Btu/hr	% Rated Input	Pilot Btu/hr	Rated TE	Tested TE	Rated Output Btu/hr	Tested Output Btu/hr	% Rated Output	Active W
1753012	Hayward 3	17500	19790	113%	0	94%	89.5%	16450	17710	108%	100.1
1753012	Hayward 4	17500	19790	113%	0	94%	89.5%	16450	17710	108%	100.1
AC2030TN	LA 104	30000	33180	111%	0	85%	81.5%	25500	27040	106%	12.6
AC2030TN	LA 105	30000	33180	111%	0	85%	81.5%	25500	27040	106%	12.6
AC2030TN	LA 106	30000	33180	111%	0	85%	81.5%	25500	27040	106%	12.6
AC2030TN	LA 107	30000	33180	111%	0	85%	81.5%	25500	27040	106%	12.6
AC3040TN	Oakland SFH	40000	41720	104%	0	83%	79.0%	33200	32960	99%	12.4
TG2030TN	Sacto 4	30000	31410	105%	0	82%	78.5%	24600	24660	100%	0.0
TG2030TN	Sacto 19 T2	30000	31410	105%	0	82%	78.5%	24600	24660	100%	0.0
TG2030TN	Sacto 19	30000	31410	105%	0	82%	78.5%	24600	24660	100%	0.0
	Average	**28500**	**30830**	**109%**	**0**	**85.7%**	**82.0%**	**24190**	**25050**	**104%**	**26.3**

Rated input capacity of retrofit furnaces was 85% that of baseline furnaces, at 28,500 Btu/hr versus 33,500 Btu/hr. However, tested input capacity in baseline furnaces was lower than its rated value in all except one of the baseline furnaces, averaging 89% of rated input. This capacity reduction is likely due to long-term wear and build-up of gunk in the gas valve.

Retrofit furnace input capacity was measured to be higher than its rated input for all retrofit furnaces, averaging 109% of rated input. This means that even though rated input of retrofit furnaces was lower than the baseline rated input their actual input capacity was slightly higher, at 30,830 Btu/hr retrofit versus 29,990 Btu/hr baseline, or 103% of the baseline input capacity. Keep in mind that the retrofit wall furnaces are brand new and operating at peak capacity. It is expected that their capacity will degrade after years of operation.

On average, the tested thermal efficiency of baseline furnaces was 1.7% lower than their rated TE, 67% versus 65.3%. However, baseline furnace tested TE was extremely variable compared to rated TE. Tested TE was higher than rated TE in five furnaces, within 1% of the rating in two furnaces, and lower in three furnaces. More detailed results included in the Baseline Laboratory Testing Report show that furnaces with lower thermal efficiency tended to have higher concentrations of oxygen in their flue gases, indicating that their fuel-air ratios were no longer in good control.

Tested TE was found to be lower than rated TE for all retrofit furnaces, on average 85.7% rated versus 82.0% tested, or 3.7% lower. This may have more to do with the test method than any defect in the retrofit furnaces. In the official test method, wall furnaces are supposed to be installed into a simulated wall assembly to reflect their installation within the wall cavity of homes. Laboratory testing done for this study did not use a wall assembly, so the furnaces would have lost more heat to their surroundings, lowering their measured efficiency.

However, each retrofit furnace had significantly higher TE than the baseline furnace it replaced. Average tested TE was 82.0% for retrofit furnaces compared to 65.3% for baseline furnaces, an increase of 16.7%.

The overall effects of capacity and efficiency changes are reflected in the furnace output capacity. Compared to their rated output capacity, tested output capacity of baseline furnaces varied a lot. On average, rated output capacity was 22,490 Btu/hr versus tested 19,190 Btu/hr, so baseline furnaces achieved 87% of their rated output capacity. In contrast, all retrofit furnaces had higher tested output capacity than their rated value. On average, rated output capacity was 24,190 Btu/hr versus tested 25,050 Btu/hr, so retrofit furnaces achieved 104% of their rated output capacity.

Each retrofit furnace had higher tested output capacity than the baseline furnace it replaced, on average 19,190 Btu/hr baseline versus 25,050 Btu/hr retrofit for a 34% increase in output capacity. The effect of larger capacity is investigated in more depth later in this report.

Output capacity only reflects the energy use of furnaces when they are actively heating. The baseline furnaces also used energy to keep pilot lights on while the furnaces were not heating. Pilot energy use varied from about 500 Btu/hr to 1,000 Btu/hr, and larger capacity furnaces tended to have higher pilot energy use. The significant effects of pilot lights on annual energy use are presented later in this report.

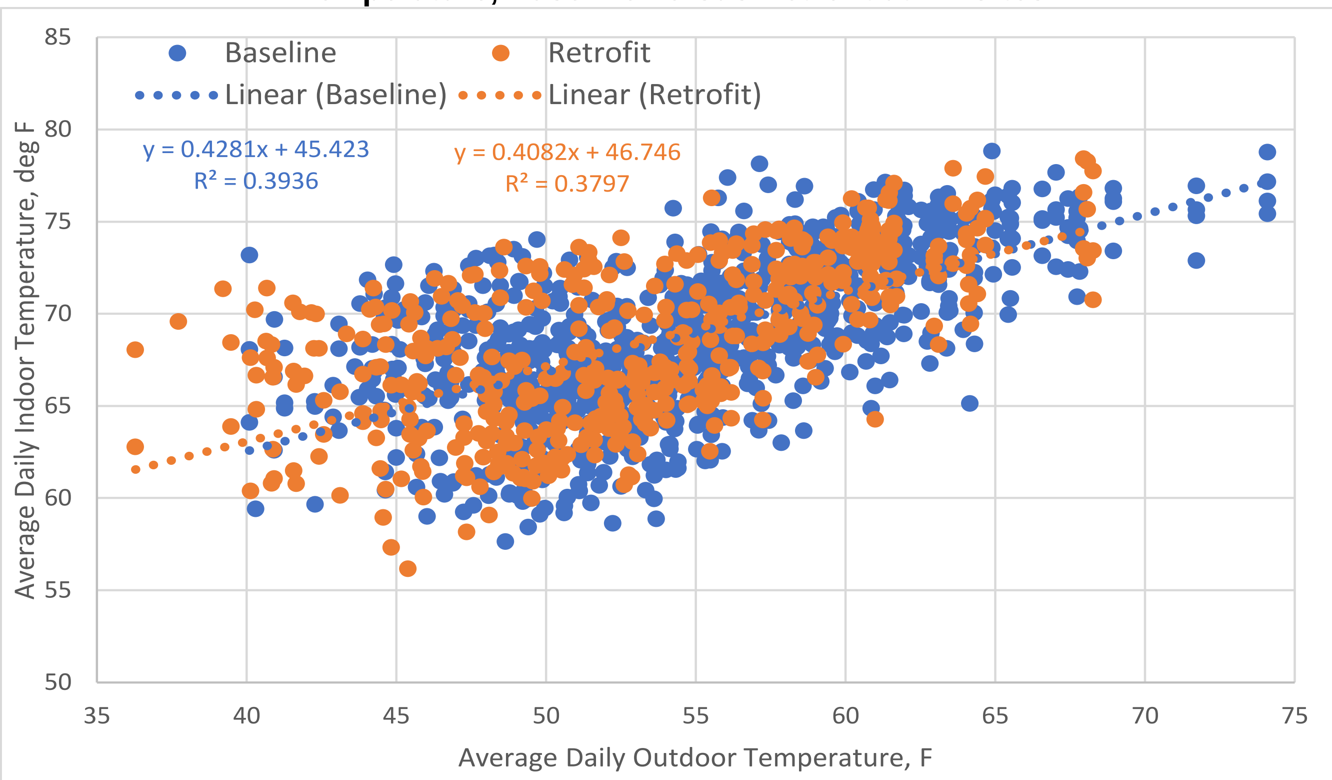
All the retrofit furnaces eliminated the use of pilot lights, replacing standing pilots with hot surface igniters that light the burner by first heating a silicon nitride ceramic probe to 2000-2500°F. Hot surface igniters draw 2 to 4 amps at 120 V as they warm, so they need a source of electrical power. The AC2030TN, AC3040TN, and 1753012 furnaces are hooked up to an AC power source either via a wall plug or a hard-wired connection. The retrofit furnaces are are all fan-type furnaces, in contrast to the baseline gravity furnaces. Electricity is used to power these retrofit furnace’s fans and their control systems. The 1753012 condensing furnace used the most power when heating at about 100 W. The AC2030TN and AC3040TN furnaces used about 12.5 W when actively heating.

The TG2030TN furnace is self-powered, instead using a battery that recharges itself when the furnace operates. This battery powers the hot surface igniter as well as the furnace fans and control system, and its reliability is a critical to the operation of this furnace.

Wall Furnace Operating Characteristics

Before investigating wall furnace operation, a comparison of indoor temperatures during the baseline and retrofit heating seasons. This check was made in order to make sure that the furnaces were providing the same approximate level of comfort. Figure 5 shows the average daily indoor temperature versus average daily outdoor temperature for baseline and retrofit sites. Regression equations for the baseline and retrofit sites are almost identical indicating comparable delivery of indoor comfort.

Figure 5: Average Daily Indoor Temperature versus Average Daily Outdoor Temperature, Baseline versus Retrofit at All Sites



Note that the indoor temperature was measured in just one spot at each site, on the wall near the furnace thermostat. Given that baseline furnaces are gravity furnaces and retrofit furnaces are fan-type furnaces, the distribution of heat throughout each space varied. This variation was not accounted for by a single indoor temperature measurement.

Operating characteristics of each furnace were investigated next. Hours of furnace use were tallied from field monitoring for every day of operation for each baseline and retrofit furnace. Hours of operation were plotted against average daily outdoor temperature for each furnace. The total length of each heating cycle for each furnace was also determined and regressed against average daily outdoor temperature. Finally, the number of cycles per day were calculated by dividing hours of furnace use by the average cycle length for each day.

Operating hours, minutes per cycle, and cycles per day are plotted versus average daily outdoor temperature in Figure 6, Figure 7, and Figure 8, and regression equations that describe operating hours and cycle length versus average daily outdoor temperature are summarized in Table 11.

Figure 6: Daily Operating Time versus Average Daily Outdoor Temperature for Baseline and Retrofit Wall Furnaces

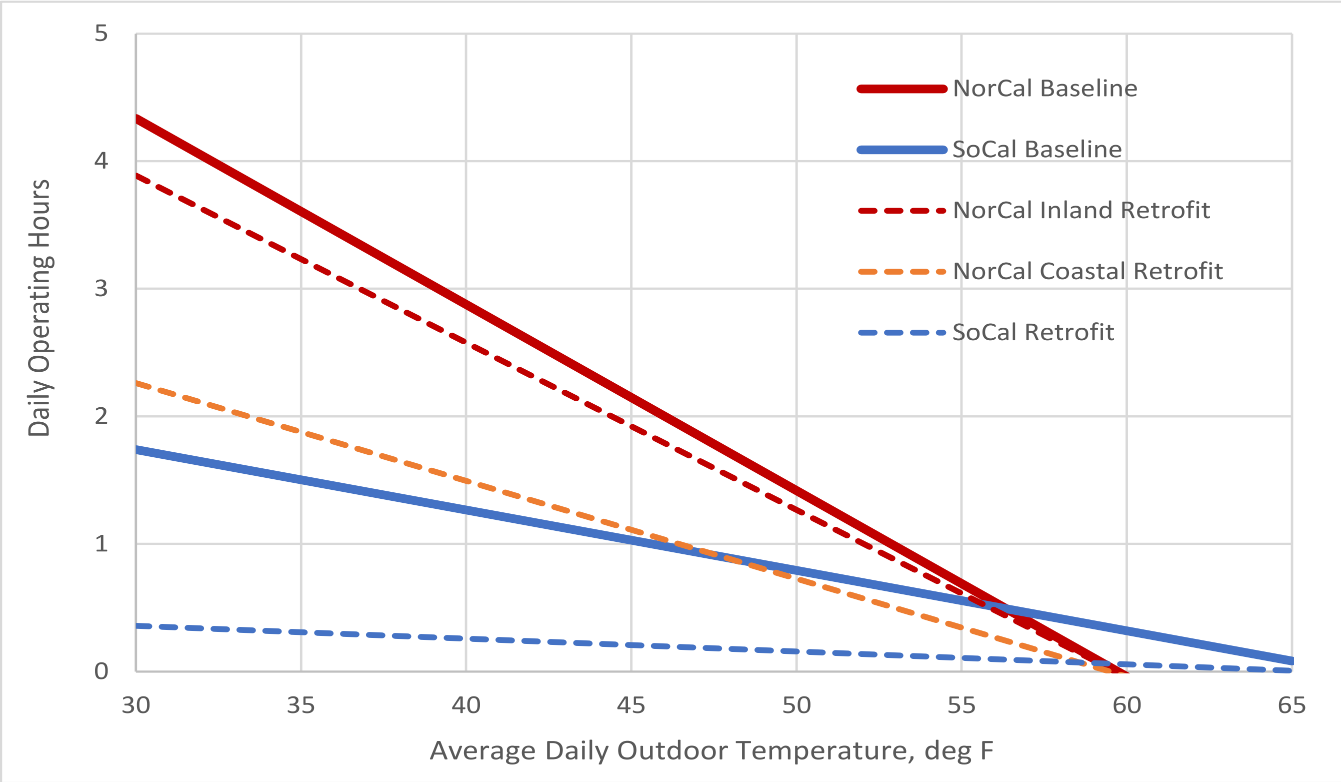


Figure 7: Cycle Length versus Average Daily Outdoor Temperature for Baseline and Retrofit Wall Furnaces

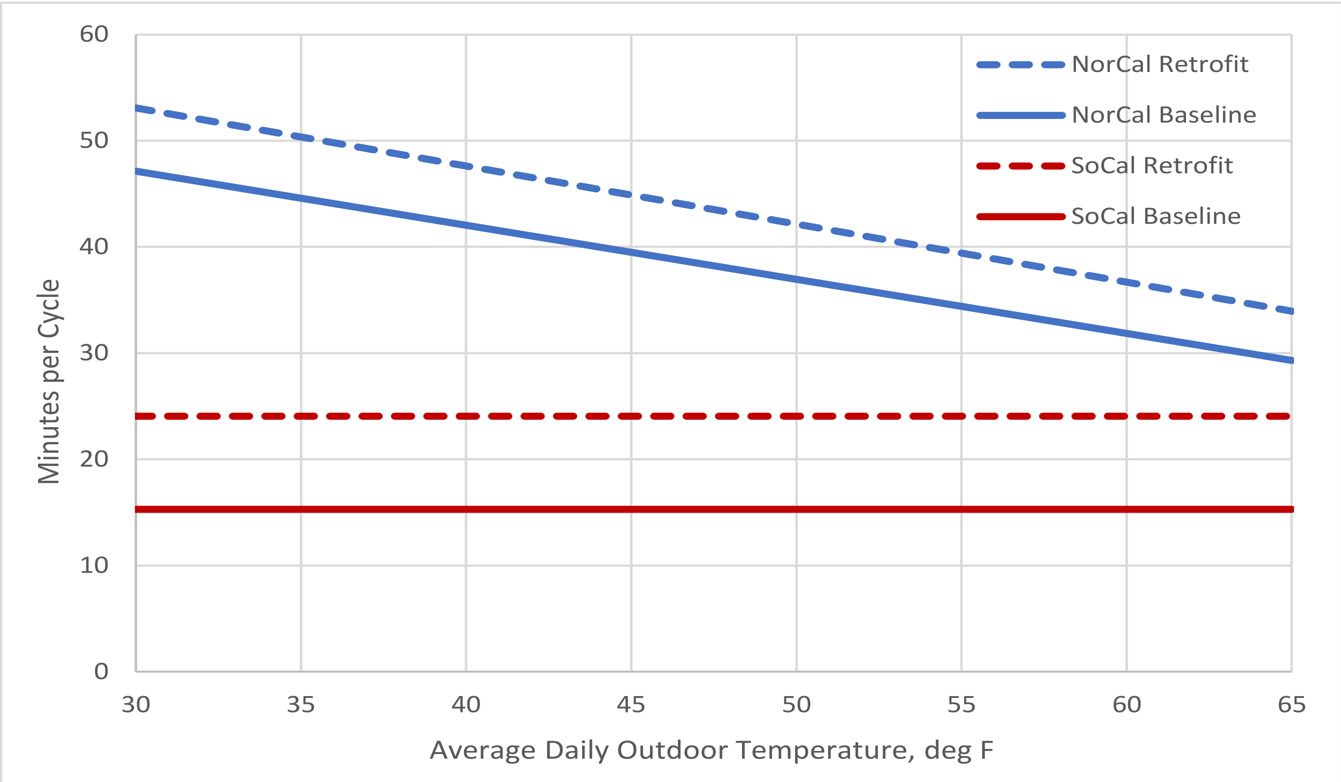


Figure 8: Cycles per Day versus Average Daily Outdoor Temperature for Baseline and Retrofit Wall Furnaces

