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solutions that transform

Small Furnaces, Big Improvements
Advanced Wall Furnaces

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March 17, 2023 Webinar

Presented Today

- Wall Furnace Project Overview
- Laboratory Testing Highlights
- Field Monitoring Highlights
- Wall Furnace Performance

Project funding from CALIFORNIA ENERGY COMMISSION & SoCalGas

What are Wall Furnaces?

- Small, simple, furnaces that heat one or two rooms, 25,000 to 50,000 Btu/hr
- Usually installed within wall cavity between studs on an inside wall
- Combustion air drawn from inside space, exhausts to roof through a flue

Wall Furnace Options	STANDARD	ADVANCED
Heat Distribution:	Gravity	Fan-type
Combustion Air:	Top vent / vented	Direct vent
Burner Ignition:	Standing pilot	Intermittent pilot or Hot surface igniter
Heat Recovery:	Non-condensing	Condensing
Emissions:	No controls	Low NOx controls
Sides:	Single-sided	Double-sided
AC Power:	Self-powered	AC power supply or Self-powered

Wall Furnace Efficiency Standards

- **Many existing furnaces are 30+ years old**
- Too old to have AFUE ratings
  - Eight of ten in this study
- Some with 50% thermal efficiency
  - Two of ten in this study

Minimum Wall Furnace Thermal Efficiency (Output Capacity / Input Capacity) Requirement from ANSI Z21.86-2016

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

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

Furnace Type	Input Capacity	AFUE 1990	AFUE 2013
Gas Wall Gravity	<10,000 Btu/hr	59%	65%
	10,000 - 12,000 Btu/hr	60%	
	12,000 - 15,000 Btu/hr	61%	
	15,000 - 19,000 Btu/hr	62%	
	19,000 - 27,000 Btu/hr	63%	
	27,000 - 46,000 Btu/hr	64%	66%
	> 46,000 Btu/hr	65%	67%
Gas Wall Fan-Type	< 42,000 Btu/hr	73%	75%
	> 42,000 Btu/hr	74%	76%

Wall Furnace Requirements

- **Emissions and Indoor Air Quality Regulations, Standards, and Guidelines**
  - None specifically apply to wall furnaces

Rule	Applies to	CO	NOx	PM2.5 & PM10
Code of Federal Regulations	Residential forced-air furnaces, wood-burning stoves	--	--	0.93 lbm/MMBtu, 2015 0.15 lbm/MMBtu, 2020
SCAQMD Rule 1111 & SJVAPCD Rule 4905	**Central furnaces**	--	**0.033 lbm/MMBtu (14 nanograms/Joule)**	--
US EPA reference levels for typical indoor pollutants	Indoor air	0 - 5 ppm normal 5 - 15 ppm properly adjusted 30 ppm improperly adjusted	--	--
National Ambient Air Quality Standards	Outside air	9 ppm 8 hours 35 ppm 1 hour	100 ppb 1 hour 53 ppb 24 hours	PM2.5 35 ug/m^3 24 hours PM10 150 ug/m^3 24 hours
California Ambient Air Quality Standards	Outside air	9 ppm 8 hours 20 ppm 1 hour	180 ppb I hour 30 ppb 24 hours	PM10 50 ug/m3 24 hours

Wall Furnace Project Logistics

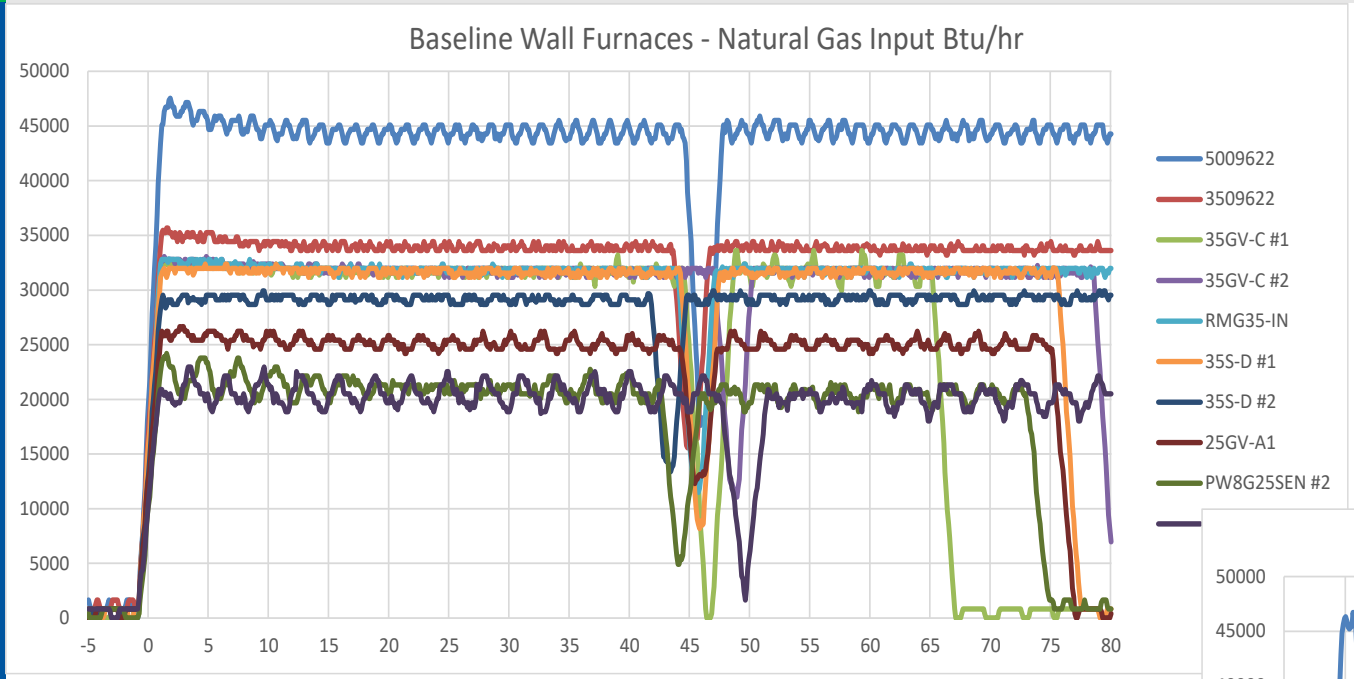
- **Laboratory Testing**
  Performance & Emissions
  - 10 **Baseline** furnaces tested
    - Actual furnaces from field tests
  - 4 **Retrofit** furnace types tested
    - New from manufacturer
    - Installed at 10 field locations

- **Field Monitoring**
  Operation & IAQ
  - 10 **Existing Baseline** furnaces monitored
    - 4 x Los Angeles, 1 x Oakland, 2 x Hayward, 3 x Sacramento
  - 10 **Advanced Retrofit** furnaces installed & monitored
    - 4 x Los Angeles
      Single-Sided, Top Vent, Fan-Type, AC Power, 30,000 Btu/hr, 85% TE, 82% AFUE, Low NOx
    - 1 x Oakland
      Double-Sided, Top Vent, Fan-Type, AC Power, 40,000 Btu/hr, 83% TE, 80% AFUE, Low NOx
    - 2 x Hayward
      Direct Vent, Fan-Type, Condensing, 17,500 Btu/hr, 94% TE, 93% AFUE
    - 3 x Sacramento
      Single-Sided, Top Vent, Fan-Type Self-Powered, 35,000 Btu/hr, 82% TE, 80% AFUE, Low NOx
      1 site dropped out, another monitored with 2 different tenants

Lab Test Procedure: Cold Start and Hot Start

- **Standby**
  - Pilot gas flow only
- **Startup**
  - Gas flow increase, O2% decrease
- **Steady State**
  - Exhaust T reaches 2°F of maximum
- **Shutdown**
  - Gas flow decrease, O2% increase
  - Ends after 1.5 minutes
- **Why these categories?**
  - To capture emissions over each furnace on-off cycle, not just runtime

