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FINAL PROJECT REPORT

# ADVANCED FOODSERVICE APPLIANCES FOR CALIFORNIA RESTAURANTS

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# PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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# ABSTRACT

The purpose of this project was to develop new products and technologies to support energy efficiency gains in the commercial foodservice marketplace. The scope covered six commercial foodservice products: conveyor ovens, convection ovens, ranges, foodservice woks, under-fired broilers, and over-fired broilers. Improvements to commercial water heating field performance were investigated as an additional task.

The methods used in this project for foodservice equipment development included literature surveys and interviews, technology assessments, prototype development, laboratory and field testing, feedback from cooking professionals and technology transfer. Technology improvements applied to the products included advanced burner systems, improved controls, changes in heat exchange surfaces and significant product redesigns.

The foodservice equipment tasks resulted in improvements in equipment efficiency of 23-63 percent from the baseline technology as measured in the laboratory and confirmed by field test data. Feedback from the field was very positive for all of the products, especially the under-fired broiler where the design also improved working conditions in commercial kitchens.

Tank-type water heaters operating in systems with no hot water recirculation offered the best system delivery efficiency. Standard-efficiency tank-type water heaters showed more degradation in performance when a recirculation pump was in use. Adding insulation to the distribution system increased the system delivery efficiency and delivery temperature at the fixtures, a topic for Title 24 in the future. Heater efficiency was found to decrease rapidly with entering water temperatures exceeding 90 degrees Fahrenheit (32 degrees Celsius) for systems where preheating of incoming water was being performed.

Three of the products studied were introduced into the marketplace during the project by Lincoln (conveyor oven), Garland (convection oven) and Royal Range (under-fired broiler). Several new research areas were also identified to further improve the efficiency of these commercial foodservice and commercial water heating products.

Keywords: commercial foodservice, water heating, conveyor oven, convection oven, range, wok, under-fired broiler

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# EXECUTIVE SUMMARY

## Introduction

In 2012 the commercial foodservice industry employed 1.475 million people in California in over 62,000 establishments, according to the National Restaurant Association. This large industry uses five to 10 times more energy per square foot than other commercial spaces, offering a significant energy savings opportunity. The technology baseline for commercial foodservice appliances is very low, with peak (full load) efficiencies in the 20-30 percent range and actual in-kitchen utilization efficiencies in the five to 10 percent range. The appliances are typically operated under full-load conditions for only a small portion of their daily operating hours, with the remaining time being operated under part-load and idle conditions. High burner firing rates with minimal control systems are standard. There are 800,000 commercial cooking appliances installed and operating in California and roughly 70 percent are powered by natural gas with few but increasing ENERGY STAR® equipment options. Most water heaters installed in foodservice facilities in California just meet the minimum efficiency standard. The potential to reduce energy use for water heating in commercial operations could be as much as 100 million therms per year with effective research and market transformation. The opportunity for efficiency improvement through technology development for this sector is very significant, offering good payback for the research and development investment.

## Project Purpose

The purpose of this project was to investigate technology opportunities in seven key product areas impacting the commercial foodservice marketplace:

1. Conveyor ovens.
2. Convection ovens.
3. Ranges.
4. Woks.
5. Under-fired charbroilers.
6. Over-fired charbroilers.
7. Water heaters.

The investigation was designed to identify new product opportunities, collect data from the laboratory and the field and pursue design options into a design or prototype phase. The research team also intended to assess the opportunity for new products or pursue new product development opportunities with commercial partners for several of the product areas.

## Project Results

Each task had specific objectives focused on the need to advance new technologies to reduce energy in the commercial foodservice marketplace by demonstrating designs that improve the cooking-energy efficiency and reduce standby energy consumption within the different cooking

appliance categories and to demonstrate the benefit of improving the thermal efficiency and improved distribution of hot water heating systems.

The objective of the commercial conveyor oven project was to significantly improve the efficiency of commercial gas conveyor ovens through adoption of advanced burners, combustion blowers, sensors or control systems improvements. This project encompassed the development, lab and/or field testing of prototype appliances, the assessment of the appliances' ability to perform and the quantification of the energy savings that high-efficiency ovens could provide to California restaurants. The efficiency goal for conveyor ovens was set at a 12 percent increase from the baseline cooking energy efficiency.

The objective of the commercial convection oven project was to improve the efficiency of commercial foodservice gas convection ovens. Typical gas-fired full-sized convection ovens have heavy load efficiencies in the mid-thirties. A majority of existing equipment in the field is older and has fewer engineered features that promote efficiency. Leakage around the door seals and high flue exhaust temperatures result in energy losses. A lower idle rate and improved combustion was achieved by addressing these two issues. It was expected that 400-470 therms per year per oven would be saved for an efficiency improvement of 30-60 percent above the baseline convection oven depending on business operating hours. This increase in baseline cooking energy efficiency more than doubled the original goal of a 14 percent increase. This project encompassed the development, lab and/or field testing of prototype appliances, the assessment of the appliances' ability to perform and the quantification of the energy savings that high-efficiency ovens could provide to California restaurants.

The objective of the commercial range project was to improve the efficiency of commercial foodservice gas open top ranges. All inventory of this equipment category is based on standard technology with little to no energy efficient features. Researchers investigated several energy savings methods and selected a pilot-off-at-night system, an on-demand burner system and an improved cooking vessel as areas of improvement for the open top range category. Three industry manufacturers partnered with this project: Montague integrated the pilot-off-at-night system into their product line, Lang produced an on-demand burner range and Eneron developed the finned-bottom Turbo Pot. This project encompassed the development, lab and/or field testing of prototype appliances, the assessment of the appliances' ability to perform and the quantification of the energy savings that high-efficiency ovens could provide to California restaurants. The cooking energy efficiency goal for open top ranges was set at a 15 percent increase from the baseline efficiency.

The objective of the commercial wok project was to significantly improve the efficiency of a commercial gas wok range through adoption of an advanced burner system to replace the existing simple jet ring style burner that used orifice spuds mounted from circular manifold pipes. This project encompassed the development, lab and/or field testing of prototype appliances, the assessment of the appliances' ability to perform and the quantification of the energy savings that high-efficiency ovens could provide to California restaurants. The cooking energy efficiency goal for commercial gas wok ranges was set at a 20 percent increase from the baseline efficiency.

The objective of the commercial under-fired charbroiler project was to increase the real-world (in-kitchen) utilization efficiency of gas charbroilers above the typical five percent and to reduce the heat gain to the space proportionally without impacting the cooking characteristics of the device or changing the look or flavor of the cooked products. This objective was addressed by designing an advanced charbroiler with a retractable hood and thermostat control to improve performance while maintaining the unique cooking characteristics of the device. This project encompassed the development, lab and/or field testing of prototype appliances, the assessment of the appliances' ability to perform and the quantification of the energy savings that high-efficiency ovens could provide to California restaurants. The cooking energy efficiency goal for under-fired charbroilers was set at a 17 percent increase from the baseline efficiency of five percent.

The objective of the commercial over-fired charbroiler project was to pursue development of a prototype in the laboratory that would increase cooking efficiency by 17 percent compared to standard designs for combination cooking and idle modes. This project encompassed the development, lab and/or field testing of prototype appliances, the assessment of the appliances' ability to perform and the quantification of the energy savings that high-efficiency ovens could provide to California restaurants.

Table 1 provides the specific energy savings goal for each appliance type:

**Table 1: Energy Savings Goal for Each Appliance Type**

| Appliance Type | Energy Savings Goal* |
|---|---|
| Conveyor Oven | 12 percent |
| Convection Oven | 14 percent |
| Range | 15 percent |
| Wok | 20 percent |
| Under-fired Broiler | 17 percent |
| Over-fired Broiler | 17 percent |

* The Energy Savings is the percentage improvement from the baseline technology Source: GTI

The objective of the commercial water heater laboratory investigation was to better predict the field performance and energy use of commercial water heaters and to investigate the efficiency savings potential of high-efficiency (condensing) storage and tankless commercial water heaters through laboratory testing under a variety of conditions. This task included comparison of water heater system performance using real world draw profiles with and without some typical retro-commissioning modifications, along with testing the impact of preheating inlet water on water heater efficiency using a solar source, for example. The resulting information could increase knowledge and provide real-world efficiencies of commercial water heaters, assess the implication of preheating incoming water on system efficiency and provide retrofit

opportunities in support of utility customer energy efficiency programs developed by investor-owned utilities for commercial water heating systems.

The project team worked with several manufacturers to determine and design technology for the commercial foodservice appliances developed and deployed for this program. The following technologies were developed and tested:

- Woks: ceramic radiant combustion system and finned bottom wok pan.
- Ranges: pot sensor, pilotless ignition and finned bottom stock pot.
- Convection oven: flue redesign and improved door seals.
- Conveyor oven: energy management system and improved combustion system.
- Under-fired charbroiler: lidded design with thermostat.
- Over-fired charbroiler: flat panel radiant burner.

Researchers worked with the project team members and manufacturers to develop and test designs for each appliance type to optimize the energy savings. Either a prototype and/or a commercially ready unit were built for field demonstration for five of the appliances types. The project team worked with two different manufacturers to address design deficiencies for the over-fired broiler. Both manufacturers determined that current construction methods could not build a unit with the tolerances needed to achieve the combustion performance required at a cost that would be feasible for mass production. The project team met with the Project Advisory Committee (PAC) and project sponsors and decided to stop development of the over-fired charbroiler and focus on the other appliance types. The scope of the assessment had also included baseline field monitoring of over-fired salamander broilers to obtain valuable usage patterns. The results of the baseline field monitoring could be used to focus further appliance improvement efforts in all the appliance categories included within the scope of this study.

Laboratory testing was conducted in accordance with American Society for Testing and Materials (ASTM) standards in addition to field demonstrations to determine the energy efficiency and other benefits for the appliances developed. The laboratory testing confirmed the energy usage and the burner safety while the field demonstration provided real world data for the energy savings of the new appliances compared to existing units. The actual energy savings of each technology significantly exceeded the project goals. The goals were significantly exceeded because they were based on actual field performance and because the performance could vary greatly depending on the cook's interaction with the equipment and the cooking loads in the establishments. The percent energy savings over the baseline was the best metric to use for this type of equipment as it incorporated "real-world" conditions in the performance metric. Table 2 provides a summary of the results.

**Table 2: Energy Savings and Benefits for Each Appliance Type**

| Appliance Type | Energy Savings Goal* | Energy Savings* | California Penetration Rate | Estimated Annual Natural Gas Savings** |
|---|---|---|---|---|
| Conveyor Oven | 12 percent | 38 percent | 50 percent | 4.1 million therms |
| Convection Oven | 14 percent | 40 percent | 35 percent | 4.2 million therms |
| Range | 15 percent | 33 percent | 50 percent | 2.7 million therms |
| Wok | 20 percent | 63 percent | 30 percent | 5.7 million therms |
| Under-fired Broiler | 17 percent | 23 percent | 50 percent | 16.7 million therms |
| Over-fired Broiler*** | 17 percent | N/A | N/A | N/A |

*The energy savings is the percentage improvement from the baseline technology.
**Based on estimates from the Pacific Gas & Electric Foodservice Technology Center (FSTC) for appliance population and usage rates and assuming the given California market penetration percentages.
*** Over-fired broiler development was cancelled.
Source: GTI

Results varied significantly for the water heater laboratory investigation depending on operating conditions. The tank-type condensing water heater offered the highest thermal efficiency. Standby loss of a high-efficiency tank-type water heater was half that of a standard-efficiency tank-type water heater. The average tank temperature was reduced compared to a standard-efficiency tank-type water heater due to the stratification in a high-efficiency tank-type water heater. Condensing tank-type water heaters operating in insulated systems with no recirculation offered great system delivery efficiency depending on the application. Eliminating recirculation through the condensing tank-type water heater allowed for stratification within the tank, enabling sufficient temperature difference for latent heat capture from exhaust gases. Operating a high-efficiency tank-type or tankless water heater with recirculation reduced the system delivery efficiency, depending on the recirculation temperature.

The investigation of energy savings through retro-commissioning and retrofit revealed that insulation of the water heater distribution system generally improved its overall performance in several ways. Less input energy was required to meet fixture demand. Delivery temperature increased under most circumstances. Bringing a flue damper back into service reduced input energy but made no difference in delivery temperature for applicable water heaters. A timeclock could reduce the input energy requirement by reducing system heat loss for applications where recirculation was not needed during specific times of the day. Installation of an aquastat for controlling a system recirculation pump appeared to result in an improvement of system delivery efficiency, but the actual improvement varied from test to test.

The evaluation of the impact of preheating water on thermal efficiency showed that thermal efficiency degraded with the increase in entering water temperature, especially above 90 degrees Fahrenheit (°F) (32 degrees Celsius (°C)), for both high-efficiency tank-type and tankless water heaters. System designers should take into account this impact of entering water

temperature on system performance. Tankless water heaters may limit output with increasing entering water temperature while tank-type heaters will not modulate in this way unless designed to do so.

New technologies were developed, tested, deployed and significant energy savings were confirmed by field demonstrations for a wok, range, convection oven, under-fired broiler and conveyor oven. The project team estimated that about 33.4 million therms and over 85 million gallons of water could be saved in California annually compared to using existing appliances. Energy-efficient designs for the range, convection oven, under-fired broiler and conveyor oven were either commercially available or would be available by early 2014. The basic design for the wok was ready for production and will be customized to meet the needs of a specific end user. A commercial unit should be available in early 2014.

Researchers concluded that tank-type water heaters operating in systems with no recirculation offered the best system delivery efficiency. The system delivery efficiency was comparable for all types of tankless and tank-type heaters when a recirculation pump was in use with the exception of the standard-efficiency tank-type heater, which exhibited a lower system efficiency when combined with a recirculation system. Adding insulation to the distribution system increased the system delivery efficiency and delivery temperature at the fixtures. This will be a topic for Title 24 in the future. Heater efficiency was found to decrease rapidly for systems where preheating of incoming water was being performed with entering water temperatures exceeding 90°F (32°C).

Further development and refinement of these technologies will be conducted before large scale adoption by the end-user occurs. California foodservice operators will be more willing to adopt practices and products that will save energy, reduce utility bills, and ultimately aid in environmental conservation with further development of these innovative technologies.

## Project Benefits

The benefits to California for the six commercial foodservice products were related to the significant efficiency improvements in this often-overlooked sector. Annual energy savings to California consumers was estimated to be 33.4 million therms (as shown in Table 2), which translated to a savings of approximately 23.3 million dollars per year for the products studied in this project. This estimate was obtained by using the 2012 U.S. Energy Information Administration's (EIA's) values for average commercial gas price of $7.13 per thousand cubic (MCF) feet for California and the EIA's estimated fuel heat content for natural gas of 10.21 therms/MCF (EIA 2013). These savings corresponded to a reduction of approximately 0.2 million metric tonnes of carbon dioxide ($CO_2$) greenhouse gases.

The benefits to California from utilizing the appropriate condensing water heater technology and optimized distribution systems in commercial facilities were significant. Existing system delivery efficiencies of gas-fired hot water systems in small restaurants were in the 30-60 percent range as shown through laboratory tests. The efficiencies would be much lower and in some cases in the single digits in many commercial hot water systems. It is possible to significantly improve system delivery efficiencies and thus improve operating efficiency to a

lesser extent in commercial facilities. The energy savings potential in California from medium to large commercial hot water systems by utilizing best practices was estimated to be in the 100 million therms range or approximately $69.8 million for gas-fired systems. Many of these best practices could be adapted to many electricity-based hot water systems for additional savings. Californians could benefit in the long term with improved system performance, energy savings and lower operating costs. The goal was to have higher efficiency systems be the norm in designing new establishments and in major retrofits of existing facilities.

# CHAPTER 1: Introduction

## 1.1 Background and Overview

This project encompasses the development and testing of six advanced technology cooking products and the advancement of commercial water heating technology focusing on the commercial foodservice sector of California. Commercial foodservice represents a significant commercial energy savings opportunity. The barriers to the technology development and commercialization proposed in this project are financial and technological in nature. Financial barriers have been largely addressed by the willingness of the utility partners to offer rebates for high-efficiency equipment. Solutions to technology barriers include thermostatic controllers, radiant burners, zoning control systems and reduced cooking temperatures. Application of these technologies must also consider changes in the behavior of equipment operators where "always-on" and high-temperature cooking practices are commonplace. Increasing awareness of energy efficiency and greenhouse gas emissions by both consumer and utility entities has enabled higher-cost technologies to compete with standard products through a reduced first cost difference after the rebates are applied. The rebates and energy savings offered by these products create an attractive payback for the restaurant owner and provide a catalyst for the development of future technology.

## 1.2 Project Objectives

The overall goal of this project is to significantly improve the efficiency of commercial gas appliances through field data collection in addition to product design and development. Specifically, this project will improve the full-load efficiency and in-kitchen utilization efficiency of commercial gas appliances. This will be accomplished by improving burners, heat exchangers, equipment design, and control systems and applying those improvements to existing commercial product lines.

This project encompassed the development, lab and/or field testing of prototype appliances, the assessment of the appliances' ability to perform, and the quantification of the energy savings that high-efficiency ovens could provide to California restaurants. The project is broken into tasks with each task covering one or more topics:

The objective of the commercial conveyor oven project in Task 1 was to significantly improve the energy efficiency of commercial gas conveyor ovens through adoption of advanced burners, combustion blowers, sensors or control systems improvements. The task goal was to increase baseline cooking energy efficiency by 12 percent.

The objective of the commercial convection oven project in Task 1 was to improve the efficiency of commercial foodservice gas convection ovens. Typical gas-fired full-sized convection ovens have heavy load efficiencies in the mid-thirties. A majority of existing equipment in the field is older and has fewer engineered features that promote efficiency. Leakage around the door seals and high flue exhaust temperatures result in energy losses. By addressing these two main

issues, a lower idle rate and improved combustion was achieved. It is expected that 400-470 therms/year per oven will be saved, for an efficiency improvement of 30-60 percent above the baseline convection oven depending on business operating hours. The task goal was to increase baseline cooking energy efficiency by 14 percent.

The objective of the commercial range project in Task 2 was to improve the efficiency of the commercial foodservice gas open top range. All inventory of this equipment category shows standard technology with little to no energy efficient features. After investigating several energy savings methods, a pilot-off-at-night system, an on-demand burner system, and an improved cooking vessel were selected as areas of improvement for the open top range category. Three industry manufacturers partnered with this project: Montague integrated the pilot-off-at-night system into their product line, Lang produced an on-demand burner range, and Eneron developed the finned-bottom Turbo Pot. The task goal was to increase baseline cooking energy efficiency by 15 percent.

The objective of the commercial wok project in Task 2 was to significantly improve the efficiency of a commercial gas wok range through adoption of an advanced burner system to replace the existing simple jet ring style burner that uses orifice spuds mounted from circular manifold pipes. This project encompasses the development, lab and/or field testing of prototype appliances, the assessment of the ability of the appliance to perform, and to quantify the energy savings high-efficiency woks could provide in restaurants. The task goal was to increase baseline cooking energy efficiency by 20 percent.

The objective of the commercial under-fired charbroiler project in Task 3 was to increase the real-world cooking efficiency of gas charbroilers above 5 percent and reduce the heat gain to the space proportionally, without impact to the cooking characteristics of the device or changing the look or flavor of the cooked products. This objective was to be addressed by designing an advanced charbroiler with retractable hood and thermostat control to improve performance while maintaining the unique cooking characteristics of the device. The task goal was to increase baseline cooking energy efficiency by 17 percent.

The objective of the commercial overfired-fired broiler project in Task 3 was to increase the real-world cooking efficiency of gas overfired broilers by 17% without impact to the cooking characteristics of the device or changing the look or flavor of the cooked products, using a concept radiant burner design that uses a sealed flame and heat recovery through a recuperator to improve efficiency. However, this project ended without the broilers reaching the full development status required for the market introduction to occur.

The results of this research are presented in the following chapters.

# CHAPTER 2:
# Conveyor Ovens

## 2.1 Summary

### 2.1.1 Introduction

Conveyor ovens represent a continually growing segment within the commercial oven category. Conveyor ovens are designed for high-volume production, consistency and ease of use. The basic design of a conveyor oven is a conveyor belt that carries food through a heated box with two open ends to produce food consistently at a rapid pace. These ovens are available in several sizes to tailor to small low-volume operations or large sit-down restaurants, and can use electricity or natural gas as an energy source. Most conveyor ovens can be stacked up to three units high, significantly increasing production capacity without requiring increased floor space. The commercial conveyor oven is one of the most energy-intensive appliances in the kitchen. With a combination of high input rates, long operating hours and low cooking-energy efficiencies, conveyor ovens are one of the most expensive appliances to operate in a commercial kitchen.

There has been little advancement in conveyor oven technology in recent years. The latest innovative feature was the incorporation of energy management systems (EMS) to reduce the "standby" energy consumption of the appliance; however, few ovens in the market have this feature. Opportunities abound for developing even more features that could contribute to the performance and efficiency improvements of this appliance type.

### 2.1.2 Purpose

The purpose of this project was to identify new technologies that could improve gas conveyor oven energy efficiency and performance. The goal was to validate a targeted 12 percent energy-efficiency gain when using advanced design equipment.

### 2.1.3 Project Objectives

The objectives of the commercial gas conveyor oven study were to:

- Characterize the energy inefficiencies of standard conveyor oven technologies through laboratory and field data collection.
- Design and develop a new prototype for the commercial foodservice conveyor oven, one which is both energy-efficient and robust.
- Compare the energy use of the standard and energy-efficient gas conveyor ovens under laboratory test conditions.
- Compare the energy use of standard and energy-efficient conveyor ovens at several field monitoring locations.
- Recommend improvements to further conveyor oven efficiency and market adoption.

### 2.1.4 Project Outcomes

Standard commercial conveyor ovens typically exhibit low cooking-energy efficiencies—between 15 percent and 30 percent-and idle energy rates at rated burner inputs between 60 and 80 kBtu/h. The majority of a conveyor oven's energy expenditure comes from a poorly-insulated cooking chamber and relatively inefficient burner designs.

Two advanced conveyor oven models were tested in compliance with ASTM F1817, the *Standard Test Method for Performance of Conveyor Ovens.* These ovens featured advanced impingement technology, digital controls, and an improved heat exchanger/efficient burner. The cooking-energy efficiency increased from 20 percent standard efficiency to a maximum of 38 percent for both advanced conveyor oven models.

The ovens also featured an optional on-board, self-contained Quest Energy Management System that optimizes gas combustion, improves heat transfer from the air impingement fan, controls the conveyor motor, and features a pizza sensor that automatically turns down oven fan speed when it senses there are no food products on the conveyor line. The advanced conveyor model was tested with and without the Quest EMS in the laboratory and in one of the field test sites. With the Quest EMS system engaged, the idle rates of the two advanced conveyor ovens were reduced by 30 percent on average.

Field monitoring sites were then selected for both standard and advanced conveyor oven energy data collection: two quick-service pizzerias, one full-service pizzeria, and a warehouse retailer. Baseline daily energy use was first established for all four sites. Working with the oven manufacturer and the participating test sites, two of the sites' preexisting conveyor ovens were then replaced with the advanced units and metered for an additional period. A Pizza Patron restaurant in Dallas, Texas was selected for baseline and replacement monitoring by Lincoln, as this test location was near the Pizza Patron's corporate headquarters and the chain represents a key chain account for the manufacturer. The second Pizza Patron site in Lynwood, CA was used to augment the baseline monitoring data and confirm the operating patterns of the Dallas. Straw Hat Pizza in Fairfield, CA was chosen as a third test site by the FNi field team for baseline monitoring and oven replacement, based on the agreed participation by the franchise owner/operator. SoCalGas contributed filed monitoring at a Costco in Norwalk, CA. This fourth test site served as a high-volume site for baseline monitoring. This site was not amenable to testing the advanced conveyor oven and was used to augment the baseline data only. The results from the field monitoring of both standard and advanced conveyor ovens at these restaurants are presented in Table 3.

**Table 3: Monitoring Results per Oven Averaged Over a Daily or Hourly Period**

| SITE | PIZZA PATRON (DALLAS, TX) | STRAW HAT PIZZA | COSTCO | PIZZA PATRON (LYNWOOD, CA) |
|---|---|---|---|---|
| **BASELINE OVENS** | | | | |
| Average Daily Energy Consumption (therms/day) | 8.0 | 7.1 | 8.8 | 6.5 |
| Average Operating Hours (h/day) | 11 | 13 | 12 | 11 |
| Average Energy Consumption Rate (kBtu/h) | 72.7 | 54.2 | 73.3 | 59.1 |
| **REPLACEMENT OVENS** | | | | |
| Average Daily Energy Consumption (therms/day) | 7.5 | 4.4 | 7.4* | 4.0* |
| Average Operating Hours (h/day) | 11 | 13 | 12* | 11* |
| Average Energy Consumption Rate (kBtu/h) | 68.2 | 33.7 | 67.3* | 36.4* |
| Average Energy Savings (%) | 6 | 38 | 16* | 38* |

*Projected
Source: FNi

### 2.1.5 Conclusions

This field study demonstrated significant energy savings from upgrading standard conveyor ovens to conveyor ovens equipped with advanced heating designs and smart controls. Better burner and heat exchanger designs brought about an increase in cooking energy-efficiency from the average baseline 20 percent to 38 percent. The 20 percent baseline was determined by a 2010 study conducted at the FSTC by Fisher-Nickel Inc., *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment* (Mills L. 2010) The spectrum of restaurant sites also characterized the usage patterns of conveyor ovens in the field, most notably showing elongated idle times and short cooking periods.

The proprietary on-board, self-contained EMS system on the advanced conveyor oven proved very effective in reducing idle energy consumption – the largest contributor to energy savings. The ability to monitor and control the functions of the oven to retain heat in the cooking chamber during extended periods of inactivity has the potential to reduce standby energy losses by 30 percent as shown by comparing Table 4 and Table 5. .

### 2.1.6 Recommendations

Although the EMS system shows great opportunity for future gas energy savings, further development is needed to increase its robustness and reliability. The optical sensors placed along the ends of the conveyor to detect the presence of food product need further development

to overcome their tendency to malfunction due the accumulation of food particles, such as cheese and flour.

The field data showed that the majority of conveyor ovens operate in a light load-condition. Even during cook loads, the conveyor oven is never filled to its maximum with food product. Consequently, energy loss during standby operation or between individual light product loads is large. This energy loss occurs at the open exit and entrance to the cooking chamber, through the chamber itself due to poor insulation, and through the exhaust vent. Further research and development should focus on containing heat within the cooking chamber, thereby decreasing standing heat and energy loss.

This study summarizes the baseline use of conveyor ovens, but only begins to characterize the opportunities for energy savings with advanced designs and controls. As such, additional field monitoring is required to fully quantify and verify the effects of these advanced technologies in pizzerias and other foodservice institutions that rely heavily on conveyor ovens.

### 2.1.7 Benefits to California

In 2010, the Pacific Gas and Electric Foodservice Technology Center (FSTC) estimated that roughly 10,900 conveyor ovens were in operation in California commercial kitchens, with most conveyors operating at a baseline efficiency of approximately 15-30 percent. The estimated annual natural gas use for conveyor ovens is 21.5 million therms. A 2010 study conducted by the FSTC by Fisher-Nickel inc., *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment* (Mills L. 2010), estimates a 50 percent market penetration of energy-efficient conveyor ovens. Based on the data gathered from Straw Hat Pizza, a 38 percent energy reduction potential can be achieved by going to a new California Energy Wise rebate-qualified conveyor oven. The California Energy Wise rebate is a commercial rebate program between California Investor-Owned Utility (IOU) companies, such as those acknowledged in this report, and the commercial food service industry. If this savings is projected across the 21.5 million therms consumed annually in California by conveyor ovens at 50 percent market penetration, a potential savings of 4.1 million therms or approximately 2.86 million dollars is possible using the aforementioned values of 7.13 dollars/MCF and 10.21 therms/MCF.

Reducing the high idle rates and increasing the cooking-energy efficiency of the gas conveyor oven by continually developing, field testing, and eventually embracing these new technologies will improve foodservice operations, reduce energy and utility costs, and aid in environmental conservation, all of which will benefit consumers in California.

## 2.2 Introduction

### 2.2.1 Background

Conveyor ovens are designed for high-volume production (speed), consistency and ease of use. While they can be used for a variety of food products, they are predominantly used by the quick-service pizza industry. The basic design of a conveyor oven is simple: The food travels through a heated cavity by means of a motorized belt, and an oversized heat source quickly cooks the food product as it travels through the baking chamber to achieve the shortest possible bake times. Conveyor ovens are highly flexible and can be used to bake or roast a wide variety

of products including pizza, casseroles, meats, breads, and pastries. The result is a fast, simple process that achieves roughly the same result every time while minimizing operator impact to the finished product. This innovation has allowed establishments to radically increase their food output while reducing the training associated with producing their signature product.

Conveyor ovens are available in many different sizes and configurations. They are available in small enough sizes to satisfy low-volume and niche operations—such as kiosks—that have limited production space, and in sizes large enough to meet the demands of high-volume operations. Most ovens can be outfitted with multiple conveyor belts, each of which may have a different operating speed. Conveyor ovens are generally used for producing a limited number of products with similar cooking requirements at high production rates. They are available in many different sizes and configurations and can be stacked up to three units high. Because of their high production rates and product consistency, conveyor ovens are preferred by large volume pizza-themed restaurants. However, due to the combination of high input rates, long operating hours and low efficiency, commercial conveyor ovens are also one of the most energy-intensive and expensive appliances to operate in a commercial kitchen.

In the 2010 PIER report by Fisher-Nickel inc. *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment* (Mills L. 2010), it was estimated that 10,900 conveyor ovens were in operation in California commercial kitchens. With most conveyor ovens operating at a baseline cooking energy efficiency of 20 percent, the estimated annual gas use was determined to be 21.5 million therms.

### 2.2.2 Objectives

The objective of this study was to demonstrate the improved efficiency from the development and testing of an advanced conveyor oven. Commercial conveyor ovens were chosen for this energy-efficiency project because they represent a significant energy load in the California foodservice industry. In addition, existing technology was available to improve the efficiency of conveyor ovens, and demonstration sites were available to compare the performance of standard and advanced units. The project team worked with Lincoln, a division of Manitowoc Foodservice (http://www.lincolnfp.com), a leading commercial foodservice manufacturer, to design and implement changes to their existing conveyor oven design to improve the efficiency. The new design was incorporated into test units and these new units were installed and monitored at several demonstration sites in Texas and California. A Pizza Patron restaurant in Dallas, Texas was selected for baseline and replacement monitoring by Lincoln, as this test location was near the Pizza Patron's corporate headquarters and the chain represents a key chain account for the manufacturer. Energy consumption and usage pattern data were acquired for each advanced oven and compared with data from the existing conveyor oven. The Gas Technology Institute (GTI) worked directly with Lincoln on designing and developing the advanced conveyor oven, and the FSTC identified locations and oversaw the field demonstrations in California while GTI oversaw field demonstrations in Texas.

## 2.3 Technology

### 2.3.1 Standard Technology

Most standard technology gas conveyor ovens utilize basic burners with only a single firing rate. The introduction of high-velocity hot air (known as air impingement technology) dramatically shortens cook times and increases productivity versus deck ovens. A major drawback to this baking process is that the high-velocity hot air escapes through the open ends of the conveyor, contributing to significant heat loss. When the oven is at idle (i.e., ready-to-cook state awaiting the next food product), there is major heat loss through the openings and the skin of the oven since the fan speed and gas input rates are held constant. While there are some additional gas burner technologies like infrared burners or using a combination of gas and electric burner technologies, the majority of conveyors installed in restaurants utilize basic burners with an air impingement baking process.

High energy use is caused by a combination of the heat loss through the open ends of the cooking cavity and unused heat loss through the flue from oversized heat source. Another significant energy loss occurs when the oven sits idle in ready-to-cook state. An oven sitting at cooking temperature, but not being used, can lose a significant amount of heat, both through the openings in the cooking chamber and through the (poorly insulated) skin of the oven. Because of the losses attributed to these design issues, the baseline efficiency of conveyor ovens can be less than 20 percent.

### 2.3.2 Advanced Technology

#### *2.3.2.1 Efficiency Improvements*

The cooking-energy efficiency of conveyor ovens can be improved through the development and application of advanced burner and heat exchanger designs. Heat transfer can be improved through a combination of advanced burner design and engineered heat exchangers. Advanced-design burners focus the flame and reduce excess air, improving the heat transfer and combustion efficiency. When coupled with better-engineered heat exchangers, these new-generation burners could reduce the energy consumption of gas conveyor ovens while performing the same amount of work (i.e., cooking the same quantity of product).

Improved control systems in combination with more effective insulation, and advanced controls will improve the daily operating efficiency of conveyor ovens by eliminating a significant amount of heat that is routinely lost when the unit is at idle. One promising control feature offered by conveyor oven manufacturers is a self-contained Energy Management System (EMS). This EMS controls the burner, impingement fan, conveyor motor, and a pizza sensor—a vision-based sensor placed along the ends of the conveyor to detect the presence of food product—that automatically turns down the energy input and/or turns off the fan when it senses that there are no products on the conveyor line.

#### *2.3.2.2 Advanced Conveyor Oven Features*

The high-efficiency conveyor oven featured in this report was manufactured by Lincoln, and incorporates advanced impingement technology, digital control panel and FastBake™ technology. The FastBake™ technology improves heat transfer from the air impingement

nozzles to either bake up to 35 percent faster for improved time of service in the existing oven, or allows for downsizing to a smaller conveyor while maintaining existing bake times. The proprietary FastBake™ technology is a Lincoln feature that optimizes the air impingement in the conveyor oven by applying large amounts of heat through proprietary air finger designs. One of the more important technologies available on the Lincoln Impinger line is the Quest Energy Management System. This control system optimizes the gas/air mixture for optimized combustion, which improves the energy efficiency and lowers CO and $CO_2$ emissions (note that there are currently no emissions standards for commercial cooking equipment). The EMS also decreases idle losses by reducing oven fan speed to retain more heated air inside the oven cavity while reducing end loss. The Impinger model was tested with and without the Quest Energy Management System in the laboratory and also in one of the field test sites.

## 2.4 In-Lab Testing

### 2.4.1 In-Lab Test Plan

The ASTM test method F1817, *Standard Test Method for Performance of Conveyor Ovens*, establishes a set method and sequence of testing for commercial foodservice equipment. Key appliance performance indicators such as preheat time, idle energy consumption, and cooking-energy efficiency are determined in the ASTM test method. The test method was applied to the Lincoln conveyor ovens in this study for in-lab testing to compare against previously-tested conveyor ovens and to quantify energy-efficiency improvements.