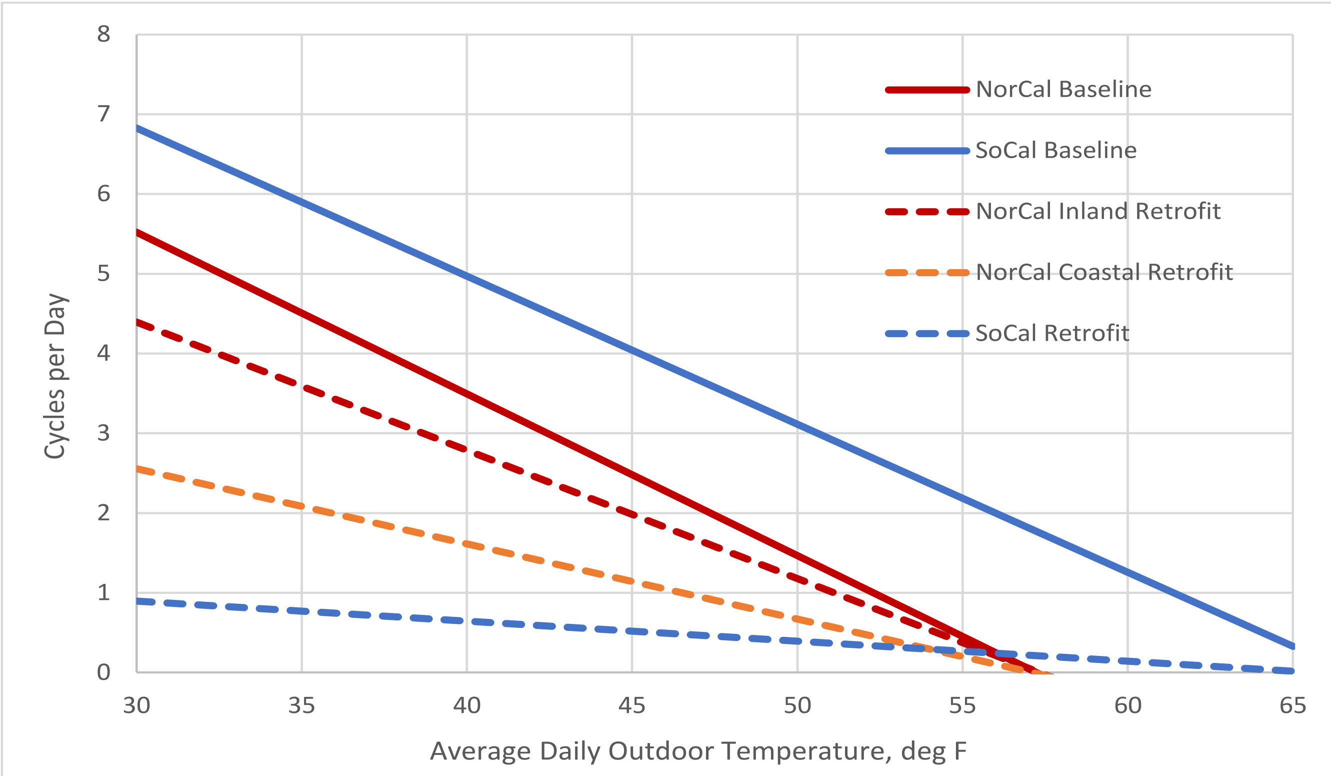


Table 11: Daily Operating Time and Cycle Length Regression Equations

Regression	Condition	NorCal Inland		NorCal Coastal		SoCal	
		y-intercept	slope	y-intercept	slope	y-intercept	slope
Daily Operating Hours vs ADOT	Baseline	**8.70**	**-0.146**	**8.70**	**-0.146**	**3.20**	**-0.0470**
	Retrofit	7.82	-0.131	4.56	-0.077	0.662	-0.0101
Daily Minutes per Cycle vs ADOT	Baseline	**62.4**	**-0.509**	**62.4**	**-0.509**	**15.3**	**0.0**
	Retrofit	69.5	-0.547	69.5	-0.547	24.1	0.0

Figure 6 shows some large decreases in operating hours. Operating hours for the Northern California Inland region, as measured in the Sacramento apartments, decreased about 20% from baseline to retrofit operation. Operating hours decreased about 50% from baseline to retrofit in the Northern California Coastal Hayward and Oakland locations, and about 90% in the Southern California Los Angeles region.

Figure 7 shows that the length of each cycle increased from baseline to retrofit furnace in both Northern and Southern California sites. Combining operating time and cycle length, Figure 8 shows that the number of furnace cycles per day decreased greatly after the furnace retrofit in Southern California locations, and decreased less dramatically in Northern California locations.

It should be noted again here that the output capacity of the retrofit furnaces was 34% bigger on average than the output capacity of the baseline furnaces, so the retrofit furnaces are able to heat the spaces they serve more quickly than the baseline furnaces. A reduction in operating hours is therefore expected if indoor temperatures were held constant, as they were found to do in Figure 5. However, this reduction in hours of use was greater than expected based on capacity changes alone.

According to feedback from occupants, there were three additional factors that contributed to a reduction in operation of the retrofit furnaces:

- First, occupants reported a lot of temperature variability when the furnaces were run at a constant setpoint. The space felt too cold before the furnace cycled on, and too hot before the furnace cycled off. The furnace controls were programmed to turn furnaces ON only after indoor temperatures were 2°F below setpoint for two minutes, and turn them OFF after indoor temperatures stayed 1°F above the thermostat setpoint for one minute. New air distribution patterns from fan-type furnaces may mean the thermostat location was also not representative of room temperature. Poor furnace ON-OFF control led to general discomfort and discouraged occupants from using the furnaces as often.
- Second, occupants also reported problems with operating the furnaces manually. The thermostat took 15 to 20 seconds just to "wake up" when occupants changed settings. Along with ON-OFF lag times, this frustration with furnace response deterred occupant furnace use.
- Third, noise levels from retrofit furnaces were higher, and were reported to be unacceptably high by two of the occupants. No sound measurements were made by the project team, but they did note that double-sided AC3040TN furnace with two supply fans was especially loud. An increase in furnace noise is inevitable when switching from a gravity furnace to a fan-type furnace, but these furnaces were loud enough when operating for occupants to limit their use.

Wall Furnace Annual Energy Use and Utility Cost Estimates

Annual energy use was estimated for all the wall furnaces based on TMY3 weather data for each field site location, and based on the actual field operating characteristics reported in Table 11. Energy use is estimated assuming the pilot light stayed lit year-round in baseline furnaces. Residential average utility rates of $19.00 per MMBtu and $0.25 per kWh are assumed to calculate annual utility cost.

ACTUAL furnace annual operation, energy use, and utility costs are reported in

Table 12, including values for baseline wall furnaces, retrofit wall furnaces, and savings. This reflects how occupants actually used the wall furnaces during field monitoring, typical weather at each location, and performance characteristics of each furnace.

AVERAGE furnace annual operation, energy use, and utility costs are reported in Table 13, including values for baseline furnaces, retrofit furnaces, and savings. These are based on operating characteristics averaged over all baseline sites and all retrofit sites. This allows comparison between individual furnaces assuming that they are all operated for the same number of hours per year. This reflects the performance characteristics of each furnace, but removes any differences due to weather or furnace operation.

Table 12: Baseline Wall Furnace TMY3 ACTUAL Annual Energy Use and Cost

BASELINE Wall Furnace Tested		ACTUAL Operation - TMY3 Annual					
Model	Field Sites	Operating hrs/year	Cycles/year	Avg Cycle Minutes	MMBtu/year	kWh/year	Utility Cost
PW8G25SEN #1	Hayward 3	330.5	568	34.9	11.086	0.0	$211
PW8G25SEN #2	Hayward 4	119.7	295	24.3	6.826	0.0	$130
25GV-A1	LA 104	21.5	127	10.2	7.093	0.0	$135
35GV-C #1	LA 105	429.1	809	31.8	17.944	0.0	$341
35GV-C #2	LA 106	143.5	643	13.4	9.475	0.0	$180
RMG35-IN	LA 107	24.8	105	14.1	5.155	0.0	$98
5009622	Oakland SF	106.1	346	18.4	14.153	0.0	$269
35S-D #1	Sacramento 4	161.5	217	44.7	11.283	0.0	$214
35S-D #2	Sacramento 15	267.9	471	34.1	13.829	0.0	$263
3509622	Sacramento 19	304.8	522	35.1	19.179	0.0	$364
	Average	**178.3**	**410**	**26.1**	**11.602**	**0.0**	**$220**

RETROFIT Wall Furnace Tested		ACTUAL Operation - TMY3 Annual					
Model	Field Sites	Operating hrs/year	Cycles/year	Avg Cycle Minutes	MMBtu/year	kWh/year	Utility Cost
1753012	Hayward 3	33.4	76	26.4	0.661	3.3	$13
1753012	Hayward 4	157.6	256	37.0	3.119	15.8	$63
AC2030TN	LA 104	27.8	117	14.2	0.922	0.3	$18
AC2030TN	LA 105	28.7	132	13.1	0.953	0.4	$18
AC2030TN	LA 106	93.1	144	38.8	3.087	1.2	$59
AC2030TN	LA 107	42.3	116	21.9	1.405	0.5	$27
AC3040TN	Oakland SFH	121.8	238	34.5	5.080	1.5	$97
TG2030TN	Sacto 4	137.0	238	34.5	4.304	0.0	$82
TG2030TN	Sacto 19 T2	285.2	268	63.9	8.959	0.0	$170
TG2030TN	Sacto 19	367.2	451	48.9	11.535	0.0	$219
	Average	**112.1**	**188**	**31.0**	**4.003**	**2.3**	**$77**

		TMY3 ACTUAL Annual Savings				
Baseline to Retrofit Description	Field Sites	Operating hrs/year	Cycles/year	MMBtu/year	kWh/year	Utility Cost
Gravity to Direct Vent Condensing	Hayward 3	297.1	491.5	10.42	-3.344	$197
Gravity to Direct Vent Condensing	Hayward 4	-37.9	39.3	3.71	-15.776	$66
Gravity to Fan-Type w/AC Power	LA 104	-6.3	9.6	6.17	-0.349	$117
Gravity to Fan-Type w/AC Power	LA 105	400.4	677.6	16.99	-0.360	$323
Gravity to Fan-Type w/AC Power	LA 106	50.5	499.2	6.39	-1.168	$121
Gravity to Fan-Type w/AC Power	LA 107	-17.6	-10.7	3.75	-0.531	$71
2-Sided Gravity to Fan-Type w/AC Power	Oakland SFH	-15.7	107.4	9.07	-1.506	$172
Gravity to Fan-Type Self-Powered	Sacto 4	24.5	-21.5	6.98	0.000	$133
Gravity to Fan-Type Self-Powered	Sacto 15 to 19 T2	-17.3	203.7	4.87	0.000	$93
Gravity to Fan-Type Self-Powered	Sacto 19	-62.5	70.7	7.64	0.000	$145
	Average	**66.2**	**222.0**	**7.60**	**-2.303**	**$144**
		37%	**54%**	**66%**		**65%**

Based on "ACTUAL" operation retrofit furnaces saved 7.6 MMBtu a year and reduced annual utility costs by $144 on average.

Table 13: Wall Furnace TMY3 AVERAGE Annual Energy Use and Cost

BASELINE Wall Furnace Tested		AVERAGE Operation - TMY3 Annual					
Model	**Field Sites**	**Operating hrs/year**	**Cycles/year**	**Avg Cycle Minutes**	**MMBtu/year**	**kWh/year**	**Utility Cost**
PW8G25SEN #1	Hayward 3	178.3	410	26.1	8.078	0.0	$153
PW8G25SEN #2	Hayward 4	178.3	410	26.1	7.980	0.0	$152
25GV-A1	LA 104	178.3	410	26.1	10.911	0.0	$207
35GV-C #1	LA 105	178.3	410	26.1	10.118	0.0	$192
35GV-C #2	LA 106	178.3	410	26.1	10.561	0.0	$201
RMG35-IN	LA 107	178.3	410	26.1	9.962	0.0	$189
5009622	Oakland SF	178.3	410	26.1	17.288	0.0	$328
35S-D #1	Sacramento 4	178.3	410	26.1	11.800	0.0	$224
35S-D #2	Sacramento 15	178.3	410	26.1	11.283	0.0	$214
3509622	Sacramento 19	178.3	410	26.1	15.037	0.0	$286
	Average	**178.3**	**410**	**26.1**	**11.302**	**0.0**	**$215**

RETROFIT Wall Furnace Tested		AVERAGE Operation - TMY3 Annual					
Model	**Field Sites**	**Operating hrs/year**	**Cycles/year**	**Avg Cycle Minutes**	**MMBtu/year**	**kWh/year**	**Utility Cost**
1753012	Hayward 3	112.1	188	31.0	2.218	11.2	$45
1753012	Hayward 4	112.1	188	31.0	2.218	11.2	$45
AC2030TN	LA 104	112.1	188	31.0	3.720	1.8	$71
AC2030TN	LA 105	112.1	188	31.0	3.720	1.8	$71
AC2030TN	LA 106	112.1	188	31.0	3.720	1.8	$71
AC2030TN	LA 107	112.1	188	31.0	3.720	1.8	$71
AC3040TN	Oakland SFH	112.1	188	31.0	4.677	1.4	$89
TG2030TN	Sacto 4	112.1	188	31.0	3.521	0.0	$67
TG2030TN	Sacto 19 T2	112.1	188	31.0	3.521	0.0	$67
TG2030TN	Sacto 19	112.1	188	31.0	3.521	0.0	$67
	Average	**112.1**	**188**	**31.0**	**3.456**	**3.1**	**$66**

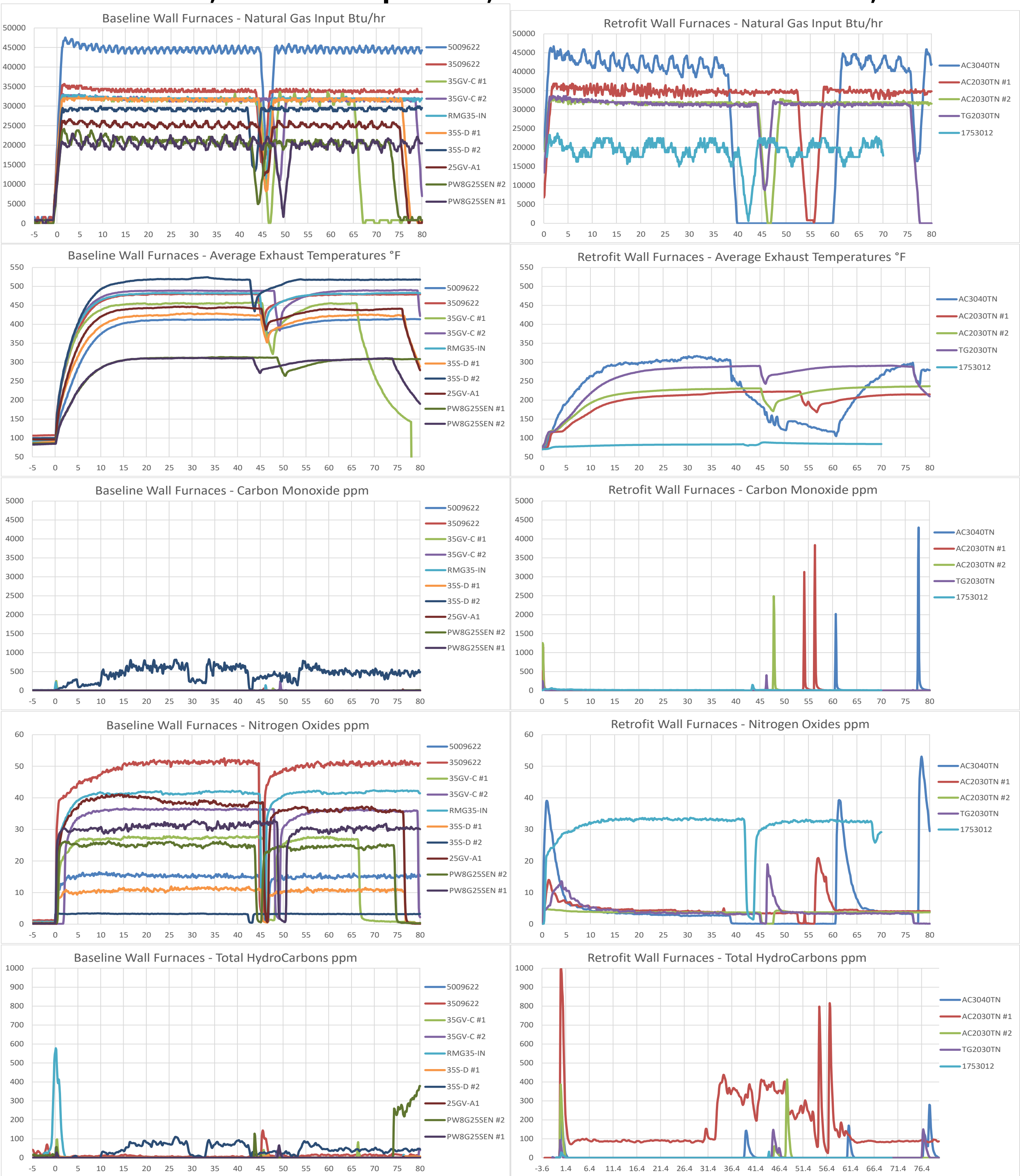
		TMY3 AVERAGE Annual Savings				
Baseline to Retrofit Description	**Field Sites**	**Operating hrs/year**	**Cycles/year**	**MMBtu/year**	**kWh/year**	**Utility Cost**
Gravity to Direct Vent Condensing	Hayward 3	66.2	222.0	5.86	-11.221	$109
Gravity to Direct Vent Condensing	Hayward 4	66.2	222.0	5.76	-11.221	$107
Gravity to Fan-Type w/AC Power	LA 104	66.2	222.0	7.19	-1.839	$136
Gravity to Fan-Type w/AC Power	LA 105	66.2	222.0	6.40	-1.839	$121
Gravity to Fan-Type w/AC Power	LA 106	66.2	222.0	6.84	-1.839	$130
Gravity to Fan-Type w/AC Power	LA 107	66.2	222.0	6.24	-1.839	$118
2-Sided Gravity to Fan-Type w/AC Power	Oakland SFH	66.2	222.0	12.61	-1.386	$239
Gravity to Fan-Type Self-Powered	Sacto 4	66.2	222.0	8.28	0.000	$157
Gravity to Fan-Type Self-Powered	Sacto 15 to 19 T2	66.2	222.0	7.76	0.000	$147
Gravity to Fan-Type Self-Powered	Sacto 19	66.2	222.0	11.52	0.000	$219
	Average	**66.2**	**222.0**	**7.85**	**-3.119**	**$148**
		37%	**54%**	**69%**		**69%**

Based on "AVERAGE" operation, retrofit furnaces saved 7.8 MMBtu a year and reduced annual utility costs by $148 on average.