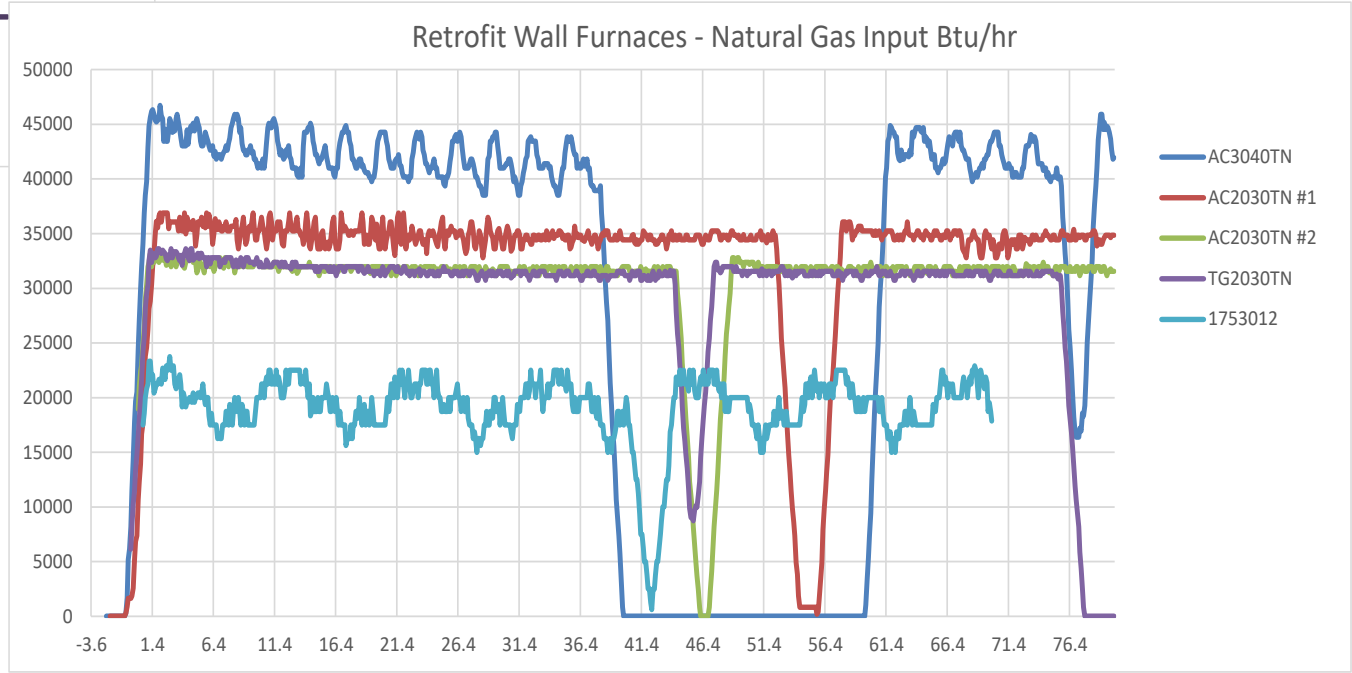
Lab Data: Wall Furnace Natural Gas Use



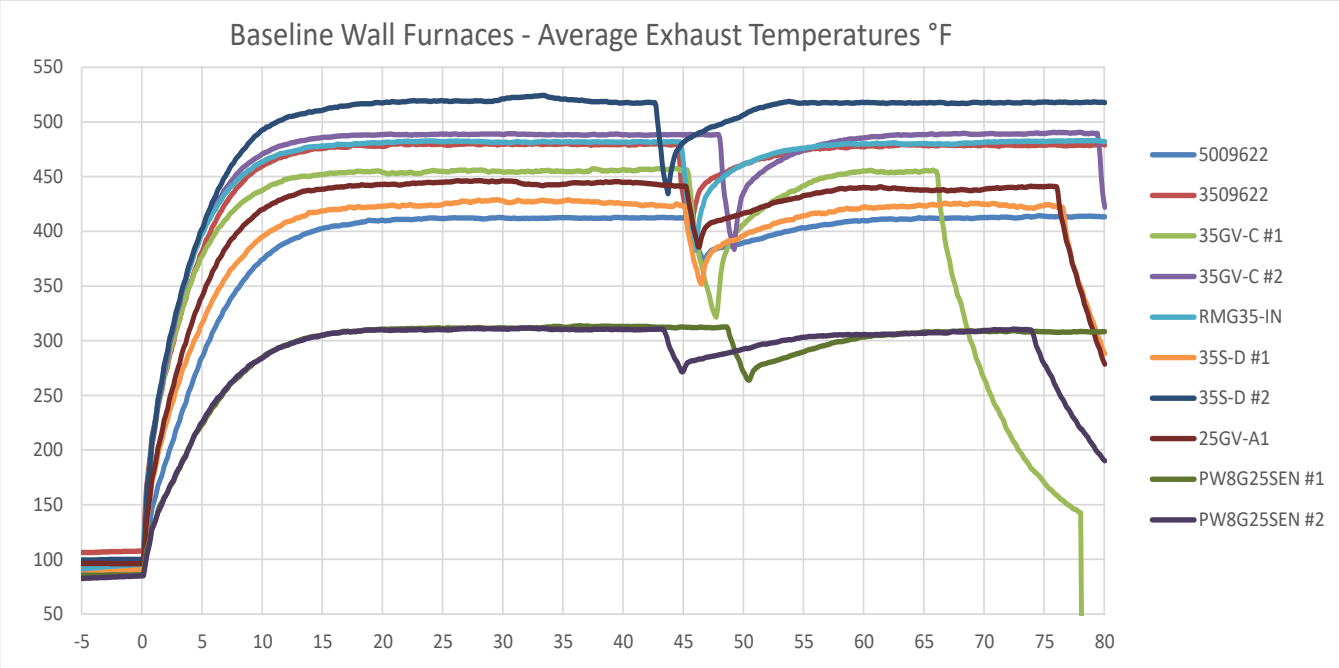
Baseline Wall Furnaces

Active natural gas use & pilot use

Retrofit Wall Furnaces



Lab Data: Wall Furnace Exhaust Temperatures

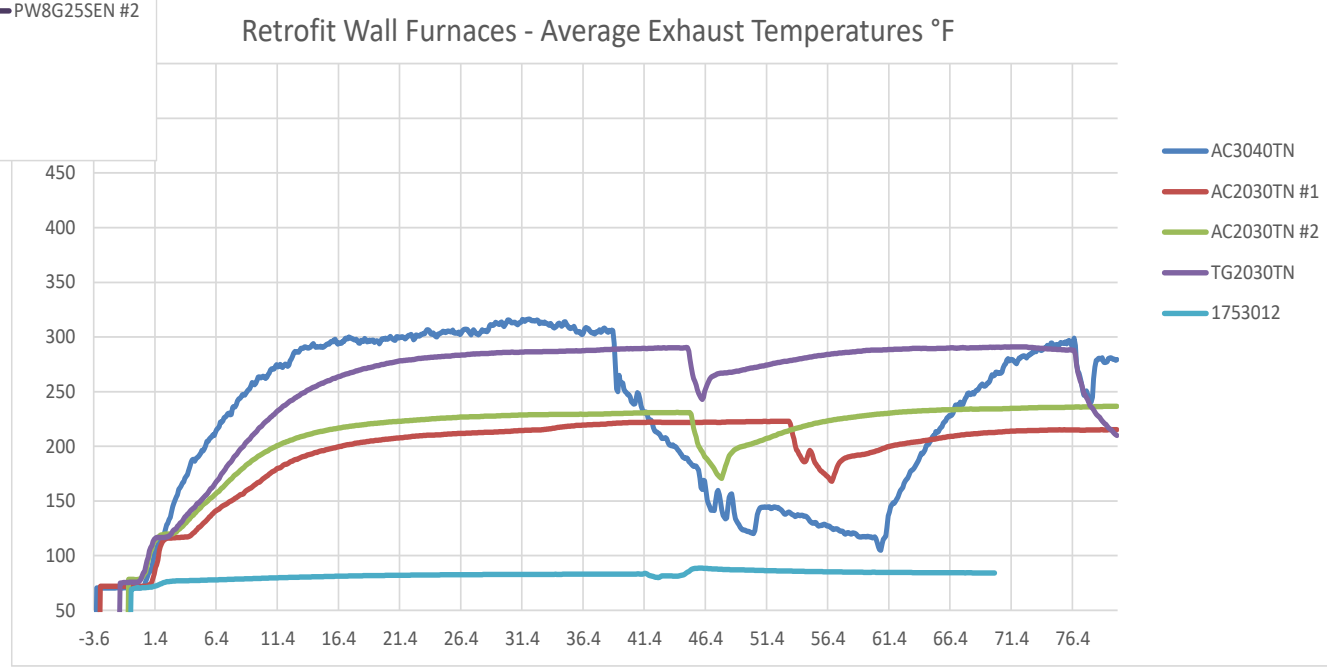


Baseline Wall Furnaces

Exhaust temperatures used to determine efficiency

Higher exhaust temperature means more wasted energy

Retrofit Wall Furnaces



Wall Furnace Fuel Use & Efficiency from Lab Data

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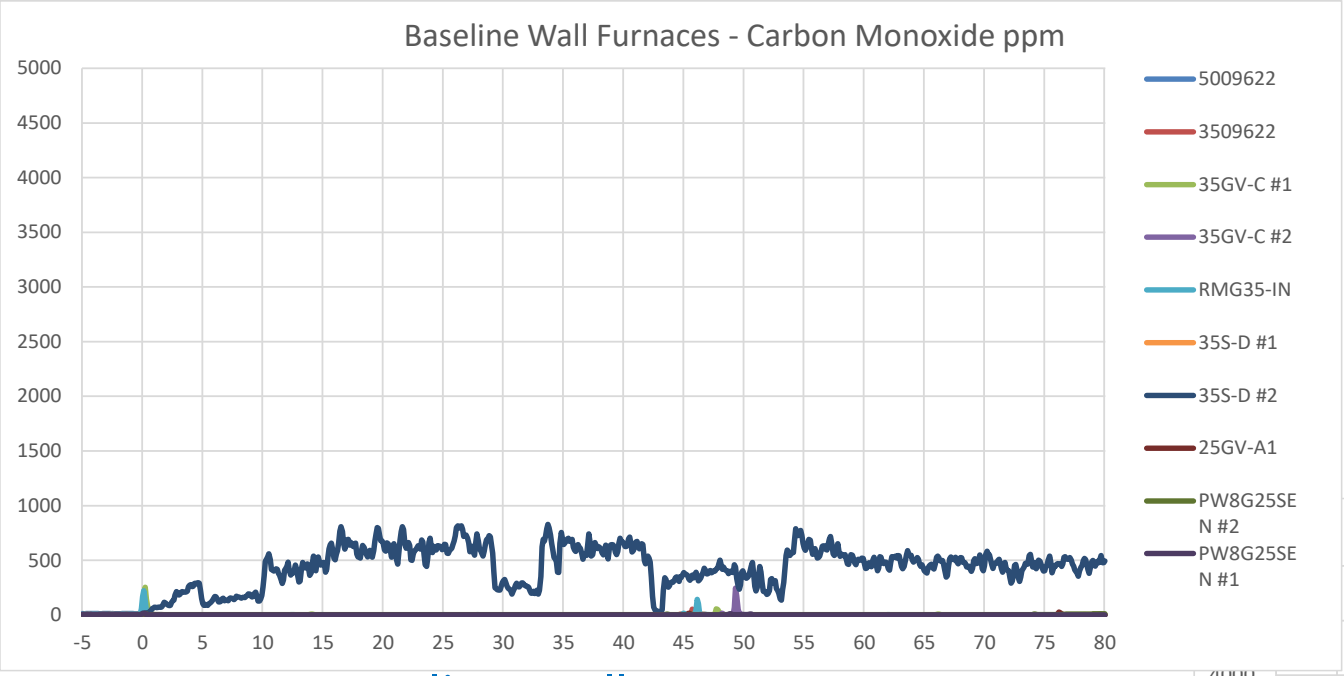
Baseline Wall Furnaces

BASELINE Wall Furnace			Natural Gas Input Capacity				Thermal Efficiency		Natural Gas Output Capacity			AC Power
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
PW8G25SEN	Hayward 3	~40	25000	20280	81%	520	70.0%	76.3%	17500	15470	88%	0
PW8G25SEN	Hayward 4	~40	25000	20210	81%	510	70.0%	71.8%	17500	14510	83%	0
25GV-A1	LA 104	~35	25000	25100	100%	750	70.0%	70.5%	17500	17700	101%	0
35GV-C #1	LA 105	~35	35000	31720	91%	520	70.0%	62.8%	24500	19920	81%	0
35GV-C #2	LA 106	~35	35000	31800	91%	570	70.0%	73.6%	24500	23400	96%	0
RMG35-IN	LA 107	~35	35000	31810	91%	500	70.0%	75.1%	24500	23890	98%	0
5009622	Oak SF	~15	50000	44500	89%	1090	76.0%	50.1%	38000	22290	59%	0
35S-D #1	Sacto 4	40+	35000	31530	90%	720	50.0%	39.0%	17500	12300	70%	0
35S-D #2	Sacto 15	40+	35000	29110	83%	710	50.0%	60.8%	17500	17700	101%	0
3509622	Sacto 19	~10	35000	33800	97%	1050	74.0%	73.2%	25900	24740	96%	0
	Average	**32**	**33500**	**29990**	**89%**	**690**	**67.0%**	**65.3%**	**22490**	**19190**	**87%**	**0**

Retrofit Wall Furnaces

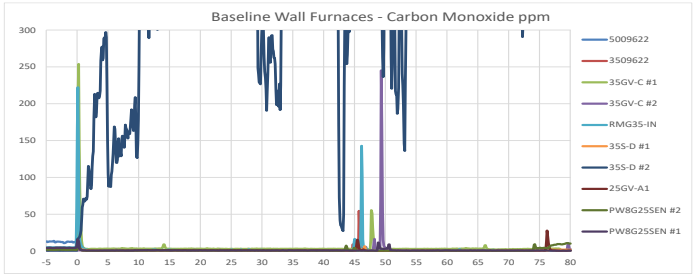
RETROFIT Wall Furnace			Natural Gas Input Capacity				Thermal Efficiency		Natural Gas Output Capacity			AC Power
Model	Field Sites	Age years	Rated Input Btu/hr	Tested Input Btu/hr	% Rated Input	Pilot Btu/hr	Rated TE	Tested TE	Output Btu/hr	Tested Output Btu/hr	% Rated Output	Active W
1753012	Hayward 3 &	0	17500	19790	113%	0	94%	89.5%	28200	30950	109.8%	100.1
AC2030TN #1	LA 104-107	0	30000	34580	115%	0	85%	81.8%	25500	26000	102.0%	12.5
AC2030TN #2	LA 104-107	0	30000	31780	106%	0	85%	81.2%	34000	33880	99.6%	12.6
AC3040TN	Oakland SFH	0	40000	41720	104%	0	83%	79.0%	24900	24810	99.6%	12.4
TG2030TN	Sacto 4, 15 &	0	30000	31410	105%	0	82%	78.5%	23370	24200	103.6%	0.0
	Average	**0**	**28500**	**30830**	**109%**	**0**	**85.7%**	**82.0%**	**24190**	**25050**	**103.9%**	**26.3**