The major tests performed on conveyor ovens included the idle energy rate, cook time, gas and electric cooking energy rate, heavy-load energy efficiency, and production capacity. The idle energy rate test was performed with and without the energy saving feature in operation. The laboratory test served to validate appliance performance before being tested at the field sites.

#### *2.4.1.1 Energy Input Rate*

Rated energy input rate is the maximum or peak rate at which the appliance consumes energy as specified on the appliance's nameplate. Measured energy input rate is the maximum or peak rate of energy consumption, which is recorded during a period when the elements are energized (such as preheat). For the purpose of this test, the appliance was cooled overnight to ambient room conditions. Then the appliance was powered on and the energy input was monitored as the cavity temperature climbed to 465°F (240°C).

#### *2.4.1.2 Idle Energy Rate*

The idle energy consumption was monitored for two hours once the oven cavity, exhaust ventilation temperatures, appliance and hood skin temperatures were stabilized. This stable condition ensured a steady state for the oven during testing to characterize the standby energy losses of the test ovens. The test plan also included an evaluation of the Quest Energy Management System to reduce idle energy consumption during non-cooking periods.

#### *2.4.1.3 Cooking-energy Efficiency Tests*

The cooking-energy efficiency test was performed with 12-inch diameter cheese pizzas, and was considered to be comparable to the pizza specification in the ASTM Standard Test Method.

Each pizza weighed an average of 1.47 ± 0.1 pounds. The pizzas were stabilized in a refrigerator overnight with the goal of achieving temperature uniformity of 39 ± 1°F (4 ± 1°C).

Pizza doneness required a final pizza temperature of 195 ± 5°F (90 ± 3°C). While determining the temperature of the cooked pizzas, an insulated surface was used to avoid influencing the pizza temperature. This final pizza temperature was measured by placing six hypodermic-style thermocouple probes on the surface of the pizza, located three inches from the center of the pizza, and equidistant from each other. The probes were allowed to penetrate the cheese and rest in the crust-sauce interface. The highest recorded average temperature of the six probes was then used to determine the temperature of each pizza tested.

For purposes of testing, the oven cavity size of 32 inches by 55 inches was rounded down to the nearest foot, in this case to two feet by four feet. This size dictated that 16 rows of three pizzas (48 total) were needed for each run of the heavy-load tests, half of which were used to stabilize the oven. The pizzas were removed from the refrigerator and loaded onto the oven conveyor belt so that no more than one minute elapsed before the cooking process began. Each row was placed on the conveyor in a V-shaped pattern so that 36 inches of pizza would fill a 32-inch conveyor. After cooking, all pizzas were measured for a final weight and temperature to use in the energy efficiency calculations.

The first half of the cooking trial was designated as a stabilization load and was not counted when calculating the elapsed time and energy consumed. Energy monitoring and elapsed time of the test were determined after the second half of the cooking trial started to enter the cooking cavity. The cook test terminated when the last pizza was completely within the cooking cavity. Total elapsed time, energy consumption, initial and final pizza weight, and initial and final pizza temperature were recorded for the cook test.

Cooking-energy efficiency, as defined by ASTM F1817 *Standard Test Methods for Performance of Conveyor Ovens*, is the ratio of the amount of energy going into the food versus the amount of energy supplied to the oven:

$$Energy\ Efficiency = \frac{Energy\ Imparted\ to\ Food\ (Btu)}{Energy\ Consumed\ by\ Oven\ (Btu)}$$

The heavy-load test was performed in triplicate to ensure that the reported cooking energy efficiency results had an uncertainty of less than ± 10 percent. The results from each test run were averaged, and the absolute uncertainty was calculated based on the standard deviation of the results, a 95 percent confidence interval (based on a 2-tailed statistical t-distribution), and degrees of freedom based on at least three tests runs.

### 2.4.2 In-Lab Test Results

#### *2.4.2.1 Standard Conveyor Oven Test Results*

The results of the ASTM F1817 test are displayed in Table 4. Commercial conveyor ovens typically yield energy efficiencies between 15 percent and 30 percent and idle energy rates at rated burner inputs of between 60 and 80 kBtu/h. With an energy efficiency of 20 percent and an idle rate of 70 kBtu/h, the standard-efficiency conveyor oven used for in-lab testing adequately

represented the models typically found in commercial pizza operations. Data from previous conveyor laboratory tests are provided to show differentiation between the heavy-load cooking-energy efficiency and idle rates of standard and high-efficiency conveyors.

**Table 4 ASTM Test Results of Standard-Efficiency Conveyor Oven Models**

| Make and Model | Conveyor Width (inches) | Baking Chamber Length (inches) | Heavy-load Cooking-energy Efficiency (%) | Idle Rate (Btu/h) |
|---|---|---|---|---|
| Standard Efficiency | 32 | 40 – 70 | 20.0 | 70,000 |

Source: FNi

#### *2.4.2.2 Advanced Conveyor Oven Test Results*

The ASTM F1817 test method was applied to the two Lincoln Impinger ovens. Table 5 displays the results. The cooking-energy efficiency increased from the 20 percent efficiency of the baseline oven to 43.8 percent for the 3270 model and 46.4 percent for the 1600 model, respectively. These advanced design ovens also included an EMS control that reduced idle energy consumption during idle (non-cooking) periods by slowing down the impingement blower, which reduced heat loss from the open ends of the ovens. Idle energy use was reduced by 30 percent on average when the system was implemented.

**Table 5: ASTM Test Results With and Without Quest EMS**

| Make and Model | Conveyor Width (inches) | Baking Chamber Length (inches) | Heavy-Load Cooking-energy Efficiency (%) | Idle Rate (Btu/h) | Percentage Reduction During Idle (%) |
|---|---|---|---|---|---|
| Lincoln Impinger 1600 | 32 | 40 | 46.4 | 36,393 | -- |
| Lincoln Impinger 1600 With Quest EMS | 32 | 40 | 46.4 | 23,402 | 35.7 |
| Lincoln Impinger 3270 | 32 | 70 | 43.8 | 53,800 | -- |
| Lincoln Impinger 3270 With Quest EMS | 32 | 70 | 43.8 | 40,800 | 24.2 |

Source: FNi

## 2.5 Field Testing

### 2.5.1 Field Test Plan

#### *2.5.1.1 Site Monitoring Instrumentation and Procedures*

The instrumentation package used for field testing of the conveyor oven included a diaphragm type positive displacement gas meter with a one-pulse/ft$^3$ output (Figure 1). A data logger was

used to log at 30-second or one-minute intervals to determine cumulative gas consumption from the meter's pulse outputs.

**Figure 1: Diaphragm Gas Meter Connected to a Data Logger**

Photo Credit: FNi

Cumulative gas consumption which was measured in cubic feet was converted into Btu using a heating value that was appropriate for each site—ranging between 1,000 to 1,025 Btu/ft³--with a temperature correction factor of 0.98 and a pressure correction factor of 0.98, according to the following formula:

$$\text{Gas Energy (Btu)} = \text{Measured Volume (ft}^3) \times K_{\text{temperature}} \times K_{\text{pressure}} \times \text{Gas Heating Value (Btu/ft}^3)$$

The temperature and pressure correction factors adjusted the measured volume to standard conditions and the regional gas heating value for the site location was used to calculate energy consumption.

Conveyor oven operating hours were determined by calculating an hourly input rate using a ten-minute moving average. In three out of the four sites, gas meters were installed on each conveyor. The fourth facility, monitored by the FSTC, was a full-service restaurant, which utilized one gas meter to measure gas flow from both conveyor ovens, though only one conveyor was operational during the monitoring period.

#### *2.5.1.2 Field Monitoring Site Selection*

Three pizza-themed restaurants and one warehouse retailer were selected for conveyor monitoring. Two of the pizza-themed restaurants were carry-out, quick-service operations; the third was a full-service operation. After the baseline daily energy usage was established, the

existing conveyors were replaced with the advanced units at two test sites—a quick service restaurant located in Dallas, TX and a full-service restaurant site in Farifield, CA—and metered for an additional period to obtain baseline daily energy usage for the advanced units as well. Conveyor use patterns and restaurant operations remained consistent for both the existing and replacement advanced conveyor ovens. The two remaining sites, a quick-service restaurant in Lynwood, CA and the warehouse retailer with a food court operation in Norwalk, CA, served as additional baseline sites. The second quick service site was used to augment the baseline monitoring data and confirm the operating patterns of the first quick service restaurant. The warehouse retailer served as a high-volume site for baseline monitoring to contrast against the more sporadic use of the restaurant sites. This site was not amenable to testing the advanced conveyor oven and was used to augment the baseline data only.

**Straw Hat Pizza**

Straw Hat Pizza in Fairfield, CA (Figure 2) is a full-service restaurant that operates an all-you-can-eat lunch buffet and cook-to-order meals for the remainder of the operating day. Straw Hat primarily offers pizza, but other food items cooked on the conveyor include breadsticks, calzone style sandwiches and chicken wings. The restaurant offers dine-in, carry-out, and delivery options to their patrons.

In this scenario, the conveyor was not expected to be loaded to full capacity for most of the day. Pizzas were cooked as-needed throughout a long operating day spanning from 10:30 am to 10 pm Sunday through Thursday, while closing at 11 pm on Friday and Saturday.

**Figure 2: Straw Hat Pizza**

Photo Credit: FNi

**Pizza Patron (Dallas, TX)**

A Pizza Patron restaurant in Dallas, Texas (Figure 3) was selected also for baseline and replacement monitoring by Lincoln, as this test location was near the Pizza Patron's corporate headquarters and the chain represents a key chain account for the manufacturer. The Dallas

location served as a proving ground for the restaurant chain and was a necessary compromise in site selection to obtain their participation. Pizza Patron is primarily a carry-out quick-service operation with limited store locations operating with a drive-thru or in-store dining. Pizza Patron primarily offers pizza, but other food items cooked on the conveyor include breadsticks and chicken wings.

It was expected that the facility operated their conveyors under part-load capacity from Sunday to Thursday to satisfy their carry-out customers during the operating hours of 11 am and 10 pm. During Friday and Saturday operations, operating hours were extended to midnight and the conveyors were expected to operate under peak load.

**Figure 3: Pizza Patron (Dallas, TX)**

Photo Credit: Pizza Patron website (www.pizzapatron.com)

**Costco (Norwalk, CA)**

Costco is a national big-box retailer with an extensive warehouse and compact, high-volume food court. Leveraging their key customer account relationship, the Costco located in Norwalk, California (Figure 4) was selected by SoCalGas Company for baseline monitoring. This test site operates Monday thru Friday from 10 am – 8:30 pm, Saturday from 9:30 am – 6 pm, and Sunday from 10 am – 6 pm. The food court is similar to a quick service pizza-themed restaurant, offering carry-out and dine-in services. The type of food cooked on the Costco conveyor was primarily pizza, but also included chicken bakes, sandwiches and churros.

**Figure 4: Costco Wholesale**

Photo Credit: FNi

**Pizza Patron (Lynwood, CA)**

A second Pizza Patron located in Lynwood, California (Figure 5) was selected for baseline monitoring to provide additional conveyor oven usage data. Pizza Patron primarily offers pizza, but other food items cooked on the conveyor include breadsticks and chicken wings. It was expected that the facility operated their conveyors under part-load capacity from Sunday to Thursday to satisfy their carry-out customers during the operating hours of 11 am and 10 pm. During Friday and Saturday operations, restaurant operating hours extended to midnight and the conveyors were expected to be operated under peak load.

**Figure 5: Pizza Patron (Lynwood, CA)**

Photo Credit: FNi

### 2.5.2 Field Test Results

#### *2.5.2.1 Straw Hat Pizza*

**Baseline results**

Baseline monitoring was conducted for about two months at Straw Hat Pizza before switching over to replacement ovens. The site used a double-stacked 40-inch conveyor, with the top oven as the primary oven and the bottom oven serving as a backup (Figure 6). During the baseline monitoring period, only the top oven was in use. The resulting energy consumption for the primary (top) oven ranged between six and eight therms per day, with an average of seven therms per day.

**Figure 6: Standard-Efficiency Ovens at Straw Hat Pizza**

Photo Credit: FNi

**Replacement Results**

The replacement Lincoln Impinger ovens (Figure 7) were equipped with improved burners and FastBake™ technology, but did not include the Quest Energy Management System, which had been pulled by the manufacturer due to reliability concerns. Store operation during the replacement monitoring period matched the baseline monitoring period, with the top oven in use daily and the bottom oven largely dormant. During both monitoring period, the bottom oven saw little to no use. When the store manager was asked about oven usage, he noted that the store did not have a sufficient demand to justify operating both ovens at the same time and that the bottom oven was used primarily as a back-up for the top (primary) oven.

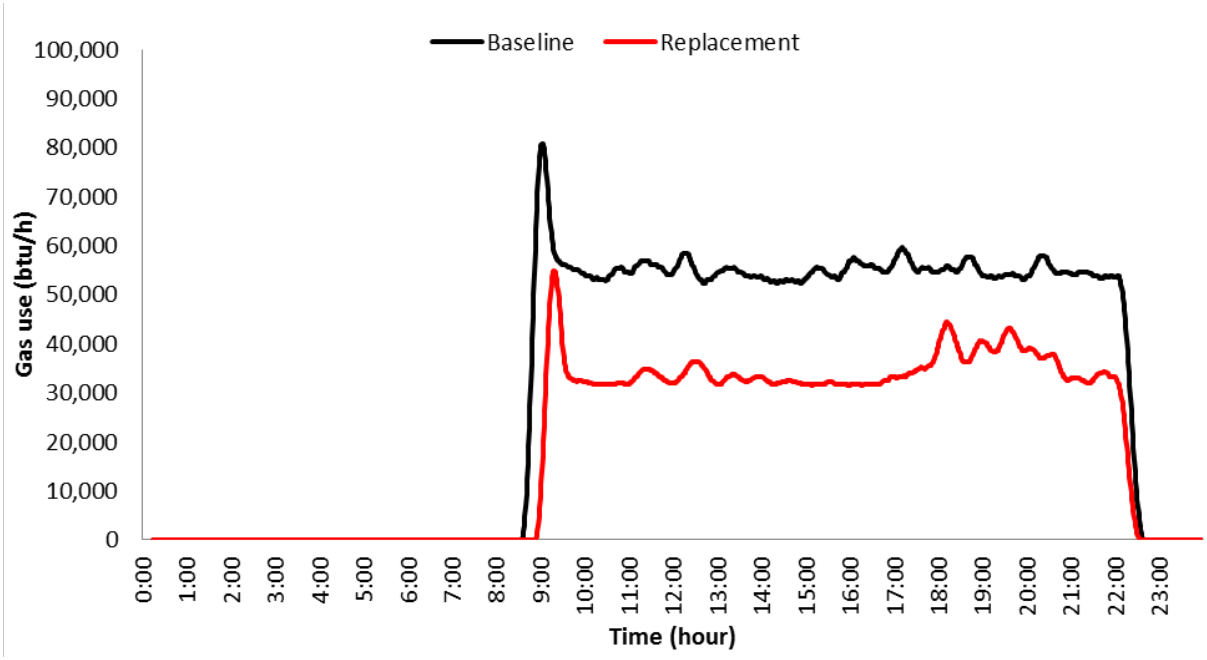
Figure 8 shows the daily usage profile for the baseline and replacement ovens. The typical day showed no peaks in energy use, despite the restaurant offering a lunchtime buffet. Feedback from Straw Hat explained business volume during the lunchtime buffet was not high enough to cause barrel loading of the conveyor oven. Baseline monitoring showed an average daily energy

consumption of seven therms while the replacement monitoring showed an average daily energy consumption of 4.5 therms, reflecting a dramatic energy reduction of 35 percent.

**Figure 7: Replacement Ovens at Straw Hat Pizza**

Photo Credit: FNi

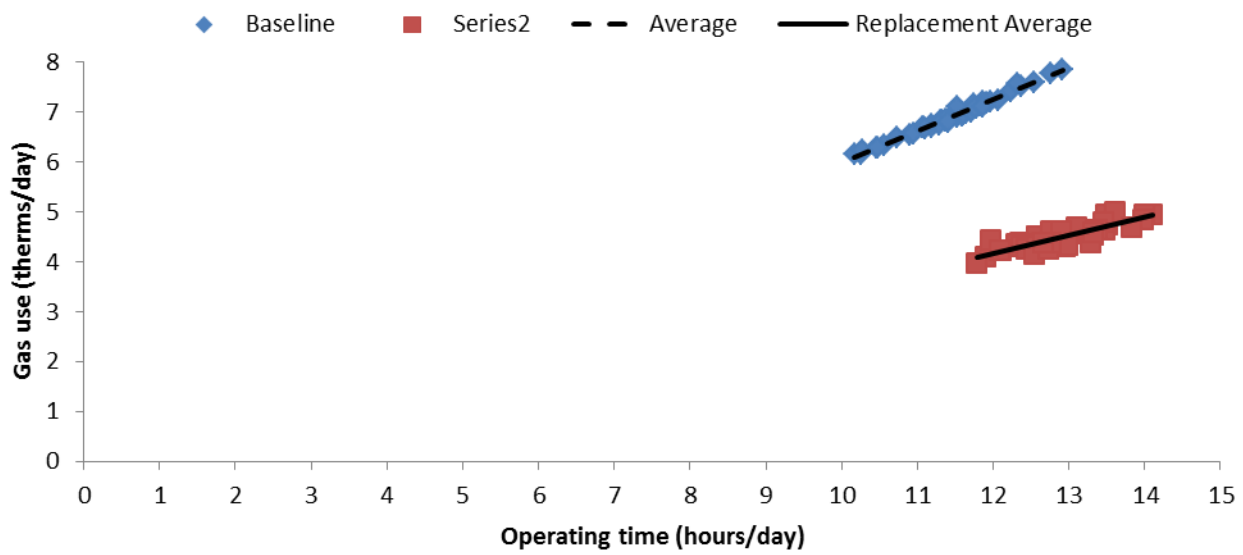
**Figure 8: Standard to Replacement Conveyor Oven Energy Profile Comparison—Straw Hat Pizza**




Source: FNi

Oven energy use and operating hours are shown in Figure 9 for a better understanding of day-to-day operational variation.

**Figure 9: Standard to Replacement Conveyor Oven Daily Energy Regression Comparison—Straw Hat Pizza**




Source: FNi

### *2.5.2.2 Pizza Patron (Dallas, TX)*

Pizza Patron monitoring in Dallas, Texas was conducted by the local gas utility provider, ATMOS Energy. Since the primary goal of the monitoring for Pizza Patron was to compare the daily gas usage between the pre-existing conveyor oven and the replacement conveyor oven, data was collected on an hourly basis. The resulting dataset allowed researchers to compare the energy usage of the baseline and replacement ovens, but was not conducive to developing a discernible energy use profile —monitoring resolution would have needed to be at one-minute intervals or more frequently to be able to determine usage profiles of the monitored appliance.

**Baseline results**

The Dallas site was used as an active test store for the restaurant chain for new equipment, and was in the process of evaluating an alternative energy-efficient conveyor oven design. These baseline conveyor ovens were considered eligible for rebate under the California Energy Wise program, based on efficiencies greater than 42 percent and idle energy rates less than 57 kBtu/h. as a test case, the baseline ovens were somewhat atypical of the standard equipment in use in other Pizza Patron locations, but they did provide a strong comparison for the technology that was to be evaluated with the replacement models.

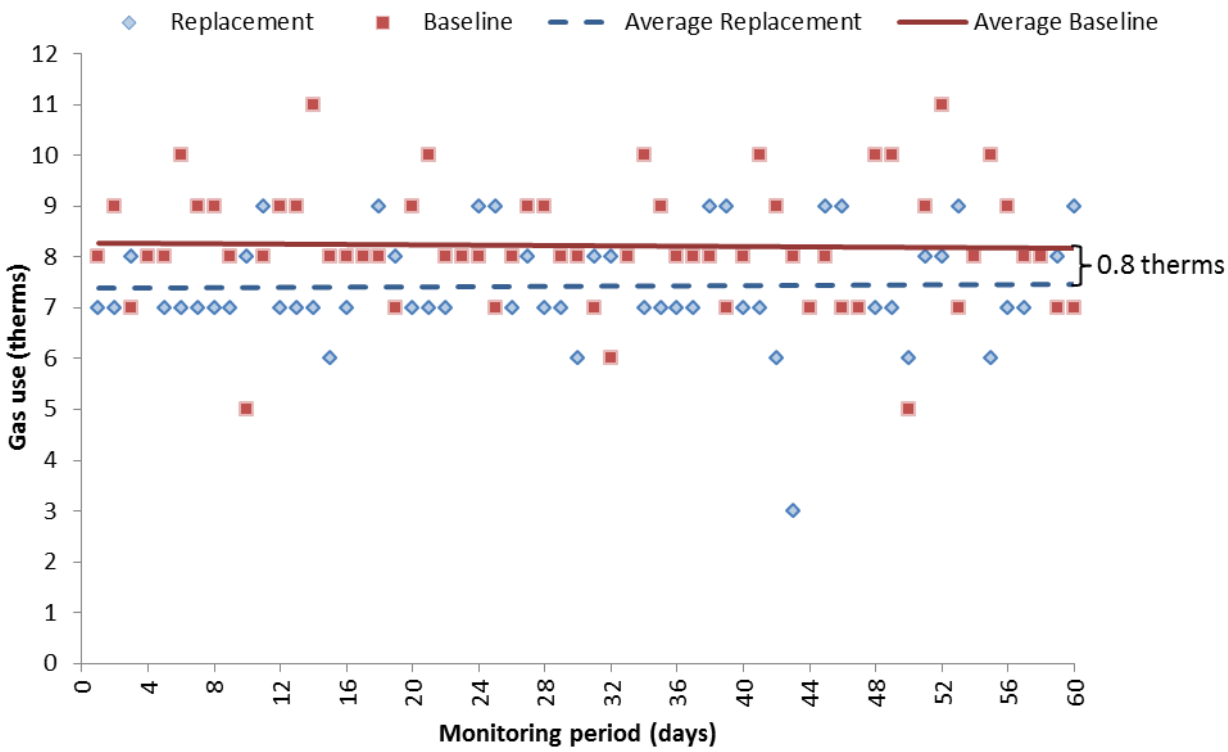
During the monitoring period, the top oven was used daily, while the bottom oven was used sporadically only on Fridays and Saturdays as a peak period backup oven. The resulting energy consumption for the primary (top) oven ranged between 5 and 11 therms per day, with an average of 8 therms per day.

**Replacement Results**

After the baseline monitoring period, the preexisting ovens were replaced with Lincoln Impinger ovens equipped with the Quest Energy Management System. Store operation during the replacement monitoring period matched the baseline period with the top oven in use daily and the bottom oven used only sporadically as a backup during peak periods. The primary (top) oven consumed daily three to nine therms per day, with an average of 7.45 therms per day during the 60-day monitoring period; a 7 percent average savings.

Figure 10 compares the monitoring results for the top ovens during the baseline and replacement monitoring periods.

**Figure 10: Primary Existing to Replacement Daily Oven Energy Consumption Comparison—Pizza Patron (Dallas, TX)**




Source: FNi

### *2.5.2.3 Costco*

The Southern California Gas Company's Engineering Analysis Center conducted a study of an existing gas conveyor pizza oven at Costco Warehouse in Norwalk, California. The conveyor ovens, pictured in Figure 11, consisted of three stacked units. Each oven had an 180,000 Btu/h burner, a belt width of 32 inches, and an oven chamber length of 70 inches. The conveyors were preheated about 45 minutes to one hour prior to the store opening at 10 am daily, and operated all day. The ovens were shut off at the end of the business day, which varied from 6 pm on the weekends and 8:30 pm on weekdays. Pizza was baked on all three decks; sandwiches were

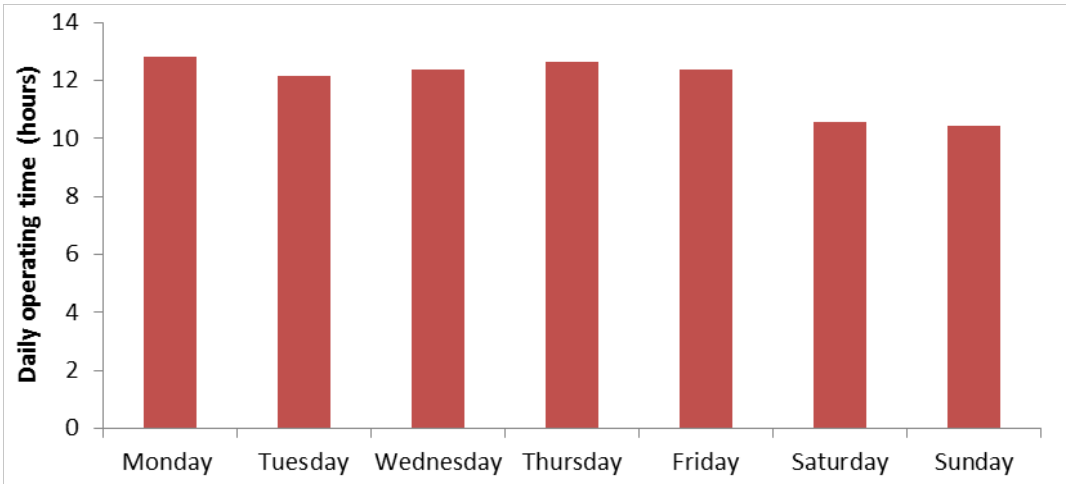
baked on the top deck, and chicken bakes and churros on the bottom deck. Bake time ranged from four to ten minutes.

**Figure 11: Existing Triple-Stack Pizza Ovens—Costco**

Photo Credit: FNi

Costco showed consistent conveyer usage patterns based on the hours of operation of the facility. The store was open for 10.5 hours on weekdays, and the conveyors operated for an average additional two hours (12.5 hours daily). On the weekends, the store was open for 8 hours and the conveyors operated for 10.5 hours. The ovens are clearly operated on a set daily schedule. The Costco schedule is shown in Figure 12.

**Figure 12: Average Daily Operating Time per Oven per Day of the Week—Costco**




Source: FNi

Table 6 summarizes the Costco baseline monitoring results, averaged over a daily and hourly periods. The results show that the amount of baked goods per day and gas use per hour per conveyer is constant during operation.

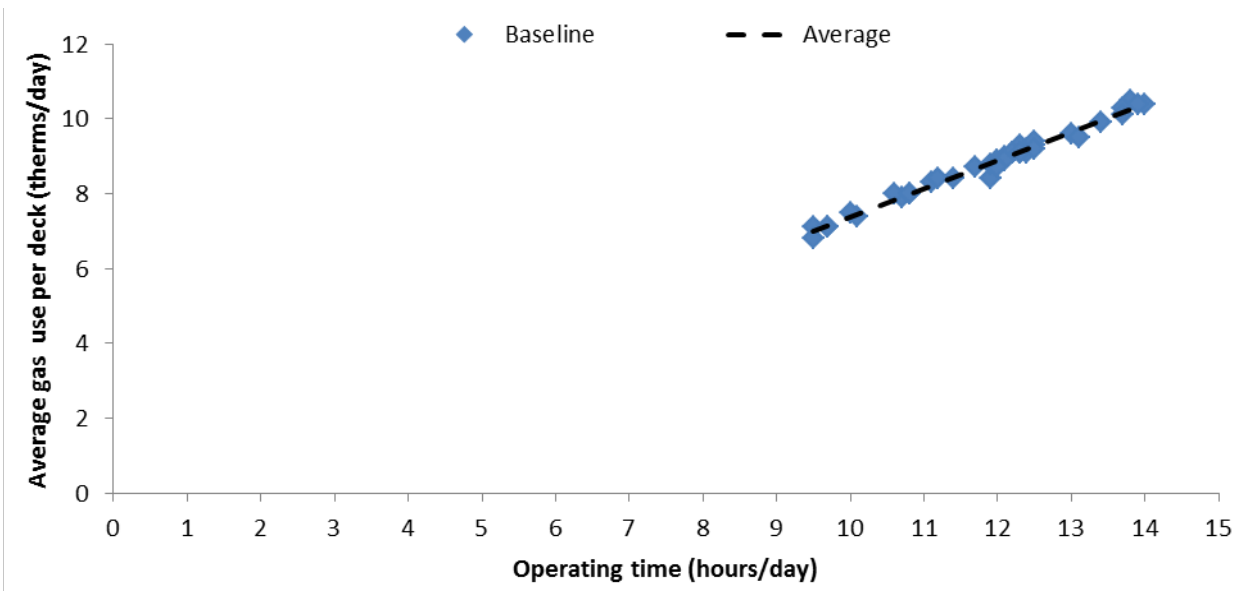
**Table 6: Baseline Monitoring Results Averaged Over a Daily or Hourly Period—Costco**

| | Total Baked Goods (Items/day) | Operating Time Per Conveyor (h/day) | Gas Use (therms/day) | Gas Use Per Baked Good (Btu/item) | Gas Use Per Hour Per Conveyor (Btu/h) |
|---|---|---|---|---|---|
| Average | 967 | 11.9 | 26.4 | 8,320 | 74,060 |
| Weekdays | 955 | 12.5 | 27.7 | 8,850 | 74,030 |
| Weekends | 978 | 10.5 | 23.4 | 7,200 | 74,110 |

Source: FNi

The results from testing the standard conveyor showed consistent energy use from all three ovens over the operating day. It appeared then that each conveyor was equally loaded throughout the day. A plot of daily gas use versus operating hours, averaged per conveyor, is shown in Figure 13.

**Figure 13: Baseline Conveyor Oven Energy Use and Hours of Operation—Costco**




Source: FNi

In this application, an EMS that would reduce the gas flow rate of each Costco conveyor when there are no baked goods in the chamber would be very beneficial. The Quest Energy Management System on the Lincoln 3270 saved 24.2 percent of the energy use when the conveyor was idling. If it is assumed that the Costco conveyors during the operating day can be idled for ⅓ of their operating time, that would be same as saying that one out of three conveyors can be idled for the entire day. A 24.2 percent savings over the ASTM idle rate for the existing conveyor oven at Costco would be equal to a gas flow rate of 34,881 Btu/h. Given these assumptions, the estimated daily savings from an EMS on each of the Costco conveyors would be equal to 4.15 therms—a 15.7 percent gas savings over the daily gas use of 26.4 therms.

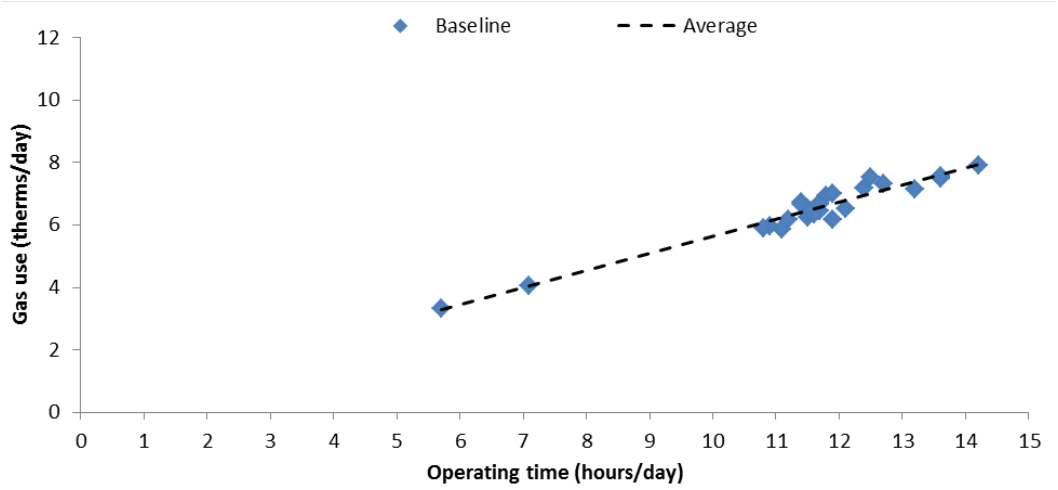
### *2.5.2.4 Pizza Patron (Lynwood, CA)*

Baseline monitoring was conducted by Southern California Gas Company for one month at the Lynwood California test site. This location used older standard-efficiency ovens (Figure 14). While the operating hours and procedures were similar to the Dallas Pizza Patron test site, the volumes were substantially lower. The resulting energy use and operating hours are summarized using the scatter plots in Figure 15 to show day-to-day operational variation at the Lynwood test site.

**Figure 14: Existing Ovens at Pizza Patron (Lynwood, CA)**

Photo Credit: FNi

**Figure 15: Baseline Conveyor Oven Energy Use and Hours of Operation—Pizza Patron (Lynwood, CA)**




Source: FNi

Due to the similarity between the baseline ovens in this Pizza Patron and the Straw Hat Pizza test locations, the savings potential of the advanced oven design can be projected. In the former test site, replacing the standard-efficiency convener ovens with the advanced-design conveyor oven resulted in a 38 percent savings. It is estimated that the advanced ovens would result in a reduction of 2.5 therms per day for the primary oven.

### 2.5.3 Summary of Results and Discussion

The use pattern of a typical conveyor oven varies during the day and week. The oven will have long periods where it sits idle, punctuated by short spans of heavy use. During the idle period, the oven remains at cooking temperature so that it is immediately ready to bake when an order comes in. Conveyor ovens are typically operated for 8 to 12 hours per day, 363 days per year. Many pizza restaurants will operate one or two conveyor ovens during the week and have an additional conveyor oven to handle the higher volume on weekends and holidays. These backup conveyor ovens may be used for only two or three hours, often during weekend dinner rushes, then shut off. Other operators may leave the ovens operating all day long, regardless of usage.

Due to the long operating times and unsophisticated controls, a conveyor oven's energy use is dominated by its idle energy rate. Preheat energy consumption represents less than 10 percent of the daily energy consumption for a conveyor oven that is turned on once over a 12-hour operating period. Average gas energy savings from the Lincoln conveyor oven ranged between 6 percent and 38 percent. The results of the field monitoring sites are summarized in Table 7.