Wall Furnace Annual Emissions Estimates

Laboratory testing followed a protocol where the furnaces were run through two consecutive heating cycles, allowing them to reach steady-state conditions on each cycle. Figure 9 compares laboratory test results for all baseline and retrofit wall furnaces during these tests.

Figure 9: Laboratory Test Results for Baseline & Retrofit Wall Furnaces: Natural Gas Use, Exhaust Temperature, Flue Gas Concentrations of CO, NOx & HC



Plots of natural gas use during testing show when the furnaces were on and off. Ignore the waviness of these lines, gas use was measured and recorded in pulses even though the fule use was steady. Baseline furnaces were rated for either 50,000 Btu/hr, 35,000 Btu/hr, or 25,000 Btu/hr, andaverage fuel use was about 10% lower than the rated values. Retrofit furnaces were rated for 40,000 Btu/hr, 30,000 Btu/hr, or 17,500 Btu/hr and actual fuel use was on average 10% higher than rated. Some trouble relighting the AC3040TN 40,000 Btu/hr retrofit furnace (blue line) can be seen in its fuel use and exhaust temperature.

Exhaust temperature shows when steady-state conditions were reached for each furnace. Higher exhaust temperature also indicates a wall furnace with lower thermal efficiency since more heat is being sent up the flue. The 1753012 condensing retrofit furnace (turquoise line) has very low exhaust temperature because it captures heat from exhaust gases to increase the furnace's efficiency.

Both carbon monoxide and hydrocarbon emissions generally show puffs of higher concentration at startup and shutdown of the wall furnaces which are relatively small for baseline furnaces, and distinctively higher for retrofit furnaces. There are two notable differences in the test data: 1) baseline furnace 35S-D #2's high sustained CO and HC concentrations (dark blue line) are indicative of very poor combustion; 2) retrofit furnace AC2030TN #1's high HC concentration (red line) which denotes a small natural gas leak either at the gas connection or within the unit.

While these high concentration puffs looks dramatic, it is important to remember that they do do not automatically translate to high emissions. The baseline furnaces had standing pilots with gas input rates of 500 to 1,000 Btu/hr, and retrofit furnaces had a standby gas input rate of zero (except for the leak with 1753012). This means exhaust gases are flowing very slowly, if ta all, so the actual emission rates are low at startup and shutdown.

The higher CO and HC startup and shutdown concentrations of the retrofit furnaces are notable. However, these higher concentrations are likely due to the lack of a pilot light that would burn more of the natural gas emissions during control valve opening and closing.

Emission rates were averaged from laboratory data for standby, startup, steady state, and shutdown modes of operation. Laboratory tested flue gas emission rates, in lbm/MMBtu, are listed in

Table 14, Table 15, and Table 16 for baseline furnaces and

Table 17, Table 18, and Table 19 for retrofit furnaces.

Table 14: Carbon Monoxide Emissions from Baseline Wall Furnaces

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

Table 15: Nitrogen Oxide Emissions from Baseline Wall Furnaces

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

Table 16: Total Hydrocarbon Emissions from Baseline Wall Furnaces

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

Table 17: Carbon Monoxide Emissions from Retrofit Wall Furnaces

Wall Furnace Tested		Carbon Monoxide, lbm/MMBtu			
Model	**Field Sites**	**Standby**	**Startup**	**Steady State**	**Shutdown**
1753012 (condensing direct vent)	Hayward 3 & 4	1.093	0.027	0.017	0.023
AC2030TN #1 (single-sided low NOx)	LA 104-107	0.620	0.045	0.001	3.106
AC2030TN #2 (single-sided low NOx)	LA 104-107	2.216	0.183	0.002	0.681
AC3040TN (double-sided low NOx)	Oakland SFH	0.230	0.145	0.348	0.048
TG2030TN (self-powered low NOx)	Sacto 4, 19	0.075	0.042	0.012	0.041
	Average	**0.846**	**0.088**	**0.076**	**0.780**

Table 18: Nitrogen Oxide Emissions from Retrofit Wall Furnaces

Wall Furnace Tested		Nitrogen Oxides, lbm/MMBtu			
Model	**Field Sites**	**Standby**	**Startup**	**Steady State**	**Shutdown**
1753012 (condensing direct vent)	Hayward 3 & 4	0.178	0.083	0.089	0.266
AC2030TN #1 (single-sided low NOx)	LA 104-107	0.027	0.018	0.012	0.019
AC2030TN #2 (single-sided low NOx)	LA 104-107	0.030	0.012	0.012	0.015
AC3040TN (double-sided low NOx)	Oakland SFH	0.077	0.032	0.043	0.032
TG2030TN (self-powered low NOx)	Sacto 4, 19	0.039	0.014	0.013	0.016
	Average	**0.070**	**0.031**	**0.034**	**0.069**

Table 19: Total Hydrocarbon Emissions from Retrofit Wall Furnaces

Wall Furnace Tested		Total Hydrocarbons, lbm/MMBtu			
Model	**Field Sites**	**Standby**	**Startup**	**Steady State**	**Shutdown**
1753012 (condensing direct vent)	Hayward 3 & 4	0.004	0.003	0.000	0.000
AC2030TN #1 (single-sided low NOx)	LA 104-107	0.171	0.160	0.258	1.499
AC2030TN #2 (single-sided low NOx)	LA 104-107	0.008	0.013	0.000	0.597
AC3040TN (double-sided low NOx)	Oakland SFH	0.004	0.013	0.026	1.386
TG2030TN (self-powered low NOx)	Sacto 4, 19	0.002	0.004	0.032	1.144
	Average	**0.038**	**0.038**	**0.063**	**0.925**

ACTUAL furnace annual carbon monoxide, nitrogen oxides, and total hydrocarbon emissions are reported in

Table 20 for baseline wall furnaces, retrofit furnaces, and the savings from retrofits. This data reflects how occupants actually used the wall furnaces during field monitoring, typical weather at each location, and performance characteristics of each furnace. ACTUAL carbon monoxide emissions are estimated to decrease on average by 2.33 pounds per year or 89%; nitrogen oxides emissions decreased by 0.65 pounds per year or 88%; and total hycrocarbon emissions decreased by 1.09 pounds per year or 92%.

Table 20: Wall Furnace TMY3 ACTUAL Annual Emissions

BASELINE Wall Furnace Tested		ACTUAL Operation - TMY3 Annual					
Model	Field Sites	Operating hrs/year	Cycles/year	Avg Cycle Minutes	CO lbm/year	NOx lbm/year	THC lbm/year
PW8G25SEN #1	Hayward 3	330.5	568	34.9	2.04	0.91	0.58
PW8G25SEN #2	Hayward 4	119.7	295	24.3	0.36	0.39	2.19
25GV-A1	LA 104	21.5	127	10.2	1.66	0.12	3.66
35GV-C #1	LA 105	429.1	809	31.8	1.39	1.53	0.10
35GV-C #2	LA 106	143.5	643	13.4	0.57	0.54	0.00
RMG35-IN	LA 107	24.8	105	14.1	0.81	0.27	1.98
5009622	Oakland SF	106.1	346	18.4	7.68	0.89	0.08
35S-D #1	Sacramento 4	161.5	217	44.7	1.05	0.73	0.04
35S-D #2	Sacramento 15	267.9	471	34.1	9.49	0.28	0.47
3509622	Sacramento 19	304.8	522	35.1	1.12	1.78	2.73
	Average	**178.3**	**410**	**26.1**	**2.61**	**0.74**	**1.18**

RETROFIT Wall Furnace Tested		ACTUAL Operation - TMY3 Annual					
Model	Field Sites	Operating hrs/year	Cycles/year	Avg Cycle Minutes	CO lbm/year	NOx lbm/year	THC lbm/year
1753012	Hayward 3	33.4	76	26.4	0.01	0.05	0.00
1753012	Hayward 4	157.6	256	37.0	0.06	0.24	0.00
AC2030TN	LA 104	27.8	117	14.2	0.10	0.01	0.07
AC2030TN	LA 105	28.7	132	13.1	0.10	0.01	0.08
AC2030TN	LA 106	93.1	144	38.8	0.23	0.04	0.25
AC2030TN	LA 107	42.3	116	21.9	0.16	0.02	0.12
AC3040TN	Oakland SFH	121.8	238	34.5	1.45	0.22	0.10
TG2030TN	Sacto 4	137.0	238	34.5	0.15	0.06	0.02
TG2030TN	Sacto 19 T2	285.2	268	63.9	0.22	0.12	0.14
TG2030TN	Sacto 19	367.2	451	48.9	0.33	0.15	0.12
	Average	**112.1**	**188**	**31.0**	**0.28**	**0.09**	**0.09**

		TMY3 ACTUAL Annual Savings				
Baseline to Retrofit Description	Field Sites	Operating hrs/year	Cycles/year	CO lbm/year	NOx lbm/year	THC lbm/year
Gravity to Direct Vent Condensing	Hayward 3	297.1	491.5	2.02	0.86	0.58
Gravity to Direct Vent Condensing	Hayward 4	-37.9	39.3	0.30	0.15	2.19
Gravity to Fan-Type w/AC Power	LA 104	-6.3	9.6	1.56	0.11	3.58
Gravity to Fan-Type w/AC Power	LA 105	400.4	677.6	1.29	1.52	0.02
Gravity to Fan-Type w/AC Power	LA 106	50.5	499.2	0.34	0.50	-0.25
Gravity to Fan-Type w/AC Power	LA 107	-17.6	-10.7	0.65	0.25	1.85
2-Sided Gravity to Fan-Type w/AC Power	Oakland SFH	-15.7	107.4	6.23	0.68	-0.02
Gravity to Fan-Type Self-Powered	Sacto 4	24.5	-21.5	0.89	0.68	0.02
Gravity to Fan-Type Self-Powered	Sacto 15 to 19 T2	-17.3	203.7	9.27	0.16	0.32
Gravity to Fan-Type Self-Powered	Sacto 19	-62.5	70.7	0.79	1.63	2.61
	Average	**66.2**	**222.0**	**2.33**	**0.65**	**1.09**
		37%	**54%**	**89%**	**88%**	**92%**

AVERAGE furnace annual carbon monoxide, nitrogen oxides, and total hydrocarbon emissions are reported in Table 21 for furnaces based on operating characteristics averaged over all baseline sites and all retrofit sites.This reflects the performance characteristics and weather for each furnace, but removes any differences due furnace operation. AVERAGE carbon monoxide emissions of retrofit furnace are estimated to decrease on average from baseline emissions by 1.96 pounds per year or 88%; nitrogen oxides emissions decreased by 0.69 pounds per year or 94%; and total hycrocarbon emissions decreased by 1.09 pounds per year or 90%

Table 21: Wall Furnace TMY3 AVERAGE Annual Emissions

BASELINE Wall Furnace Tested		AVERAGE Operation - TMY3 Annual					
Model	Field Sites	Operating hrs/year	Cycles/year	Avg Cycle Minutes	CO lbm/year	NOx lbm/year	THC lbm/year
PW8G25SEN #1	Hayward 3	178.3	410	26.1	2.06	0.59	0.58
PW8G25SEN #2	Hayward 4	178.3	410	26.1	0.36	0.55	2.57
25GV-A1	LA 104	178.3	410	26.1	1.64	0.54	3.60
35GV-C #1	LA 105	178.3	410	26.1	1.05	0.71	0.06
35GV-C #2	LA 106	178.3	410	26.1	0.56	0.62	0.00
RMG35-IN	LA 107	178.3	410	26.1	0.84	0.71	2.03
5009622	Oakland SF	178.3	410	26.1	7.63	1.27	0.12
35S-D #1	Sacramento 4	178.3	410	26.1	1.05	0.78	0.06
35S-D #2	Sacramento 15	178.3	410	26.1	5.97	0.25	0.29
3509622	Sacramento 19	178.3	410	26.1	1.12	1.26	2.71
	Average	**178.3**	**410**	**26.1**	**2.23**	**0.73**	**1.20**

RETROFIT Wall Furnace Tested		AVERAGE Operation - TMY3 Annual					
Model	Field Sites	Operating hrs/year	Cycles/year	Avg Cycle Minutes	CO lbm/year	NOx lbm/year	THC lbm/year
1753012	Hayward 3	112.1	188	31.0	0.04	0.15	0.00
1753012	Hayward 4	112.1	188	31.0	0.04	0.15	0.00
AC2030TN	LA 104	112.1	188	31.0	0.30	0.04	0.25
AC2030TN	LA 105	112.1	188	31.0	0.30	0.04	0.25
AC2030TN	LA 106	112.1	188	31.0	0.30	0.04	0.25
AC2030TN	LA 107	112.1	188	31.0	0.33	0.05	0.28
AC3040TN	Oakland SFH	112.1	188	31.0	0.99	0.15	0.07
TG2030TN	Sacto 4	112.1	188	31.0	0.12	0.04	0.01
TG2030TN	Sacto 19 T2	112.1	188	31.0	0.12	0.04	0.01
TG2030TN	Sacto 19	112.1	188	31.0	0.12	0.04	0.01
	Average	**112.1**	**188**	**31.0**	**0.27**	**0.07**	**0.12**

		TMY3 AVERAGE Annual Savings				
Baseline to Retrofit Description	Field Sites	Operating hrs/year	Cycles/year	CO lbm/year	NOx lbm/year	THC lbm/year
Gravity to Direct Vent Condensing	Hayward 3	66.2	222.0	2.03	0.45	0.58
Gravity to Direct Vent Condensing	Hayward 4	66.2	222.0	0.33	0.40	2.57
Gravity to Fan-Type w/AC Power	LA 104	66.2	222.0	1.34	0.50	3.34
Gravity to Fan-Type w/AC Power	LA 105	66.2	222.0	0.75	0.67	-0.19
Gravity to Fan-Type w/AC Power	LA 106	66.2	222.0	0.25	0.58	-0.25
Gravity to Fan-Type w/AC Power	LA 107	66.2	222.0	0.51	0.66	1.75
2-Sided Gravity to Fan-Type w/AC Power	Oakland SFH	66.2	222.0	6.64	1.22	0.05
Gravity to Fan-Type Self-Powered	Sacto 4	66.2	222.0	0.93	0.63	0.04
Gravity to Fan-Type Self-Powered	Sacto 15 to 19 T2	66.2	222.0	5.86	0.20	0.28
Gravity to Fan-Type Self-Powered	Sacto 19	66.2	222.0	1.01	1.22	2.70
	Average	**66.2**	**222.0**	**1.96**	**0.69**	**1.09**
		37%	**54%**	**88%**	**94%**	**90%**

Effect of Standing Pilot Operation

Energy and emissions estimates for baseline furnaces made previously in this report assumed that the standing pilot was left on all year at all sites. Here we estimate the energy and emissions savings that would happen if the pilot was shut off for six months of the year when the furnace was not needed for heat.

Table 22, Table 23, andTable 24 show that urning off the pilot on baseline furnaces reduces annual natural gas use by 3.08 MMBtu or 26% and saves $58 a year, while installing retrofit furnaces reduces natural gas use by 8.18 MMBtu or 70% and saves $155 a year.