Lab Data: Wall Furnace Carbon Monoxide in Flue Gases

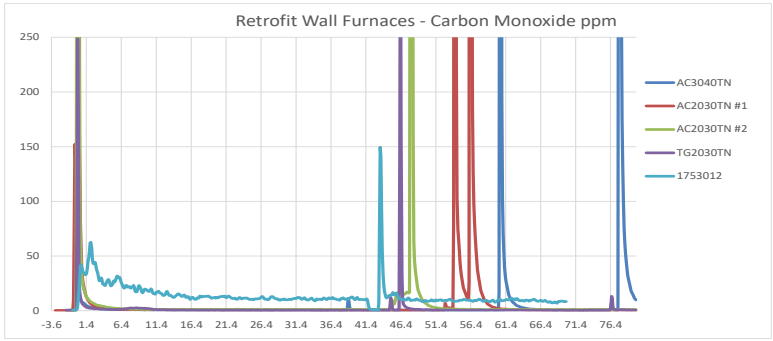


Baseline Wall Furnaces

Suspected gas leak on one unit

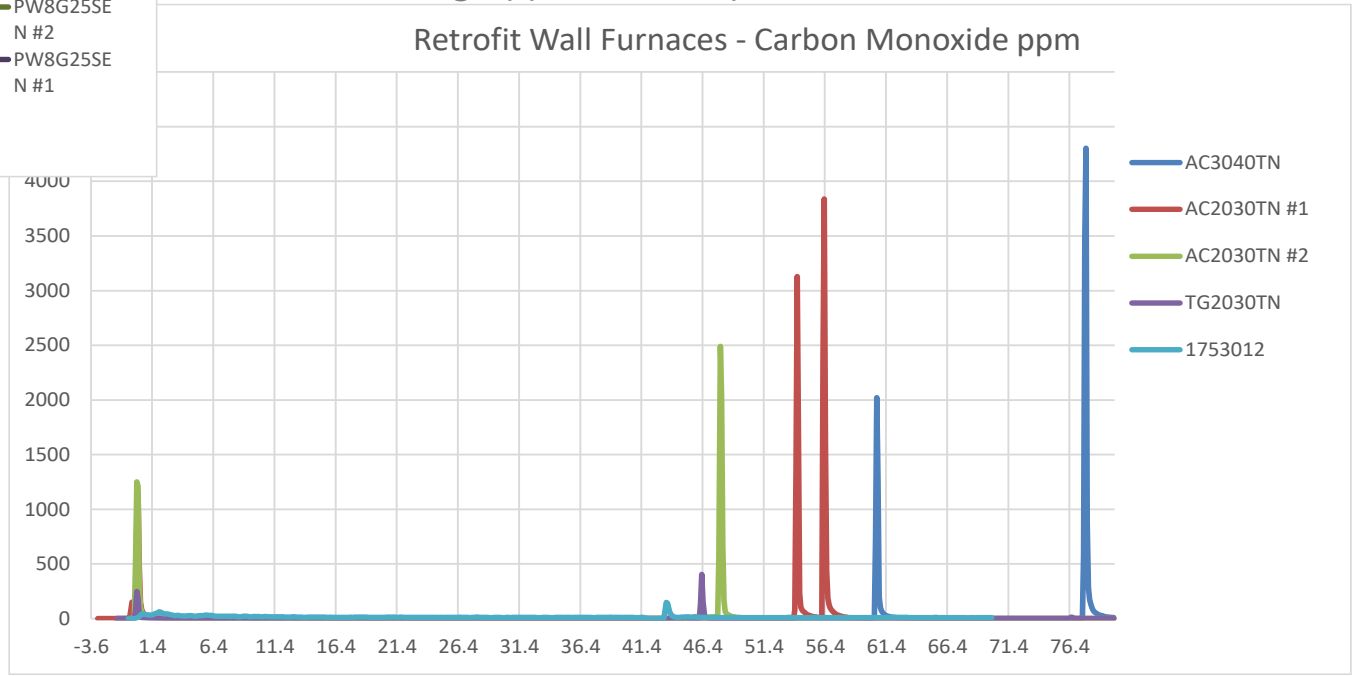


WALL FURNACES | 3-17-23 #11

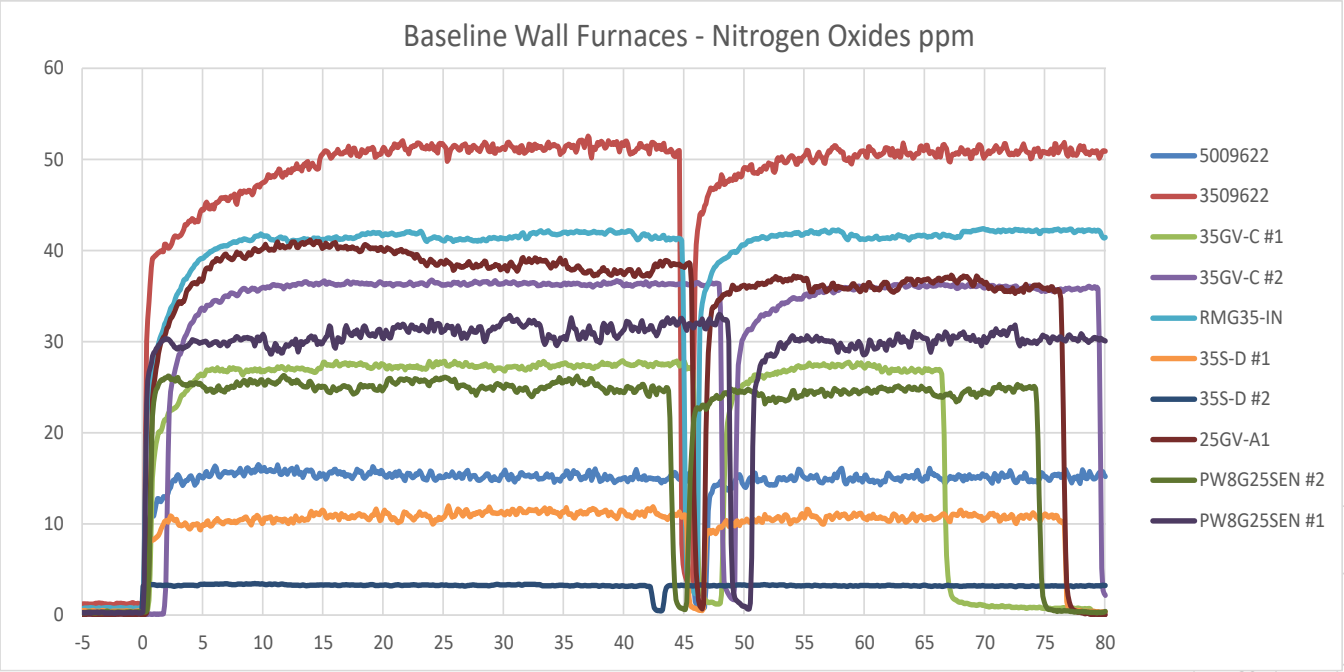


Retrofit Wall Furnaces

Puffs of high ppm at startup & shutdown



Lab Data: Wall Furnace Nitrogen Oxides in Flue Gases

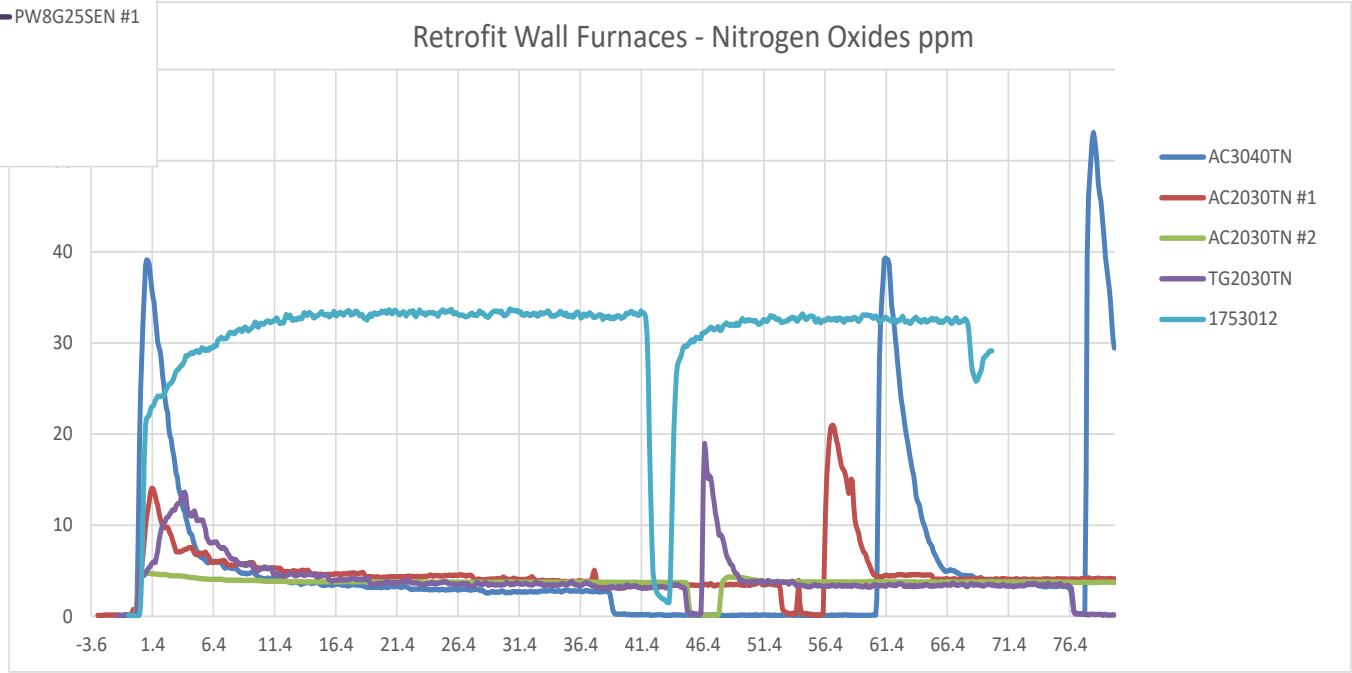


Baseline Wall Furnaces

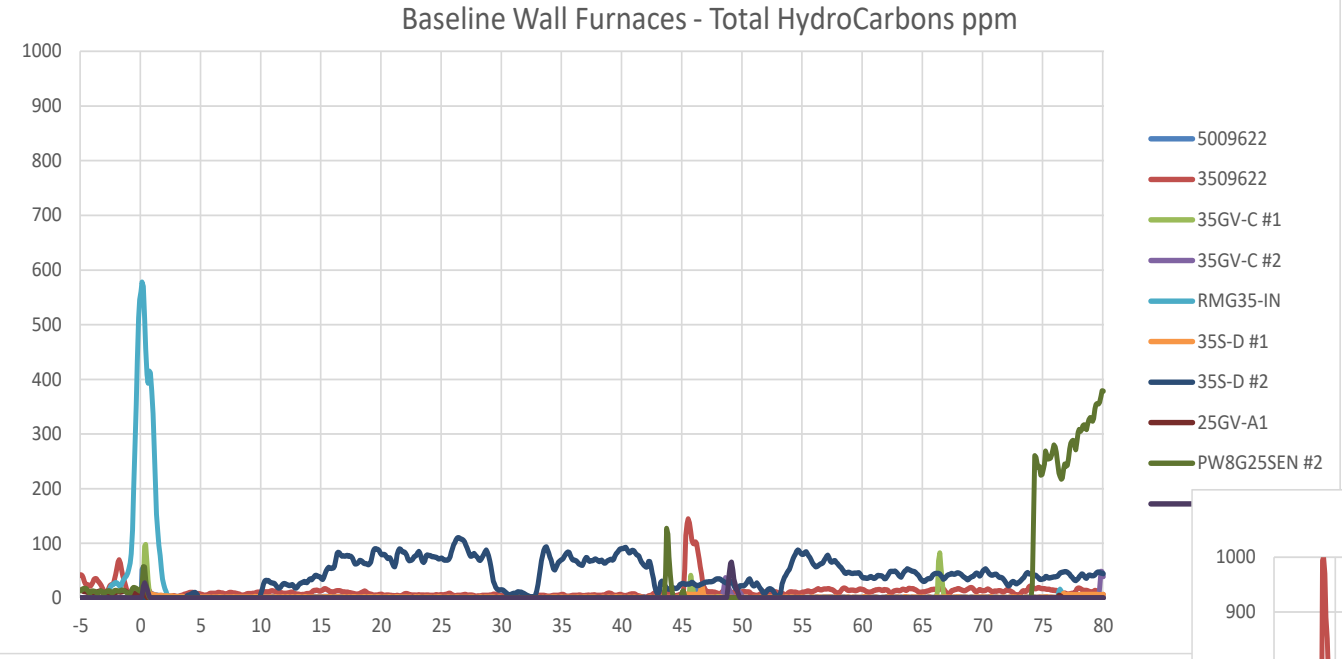
Lots of variability in NOx levels

Retrofit Wall Furnaces

Low NOx models are working



Lab Data: Wall Furnace Total Hydrocarbons in Flue Gases

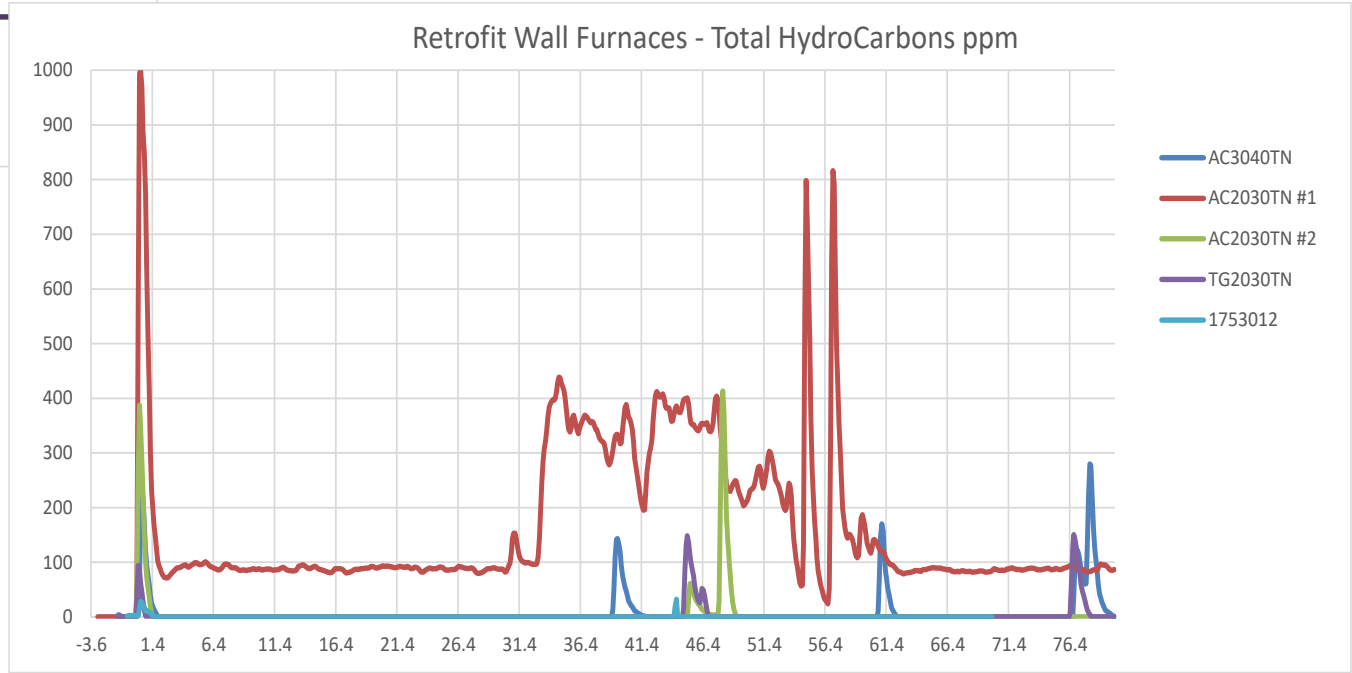


Baseline Wall Furnaces

Suspected gas leak on one unit

Retrofit Wall Furnaces

Puffs of high ppm at startup & shutdown



Baseline & Retrofit Emission Rates from Lab Data

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

Wall Furnace Tested			Carbon Monoxide, lbm/MMBtu			
Manufacturer	Model	Field Site	Standby	Startup	Steady State	Shutdown
Williams	1753012	Hayward 3 & 4 Retrofit	1.093	0.027	0.017	0.023
Williams	AC2030TN #1	LA 104-107 Retrofit	0.620	0.045	0.001	3.106
Williams	AC2030TN #2	LA 104-107 Retrofit	2.216	0.183	0.002	0.681
Williams	AC3040TN	Oakland SF Retrofit	0.230	0.145	0.348	0.048
Williams	TG2030TN	Sacramento 4, 15 & 19 Retrofit	0.075	0.042	0.012	0.041
		Average	**0.846**	**0.088**	**0.076**	**0.780**

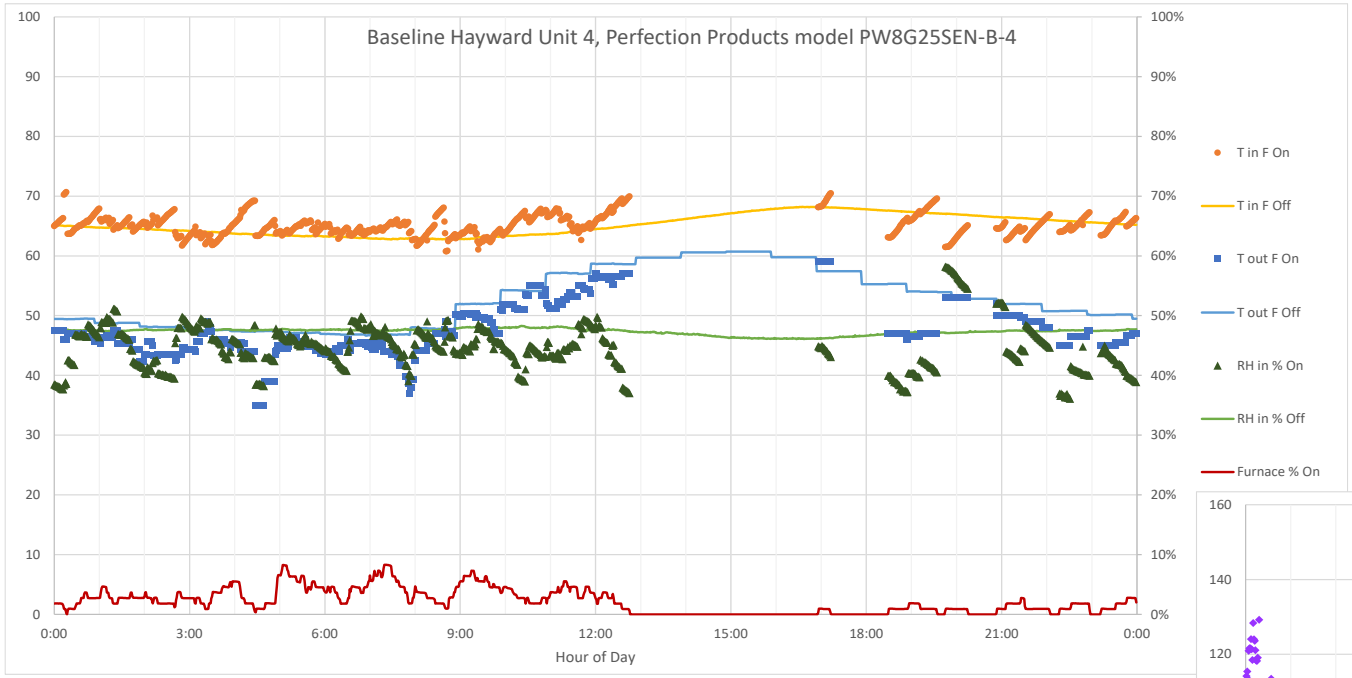