**Table 7: Summary of Monitoring Results per Oven Averaged Over a Daily or Hourly Period**

| SITE | PIZZA PATRON (DALLAS, TX) | STRAW HAT PIZZA (FAIRFIELD, CA) | COSTCO (NORWALK, CA) | PIZZA PATRON (LYNWOOD, CA) |
|---|---|---|---|---|
| **BASELINE OVENS** | | | | |
| Average Daily Energy Consumption (therms/day) | 8.0 | 7.1 | 8.8 | 6.5 |
| Average Operating Hours (h/day) | 11 | 13 | 12 | 11 |
| Average Energy Consumption Rate (kBtu/h) | 72.7 | 54.2 | 73.3 | 59.1 |
| **REPLACEMENT OVENS** | | | | |
| Average Daily Energy Consumption (therms/day) | 7.5 | 4.4 | 7.4* | 4.0* |
| Average Operating Hours (h/day) | 11 | 13 | 12* | 11* |
| Average Energy Consumption Rate (kBtu/h) | 68.2 | 33.7 | 67.3* | 36.4* |
| Average Energy Savings (%) | 6 | 38 | 16* | 38* |

*Projected
Source: FNi

## 2.6 Conclusion and Recommendations

### 2.6.1 Conclusions

The results showed a clear opportunity to advance state-of-the-art conveyor ovens by developing more efficient designs that maintain the functionality required by operators. This advancement will be accomplished by decreasing the energy lost when the oven is not cooking product while still kept in a ready-to-cook or idle state through improved insulation and advanced controls. The cooking-energy efficiency of the conveyor oven will be most impacted through the development and application of advanced burner and heat exchanger designs. Through this project, GTI began exploratory development of advanced conveyor ovens that reduce standby losses and improve efficiency.

There is also an opportunity for energy savings in the conveyor oven category through what is being termed by the industry as a standalone EMS specifically designed for conveyor ovens. An EMS is able to monitor and control the functions of the conveyor oven to bring the energy consumption of the appliance down during periods of inactivity. Feedback from operators at each test site indicates that peak business sales are during lunch and dinner hours, with the time between both meals representing the lightest periods. These hours of operation where the oven is predominantly in standby represent an opportunity for energy savings that can be derived from the EMS. This strategy has the potential to reduce conveyor oven energy consumption by 16 percent, based on laboratory testing and assuming that the ovens are in standby mode for a third of the hours operated.

In each of the test sites, energy consumption was driven by high standby losses, evidenced by the relatively flat energy-use profile independent of cooking activity. Correct application of the EMS is crucial to achieve energy savings. In high-volume operations, such as concession stands and sporting events, there is a constant flow of customers. The constant demand from such operations would not be able to engage the energy-saving feature of the EMS and would not be the best application of this technology.

The improved design of the conveyor oven adds cost to the burner assembly and the control system. The incremental cost of the components is $300, based on a street price for the new product that is $1000 more than the price of the baseline product with a list price markup of 3.3. Based on a savings of 800 therms per year, 10.21 therms/Mcf and the EIA gas cost of $7.13 per Mcf, the expected payback based on component cost is 0.5 years and based on street price is 1.8 years. These economics, and the fact that the equipment has the same footprint as the standard product, support using this product as a part of the kitchen design in new restaurants and as a drop-in replacement in existing restaurants.

Based on previous PIER research done in project 500-06-028, *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment*, an installed base of 10,900 conveyor ovens consume an estimated 21.5 million therms or 2.86 million dollars annually in California. Current qualifying ovens under the California Energy Wise program put the highest efficiency ovens at 47 percent cooking-energy efficiency. The remaining 53 percent is energy not utilized for cooking the product; escaping through the ends of the oven, through the oven itself, and out

the exhaust flue. The report also assumed a 50 percent market penetration potential for energy-efficient conveyor ovens. Based on the data collected from Straw Hat Pizza, a potential 38 percent energy reduction can be achieved by going to a new rebate-qualified conveyor oven. Reflected across the 21.5 million therms consumed and a 50 percent market penetration of energy-efficient models, a potential savings of 4.1 million therms is possible.

### 2.6.2 Recommendations

Feedback from equipment installers and service technicians in the field indicate more robustness in the EMS system is needed for conveyor ovens. Current EMS systems utilize a vision-based sensor placed along the ends of the conveyor to detect the presence of food product. Field reports suggest that the feedback sensors are prone to blockage from food products such as cheese and flour, resulting in false readings that incorrectly inform the EMS to stay out of idle mode. A more robust EMS system that can withstand the vigor of commercial operation is needed to fully capture the energy savings of conveyor ovens.

The three main areas of energy loss include the end loss from the open entrance and exit of the oven, the heat loss through the oven itself (a result of low amounts of insulation), and the heat energy lost through the exhaust vent. Field data from the test sites indicated that conveyor ovens spend a majority of their time in standby/idle mode during the operating day. To increase the efficiency of the conveyor oven, it is very important to minimize these three main areas of energy loss when running in standby mode.

The field data showed that the majority of conveyor ovens operate in a light load condition. Even during cook loads, the conveyor oven is never filled to its maximum with food product. Consequently, energy loss during standby operation or between individual light product loads is large. It is recommended that more research and development be spent on reducing the energy consumption of conveyor ovens under light-load conditions.

Additional field testing should be conducted in the conveyor oven category. The data captured from this project helped to begin characterizing the energy use of conveyor ovens. However, more research is needed to completely characterize this appliance. The ultimate goal is to be able to significantly reduce the estimated 21.5 million therms consumed by conveyor ovens in California each year.

# CHAPTER 3: Convection Ovens

## 3.1 Summary

### 3.1.1 Introduction

From baking and roasting to warming and reheating, convection ovens can be used for all types of food preparation, including foods typically prepared using other appliances (e.g., griddles, fryers, etc.). As a result of their versatility and diversity, convection ovens can be found in a variety of foodservice operations.

The concept behind the modern forced-air convection oven is simple. When food cooks inside a standard oven, it is surrounded by an insulating layer of air that is cooler than the overall oven cavity temperature. In a convection oven, a motorized fan (or blower) forces the heated air to move throughout the oven's cavity, thereby stripping away the layer of cooler air next to the food. The result is a faster, more even cooking process than can be provided by standard, natural convection, or radiant-heat ovens.

Gas convection ovens have relatively low energy efficiencies in comparison with other ENERGY STAR® categories of commercial kitchen equipment. These inefficiencies stem from the predominance of low-cost, inefficient burner designs, controls, and poor cavity insulation. Even the best-in-class convection ovens exhibit significant idle energy losses. Therefore, reducing idle energy consumption will have a significant impact on overall energy savings.

### 3.1.2 Purpose

The purpose of this project was to identify new technologies that could improve gas convection oven energy efficiency and performance. The goal was to validate a targeted 14 percent energy-efficiency gain when using an advanced design oven.

### 3.1.3 Project Objectives

The objectives of the commercial gas convection oven study were to:

- Characterize the energy inefficiencies of standard convection oven technologies through laboratory and field data collection.
- Design and develop a new prototype for the commercial foodservice convection oven, which is both energy-efficient and robust, that was brought to production as an ENERGY STAR®-qualified product.
- Compare the energy use of the standard and energy-efficient gas convection ovens under laboratory test conditions.
- Compare the energy usage of standard and energy-efficient convection ovens at several field-monitoring locations.
- Recommend improvements to further convection oven efficiency and market adoption.

### 3.1.4 Project Outcomes

Convection ovens come in two types of designs: direct-fired and indirect-fired. Since the burners of direct-fired convection ovens are placed directly in-cavity, this allows flue gases to circulate throughout the cavity and thus interact with food product. Since this is not always a positive attribute, indirect-fired convection ovens make up the majority of the convection oven market. Lab testing demonstrated that the most excessive heat losses from convection ovens occurred in the flue exhaust and through the door seals. Typical convection ovens use sheet metal flanges to act as door seals due to durability and ease of manufacturing. However, they are considered to be an ineffective strategy for sealing the oven cavity and are therefore a detriment to idle energy performance. Inexpensive burners and heat transfer surfaces also prevent efficient heat extraction from the hot gasses.

The aforementioned high idle energy consumption of convection ovens can be mitigated by improved cavity door design adding insulation and decreasing flue losses through better heat exchanger design. The Gas Technology Institute (GTI) and the Garland Group designed a convection oven prototype that incorporated these energy-saving technologies. High-temperature silicone gaskets around the oven door replaced the sheet metal flanges, which improved efficiency and reduced standby heat loss. GTI and the Garland Group also implemented an exhaust flue re-routing system, which improved heat transfer between the flue gases and the oven cavity.

Pacific Gas and Electric's Foodservice Technology Center (FSTC) laboratory applied the ASTM Test Method F1496, *Standard Test Method for Performance of Convection Ovens,* to this new ENERGY STAR® convection oven the idle energy rate with the oven maintaining an average temperature of 350°F (177°C) in the cavity was 12,400 Btu/h. The heavy-load cooking-energy efficiency tests resulted in a gas cooking energy rate of 49,700 Btu/h, and a cooking-energy energy efficiency of 44 percent.

Four diverse test sites were selected for convection oven field monitoring: a sit-down fine dining establishment (Bridges Restaurant & Bar in Danville, CA), a production cooking facility (Melon's Catering in San Francisco, CA) and a cafeteria-style restaurant (San Ramon Valley Conference Center (SRVCC)). The results from both standard and energy-efficient convection oven field monitoring are presented in Table 8.

**Table 8: Field Monitoring Results**

| **Site** | **Bridges Restaurant** | **Melon's Catering** | **SRVCC** |
|---|---|---|---|
| Approx. Oven Operating Time (h) | 14 | 14 | 14 |
| Baseline Monitoring (therms/day) | 3.71 | 4.35 | 3.89 |
| Replacement Monitoring (therms/day) | 1.22 | 3.05 | 3 |
| % Change | 67% | 30% | 23% |

Source: FNi

### 3.1.5 Conclusions

The cooking-energy efficiency and performance of gas convection ovens can be increased with simple enhancements to burner efficiency, heat transfer and door seal designs. The pervasiveness of decades-old, durable, functional, but very inefficient convection ovens in the restaurant industry is a major obstacle to penetrating the market with ENERGY STAR®-qualified models. The increased production cost for the energy-efficient design was estimated to $200 or less than 5 percent to the overall cost of the oven, based on list price.

In this study, across the three test sites, there was an average gas energy reduction of 40 percent after the advanced convection oven replacement. The field monitoring data showed that restaurants leave convection ovens operating during their entire periods of operation, regardless of current business or level of volume. Thus, lower idle energy rates were the major factor in reducing the convection oven energy use at the three test sites.

### 3.1.6 Recommendations

This study demonstrated dramatic energy savings from the replacement of standard-efficiency gas convection ovens. However, the advanced convection oven in this study only exhibited the minimum ENERGY STAR®-qualified energy efficiency level of 44 percent. More field replacement studies are needed with even higher efficiency convection ovens to fully assess the potential energy saving benefits.

It is recommended that further research and development be conducted on gas convection ovens to push the upper limit of energy efficiency beyond the current best-in-class 54 percent and idle energy rate of 13,000 Btu/h.

### 3.1.7 Benefits to California

In 2010, the FSTC estimated that 65,000 gas convection ovens were in operation in California commercial kitchens. The estimated annual natural gas use for these convection ovens was 30 million therms. If 35 percent of the ovens in California were selectively replaced with energy-efficient convection ovens, each reducing energy use by 40 percent, the total annual savings would be on the order of 4.2 million therms or 2.93 million dollars.

California foodservice operators stand to benefit from the adoption of energy-efficient, well-insulated convection oven technology. Reducing the industry's reliance on outdated, stagnant convection oven technology by embracing (and improving upon) new energy-efficient convection oven designs will provide immediate gas energy savings and reduce carbon emissions.

## 3.2 Introduction

### 3.2.1 Background

One of the most common cooking appliances found in a commercial kitchen is the convection oven. In 2010, the Foodservice Technology Center (FSTC) conducted a study *Characterizing the Energy Efficiency Potential of Gas-fired Commercial Foodservice Equipment*, which estimated that there were over 65,000 convection ovens currently in use in California, with an energy load of 30 million therms per year. Convection ovens use a cooking chamber similar in design to the

oven found in most homes, with the exception that commercial convection ovens use fans to force hot air through the cooking chamber to convectively cook food products. The moving air improves the cook times and uniformity of the final products.

Gas convection ovens exhibit relatively low efficiencies, due in part to the prevalence of inexpensive, low-efficiency burner designs and controls, poor heat transfer and ineffective sealing of the cooking cavity. Even convection ovens that have achieved ENERGY STAR®-level efficiencies still exhibit significant standby losses, impacting the overall utilization efficiency. Since convection ovens typically spend a large portion of their operating time in a ready-to-cook or idle mode, reducing the idle (standby) energy use of a convection oven will have a significant impact on reducing the overall energy use.

In addition to being inefficient, convection ovens have a long life span, which is why there is a large inventory of inefficient convection ovens in California. Field audits conducted by the FSTC show there are many old convection ovens still in use, with service life as high as 30 years. The convection oven shown in Figure 16 was pulled from a neighborhood bakery in Oakland, California. At the time of discovery, this unit was still in use despite its dramatic signs of age.

**Figure 16: Existing Convection Oven Recently Pulled from Service**

Photo Credit: FNi

### 3.2.2 Objectives

The objective of this field monitoring study was to demonstrate the effectiveness of energy efficient convection ovens by verifying performance in commercial kitchens. The goal was to validate a targeted 14 percent energy-efficiency gain when using advanced design equipment, demonstrated through the following measures:

- Solicit and collect field data to characterize the energy inefficiencies of standard convection oven technologies.

- Determine the percent efficiency gain of test sites by replacing standard-efficiency convection ovens with ENERGY STAR® convection ovens.
- Determine the percent efficiency gain of best-in-class convection ovens with ENERGY STAR® convection ovens.
- Recommend future improvements to convection oven design and use.

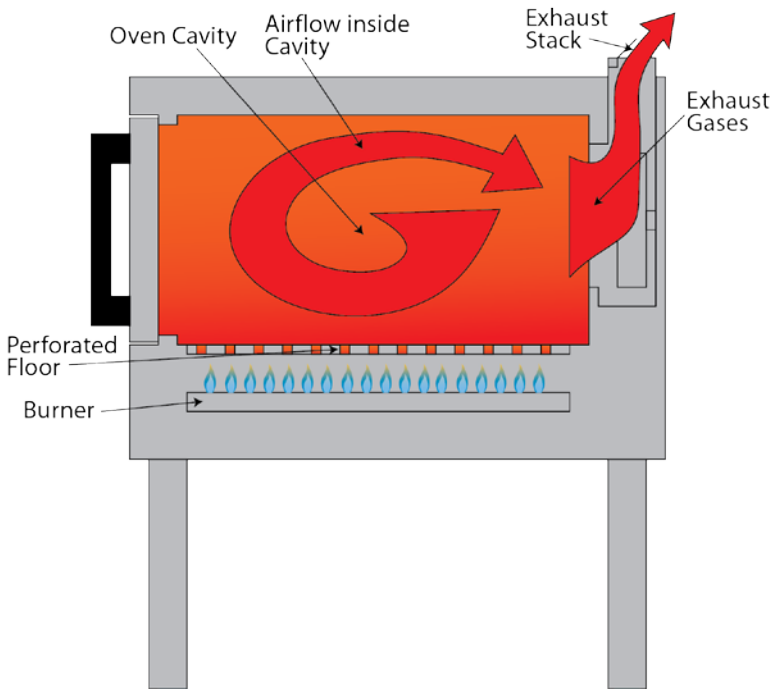
## 3.3 Technology

### 3.3.1 Standard Technology

The concept behind a convection oven involves the use of a motorized fan inside the cooking cavity to strip away the insulating layer of cooler air surrounding food items. Most modern gas-fired convection ovens share a basic design. Gas burners are located underneath or around a cavity designed to accommodate standard-sized baking pans (18" by 26"). A fan located to the side or the rear of the oven cavity circulates air throughout the oven cavity.

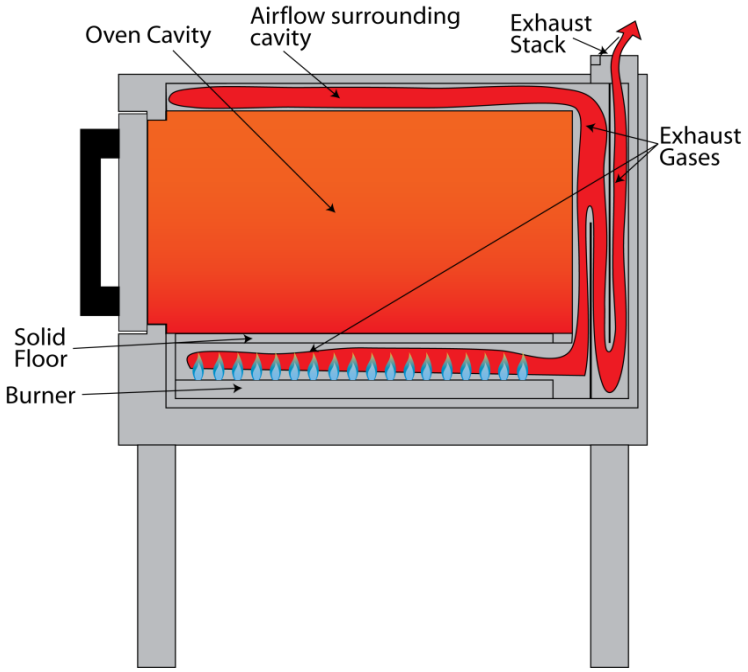
Most gas convection ovens use atmospheric burners. Traditionally, gas convection ovens were based on direct-fired designs where the products of combustion entered the cooking cavity. Direct-fired convection oven designs place the burner in the oven cavity, allowing the hot flue gases to circulate throughout the cavity (Figure 17). Indirect-fired oven designs separate the products of combustion from the oven cavity and transfer heat through a heat exchanger (Figure 18). Indirect-fired ovens are oven referred to as "muffle" ovens. While direct-fired ovens are simpler in design, the combustion products interact with the food product in ways that are not always desired. As a result, most convection ovens on the market are indirect-fired.

**Figure 17: Direct-Fired Convection Oven**




Source: FNi

**Figure 18: Indirect-Fired Convection Oven**




Source: FNi

### 3.3.2 Advanced Technology

Minimizing the temperature loss of escaping hot air from the cooking appliance reduces the energy the cooking appliance has to consume to maintain the set-point temperature. Improved sealing of the cooking appliance, such as high-temperature silicon gasketing around the door, improves efficiency. Additional efficiency gains are also possible by optimizing the flue to extract as much heat as possible from the combustion gases prior to exhausting. The air flowing through the exhaust flue contains most of the heat energy from burning natural gas. The more heat that is transferred from the flue gases and into the cooking cavity, the more efficient the oven becomes. Advanced heat exchangers and advanced insulating materials can help further boost convection oven efficiencies by pulling more heat out of the exhaust and retaining more of that heat within the oven.

### 3.3.3 Appliance Developed

GTI worked with the Garland Group on the convection oven project to develop a new direct-fired oven, which was evaluated within the scope of this field test. During the R&D phase, excessive heat from the oven cavity was shown to be lost around the door seals and the exhaust flue. Typical convection ovens use sheet metal flanges to act as door seals due to their durability and ease of manufacturing.

When these sheet metal flanges were replaced with high-temperature silicone seals, the standby energy loss was reduced. The research yielded a better understanding of the energy flow in the convection oven during idle and cooking. From the research, energy loss in the exhaust flue was identified, and routing of the flue gas was optimized to reduce exhaust rates. This allowed for more heat transfer time between the combustion gas and the oven. After incorporating better

door seals and rerouting of the flue gas exhaust, the standby loss was reduced from 16.9 kBtu/h to 11.4 kBtu/h. An image of the Garland convection oven is shown in Figure 19.

**Figure 19: Garland ENERGY STAR® Convection Oven**

Source: FNi

## 3.4 In-lab Testing and Results

### 3.4.1 ASTM Testing of Advanced Unit

ASTM test methods establish a set method and testing sequence for commercial foodservice equipment. Appliance performance factors such as preheat time, idle energy consumption, and cooking-energy efficiency are determined in the ASTM test method. Before the ENERGY STAR® Garland oven was installed in the field test site, its performance and efficiency was measured in the FSTC laboratory by applying ASTM test method F1496: *Standard Test Method for the Performance of Convection Ovens*. Figure 20 illustrates ASTM testing in the lab.

### 3.4.2 ASTM Test Results

Preheat in the lab took a duration of 12.3 minutes to reach 340°F (170°C) at a gas energy consumption of 12.8 kBtu. The measured idle energy rate was 11.6 kBtu/h, while the heavy-load cooking-energy efficiency was 44 percent with an energy rate of 49.7 kBtu/h. A summary of the ASTM test data is shown in Table 9.

**Figure 20: ASTM Lab Testing**

Photo Credit: FNi

**Table 9: ASTM Test Data of Garland Convection Oven**

**Energy Input Rate**

| | |
|---|---|
| Rated Energy Input Rate (Btu/h) | 60,000 |
| Measured Energy Input Rate (Btu/h) | 60,500 |
| Difference (%) | 0.83% |

**Preheat to 340°F**

| | |
|---|---|
| Duration (min) | 12.3 |
| Gas Energy Consumption (Btu) | 12,800 |

**Idle Energy Rate at 350°F**

| | |
|---|---|
| Idle Energy Rate (Btu/h) | 11,600 |
| Control Idle Energy Rate (W) | 715 |

**Heavy-Load Cooking-energy Efficiency**

| Food Product | Russet Potatoes |
|---|---|
| Cook Time (min) | 48 |
| Gas Cooking Energy Rate (Btu/h) | 49,700 |
| Control Energy Rate (W) | 635 |
| Energy to Food (Btu/lb) | 552 |
| Energy to Appliance (Btu) | 39,772 |
| Cooking-energy Efficiency (%) | 44 |
| Production Capacity (lb/h) | 90 |

Source: FNi

## 3.5 Field Testing

### 3.5.1 Field Test Plan

#### *3.5.1.1 Site Selection*

Three test sites were selected for the field testing, all in the San Francisco Bay Area. A sampling of various business types with different usage profiles were used: a sit-down fine dining establishment with variable business flow and a rotating menu (Bridges Restaurant & Bar), a production cooking facility (Melon's catering) and a cafeteria with a set business flow (San Ramon Valley Conference Center (SRVCC).

**Bridges Restaurant & Bar**

Bridges Restaurant & Bar (Bridges), shown in Figure 21, is a 5,000-square-foot, fine-dining restaurant with a 107-seat dining room, 26-seat bar, and 48-seat patio. Danville is a city located in the East Bay of the San Francisco Bay Area with an approximate population of 42,000. The restaurant has been in operation for approximately 25 years and occupies a building that is several years older and has had prior restaurants as tenants. The restaurant operates seven days a week, from 11 am to 2 pm for lunch and from 5 pm to 9 pm for dinner. Baseline monitoring was conducted with a standard-efficiency, double-stack convection oven (Figure 22, left); energy-efficient monitoring was done with a double-stack Garland MCO-GS convection oven (Figure 22, right).

Bridges's hot line is pictured in Figure 23.

**Figure 21: Bridges Restaurant**

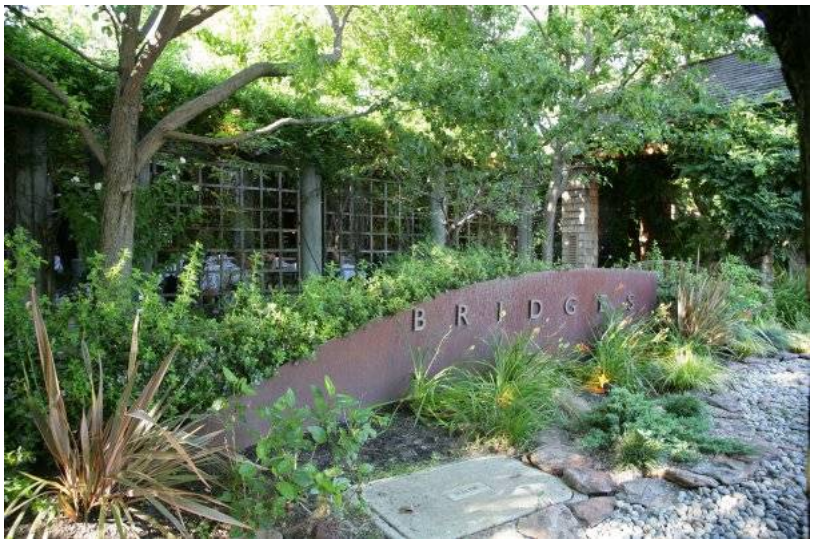



Photo Credit: FNi

**Figure 22: Standard-Efficiency Oven (Left) and ENERGY STAR® Garland Oven (Right)**

Photo Credit: FNi

**Figure 23: Bridges Hot Line**

Photo Credit: FNi

### Melon's Catering

Melon's Catering (Melon's) is a 3,000-square-foot catering kitchen located in South San Francisco. The business caters to a wide variety of events and serves a varied menu of fine dining French fusion cuisine. FSTC conducted an energy audit on Melon's as a result of the owner's participation in the San Francisco County Green Business program, which requires onsite inspection systems, including cooking appliances (which make up a large quantity of energy use in the business). Baseline monitoring was conducted with a standard-efficiency,

double-stack convection oven; energy-efficient monitoring was done with a double-stack Garland MCO-GS convection oven (Figure 24). Melon's hot line is pictured in Figure 25.

**Figure 24: Energy-Efficient Garland Oven at Melon's**

Photo Credit: FNi

**Figure 25: Melons' Hot Line**

Photo Credit: FNi

**San Ramon Valley Conference Center**

The San Ramon Valley Conference Center (SRVCC), pictured in Figure 26, is a cafeteria-style operation located in the city of San Ramon with a 100-seat dining room and 16-seat patio that serves between 100 and 300 meals per day. The hot line is fully-equipped with a variety of commercial appliances used for large-batch cooking. The kitchen operates 14 hours Monday through Thursday serving breakfast, lunch, and dinner, and eight hours on Friday serving breakfast and lunch. The kitchen is closed on weekends and holidays.

Baseline monitoring was conducted with an ENERGY STAR®, double-stack convection oven. Energy-efficient monitoring was done with a best-in-class ENERGY STAR® double-stack Duke 613 convection oven (Figure 27).

**Figure 26: SRVCC Cafeteria**

Photo Credit: FNi

**Figure 27: Best-In-Class Oven at SRVCC**

Photo Credit: FNi

### *3.5.1.2 Site Monitoring Instrumentation and Procedures*

The instrumentation package used for field testing of the convection oven consisted of a diaphragm-type positive displacement gas meter with a one pulse/$ft^3$ output. A data logger was used to log at a 60-second interval and store cumulative pulse output data from the gas meters.

Instrumentation setup at the SRVCC was a special case where the hot line had individual gas meters installed for each appliance (Figure 28). All other test sites used smaller positive displacement diaphragm type meters plumbed in-line with the cooking appliance to monitor gas consumption (Figure 29). The data logger (Figure 30) date- and time-stamped the cubic feet of gas consumed, recording at 60-second intervals. The information gathered was analyzed for usage trends and consumption profiles.

**Figure 28: Gas Meter Closet at SRVCC**

Photo Credit: FNi

**Figure 29: Typical Instrumentation Setup**

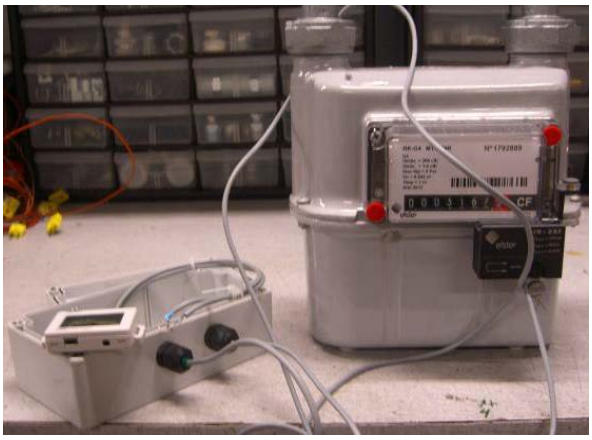


Photo Credit: FNi

**Figure 30: Data Logger**

Photo Credit: FNi

## 3.5.2 Field Results

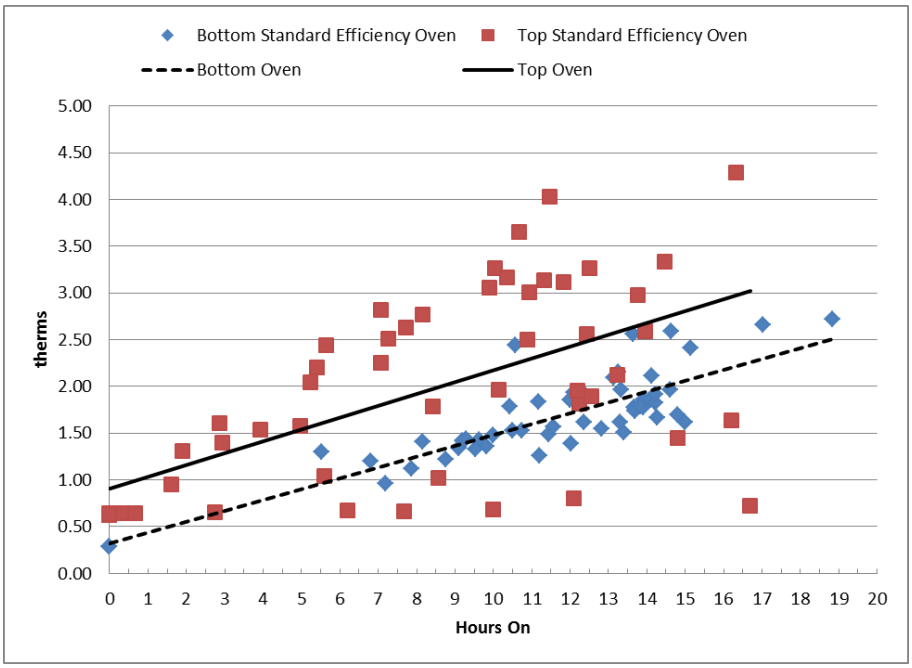
### *3.5.2.1 Bridges*

Baseline Results

The standard-efficiency oven in use at Bridges was a double-stack convection oven that was over 20 years old. The bottom oven had a broken on/off gas knob that prevented the oven from being completely shut off at the end of the night. As a result, the burner of the bottom oven would still cycle at the lowest temperature set-point. This caused the bottom oven to produce higher than standard gas consumption. For the sake of accuracy, the bottom oven's field data was omitted for averaging the energy consumption of the convection ovens. The oven was monitored over 54 days, and was determined to consume gas at an average rate of 3.71 therms per day.

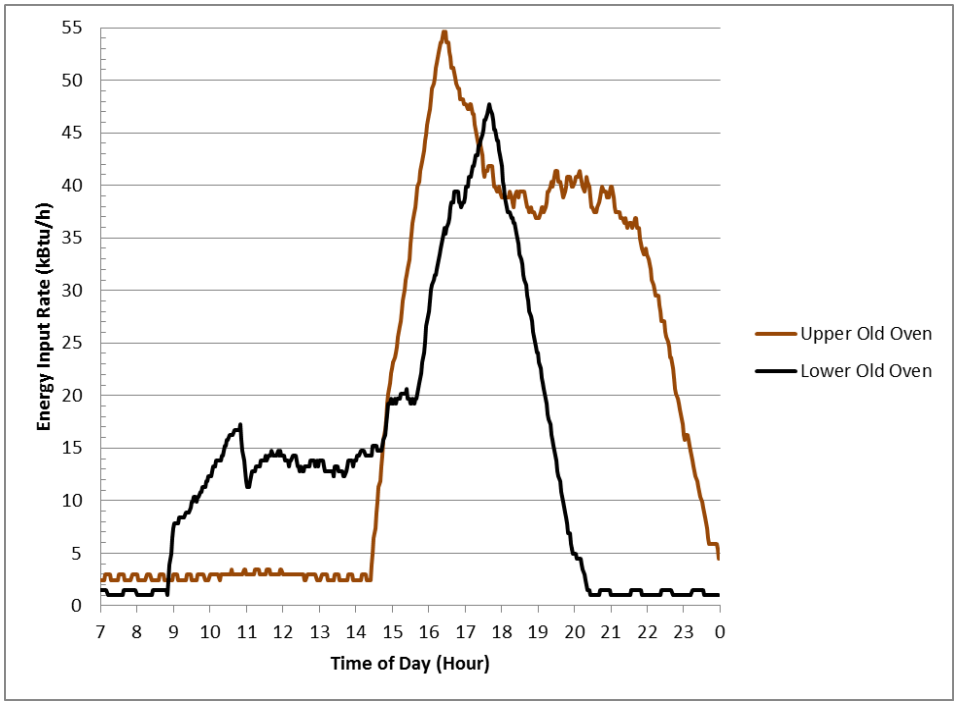
The energy consumption and regression lines for the top and bottom cavity of Bridges's standard oven are shown in Figure 31. The input rates for the top and bottom cavity of Bridges's standard oven are shown in Figure 32.

**Figure 31: Bridges Standard Convection Oven Gas Consumption**




Source: FNi

**Figure 32: Bridges Standard Convection Oven Input Rate**



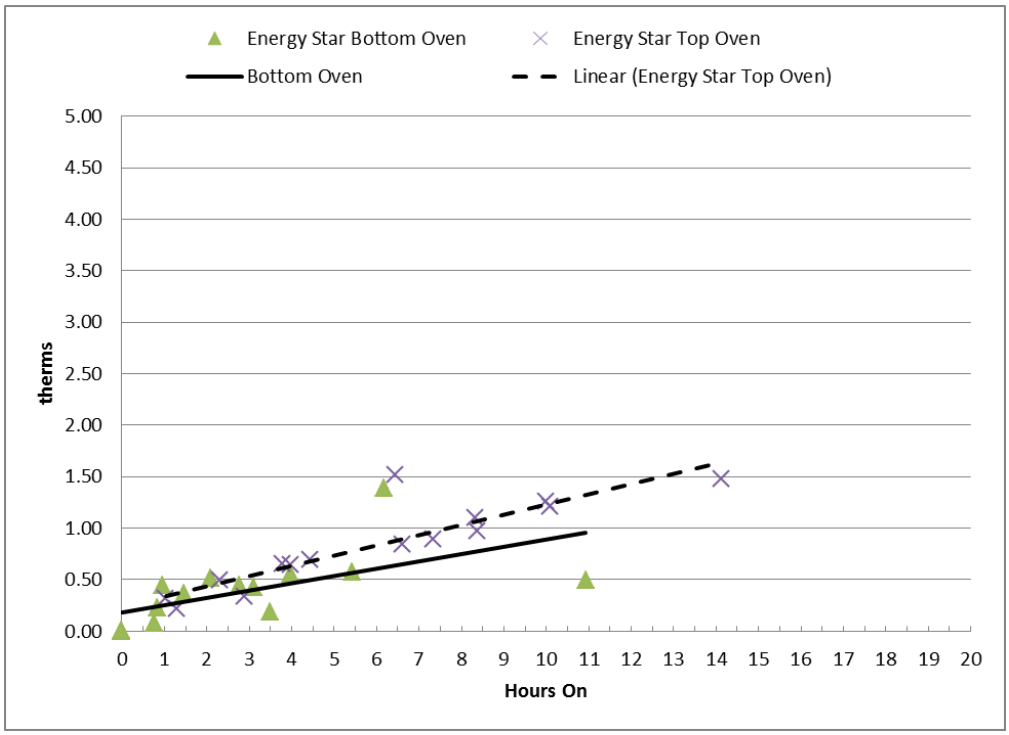

Source: FNi

Replacement Results

Energy-efficiency testing was performed with a double-stack ENERGY STAR® Garland MCO-GS-10-ESS convection oven. The oven was monitored over 15 days, and was shown to consume gas at an average rate of 1.22 therms per day; a 67 percent energy reduction when compared with Bridges' standard-efficiency oven. The daily hours of convection oven use also decreased after replacing the equipment. The executive chef and the dessert chef at Bridges noted higher production capacity and reduced radiant heat off the line, and were generally satisfied with the replacement oven. Feedback from the restaurant indicated the operators were not comfortable turning off the standard-efficiency oven at the end of the night for concern over the equipment not performing the following day. To avoid potential downtime, the operator chose to continue using the existing oven without repair. After replacing the ovens, overall energy usage decreased as a result of both the efficiency gains from the Garland ENERGY STAR® oven design as well as from reduced hours of operation. Data analysis indicates 37 percent of the energy savings was the result of operator use of the ovens and the remainder 30 percent was a result of the efficiency gain from the oven.