Table 22: Baseline Wall Furnace Energy Use with Pilot On All Year

BASELINE WALL FURNACES						Pilot on All Year			
Manufacturer	Model	Field Sites	Operating hrs/year	Input Btu/hr	Pilot Btu/hr	Total MMBtu/year	Heating %	Pilot %	Annual Energy Cost
Perfection Products	PW8G25SEN #1	Hayward 3	330.5	20,280	520	11.09	60%	40%	$211
Perfection Products	PW8G25SEN #2	Hayward 4	119.7	20,210	510	6.83	35%	65%	$130
Williams	25GV-A1	LA 104	21.5	25,100	750	7.09	8%	92%	$135
Williams	35GV-C #1	LA 105	429.1	31,720	520	17.94	76%	24%	$341
Williams	35GV-C #2	LA 106	143.5	31,800	570	9.48	48%	52%	$180
Williams	RMG35-IN	LA 107	24.8	31,810	500	5.16	15%	85%	$98
Williams	5009622	Oakland SF	106.1	44,500	1090	14.15	33%	67%	$269
Holly General	35S-D #1	Sacramento 4	161.5	31,530	720	11.28	45%	55%	$214
Holly General	35S-D #2	Sacramento 15	267.9	29,110	710	13.83	56%	44%	$263
Williams	3509622	Sacramento 19	304.8	33,800	1050	19.18	54%	46%	$364
		Baseline Average	**190.9**	**29,990**	**690**	**11.64**	**49%**	**51%**	**$221**

Table 23: Baseline Wall Furnace Energy Use with Pilot On Half the Year

BASELINE WALL FURNACES						Pilot on for Half the Year			
Manufacturer	Model	Field Sites	Operating hrs/year	Input Btu/hr	Pilot Btu/hr	Total MMBtu/year	Heating %	Pilot %	Annual Energy Cost
Perfection Products	PW8G25SEN #1	Hayward 3	330.5	20,280	520	8.81	76%	24%	$167
Perfection Products	PW8G25SEN #2	Hayward 4	119.7	20,210	510	4.59	53%	47%	$87
Williams	25GV-A1	LA 104	21.5	25,100	750	3.81	14%	86%	$72
Williams	35GV-C #1	LA 105	429.1	31,720	520	15.67	87%	13%	$298
Williams	35GV-C #2	LA 106	143.5	31,800	570	6.98	65%	35%	$133
Williams	RMG35-IN	LA 107	24.8	31,810	500	2.97	27%	73%	$56
Williams	5009622	Oakland SF	106.1	44,500	1090	9.38	50%	50%	$178
Holly General	35S-D #1	Sacramento 4	161.5	31,530	720	8.13	63%	37%	$154
Holly General	35S-D #2	Sacramento 15	267.9	29,110	710	10.72	73%	27%	$204
Williams	3509622	Sacramento 19	304.8	33,800	1050	14.58	71%	29%	$277
		Baseline Average	**190.9**	**29,990**	**690**	**8.56**	**67%**	**34%**	**$163**

Table 24: Retrofit Wall Furnace Energy Use with No Standing Pilot

Retrofit WALL FURNACES						No Standing Pilot			
Manufacturer	Model	Field Sites	Operating hrs/year	Input Btu/hr	Pilot Btu/hr	Total MMBtu/year	Heating %	Pilot %	Annual Energy Cost
Williams	1753012	Hayward 3	33.4	19,790	-	0.66	100%	0%	$13
Williams	1753012	Hayward 4	157.6	19,790	-	3.12	100%	0%	$63
Williams	AC2030TN	LA 104	27.8	33,180	-	0.92	100%	0%	$18
Williams	AC2030TN	LA 105	28.7	33,180	-	0.95	100%	0%	$18
Williams	AC2030TN	LA 106	93.1	33,180	-	3.09	100%	0%	$59
Williams	AC2030TN	LA 107	42.3	33,180	-	1.40	100%	0%	$27
Williams	AC3040TN	Oakland SFH	121.8	41,720	-	5.08	100%	0%	$97
Williams	TG2030TN	Sacramento 4	137.0	31,410	-	4.30	100%	0%	$82
Williams	TG2030TN	Sacramento 19 T2	285.2	31,410	-	8.96	100%	0%	$170
Williams	TG2030TN	Sacramento 19	367.2	31,410	-	11.53	100%	0%	$219
		Retrofit Average	**112.1**	**30,830**	**-**	**3.46**	100%	**0%**	**$66**

Table 25, Table 26, and Table 27 show that turning off the pilot for half the year on baseline furnaces reduces reduces carbon monoxide, nitrogen oxides, and total hydrocarbon emissions by 31%, 13%, and 45% respectively, but replacing baseline furnaces with retrofit furnaces reduces all emissions by about 90%.

Table 25: Baseline Wall Furnace Emissions with Pilot On All Year

BASELINE Wall Furnace Tested			ACTUAL Operation - TMY3 Annual			Pilot on All Year		
Manufacturer	Model	Field Sites	Operating hrs/year	Cycles/year	Avg Cycle Minutes	CO lbm/year	NOx lbm/year	THC lbm/year
Perfection Products	PW8G25SEN #	Hayward 3	330.5	567.5	34.9	2.04	0.91	0.58
Perfection Products	PW8G25SEN #	Hayward 4	119.7	295.1	24.3	0.36	0.39	2.19
Williams	25GV-A1	LA 104	21.5	126.8	10.2	1.66	0.12	3.66
Williams	35GV-C #1	LA 105	429.1	809.4	31.8	1.39	1.53	0.10
Williams	35GV-C #2	LA 106	143.5	643.0	13.4	0.57	0.54	0.00
Williams	RMG35-IN	LA 107	24.8	105.4	14.1	0.81	0.27	1.98
Williams	5009622	Oakland SF	106.1	345.6	18.4	7.68	0.89	0.08
Holly General	35S-D #1	Sacramento 4	161.5	216.7	44.7	1.05	0.73	0.04
Holly General	35S-D #2	Sacramento 15	267.9	471.3	34.1	9.49	0.28	0.47
Williams	3509622	Sacramento 19	304.8	521.6	35.1	1.12	1.78	2.73
		Average	**190.9**	**410.2**	**27.9**	**2.61**	**0.74**	**1.18**

Table 26: Baseline Wall Furnace Emissions with Pilot On Half the Year

BASELINE Wall Furnace Tested			ACTUAL Operation - TMY3 Annual			Pilot on for Half the Year		
Manufacturer	Model	Field Sites	Operating hrs/year	Cycles/year	Avg Cycle Minutes	CO lbm/year	NOx lbm/year	THC lbm/year
Perfection Products	PW8G25SEN #1	Hayward 3	330.5	567.5	34.9	1.00	0.96	0.30
Perfection Products	PW8G25SEN #2	Hayward 4	119.7	295.1	24.3	0.18	0.34	1.34
Williams	25GV-A1	LA 104	21.5	126.8	10.2	0.83	0.09	1.82
Williams	35GV-C #1	LA 105	429.1	809.4	31.8	0.96	1.45	0.07
Williams	35GV-C #2	LA 106	143.5	643.0	13.4	0.31	0.46	0.00
Williams	RMG35-IN	LA 107	24.8	105.4	14.1	0.41	0.17	1.00
Williams	5009622	Oakland SF	106.1	345.6	18.4	3.81	0.72	0.08
Holly General	35S-D #1	Sacramento 4	161.5	216.7	44.7	0.52	0.62	0.04
Holly General	35S-D #2	Sacramento 15	267.9	471.3	34.1	9.49	0.19	0.47
Williams	3509622	Sacramento 19	304.8	521.6	35.1	0.56	1.51	1.41
		Average	**190.9**	**410.2**	**27.9**	**1.81**	**0.65**	**0.65**

Table 27: Retrofit Wall Furnace Emissions with No Standing Pilot

RETROFIT Wall Furnace Tested			ACTUAL Operation - TMY3 Annual			No Standing Pilot		
Manufacturer	Model	Field Sites	Operating hrs/year	Cycles/year	Avg Cycle Minutes	CO lbm/year	NOx lbm/year	THC lbm/year
Williams	1753012	Hayward 3	33.4	76.0	26.4	0.01	0.05	0.00
Williams	1753012	Hayward 4	157.6	255.8	37.0	0.06	0.24	0.00
Williams	AC2030TN	LA 104	27.8	117.2	14.2	0.10	0.01	0.07
Williams	AC2030TN	LA 105	28.7	131.7	13.1	0.10	0.01	0.08
Williams	AC2030TN	LA 106	93.1	143.8	38.8	0.23	0.04	0.25
Williams	AC2030TN	LA 107	42.3	116.1	21.9	0.16	0.02	0.12
Williams	AC3040TN	Oakland SFH	121.8	238.1	34.5	1.45	0.22	0.10
Williams	TG2030TN	Sacto 4	137.0	238.1	34.5	0.15	0.06	0.02
Williams	TG2030TN	Sacto 19 T2	285.2	267.7	63.9	0.22	0.12	0.14
Williams	TG2030TN	Sacto 19	367.2	450.9	48.9	0.33	0.15	0.12
		Average	**112.1**	**188.2**	**31.0**	**0.28**	**0.09**	**0.09**

Indoor Air Quality Improvements from Retrofit Furnaces

Concentrations of carbon monoxide, nitrogen oxides, and particulate matter were recorded at all sites during field monitoring of furnace and retrofit furnaces. Table 28 and Table 29 show overall average and maximum IAQ concentations for all furnaces while they were on and actively heating as well as when the furnaces were off between heating cycles.

Table 28: Average IAQ Concentrations
Baseline and Retrofit Furnaces Off and On

AVERAGES Field Site	CO Off ppmx10	CO On ppmx10	NOx Off ppb/10	NOx On ppb/10	PM2.5 Off ug/m3	PM2.5 On ug/m3	PM10 Off ug/m3	PM10 On ug/m3
Hayward 3	23.5	23.4	32.3	30.9	6.0	3.0	6.5	0.1
Hayward 4	9.8	12.4	22.0	23.1	5.9	3.1	6.5	3.2
LA 104	17.7	43.3	24.8	45.2	10.9	5.1	9.7	4.7
LA 105	24.2	23.9	2.8	3.7	26.3	33.8	29.3	36.8
LA 106	17.3	16.5	1.3	2.0	15.5	21.7	17.5	23.6
LA 107	31.2	31.4	26.2	24.5	12.8	13.3	15.0	38.0
Oak SF	4.2	5.5	5.3	3.3	5.7	9.4	6.2	10.1
Sacto 4	10.4	10.8	49.4	47.7	33.1	28.4	37.1	31.0
Sacto 15	9.3	10.8	1.8	2.4	10.2	9.1	10.3	9.1
Sacto 19	9.1	10.9	7.9	7.5	25.5	28.0	26.5	28.8
AVERAGES Field Site	**CO Off ppmx10**	**CO On ppmx10**	**NOx Off ppb/10**	**NOx On ppb/10**	**PM2.5 Off ug/m3**	**PM2.5 On ug/m3**	**PM10 Off ug/m3**	**PM10 On ug/m3**
Hayward 3	11.6	12.2	31.4	33.7	29.4	21.1	36.0	25.2
Hayward 4	8.6	10.4	22.1	17.3	11.6	7.7	13.1	8.0
LA 104	14.3	0.0	58.5	23.8	6.7	2.2	7.5	2.5
LA 105	12.3	0.0	8.2	1.0	39.6	57.7	44.6	65.0
LA 106	13.4	16.6	25.3	29.3	11.5	13.0	12.8	14.3
LA 107	29.4	0.0	23.3	1.7	9.5	2.5	12.9	3.7
Oak SF	2.1	2.8	7.1	7.3	20.4	20.9	23.3	23.6
Sacto 4	12.5	15.3	49.9	54.1	29.7	26.9	33.4	29.7
Sacto 19	41.7	63.6	10.0	9.6	37.8	37.8	38.4	38.4
Sacto 19 T2	13.7	15.6	10.7	10.3	19.9	13.6	20.0	13.7
Average IAQ Concentrations	**CO Off ppmx10**	**CO On ppmx10**	**NOx Off ppb/10**	**NOx On ppb/10**	**PM2.5 Off ug/m3**	**PM2.5 On ug/m3**	**PM10 Off ug/m3**	**PM10 On ug/m3**
Baseline Average	15.7	18.9	17.4	19.0	15.2	15.5	16.5	18.5
Retrofit Average	15.9	13.6	24.7	18.8	21.6	20.4	24.2	22.4
Reduction	-0.3	5.2	-7.3	0.2	-6.4	-4.9	-7.7	-3.9
% Reduction	-2%	28%	-42%	1%	-42%	-31%	-47%	-21%
Comparative Limit	50-150 ppmx10 inside properly adjusted (US EPA)		3.0 ppb/10 24 hour outside (CAAQS)		35 ug/m3 24 hour outside (NAAQS)		50 ug/m3 24 hour outside (CAAQS)	

Average IAQ concentrations increase about 10% when the baseline furnace was ON versus when it was OFF, and decrease about 13% when the retrofit furnace was ON versus OFF. Except for carbon monoxide and nitrogen oxides when the furnace was ON, IAQ pollutant concentrations were 20% to 40% higher with the retrofit furnace than with the baseline furnace.

Table 29: Maximum IAQ Concentrations
Baseline and Retrofit Furnaces Off and On

MAXIMUMS Baseline	CO Off ppmx10	CO On ppmx10	NOx Off ppb/10	NOx On ppb/10	PM2.5 Off ug/m3	PM2.5 On ug/m3	PM10 Off ug/m3	PM10 On ug/m3
Hayward 3	49.1	34.1	93.3	57.2	106.3	9.6	112.1	0.1
Hayward 4	43.2	20.1	61.7	29.6	132.0	7.9	151.2	8.2
LA 104	84.9	47.4	117.8	48.0	62.2	5.9	52.1	5.4
LA 105	24.2	23.9	2.8	3.7	26.3	33.8	29.3	36.8
LA 106	104.7	25.3	9.9	2.9	197.4	33.6	221.6	36.6
LA 107	50.9	31.4	67.2	24.5	22.5	13.3	83.4	38.0
Oak SF	12.5	7.4	26.4	7.5	44.3	29.6	48.7	31.1
Sacto 4	30.0	17.5	138.5	74.2	353.7	91.2	403.6	100.3
Sacto 15	29.9	19.5	6.5	4.1	119.9	25.3	121.0	25.5
Sacto 19	26.4	18.8	24.3	13.3	277.8	108.5	306.3	112.2
MAXIMUMS Retrofit	**CO Off ppmx10**	**CO On ppmx10**	**NOx Off ppb/10**	**NOx On ppb/10**	**PM2.5 Off ug/m3**	**PM2.5 On ug/m3**	**PM10 Off ug/m3**	**PM10 On ug/m3**
Hayward 3	133.0	12.5	74.9	34.3	336.4	21.8	456.0	26.0
Hayward 4	37.5	12.5	49.6	20.3	195.3	12.3	224.6	12.7
LA 104	34.1	0.0	110.8	23.8	17.7	2.2	19.5	2.5
LA 105	41.7	0.0	31.6	1.0	294.0	58.3	331.5	65.7
LA 106	59.5	16.9	63.8	30.8	62.6	13.3	69.2	14.6
LA 107	67.2	0.0	69.0	1.7	69.9	2.5	92.2	3.7
Oak SF	9.0	3.6	15.9	9.4	76.8	29.5	87.7	33.9
Sacto 4	29.0	19.3	122.5	72.8	226.8	46.5	255.6	51.7
Sacto 19	260.3	205.6	24.1	16.5	330.2	129.7	337.3	132.5
Sacto 19 T2	35.8	24.5	26.0	13.1	244.2	29.4	244.2	29.4

Maximum IAQ concentrations were found in previous analysis to be lower while the furnace was ON than when it was OFF for both baseline and retrofit furnaces. Indoor pollutants may originate from the wall furnaces and/or from indoor ranges or water heaters. It is theorized that furnace operation removes indoor pollutants by pulling room air for combustion.

Indoor pollutant concentrations for retrofit furnaces tend to be slightly lower than baseline furnace concentrations when the furnaces are ON. Indoor pollutant concentrations are higher in retrofit furnaces when the furnaces are OFF. It is possible that pilot operation in baseline furnaces helps to remove indoor pollution by pulling in some room air for combustion.

Retrofit Wall Furnace Cost-Benefit Analysis

A survey of the wall furnaces and their costs was carried out by checking online specifications and list prices. The list price or estimated price was multiplied by 1.10 to estimate added taxes and then rounded to the nearest $10. Figure 10 shows the cost of the full range of wall furnaces available from the primary manufacturer, Williams Comfort Products. Bars in orange are the retrofit furnaces installed in this project, with bars in red designated as the comparable standard replacement wall furnace. Table 30 includes additional details about the retrofit and standard furnaces, installation costs, and the total incremental cost for retrofit furnaces.

Figure 10: Wall Furnace Characteristics and Costs
(top to bottom: thermal efficiency, input Btu/hr, distribution type, sides, combustion air)

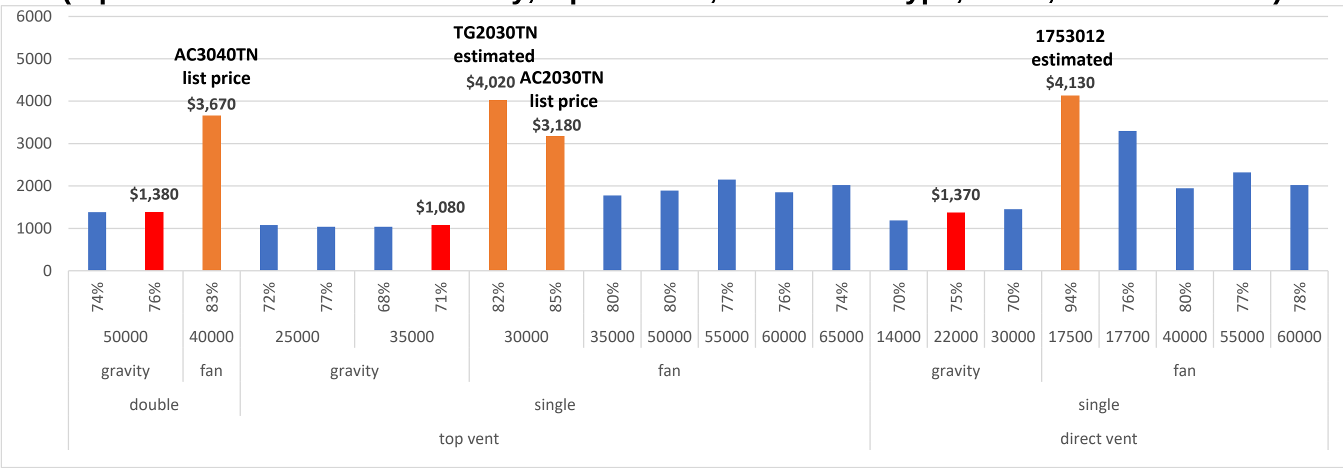


Table 30: Wall Furnace Detailed Characteristics and Costs

Advanced Wall Furnace	Standard Wall Furnace	Installation Cost	Incremental Cost
AC2030TN top vent, single-sided, fan-type, 30,000 Btu/hr input, 85% thermal efficiency, AC power **$3,180** (list x 1.1)	**3509822** top vent, single-sided, gravity, 35,000 Btu/hr input, 71% thermal efficiency, No power needed **$1,080** (list x 1.1)	Retrofit and standard installation costs assumed to be equal	$3,180 - $1,080 = **$2,100**
AC3040TN top vent, double-sided, fan-type, 40,000 Btu/hr input, 83% thermal efficiency, AC power **$3,670** (list x 1.1)	**5009622** top vent, single-sided, gravity, 50,000 Btu/hr input, 74% thermal efficiency, No power needed **$1,380** (list x 1.1)	Retrofit and standard installation costs assumed to be equal	$3,670- $1,380 = **$2,290**
TG2030TN top vent, single-sided, fan-type, 30,000 Btu/hr input, 82% thermal efficiency, Self-charging battery **$4,020** (estimated x 1.1)	**3509822** top vent, single-sided, gravity, 35,000 Btu/hr input, 71% thermal efficiency, No power needed **$1,080** (list x 1.1)	Retrofit and standard installation costs assumed to be equal	$4,020 - $1,080 = **$2,940**
1753012 direct vent, single-sided, fan-type, 17,500 Btu/hr input, 94% thermal efficiency, condensing **$4,130** (estimated x 1.1)	**2203822** direct vent, single-sided, gravity, 22,000 Btu/hr input, 75% thermal efficiency, non-condensing **$1,370** (list x 1.1)	Extra $150 assumed for installing condensate drain	$4,130 - $1,370 + $150= **$2,910**

Two of the furnaces tested in this study are not yet available on the market, and list prices could not be found. Costs were estimated for the TG2030TN and 1753012 furnaces based on other furnace prices with additions for different furnace features.