Wall Furnace Tested			Nitrogen Oxides, lbm/MMBtu			
Manufacturer	Model	Field Site	Standby	Startup	Steady State	Shutdown
Perfection Prod	PW8G25SEN #1	Hayward 3 Baseline	0.049	0.102	0.105	0.125
Perfection Prod	PW8G25SEN #2	Hayward 4 Baseline	0.021	0.095	0.133	0.309
Williams	25GV-A1	LA 104 Baseline	0.009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

Wall Furnace Tested			Nitrogen Oxides, lbm/MMBtu			
Manufacturer	Model	Field Site	Standby	Startup	Steady State	Shutdown
Williams	1753012	Hayward 3 & 4 Retrofit	0.178	0.083	0.089	0.266
Williams	AC2030TN #1	LA 104-107 Retrofit	0.027	0.018	0.012	0.019
Williams	AC2030TN #2	LA 104-107 Retrofit	0.030	0.012	0.012	0.015
Williams	AC3040TN	Oakland SF Retrofit	0.077	0.032	0.043	0.032
Williams	TG2030TN	Sacramento 4, 15 & 19 Retrofit	0.039	0.014	0.013	0.016
		Average	**0.070**	**0.031**	**0.034**	**0.069**

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

Wall Furnace Tested			Total Hydrocarbons, lbm/MMBtu			
Manufacturer	Model	Field Site	Standby	Startup	Steady State	Shutdown
Williams	1753012	Hayward 3 & 4 Retrofit	0.004	0.003	0.000	0.000
Williams	AC2030TN #1	LA 104-107 Retrofit	0.171	0.160	0.258	1.499
Williams	AC2030TN #2	LA 104-107 Retrofit	0.008	0.013	0.000	0.597
Williams	AC3040TN	Oakland SF Retrofit	0.004	0.013	0.026	1.386
Williams	TG2030TN	Sacramento 4, 15 & 19 Retrofit	0.002	0.004	0.032	1.144
		Average	**0.038**	**0.038**	**0.063**	**0.925**