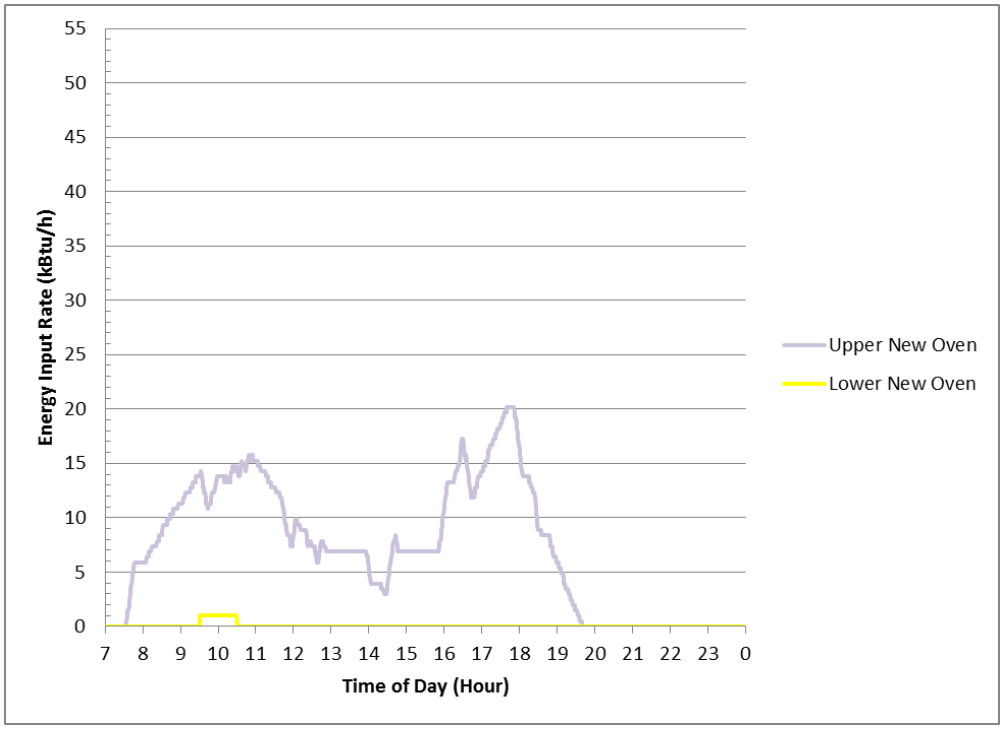
The energy consumption and regression lines for the top and bottom cavity of Bridges' ENERGY STAR® oven are shown in Figure 33. The input rates for the top and bottom cavity of Bridges' ENERGY STAR® oven are shown in Figure 34.

**Figure 33: Bridges ENERGY STAR® Convection Oven Gas Consumption**




Source: FNi

**Figure 34: Bridges ENERGY STAR® Convection Oven Input Rate**




Source: FNi

### *3.5.2.2 Melon's Catering*

Baseline results

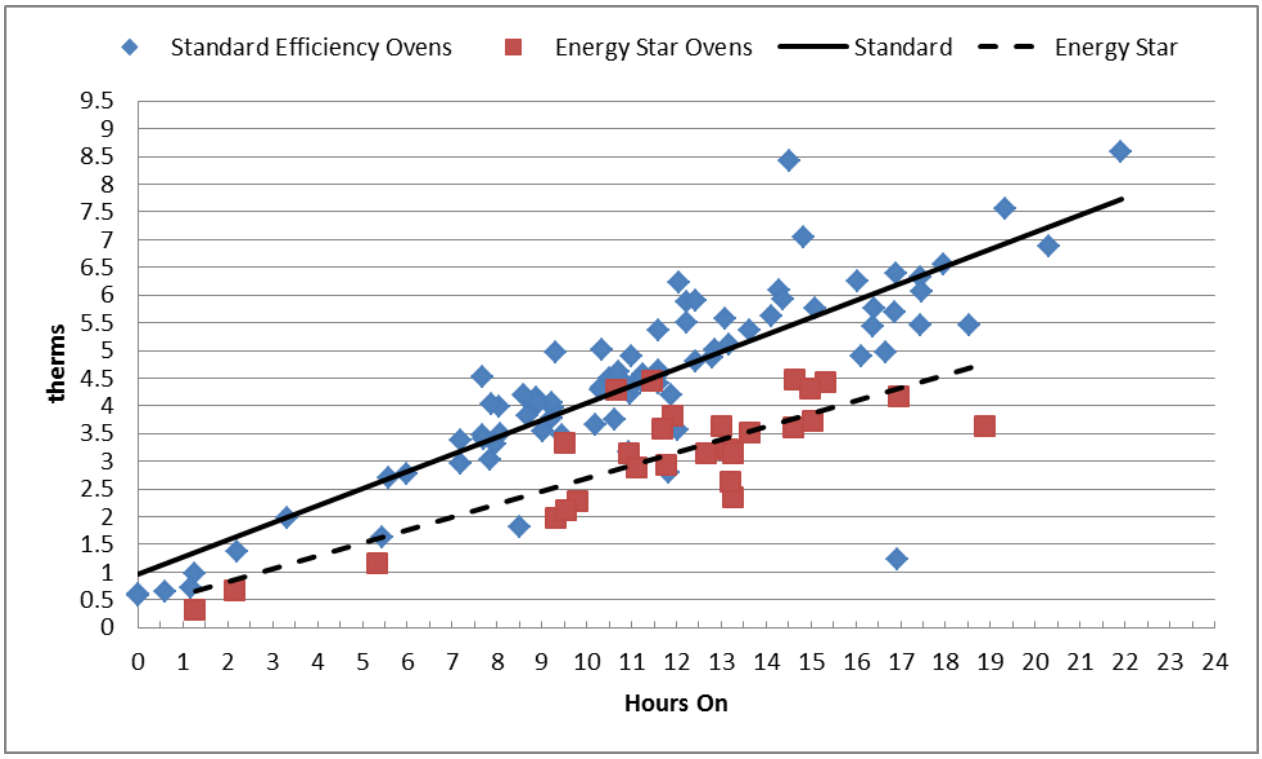
The standard-efficiency oven in use at Melon's was a double-stack convection oven that was more than 20 years old. The oven was monitored over a 90-day period to account for the variability in day-to-day operation. The average energy consumption during the baseline monitoring period was 4.35 therms per day.

Replacement Results

Energy-efficiency testing was performed with a double-stack Garland MCO-GS-10-ESS convection oven. The oven was monitored over a 30-day period, and was determined to consume gas at an average rate of 3.05 therms per day; a 30 percent reduction when compared with Melon's standard-efficiency oven. The post-monitoring satisfaction survey noted faster cook times and overall satisfaction with replacement ENERGY STAR® oven.

The general trend of the scatter plot in Figure 35 shows an overall reduction in the quantity of gas and operation between the standard-efficiency oven and the ENERGY STAR® oven.

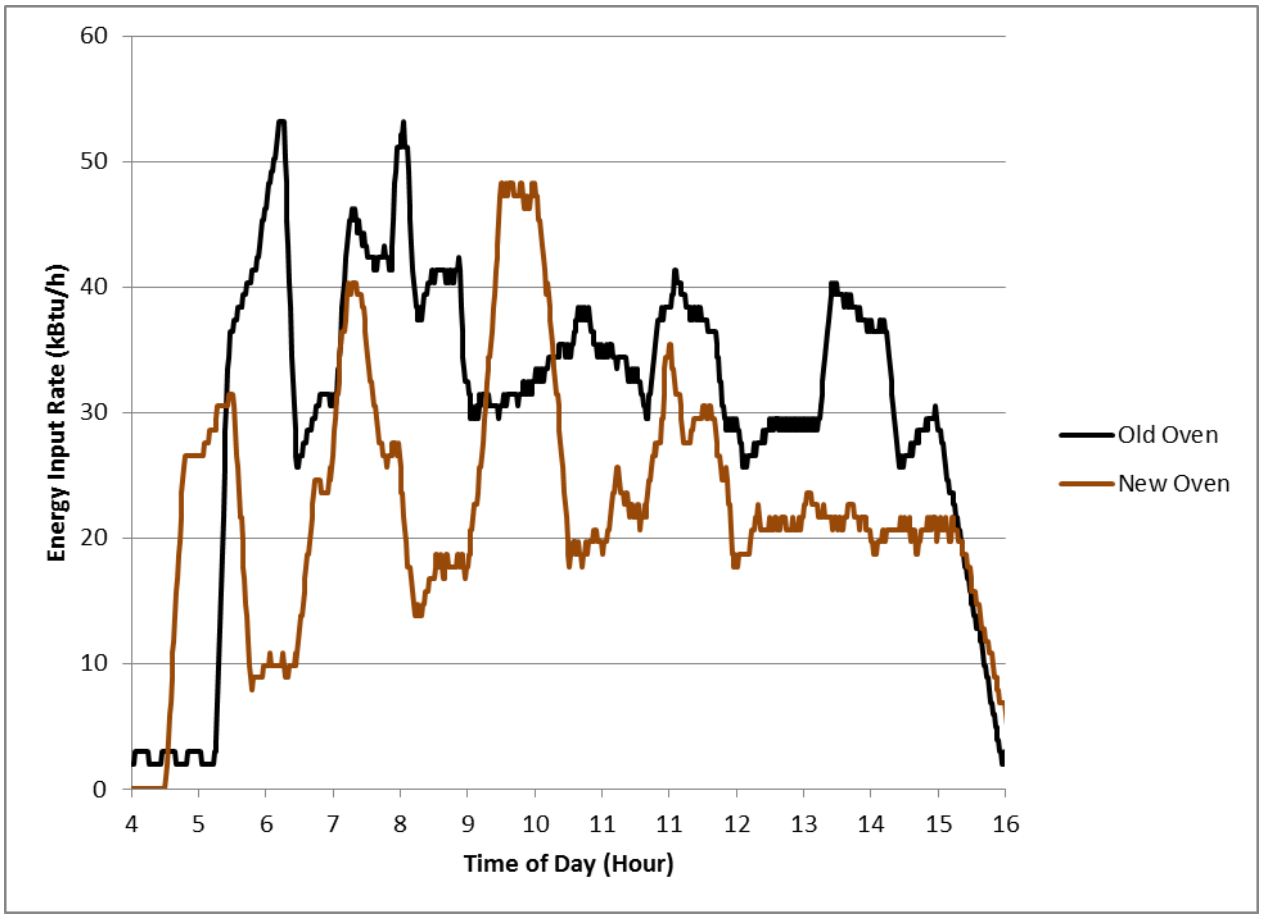
**Figure 35: Melon's Convection Oven Gas Consumption**




Source: FNi

Figure 36 shows the differences in input rates between Melon's standard oven and their ENERGY STAR® replacement oven.

**Figure 36: Melon's Convection Oven Input Rate**




Source: FNi

### *3.5.2.3 San Ramon Valley Conference Center*

Baseline Results

The existing ENERGY STAR® convection oven was monitored for 36 days, yielding an average daily gas consumption rate of 389 kBtu/day or 3.89 therms/day.

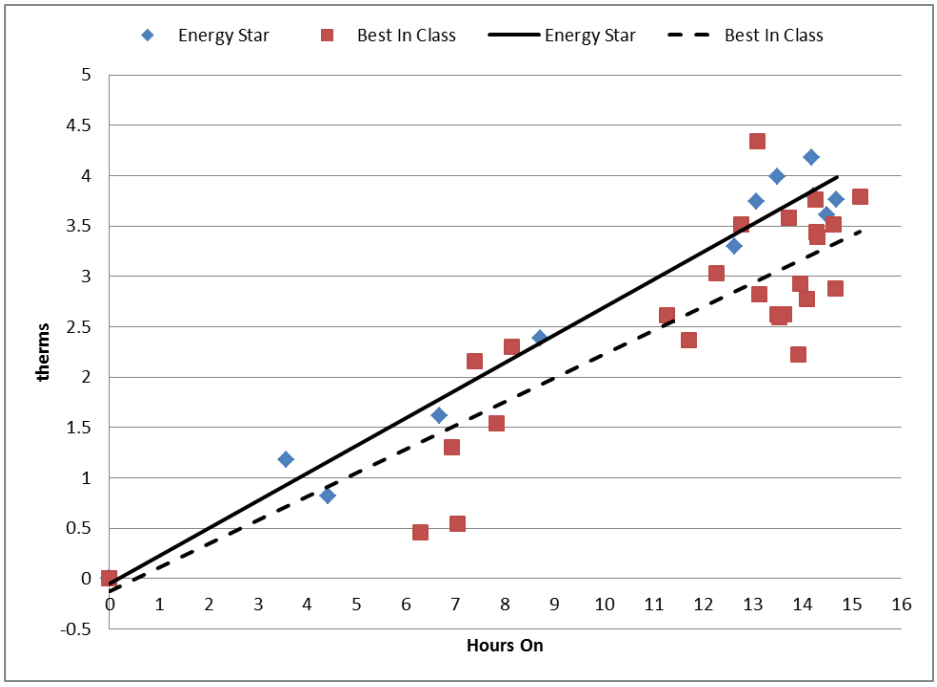
Replacement Results

Energy-efficiency testing was performed with a best-in-class double-stack Duke convection oven, which was monitored over 31 days. The oven consumed gas at an average rate of 300 kBtu/day, or three therms, of gas; a 23 percent reduction in energy use when compared with the SRVCC's existing energy-efficiency oven. Hours of operation did not change at this test site during the monitoring period of the Duke oven. Overall convection oven energy use decreased as a result of the efficiency gains from the best-in-class performance of the Duke oven over a basic ENERGY STAR® oven.

The general trend of the scatter plot in Figure 37 shows an overall reduction in the quantity of gas and operation between the existing ENERGY STAR® oven and the best-in-class replacement.

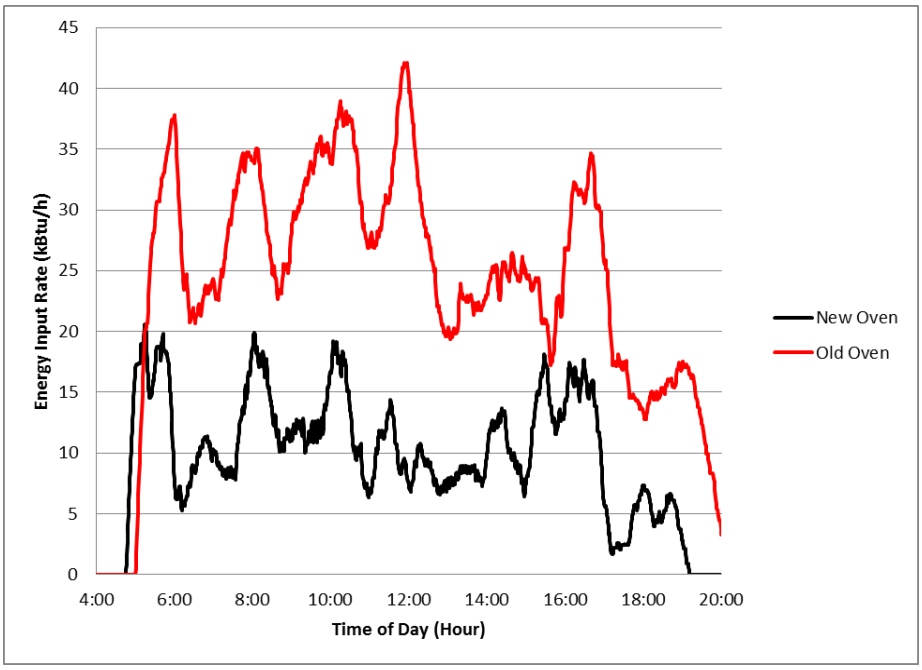
Figure 38 shows the differences in input rates between SRVCC's ENERGY STAR® oven and their best-in-class replacement oven.

**Figure 37: SRVCC Convection Oven Gas Consumption**




Source: FNi

**Figure 38: SRVCC Input Rate**




Source: FNi

### 3.5.3 Summary of Results and Discussion

As illustrated in Table 10, all sites exceeded the study's 14 percent energy reduction target. The replacement ovens ran under the same hours of operation at a higher efficiency by burning less natural gas.

**Table 10: Summary of Results**

| Site | Bridges Restaurant | Melon's Catering | SRVCC |
|---|---|---|---|
| Baseline Monitoring (therms/day) | 3.71 | 4.35 | 3.89 |
| Replacement Monitoring (therms/day) | 1.22 | 3.05 | 3 |
| % Change | 67% | 30% | 23% |

Source: FNi

## 3.6 Conclusions and Recommendations

### 3.6.1 Conclusions

Two test sites showed potential energy savings when upgrading from standard-efficiency convection ovens to ENERGY STAR® convection ovens. Additional savings were achieved for a third site when replacing an ENERGY STAR® convection oven with the best-in-class ENERGY STAR® gas convection oven. Given the longevity of convection ovens, there are many units still in operation that are old and inefficient. Tapping into this market with ENERGY STAR® convection ovens is a worthwhile effort for the operators to save energy and more importantly save money on their bill.

The improved design of the convection oven is estimated to add $200 to the MSRP, with $50 being attributed to seal improvement with the silicone gasket and approximately $150 for the heat exchanger alterations. Based on previous estimates, convection ovens in California use on average 462 therms per year; assuming a 40 percent reduction in energy use, convection ovens would save $129 per year. Using previously mentioned EIA estimates for gas cost and energy content, one therm would cost approximately $0.70. Therefore, yearly savings would be $90 for a convection oven leading to a payback period of 2.2 years.

California has an estimated 65,000 convection ovens in service consuming an estimated 30 million therms. By adopting ENERGY STAR® convection ovens, a potential reduction of 4.2 million therms would be possible assuming an energy savings of 40 percent per oven and a 35 percent market penetration. This translates to saving an estimated 2.93 million dollars assuming a 2012 average commercial natural gas cost of 7.13 dollars/MCF and a heating value of 10.21 therms/MCF (EIA 2013)

The field monitoring data also confirmed that foodservice establishments leave equipment running during operating hours without business flow affecting usage patterns. Prior to solid field monitoring data, there was no evidence to confirm whether operators turned off equipment in the middle of the day, or whether they left equipment running during operating

hours. This data showed that hours of operation, not business flow, governs the daily energy consumption.

### 3.6.2 Recommendations

When comparing convection ovens against other similar foodservice categories, there remains room for efficiency improvements. ASTM testing showed cooking efficiency values for the gas-fired ENERGY STAR® convection ovens to be between 44 percent and 47 percent efficiency, compared to the 50 percent – 60 percent maximum efficiency for other gas cooking appliances used in commercial food service. In contrast, a combination oven which is able to operate in steam or convection mode has an efficiency of 60 percent while running in convection mode. It is recommended that further research be conducted on gas convection ovens to push the upper limit of energy-efficiency beyond the current best-in-class 54 percent and idle energy rate of 13,000 Btu/h.

Because the energy footprint of commercial ovens is so significant, it is worth investing future PIER foodservice work towards the research and development in convection oven energy-efficiency gains. Further efficiency improvements can be fostered through additional research and development to extract more heat energy from combustion and retaining it within the oven. These improvements can be driven through more aggressive education and promotion of the advanced technologies via rebates for convection ovens.

# CHAPTER 4:
# Open Burner Ranges

## 4.1 Summary

### 4.1.1 Introduction

The open-burner range top is one of the most versatile and widely-used pieces of commercial cooking equipment. The most common configuration consists of six open gas burners with a standard oven incorporated underneath. Though the commercial range top is similar to the residential stove, the major difference is durability and production capacity; a foodservice range must withstand constant use and abuse while preparing tens or hundreds of meals a day.

The most common type of range top uses open burners, applying flame directly to the bottom of the pot or pan. This type of burner is inherently sturdy, inexpensive, and responds instantly when the burner is turned on and adjusted. The visible flame provides direct user feedback on the amount of heat applied to the pan, enhancing the operator's control. The energy consumption of range top burners is more reliant on end-user operation than most other commercial kitchen appliances. Input to the burner is manually controlled by the operator, which can lead to unnecessary burner on-time. As the operators remove the cooking utensils, the burner may inadvertently be left on until a new utensil (or pan) is placed on the burner. Thus there is potential for energy savings in gas range tops, which is dependent upon adequately addressing end-user behaviors and incorporating redesigns of antiquated technologies.

### 4.1.2 Purpose

The purpose of this project was to identify new technologies that could improve open range top energy efficiency and performance. The goal was to determine energy-efficiency gain and gas energy savings when using advanced equipment.

### 4.1.3 Project Objectives

The objective of this field study was to introduce and study new technologies which could decrease energy use of the conventional gas ranges. The goal was to determine energy-efficiency gain when using advanced equipment. This gain was demonstrated through the following measures:

- Characterize the energy inefficiencies of standard range technologies through laboratory and field data collection.
- Design and develop a new prototype for commercial foodservice range that is both energy-efficient and robust.
- Compare standard and energy-efficient burner and pot design in energy use in laboratory conditions.
- Characterize user behavior when using the gas range and determine if open burners are left on unnecessarily.

- Examine restaurant range energy use with a two different burner designs.
- Evaluate a semi-automatic pilot ignition system in a restaurant operation.
- Recommend future improvements to further range efficiency.

### 4.1.4 Project Outcomes

The typical input rating for an open gas range burner is 20 to 30 kBtu/h. FSTC researchers have discovered that higher input burners do not necessarily use significantly more energy during the ASTM water boil test than their lower input counterparts due to relative decrease in boil time.

It is common practice for range burners to be left on with cooking vessels removed during operating hours. To mitigate this wasteful gas usage, several companies have designed automatic burner shutoff/re-ignition systems using some variation of cookware detection to trigger burners on/off. To help assess the potential gas-savings of automatic burner shutoff for ranges, the FSTC installed a customized flame sensing device at the San Ramon Valley Conference Center cafeteria to monitor the time that the gas burners were left on and unused. Backup monitoring with video surveillance and gas metering helped verify the results of the ultraviolet flame sensor. The field study showed that range burners were only left open and on less than 3 percent of the time.

Both a high-input burner range (30 kBtu/h per burner) and low-input burner range (20 kBtu/h per burner) were tested in laboratory in accordance with ASTM F1521 *Standard Test Methods for Performance of Range Tops.* Ranges were also tested in-laboratory with finned-bottom Turbo Pots and "turbo" pan prototypes. This advanced cookware features heat sink "fins" on the bottom of each pot and pan to increase surface area to capture more heat from the burner and consequently cook food product faster and more efficiently. Compared to flat-bottomed pots and pans, the Turbo Pot cookware exhibited a cooking-energy efficiency increase from around 30 percent to as high as 57 percent, depending on the style of range burner. Production capacity increased as well from 28 to 39 pounds more food product per hour.

The existing high-input burner at the cafeteria site was monitored for gas energy consumption. The high input burner was then replaced with a low-input burner range for further monitoring. The cafeteria's standard pot and pan inventory was replaced with all new Turbo Pots and Pans. The finned bottom cookware replacement in conjunction with a low input burner saw gas energy savings of 32.9 percent. The combination of the low input burners with the Turbo Pots was designed to meet or exceed the cooking performance of the high input burners with flat bottom pots, while reducing the gas energy usage in the field. The results of these field replacement studies are presented in Table 11.

**Table 11: Field Range Upgrade and Cookware Upgrade Results**

| Range Type | Cookware Type | Daily Range Energy Consumption (therms) | Energy Savings |
|---|---|---|---|
| High Input Burner | Flat Bottom Pots / Pans | 2.92 | |
| Low Input Burner | Finned Turbo Pots/Turbo Pans | 1.96 | +32.9% |

Source: FNi

The replacement low input burner range came equipped with a semi-automatic pilot ignition system, where pilots can be shut off overnight and re-lit the following operating day. This system was not utilized to its full effect at the cafeteria-style field site because of the extended time it took to engage the flame proofer for each burner. This range had a total pilot input rate of 6 kBtu/h, which when left on overnight caused unnecessary gas energy consumption. If all six pilot lights were left on when nothing was cooking on the range, it would result in the range gas consumption increasing by one therm per day.

### 4.1.5 Conclusions

The simple, almost archaic technology of the gas range poses some challenges for improvement in design and controls. Manufacturer research and development teams have avoided tackling the gas range top for this reason. However, several of the more proactive manufacturers have introduced innovative technologies for the range top that have yet to be fully embraced by the restaurant industry. This report examined the viability of these technologies including advanced burner designs, automatic flame sensor shutoff/re-ignition, automatic pilot ignition, and efficient cooking vessel designs.

Using automatic flame shutoffs as a way to address open burners that have been left on seems like the right path for future development. Yet there are still issues with the design and real-world implementation that prevents the system from being ready for field testing at this time. This particular field study demonstrated that certain establishments with well-trained staff will not experience significant energy savings—even with a fully functional automatic flame shutoff—if their burners are covered and in use 97 percent of the time.

Utilizing automatic pilot ignition systems would seem like a surefire method for energy savings. Current automatic pilot ignition systems are not reliable enough to use in a restaurant operation, so a manufacturer developed a semi-automatic pilot ignition system designed to be turned off outside of normal operating hours only. However, due to the system's long ignition times, kitchen staff at the test location did not use the system consistently and simply left the pilots on throughout the day. Pilot energy adds up quickly; if utilized properly, an automatic pilot ignition system could reduce daily energy consumption significantly.

One of the most promising ways to save energy with the gas range was a redesign of the cooking vessel rather than the range itself. Adding heat sink technology to the bottom of pots

and pans decreased water boil times for the ASTM testing and thereby increased the efficiencies of the ranges. Upgrading the cafeteria-style site to the more evenly dispersed heat of a low input burner range and the finned-bottom Turbo Pots and pans demonstrated a total energy savings of 33 percent.

Problems of practicality, ease-of-use, and commercial viability seem to be hurdles facing these up-and-coming technologies. The promising performance of advanced burner and cookware design displayed in this field study has proven that the gas range top can perform better and save more energy. However, manufacturers' R&D teams must continue developing and improving upon the aforementioned technologies if they are to be accepted and adopted by the foodservice industry.

### 4.1.6 Recommendations

Further development and tweaking of these technologies is needed before large scale adoption by the end-user occurs. With the range top being largely dependent upon the user for energy-efficient operation, more field monitoring of diverse restaurant locations is needed to quantify range top operators' behavior.

This study has confirmed that opportunities for range top energy savings exist however. The finned Turbo Pot offers the most potential for range top energy savings, and more replacement programs for kitchens should be pursued. More field studies need to be performed determining the energy reduction when using the Turbopot with higher input rangetop burners and dedicated stock pot ranges with individual burners greater than 40kBtu/h. Finned Bottom Pots need to be more widely adopted by the industry and should be promoted by both energy utilities and range manufacturers to increase overall system efficiency.

Perfecting the automatic pilot ignition should be one of the top goals for range top manufacturers. This study demonstrated significant energy use by the ranges' pilot systems. The California Energy Commission should consider regulations that would require pilotless ignition for all new range burners sold in California once the technology has been validated and improved.

Future technological development of commercial open range tops should focus on improved efficient burner designs, particularly power burner integration. Of course practicality and market viability should be of the utmost priority in developing these technologies.

### 4.1.7 Benefits to California

According to a 2010 PIER report study by Fisher-Nickel, inc. *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment*, it was estimated that open range tops consume 16.6 million therms per year in California. Considering the findings of this study, a market penetration of 50 percent, as well as the adoption of reduced input burners and finned bottom cookware designs, restaurant operators in California could save up to 2.7 million therms annually which translates to an estimated savings of 1.9 million dollars. This estimate was obtained by using the 2012 price of 7.13 dollars/MCF of natural gas and the estimated heating value of 10.21 therms/MCF of natural gas (EIA 2013) Factoring in the gas savings potential of

the other technologies explored in this report, such as the automatic pilot ignition system, could produce even more dramatic savings.

With further development of these innovative (but admittedly still imperfect) range top technologies, California foodservice operators will be more willing to adopt practices and products that will save energy, reduce utility bills, and ultimately aid in environmental conservation.

## 4.2 Introduction

### 4.2.1 Background

In addition to being widely used, the commercial range top is also one of the most versatile cooking appliances, lending itself to numerous burner configurations. Typically, a range top configuration consists of six open gas burners with a standard oven incorporated underneath. Though the commercial range top is similar to the residential stove, the major difference is durability and burner input; a foodservice range must withstand constant use and abuse while preparing tens or hundreds of meals a day.

Standard gas range tops employ decades-old technology to provide heat to a pot or pan from below. Range tops are not suitable for cooking timers or computers, but rather come equipped with a simple knob that controls input to each burner. Burners are not responsive to the temperature of the pot or pan, thus making the attentiveness of the operator critical to maintaining functional cookware.

The gas industry must continue to evolve the design and functionality of the gas range top if this appliance is to retain its position in commercial foodservice.

### 4.2.2 Objectives

The objective of this field study was to introduce and study new technologies which could decrease energy use of the conventional gas ranges. The goal was to determine energy-efficiency gains when using advanced range features as well as advanced cooking vessels. The predicted cooking-energy efficiency gain was determined to be at least a 15 percent gain over baseline technology. These gains shall be demonstrated through the following measures:

- Characterize the energy inefficiencies of standard range technologies through laboratory and field data collection.
- Compare standard and energy efficient burner and pot design in energy use in laboratory conditions.
- Characterize user behavior when using the gas range and determine if open burners are left on.
- Examine restaurant range energy usage with low input burners and finned bottom pots.
- Determine the energy impact of range pilots and the feasibility of an automatic pilot range.
- Recommend future improvements to further range efficiency.

## 4.3 Technology

### 4.3.1 Standard Technology

#### *4.3.1.1 Cooking Process*

All range tops provide heat to a pot or pan from below. The method of heat delivery to the pot may vary, but the cooking process is always a function of the heat being delivered from the bottom of the pot/pan. One way in which this cooking process may be affected is through the heated area, or size of the heating pattern. Some range top heating strategies provide uniform heat over a larger area, while others concentrate the heat in one spot. This becomes a significant performance factor if the range top is used in a process such as cooking pancakes, where surface uniformity is important. However, the choice of pan construction and materials can also be used to mitigate unevenness in the heating source.

#### *4.3.1.2 Controls*

Range tops are generally not amenable to timers or cooking computers; most range top cooking demands the attention of the operator. Controls on the range top are typically very simple. There is usually an infinite control knob to regulate the input of each burner or element. The controls are calibrated in terms of the percentage of input, as the burner does not generally sense the temperature of the pot.

#### *4.3.1.3 Open Burners and Discrete Elements*

Open gas burners remain the burner of choice for most operators. They are inherently sturdy, inexpensive, and respond instantly when the burner is turned on and adjusted. The visible flame provides direct feedback on the heat to the pan, enhancing the operator's control, and can ignite spattered grease to "flash" flame inside the pan during display cooking.

The open gas burner has two typical designs. The first is a hollow ring of cast iron or steel with holes that jets gas upwards towards the cooking vessel (Figure 39). A similar design is the star burner, which has arms radiating from a central hub spreading its flame over the pot bottom (Figure 40).

**Figure 39: Ring Burner Design**

Photo Credit: Commercial Gas Range Top Technology Overview

**Figure 40: Star Burner Design**

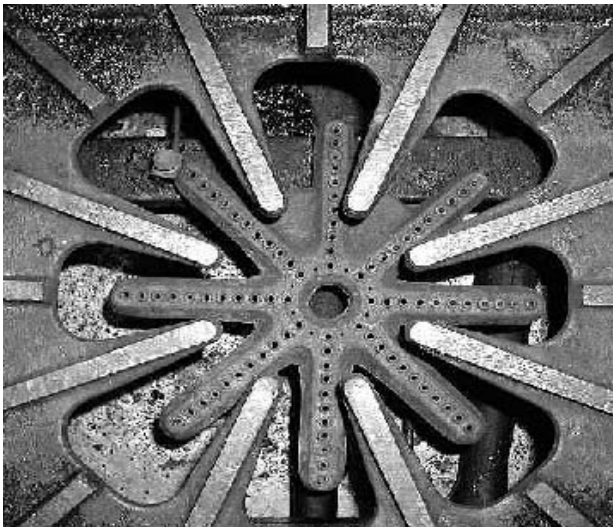


Photo Credit: Commercial Gas Range Top Technology Overview

Each burner design has the gas mixed with primary air at an air shutter on the manifold. Secondary air provides most of the oxygen for combustion, combining with the gas as it jets from the burner. The flame is controlled with a gas valve mounted on the front of the range.

The burner is set into the surface of the range top and covered by a metal grate, which supports the cooking vessel. Grates are designed so that pots can be slid easily from burner to burner, and are stable in any position. Normally with this grate design, a spill tray will be underneath the burner to catch falling particles and/or drips. The grates may be removable, and on some range tops the burner heads lift off for easy cleaning.