It is assumed that retrofit furnaces are to replace an already existing furnace of equal size and shape. This means the AC2030TN, AC3040TN, and TG2030TN furnaces would get installed into an existing cavity on an interior wall. Installation into a different sized wall cavity could include extra costs for patching and repairing drywall.

Installation of a replacement wall furnace often includes various extra that would be done whether the replacement furnace is standard or advanced. Most common extras include replacement of the exhaust flue and repair of the flashing around the exhaust flue where it exits the roof.

The AC2030TN, AC2040TN, and 1753012 furnaces also required a source of AC power. AC power can be accessed by plugging the included cord into a wall outlet, although the furnaces could also be hard-wired to power with some additional labor from an electrician. This study assumes that furnaces can be plugged into a wall socket at no additional cost.

The 1753012 direct vent condensing furnace is assumed to be installed in place of an existing direct vent furnace on an outside wall. The only additional cost assumed for this furnace installation is to route the included drain hose that outside the building or to an interior drain. The cost of this upgrade is assumed to be $150.

During this project the 1753012 direct vent condensing furnaces replaced existing top vent gravity wall furnaces installed within interior wall cavities. A lot of extras were needed to make this work. The 1753012 furnaces would not fit in theses wall cavities, so were installed against the wall and repairs were made to cover the cavity. The furnaces needed ducting to pull in air from the outside, and flue extensions to reach the existing flue. The materials and labor were very costly, on top of an already expensive furnace, so it is not recommended that this type of furnace retrofit be done.

Cost-benefit analyses are done to determine simple paybacks for the retrofit wall furnaces, where the payback period is calculated as follows:

Simple payback, years = (Advanced Furnace Cost – Standard Furnace Cost + Installation Cost Added – Incentive) / Annual Energy Savings

Incentives denote utility payments made to encourage adoption of energy efficiency technologies. No incentive was assumed to make the first round of simple payback calculations. The payback period was found for the three different furnace operating scenarios in

Table 31, Table 32, and Table 33:

1. Under ACTUAL estimated use patterns for a TMY3 year, assuming the baseline furnace pilot stays on all year
2. Under ACTUAL estimated use patterns for a TMY3 year, assuming the baseline furnace pilot stays on for only half the year
3. Under AVERAGE estimated use patterns for a TMY3 year, assuming the baseline furnace pilot stays on all year

Table 31: Wall Furnace Cost-Benefit under ACTUAL Usage Patterns with Baseline Furnace Pilot on All Year, Scenario 1

Baseline to Retrofit Description	Field Sites	Annual Energy Cost Savings	Advanced Furnace Cost	Standard Furnace Cost	Installation Cost Added	Incremental Cost	Payback Years	Adv Cost for 7.5 Year Payback	Incentive Amount	Incentivized Payback
Gravity to Direct Vent Condensing	Hayward 3	$197	$4,130	$1,370	$150	$2,910	14.8	$3,450	$750	7.5
Gravity to Direct Vent Condensing	Hayward 4	$66	$4,130	$1,370	$150	$2,910	43.8	$2,470	$750	7.5
Gravity to Fan-Type w/AC Power	LA 104	$117	$3,180	$1,080	$0	$2,100	17.9	$2,710	$750	7.5
Gravity to Fan-Type w/AC Power	LA 105	$323	$3,180	$1,080	$0	$2,100	6.5	$4,250	$750	7.5
Gravity to Fan-Type w/AC Power	LA 106	$121	$3,180	$1,080	$0	$2,100	17.3	$2,740	$750	7.5
Gravity to Fan-Type w/AC Power	LA 107	$71	$3,180	$1,080	$0	$2,100	29.5	$2,360	$750	7.5
2-Sided Gravity to Fan-Type w/AC Power	Oakland SFH	$172	$3,670	$1,380	$0	$2,290	13.3	$3,420	$750	7.5
Gravity to Fan-Type Self-Powered	Sacramento 4	$133	$4,020	$1,080	$0	$2,940	22.2	$2,820	$750	7.5
Gravity to Fan-Type Self-Powered	Sacto 15 to 19 T2	$93	$4,020	$1,080	$0	$2,940	31.8	$2,520	$750	7.5
Gravity to Fan-Type Self-Powered	Sacramento 19	$145	$4,020	$1,080	$0	$2,940	20.2	$2,920	$750	7.5
	Average	**$144**	**$3,670**	**$1,170**	**$30**	**$2,530**	**21.7**	**$2,970**	**$750**	**7.5**

Table 32: Wall Furnace Cost-Benefit under ACTUAL Usage Patterns with Baseline Furnace Pilot on Half the Year, Scenario 2

Baseline to Retrofit Description	Field Sites	Annual Energy Cost Savings	Advanced Furnace Cost	Standard Furnace Cost	Installation Cost Added	Incremental Cost	Payback Years	Adv Cost for 7.5 Year Payback	Incentive Amount	Incentivized Payback
Gravity to Direct Vent Condensing	Hayward 3	$154	$4,130	$1,370	$150	$2,910	18.9	$3,120	$750	7.5
Gravity to Direct Vent Condensing	Hayward 4	$24	$4,130	$1,370	$150	$2,910	121.1	$2,150	$750	7.5
Gravity to Fan-Type w/AC Power	LA 104	$55	$3,180	$1,080	$0	$2,100	38.4	$1,990	$500	7.5
Gravity to Fan-Type w/AC Power	LA 105	$279	$3,180	$1,080	$0	$2,100	7.5	$3,680	$500	7.5
Gravity to Fan-Type w/AC Power	LA 106	$74	$3,180	$1,080	$0	$2,100	28.5	$2,130	$500	7.5
Gravity to Fan-Type w/AC Power	LA 107	$30	$3,180	$1,080	$0	$2,100	71.1	$1,800	$500	7.5
2-Sided Gravity to Fan-Type w/AC Power	Oakland SFH	$81	$3,670	$1,380	$0	$2,290	28.2	$2,490	$500	7.5
Gravity to Fan-Type Self-Powered	Sacramento 4	$73	$4,020	$1,080	$0	$2,940	40.5	$2,130	$500	7.6
Gravity to Fan-Type Self-Powered	Sacto 15 to 19 T2	$33	$4,020	$1,080	$0	$2,940	87.9	$1,830	$500	7.5
Gravity to Fan-Type Self-Powered	Sacramento 19	$58	$4,020	$1,080	$0	$2,940	50.8	$2,010	$500	7.4
	Average	**$86**	**$3,670**	**$1,170**	**$30**	**$2,530**	**49.3**	**$2,330**	**$550**	**7.5**

Table 33: Wall Furnace Cost-Benefit under AVERAGE Usage Patterns with Baseline Furnace Pilot on All Year, Scenario 3

Baseline to Retrofit Description	Field Sites	Annual Energy Cost Savings	Advanced Furnace Cost	Standard Furnace Cost	Installation Cost Added	Incremental Cost	Payback Years	Adv Cost for 7.5 Year Payback	Incentive Amount	Incentivized Payback
Gravity to Direct Vent Condensing	Hayward 3	$109	$4,130	$1,370	$150	$2,910	26.8	$2,780	$750	7.5
Gravity to Direct Vent Condensing	Hayward 4	$107	$4,130	$1,370	$150	$2,910	27.3	$2,770	$750	7.5
Gravity to Fan-Type w/AC Power	LA 104	$136	$3,180	$1,080	$0	$2,100	15.4	$2,600	$500	7.5
Gravity to Fan-Type w/AC Power	LA 105	$121	$3,180	$1,080	$0	$2,100	17.3	$2,490	$500	7.5
Gravity to Fan-Type w/AC Power	LA 106	$130	$3,180	$1,080	$0	$2,100	16.2	$2,550	$500	7.5
Gravity to Fan-Type w/AC Power	LA 107	$118	$3,180	$1,080	$0	$2,100	17.8	$2,470	$500	7.5
2-Sided Gravity to Fan-Type w/AC Power	Oakland SFH	$239	$3,670	$1,380	$0	$2,290	9.6	$3,670	$500	7.5
Gravity to Fan-Type Self-Powered	Sacramento 4	$157	$4,020	$1,080	$0	$2,940	18.7	$2,760	$500	7.5
Gravity to Fan-Type Self-Powered	Sacto 15 to 19 T2	$147	$4,020	$1,080	$0	$2,940	19.9	$2,690	$500	7.5
Gravity to Fan-Type Self-Powered	Sacramento 19	$219	$4,020	$1,080	$0	$2,940	13.4	$3,220	$500	7.5
	Average	**$148**	**$3,670**	**$1,170**	**$30**	**$2,530**	**18.2**	**$2,800**	**$550**	7.5

Paybacks based on list and estimated prices were very high, 21.7, 49.3, and 18.7 years for furnace operating scenarios 1, 2, and 3.

The payback equation was also flipped around in order to calculate what the advanced furnace cost should be to get a payback of 7.5 years, assuming incentives of $750 for condensing wall furnaces and $500 for high efficiency wall furnaces:

Advanced Furnace Cost = 7.5 years x Annual Energy Savings + Standard Furnace Cost - Intallation Cost Added + Incentive

The three right columns of

Table 31, Table 32, and Table 33 show that to achieve a simple payback of 7.5 years, furnace costs would need to be reduced from by an average of $700, $1,340, or $870 for furnace operating scenarios 1, 2 or 3. This also assumes that utility inicentives of $750 and $500 would be offered for condensing and non-condensing furnaces.

Wall Furnace Installation and Operation Issues

Problems with retrofit wall furnaces fall into five categories which are discussed below: installation issues, self-charging problems, noise levels, thermostat operation, and comfort delivery.

Installation Issues

Some installation issues with the retrofit furnaces point to the need for more contractor training and experience:

- A gas leak occurred on Sacramento apartment 4's TG2030TN furnace. This was a contractor installation issue not specific to wall furnaces. Making safe, sealed gas connections is a standard part of hooking up any gas appliance, but too many HVAC professionals do not do this correctly. This points to the need for better contractor training in general to ensure that all gas connections are checked for leaks using a soap solution.
- A thermostat battery was no tinstalled on Sacramento apartment 4's TG2030TN furnace. This can be explained by realizing that standard wall furnaces provide power to the thermostat via the pilot system so thermostat batteries are generally only needed as backup on standard wall furnace installations. However, these batteries should always be installed as a matter of course.

Various system components may also needed to be replaced or added when installing any new wall furnace:

- Existing exhaust flues are often replaced when the wall furnace is replaced. Contractors attest that existing flues are dirty, rusted, broken, incorrectly sized, improperly flashed where they exit the roof, or lack a proper vent cap.
- If the existing and retrofit furnaces are not the same size, some work may need to be needed to resize the wall cavity or repair a wall. Making the cavity taller is fairly simple, but if the existing cavity is too tall there may be some labor involved to drywall, patch, and paint the wall behind the furnace.
- The AC2030TN and AC3040TN furnaces needed connections to AC power. This can be done inexpensively by plugging it into a nearby wall outlet, or for some extra expense by hard-wiring it to AC power.
- The 1753012 wall furnace was a condensing furnace with a drain pipe that needed to either be routed to the outside, hooked up to a drain inside the home, or attached to a condensate drain pump. The temporary Hayward installations used a drain pan under the units, but this is not recommended as the pan could overflow or contribute to mold formation.

Self-Charging Battery Problems

The TG2030TN furnaces in Sacramento apartments 15 and 19 appear experienced problems with their self-charging systems. Note that these furnaces were still considered to be experimental and were not yet available on the market at the time of testing. A self-charging battery is used to power the furnace control system, the hot surface igniter, and the furnace fans. This battery loses charge when the furnace has not been operated for a while and can then fail to ignite or operate the furnace.

The wall furnace in apartment 15 stopped working, and although Williams never gave a diagnosis of the problem, we surmise that the self-charging battery was not adequately charged upon initial installation, and was unable to be recharged or hold a charge. Replacement batteries also failed to work. This furnace was ultimately removed without the project team being able to collect any post-retrofit.

There were similar self-charging battery problems with apartment 19's furnace, but the replacement battery there was able to be charged and kept the system operating for the rest of the 2021-22 heating season. The furnace in apartment 19 also kept running without any operational problems through some additional monitoring during November and December 2022. This may have been helped along by cold weather and subsequent regular wall furnace operation in the two apartments over this period, enabling the self-charging batteries to stay charged.

Making the self-charging batteries more reliable is extremely important. Discussions with Williams indicated that they were aware of these problems and working to fix them. They said they have both improved the battery and adjusted the furnace control system so that it shuts down after the furnace has been inoperable to keep the battery charge intact. However, these improvements are expected to be applied to future versions of the TG2030TN furnaces, were not tested during this project, and therefore cannot be certified as reliable by this project team. We recommend more testing of future versions of the TG2030TN to ensure reliability of this wall furnace's operation.

It is also important for Williams to add instructions for battery charging to their furnace manuals. This should be no more difficult than lighting the pilot for standard wall furnaces, so proper battery charging procedures can be learned by contractors and occupants with adequate training and directions.

Noise Levels

Noise levels from the AC- and TG- wall furnace models were reported to be unacceptably high by two of the occupants. No noise level measurements were made, but the project team did also report that double-sided AC3040TN furnace with two supply fans was especially loud.

Some increase in furnace noise is inevitable when switching from a gravity furnace to a fan-type furnace. But unlike other fan-powered equipment used in homes, wall furnaces are not currently subject to any noise level requirements, or even any requirement to test and report noise ratings in their specifications.

According to ASHRAE Standard 62.2 (ASHRAE 2013), ventilation fans inside habitable space that are used intermittently, like bathroom fans and range hoods, are required to operate at sound levels below 3 sones (43.74 dB). Fans that operate continuously like whole house fans are required to stay below 1 sone (28 dB), even if they are not in habitable space.

Without keeping their noise levels down, these more efficient wall furnaces risk not being able to gain consumer acceptance. It is recommended that they at least test and report sound levels and strive to adhere to the standards that apply to ventilation fans.

Thermostat Operation

Wall furnace thermostat controls for the AC2030TN, AC3040TN, and TG2030TN furnaces were slow to respond.

- Thermostats took 15 to 20 seconds to wake up when occupants changed settings. Considering that wall furnaces tend to be operated manually much more frequently than central furnaces, this can be a frequently annoying issue for occupants.
- Thermostats also have a one-minute delay programmed into their controls, turning the furnace on only after the space temperature has been 2°F below the thermostat setpoint for one minute, and turning the furnace off only when space temperature has been 1°F above the thermostat for one minute.

Realizing again that the typical wall furnace user operates the furnace manually, imagine an occupant going to adjust thermostat, needing to wait 15 seconds for it to wake up, adjusting the thermostat setpoint, then waiting another minute for the system to start or stop heating. While some users will understand there is a lag time, many users are likely to keep raising or lowering the setpoint in frustration until they get a response.

Thermostats should “wake up” instantly at the push of any button. Much shorter burner on-off delay times are also recommended. Some indication that the thermostat setting has been changed can also greatly improve operator satisfaction.

Comfort Delivery

Occupants using the AC2030TN and 1753012 furnaces reported a lot of temperature variability when the furnaces were run at a constant setpoint. The space felt too cold before the furnace cycled on, and too hot before the furnace cycled off.

It must first be noted that these fan-type furnaces distribute heat very differently from the baseline gravity furnaces. Occupants who are used to the previous gravity furnace are going to have a very different experience with a fan-type furnace, since they will likely now have more warm air flowing around them while the furnace is on.