Field Data: Tin, Tout, RHin, % On, Watts vs Time of Day



Baseline Wall Furnace

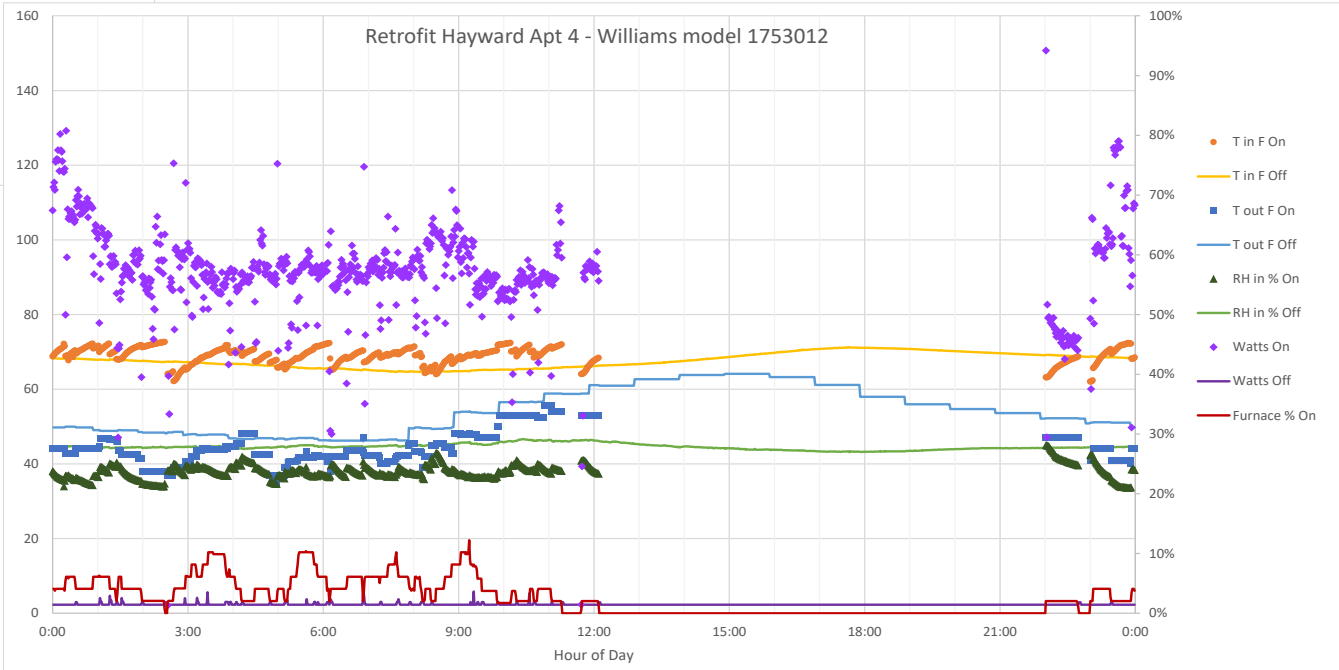
Top Vent Gravity

HAYWARD 4

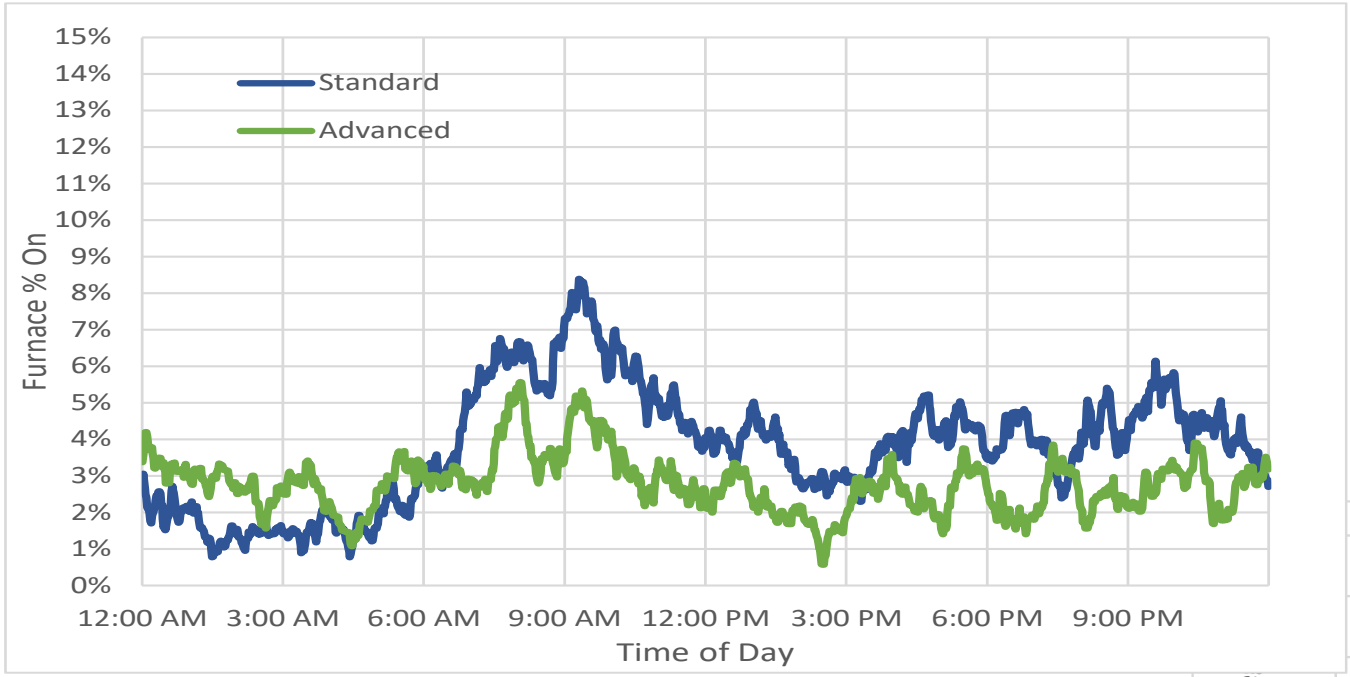
Average Heating Season
On & Off Operation

Retrofit Wall Furnace

Direct Vent Fan-Type Condensing



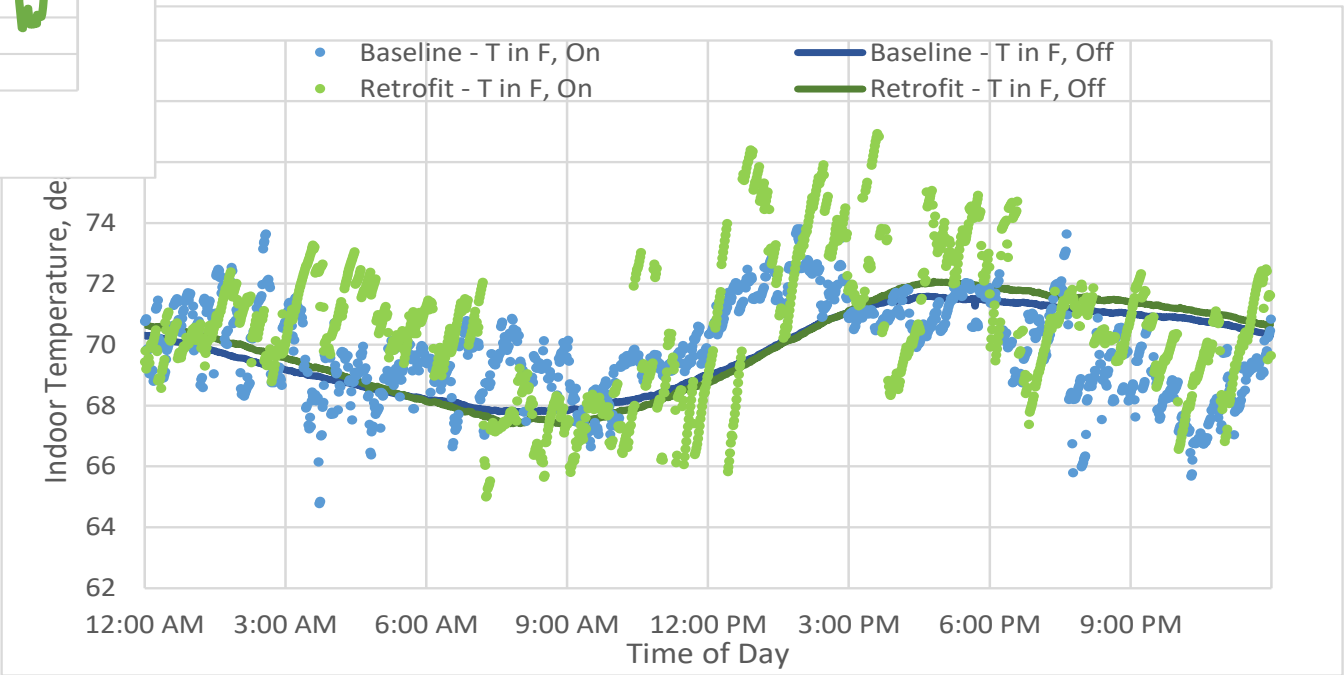
Operation vs Time of Day from Field Data



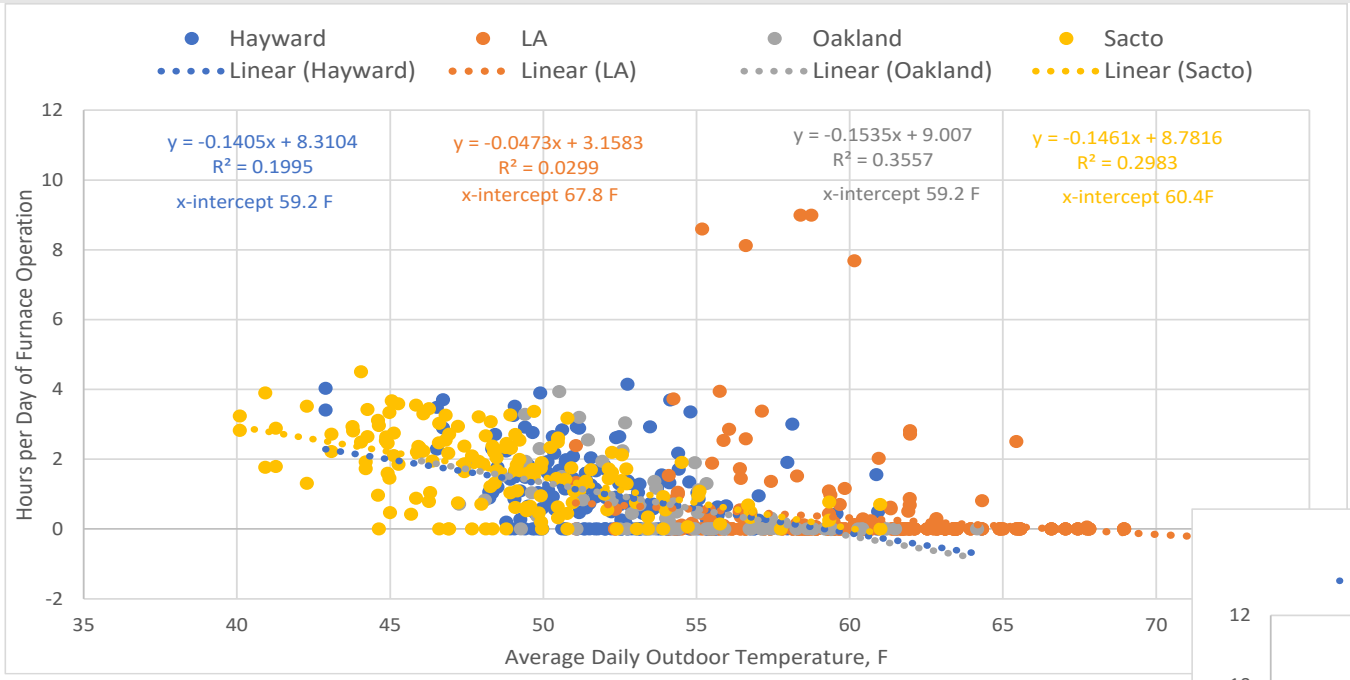
Average of All Sites
% On vs Time of Day

Reduced operating hours due to greater output capacity & better heat distribution

Average of All Sites
Indoor T vs Time of Day



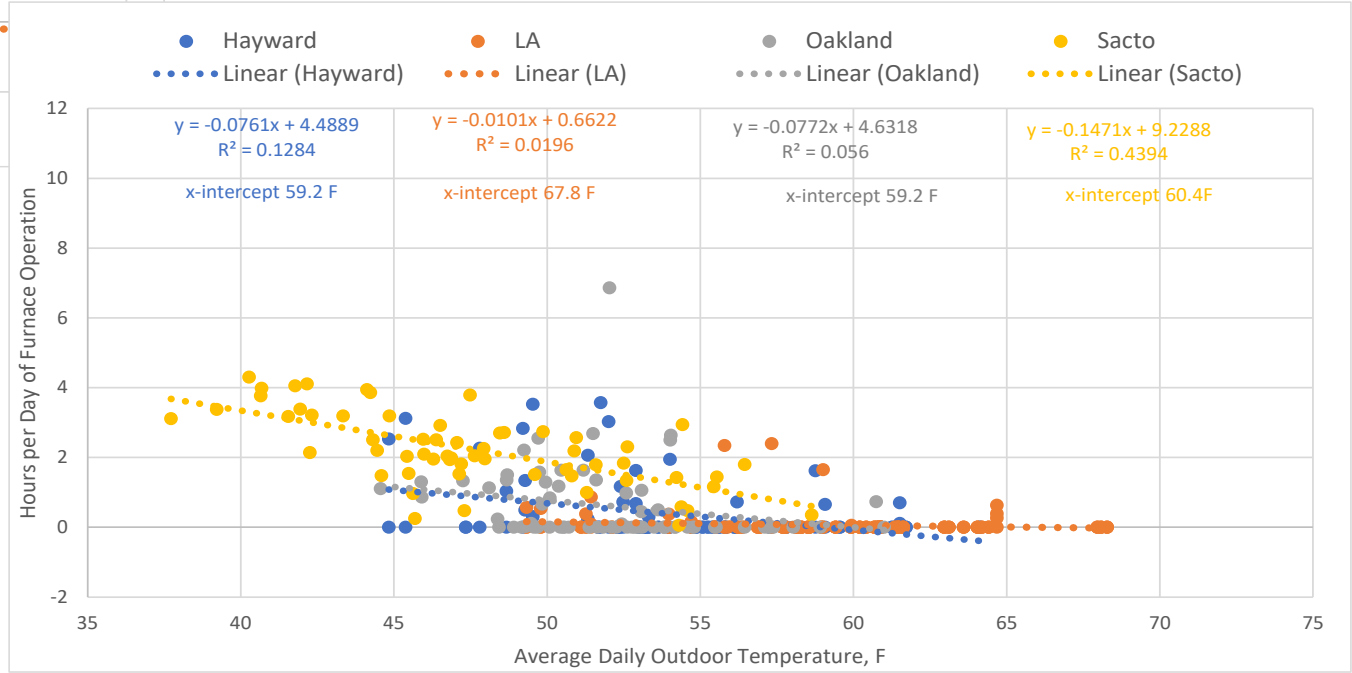
Operation vs Outdoor Temperature from Field Data