The typical input rating for an open gas burner is 20 to 25 kBtu/h, with manufacturers offering 30 kBtu/h burners and higher as an option. Until recently, the higher-input burners only were used in the most demanding production applications. However, they now are becoming the industry standard for heavy-duty ranges as manufacturer marketing focuses on higher input ratings over energy-efficiency. Studies at the FSTC indicate that, contrary to what one might intuitively think, under normal operating conditions these higher input burners do not use significantly more energy to cook (*Montague Model V136-5 Heavy-Duty Open Top Gas Range Appliance Performance in Production* and *Montague Model V136-5 Heavy Duty 30,000 Btu/h Open Top Gas Range In-Kitchen Appliance Performance Report*).. Although the gas input is higher, the cook time is correspondingly shorter. However, the net effect of these more powerful burners could be an increase in energy consumption if the burners were left on between cooking events, as sometimes happens in high-profile display kitchens or on sauté lines.

### 4.3.2 Advanced Technology

#### *4.3.2.1 Automatic Burner Shut Off and Re-Ignition*

In catering kitchens it is often more practical to leave open-flame burners lit when not being used, rather than turning the gas off and re-lighting it each time when needed. Gaz de France, along with Madec-Mater Company, has patented the Top-Flam–an automatic shutoff and re-ignition device that is triggered by cookware detection. They claim energy savings of around 50 percent. A similar burner control system was developed in the United States by Leonard Grech and documented by the U. S. Department of Energy's Office of Industrial Technology. This system uses a small, vertically-mounted, spring-loaded piston that controls a gas valve. When a pot is placed on the burner, the piston is depressed and the gas valve is opened. When the pot is removed, the piston returns to its original position and the burner is turned off. Lang (www.langworld.com) has developed a similar spring-loaded burner system, shown in Figure 41. The system uses a ball sensor to detect the presence of a pot or pan. The curved sensor shape facilitates moving pans abound the range and enhances the usability of the feature.

**Figure 41: Lang Range with Spring-Loaded Burner Shutoff Technology**

Photo Credit: Lang

#### *4.3.2.2 Pilotless Ignition System*

Almost all gas ranges utilize a standing pilot. The number of pilots is usually equal to the number of burner, but in some cases, two burners will share a common pilot. The six-burner range is the most common range found in a restaurant, and some establishments have several ranges. A typical standing pilot is close to 500 Btu/h and is on 24/7—regardless of whether the burner is being used or not. This pilot rate multiplied by the number of burners quickly adds up to a significant yearly contribution to the gas bill.

Ranges with no pilots are uncommon. Pilot-less burners require the user to utilize a match or a lighter to each burner and encourages them to leave the burners on without cooking. Automatic pilot systems were developed decades ago and include several different types. The first type is a fully-automatic pilot system that causes a spark just as the burner is lit. This system eliminates the pilot light completely and is the most energy-efficient. It has found its way into the residential market with great popularity, however was not able to penetrate the rigorous commercial cooking market. This is primarily due to the fact that the spark ignition system is fragile and has to be cleaned frequently in order to work properly. High cooking temperatures and frequent spillage of food products, as well as careless cleaning procedures around the spark igniter in the commercial restaurant sector has rendered most of these designs unreliable.

Another burner lighting design is a semi-automatic pilot ignition system. It uses indirect spark ignition for the burner, lighting the pilot using the spark. The spark plug is covered, protecting it from spills and cleaning procedures. The burner input knob has two positions, one where the pilot is on another when the pilot is off; the spark is ignited using a separate button. The flame proofer—a thermal expansion device next to the pilot that automatically shuts off the gas to the pilots once they have cooled off—needs to be heated up first for the pilots to stay on. The operator depresses the burner input knob for a few seconds during the lighting procedure until the flame proofer thermocouple is heated enough for the pilot gas valve to stay open. The pilots should be left on throughout the restaurant operation hours, and the operator should turn the burners to the complete off position when the restaurant is closed. Montague Company's flame proofer design is illustrated in Figure 42.

**Figure 42: Montague Semi-Automatic Indirect Pilot Ignition System with the Protective Cover Removed**

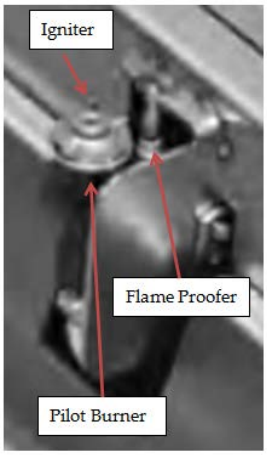



Photo Credit: Montague Company

#### 4.3.2.3 More Efficient Cooking Vessel Design

Where previous efforts to increase energy efficiency have focused on the range top itself, Eneron, Inc. (www.turbopot.com) has taken the approach of improving the cooking vessel. Their unique pot design uses aluminum fin channels to increase effective surface area exposed to the burner flame, maximizing the amount of heat transferred to the bottom of the pot. This finned technology results in increased heat transfer between any gas burner and the cooking

medium, resulting in faster cook times and increased cooking efficiency. Figure 43 shows the range flame being captured by the fins of the pot without spilling over the edge.

**Figure 43: Eneron Turbo Pot Heated by a Conventional Gas Burner**

Photo Credit: Eneron, Inc.

## 4.4 In-lab Testing

### 4.4.1 In-Lab Test Plan

#### *4.4.1.1 Range Top Performance Method*

ASTM Standard F1521-03 *Standard Test Methods for Performance of Range Tops*, developed at the FSTC Foodservice Technology Center, provides a means to compare performance and energy use of range tops. The test method provides results for maximum rate of energy input, temperature uniformity of heating surface, cooking-energy efficiency and production capacity.

Production capacity is the amount of food that a burner or element can cook in a given time, expressed as gallons of water that can be raised from 70°F to 200°F (21°C to 93°C) in one hour. This provides an indication of the "speed" of a burner. Maximum rate of energy input is a rough index of the "power" of a range top. The test method reports the total energy input rate for all the burners on a range top. It is more common in catalogs to see a rating for individual burners or elements. For a given type of burner or element, a higher rate of energy input generally indicates that the burner can supply more heat to the pan. This conclusion is only true when comparing similar burners; a high-efficiency burner can use less energy, but performs more work than a low-efficiency burner (i.e., cook the same quantity of food in less time).

Cooking-energy efficiency, as defined by the ASTM Standard Test Methods for Performance of Range Tops, is the ratio of the amount of energy going into the food and the cooking vessel versus the amount of energy supplied to the burner:

$$Energy\ Efficiency = \frac{Energy\ Imparted\ to\ Food\ (Btu) + Energy\ Imparted\ to\ Cooking\ Vessel\ (Btu)}{Energy\ Consumed\ by\ Appliance\ (Btu)}$$

Energy efficiency is determined by heating water from 70°F to 200°F (21°C to 93°C) at the full-energy input rate.

The instrumentation package that was used for lab testing included a diaphragm-type positive displacement gas meter with a one pulse per 0.1 $ft^3$ output. A data logger processed and stored cumulative gas consumption from the meter's pulse outputs at one minute intervals.

#### *4.4.1.2 Advanced Automatic Burner Shutoff Technology Performance Test Plan*

Southern California Gas Company has conducted testing on the countertop range with the on-demand burners after a service technician adjusted the minimum input of all the burners. The test was conducted using a new 8" diameter Turbo Fry Pan (two pounds with light handle) and set to operate from low to high input rates. The proposed solution was to use the Turbo Fry Pans for the first field test. This posed the question of whether customers would be willing to replace all of their pans to Turbo Fry Pans and if they would always use pans that work on this cooktop. A weight limitation was insufficient to determine if a pan could be used for this cook top; the handle weight, in proportion to the pan weight, was also considered.

#### *4.4.1.3 Advanced Cooking Vessel Energy Performance Test Plan*

A standard aluminum, 12-inch diameter stock pot, with a capacity of 24 quarts, was used for baseline testing. The baseline pot was purchased off the shelf from a restaurant supply house and represented a typical cooking vessel designed for use on a commercial range top. The Eneron, Inc. finned-bottom stock pot (Turbo Pot) was the same model as the standard pot, with the bottom modified to include 1/16-inch wide aluminum fins. The fins were ⅝-inch high and spaced ⅛-inch apart. The standard pot, shown in Figure 44, is compared with the Turbo Pot design, shown in Figure 45.

**Figure 44: Standard Pot**

Photo Credit: FNi

**Figure 45: Turbo Pot Prototype**

Photo Credit: FNi

Each pot was tested on three range tops for this study: Two -high-input burner range tops rated at 30,000 Btu/h per burner (Range A and Range B) and a low-input burner range top rated at 20,000 Btu/h per burner (Range C). Each range had different burner designs and produced unique flame patterns.

Setup and Instrumentation

The range tops were installed under a four-foot-deep canopy hood that was six feet, six inches above the floor. The hood operated at a nominal exhaust rate of 300 cubic feet per minute (cfm) per linear foot of hood. There was a minimum of six inches of clearance between the vertical plane of the front of the range and the edge of the hood. During testing, the room was maintained at 75 ± 5°F.

Thermocouples were used to monitor the ambient temperature of the lab and the inlet temperature of the natural gas. A pressure gauge was used to monitor the gas pressure. A barometric pressure gauge was used to monitor the barometric pressure in the laboratory. Natural gas consumption was measured using a positive displacement-type gas meter that generated a pulse every 0.1 $ft^3$.

The stockpot lid had a ¼" hole drilled near its center to allow a thermocouple to pass through. A ⅛-inch diameter, beaded, type-K thermocouple was inserted from the top of the lid, and reached down to approximately 2" above the bottom of the stockpot. This probe monitored the temperature of the water during the tests. The lid and thermocouple are shown in Figure 46.

**Figure 46: Lid (Left) and Thermocouple (Right)**

Photo Credit: FNi

Energy Efficiency and Production Capacity

The cooking-energy efficiency and production capacity were determined by heating 20 pounds of water from 70°F to 200°F (21°C to 93°C). Testing began with the standard pot on Range A. The front right burner was first stabilized with a 14" standard pot containing 20 pounds of 70°F (21°C) water and the burner operating at 50 percent input. After 30 minutes the stabilization pot was removed, the burner was increased to full input, and the test pot containing the 70°F (21°C) water was placed on the range top. The test began just as the pot was placed on the burner, with the lid in place and the pot centered on the burner grate. No other burner operated during the test, and the pot was not disturbed at any time. The test ended when the thermocouple indicated the water temperature reached 200°F (93°C).

This test was repeated two additional times for a total of three test runs. After the third test on the standard pot, testing progressed to Turbo Pots.

After completing three tests using each pot on Range A, the procedure sequence was repeated on Range B and Range C. Three tests were performed for each scenario as required by the ASTM test method to ensure that the reported cooking-energy efficiency and production capacity results had an experimental uncertainty within ± 10.0 percent. The results from the individual test runs were averaged, and the absolute uncertainty calculated based on the standard deviation of the results.

Simmer Energy Rate

The simmer energy rate test determined if there was a reduction in energy use when the Turbo Pots were used to hold water at a steady simmer. To conduct the test, the standard pot was filled with 20 pounds of water and placed on the range top. After raising the water temperature to 205°F, the lid was removed from the pot and the burner was adjusted to hold the water temperature at 205 ± 1°F. Time and energy was monitored for one hour to allow calculation of the simmer energy rate.

#### *4.4.1.4 Flame Sensor Calibration Test Plan*

As a result of the theory that most restaurants leave their range burners on without cooking on them, a measurement metric was developed. The flame sensor is an ultraviolet radiation bulb calibrated within the flame ultraviolet wavelength range (180 – 260 nm). It is connected to a signal processing circuit that powers the bulb and converts the output signal to 5V pulses, with their frequency being proportional to the flame intensity. This setup is mainly used for fire detection, and is able to detect the flame of a match from more than 15 feet away. The first step in testing this setup was to determine the proportionality of the pulse frequency output to the size of the flame on the range top. Almost all gas ranges are equipped with pilot burners, which are essentially open flames, and are usually on all day. So it is important to establish a difference between an open pilot and an open burner. A six-burner test range was set up in the lab with two flame sensors mounted inside the front of the ventilation hood, and the bulb adjusted facing down at the cooking surface to simulate the actual setup in the restaurant. Flame sensor readings were recorded every second and averaged for a period of one minute. Six different sized pots were used on the appliance, ranging from a large 13 stock pot to a 6" sauce pan. The flame under the pot was adjusted according to the size of the pot so that no flame would go beyond the pot's base area footprint. The burners were turned on consecutively underneath the pots at one-minute intervals and the flame sensor pulse output was recorded. The pots were loaded onto the burners from smallest to largest and from largest to smallest.

### 4.4.2 In-lab Test Results

#### *4.4.2.1 Range Top Energy Efficiency Results*

In-lab ASTM testing was performed on two ranges with different burner designs. The high-input burner range had 30 kBtu/h burners and utilized one pilot for every two burners. The low-input burner range had 20 kBtu/h burners and used spark igniters to light its pilots for each burner. Table 12 and Table 13 show the summary of in-lab water heating energy efficiency and production performance, with the range models illustrated in Figure 47 and Figure 48.

**Table 12: High-Input Burner Range Lab Results**

| Input Energy Rate | All Burners | Single Burner |
|---|---|---|
| Rated Energy Input Rate (Btu/h) | 180,000 | 30,000 |
| Measured Energy Input Rate (Btu/h) | 153,725 | 28,520 |
| Difference (%) | 14.6 | 4.9 |
| **Pilot Idle Rate** | | |
| 6-burner Pilot Idle Rate (Btu/h) | 1,913 | |
| **Burner Heat-up Energy Efficiency** | | |
| Final Water Temperature (°F) | 200 | |
| Time (min) | 15.08 | |
| Gas Energy Rate (Btu/h) | 27,712 | |
| Energy to Water (Btu/lb) | 132 | |
| Energy to Pot (Btu/lb) | 29 | |
| Energy to Appliance (Btu/lb) | 348 | |
| Cooking-energy Efficiency (%) | 40.1 ± 2.3 | |
| Production Capacity (lb/h) | 79.6 ± 5.7 | |

Source: FNi

**Figure 47: Wolf Model C36C-6**

Photo Credit: FNi

**Table 13: Low-Input Burner Range Lab Results**

| Input Energy Rate | All Burners | Single Burner |
|---|---|---|
| Rated Energy Input Rate (Btu/h) | 120,000 | 20,000 |
| Measured Energy Input Rate (Btu/h) | 118,510 | 20,560 |
| Difference (%) | 1.2 | 2.8 |
| **Pilot Idle Rate** | | |
| 6-burner Pilot Idle Rate (Btu/h) | 5,897 | |
| **Burner Heat-up Energy Efficiency** | | |
| Final Water Temperature (°F) | 200 | |
| Time (min) | 22.56 | |
| Gas Energy Rate (Btu/h) | 20,405 | |
| Energy to Water (Btu/lb) | 130 | |
| Energy to Pot (Btu/lb) | 29 | |
| Energy to Appliance (Btu/lb) | 384 | |
| Cooking-energy Efficiency (%) | 35.6 ± 2.6 | |
| Production Capacity (lb/h) | 53.2 ± 2.0 | |

Source: FNi

**Figure 48: Montague Model 136-5**

Photo Credit: Montague

#### *4.4.2.2 Advanced Automatic Burner Shutoff Technology Performance Results*

During the initial in-laboratory evaluation of the automatic burner shutoff technology, the unit was found to exhibit erratic burner ignition when a test pan was removed then replaced with the burner set to operate at minimum setting. The ignition issues were reduced by increasing the input rate at the low setting and by using the 2-pound, 8" Turbo Fry Pan. However, additionally there were still issues were found and areas described below:

- Ignition delays occurred when user was not careful to place the center weight of the pan on top of the ball. This occurred mainly at low and medium fire when a small (8-inch) sauté pan was used.. The countertop range was found to have issues igniting due to the

center weight of the pan not being on the center of the pan (the center weight of the empty sauté pan was offset by the weight of the handle, so the pan had to be moved slightly to center its weight upon the sensorfrom). As a result, in order for the operator to ignite the burner, the user would be required to press down on the ball while moving the pan around until the center weight of pan is found.

- Flashback occurred when the ignition was delayed for several minutes under the low and medium settings (Figure 49).
- Burner operated at low or medium input rate even though the knob was set to high input rate when lighter (e.g., 2-pounds or less) pans were used.

**Figure 49: Flashback Effect from Delayed Ignition**

Photo Credit: SoCal Gas

According to the testing staff, this technology has potential to save gas. However, the on-demand burner poses some concerns due to the fact that the ignition of the burner is not 100 percent reliable and will only work consistently with larger, heavier pans. The ignition problem needs to be addressed before installing the counter top range at the first test site. The lab study concluded that the on-demand burner was not ready to be tested in the field.

#### *4.4.2.3 Advanced Cooking Vessel Energy Performance Results*

Three test runs were performed for each stockpot on each of the three different standard-efficiency range tops to determine energy efficiency and production capacity. Ranges A and B were representative of the baseline range for the field test portion and Range C was representative of the replacement range for the filed test portion. The results from Range A are reported in Table 14. The results from Range B are reported in Table 15. The results from Range C are reported in Table 16.

**Table 14: Finned Pot Performance Comparison Results on Range A**

| | Standard Pot | Turbo Pot |
|---|---|---|
| Burner Energy Rate (Btu/h) | 28,800 | 29,000 |
| Heat-up Time (min) | 21.4 | 14.4 |
| Production Capacity (lb/h) | 56.0 ± 1.1 | 83.5 ± 2.3 |
| Cooking-energy Efficiency (%) | 27.0 ± 0.8 | 40.7 ± 1.2 |

Source: FNi

**Table 15: Finned Pot Performance Comparison Results on Range B**

| | Standard Pot | Turbo Pot |
|---|---|---|
| Burner Energy Rate (Btu/h) | 31,600 | 31,500 |
| Heat-up Time (min) | 15.8 | 10.9 |
| Production Capacity (lb/h) | 76.1 ± 1.9 | 109.8 ± 2.0 |
| Cooking-energy Efficiency (%) | 33.5 ± 0.5 | 49.6 ± 0.4 |

Source: FNi

**Table 16: Finned Pot Performance Comparison Results on Range C**

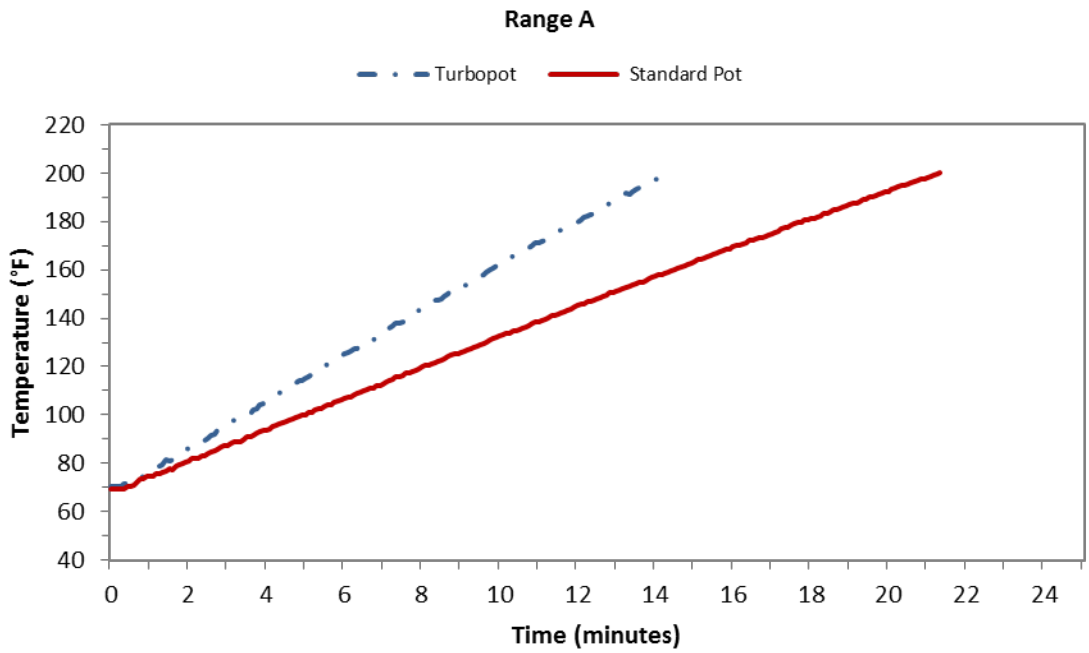
| | Standard Pot | Turbo Pot |
|---|---|---|
| Burner Energy Rate (Btu/h) | 21,920 | 22,170 |
| Heat-up Time (min) | 24.0 | 13.5 |
| Production Capacity (lb/h) | 50.1 ± 1.1 | 89.1 ± 4.8 |
| Cooking-energy Efficiency (%) | 31.7 ± 0.8 | 57.4 ± 2.6 |

Source: FNi

The results for the Turbo Pots showed a substantial improvement over the standard stockpot. Heat-up time was shortened using the Turbo Pot by 5 to 10 minutes, depending on the style of the range burner. The reduced heat-up time resulted in production capacity increases ranging from 28 to 39 pounds or water per hour depending on the style of the range burner. Cooking-energy efficiency was increased over the standard pot from 48 percent to 81 percent, depending on the style of the range burner.

Figure 50 plots the temperature rise of the water in each pot on burner Range A. Each line represents the average result from three test runs.

**Figure 50: Turbo Pot Heat-up Times Compared to Standard Pots**




Source: FNi

Simmer Energy Rate Results

The simmer energy rate test determined if there was a reduction in energy use when the Turbo Pots were used to hold water at a steady simmer. To conduct the test, the standard pot was filled with 20.0 pounds of water and placed on Range C. After raising the water temperature to 205°F, the lid was removed from the pot and the burner was adjusted to hold the water temperature at 205 ± 1°F. Time and energy was monitored for one hour to allow calculation of the simmer energy rate. Table 17 illustrates the results.

**Table 17: Finned Pot Simmer Comparison Results for Range C**

| | Standard Pot | Turbo Pot |
|---|---|---|
| Test Time (min) | 60.0 | 60.0 |
| Average Water Temperature (°F) | 204 | 204 |
| Burner Energy Rate (Btu/h) | 11,180 | 8,080 |

Source: FNi

The Eneron, Inc. Turbo Pot allowed Range C to operate about 3,100 Btu/h lower than the standard pot while holding a steady simmer. This result also illustrates that the energy to

simmer a pot of water is much lower than the input rate, being 51 percent of the full input rate with a standard pot and only 37 percent of the full burner input rate with the low input burner. Simmer rates are expected to be a lesser percentage of the input when using high input burners.

Using the Turbo Pots proved to be a remarkably effective method of increasing range top performance with a minimal increase in equipment cost. Published list prices range from $87 - $209 for varying sizes of stock pots (Central Restaurant Products).. Heat-up times were substantially reduced and production capacities increased. Energy performance was also significantly improved. By simply using an advanced pot design, the 25 – 30 percent energy efficiency of a standard, gas-fired range top was raised to over 40 percent. When used on a range top with energy efficiency in the low 30's, the number approached 60 percent.

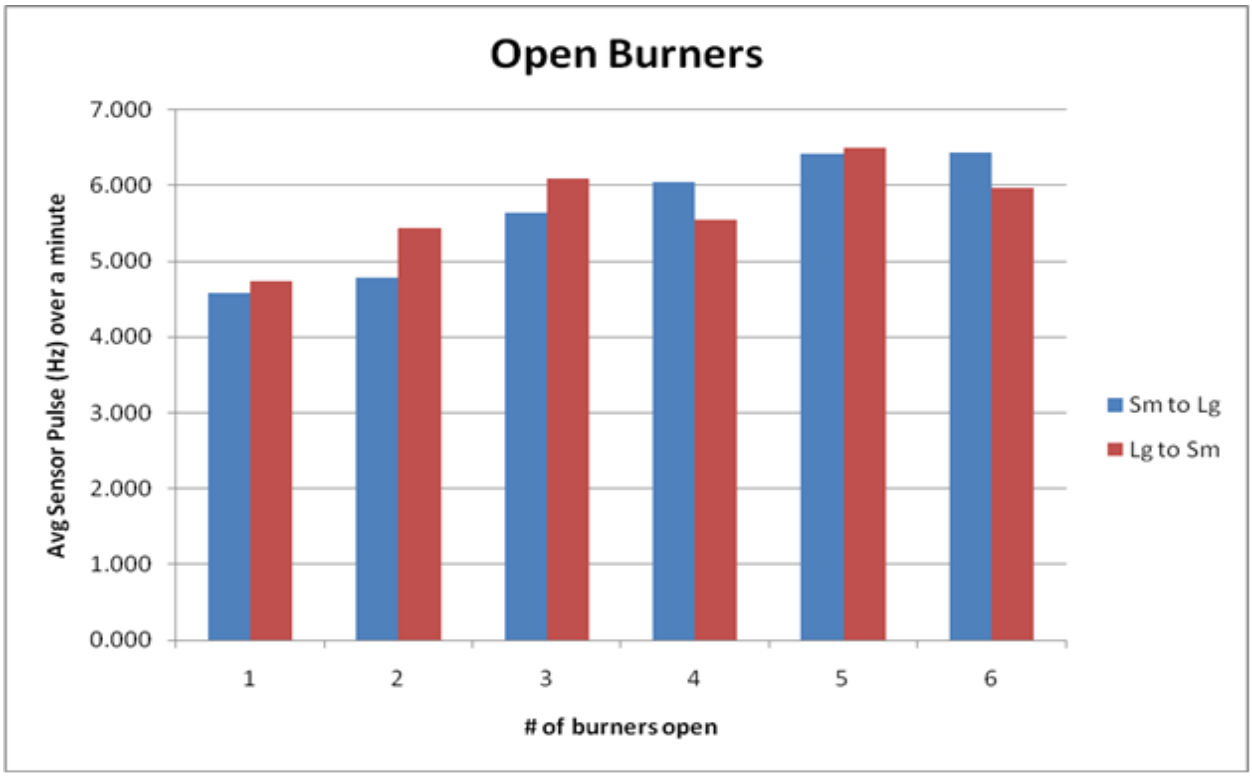
The benefits were not limited to full-input operation, as shown by the simmer tests. Less energy was required to maintain temperature, meaning a further increase in savings.

#### *4.4.2.4 Flame Sensor Calibration and In Lab Test Results*

Calibration testing of the flame sensor established pulse thresholds during intervals when the flame and pilots were off; pulse thresholds during intervals when flames were on but burners covered by pots, and pulse thresholds during intervals when flames were on and the burners uncovered.

It was determined that, when all the flames and pilots were off, the flame sensor read 0; the average sensor pulse reading was between 3 and 4 when all the burners are on, but covered by pots. A low non-zero reading was caused by a small amount of UV radiation escaping from the pot footprint that triggered the sensor; also most of the surfaces in the kitchen were metallic and reflective, which would have caused an indirect view of the flame by the sensor. Another reason for a non-zero reading was that the flame sensor could not be installed directly above the burners due to heat and grease concerns. Instead, it was mounted at a slight angle from the vertical view of the burners (causing it to detect the edge of the flame covered by the pot). When there were less than six pots on the range, an exposed pilot light was in the direct view of the sensor, which triggered a pulse reading between 3 and 4. Next the pots were consecutively removed from the burners at intervals of one minute and the flame was left on. The unloading was done smallest to largest, and then repeated in opposite order. Figure 51describes the results.

**Figure 51: Flame Sensor Sensitivity with Open Burners**




Source: FNi

As the pots were unloaded and the flame was left on, it is evident from the graph above that the flame sensor detected the first open burner by increasing its pulse output to roughly 4.5 pulses from 3.5 seen in the previous test when all the burners were covered. When all six burners were open, the sensor output almost six pulses. From this testing it was difficult to tell exactly how many burners were open, because the pulse output was not linearly proportional to the number of open burners. Since the pulse output depended on the flame size, the flame location relative to the sensor and reflective objects around it, detecting a difference between one or two open burners in a restaurant kitchen would be almost impossible. Comparing properly-covered burners and open burners, the data from this test was used to establish a pulse threshold to define whether a burner is open. This threshold is the pulse output reading during normal range operation when all the flames are covered by pots. In this test, it was safe to call four pulses the threshold, so it was safe to assume that a reading above four pulses meant that there was an open burner. Several tests were run in the lab to determine this threshold and it was found to fluctuate around 3.5 pulses, depending on the pot placement and the intensity of the burner flame as well as the amount of reflective stainless steel panels around the range.

Figure 52 shows the camera and processing unit that were used in the lab testing of the flame sensor.

**Figure 52: UV Flame Sensor / Processing Unit (Left), Video Surveillance Camera (Right), Mounted in Lab Setting**

Photo Credit: FNi

## 4.5 Field Testing

### 4.5.1 Field Test Plan

#### *4.5.1.1 Site Monitoring Instrumentation and Procedures*

The test site had a set of diaphragm-type positive displacement gas meters already installed in a utility closet with an output 0.1 $ft^3$ per pulse (Figure 53). A data logger was used to log these pulses at one-minute intervals, and process them in order to calculate cumulative gas consumption from the meter's pulse outputs. The range ovens were connected to a separate gas supply that bypassed the meters. Each of the two ranges was monitored on a separate gas meter and data-logging channel.

**Figure 53: Filed Monitoring Gas Meter Connected to a Data Logger in the Field**

Photo Credit: FNi

Range operation hours were determined by calculating an hourly input rate using a ten-minute moving average. Anything higher than the pilot moving average was considered periods that

the appliance was on. Cubic feet were converted into Btu using a heating value of 1,025 Btu/scf, a temperature correction factor of 0.98, and a pressure correction factor of 0.98.

#### *4.5.1.2 Field Monitoring Site Selection*

As part of the Foodservice Technology Center evaluation of range energy usage technologies, the units were installed in the kitchen of the San Ramon Valley Conference Center (Figure 54), previously known as the PG&E production test kitchen. The large cafeteria-style operation serves between 100 and 300 meals per day and serves breakfast, lunch and dinner on weekdays. It has two six burner ranges to accommodate menus that differ every day.

**Figure 54: San Ramon Valley Conference Center Cafeteria Outdoor Dining Area**

Photo Credit: FNi

Once the restaurant was selected for gas range monitoring, the feasibility of the range pot sensor was analyzed. In order to determine the potential savings of an automatic range burner shutoff system, the amount of time the range was left on needed to be analyzed. Two different methods were used to determine whether the kitchen staff was leaving the burners on.

The same restaurant was used to evaluate energy use of a range with high input burners and low input burners, as well as to evaluate the potential energy savings while incorporating to an automatic pilot. Finned pots and pans were given to the restaurant operator and their energy savings analyzed. This restaurant was used to evaluate a wide variety of range top energy-saving features.

## 4.6 Field Test Results

### 4.6.1 San Ramon Valley Conference Center Burner Left On Study

Gas ranges are significant energy consumers in the kitchen throughout the day, whether it is used for quick sautéing or cooking stocks and sauces over the period of the day. Often gas burners will be left on for extended periods of time. The amount of time an open burner gets left on depends on the kitchen staff and the type of cooking operation.

This flame sensor testing was performed to investigate the energy savings potential of automatic shutoff burners for gas ranges.

A flame sensing device was made consisting of a sensor bulb and a powered filtering circuit to indicate if an open burner is present on the range. The sensor was installed over both ranges (one of which is shown in Figure 55). Additional backup monitoring devices such as video surveillance and gas metering were installed in the kitchen to verify the proper sensor operation. Burner flame data was recorded using a data acquisition device for a period of several weeks.

**Figure 55: One of the Six-Burner Ranges Monitored at Restaurant**

Photo Credit: FNi

#### *4.6.1.1 Flame Sensor Details: Site Monitoring*

Flame sensor data was gathered on both ranges for nine non-consecutive days. Figure 56 and Figure 57 show the ranges, and the reflective surfaces surrounding them.

**Figure 56: Two Ranges Monitored in Cafeteria-Style Kitchen**

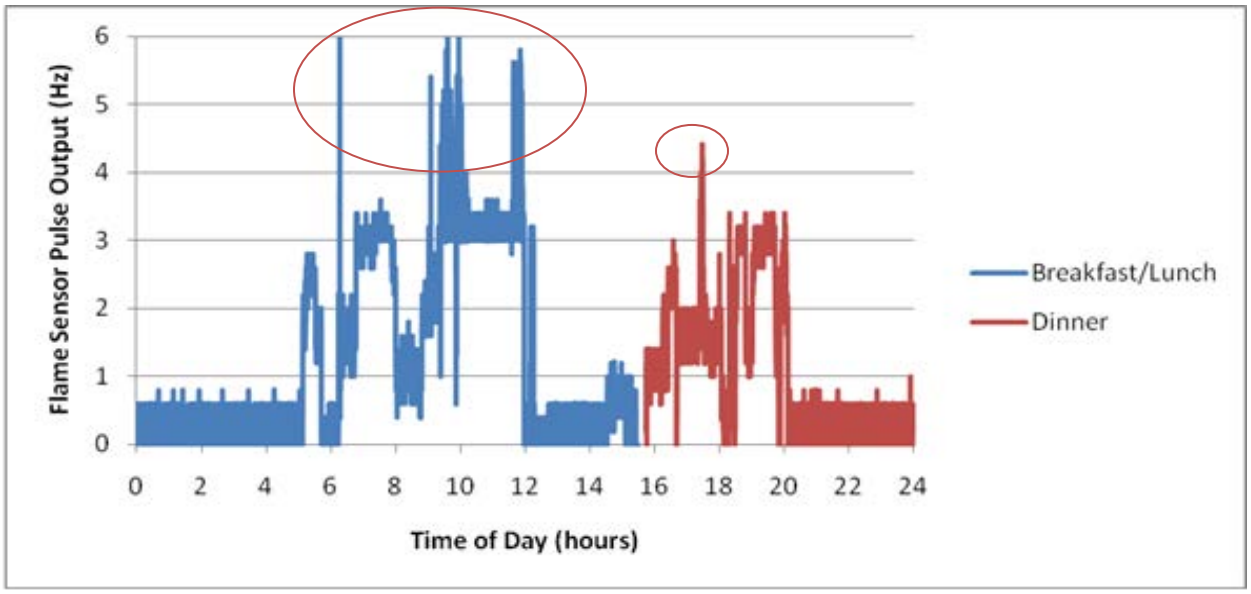
Photo Credit: FNi

**Figure 57: Reflective Surfaces Highlighted in Cafeteria-Style Kitchen**

Photo Credit: FNi

The data was gathered between lunch and dinner. Figure 58 presents the profile of a typical 24-hour day:

**Figure 58: Daily Flame Detection Profile**

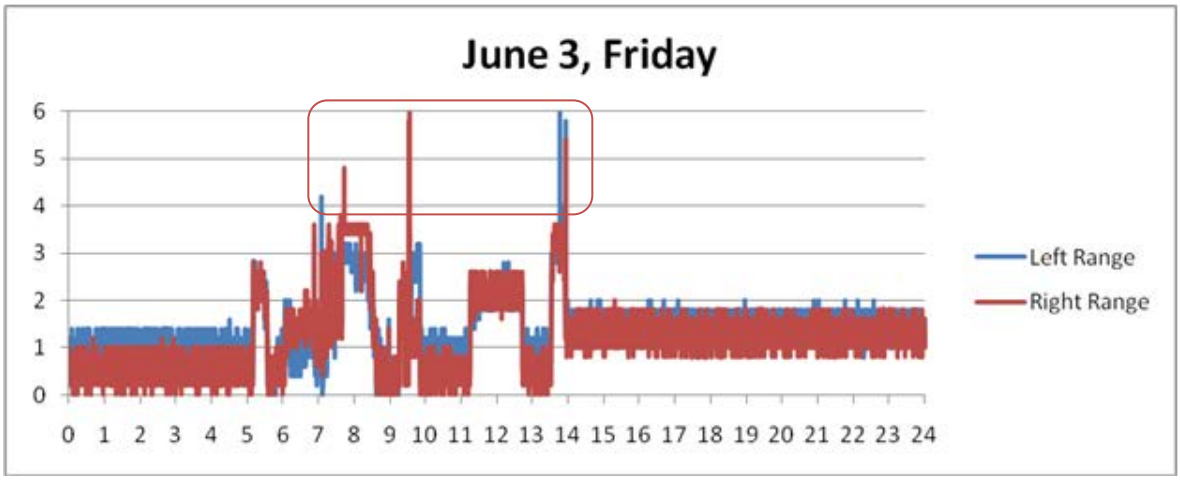



Source: FNi

If a threshold of four pulses is chosen, three distinct peaks above four pulses are seen between the hours of 6 am and noon and one peak around dinner. This means it is highly likely that the sensor detected a large open flame during those peaks. The kitchen is closed between 8 pm and

5 am; however there is a reading above zero for the sensor during this time, which is most likely due to the pilot lights and background light noise caused by reflective surfaces. A few weeks into the monitoring process, a second flame sensor was installed to monitor the second range in the kitchen in order to establish if a single sensor is picking up flame signals from both ranges. Monitoring results using the two flame sensors are illustrated in Figure 59.