Air distribution patterns from a fan-type furnace may also mean the thermostat is no longer in the most representative spot to sense space temperatures and control furnace on-off operation. Forced-air systems with thermostatic controls tend to struggle to keep occupants comfortable, because warm air is not always evenly distributed throughout a room. Thermostat placement is very important. Advances in the use of wireless remote temperature sensors can also make a huge difference by allowing occupants to move sensors to a spot that optimizes their comfort.

Thermostat controls also contribute to the reported comfort problems. The furnaces currently turn on only when temperatures are 2°F below the thermostat setpoint for one minute, and turn the furnace off when space temperature has been 1°F above the thermostat for one minute. This adds up to a total differential of 3°F. This is quite a bit higher than the generally recommended differential of 0.5 to 1.0°F for non-compressor-based heating systems, said to optimize comfort without causing excessive cycling and associated wear and tear on equipment. It is recommended that on-off controls be changed so furnaces turn on when temperature is 1°F below the thermostat setpoint for 30 seconds or less and turn off when temperature is 0.5°F above the thermostat setpoint for 30 seconds or less.

Conclusion

Wall furnace field monitoring and laboratory testing measured energy use, use patterns, emissions, and indoor air quality. Comparisons of furnace performance, operating characteristics, energy use, emissions, and indoor air quality improvements are below.

Energy Characteristics

Table 34 lists important energy use characteristics of the baseline and retrofit furnaces found during laboratory testing and field monitoring:

- Retrofit furnaces had 15% lower average **rated input capacity** than baseline furnaces
- Retrofit furnaces had 3% higher average **tested input capacity** than baseline furnaces
- All retrofit furnaces eliminated the use of standing pilots
- Average tested thermal efficiency of retrofit furnaces increased by 17 percentage points
- Retrofit furnaces had 31% higher average tested output capacity than baseline furnaces
- Three of the four tested retrofit furnace types used external AC power

Table 34: Baseline and Retrofit Wall Furnace Energy Characteristics

BASELINE Wall Furnace				Natural Gas Input Capacity				Thermal Efficiency		Natural Gas Output Capacity			AC Power
Manufacturer	Model	Field Sites	Age years	Rated Input Btu/hr	Tested Input Btu/hr	% Rated Input	Pilot Btu/hr	Rated TE	Tested TE	Output Btu/hr	Tested Output Btu/hr	% Rated Output	Active W
Perfection Products	PW8G25SEN	Hayward 3	~40	25000	20280	81%	520	70.0%	76.3%	17500	15470	88%	0
Perfection Products	PW8G25SEN	Hayward 4	~40	25000	20210	81%	510	70.0%	71.8%	17500	14510	83%	0
Williams	25GV-A1	LA 104	~35	25000	25100	100%	750	70.0%	70.5%	17500	17700	101%	0
Williams	35GV-C #1	LA 105	~35	35000	31720	91%	520	70.0%	62.8%	24500	19920	81%	0
Williams	35GV-C #2	LA 106	~35	35000	31800	91%	570	70.0%	73.6%	24500	23400	96%	0
Williams	RMG35-IN	LA 107	~35	35000	31810	91%	500	70.0%	75.1%	24500	23890	98%	0
Williams	5009622	Oak SF	~15	50000	44500	89%	1090	76.0%	50.1%	38000	22290	59%	0
Holly General	35S-D #1	Sacto 4	40+	35000	31530	90%	720	50.0%	39.0%	17500	12300	70%	0
Holly General	35S-D #2	Sacto 15	40+	35000	29110	83%	710	50.0%	60.8%	17500	17700	101%	0
Williams	3509622	Sacto 19	~10	35000	33800	97%	1050	74.0%	73.2%	25900	24740	96%	0
		Baseline Average	**32**	**33500**	**29990**	**89%**	**690**	**67.0%**	**65.3%**	**22490**	**19190**	**87%**	**0**
RETROFIT Wall Furnace				Natural Gas Input Capacity				Thermal Efficiency		Natural Gas Output Capacity			AC Power
Manufacturer	Model	Field Sites	Age years	Rated Input Btu/hr	Tested Input Btu/hr	% Rated Input	Pilot Btu/hr	Rated TE	Tested TE	Output Btu/hr	Tested Output Btu/hr	% Rated Output	Active W
Williams	1753012	Hayward 3	0	17500	19790	113%	0	94%	89.5%	16450	17710	108%	100.1
Williams	1753012	Hayward 4	0	17500	19790	113%	0	94%	89.5%	16450	17710	108%	100.1
Williams	AC2030TN	LA 104	0	30000	33180	111%	0	85%	81.5%	25500	27040	106%	12.6
Williams	AC2030TN	LA 105	0	30000	33180	111%	0	85%	81.5%	25500	27040	106%	12.6
Williams	AC2030TN	LA 106	0	30000	33180	111%	0	85%	81.5%	25500	27040	106%	12.6
Williams	AC2030TN	LA 107	0	30000	33180	111%	0	85%	81.5%	25500	27040	106%	12.6
Williams	AC3040TN	Oakland SFH	0	40000	41720	104%	0	83%	79.0%	33200	32960	99%	12.4
Williams	TG2030TN	Sacto 4	0	30000	31410	105%	0	82%	78.5%	24600	24660	100%	0.0
Williams	TG2030TN	Sacto 19 T2	0	30000	31410	105%	0	82%	78.5%	24600	24660	100%	0.0
Williams	TG2030TN	Sacto 19	0	30000	31410	105%	0	82%	78.5%	24600	24660	100%	0.0
		Retrofit Average	**0**	**28500**	**30830**	**109%**	**0**	**85.7%**	**82.0%**	**24190**	**25050**	**104%**	**26.3**
		Savings		**5000**	**-840**	**-19%**	**690**	**-19%**	**-17%**	**-1700**	**-5860**	**-17%**	**-26.3**
		% Savings		**15%**	**-3%**	**-22%**	**100%**	**-28%**	**-25%**	**-8%**	**-31%**	**-19%**	**-100%**

Energy Savings

Table 35 lists the operating characteristics of the baseline and retrofit wall furnaces, and calculates their energy use, energy costs, and savings under TMY3 conditions, finding that:

- Retrofit furnace average annual operating hours are reduced by 66 hours or 37%
- Annual energy savings of retrofit furnaces is 7.6 MMBtu on average, or 66%
- Average annual utility cost savings was $144

Table 35: Baseline and Retrofit Annual Energy Use, Energy Cost, and Savings during ACTUAL Operation under TMY3 Weather Conditions

Wall Furnace Tested			ACTUAL Operation - TMY3 Annual					
Manufacturer	Model	Field Sites	Operating hrs/year	Cycles/year	Avg Cycle Minutes	MMBtu/year	kWh/year	Utility Cost
Perfection Products	PW8G25SEN #1	Hayward 3 Baseline	330.5	568	34.9	11.086	0.0	$211
Perfection Products	PW8G25SEN #2	Hayward 4 Baseline	119.7	295	24.3	6.826	0.0	$130
Williams	25GV-A1	LA 104 Baseline	21.5	127	10.2	7.093	0.0	$135
Williams	35GV-C #1	LA 105 Baseline	429.1	809	31.8	17.944	0.0	$341
Williams	35GV-C #2	LA 106 Baseline	143.5	643	13.4	9.475	0.0	$180
Williams	RMG35-IN	LA 107 Baseline	24.8	105	14.1	5.155	0.0	$98
Williams	5009622	Oakland SF Baseline	106.1	346	18.4	14.153	0.0	$269
Holly General	35S-D #1	Sacramento 4 Baseline	161.5	217	44.7	11.283	0.0	$214
Holly General	35S-D #2	Sacramento 15 Baseline	267.9	471	34.1	13.829	0.0	$263
Williams	3509622	Sacramento 19 Baseline	304.8	522	35.1	19.179	0.0	$364
		Baseline Average	**178.3**	**410**	**26.1**	**11.602**	**0.0**	**$220**
Manufacturer	Model	Field Sites	Operating hrs/year	Cycles/year	Avg Cycle Minutes	MMBtu/year	kWh/year	Utility Cost
Williams	1753012	Hayward 3 Retrofit	33.4	76	26.4	0.661	3.3	$13
Williams	1753012	Hayward 4 Retrofit	157.6	256	37.0	3.119	15.8	$63
Williams	AC2030TN	LA Avg Retrofit	48.0	127	22.0	1.592	0.6	$30
Williams	AC2030TN	LA 104 Retrofit	27.8	117	14.2	0.922	0.3	$18
Williams	AC2030TN	LA 105 Retrofit	28.7	132	13.1	0.953	0.4	$18
Williams	AC2030TN	LA 106 Retrofit	93.1	144	38.8	3.087	1.2	$59
Williams	AC2030TN	LA 107 Retrofit	42.3	116	21.9	1.405	0.5	$27
Williams	AC3040TN	Oakland SFH	121.8	238	34.5	5.080	1.5	$97
Williams	TG2030TN	Sacramento 4 Retrofit	137.0	238	34.5	4.304	0.0	$82
Williams	TG2030TN	Sacramento 19 T2 Retrofit	285.2	268	63.9	8.959	0.0	$170
Williams	TG2030TN	Sacramento 19 Retrofit	367.2	451	48.9	11.535	0.0	$219
		Retrofit Average	**112.1**	**188**	**31.0**	**4.003**	**2.3**	**$77**
			Reductions In:			TMY3 ACTUAL Annual Savings		
			Operating hrs/year	Cycles/year	Avg Cycle Minutes	MMBtu/year	kWh/year	Utility Cost
			297.1	491.5	8.6	10.425	-3.3	$197
			-37.9	39.3	-12.6	3.707	-15.8	$66
			-6.3	9.6	-4.1	6.171	-0.3	$117
			400.4	677.6	18.7	16.992	-0.4	$323
			50.5	499.2	-25.4	6.388	-1.2	$121
			-17.6	-10.7	-7.8	3.751	-0.5	$71
			-15.7	107.4	-16.1	9.072	-1.5	$172
			24.5	-21.5	10.2	6.979	0.0	$133
			-17.3	203.7	-29.8	4.870	0.0	$93
			-62.5	70.7	-13.8	7.645	0.0	$145
		Savings Average	**66.2**	**222.0**	**-4.9**	**7.600**	**-2.3**	**$144**
		Percent Savings	**37%**			**66%**		**65%**

Emission Reductions

Table 36 lists estimated annual emissions of carbon monoxide, nitrogen oxides, and total hydrocarbons in baseline and retrofit furnaces under TMY3 conditions. Reductions in emissions in retrofit furnaces are substantial, with 89% reduction in CO emissions, 88% reduction in NOx emissions, and 92% reduction in THC emissions. The bulk of CO and THC emissions are due to elimination of the standing pilot, while the reduction in NOx emissions is mostly due to better combustion during active heating operation.

Table 36: Baseline and Retrofit Annual CO, NOx, and THC Emissions and Savings during ACTUAL Operation under TMY3 Weather Conditions

Wall Furnace Tested			ACTUAL Operation - TMY3 Annual					
Manufacturer	**Model**	**Field Sites**	**Operating hrs/year**	**Cycles/year**	**Avg Cycle Minutes**	**CO lbm/year**	**NOx lbm/year**	**THC lbm/year**
Perfection Products	PW8G25SEN #1	Hayward 3 Baseline	330.5	568	34.9	2.04	0.91	0.58
Perfection Products	PW8G25SEN #2	Hayward 4 Baseline	119.7	295	24.3	0.36	0.39	2.19
Williams	25GV-A1	LA 104 Baseline	21.5	127	10.2	1.66	0.12	3.66
Williams	35GV-C #1	LA 105 Baseline	429.1	809	31.8	1.39	1.53	0.10
Williams	35GV-C #2	LA 106 Baseline	143.5	643	13.4	0.57	0.54	0.00
Williams	RMG35-IN	LA 107 Baseline	24.8	105	14.1	0.81	0.27	1.98
Williams	5009622	Oakland SF Baseline	106.1	346	18.4	7.68	0.89	0.08
Holly General	35S-D #1	Sacramento 4 Baseline	161.5	217	44.7	1.05	0.73	0.04
Holly General	35S-D #2	Sacramento 15 Baseline	267.9	471	34.1	9.49	0.28	0.47
Williams	3509622	Sacramento 19 Baseline	304.8	522	35.1	1.12	1.78	2.73
		Baseline Average	**178.3**	**410**	**26.1**	**2.61**	**0.74**	**1.18**
Manufacturer	**Model**	**Field Sites**	**Operating hrs/year**	**Cycles/year**	**Avg Cycle Minutes**	**CO lbm/year**	**NOx lbm/year**	**THC lbm/year**
Williams	1753012	Hayward 3 Retrofit	33.4	76	26.4	0.01	0.05	0.00
Williams	1753012	Hayward 4 Retrofit	157.6	256	37.0	0.06	0.24	0.00
Williams	AC2030TN	LA Avg Retrofit	48.0	127	22.0	0.16	0.02	0.12
Williams	AC2030TN	LA 104 Retrofit	27.8	117	14.2	0.10	0.01	0.07
Williams	AC2030TN	LA 105 Retrofit	28.7	132	13.1	0.10	0.01	0.08
Williams	AC2030TN	LA 106 Retrofit	93.1	144	38.8	0.23	0.04	0.25
Williams	AC2030TN	LA 107 Retrofit	42.3	116	21.9	0.16	0.02	0.12
Williams	AC3040TN	Oakland SFH	121.8	238	34.5	1.45	0.22	0.10
Williams	TG2030TN	Sacramento 4 Retrofit	137.0	238	34.5	0.15	0.06	0.02
Williams	TG2030TN	Sacramento 19 T2 Retrofit	285.2	268	63.9	0.22	0.12	0.14
Williams	TG2030TN	Sacramento 19 Retrofit	367.2	451	48.9	0.33	0.15	0.12
		Retrofit Average	**112.1**	**188**	**31.0**	**0.28**	**0.09**	**0.09**
			Reductions In:			**TMY3 ACTUAL Annual Savings**		
			Operating hrs/year	**Cycles/year**	**Avg Cycle Minutes**	**CO lbm/year**	**NOx lbm/year**	**THC lbm/year**
			297.1	491.5	8.6	2.02	0.86	0.58
			-37.9	39.3	-12.6	0.30	0.15	2.19
			-6.3	9.6	-4.1	1.56	0.11	3.58
			400.4	677.6	18.7	1.29	1.52	0.02
			50.5	499.2	-25.4	0.34	0.50	-0.25
			-17.6	-10.7	-7.8	0.65	0.25	1.85
			-15.7	107.4	-16.1	6.23	0.68	-0.02
			24.5	-21.5	10.2	0.89	0.68	0.02
			-17.3	203.7	-29.8	9.27	0.16	0.32
			-62.5	70.7	-13.8	0.79	1.63	2.61
		Savings Average	**66.2**	**222.0**	**-4.9**	**2.33**	**0.65**	**1.09**
		Percent Savings	**37%**			**89%**	**88%**	**92%**

Indoor Air Quality Improvements

Table 37 lists the average and maximum indoor air concentrations of carbon monoxide, nitrogen oxides, and particulate matter (PM2.5 and PM10) when furnaces are off and on for baseline and retrofit furnaces. Compative limits are based on various national and California standards for indoor or outdoor air quality. Values in red exceed the comparative limits. The effect of retrofit wall furnaces on indoor air quality is mixed:

- When furnaces were ON, average CO and NOx concentrations and maximum NOx, PM2.5, and PM10 concentrations were reduced
- Concentrations of indoor air pollutants were always higher for retrofit furnaces than for baseline furnaces when the furnaces were OFF
- All maximum pollutant concentrations were reduced when baseline and retrofit furnaces were ON compared to when they were OFF

Table 37: Average and Maximum Concentrations of Indoor Air Pollutants during Baseline and Retrofit Wall Furnace Operation

Average IAQ Concentrations	CO Off ppmx10	CO On ppmx10	NOx Off ppb/10	NOx On ppb/10	PM2.5 Off ug/m3	PM2.5 On ug/m3	PM10 Off ug/m3	PM10 On ug/m3
Baseline Average	15.7	18.9	17.4	19.0	15.2	15.5	16.5	18.5
Retrofit Average	15.9	13.6	24.7	18.8	21.6	20.4	24.2	22.4
Reduction	-0.3	5.2	-7.3	0.2	-6.4	-4.9	-7.7	-3.9
% Reduction	-2%	28%	-42%	1%	-42%	-31%	-47%	-21%
Comparative Limit	50-150 ppmx10 inside properly adjusted (US EPA)		3.0 ppb/10 24 hour outside (CAAQS)		35 ug/m3 24 hour outside (NAAQS)		50 ug/m3 24 hour outside (CAAQS)	
Maximum IAQ Concentrations	**CO Off ppmx10**	**CO On ppmx10**	**NOx Off ppb/10**	**NOx On ppb/10**	**PM2.5 Off ug/m3**	**PM2.5 On ug/m3**	**PM10 Off ug/m3**	**PM10 On ug/m3**
Baseline Average	45.6	24.5	54.9	26.5	134.2	35.9	152.9	39.4
Retrofit Average	70.7	29.5	58.8	22.4	185.4	34.5	211.8	37.3
Reduction	-25.2	-5.0	-4.0	4.1	-51.2	1.3	-58.9	2.2
% Reduction	-55%	-20%	-7%	16%	-38%	4%	-38%	5%
Comparative Limit	50-150 ppmx10 inside properly adjusted (US EPA)		18 ppb/10 1 hour outside (CAAQS)		35 ug/m3 24 hour outside (NAAQS)		50 ug/m3 24 hour outside (CAAQS)	

There were other sources of indoor pollution at these sites, in particular gas ranges and water heaters. Emissions from these retrofit furnaces were substantially reduced from the baseline furnace levels. If wall furnaces were the largest source of indoor air pollution at the project sites, indoor pollutant concentrations would have dropped dramatically after the retrofit furnaces were installed. It therefore seems that wall furnaces are not the largest source of indoor pollution at these sites.