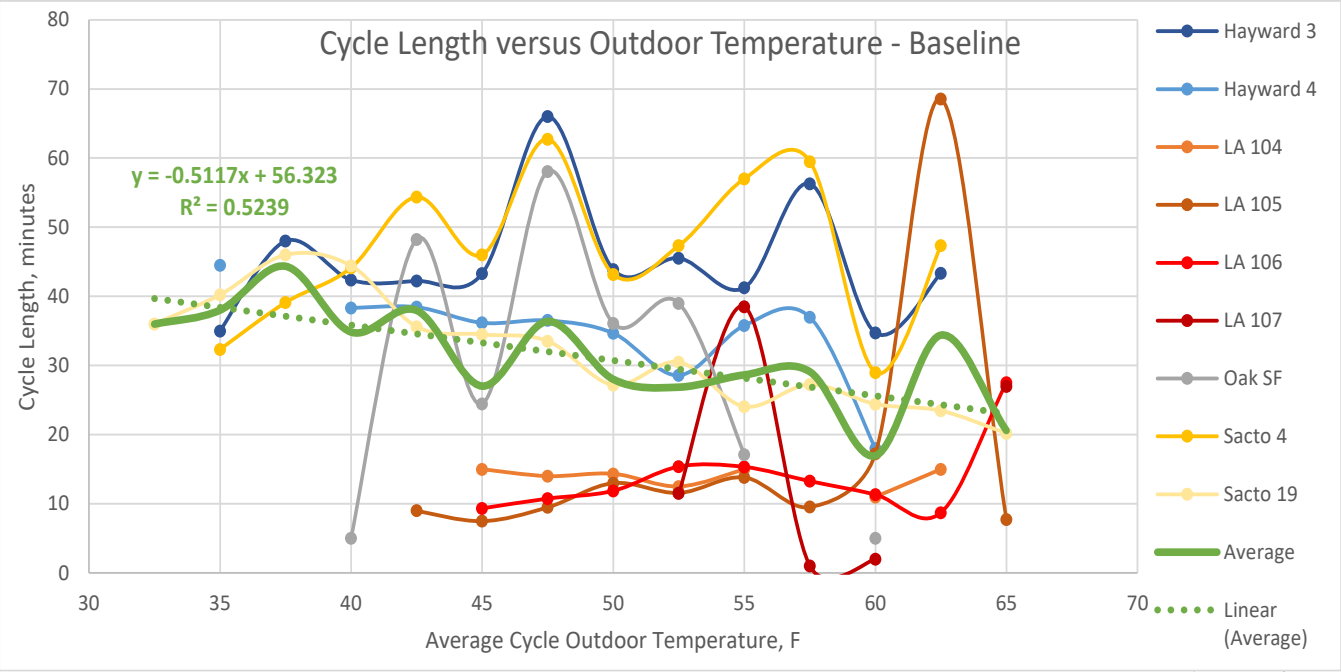
Baseline Wall Furnaces

Used to estimate daily hours of use over typical meteorological year (TMY)

Retrofit Wall Furnaces



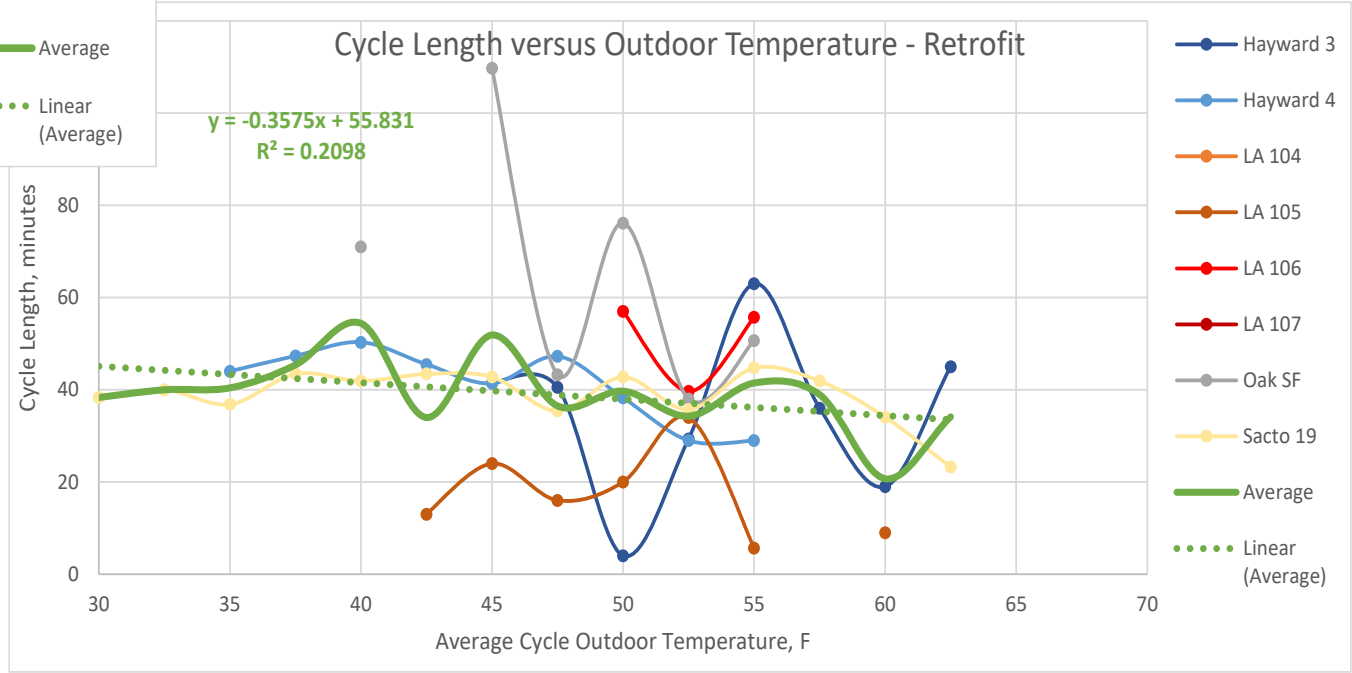
Cycle Length vs Outdoor Temperature from Field Data