**Figure 59: Possible Open Burner Events Throughout the Day**




Source: FNi

The two sensor output signals are very close to one another; however the extreme peaks are detected by different units, indicating which range was left with an open burner. This graph shows a typical Friday at the kitchen, where the kitchen closes after 3 pm. The background noise is raised up to two pulses by the end of the day, which could mean that pilots remain on for the weekend. If the threshold is again considered to be four pulses, there are three distinct peaks between the hours of 7 am and 2 pm, indicating a large open flame. Five data sets were gathered on nonconsecutive days. The results are listed in Table 18:

**Table 18: Possible Open Burner Durations Based On Pulse Output Threshold**

| Date | Monitoring Time (hr) | Cook Time 1.0 Pulse Threshold (hr) | Open Burner 3.5 Pulse Threshold (hr) | Open Burner 4.0 Pulse Threshold (hr) |
|---|---|---|---|---|
| 5/24/11 | 22.47 | 6.878 | 0.2278 | 0.1097 |
| 5/26/11 | 23.76 | 9.678 | 0.7625 | 0.3556 |
| 6/03/11 | 24.00 | 4.989 | 0.0694 | 0.0250 |
| 6/10/11 | 8.000 | 6.833 | 0.9486 | 0.1986 |
| 6/11/11 | 8.000 | 3.597 | 0.2167 | 0.1347 |

Source: FNi

The threshold is integral to interpreting the field test data; however the threshold can fluctuate based on several factors described in the calibration section. This five-day data set could be interpreted with a threshold of 3.5 pulses resulting in an open flame 6.96 percent of the cook

time, or with a threshold of 4.0 pulses resulting in an open flame 1.95 percent of the cook time. To interpret the data correctly, a secondary verification monitoring device had to be installed.

#### *4.6.1.2 Flame Sensor Details: Video Surveillance*

Two cameras were installed inside the kitchen hood facing the range tops, the video was wirelessly streamed to a router and then recorded. A total of 32 hours of video was recorded during the kitchen's busiest hours: 6 am until noon. A sample of that video is illustrated in Figure 60:

**Figure 60: Typical Cooking Operation at the Monitored Kitchen (Actual Captured Footage)**

Photo Credit: FNi

After visually analyzing 32 hours of captured footage, only three instances of an open burner were detected. Table 19 shows these results

**Table 19: Open Burner Durations Based on Video Surveillance**

| Date | Camera | Time | Number of Open Burners | Total Duration (min) |
|---|---|---|---|---|
| 6/3/11 | Right | 7:21:45 – 7:22:38 | 1 | 0:53 |
| 6/9/11 | Right | 7:48:03 – 7:51:16 | 1 | 3:13 |
| 6/9/11 | Left | 9:49:55 – 9:51:08 | 2 | 1:13 |

Source: FNi

This footage is illustrated in Figure 61.

**Figure 61: Actual Video Footage of Open Burners**

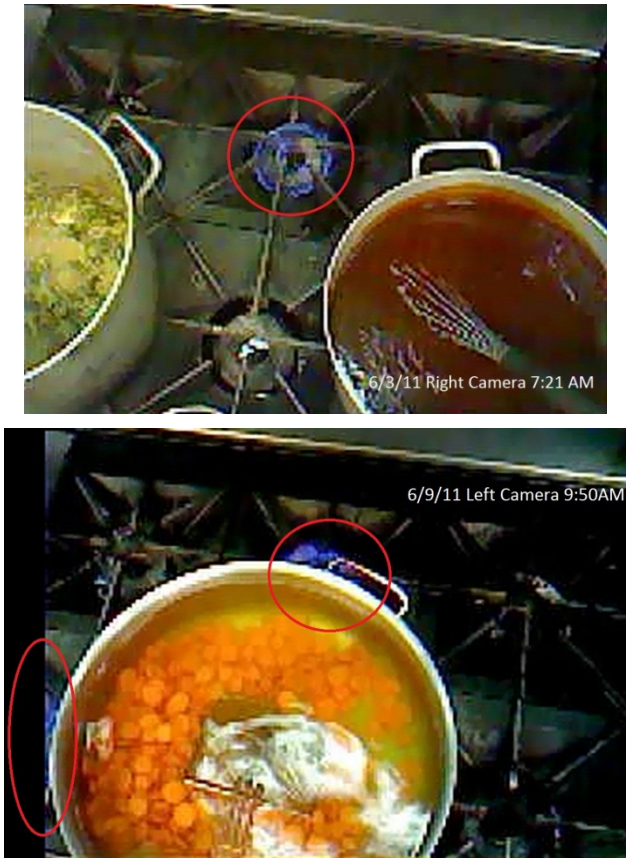



Photo Credit: FNi

From the visual results, the burners were on for 5 minutes and 19 seconds over a period of 32 hours of intermittent cook time recording. The video data suggests that the burner was an open burner 0.26 percent of the cooking time; however, the flame sensor data gathered over five days states that there was an open burner 1.95 percent (4.0 pulse threshold) of the cooking time. These results are inconsistent, though there might be other reasons for this deviation. The restaurant uses a chafing dish that occupies half the cooking surface, but the staff uses four burners to heat it (Figure 62). The results is partially open flames that are highly visible to the sensor (resulting in higher pulses) and to the camera.

**Figure 62: Chafing Dishes Heated by Four Burners, Leaving Exposed Flames**

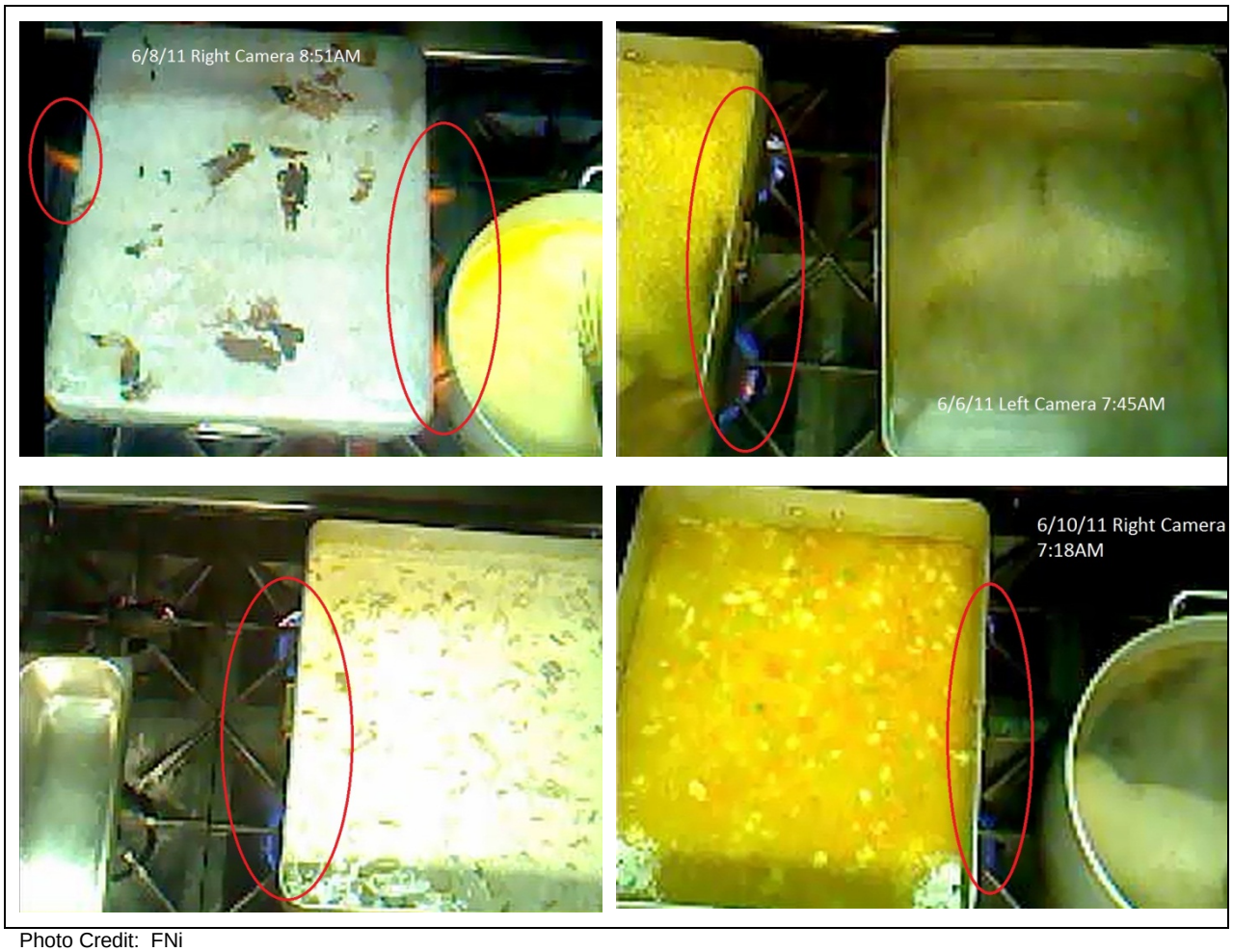



Photo Credit: FNi

Based on the video data, there were over 51:36 minutes and 36 seconds of open flames caused by an improperly aligned chafing dish. Open burner durations are broken out in Table 20.

**Table 20: Open Burner Durations Caused by the Chafing Dish**

| Date | Camera | Time | Total Duration (min:sec) |
|---|---|---|---|
| 6/3/11 | Right | 9:30:52 – 9:33:40 | 2:48 |
| 6/6/11 | Left | 7:43:58 – 8:00:00+ | 16:02+ |
| 6/8/11 | Right | 8:48:10 – 9:00:00+ | 11:50+ |
| 6/10/11 | Right | 7:09:03 – 7:30:07 | 20:56 |

Source: FNi

This is significantly more time than due to a fully-uncovered burner. If the uncovered chafing dish burner time is added to the fully uncovered burner the duration is 56 minutes and 55

seconds, which means there was an open flame 2.96 percent of the viewed cooking time. Combined open-flame video results are closer to the sensor data.

### 4.6.2 San Ramon Valley Conference Center: Range Replacement Study

#### *4.6.2.1 Baseline Equipment*

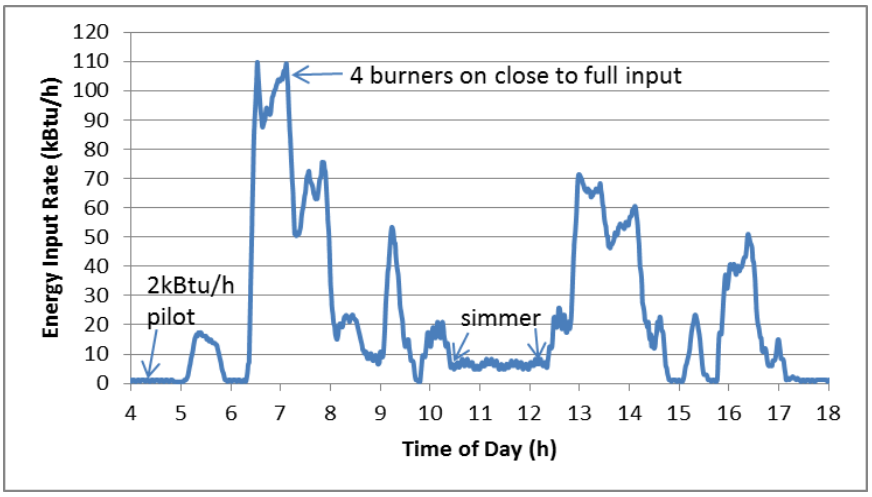
The cafeteria at the San Ramon Valley Conference center has been in operation for over 25 years. The ranges monitored are shown in Figure 63. The maximum input of the each of the two ranges was 180 kBtu/h, with six adjustable 30 kBtu/h burners. The gas metering equipment was installed on the range, with the oven disconnected. The monitoring continued over a period of two months.

**Figure 63: Dual Ranges With High Input Burners in the SRVCC Kitchen**

Photo Credit: FNi

On Monday through Thursday, the cooking started around 6 am and ended around 4 pm. Most of the heavy range use was in the early hours of the day before lunch. Friday is a half-day operation, and the cafeteria is closed on Saturday and Sunday. The average time at least one burner was on during the entire baseline monitoring period was 11 hours per day per range excluding Fridays and weekends. Throughout the day, burner input rates were continuously being adjusted, resulting in an average input rate of 27 kBtu/h. This means that the average input rate was less than a single burner maximum rate. However it was impossible to distinguish from the gas data whether one burner was turned on maximum input, or whether several burners were on partially. The ranges had one pilot for every two burners and resulted in a 2 kBtu/h standing pilot per range. The staff did not turn off the pilot at night. This means that 0.26 therms per day per range are used for pilot energy when the range is not in use. If the pilot is left over the weekend it results in 0.48 therms per weekend day. A typical weekday profile is shown in Figure 64.

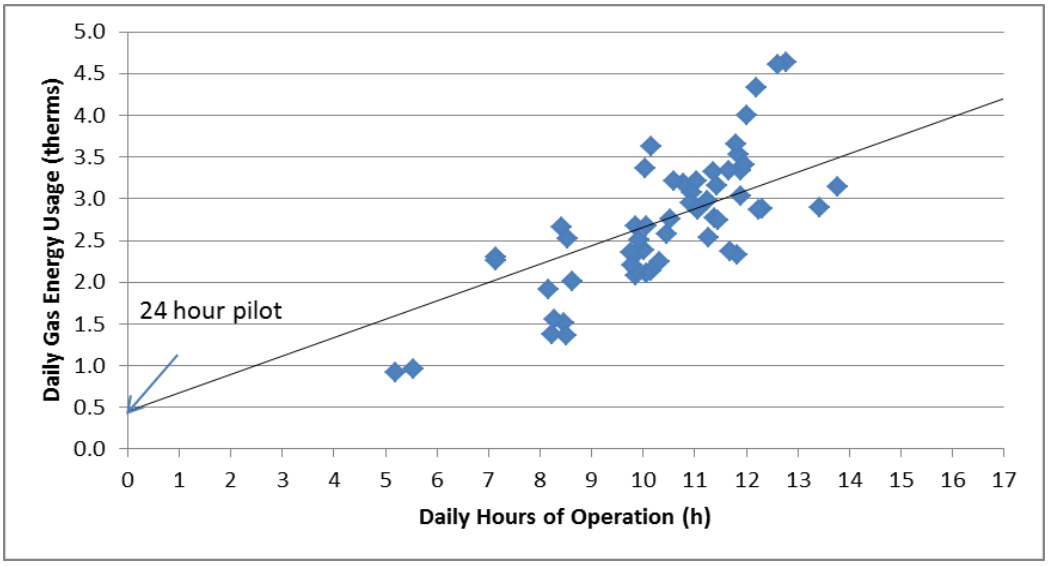
**Figure 64: Tuesday, November 15, Typical High Input Burner Range Daily Energy Profile**




Source: FNi

The average daily gas consumption of the 30 kBtu/h burner range was 2.92 therms per day per six-burner range, averaged over 56 days of monitoring (excluding Fridays and weekends). The daily energy usage varied from 0.9 to 4.7 therms depending on the menu that day. Range energy usage and operation hours were summarized using the scatter plots in Figure 65 to show day-to-day operational variation. A regression line was constructed showing the daily pilot energy consumption as the Y-axis intercept, as it is a constant source of consumption.

**Figure 65: High Input Burner Range Energy Use and Hours of Operation**




Source: FNi

### *4.6.2.2 Low Input Burner Range Replacement*

After baseline monitoring was completed, the 30 kBtu/h high input burner ranges were replaced with low input burner ranges that have a semi-automatic ignition system described in section 2.2 (shown in Figure 66). The dimensions of the replacement ranges were the same as

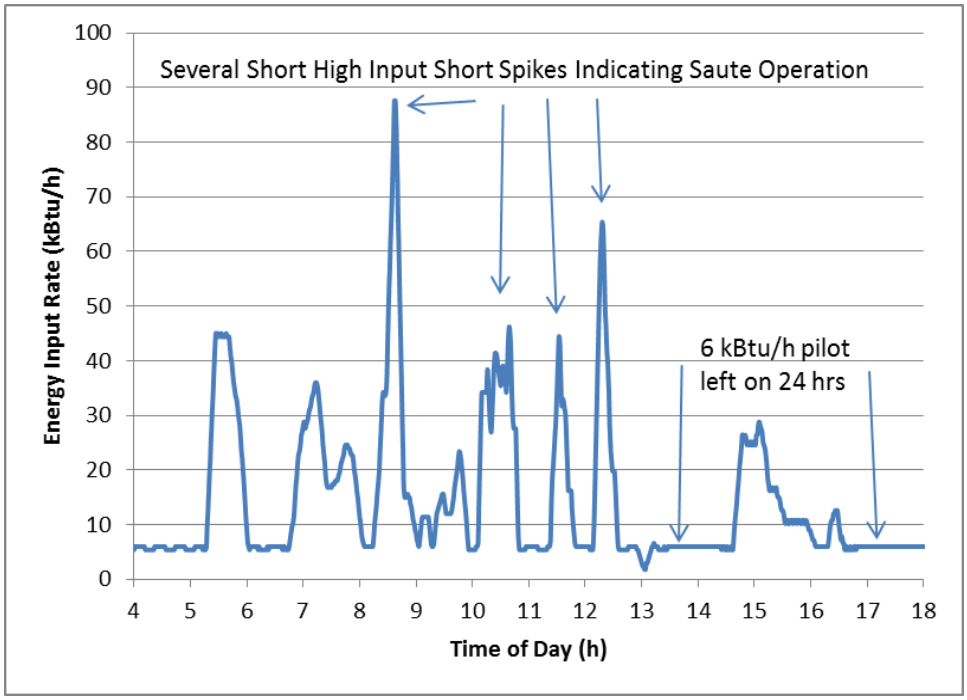
the baseline model. The two replacement ranges had six adjustable 20 kBtu/h burners for a total input rate of 120 kBtu/h. The convection oven energy was separated from the ranges.

**Figure 66: Replacement Low Input-Burner Ranges Installed on the SRVCC Kitchen Line**

Photo Credit: FNi

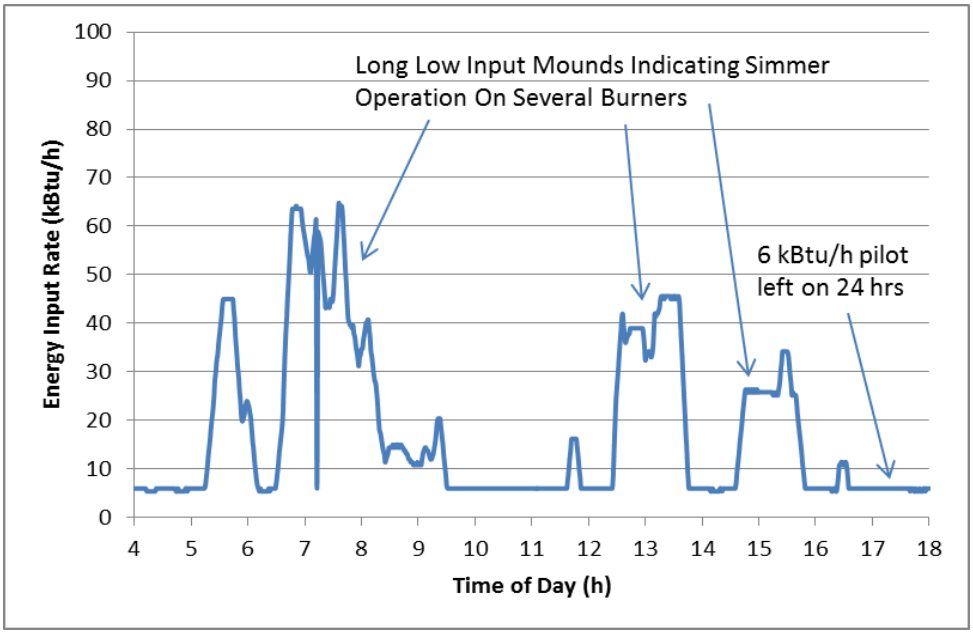
Each burner had a 1 kBtu/h pilot (for a total of 6 kBtu/h per range) with an individual spark igniter, so that the users can turn the pilots off at night and ignite them in the morning without the use of a lighter using the semi-automatic ignition system. The kitchen staff was taught how use the ignition system and was instructed to turn off the pilots at night. All cooking was instructed to be performed with all the pilots on. Several months of data were analyzed (from May through July). Two types of typical weekday profiles are shown in Figure 67 and Figure 68.

**Figure 67: Thursday June 14, Typical Low Input Burner Range Sauté Energy Profile (2.65 Therms in 6.9 Hours of Cooking)**




Source: FNi

**Figure 68: Thursday May 24, Typical Low Input Burner Range Simmer Energy Profile (3.10 Therms in 6.9 Hours of Cooking)**



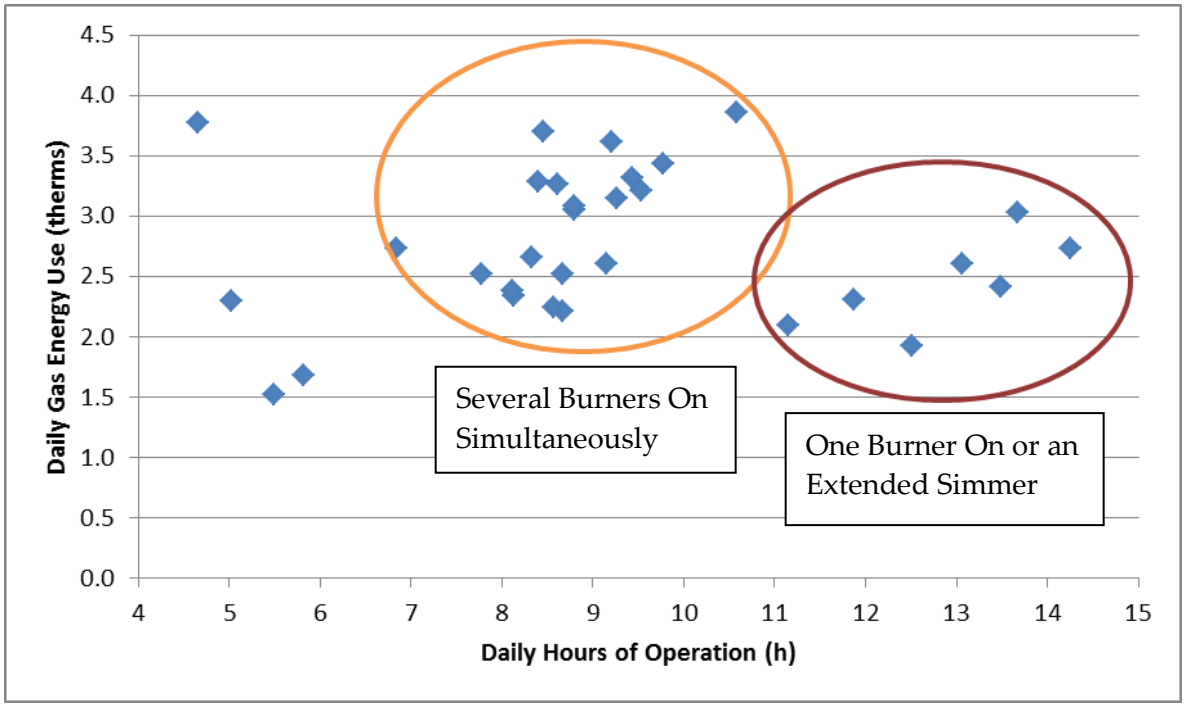

Source: FNi

As seen from the daily energy profiles, the graphs look very different based on the operation, however the cooking hours are almost identical. This difference was due to the fact that the

menu in the cafeteria style restaurant varied significantly from day to day. Figure 67 shows short operation at high input rates, suggesting that dishes were sautéed at high input rates for short time periods. Figure 68 shows lower peak inputs but the burner on longer, suggesting that pots were simmering for long periods of time. The difference between these two different cooking profiles, driven by the change of menu, is due to the different durations for which burners are engaged, even though the daily energy consumption is similar. This difference between cooking profiles results in similar cooking hours yielding different daily energy consumption. This difference is also highlighted by the variability in the energy-time relationship in Figure 69. Figure 67 and Figure 68 also illustrate that the staff was not turning off the pilots at night, resulting in a 6 kBtu/h pilot energy use.

The average daily gas consumption of the low input range was 2.74 therms per day per six-burner range, averaged over 31 days of monitoring (excluding Fridays and weekends). The total daily energy use varied from 1.5 to 3.9 therms, depending on the menu that day. At least one burner on the range was on for 9.3 hours per day, which meant that all the burners were turned off and it not being cooked on for at least 14.7 hours. Leaving all six pilot burners (1 kBtu/h each for a total of 6 kBtu/h per range) on during that time resulted in a 0.88 therm pilot energy consumption when the burners were off. Range energy use and hours of operation were summarized using the scatter plots in Figure 69 to show day-to-day operational variation.

**Figure 69: Low Input Burner Range Energy Use and Hours of Operation**




Source: FNi

There was no definite pattern to the scatter plot shown above; however range energy usage depended heavily on how many burners were on simultaneously and the style of cooking (i.e., simmer versus sauté).

### 4.6.3 San Ramon Valley Conference Center: Turbo Pot Use

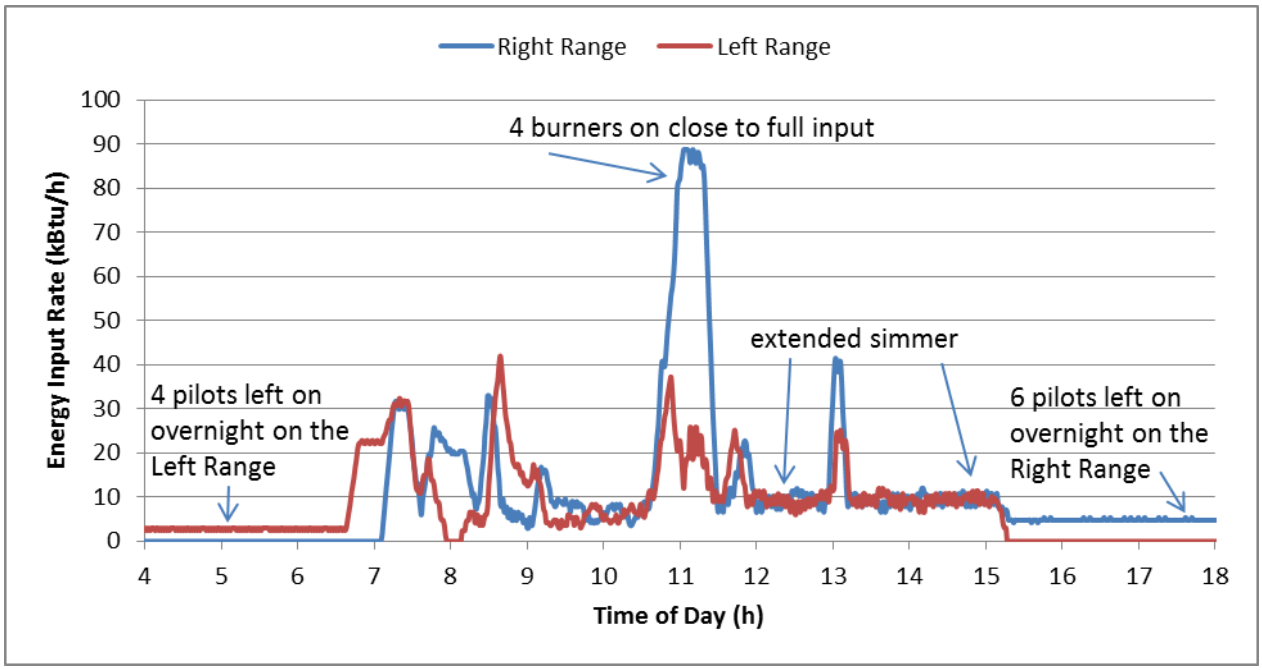
After the initial phase of monitoring the replacement (low-input burner) range was completed using conventional (flat-bottom) pots, all the standard-sized flat bottom pots and pans were replaced with finned bottom pots (shown in Figure 70).

**Figure 70: Turbo Pots for the Low Input Burner Range Replacement**

Photo Credit: FNi

The kitchen staff was instructed to use the Turbo Pots in a similar fashion as the flat bottom pots, but were told that they would require a smaller burner input rate to achieve the same results. It took the staff several months to get used to the new pots, and the chef said that it was easier to burn the product in the finned sauté pans. However, they were impressed with faster boil times for their pasta water and stocks. The research team analyzed a month of data and determined that throughout the day, the burner input rates were adjusted constantly and that the average input rate was 25 kBtu/h for the entire six burner range. A typical weekday profile for the two monitored ranges is shown in Figure 71.

**Figure 71: Daily Energy Profile for Low Input Burner Dual Range with Turbo Pots**



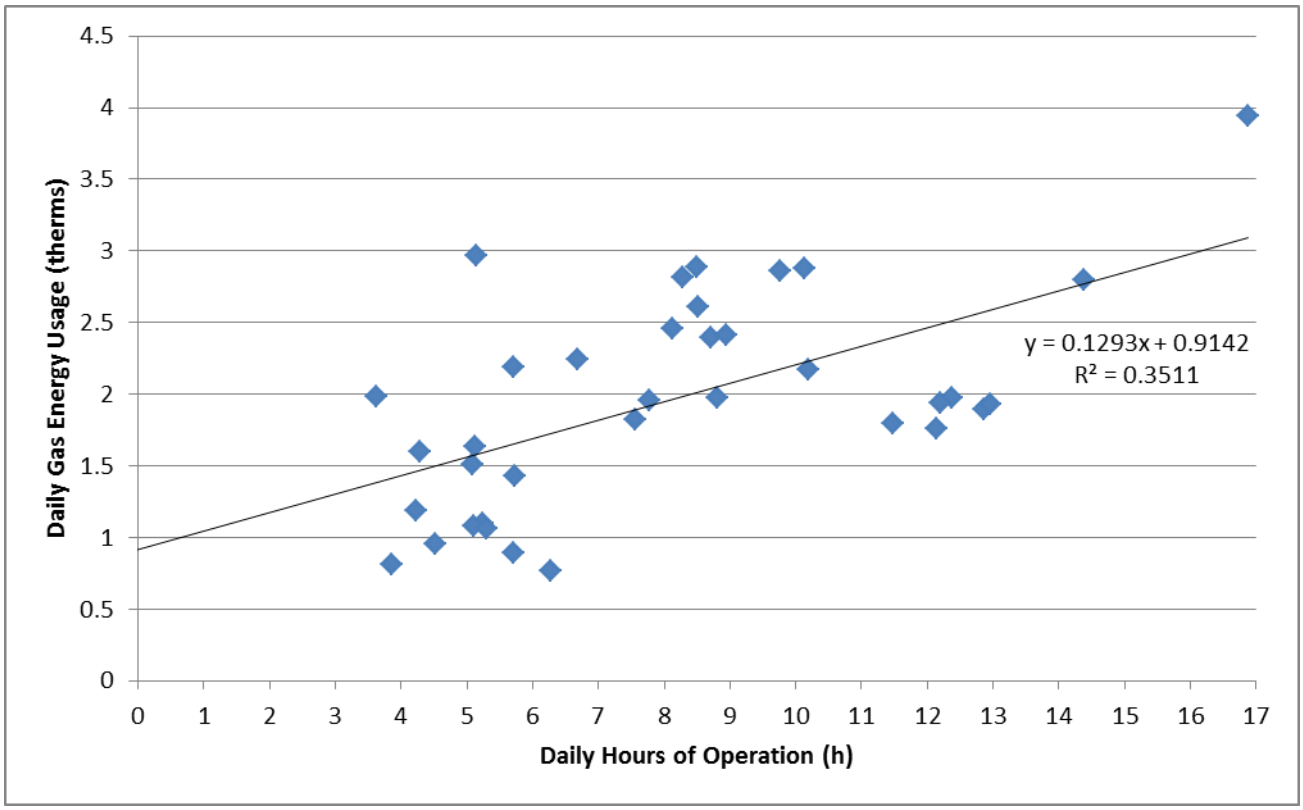

Note: Data from Thursday January 24th, 2013; the left range consumed 1.9 therms in 7.4 hours (shown in blue) and the right range consumed 1.3 therms in 7.1 hours of cooking (shown in red).