Drops in indoor pollution levels when furnaces were ON indicate that retrofit furnaces do somewhat improve indoor air quality compared to baseline furnaces. This indicates that some wall furnace pollutants do likely make their way into the indoor spaces, and the lower emitting retrofit furnaces have less pollution getting indoors. .

But when the furnaces were OFF, which is most of the time, indoor air quality was better on average when the baseline furnaces were installed. This surprising result may be due to the standing pilot. Its continual, low-level combustion appears to draw polluted air from the indoor space and exhaust it through the wall furnace flue.

The beneficial effect of wall furnace operation on indoor air quality also seems to be confirmed by drops in maximum pollutant concentrations when furnaces are ON. It is theorized that they draw air from the space for combustion when they operate, and reduce the worst pollutant concentrations.

The seemingly beneficial effects of wall furnace operation, including pilot light operation, is not a reason to keep baseline wall furnaces and their standing pilots. It instead points to the need to reduce other sources of indoor pollution and improve indoor ventilation, while incorporating energy efficient wall furnaces with lower emissions.

Furnace Costs and Operating Issues

The advanced retrofit wall furnaces studied in this project can save substantial amounts of energy and emissions, but their cost and various operating issues are currently an obstacle to their widespread adoption.

First, the incremental costs of advanced retrofit furnaces over standard baseline furnaces range from $2100 to $2940. Two of the retrofit furnaces tested in this project are not yet available on the market, so their purchase prices were estimated, but online list prices were used for replacement baseline and retrofit furnaces. The retrofit furnace prices are currently much higher than standard, minimally efficient furnaces.

This led to high simple payback periods for retrofit furnaces compared to standard efficiency furnaces with standing pilots that operate all year, ranging from 6.5 to 43.8 years, and averaging 21.7 years. While these furnaces should generally have a longer life than their payback period, their installation does not make sense from an economic perspective based on utility bill savings alone. Utility incentives for these furnaces can help make them more economically feasible, but advanced furnace prices must be reduced in order to gain substantial market share in the future.

HVAC contractors need more training on both the basics of wall furnace installation, as well as these specific retrofit technologies. Wall furnaces are a relatively simple technology for an HVAC technician to install, but there are still important safety procedures that cannot be skipped, in particular making sure there are no gas leaks. Technicians will also need training in how these retrofit furnaces differ from standard furnaces. Better installation instructions are needed to help size, install, set up, and troubleshoot the retrofit furnaces.

The self-charging batteries used on one of the retrofit models are a promising advance, but need to be more reliable and come with clearer operating instructions. They had trouble holding charge, and were difficult to recharge. The manufacturer has promised improvements in the battery operation, but it will need to tested more and deemed more reliable before this technology can be recommended for general use.

Noise levels from these fan-type retrofit furnaces was sometimes unacceptably high, not surprising for occupants who are used to the relatively quiet gravity furnaces when presented with a fan-type furnace. These fan-type furnaces do not currently report on noise levels. It is recommended they strive to adhere to levels mandated for intermittent indoor fans

Thermostats and controls for the retrofit wall furnaces need to be more instantly responsive to occupants' changes of setting, and furnaces should turn on and off more quickly in response to indoor temperatures. These fan-type retrofit furnaces distribute heat differently from gravity furnaces. The use of wireless thermostats and/or temperature sensors could give more representative control over occupant comfort than a traditional wall thermostat.

Next Steps

Future work should concentrate on verifying the savings results found in this project, studying effects on indoor air quality in more depth, and testing future iterations of these furnace products with improved batteries, reduced noise levels, and better controls. Furnace costs should also be reinvestigated after these advanced furnaces have been on the market for a couple of years.

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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.
While standard furnaces vent hot combustion gases outside, **condensing** furnaces run combustion air through a heat exchanger to heat incoming air. This cools the exhaust to

temperatures under 100°F so that its water vapor condenses into a liquid. Condensing furnaces must be connected to drains so the condensate water is removed from the building. 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.

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 38. 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 38: 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 39 lists the current minimum AFUE requirements for new wall furnaces. AFUE minimums were raised by at least 2% for furnaces manufactured after 2013.

Table 39: 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>

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 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 40 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 40: Emissions and Indoor Air Quality Regulations, Standards and Guidelines

Rule	Equipment	CO	NOx	PM2.5 & PM10
Code of Federal Regulation (CFR)	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 (SCAQMD)	Central furnaces	n/a	0.033 lbm/MMBtu (14 nanograms/Joule)	n/a
US EPA reference levels of typical indoor air pollutants (US EPA)	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 (NAAQS)	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 (CAAQS)	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

Appendix B: Baseline Field Monitoring Results Summary

The baseline wall furnaces studied in this project were existing furnaces that were in service in California homes. The furnaces were 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 in side-by-side apartments in Hayward (apartments 3 and 4)
- Four in a retirement apartment community in Los Angeles (104, 105, 106, and 107)
- One in a single-family home in Oakland (SFH)
- Three in multifamily apartments in Sacramento (4, 15, and 19)

These ten existing wall furnaces were all vented gravity non-condensing furnaces with standing pilots. They ranged in age from about 10 years to more than 40 years, with input capacities between 25,000 and 50,000 Btu/hr and 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.

The field monitoring performed by the research team included:

- Physical inspection of the wall furnaces and combustion safety checks
- Heating season measurement of furnace operation
- Heating season measurement of indoor temperature and humidity
- Heating season measurement of indoor air quality (IAQ) in terms of concentrations of carbon monoxide, nitrogen oxides, and particulate matter (PM2.5 and PM10)

The operation of existing baseline wall furnaces was monitored at ten sites. Table 41 summarizes the operating hours per day, cycles per day and minutes per cycle for these furnaces.

Table 41: Summary of Baseline Wall Furnace Operation

Site	Manufacturer	Model	Average Operating Hours per Day	Average Furnace Cycles per Day	Average Furnace Cycle Minutes
Hayward 3	Perfection Products	PW8G25SEN #1	1.36	1.77	46.1
Hayward 4	Perfection Products	PW8G25SEN #2	0.55	0.92	35.9
LA 104	Williams	25GV-A1	0.07	0.30	13.8
LA 105	Williams	35GV-C #1	0.89	1.91	28.1
LA 106	Williams	35GV-C #2	0.34	1.52	13.5
LA 107	Williams	RMG35-IN	0.07	0.25	17.3
Oak SF	Williams	5009622	0.67	1.08	37.2
Sacto 4	Holly General	35S-D #1	1.41	1.73	48.8
Sacto 15	Holly General	35S-D #2	2.18	3.77	34.6
Sacto 19	Williams	3509622	2.17	4.18	31.3
Average			**0.97**	**1.73**	**33.6**

The Los Angeles furnaces were used less often, while the Sacramento furnaces operated for the greatest number of hours per day. Furnace cycles also tended to be shortest in Los Angeles at less than 30 minutes per cycle, and over 30 minutes in Northern California On average, furnaces operated for an hour a day, cycling 1.7 times at 34 minutes per cycle. These averages do not tell the whole story, though. Both operating hours and cycle length tend to increase when outdoor temperatures get colder. Based on the average daily outdoor temperature, wall furnace operating hours in Northern and Southern California and cycle length throughout all of California can be estimated as:

- NorCal Daily Operating Hours = 8.7 – 0.146 x Average Daily Outdoor Temperature, ºF,
- SoCal Daily Operating Hours = 3.2 – 0.047 x Average Daily Outdoor Temperature, ºF
- Cycle Minutes = 63.5 – 0.64 x Average Daily Outdoor Temperature, ºF

Indoor pollutant levels were also measured during field monitoring, and the average and maximum indoor pollutant concentrations are listed in Table 42 and Table 43.

Table 42: Average Carbon Monoxide and Nitrogen Oxides Concentrations (top) and Average Particulate Matter PM2.5 and PM10 Concentrations (bottom) at All Sites when Baseline Furnaces are On and Off

AVERAGES Field Site	Regional CO ppmx10	CO Off ppmx10	CO On ppmx10	CO On-Off Difference %	Regional NOx ppb/10	NOx Off ppb/10	NOx On ppb/10	NOx On-Off Difference %
Hayward 3	4.7	23.5	23.4	0%	2.0	32.3	30.9	-4%
Hayward 4	4.7	9.8	12.4	26%	2.0	22.0	23.1	5%
LA 104	5.6	17.7	43.3	145%	4.1	24.8	45.2	83%
LA 105	5.2	24.2	23.9	-1%	3.7	2.8	3.7	31%
LA 106	5.2	17.3	16.5	-5%	3.7	1.3	2.0	51%
LA 107	5.4	31.2	31.4	1%	3.9	26.2	24.5	-7%
Oak SF	4.7	4.2	5.5	30%	2.5	5.3	3.3	-37%
Sacto 4	4.1	10.4	10.8	4%	2.4	49.4	47.7	-4%
Sacto 15	3.8	9.3	10.8	16%	2.2	1.8	2.4	30%
Sacto 19	3.9	9.1	10.9	19%	2.1	7.9	7.5	-5%
Average	**4.7**	**15.7**	**18.9**	**21%**	**2.9**	**17.4**	**19.0**	**9%**
Comparative Limit	50-150 ppmx10 inside properly adjusted (US EPA)				3.0 ppb/10 24 hour outside (CAAQS)			

AVERAGES Field Site	Regional PM2.5 ug/m3	PM2.5 Off ug/m3	PM2.5 On ug/m3	PM2.5 On-Off Difference %	PM10 Off ug/m3	PM10 On ug/m3
Hayward 3	9.8	6.0	3.0	-50%	6.5	0.1
Hayward 4	9.8	5.9	3.1	-48%	6.5	3.2
LA 104	13.1	10.9	5.1	-53%	9.7	4.7
LA 105	12.5	26.3	33.8	29%	29.3	36.8
LA 106	12.3	15.5	21.7	40%	17.5	23.6
LA 107	12.7	12.8	13.3	4%	15.0	38.0
Oak SF	7.0	5.7	9.4	65%	6.2	10.1
Sacto 4	16.1	33.1	28.4	-14%	37.1	31.0
Sacto 15	13.5	10.2	9.1	-11%	10.3	9.1
Sacto 19	15.0	25.5	28.0	10%	26.5	28.8
Average	**12.2**	**15.2**	**15.5**	**2%**	**16.5**	**18.5**
Comparative Limit	35 ug/m3 24 hour outside (NAAQS)				50 ug/m3 24 hour outside (CAAQS)	

As seen in Table 42, the overall ***average*** indoor concentrations of CO, NOx, PM2.5, and PM10 increased by 21%, 9%, 2% and 13% respectively when the furnaces were operating compared to when they were off. However, there is a lot of variability in the averages from site to site. Half of the sites saw average indoor pollutants increase when the furnaces run, either due to flue gas emissions leaking into the space, pollutants being drawn into the living room from other spaces, or existing pollutants being stirred up by air circulation. The other half of the wall furnaces saw average indoor pollutant levels decrease, most likely because they draw air from the indoor space for combustion.

Table 43: Maximum Carbon Monoxide and Nitrogen Oxides Concentrations (top) and Maximum Particulate Matter PM2.5 and PM10 Concentrations (bottom) at All Sites when Baseline Furnaces are On and Off

MAXIMUMS Field Site	Regional CO ppmx10	CO Off ppmx10	CO On ppmx10	CO On-Off Difference %	Regional NOx ppb/10	NOx Off ppb/10	NOx On ppb/10	NOx On-Off Difference %
Hayward 3	6.2	49.1	34.1	-31%	3.1	**93.3**	**57.2**	-39%
Hayward 4	6.2	43.2	20.1	-53%	3.1	**61.7**	**29.6**	-52%
LA 104	7.8	84.9	47.4	-44%	7.6	**117.8**	**48.0**	-59%
LA 105	7.6	24.2	23.9	-1%	7.1	2.8	3.7	31%
LA 106	7.4	104.7	25.3	-76%	7.0	9.9	2.9	-70%
LA 107	7.6	50.9	31.4	-38%	7.3	**67.2**	**24.5**	-64%
Oak SF	7.0	12.5	7.4	-41%	5.1	**26.4**	7.5	-72%
Sacto 4	5.6	30.0	17.5	-42%	4.0	**138.5**	**74.2**	-46%
Sacto 15	5.2	29.9	19.5	-35%	3.7	6.5	4.1	-38%
Sacto 19	5.1	26.4	18.8	-29%	3.3	**24.3**	**13.3**	-45%
Average	**4.9**	**45.6**	**24.5**	**-46%**	**5.1**	**54.9**	**26.5**	**-52%**
Comparative Limit	**50-150 ppmx10 inside properly adjusted (US EPA)**				**18 ppb/10 1 hour outside (CAAQS)**			

MAXIMUMS Field Site	Regional PM2.5 ug/m3	PM2.5 Off ug/m3	PM2.5 On ug/m3	PM2.5 On-Off Difference %	PM10 Off ug/m3	PM10 On ug/m3
Hayward 3	13.3	**106.3**	9.6	-91%	**112.1**	0.1
Hayward 4	13.3	**132.0**	7.9	-94%	**151.2**	8.2
LA 104	16.5	**62.2**	5.9	-91%	**52.1**	5.4
LA 105	14.7	26.3	33.8	29%	29.3	36.8
LA 106	15.5	**197.4**	33.6	-83%	**221.6**	36.6
LA 107	15.8	22.5	13.3	-41%	**83.4**	38.0
Oak SF	8.7	**44.3**	29.6	-33%	48.7	31.1
Sacto 4	22.8	**353.7**	**91.2**	-74%	**403.6**	**100.3**
Sacto 15	19.4	**119.9**	25.3	-79%	**121.0**	25.5
Sacto 19	20.1	**277.8**	**108.5**	-61%	**306.3**	**112.2**
Average	**16.0**	**134.2**	**35.9**	**-73%**	**152.9**	**39.4**

In contrast, the ***maximum*** indoor pollutant concentrations listed in Table 43 decreased at all sites when the furnaces operated. The overall maximum indoor concentrations of CO, NOx, PM2.5, and PM10 decreased by 46%, 52%, 73% and 74% respectively when the furnaces were operating compared to when they were off. The wall furnaces significantly improve indoor air quality by reducing maximum levels of indoor air pollutants, most likely by drawing air for combustion from the indoor space.

Appendix C: Retrofit Field Monitoring Results Summary

The retrofit wall furnaces studied in this project were installed in California homes in place of existing baseline furnaces. The furnaces were monitored in the field over a heating season. Additional samples of the retrofit furnaces were shipped to Des Plaines, IL facilities for testing in GTI Energy's Residential and Commercial Equipment laboratory (documented in the Baseline Wall Furnace Laboratory Testing Report for this project).

Nine retrofit wall furnaces were tested:

- Two 1753012 direct vent condensing furnaces side-by-side apartments in Hayward (apartments 3 and 4)
- Four AC2030TN vented fan-type furnaces in a retirement apartment community in Los Angeles (104, 105, 106, and 107)
- One AC3040TN vented fan-type double-sided furnace in a single-family home in Oakland (SFH)
- Two TG2030TN vented fan-type self-powered furnaces in multifamily apartments in Sacramento (4 and 19), with apartment 19's furnace operated by two different tenants

The field monitoring performed by the research team included:

- Heating season measurement of furnace operation
- Heating season measurement of indoor temperature and humidity
- Heating season measurement of indoor air quality (IAQ) in terms of concentrations of carbon monoxide, nitrogen oxides, and particulate matter (PM2.5 and PM10)

The operation of retrofit wall furnaces was monitored at nine sites. Table 44 summarizes the operating hours per day, cycles per day and minutes per cycle for these furnaces.

Table 44: Summary of Retrofit Wall Furnace Operation

Model	Field Sites	Operating Hrs/Day	Cycles/Day	Cycle Minutes
1753012 (condensing direct vent)	Hayward 3	0.13	0.24	32.5
1753012 (condensing direct vent)	Hayward 4	0.59	0.80	44.0
AC2030TN (single-sided low NOx)	LA 104	0.06	0.28	13.0
AC2030TN (single-sided low NOx)	LA 105	0.06	0.31	11.0
AC2030TN (single-sided low NOx)	LA 106	0.24	0.34	41.6
AC2030TN (single-sided low NOx)	LA 107	0.09	0.27	19.0
AC3040TN (double-sided low NOx)	Oakland SFH	0.63	0.51	73.6
TG2030TN (self-powered low NOx)	Sacto 4	1.06	1.91	33.5
TG2030TN (self-powered low NOx)	Sacto 19	2.43	3.61	40.3
TG2030TN (self-powered low NOx)	Sacto 19 T2	1.98	2.14	55.5
	Average	**0.89**	**1.23**	**43.3**

The Los Angeles furnaces were used less often, while the Sacramento furnaces operated for the greatest number of hours per day. On average, furnaces operated for 0.9 hours a day, cycling 1.2 times a day at 43 minutes per cycle.These averages do not tell the whole story, though. Both operating hours and cycle length tend to increase when outdoor temperatures get colder. Based on the average daily outdoor temperature, wall furnace operating hours and cycle length can estimated for different California locations as:

NorCal Coastal Daily Operating Hours = 4.56 - 0.076 x Average Daily Outdoor Temperature,ºF

NorCal Inland Daily Operating Hours = 7.82 - 0.131 x Average Daily Outdoor Temperature, ºF

SoCal Daily Operating Hours = 0.66 - 0.010 x Average Daily Outdoor Temperature, ºF

Cycle Minutes = 63.5 - 0.64 x Average Daily Outdoor Temperature, ºF

Indoor pollutant levels were also measured during field monitoring, and the average and maximum indoor pollutant concentrations are listed in Table 45 and Table 46.