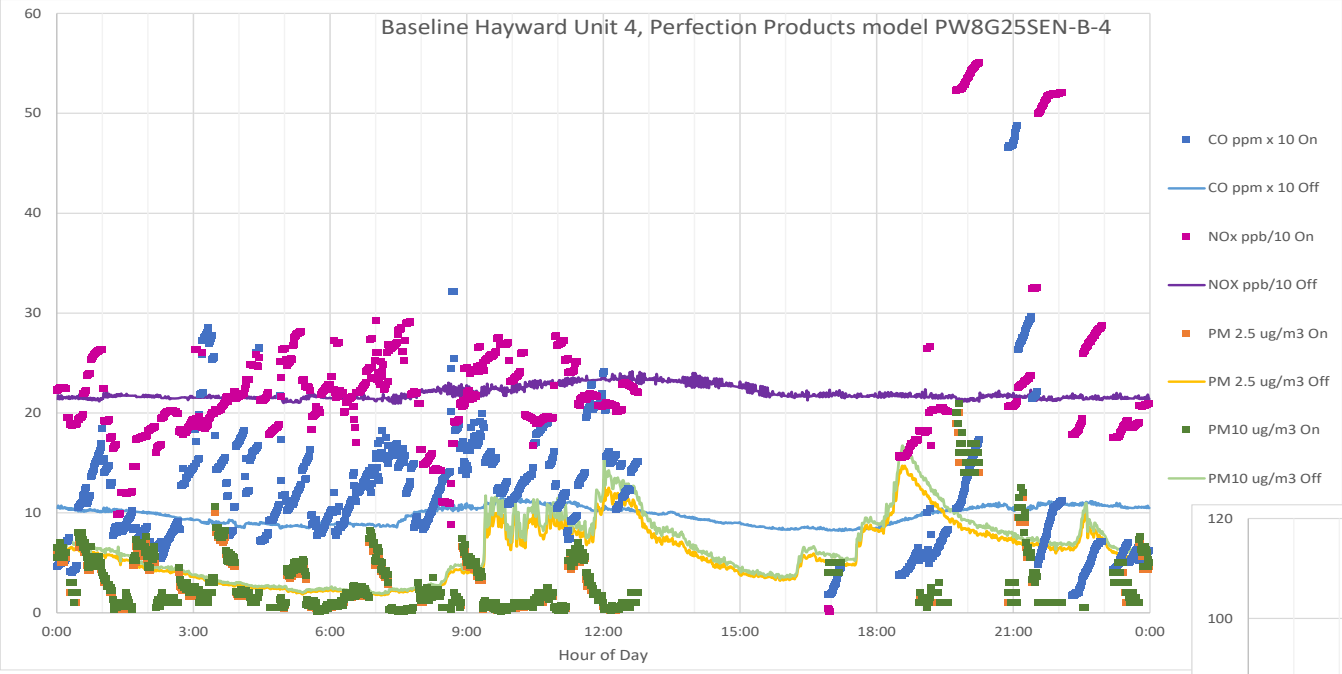
Baseline Wall Furnaces

Operating hours & cycle length >> cycles per day
Used to estimate emissions

Retrofit Wall Furnaces



Field Data: Indoor CO, NOx, PM2.5, PM10



Baseline Wall Furnace

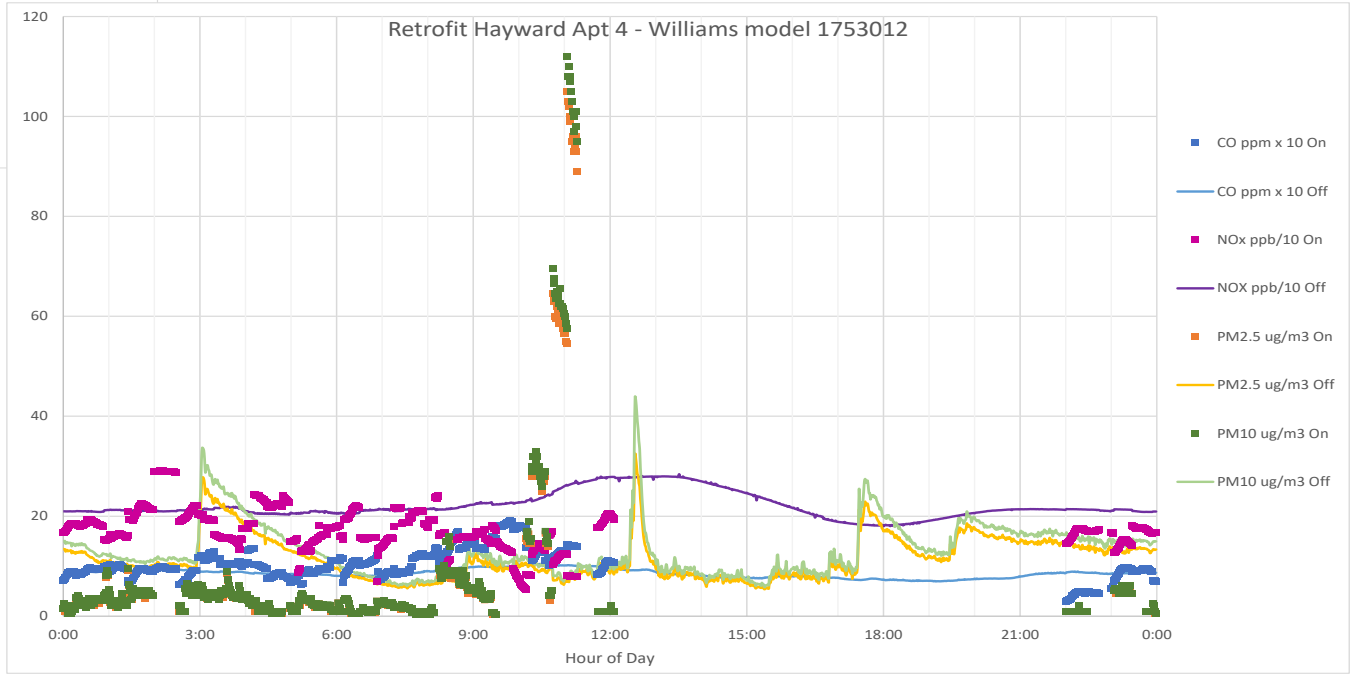
Top Vent Gravity

HAYWARD 4

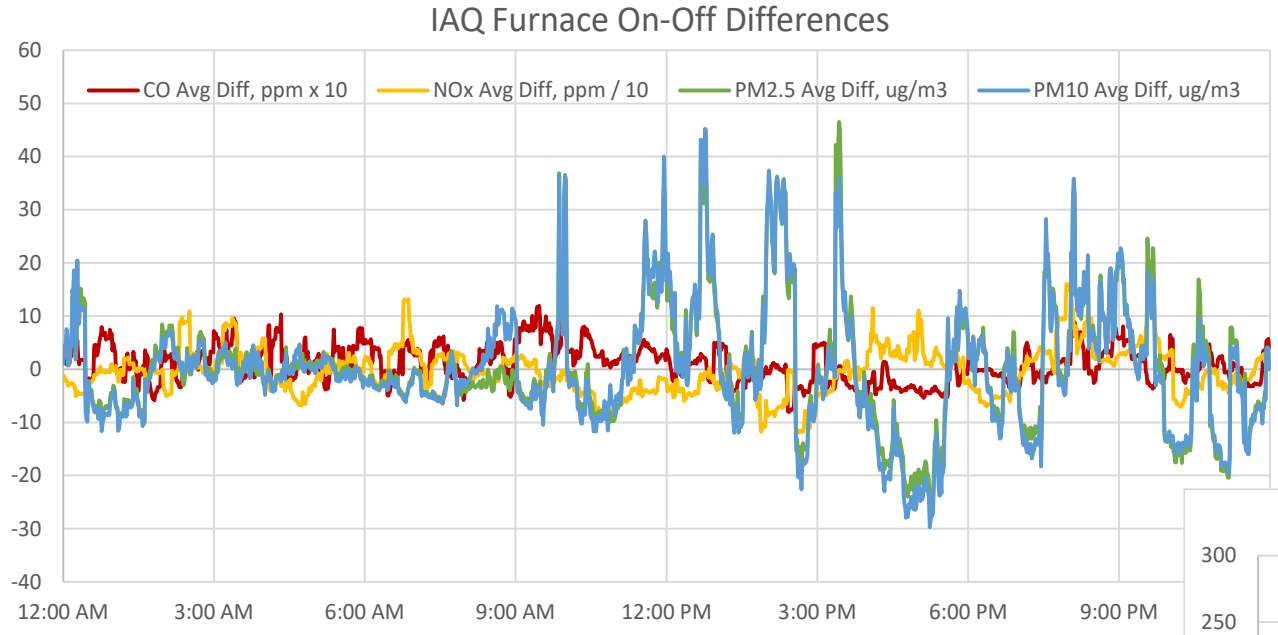
Average Heating Season
On & Off Operation

Retrofit Wall Furnace

Direct Vent Fan-Type Condensing



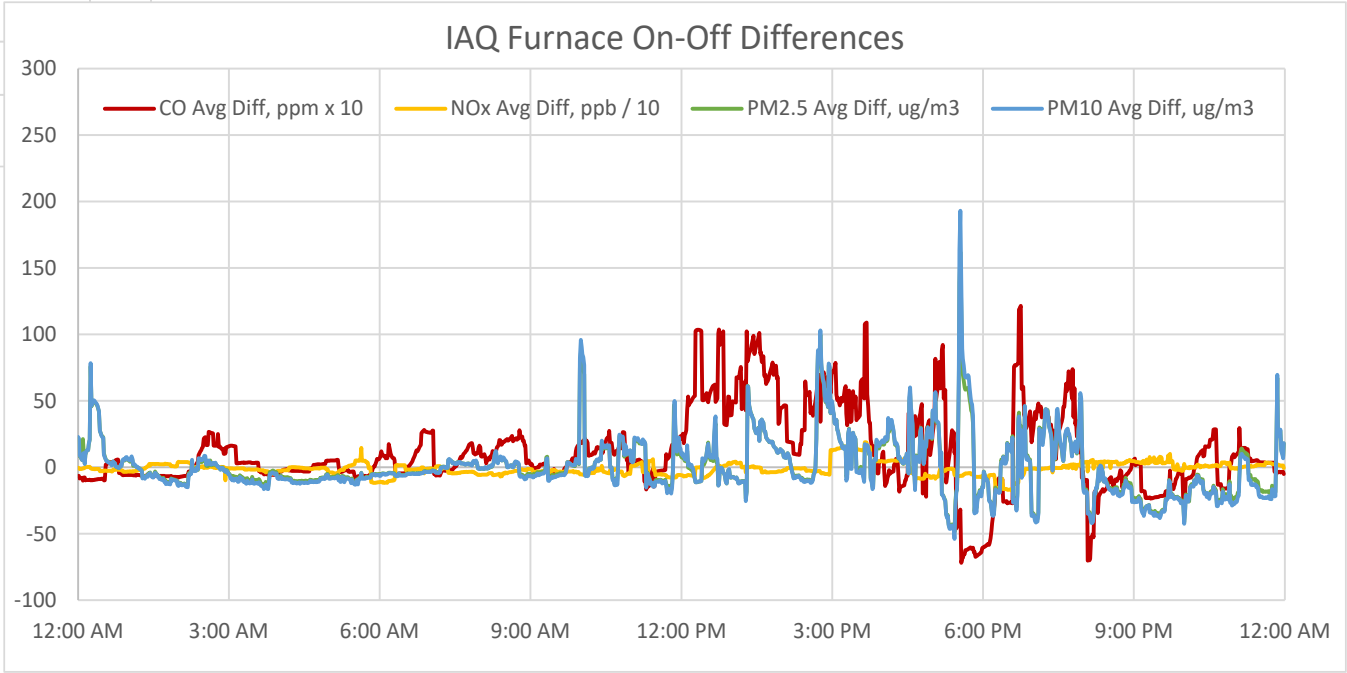
IAQ Delta On-Off vs Time of Day from Field Data



Baseline Wall Furnaces

Indoor pollutant concentrations while furnaces were on & off show how furnaces impact IAQ

Retrofit Wall Furnaces



Operability & Reliability from Field Data

- Installation
  - Contractor training on new technology
  - Additional components may be needed
    - New exhaust flue, resizing of wall cavity
    - AC power access, either plug in or hard-wire
    - Drain access for condensing furnaces
- Controls
  - Need to reduce response time
  - Need to tighten deadband
- Fan-type furnaces
  - Noisier than gravity furnaces
    - ASHRAE Standard 62 requires 3 sones or less for intermittent ventilation fans
  - But have better heat distribution
- Self-charging batteries
  - Improvements made but not yet tested
  - Charging procedures need clarification
- **All issues can be easily remedied**

Annual Energy & Cost Savings

Annual	Baseline	Retrofit	Savings	% Savings
Operating Hours	188	118	**70**	**37%**
Cycles	420	210	**210**	**50%**
MMBtu	11.5	3.7	**7.8**	**68%**
kWh	0	2.4	**-2.3**	**+100%**
Utility Cost	$220	$70	**$150**	**68%**

- More efficient units without standing pilots
- More output & distribution > fewer operating hours
- Solid energy & cost savings

BASELINE Wall Furnace			ACTUAL Operation - TMY3 Annual - Pilot on All Year					
Manufacturer	Model	Field Site	Operating hrs/year	Cycles/year	Avg Cycle Minutes	MMBtu/year	kWh/year	Utility Cost
Perfection Products	PW8G25SEN #1	Hayward 3	385.3	568	40.7	12.17	0.0	$231
Perfection Products	PW8G25SEN #2	Hayward 4	156.3	295	31.8	7.55	0.0	$143
Williams	25GV-A1	LA 104	23.0	113	12.2	7.13	0.0	$135
Williams	35GV-C #1	LA 105	298.0	721	24.8	13.85	0.0	$263
Williams	35GV-C #2	LA 106	114.0	573	11.9	8.55	0.0	$163
Williams	RMG35-IN	LA 107	23.9	94	15.3	5.13	0.0	$97
Williams	5009622.0	Oakland SF	189.3	346	32.9	17.77	0.0	$338
Holly General	35S-D #1	Sacto 4	170.2	237	43.1	11.55	0.0	$219
Holly General	35S-D #2	Sacto 15	262.5	515	30.6	13.67	0.0	$260
Williams	3509622.0	Sacto 19	262.4	570	27.6	17.79	0.0	$338
		Baseline Average	**188.5**	**417**	**27.1**	**11.52**	**0.0**	**$219**
RETROFIT Wall Furnace			**ACTUAL Operation - TMY3 Annual - No Standing Pilot**					
Manufacturer	Model	Field Site	Operating hrs/year	Cycles/year	Avg Cycle Minutes	MMBtu/year	kWh/year	Utility Cost
Williams	1753012	Hayward 3	36.5	83	26.4	0.72	3.6	$15
Williams	1753012	Hayward 4	166.0	269	37.0	3.28	16.6	$67
Williams	AC2030TN	LA 104	20.0	84	14.2	0.66	0.3	$13
Williams	AC2030TN	LA 105	19.0	87	13.1	0.63	0.2	$12
Williams	AC2030TN	LA 106	78.6	121	38.8	2.61	1.0	$50
Williams	AC2030TN	LA 107	28.9	79	21.9	0.96	0.4	$18
Williams	AC3040TN	Oakland SFH	178.0	240	44.5	7.43	2.2	$142
Williams	TG2030TN	Sacto 4	128.5	223	34.5	4.03	0.0	$77
Williams	TG2030TN	Sacto 19 T2	239.0	224	63.9	7.51	0.0	$143
Williams	TG2030TN	Sacto 19	292.8	360	48.9	9.20	0.0	$175
		Retrofit Average	**118.7**	**208**	**34.3**	**3.70**	**2.4**	**$71**
TMY3 Actual Annual Savings								
Baseline to Retrofit Description		Field Site	Operating hrs/year	Cycles/year	Avg Cycle Minutes	MMBtu/year	kWh/year	Utility Cost
Gravity to Direct Vent Condensing		Hayward 3	348.8	485	14.4	11.45	-3.6	$217
Gravity to Direct Vent Condensing		Hayward 4	-9.7	26	-5.2	4.26	-16.6	$77
Gravity to Fan-Type w/AC Power		LA 104	3.0	29	-2.0	6.47	-0.3	$123
Gravit			279.0	633	11.7	13.22	-0.2	$251
Gravit			35.4	451	26.9	5.95	-1.0	$113
Gravit			-5.0	14	-6.6	4.17	-0.4	$79
2-Side			11.3	106	11.6	10.34	-2.2	$196
Gravity to Fan-Type Self-Powered		Sacto 4	41.7	13	8.6	7.52	0.0	$143
Gravity to Fan-Type Self-Powered		Sacto 15 to 19 T2	23.4	291	33.4	6.17	0.0	$117
Gravity to Fan-Type Self-Powered		Sacto 19	-30.4	210	21.2	8.60	0.0	$163
		Savings	**69.7**	**226**	**18.5**	**7.81**	**-2.4**	**$148**
		% Savings	**37%**	**54%**	**68%**	**68%**		**68%**