Source: FNi

As seen from the daily energy profile, both ranges had fairly similar energy use profiles. There was also more input adjustment with the Turbo Pots than with conventional flat bottom pots. This particular profile shows how the staff operated the pilots before and after restaurant hours. The left range pilots were left on from the previous day and the right range pilots were turned off. After the end of the day, the operator turned off the pilots on the left range but kept the right range pilots on. There were several days of operation when all the pilots on both ranges were left on; sometimes they were left on over the weekend when the restaurant was closed. At least one burner was on each range for an average of 7.8 hours per day, which means that the range was not being cooked on for 16.2 hours. Leaving all six pilot burners on during the time when the burners were off (at 1 kBtu/h each for a total of 6 kBtu/h per range) resulted in a 0.97 therm daily pilot energy consumption.

The average daily gas consumption of the low input burner range with Turbo Pots was 1.96 therms per day per six-burner range, averaged over 36 days of monitoring (excluding Fridays and weekends) from February through April. Days when the range was used less than three hours per day were dropped from the data set. The daily energy use varied from 0.8 to 3.9 therms, depending on the menu that day. Range energy use and hours of operation were summarized using the scatter plots in Figure 72 to show day-to-day operational variation.

**Figure 72: Low Input Burner Range with Turbo Pots Energy Use and Hours of Operation**




Source: FNi

Analysis of individual day data showed that the operator left at least one of the ranges with the pilots on. Often all six pilots were left on; however there are some days when only four out of six pilots were left on overnight. When graphing all the days monitored in Figure 72 a regression can be made. The Y axis intercept of the regression shows the average daily pilot energy usage. If all six pilots were left on, the pilot energy contribution would be 1.44 therms (i.e., 6 kBtu/h x 24 hours); the graph shows that only 0.91 therms contributed to the daily gas consumption during the monitoring period. All the pilots were expected to be on during the cooking hours which were found to be 7.8 hours per day, which means that pilot energy contribution during cooking was 6 kBtu/h x 7.8 hours = 0.47 therms. The monitoring period yielded results of 0.97 therm per day pilot usage if all six pilots were left on (1.44 – 0.47 therms) and an actual 0.44 therm per day pilot energy usage when all burners are off (0.91 – 0.47 therms). This indicates that all the pilots were on during non-cooking hours for 45 percent of the time or alternatively 45 percent of the pilots were on during all non-cooking hours. The latter of which is supported by the earlier discussion on **Figure 71** and off-hours pilot usage.

## 4.7 Summary of Results and Discussion

Incorporating automatic burner shutoff technology at SRVCC would not be very useful, since it was found that the staff was leaving an open burner on the range less than 3 percent of the monitored time. Although the personnel at the current monitoring site were very well trained

and did not leave open burners for extended periods of time, this same monitoring technique could be employed in bigger restaurants, where there may be less oversight and training, as well as a higher potential for energy savings.

During the monitored period, the daily gas energy use on the high input burner ranges was reduced from 2.92 therms using standard pots to 1.96 therms with the low input burner ranges using Turbo Pots. The combination of these two technologies resulted in a 33 percent reduction in gas energy use. Table 21 below shows the incremental savings at the San Ramon Valley Conference Center.

**Table 21: Field Range Upgrade and Cookware Upgrade Results**

| Test Case | Range | Cookware | Daily Range Energy Consumption | Energy Savings |
|---|---|---|---|---|
| Baseline | 30 kBtu/h Burner | Flat Bottom Pots / Pans | 2.92 | N/A |
| Replacement | 20 kBtu/h Burner | Finned Turbo Pots/Turbo Fry Pans | 1.96 | +32.9% |

Source: FNi

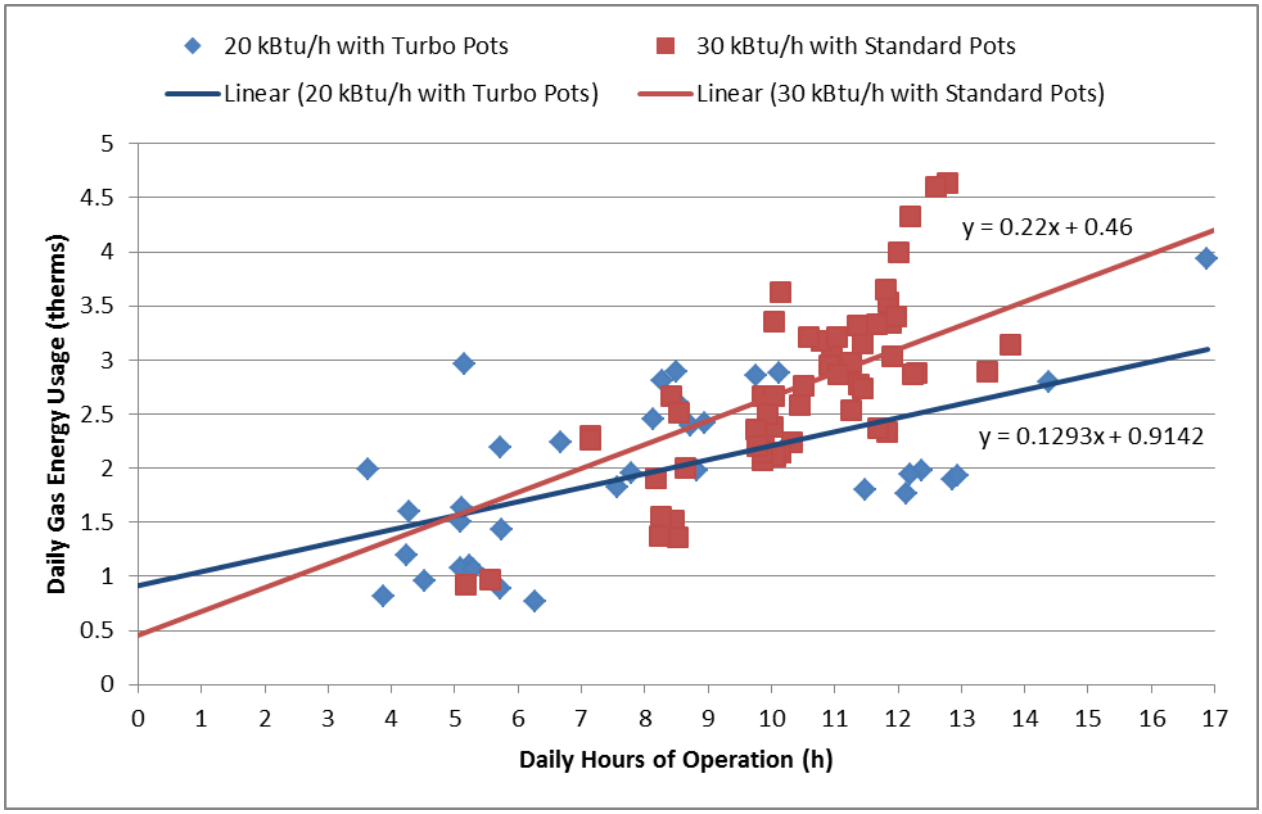
The replacement low input burner range had a semi-automatic pilot ignition system where the user was encouraged to turn it off at night. However it was not utilized very often and it was found that the pilots were left on at night almost 50 percent of the time. The pilots were left on largely due to the long heat-up times for the pilot's flame proofer, which takes several seconds to heat up and keep the pilot valve open. Several seconds might seem like a short time, but if it takes a few attempts for the user to light the pilot, which may add up to half a minute to light each pilot. With six pilots per range and two ranges in the kitchen, it may take some users up to ten minutes to engage all the pilots. Performing this operation on a daily basis discourages some of the range operators from shutting off the pilots at night, so most of the days monitored, the pilots for at least one of the ranges were left on. The range had a pilot for each burner resulting in a total pilot input rate of 6 kBtu/h per range, which was quite high—these pilots were not designed to be left on for long periods without cooking. The staff seldom left all six pilot lights on, but at least two of them were left on overnight. If all six pilot lights were left on when nothing was being cooked on the range, it would result in 97,200 Btu of energy consumed per day ((24 hours per day – 7.8 hours of cooking) x 6 kBtu/h pilot), or 0.97 therms per day—almost 50 percent of the 1.96 therms daily energy consumed by the Turbo Pots. In reality, the partial leaving pilots on at night resulted in a 0.44 therm contribution to the total daily energy consumption which was a 22 percent contribution to total range gas consumption.

A previous study on open-top gas ranges had shown 0.26 therms of pilot energy use per day for one 6-burner range used at the same location (*Montague Model V136-5 Heavy Duty Open Top Gas Range Appliance Performance in Production*). The pilot energy rate of the older ranges was only1.8 kBtu/h and their total daily energy use was 2.1 therms, meaning that pilot energy accounted for 12.4 percent of the daily energy of the older ranges, where the pilots were always left on overnight. The new semi-automatic ignition range used almost double the pilot energy, which

shows that well-designed conventional pilots can use less energy than a semi-automatic ignition pilot system—especially when the semi-automatic ignition system is improperly used.

Figure 73 shows the regression comparison between the low input burner range with the Turbo Pots and the high input burner range with the standard pots.

**Figure 73: Range Energy Savings Comparison**




Source: FNi

The pilot energy shows a significant difference between the two graphs under low daily operating hours, because low-input pilots use less energy at low burner operating hours despite being on all day. The usage of the Turbo Pots in conjunction with the low input rate burners reduces the slope of the line by achieving lower overall simmer input rates while achieving faster cook times. Notwithstanding the high input burner range's pilot rate, the range with the Turbo Pots began using less energy after 5 hours of daily operation. With proper pilot shut-off practices, the intercept of the low-input burner range (blue line) would lower, which would add additional savings. With average operating times around to 8 to 11 hours, the separation between the regression lines reflects the energy reduction.

The range operator was instructed on how to use the semi-automatic pilot system. However, there were several staff members that used the range; most of them do not work every day at the restaurant. The range energy profiles indicated that some days the operator turned off the pilot at night, some days they did not. After discussing the pilot use with the chef, he stated that the ignition system is not very robust and, according to him, takes the operator several minutes

to light each pilot using the spark ignition. Having two six burner ranges in that kitchen means that starting all 12 pilots would take a significant amount of staff time.

## 4.8 Conclusions and Recommendations

### 4.8.1 Conclusion

The gas range is an appliance that has been around for centuries. Developments in other gas appliances like fryers, griddles and combination ovens have taken leaps over the past few decades. The technology of the gas range, however, has remained virtually unchanged during that time. This report outlines several potential range energy-saving technologies such as burner design, automatic flame shutoff, pilotless ignition, and cooking vessel design, as well as their energy impact in the lab and in the field.

The energy impact of leaving open burners with flames heating up nothing but the air around it seems very dramatic, and it has been proposed that burner shut-off technology should be developed for the range to reduce operating time without a cooking vessel. A spring-loaded burner shut-off system provided a potential solution; however it takes a great deal of attention from the operator for the mechanism to work properly under the right pressure of the cooking vessel. Most of the time chefs leave open burners during a sauté operation that is done with a lighter weight pan. Sometimes it is necessary to lift the pan in order to coat the ingredients in the cooking sauce. In both those instances the shutoff mechanism relies on the small weight of the pan to reignite the burner which has proven to be inconsistent in a lab scenario. While this technology shows promise, the current design has some challenges in replacing standard range burner technology for many types of operations.

Within the scope of this range project, a sub-study was performed in the real-world kitchen using optical flame sensor technology to analyze the actual time a burner remains open and thus quantify the energy-saving potential (or lack thereof). Combining video surveillance with the flame sensor resulted in a better understanding of how ranges are being used. After studying the data, it was found that the burners were being left on without a cooking vessel less than 3 percent of the time for the commercial kitchen being studied. It is recognized, however, that this is highly dependent on how well the staff is trained and could vary from one foodservice operation to another.

Pilotless ignition is a well-established technology, used extensively in residential ranges. Because of the proximity tolerances of the igniter to the flame, as well as the extra wiring required, true pilotless ignition has proven to be too unreliable to be marketed on a large scale. A semi-automatic pilot ignition system was developed by one manufacturer and field tested within the scope of this PIER study. However, delays caused by the flame proving system were viewed as a deterrent by kitchen staff, who left the pilots burning during non-cooking times rather than diligently shutting them off and spending the extra effort to relight them. The individual pilots themselves consumed a significant amount of energy, while overall; the cooking energy use of the test range was determined to be relatively low when compared to other appliances. Thus, the pilot energy use was a significant component of the total range consumption in this foodservice operation.

Thinking outside the box has caused some companies to focus on the cooking vessel rather than the range itself. Heat sink technology from the computer industry has been applied in reverse to the bottom of a cooking pot. Laboratory studies have been conducted comparing the heat-up times and efficiencies of flat bottom pots compared to finned bottom pots. The test was conducted on three different ranges and resulted in reducing water heating times by 44 percent and increasing heat-up efficiency up to 60 percent.

The high-input rated ring-burner ranges were replaced by low-input star burners and standard pots were replaced by finned Turbo Pots at a cafeteria style restaurant. This field study of upgrading to-low input burner ranges, in conjunction with finned bottom pots, led to a 33 percent reduction in energy use by the field tested ranges.

There are many energy-saving technologies for gas ranges out there. However, only a few of them have become commercially viable and practical. Developments to the passive burner design and to the cooking vessel have shown significant energy savings, while also increasing the performance of the gas range. It is up to the manufacturers to continue developing the other technologies mentioned in this report to be more durable and foolproof before the restaurant industry adopts them.

The most significant contributor to energy savings for the open-burner range was Eneron's Turbo Pot. According to the manufacturer's website, after some de-rating, the cost of a finned bottom Turbo Pot is approximately $100 (Eneron). The Turbo bot increased cooking energy efficiency from the baseline by between 48 percent and 81 percent depending on what type of burner was being used. Through field testing this translated to a 33 percent reduction in energy use with the use of the low-input burners, saving the user $122 per year per range. Accordingly the payback period for this technology is less than a year, approximately 0.8 years, and the manufacturer claims that even shorter payback periods have been achieved in a commercial setting (Eneron).

In a 2010 PIER report by Fisher-Nickel, inc. on *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment,* it was estimated that 45,000 open top gas ranges were in operation in California commercial kitchens. With most ranges operating at a baseline efficiency of approximately 30 percent, the estimated annual gas use was 16.6 million therms in California. If 50 percent of the gas ranges in California were converted to low input burners in conjunction with finned bottom pots, this could result in an annual savings of 2.7 million therms. Eliminating continuous standing pilots from half the installed base of commercial ranges has the potential to reduce gas consumption by another 1.1 million therms per year. Using the 2012 price for commercial natural gas of 7.13 dollars/MCF and a heating value of 10.21 therms/MCF, this represents a potential savings of approximately 2.6 million dollars for California food service providers (EIA 2013) by combining the a pilot off at night system with the finned bottom stockpots.

### 4.8.2 Recommendations

While there are technical issues that must be overcome before the different variations of the advanced range is a market reality, the research concluded that it was possible to create an

improved range top that met the expectations of end-users and the industry alike while reducing energy use significantly. With this in hand, the energy efficiency community and gas industry needs to continue R&D work on advanced gas range concepts, focusing on developing commercial-grade, higher-efficiency burners. Future research should continue along these paths, with emphasis on the following:

1. Development of higher efficiency burners: passive open burner technology does not have much room for improvement; however powered burners have shown energy efficiency improvement potential when properly integrated into the range as shown in the *Commercial Gas Range Top Technology Overview White Paper.*
2. Conduct more energy field monitoring of finned bottom pots in combination with different range burner types and energy inputs. While it was found that the finned bottom pots paired with low input burners yielded significant energy savings, more field studies should be performed on energy usage of finned bottom pots with high input (e.g., 30-35 kBtu/h per burner) standard-efficiency range tops and dedicated stockpot ranges with burners >40kBtu/h.
3. The pilot energy use was shown to be a significant component the total range energy use at the cafeteria test site. Reducing the energy consumption of conventional pilots and/or having single pilots for multiple burners are passive steps to pilot energy reduction. The possibility of reducing the number of pilot lights could be investigated as well as the possibility of using a single pilot for all six burners.
4. Automatic pilotless ignition technology needs to be researched and field tested. Pilotless ignition systems need to be more robust and reliable for use in a heavy-duty restaurant operation. Spark ignition times need to be reduced for the staff to use them reliably.
5. The Turbo Pot needs to be more widely adopted by the industry and should be promoted by both energy utilities and range manufacturers to increase overall system efficiency. Stock pot ranges should be sold with finned bottom pots because they have the highest overall savings potential based on their input rate and operation time. More development work on sauté pans is warranted.
6. The Energy Commission should consider regulations that facilitate the adoption of pilotless ignition for all new range burners solid in California once the operation of such a system has become more user-friendly. Such regulation could be considered technology-forcing, where it would drive the manufacturers to develop more robust ignition system that has been in use in residential applications for decades.

# CHAPTER 5: Wok Ranges

## 5.1 Summary

### 5.1.1 Introduction

Wok ranges are an essential commercial kitchen appliance for preparing Asian-style cuisine. Wok ranges feature a stainless steel body with one or more cooking wells to heat a round-bottomed cooking vessel known as a wok pan. A wok's cooking versatility makes it the workhorse of most Asian-style restaurants. Chefs can use the wok range for frying, poaching, braising, searing, and steaming. Most wok ranges also require constant surface cooling with fresh water to prevent operator burns and structural warping from high temperatures. Wok ranges typically use a gallon of water per minute to keep surfaces cool.

Although wok ranges feature gas valves at knee-level for input adjustment, most wok ranges are operated at maximum input. Energy input rates range from 50 kBtu/h to as high as 160 kBtu/h or more, depending on the type of burner. These high input rates facilitate the short-term, high-temperature cooking process required for Asian-style dishes. As such, the wok range exhibits notoriously low gas energy efficiencies, which range between 10 percent and 15 percent, according to testing conducted by both FSTC and GTI (*Wok Water Saver Performance Test* and *Town EcoDeck E-2-SS-N Wok Range Expanded Test Report*). New technologies exist that could increase the energy performance of wok ranges, but they have yet to be fully embraced by the foodservice industry.

### 5.1.2 Purpose

The purpose of this report was to identify new technologies that could improve wok range energy efficiency and performance. The goal was to validate a targeted 20 percent energy-efficiency gain when using advanced design equipment.

### 5.1.3 Project Objectives

The objectives of the commercial gas wok range study were to:

- Characterize the energy inefficiencies of current wok range technologies through laboratory and field data collection.
- Design and develop new prototype for a commercial foodservice wok range which is both energy efficient and robust.
- Compare standard and energy-efficient wok ranges in energy use, water use, and practicality.
- Recommend future improvements to further wok range efficiency.

### 5.1.4 Project Outcomes

Wok range burners, wells, and frame construction designs are fairly simple but can cause functional challenges in a working commercial kitchen. For construction, ranges typically

employ conventional ring-style burners; burner wells or chambers are cylinders which extend from the rim upon which the wok pan sits to the opening in the bottom of the appliance frame where the burner is positioned. They are designed to insulate and direct the flame to the bottom of the wok pan. Frame construction is stainless steel, which can warp due to the high-temperature operation of the wok range. A water inlet is provided to actively cool the surfaces of the wok range during cooking.

The advanced wok prototype came equipped with improvements to these traditional, outdated designs of the wok range. A Micron-Fiber Tech custom cylindrical mesh burner was designed to improve heat transfer from the burner to the wok pan. An ignition system was installed to eliminate the need for a standing pilot. A ceramic burner chamber was installed to replace the hollow conventional burner well. This chamber was designed to focus heat toward the bottom of the wok pan and away from the wok range's stainless steel structure, effectively reducing the reliance on cooling water for the wok frame. A prototype wok pan from Eneron, Inc. with heat-sink fins attached to its bottom was also employed to enhance heat transfer.

The prototype wok range tested in-laboratory alongside the standard-efficiency wok range in accordance with ASTM F1991-99 *Standard Test Method for Performance of Chinese (Wok) Ranges*. The standard wok range performed at a measured energy input rate of 120,767 Btu/h, a cooking-energy efficiency of 13 percent, a production capacity of 121.54 lb/h, and a standing pilot energy rate of 1,613 Btu/h. The advanced prototype wok range, equipped with the cylindrical mesh burner and ceramic burner well, exhibited a measured energy input of 52,767 Btu/h, a cooking-energy efficiency of 23 percent, a production capacity of 79 lb/h, and no pilot energy rate due to the ignition system. When the Turbo Wok pan was tested with the prototype wok range, the energy efficiency increased to 35 percent and the production capacity increased to 122 lb/h. The prototype was not equipped with a water inlet for surface cooling, which does offer significant utility savings however measures must be taken to ensure its safety and long-term durability.

Two site locations were selected for baseline energy use monitoring of the wok range: Safeway, a grocery store with a batch-cooking "China Express" takeout buffet and Yiping, an upscale cook-to-order Chinese restaurant. The current and projected energy use and cost for Safeway and Yiping are presented in Table 22 and Table 23 below.

**Table 22: Projected Savings with Energy-Efficient Two-Burner Wok Range at Safeway**

| | Current Wok Range | Prototype Wok Range with Standard Wok Pan | Prototype Wok Range with Turbo Wok Pan |
|---|---|---|---|
| Energy Use (Therms/day) | 6.71 | 3.83 | 2.51 |
| Water Use (gal/day) | 497.61 | 0.00 | 0.00 |
| Annual Energy Cost ($)* | 2,449 | 1,397 | 917 |
| Annual Water Cost ($)† | 2,428 | 0 | 0 |
| **Total Utility Cost ($)** | **4,962** | **1,397** | **917** |

Source: FNi

* Based on estimate of $1.00 per therm for PG&E service territory.

†Based on averaged water and sewer costs for Bay Area.

**Table 23: Projected Savings with Energy-Efficient Two-Burner Wok Range at Yiping**

| | Current Wok Range | Prototype Wok Range with Standard Wok Pan | Prototype Wok Range with Turbo Wok Pan |
|---|---|---|---|
| Energy Use (therms/day) | 9.89 | 5.64 | 3.70 |
| Water Use (gal/day) | 480.00 | 0.00 | 0.00 |
| Annual Energy Cost ($)* | 3,610 | 2,059 | 1,350 |
| Annual Water Cost ($)† | 2,342 | 0 | 0 |
| **Total Utility Cost ($)** | **5,952** | **2,059** | **1,350** |

* Based on estimate of $1.00 per therm for PG&E service territory.

†Based on$10.00/CCF average water and sewer costs for the San Francisco Bay Area.

Source: FNi

### 5.1.5 Conclusions

The cooking-energy efficiency and overall performance of gas wok ranges can be drastically increased through the adoption and implementation of new technologies, including but not limited to the use of cylindrical mesh burners, ceramic burner chambers, and bottom-finned wok pans. In-laboratory testing confirmed an energy-efficiency increase from 13 percent to almost 35 percent with the utilization of these innovations. The gas energy-savings between the two restaurant sites in this study was projected to be 63 percent. Without the need for a water connection, the prototype would also save substantial utility costs.

The two field sites pay an average of $5,457 each year on wok range utility costs. Adopting an advanced wok range, such as the prototype, with an array of Turbo Wok pans would potentially save these sites an average of approximately 79 percent on their utility bill each year on natural gas and water, with an average of 55 percent of the savings being attributed to the absence of a water inlet. Based on the parts need for construction of the prototype, GTI

estimates the cost adder of the new wok design to be about $350 and Eneron estimates the cost adder for the Turbo Wok to be about $60.

### 5.1.6 Recommendations

Rigorous field monitoring of advanced wok ranges is needed to adequately assess the real-world viability of these technologies and verify the potential energy savings detailed in this report. Issues of practicality, versatility, and durability seem to be the major obstacles to the acceptance of these innovations in the restaurant industry. The varying types of cooking performed on a wok range should also be explored as possible effects on energy consumption. Field research on the Turbo Wok pan is needed to determine handling and ease-of-use in a commercial kitchen setting. Further lab and field testing is needed to determine the heat transfer to the prototype wok range frame *without* a water inlet. The advanced prototype without cooling water could present safety, maintenance, and general cooking (steaming) issues.

### 5.1.7 Benefits to California

In 2010, the Pacific Gas & Electric FSTC estimated that roughly 38,987 wok ranges were in operation in California commercial kitchens, with most wok ranges operating at a baseline efficiency of approximately 10 – 15 percent. Additionally, each burner well uses an average of one gallon per minute of water to cool the surfaces of the appliance, consuming an estimated 85 million gallons per year in California. The estimated annual natural gas use for woks is 30 million therms. Theoretically, if 30 percent of the wok ranges in California were selectively replaced with advanced wok ranges, this could result in 63 percent energy savings for those ranges. Sixty-three percent energy savings on 11,696 wok ranges could result in an annual savings of about 5.7 million therms in California which represents an estimated 4 million dollars in natural gas using the aforementioned values of 10.21 therms per MCF and 7.13 dollars per MCF (EIA 2013).

Reducing the notoriously high gas and water use of the gas wok range by continually improving, field testing, and eventually embracing these new technologies will improve foodservice operations, reduce energy and utility costs, and help environmental conservation—all of which will improve the quality of life for Californians.

## 5.2 Introduction

### 5.2.1 Background

The wok range uses high-intensity burners to cook a variety of foods in Asian restaurants. A typical wok range, shown in Figure 74, will feature a stainless steel body with several cooking wells to heat a round-bottomed cooking vessel known as a wok pan. Used primarily to cook eastern dishes, wok ranges employ high-intensity burners to offer a range of cooking styles—including frying, poaching, braising, searing, and steaming.

The high heat intensity required for wok cooking has been a central obstacle to energy-efficient upgrades. Aside from increasingly expensive energy costs, typical wok ranges require constant surface cooling with fresh water. The Alliance for Water Efficiency estimates that the operator

of a two-burner wok range can expect to use a gallon of water per minute to cool the surfaces during operation. After being used to remove heat from the range, waste water runs directly to the drain. If water is not used, the stainless steel surfaces around the wok wells can reach high temperatures, putting operators in danger of burns and warping the table surfaces due to high thermal stresses.

The wok range requires large amounts of water and gas and only achieves efficiencies ranging between 10 percent and 15 percent, according to a 2010 FSTC study *Characterizing the Energy Efficiency Potential of Gas-fired Commercial Foodservice Equipment*. The same study also found there are approximately 38,987 wok range burner wells estimated to exist in California. While there have been efforts to improve efficiency, new technologies have not yet penetrated the market to provide utility and monetary savings to these wok ranges. Figure 74 shows a wok range with three burner wells.

**Figure 74: Commercial Foodservice Wok Range**

Photo Credit: GTI report Advanced Foodservice Appliances for California Restaurants

### 5.2.2 Objectives

The objective of this project was to introduce and study new technologies which could decrease the water and energy use of the conventional wok range. The goal was to validate a targeted 20 percent energy-efficiency gain when using advanced design equipment via the following measures:

- Characterize the energy inefficiencies of current wok range technologies through laboratory and field data collection.
- Design and develop a new prototype for a commercial foodservice wok range that is both energy-efficient and robust.
- Compare standard and energy-efficient wok ranges in energy use, water use, and practicality.

- Recommend future improvements to further wok range efficiency.

## 5.3 Technology

### 5.3.1 Standard Technology

The traditional wok range utilizes crude burner technology to provide low-cost products to the end-user. Unfortunately, the conventional design of the burner wells, burners, and frame construction can be problematic in practice and lead to heightened utility costs.

#### *5.3.1.1 Burner Wells*

Wok ranges typically feature multiple cooking wells, each tailored to the application of the cooking. These chambers, featured in Figure 75, are cylinders that extend from the rim upon which the wok pan sits to the opening in the bottom of the appliance where the burner is positioned. These chambers range in diameter from 10 to 20 inches and consist of cast iron, steel, and ceramic. The purpose of this well is to insulate the flame to focus heat to the bottom of the wok pan.

**Figure 75: Commercial Foodservice Wok Range Ring Burner**

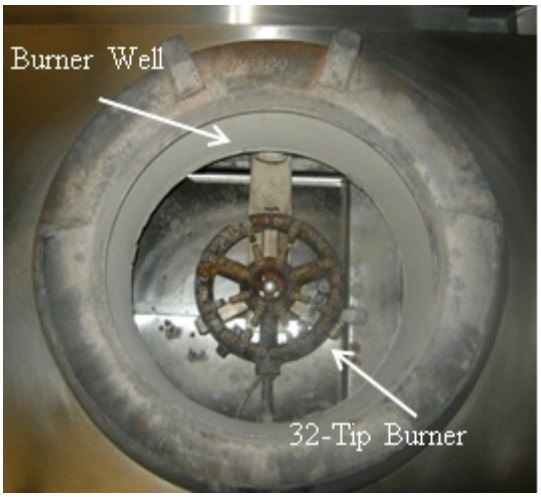



Photo Credit: FNi

#### *5.3.1.2 Burners*

Wok ranges typically utilize simple jet ring style burners with orifice spuds mounted on circular manifold pipes. The energy input rates of these burners range from 50 kBtu/h to 120 kBtu/h, depending on the style of cooking and the level of heat required. While propane and butane burners exist for certain appliances, natural gas is the most common fuel type. The controls for these burners are typically L-shaped valves located at knee height. All the air required for combustion flows from the open bottom of the cylindrical burner well.

#### *5.3.1.3 Frame Construction*

Stainless steel is standard for the external surfaces of the wok ranges, as seen in Figure 74. The combination of the high heat intensity of the burners and the thermal cycling cause stresses in the stainless steel surfaces, often resulting in warping the body of the wok range. To prevent

warping, wok ranges are actively cooled with flowing water. The flow, commonly found to be one gallon per minute during operation, flows from the water inlet and down the drain. The operational costs for a wok are especially high due to the dual utility requirements of this appliance.

### 5.3.2 Advanced Technology

The energy-efficient prototype, manufactured by Royal Range of California, Inc. (www.royalranges.com), includes several significant changes to the burner and burner well designs to focus the heat on the wok pan itself, and to reduce the amount of air that moves through the combustion system. The design change, does not alter the sheet metal components or structure of a standard range. However, the increased efficiency does aim to reduce the thermal strain experienced during operation.

**Figure 76: Royal Wok Range Prototype**

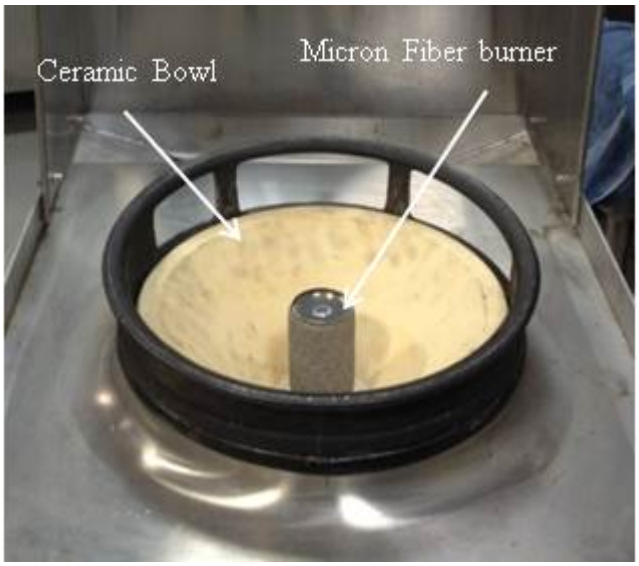



Photo Credit: GTI

#### *5.3.2.1 Burner*

A Micron Fiber-Tech custom cylindrical mesh burner, indicated in Figure 76, was designed to increase the radiant component of the heat transfer to the wok pan. An air-fuel mixer was installed upstream, along with a blower, to provide combustion-ready gas to the burner. In addition, an ignition module was installed to eliminate the need for a standing pilot. The energy input rate for this burner was determined to be 52,767 Btu/h in comparison to the measured 120,767 Btu/h of the standard wok.

#### *5.3.2.2 Ceramic Bowl*

A ceramic burner bowl, shown in Figure 76, was installed in lieu of the hollow cylindrical burner well. The burner heats the ceramic bowl which radiates heat toward the round-bottomed wok pan and away from the sheet metal structure.

## 5.4 In-lab Testing and Results

### 5.4.1 ASTM Testing of Advanced Unit

#### *5.4.1.1 In-lab Test Plan*

The Foodservice Technology Center (FSTC) examined the operation and performance of standard and advanced technology wok ranges under controlled conditions of the ASTM designation F1991-99 *Standard Test Method for Performance of Chinese (Wok) Range*. This test method characterizes gas-powered range performance using the energy input rate, pilot energy rate, heatup energy efficiency, and production capacity.

In addition to the procedures specified in ASTM F1991-99, a performance test was run to determine the impact of water cooling on the unit. The performance test involved operating the range with gas settings on the full "on" position for one hour. During this test, nine type-K thermocouple probes were welded on the counter, deck, and backsplash (shown in Figure 77) to monitor temperatures throughout the tests using a data acquisition system. This test was run under two conditions; with 2.5 gal/min of water running over the deck and without water running at all. The rate of water flow was controlled by setting the deck wash valve to the maximum "open" setting.

**Figure 77: Thermocouple Placement for Performance Test**

Photo Credit: FNi

#### *5.4.1.2 Equipment Selection*

Standard Technology Wok Range

**Figure 78: Standard Wok Range**

Source: FNi

A commercial-grade wok range, shown in Figure 78, was selected to establish benchmark energy efficiency, production capacity, and water usage. The two-burner baseline range featured a 75,000 Btu/h-rated, 16-tip burner and a 116,000 Btu/h-rated, 32-tip burner. The cumulative rated input of 196,000 Btu/h is typical of commercial two-well wok range units. Controls include an adjustable stainless steel "L-shaped" gas control valve to vary the input to each burner. The deck cooling water valve releases 2.5 gal/min when fully opened. The appliance was determined to be within standard ranges of both energy and water use for commercial wok ranges.

Advanced Technology Wok Range

The advanced range technologies, including micro mesh premix burner and ceramic burner bowl, were implemented in a prototype wok range featured in Figure 79. The goal of this product was to direct more of the generated heat to the wok pan, increasing the energy efficiency and eliminating the need to actively cool the range surfaces. The prototype features an ignition module to eliminate the need for a standing pilot, further reducing the total gas consumption.

In addition to the updated range technology, a prototype wok pan, designed and manufactured by Eneron, Inc. (www.turbopot.com), was evaluated to determine further efficiency gains were possible by improving heat transfer to the cooking utensil. Figure 80 displays the rounded bottoms of a traditional wok pan (left) as well as the prototype "Turbo Wok" pan. Heat-sinking fins were welded to the rounded bottom of the wok pan in order to absorb more of the heat from the burner.