Table 45: Average Carbon Monoxide and Nitrogen Oxides Concentrations (top) and Average Particulate Matter PM2.5 and PM10 Concentrations (bottom) at All Sites when Retrofit Furnaces are On and Off

AVERAGES Field Site	Regional CO ppmx10	CO Off ppmx10	CO On ppmx10	CO On-Off Difference %	Regional NOx ppb/10	NOx Off ppb/10	NOx On ppb/10	NOx On-Off Difference %
Hayward 3	3.9	11.6	12.2	5%	1.2	31.4	33.7	7%
Hayward 4	4.0	8.6	10.4	21%	1.3	22.1	17.3	-22%
LA 104	4.7	14.3	0.0	-100%	3.2	58.5	23.8	-59%
LA 105	5.0	12.3	0.0	-100%	3.5	8.2	1.0	-88%
LA 106	5.0	13.4	16.6	24%	3.5	25.3	29.3	16%
LA 107	5.0	29.4	0.0	-100%	3.5	23.3	1.7	-93%
Oak SF	5.3	2.1	2.8	31%	3.2	7.1	7.3	2%
Sacto 4	4.4	12.5	15.3	22%	4.7	49.9	54.1	8%
Sacto 19	6.5	41.7	63.6	53%	2.2	10.0	9.6	-4%
Sacto 19 T2	4.4	13.7	15.6	14%	4.7	10.7	10.3	-4%
Average	**4.8**	**15.9**	**13.6**	**-14%**	**3.1**	**24.7**	**18.8**	**-24%**
Comparative Limit	**50-150 ppmx10 inside property adjusted (US EPA)**				**3.0 ppb/10 24 hour outside (CAAQS)**			

AVERAGES Field Site	Regional PM2.5 ug/m3	PM2.5 Off ug/m3	PM2.5 On ug/m3	PM2.5 On-Off Difference %	PM10 Off ug/m3	PM10 On ug/m3	PM10 On-Off Difference %
Hayward 3	8.7	29.4	21.1	-28%	36.0	25.2	-30%
Hayward 4	8.7	11.6	7.7	-33%	13.1	8.0	-38%
LA 104	9.4	6.7	2.2	-67%	7.5	2.5	-66%
LA 105	11.1	39.6	57.7	46%	44.6	65.0	46%
LA 106	11.1	11.5	13.0	13%	12.8	14.3	12%
LA 107	11.1	9.5	2.5	-74%	12.9	3.7	-72%
Oak SF	10.6	20.4	20.9	3%	23.3	23.6	1%
Sacto 4	6.6	29.7	26.9	-9%	33.4	29.7	-11%
Sacto 19	12.5	37.8	37.8	0%	38.4	38.4	0%
Sacto 19 T2	6.6	19.9	13.6	-32%	20.0	13.7	-32%
Average	**9.6**	**21.6**	**20.4**	**-6%**	**24.2**	**22.4**	**-7%**
Comparative Limit	**35 ug/m3 24 hour outside (NAAQS)**				**50 ug/m3 24 hour outside (CAAQS)**		

As seen in Table 45, the overall ***average*** indoor concentrations of CO, NOx, PM2.5, and PM10 decreased by 14%, 24%, 6% and 7% respectively when the furnaces were operating compared to when they were off. However, there is a lot of variability in the averages from site to site. About half of the sites saw average indoor pollutants increase when the furnaces run, either due to flue gas emissions leaking into the space, pollutants being drawn into the living room from other spaces, or existing pollutants being stirred up by air circulation. The other half of the wall furnaces saw average indoor pollutant levels decrease, most likely because they draw air from the indoor space for combustion.

Table 46: Maximum Carbon Monoxide and Nitrogen Oxides Concentrations (top) and Maximum Particulate Matter PM2.5 and PM10 Concentrations (bottom) at All Sites when Retrofit Furnaces are On and Off

MAXIMUMS Field Site	Regional CO ppmx10	CO Off ppmx10	CO On ppmx10	CO On-Off Difference %	Regional NOx ppb/10	NOx Off ppb/10	NOx On ppb/10	NOx On-Off Difference %
Hayward 3	5.8	49.1	34.1	-31%	2.2	93.3	57.2	-39%
Hayward 4	5.8	37.5	12.5	-67%	2.2	49.6	20.3	-59%
LA 104	7.7	34.1	0.0	-100%	7.7	110.8	23.8	-79%
LA 105	7.2	41.7	0.0	-100%	7.2	31.6	1.0	-97%
LA 106	7.2	59.5	16.9	-72%	7.2	63.8	30.8	-52%
LA 107	7.2	67.2	0.0	-100%	7.2	69.0	1.7	-97%
Oak SF	7.5	9.0	3.6	-60%	5.3	15.9	9.4	-41%
Sacto 4	6.0	29.0	19.3	-34%	5.9	122.5	72.8	-41%
Sacto 19	7.6	260.3	205.6	-21%	3.5	24.1	16.5	-32%
Sacto 19 T2	6.0	35.8	24.5	-32%	5.9	26.0	13.1	-50%
Average	**6.8**	**62.3**	**31.6**	**-49%**	**5.4**	**60.7**	**24.7**	**-59%**
Comparative Limit	**50-150 ppmx10 inside property adjusted (US EPA)**				**18 ppb/10 1 hour outside (CAAQS)**			

MAXIMUMS Field Site	Regional PM2.5 ug/m3	PM2.5 Off ug/m3	PM2.5 On ug/m3	PM2.5 On-Off Difference %	PM10 Off ug/m3	PM10 On ug/m3	PM10 On-Off Difference %
Hayward 3	11.1	106.3	9.6	-91%	112.1	0.1	-100%
Hayward 4	11.2	195.3	12.3	-94%	224.6	12.7	-94%
LA 104	12.9	17.7	2.2	-87%	19.5	2.5	-87%
LA 105	14.0	294.0	58.3	-80%	331.5	65.7	-80%
LA 106	14.0	62.6	13.3	-79%	69.2	14.6	-79%
LA 107	14.0	69.9	2.5	-96%	92.2	3.7	-96%
Oak SF	12.7	76.8	29.5	-62%	87.7	33.9	-61%
Sacto 4	9.4	226.8	46.5	-79%	255.6	51.7	-80%
Sacto 19	17.8	330.2	129.7	-61%	337.3	132.5	-61%
Sacto 19 T2	9.4	244.2	29.4	-88%	244.2	29.4	-88%
Average	**12.7**	**162.4**	**33.3**	**-79%**	**177.4**	**34.7**	**-80%**
Comparative Limit	**35 ug/m3 24 hour outside (NAAQS)**				**50 ug/m3 24 hour outside (CAAQS)**		

In contrast, the ***maximum*** indoor pollutant concentrations listed in Table 46 decreased at all sites when the furnaces operated. The overall maximum indoor concentrations of CO, NOx, PM2.5, and PM10 decreased by 49%, 59%, 79% and 80% respectively when the furnaces were operating compared to when they were off. The wall furnaces significantly improve indoor air quality by reducing maximum levels of indoor air pollutants, most likely by drawing air for combustion from the indoor space.

Emission rates of carbon monoxide, nitrogen oxides, and hydrocarbons are highly variable from furnace to furnace, and are very different during standby, startup, steady state. Table 47 sums up emissions during different operating modes for the retrofit wall furnaces, calculated from laboratory test results for the actual operation at each site, as well as for normalized operation over 0.9 hours and 1.2 cycles a day.

Table 47: Overall Flue Gas Emission Rates of Retrofit Wall Furnaces during Actual and Normalized Operation

Wall Furnace Tested		Actual Emission Rates			Normalized Emission Rates		
Model	Field Sites	CO lbm/MMBtu	NOx lbm/MMBtu	THC lbm/MMBtu	CO lbm/MMBtu	NOx lbm/MMBtu	THC lbm/MMBtu
1753012 (condensing direct vent)	Hayward 3	0.022	0.086	0.002	0.021	0.086	0.001
1753012 (condensing direct vent)	Hayward 4	0.021	0.087	0.001	0.021	0.086	0.001
AC2030TN (single-sided low NOx)	LA 104	0.114	0.015	0.086	0.073	0.014	0.094
AC2030TN (single-sided low NOx)	LA 105	0.114	0.015	0.086	0.073	0.014	0.094
AC2030TN (single-sided low NOx)	LA 106	0.076	0.014	0.093	0.073	0.014	0.094
AC2030TN (single-sided low NOx)	LA 107	0.114	0.015	0.086	0.073	0.014	0.094
AC3040TN (double-sided low NOx)	Oakland SFH	0.304	0.040	0.022	0.272	0.039	0.019
TG2030TN (self-powered low NOx)	Sacto 4	0.036	0.013	0.004	0.031	0.013	0.007
TG2030TN (self-powered low NOx)	Sacto 19	0.032	0.013	0.005	0.031	0.013	0.007
TG2030TN (self-powered low NOx)	Sacto 19 T2	0.027	0.013	0.012	0.031	0.013	0.007
	Average	**0.086**	**0.031**	**0.040**	**0.070**	**0.031**	**0.042**

No single furnace had the highest or lowest emission rates for all three pollutants. This reflects the different operating modes during which carbon monoxide, nitrogen oxides, and hydrocarbons are emitted, as well as the effects that operating hours and cycle lengths have on wall furnace emissions.

There are no standards or limits on carbon monoxide or hydrocarbon emission rates. SCAQMD and SJVAPCD have a 0.033 lbm/MMBtu limit on nitrogen oxides emissions from central furnaces (see Appendix B). Although this standard does not currently apply to wall furnaces, the AC and TG series furnaces were designed to have low NOx emissions. The Los Angeles AC2030TN and Sacramento TG2030TN retrofit wall furnaces would meet this limit, and the Oakland AC3040TN just exceeds this limit. The Hayward condensing 1753012 furnace was not designed for low NOx emissions, and its NOx emissions are more than double the central furnace 0.033 lbm/MMBtu limit.

Retrofit furnaces also exhibited some installation and operation issues:

- Installations may need to include replacement of existing exhaust flues, resizing of the wall cavity, connection to AC power, and/or hookup to a drain for condensing furnaces
- Switching from a gravity furnace to fan-type furnace means the new furnace is inherently noisier than the old furnace, although some of these furnaces were deemed unacceptably loud by tenants in this study. Manufacturers need to make efforts to keep furnace noise below 45 dB, and to report noise levels in their specifications.
- Fan-type furnaces will also distribute heat differently from gravity furnaces, and the thermostat may need to be relocated to better monitor room temperature, or better yet, equip the system with a wireless remote temperature sensor.
- For three of the retrofit models tested, furnace capacity can be adjusted via the thermostat settings, but manufacturers should include thermostat instructions with the wall furnace installation instructions and give guidance about how to optimize capacity.

Appendix D: Baseline Laboratory Testing Results Summary

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 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.

Table 48 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 48: 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 49 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 49: 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 50 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 50: 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.

Appendix E: Retrofit Laboratory Testing Results Summary

This project tested five retrofit wall furnaces which came directly from the manufacturer, Williams Comfort Products:

- One Williams 1753012 – direct vent, fan-type, condensing wall furnace with a hot surface igniter and a two-stage heat exchanger, rated at 17,500 Btu/hr, 94% thermal efficiency, and 93% AFUE
- Two Williams AC2030TN – top vent, fan-type, single-sided, low NOx wall furnace with an intermittent pilot, rated at 30,000 Btu/hr, 85% thermal efficiency, 82% AFUE
- One Williams AC3040TN – top vent, fan-type, double-sided low NOx wall furnace with an intermittent pilot, rated at 40,000 Btu/hr, 83% thermal efficiency, 82% AFUE
- One Williams TG2030TN – top vent, fan-type, single-sided, low NOx wall furnace with an intermittent pilot, powered by a rechargeable battery, rated at 30,000 Btu/hr, 82% thermal efficiency, 80% AFUE.

Table 51 lists the rated and measured natural gas flows of each wall furnace, and their electrical power draw. All of these furnaces used more natural gas than their rated input, for an average 109% of rated input. None of these furnaces has a standing pilot, so their pilot gas use was zero. The Williams 1753012 condensing furnace used the most electricity during active heating and standby. The Williams AC2030TN furnaces drew about 12.5 watts only while active, and the AC3040TN furnace drew 12.5 watts all the time. The TG2030TN furnace was self-powered by a rechargeable battery, so did not draw any electrical power.

Table 51: Retrofit Wall Furnace Natural Gas Input and Electrical Power

Wall Furnace Tested		Natural Gas Input				AC Power	
Model	**Field Sites**	**Rated Btu/hr**	**Tested Btu/hr**	**% Rated Input**	**Pilot Btu/hr**	**Active W**	**Standby W**
1753012 (condensing direct vent)	Hayward 3 & 4	17500	19790	113%	0	100.1	0.0
AC2030TN #1 (single-sided low NOx)	LA 104-107	30000	34580	115%	0	12.5	0.0
AC2030TN #2 (single-sided low NOx)	LA 104-107	30000	31780	106%	0	12.6	0.1
AC3040TN (double-sided low NOx)	Oakland SFH	40000	41720	104%	0	12.4	0.0
TG2030TN (self-powered low NOx)	Sacto 4, 15 & 19	30000	31410	105%	0	0.0	0.0
	Average	**29500**	**31856**	**109%**	**0**	**27.5**	**0.0**

Table 52 lists the rated and test-derived thermal efficiency and AFUE for each unit. All of these furnaces exceeded the 75% minimum thermal efficiency required by the American National Standards Institute regulations (ANSI Z21.86 2016) for fan-type wall furnaces. They also exceeded the minimum AFUE required by the Code of Federal Regulations (CFR 430.32 2022), 75% and 76% for furnaces below and above 42,000 Btu/hr rated input. However, all efficiencies derived from these laboratory tests were lower than their rated efficiencies, with thermal efficiency 3.8% lower and AFUE 3.1% lower on average.

Table 52: Retrofit Wall Furnace Thermal Efficiency and AFUE

Wall Furnace Tested		Thermal Efficiency		AFUE	
Model	Field Sites	Rated TE	Tested TE	Rated AFUE	Tested AFUE
1753012 (condensing direct vent)	Hayward 3 & 4	94%	89.5%	93%	88.0%
AC2030TN #1 (single-sided low NOx)	LA 104-107	85%	81.8%	82%	80.4%
AC2030TN #2 (single-sided low NOx)	LA 104-107	85%	81.2%	82%	79.9%
AC3040TN (double-sided low NOx)	Oakland SFH	83%	79.0%	80%	77.8%
TG2030TN (self-powered low NOx)	Sacramento 4, 15 & 19	82%	78.5%	80%	77.3%
	Average Retrofit	**87.0%**	**83.0%**	**85.2%**	**81.7%**

Table 53 lists preliminary energy use and emissions for each wall furnace. This is based on a typical day of operation as found during field testing of retrofit units, where the furnace cycles 1.0 times a day for 42 minutes per cycle and remains in standby for the rest of the day.

Table 53: Retrofit Wall Furnace Energy Use and Emission Rates for a Typical Day of Operation

Wall Furnace Tested		Average Energy Use and Emission Rates				
Model	Field Sites	Btu/Day	kWh/Day	CO lbm/MMBtu	NOx lbm/MMBtu	THC lbm/MMBtu
1753012 (condensing direct vent)	Hayward 3 & 4	13853	0.070	0.021	0.086	0.001
AC2030TN #1 (single-sided low NOx)	LA 104-107	24206	0.009	0.028	0.015	0.170
AC2030TN #2 (single-sided low NOx)	LA 104-107	22246	0.011	0.127	0.012	0.010
AC3040TN (double-sided low NOx)	Oakland SFH	29204	0.009	0.270	0.039	0.018
TG2030TN (self-powered low NOx)	Sacto 4, 19	21987	0.000	0.031	0.013	0.006
	Average	**22299**	**0.020**	**0.096**	**0.033**	**0.041**

Not surprisingly, the largest capacity Williams AC3040TN furnace is estimated to use the most natural gas, and the smallest capacity Williams 1753012 furnace would use the least natural gas. The 1753012 furnace also uses the most electricity.

As for flue gas emissions:

- The Williams AC3040TN furnace had the highest CO emission rate due to relatively high CO emissions during steady state operation.
- The Williams 1753012 condensing furnace had the highest NOx emissions of these retrofit furnaces, due to high NOx emissions during steady state heating operation. The other three retrofit models were all low NOx furnaces, and substantial effort from the manufacturer appears to have gone into reducing their NOx emissions.
- The AC2030TN #1 furnace had a high total hydrocarbon emission rate, while the AC2030TN #2 furnace had low hydrocarbon emissions. The #1 furnace appears to have had a small natural gas leak which may be representative of leaks in actual installations.

There are no standards or regulations 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 to keep nitrogen oxide emissions below 0.033 lbm/MMBtu. The AC2030TN and TG2030TN furnaces stay below this limit, while the AC3040TN furnace just exceeds the NOx limit. The 1753012 condensing furnace has an NOx emission rate that is 2.5 times the limit.