$19 per MMBtu,
$0.25 per kWh

Annual Emission Reductions

Annual	Baseline	Retrofit	Savings	% Savings
Operating Hours	188	118	**70**	**37%**
Cycles	420	210	**210**	**50%**
CO lbm	2.39	0.32	**2.07**	**87%**
NOx lbm (lbm/MMBtu)	0.70 (0.061)	0.10 (0.031)	**0.60 (0.030)**	**86%**
THC lbm	1.21	0.08	**1.12**	**93%**

- Fewer operating hours & cycles, no standing pilot
- Improved combustion, low NOx controls
- Much lower emissions

BASELINE Wall Furnace			ACTUAL Operation - TMY3 Annual - Pilot on All Year					
Manufacturer	Model	Field Site	Operating hrs/year	Cycles/year	Avg Cycle Minutes	CO lbm/year	NOx lbm/year	THC lbm/year
Perfection Products	PW8G25SEN #1	Hayward 3	385.3	568	40.7	2.02	1.02	0.58
Perfection Products	PW8G25SEN #2	Hayward 4	156.3	295	31.8	0.37	0.43	2.57
Williams	25GV-A1	LA 104	23.0	113	12.2	1.66	0.12	3.66
Williams	35GV-C #1	LA 105	298.0	721	24.8	1.13	0.97	0.07
Williams	35GV-C #2	LA 106	114.0	573	11.9	0.55	0.43	0.00
Williams	RMG35-IN	LA 107	23.9	94	15.3	0.81	0.26	1.98
Williams	5009622.0	Oakland SF	189.3	346	32.9	7.61	1.22	0.10
Holly General	35S-D #1	Sacto 4	170.2	237	43.1	1.04	0.71	0.04
Holly General	35S-D #2	Sacto 15	262.5	515	30.6	7.57	0.26	0.36
Williams	3509622.0	Sacto 19	262.4	570	27.6	1.12	1.56	2.74
		Baseline Average	**188.5**	**417**	**27.1**	**2.39**	**0.70**	**1.21**
RETROFIT Wall Furnace			**ACTUAL Operation - TMY3 Annual - No Standing Pilot**					
Manufacturer	Model	Field Site	Operating hrs/year	Cycles/year	Avg Cycle Minutes	CO lbm/year	NOx lbm/year	THC lbm/year
Williams	1753012	Hayward 3	36.5	83	26.4	0.02	0.06	0.00
Williams	1753012	Hayward 4	166.0	269	37.0	0.07	0.28	0.01
Williams	AC2030TN	LA 104	20.0	84	14.2	0.08	0.01	0.06
Williams	AC2030TN	LA 105	19.0	87	13.1	0.07	0.01	0.06
Williams	AC2030TN	LA 106	78.6	121	38.8	0.22	0.04	0.24
Williams	AC2030TN	LA 107	28.9	79	21.9	0.11	0.01	0.08
Williams	AC3040TN	Oakland SFH	178.0	240	44.5	2.04	0.29	0.15
Williams	TG2030TN	Sacto 4	128.5	223	34.5	0.14	0.05	0.02
Williams	TG2030TN	Sacto 19 T2	239.0	224	63.9	0.19	0.10	0.12
Williams	TG2030TN	Sacto 19	292.8	360	48.9	0.26	0.12	0.10
		Retrofit Average	**118.7**	**208**	**34.3**	**0.32**	**0.10**	**0.08**
TMY3 Actual Annual Savings								
Baseline to Retrofit Description	Field Site		Operating hrs/year	Cycles/year	Avg Cycle Minutes	CO lbm/year	NOx lbm/year	THC lbm/year
Gravity to Direct Vent Condensing	Hayward 3		348.8	485	14.4	2.01	0.96	0.58
Gravity to Direct Vent Condensing	Hayward 4		-9.7	26	-5.2	0.30	0.15	2.56
Gravity to Fan-Type w/AC Power	LA 104		3.0	29	-2.0	1.58	0.11	3.60
Gravity to Fan-Type w/AC Power	LA 105		279.0	633	11.7	1.05	0.96	0.01
Gravity to Fan-Type w/AC Power	LA 106		35.4	451	-26.9	0.34	0.40	-0.23
Gravity to Fan-Type w/AC Power	LA 107		-5.0	14	-6.6	0.70	0.24	1.89
2-Sided Gravity to Fan-Type w/AC Pow	Oakland SF		11.3	106	-11.6	5.57	0.93	-0.05
Gravity to Fan-Type Self-Powered	Sacto 4		41.7	13	8.6	0.90	0.65	0.02
Gravity to Fan-Type Self-Powered	Sacto 15 to 19 T2		23.4	291	-33.4	7.39	0.16	0.24
Gravity to Fan-Type Self-Powered	Sacto 19		-30.4	210	-21.2	0.86	1.44	2.64
		Savings	**69.7**	**210**	**-7.2**	**2.07**	**0.60**	**1.12**
		% Savings	**37%**	**50%**	**-27%**	**87%**	**86%**	**93%**

Indoor Air Quality Improvements

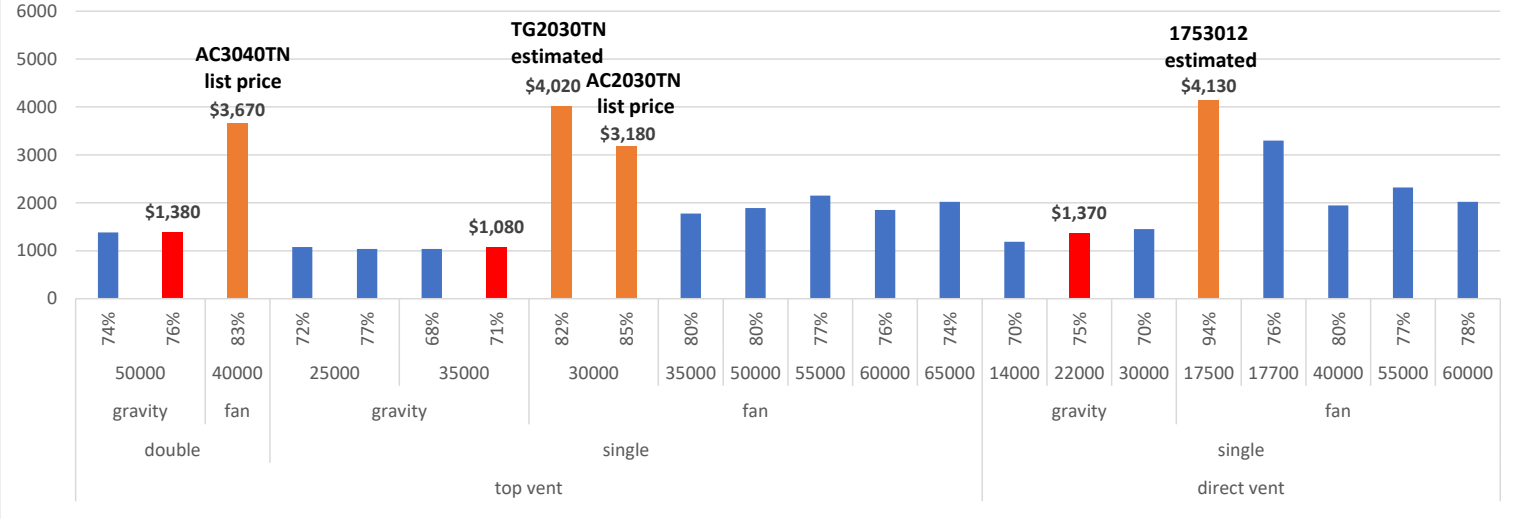
Average IAQ Concentrations	CO Off ppmx10	CO On ppmx10	NOx Off ppb/10	NOx On ppb/10	PM2.5 Off ug/m3	PM2.5 On ug/m3	PM10 Off ug/m3	PM10 On ug/m3
Baseline Average	15.7	18.9	17.4	19.0	15.2	15.5	16.5	18.5
Retrofit Average	15.9	13.6	24.7	18.8	21.6	20.4	24.2	22.4
Reduction	-0.3	5.2	-7.3	0.2	-6.4	-4.9	-7.7	-3.9
% 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)	

- Retrofits did not improve IAQ
  - Despite large emission reductions
- Operating the furnace improves IAQ
  - Max concentrations lower when ON
  - Even running the pilot improves IAQ

- Wall furnaces are not driving IAQ
- Need to control indoor pollutants via source reduction, dedicated ventilation

Cost Effectiveness



- Advanced wall furnace costs are high compared to standard wall furnaces
- Low energy use reduces furnace cost effectiveness
- Simple payback long right now, utility incentives needed

Baseline to Retrofit Description	Field Site	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	$217	$4,130	$1,370	$150	$2,910	13.4	$3,590	$750	7.5
Gravity to Direct Vent Condensing	Hayward 4	$77	$4,130	$1,370	$150	$2,910	37.9	$2,550	$750	7.6
Gravity to Fan-Type w/AC Power	LA 104	$123	$3,180	$1,080	$0	$2,100	17.1	$2,500	$500	7.5
Gravity to Fan-Type w/AC Power	LA 105	$251	$3,180	$1,080	$0	$2,100	8.4	$3,460	$500	7.5
Gravity to Fan-Type w/AC Power	LA 106	$113	$3,180	$1,080	$0	$2,100	18.6	$2,430	$500	7.5
Gravity to Fan-Type w/AC Power	LA 107	$79	$3,180	$1,080	$0	$2,100	26.5	$2,170	$500	7.5
2-Sided Gravity to Fan-Type w/AC Power	Oakland SFH	$196	$3,670	$1,380	$0	$2,290	11.7	$3,350	$500	7.5
Gravity to Fan-Type Self-Powered	Sacramento 4	$143	$4,020	$1,080	$0	$2,940	20.6	$2,650	$500	7.5
Gravity to Fan-Type Self-Powered	Sacto 15 to 19 T2	$117	$4,020	$1,080	$0	$2,940	25.1	$2,460	$500	7.5
Gravity to Fan-Type Self-Powered	Sacramento 19	$163	$4,020	$1,080	$0	$2,940	18.0	$2,800	$500	7.5
	Average	**$148**	**$3,670**	**$1,170**	**$30**	**$2,530**	**19.7**	**$2,800**	**$550**	7.5

Takeaways for Advanced Wall Furnaces

- Wall furnaces are operated sparingly
- Advanced furnaces reduce energy use & utility costs by 68%
- Advanced furnaces reduce emissions by at least 86%
  - All achieved 0.033 lbm/MMBtu NOx limit except the condensing & double-sided furnaces
- Wall furnaces do not drive IAQ
- Work underway to reduce noise, improve controls, ensure reliability
- Cost effectiveness currently high, utility incentives needed for now

FOR MORE INFO https://www.gti.energy/california-wall-furnaces/

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