**Figure 79: Royal Wok Prototype**

Photo Credit: FNi

**Figure 80: Standard Wok Pan (Left) and Turbo Wok Pan (Right) Used for ASTM Testing**

Photo Credit: FNi

## 5.4.2 In-Lab Results

### *5.4.2.1 Standard Wok Range*

Standard Wok Range Energy Use

The results of the ASTM F1991-99 tests are displayed in Table 24. Commercial wok ranges typically yield energy efficiencies between 10 percent and 15 percent with rated burner inputs between 100 and 150 kBtu/h. With an energy efficiency of 13 percent and measured input of 121 kBtu/h, the baseline 32-tip wok burner adequately represented the wok range typically found in commercial foodservice establishments.

**Table 24: ASTM Test Results for Standard Wok Range**

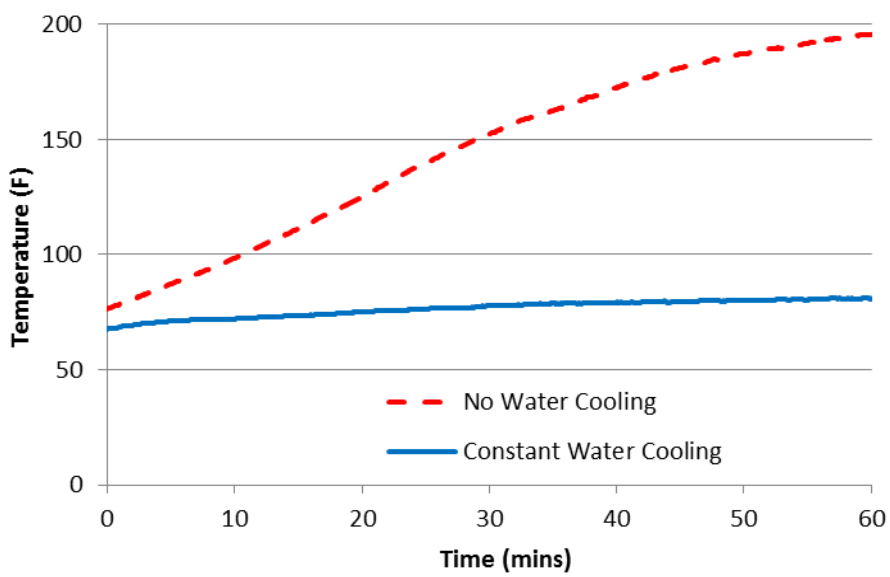
| | 32-Tip Burner | 16-Tip Burner |
|---|---|---|
| Measured Energy Input Rate (Btu/h) | 120,767 | 76,835 |
| ASTM Heatup-energy Efficiency (%) | 13.00 | 13.64 |
| ASTM Production Capacity (lb/h) | 121.54 | 79.47 |
| Pilot Energy Rate (Btu/h) | 1,613 | 1,613 |

Source: FNi

Standard Wok Range Water Use

The temperature of the wok range surface was significantly reduced with fresh tap water running over the deck area. Figure 81 displays the average temperatures of the deck during the hour-long tests and compares the surface temperatures with and without the presence of cooling water streams across the deck.

**Figure 81: Deck Temperatures During Performance Test**




Source: FNi

Table 25 shows the temperature rise of the counter, deck, and backsplash surfaces both without water and with water running actively over the deck surface.

**Table 25: Temperature Summary after Hour-Long Performance Test**

| | Constant Water Cooling (°F) | No Water Cooling (°F) |
|---|---|---|
| Counter | 124.6 | 140 |
| Deck | 81.1 | 196 |
| Backsplash | 255.1 | 252.9 |

Source: FNi

These results are representative of surface temperatures experienced by standard commercial wok ranges. Hot sheet metal not only puts the appliance under great thermal stress, but also puts the operator in danger of burns. Wok ranges use tap water to cool and then run the water directly to the drain. Figure 82 shows waste water from a wok range at one of the field sites examined in the field study. While manufacturers are working towards using passive cooling techniques, a majority of wok ranges still require active running water to cool the range surfaces. While the in-lab testing showed that 2.5 gal/min are consumed for cooling with this appliance, the Alliance for Water Efficiency estimates that wok ranges typically use water at the rate of one gallon per minute during operation. The figure of one gal/min will be used as the benchmark water use for the purpose of this study when applicable.

**Figure 82: Wok Range Waste Water**

Source: GTI

#### *5.4.2.2 Advanced Wok Range*

Advanced Wok Range Energy Use

The ASTM 1991-99 test method was applied to the advanced wok range with both the traditional wok pan and the Turbo Wok pan. Table 26 displays the results. The advanced technology range brings the efficiency up to nearly 23 percent efficiency with a traditional (round bottom) wok pan and up to nearly 35 percent with the prototype Turbo Wok pan. Production capacity of the advanced technology range, or the amount of product cooked in one hour, is comparable to the production capacity of a traditional 75,000 Btu burner, while consuming significantly less energy. This production capacity was greatly enhanced with the addition of the Turbo Wok pan with the advanced technology range.

**Table 26: ASTM Test Results for Royal Wok Pan Prototype**

| | Traditional Wok Pan | Turbo Wok Pan |
|---|---|---|
| Measured Energy Input Rate (Btu) | 52,767 | 52,767 |
| ASTM Heatup-energy Efficiency (%) | 22.79 | 34.77 |
| ASTM Production Capacity (lb/h) | 79.00 | 122.35 |
| Pilot Energy Rate (Btu/h) | 0 | 0 |

Source: FNi

Advanced Wok Range Water Use

The advanced wok model does not use water during operation. Water-free units offer substantial utility savings. However, the unit must be verified to be both safe and structurally sound at operating temperatures. A study of this technology previously conducted by GTI, *Wok Burner Improvements and Testing* (GTI Project No. 20574) ascertained that the chef experienced less heat during cooking with this model. The chef also noted that the design cooked slightly better with the improved concentration of heat at the bottom of the wok pan. These qualities indicated that more heat was absorbed by the food and wok pan than the range itself. Future studies monitoring the temperature of the sheet metal on the prototype structure will be useful in demonstrating that the equipment is maintained at sustainable and safe temperature during operation.

## 5.5 Field Testing

### 5.5.1 Field Test Plan

#### *5.5.1.1 Site Monitoring Instrumentation and Procedures*

The instrumentation package used for field testing of the wok ranges included a diaphragm-type positive displacement gas meter with a one pulse/ft$^3$ output (Figure 83). A data logger was used to log data at 30-second or one-minute intervals and to process and store cumulative gas consumption from the meter's pulse outputs.

**Figure 83: Diaphragm Gas Meter Connected to Data Logger**

Photo Credit: FNi

Wok range operating hours were determined by calculating an hourly input rate using a ten-minute moving average. Anything higher than the pilot moving average (10 kBtu/h) was considered hours the appliance was in operation.

Cubic feet of gas consumption were converted into Btu using a heating value of 1,025 Btu/ft$^3$, a temperature correction factor of 0.98, and a pressure correction factor of 0.98. The full-service restaurant monitored by FSTC utilized one gas meter to measure gas flow from both the baseline and prototype wok range models.

#### *5.5.1.2 Site Selection*

The sites selected for the field study cover the range of service styles found in Asian restaurants. Both restaurants serve lunch and dinner and have menus featuring common American-Eastern dishes.

**Safeway**

Safeway operates a buffet-style food line for Chinese take-out. Located in the deli/hot food section of the San Ramon Safeway is their "China Express," a takeout buffet where the food is prepared in batches and held in steam tables. The menu rarely changes and offers popular American Chinese cuisine such as sweet-and-sour pork and chicken chow mein. Most of their offerings are prepared in the two-burner natural gas wok range featured in Figure 84 and held to temperature. The cooking is conducted in batches to stock the steam table which holds the food at temperature. Located inside of a grocery store, this quick-service eatery experiences peak traffic during the lunch and dinner hours. Most of the cooking is performed shortly before these peak times.

Safeway's storefront is depicted in Figure 85 (left).

**Figure 84: Safeway Wok Range**

Photo Credit: FNi

**Yiping**

Yiping is an upscale Chinese restaurant located in San Ramon that uses traditional Chinese cooking methods along with locally sourced organic ingredients. The atmosphere is that of a casual dining experience, with a diverse menu that exemplifies authentic Chinese cuisine. A typical meal here has several courses, served family style, and the majority of the menu is prepared using their two-burner wok range. Unlike Safeway, Yiping uses a "cook-to-order" style, where individual dishes are prepared upon requests from the customer. Peak traffic occurs during the business lunch rush and dinner.

Yiping's storefront is depicted in Figure 85 (right).

**Figure 85: Field Study Test Sites**

Photo Credit: FNi

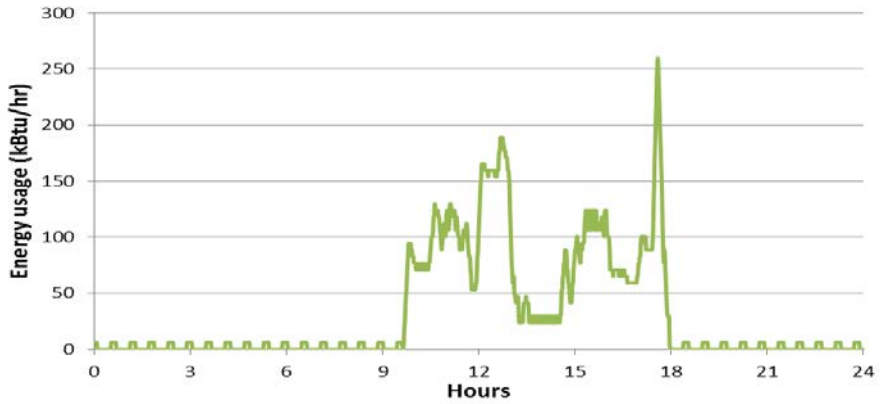
## 5.5.2 Field Test Results

### *5.5.2.1 Safeway*

Figure 86 shows a typical energy use profile over a day. The burners are turned on and sustained over blocks of time. This trend is indicative of batch cooking, where a large quantity

of food is cooked at the same time, then the burners are turned off. The standing pilot was typically left on overnight as well as during operating hours.

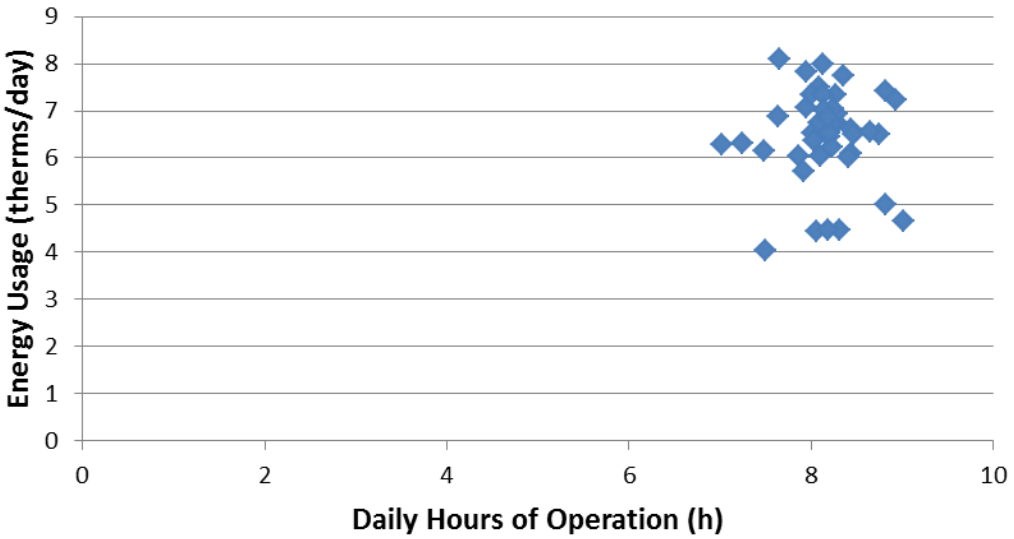
**Figure 86: Wednesday September 19, Typical Energy Profile Of Wok Range at Safeway**




Source: FNi

The wok range was monitored for a six-week period for energy use. Plotted in Figure 87, the wok range was consistently operated over long periods during the day—between 7.5 and 9 hours—and consumed between 4 and 8 therms per day. It was noticed that water was being used to cool the surfaces of the range. The water flow rate was sampled and found to be 0.97 gal/min during operation.

**Figure 87: Safeway Wok Energy Use and Hours of Operation**




Source: FNi

A comparison can be drawn between the standard wok range currently used in Safeway and the prototype wok range tested under laboratory conditions. Assigning the standard efficiency to the Safeway range and extrapolating using data gathered under ASTM test method F1991-99, it can be inferred that the wok range prototype would significantly reduce the water and energy

usage while cooking the same amount of food. Table 27 shows the estimated savings that could be achieved using the advanced technology wok range.

**Table 27: Projected Savings with Energy-efficient Two-Burner Wok Range at Safeway**

| | Current Wok Range | Prototype Wok Range with Standard Wok Pan | Prototype Wok Range with Turbo Wok Pan |
|---|---|---|---|
| Energy Use (Therms/day) | 6.71 | 3.83 | 2.51 |
| Water Use (gal/day) | 497.61 | 0.00 | 0.00 |
| Annual Energy Cost ($)* | 2,449 | 1,397 | 917 |
| Annual Water Cost ($)† | 2,428 | 0 | 0 |
| **Total Utility Cost ($)** | **4,877** | **1,397** | **917** |

Source: FNi

* Based on estimate of $1.00 per therm for PG&E service territory.

†Based on $10.00/CCFHCF average water and sewer costs for Bay Area.

### *5.5.2.2 Yiping*

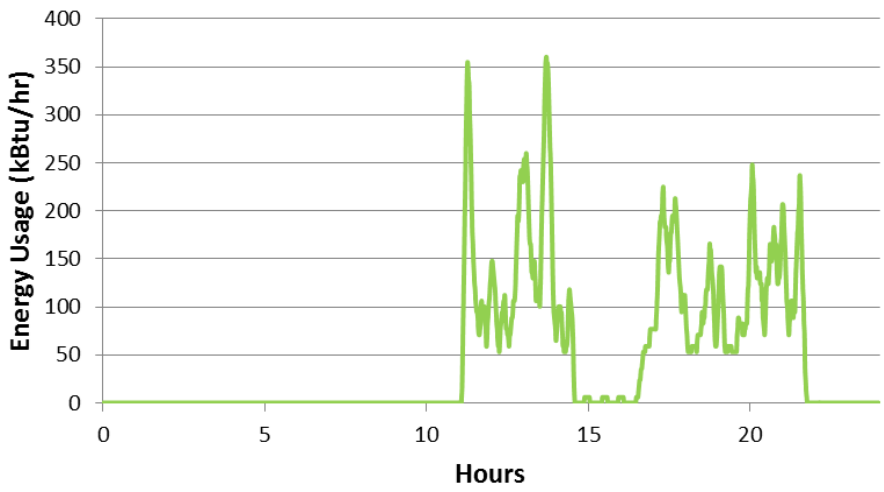
Yiping's wok range is shown in Figure 88. The range is operated on a cook-to-order basis, meaning that some or all of the burners were constantly being turned on and off, depending on the orders coming in. This behavior is represented in the energy usage profile sample in Figure 89. Over the course of a day, the wok range was operated for an average of 8 hours per day to serve the lunch and dinner meals.

The double-burner wok range was monitored for nine weeks for energy use. The data collected on energy use, time, and energy is displayed in Figure 90. The wok range is typically operated between seven and nine hours each day and consumed between 6.5 and 13 therms. The average energy use was approximately 10 therms/day. Unlike Safeway, the energy consumption showed a much stronger relationship to the hours of use.

**Figure 88: Yiping Wok Range**

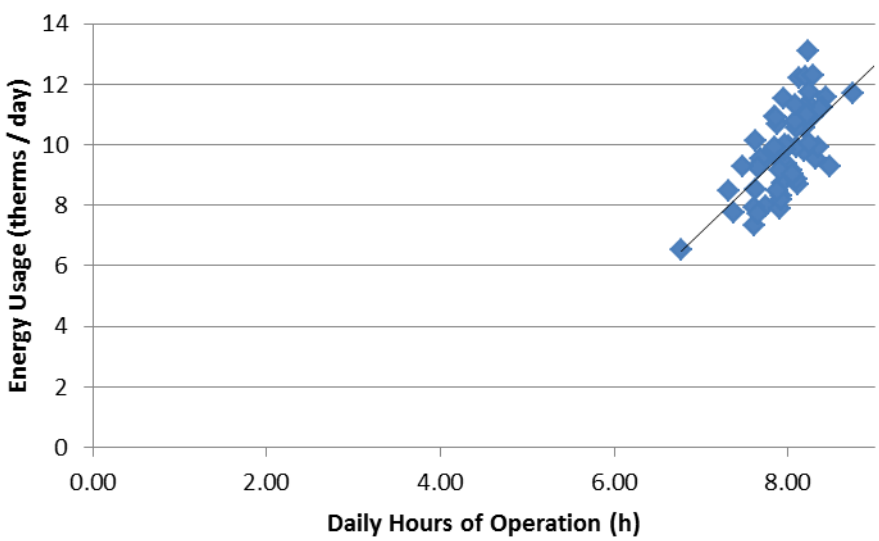
Photo Credit: FNi

**Figure 89: Wednesday February 22, Typical Energy Profile Of Wok Range at Yiping**




Source: FNi

**Figure 90: Yiping Wok Range Energy Use and Hours of Operation**




Source: FNi

Substituting an energy-efficient wok range for the current technology was projected to yield significant energy and water savings in a cook-to-order environment. For Yiping, replacing the two burners with the prototype technology developed in this study was expected to save an estimated 175,200 gallons of water and 2,259 therms annually when using the Turbo Wok pan. Table 28 shows the anticipated utility and cost savings to the end user.

**Table 28: Projected Savings with Energy-efficient Two-Burner Wok Range at Yiping**

| | Current Wok Range | Prototype Wok Range with Standard Wok Pan | Prototype Wok Range with Turbo Wok Pan |
|---|---|---|---|
| Energy Use (therms/day) | 9.89 | 5.64 | 3.70 |
| Water Use (gal/day) | 480.00 | 0.00 | 0.00 |
| Annual Energy Cost ($)* | 3,610 | 2,059 | 1,350 |
| Annual Water Cost ($)† | 2,342 | 0.00 | 0.00 |
| **Total Utility Cost ($)** | **5,952** | **2,059** | **1,350** |

Source: FNi

* Based on estimate of $1.00 per therm for PG&E service territory.

†Based on$10.00/CCFHCF average water and sewer costs for the San Francisco Bay Area.

### 5.5.3 Results and Discussion

The benefits of the technology developed in this study are increased cooking efficiency, eliminating the need for water cooling, and providing quality food at the necessary production rate. Under laboratory conditions, the wok range prototype demonstrated all of these benefits. Table 29 compares the ASTM F1991-99 test method performance metrics for the baseline and prototype wok ranges. Using less than half of the energy, the wok prototype effectively transfers more heat to the cooking product, increasing the efficiency and eliminating the need for cooling water. Even with these savings, the prototype still achieves the same production capacity as the baseline wok as defined, indicating that it can maintain the same cooking rate in commercial kitchens.

**Table 29: ASTM Test Comparison of Current and Prototype Wok Ranges**

| | Current Wok Range | Prototype Wok Range |
|---|---|---|
| Measured Energy Input Rate (Btu) | 120,767 | 52,767 |
| ASTM Heatup Energy Efficiency (%) | 13.00 | 34.77 |
| ASTM Production Capacity (lb/h) | 121.54 | 122.35 |
| Pilot Energy Rate (Btu/h) | 1,613 | 0 |

Source: FNi

The energy and water usage profiles explored in the field study can achieve significant utility savings with new technologies. As of now, both sites studied are spending approximately $5000 on water and energy for the wok alone. Based on the quality, production capacity, and energy efficiency determined at the Foodservice Technology Center, these establishments can expect comparable food quality, less energy input, and the complete elimination of water cooling. Given the potential gains of the prototype, a feasibility study should follow in order to examine the robustness of the advanced technologies in a commercial restaurant setting.

## 5.6 Conclusions and Recommendations

### 5.6.1 Conclusions

Wok ranges are essential to cooking eastern dishes and are found commonly in Asian food establishments. According to a 2010 FSTC study *Characterizing the Energy Efficiency Potential of Gas-fired Commercial Foodservice Equipment* , an estimated 38,987 wok range burners currently in California currently experience an efficiency of 10 – 15 percent. In addition, each burner well uses an average of one gallon per minute of water to cool the surfaces of the appliance, resulting in an estimated 85 million gallons per year in California. The estimated energy load in California for this appliance alone is 30 million therms.

The wok range prototype examined in this study demonstrates the potential to significantly reduce water and natural gas usage in commercial foodservice establishments. With a redesigned burner, burner well, and wok pan, the 20 percent energy savings target was surpassed to achieve an efficiency of 35 percent with the use of the Turbo Wok pan, an increase over baseline efficiency of approximately 75 percent. In addition, the wok range prototype eliminated the need for cooling water.

The field sites in this study paid an average of $5,457 per year to provide natural gas and water to the appliance. With the implementation of the prototype wok, these establishments could save approximately 79 percent on their utility bill in energy and water combined, with an average of 55 percent of the savings being attributed to the absence of a water inlet. The substantial savings potential for the wok range makes it a strong candidate for further improvements, feasibility studies, and market validation tests.

With the improved burner and well design, the elimination of the need for water cooling and a standing pilot light, and the use of the Eneron "Turbo Wok" pan, the wok range was able to garner a reduction of energy use of 63 percent. Based on previous estimates, a typical wok range in California will use 769 therms per year. Through the use of the prototype wok and pan has the potential to reduce this use by 484 therms. Based on previous estimates this translates to a savings of $339 per year, yielding a payback period between 1.5 and 3 years.

Provided the in-lab efficiency can be translated to commercial foodservice industry, California stands to reduce its natural gas use dedicated to wok ranges by 19 million therms per year assuming 100 percent market penetration. Also by assuming 100 percent market penetration, the need for water to cool the surfaces can be completely eliminated, saving California an estimated 85 million gallons per year. Respectively, California would save approximately 13.3 million dollars in natural gas and 1.14 million dollars in water consumption yielding a total savings of approximately 14.4 million dollars. In order for this technology transfer to occur, the unit must be optimized for safety, robustness and scalability by manufacturers. The utility and cost savings can then be assessed in the field, where restaurant operators will also have the opportunity to embrace the new technology.

### 5.6.2 Recommendations

In order for California to realize the maximum natural gas savings potential, the technology in this study must be made robust enough for commercial kitchen cooking and scalable for mass

production. Although quantitative data has been collected on the prototype performance in the lab, working prototypes need to be developed and placed in various foodservice operations to assess the strength of the design, as well as the quality and consistency of the food product.

While the prototype is currently operated without water, the temperature of the range needs to be assessed for the next generation prototype. If the temperatures are too high, the operator is in danger of burns and the equipment more prone to failure. A thorough assessment of the heat transfer should be determined during the development of the next generation prototype.

Future field studies should monitor input energy, water use, cook time, as well as the exact amount and type of cooking product that is used. Working with chain restaurants in this way will have the greatest impact towards gaining widespread acceptance of the new technology. In addition, the data collected in the field will substantiate the aforementioned savings claims to restaurant owners and the state of California.

# CHAPTER 6:
# Under-Fired Broilers

## 6.1 Summary

### 6.1.1 Introduction

The annual energy cost of operating an under-fired broiler can often exceed the purchase price of the equipment. As such, the commercial under-fired broiler is one of the most energy-intensive appliances in the kitchen. These appliances typically operate close to their peak energy input rate, regardless of whether or not they are cooking. The high operating temperatures place a tremendous load on HVAC systems, requiring high exhaust flow rates and introducing a significant amount of heat into the surrounding kitchen space. The benefit to an operator is the signature taste, aroma and appearance that cannot be achieved through other cooking processes. The characteristic charred quality of the food leads to a widespread use throughout the foodservice industry. Since under-fired broilers have continued to employ the same basic design for over 30 years, there is a clear opportunity to provide significant energy savings through improved broiler design and controls.

### 6.1.2 Purpose

The purpose of this report was to identify new technologies that could improve under-fired broiler energy-efficiency and performance. The goal was to determine energy-efficiency gain and gas energy savings when using advanced equipment.

### 6.1.3 Project Objectives

The objectives of the commercial gas under-fired broiler study were to:

- Characterize the energy inefficiencies of standard under-fired broiler technologies through laboratory and field data collection.
- Design and develop a new prototype for a commercial foodservice broiler which is robust and able to achieve at least 17 percent energy savings over traditional broiler technology.
- Compare standard and energy-efficient lidded thermostatically-controlled broilers in energy use in both idle and cooking laboratory conditions.
- Examine restaurant broiler energy usage with a standard and lidded broiler at several different field monitoring locations.
- Provide recommendations that will continue to advance under-fired broiler efficiency while transforming the market for this appliance category.

### 6.1.4 Project Outcomes

The conventional under-fired broiler's design has not changed much in the past 30 years. Broilers have an input rating of about 15,000 Btu/h per burner and typically two burners per foot of grate width with as much as 500-2,500 Btu/h for the standing pilot alone. The heavy-load cooking energy-efficiency range for a conventional under-fired broiler is 20-30 percent,

relatively low in comparison with other commercial kitchen appliances. Standard under-fired broilers also are not thermostatically-controlled, display poor heating uniformity across the cooking surface, and pose a challenge to ventilation systems due to their intense thermal plumes.

Testing at the FSTC shows that idle energy rates can be reduced by adding a lid element to an under-fired broiler. Although it is not expected of the operator to have the lid down during cooking operation, the closed lid would also retain radiant heat more effectively in the cooking zone, improve ventilation hood performance, and increase production capacity (faster cook times). With future generations of lidded broilers, it is conceivable that the operator would do some cooking with the lid down, improving heat transfer to food product and consequently lowering the cooking energy rate. Improved burner design could also help with under-fired broiler energy-efficiency gain. The FSTC has tested broilers equipped with infrared (IR) burners, which has shown cooking-energy efficiency gains between 37 percent and 53 percent over standard broilers equipped with atmospheric burners. Heat distribution is also much improved with the use of IR burners.

The prototype advanced under-fired broiler referenced in this report featured a lid, thermostatic control, and ceramic infrared burners. FSTC researchers tested the prototype in laboratory conditions by applying the American Society for Testing & Materials F1695 *Standard Test Method for Performance of Underfired Broilers*. The energy input rate was measured at 88,500 Btu/h. The temperature uniformity test with steel discs resulted in only a 160°F temperature differential as opposed to a more than 200°F differential for standard-efficiency broilers. With the lid up, the broiler preheated in 16.2 min while consuming 25,600 Btu. With the lid down, the broiler preheated in 12.0 min while consuming 19,180 Btu. During the cooking-energy efficiency tests with ⅓-lb hamburger patties, the prototype displayed an energy-efficiency of 44.7 ± 0.7 percent, a production capacity of 62.7 ± 0.6 lbs/h, and a cooking energy rate of 60,830 Btu/h with the lid up. With the lid down, the energy efficiency was 52.9 ± 1.3 percent, the production capacity was 69.5 ± 0.1, and the cooking energy rate was 57,570 Btu/h. The idle rate tests yielded 65,110 Btu/h with the lid up and 53,860 Btu/h with the lid down. The pilot energy rate was measured to be 2,960 Btu/h.

The FSTC has determined that the advanced broiler designs had an average cooking-energy efficiency of 43.5 percent versus standard designs at 30.3 percent, a relative 43 percent efficiency improvement.

Four restaurants were selected for standard broiler monitoring. After the baseline daily energy usage and appliance hours of operation were measured, the old standard broilers were replaced with lidded thermostatically-controlled broilers of the same size. Each restaurant represented a different cooking operation: cook-to-order, batch-cooking, cafeteria-style. The results from the field monitoring of both standard and advanced broilers at these restaurants are presented in Table 30 below.

**Table 30: Lidded Broiler Replacement Energy Impacts at Monitored Restaurant Locations**

| Location | Operation | Hours Broiler is On, Pre – Post (h) | Un-lidded Broiler Daily Energy Consumption (therms) | Lidded Broiler Daily Energy Consumption (therms) | Energy Savings |
|---|---|---|---|---|---|
| Prather Ranch | Cook-to-order | 10.2 – 10.1 | 7.48 | 6.09 | 19 % |
| High Tech Burrito | High Batch Cooking, no idle | 6.2 – 6.7 | 3.49 | 3.59 | None* |
| SRVCC Cafeteria | Batch Cooking, long idle | 13.4 – 13.1 | 11.57 | 8.48 | 26 % |
| Norm's Place | Cook-to-order | 12.8 | 9.48 | 7.27 (projected) | 23.3% (projected) |

*The lid was not used as food was batch-cooked in a continuous manner for relatively short periods of time with little to no periods of idle operation.
Source: FNi

### 6.1.5 Conclusions

The cooking-energy efficiency and overall performance of gas under-fired broilers can be increased through the adoption and implementation of new technologies including, but not limited to, the use of a broiler lid, infrared burners, and thermostatic controls. Cooking with the lid down has the potential to almost double the cooking efficiency, but the restaurant operator is not necessarily expected to cook with the lid down. However, the biggest energy savings potential for the lidded under-fired broiler is in the reduced idle rates when the lid is down and the thermostat engaged. The overall approach is anticipated to add approximately 10 - 15 percent to the initial cost of the equipment.

The potential gas energy savings upon upgrading to a lidded, thermostatically-controlled broiler was 23 percent averaged across two of the restaurant locations. The cafeteria-style restaurant experienced the most energy savings due to the broiler idling for long periods with the lid down. The batch-cooking restaurant did not see energy savings due to continuous cooking on the broiler and the operator not using the lid. The operating time was relatively short in comparison to the other sites and once cooking ceased, the broiler was simply turned off. As such, certain restaurant sites will benefit more than others from the use of lidded, thermostatically-controlled broilers.

### 6.1.6 Recommendations

Further field monitoring of lidded, thermostatically-controlled under-fired broilers is needed to adequately qualify the treatment of broiler lids by operators in the field. Education and training of kitchen staff on the optimal operation of lidded, thermostatically-controlled broilers is integral to maximum energy savings.

Refinement of the lidded broiler is needed before there will be widespread market adoption. Restaurant operators commented that the lid was too heavy and that the risk of burning oneself became a factor. A lid handle extension could possibly alleviate some of these issues. Often only a small portion of the broiler surface was being used in the field to cook food product, while the rest of the surface expended wasteful energy and heat. A split broiler lid should also be considered. Automatic pilot ignition systems, better lid insulation, and the use of demand response ventilation systems with the lidded broiler are all possible energy-saving enhancements. A two-stage gas value controlled by lid position may be an alternative to the thermostat and should be researched.

Overall, there is great potential savings with the lidded broiler, especially in restaurants that leave their units idling for long periods. For large scale market adoption, the lidded broiler concept will need to be refined and promoted by the manufacturers. Once the industry and the end-users become aware of the large potential savings of the lidded broiler, more manufacturers will begin adopting and improving the technology.

### 6.1.7 Benefits to California

In the 2010 PIER study, *Characterizing the Energy Efficiency Potential of Gas-fired Commercial Foodservice Equipment*, the FSTC estimated that roughly 42,000 under-fired broilers were in operation in California commercial kitchens. With most under-fired broilers operating at a baseline efficiency of approximately 30 percent, the estimated annual natural gas use was 122 million therms in California. Based on this FSTC study in the four restaurants, average daily energy usage of the standard broiler is 8.0 therms. The three out of four of the sites selected for this project used 9.5 therms per day and were good candidates for replacement with a lidded broiler (being used more than 8 hours a day). If 50 percent of the broilers in California were selectively switched to advanced lidded broilers based on their hours of idle operation, this could result in 23 percent savings. Twenty-three percent savings from well-selected sites with 21,000 standard-efficiency broilers averaging 9.5 therms per day and operating 364 days per year could result in an annual savings of 16.7 million therms. Monetarily speaking, savings on natural gas would total to an estimated 11.7 million dollars annually.

California foodservice operators stand to benefit the most from the adoption of lidded, infrared, and thermostatically-controlled broiler technology. Reducing the notoriously high gas use of the (until recently) antiquated technology of the under-fired broiler through embracing these new technologies will improve foodservice operations, reduce utility bills, and reduce carbon emissions.

## 6.2 Introduction

### 6.2.1 Background

Broiling is cooking by exposing food to direct radiant heat, either on a grill over a burner (under-fired) or below a gas burner (over-fired). Under-fired broiling differs from roasting and baking in that the food is turned during the process so as to cook one side at a time. Temperatures are higher for broiling than for roasting. Most commercial appliances broil between 600°F (315°C) and 1,000°F (540°C). All broilers use a “grid”, which is the grill or grate

on which the food is placed for cooking. In most types of broilers, the grid is hot enough to sear a pattern onto the product; this is the most visually identifiable characteristic of broiling. The benefit to an operator is the signature taste, aroma and appearance that cannot be achieved through other cooking processes. The charred quality of the food leads to widespread use throughout the foodservice industry.

The commercial under-fired broiler is one of the most energy-intensive appliances in the kitchen. The under-fired broiler, with the combination of high input rates, long operating hours, and low efficiency, makes it one of the most expensive appliances to operate in a commercial kitchen. Broilers are one of the few appliances in the commercial kitchen where the annual energy cost can exceed the purchase price of the equipment. These appliances typically operate at close to their peak energy input rate—regardless of whether or not they are cooking. The high operating temperatures place a tremendous load on HVAC systems, requiring high exhaust flow rates and introducing a significant amount of radiant heat into the surrounding kitchen space. Since under-fired broilers have continued to employ the same basic design for over 30 years, there is an opportunity to provide significant energy savings through better broiler design and controls.

### 6.2.2 Objectives

The objective of this field study was to introduce and study new technologies that could decrease energy use of the conventional under-fired broiler. The goal was to determine energy-efficiency gain when using advanced equipment. This gain was demonstrated through the following measures:

- Characterizing the inefficiencies of standard under-fired broiler technologies by collecting laboratory and field data.
- Designing and developing a new prototype for a commercial foodservice broiler that is robust and able to achieve at least 17 percent energy savings over traditional broiler technology.
- Comparing standard and energy-efficient lidded thermostatically-controlled broilers in energy use under both idle and cooking laboratory conditions.
- Examine restaurant broiler energy usage with a standard and lidded broiler at several different field monitoring locations.
- Recommend future improvements to further under-fired broiler efficiency.

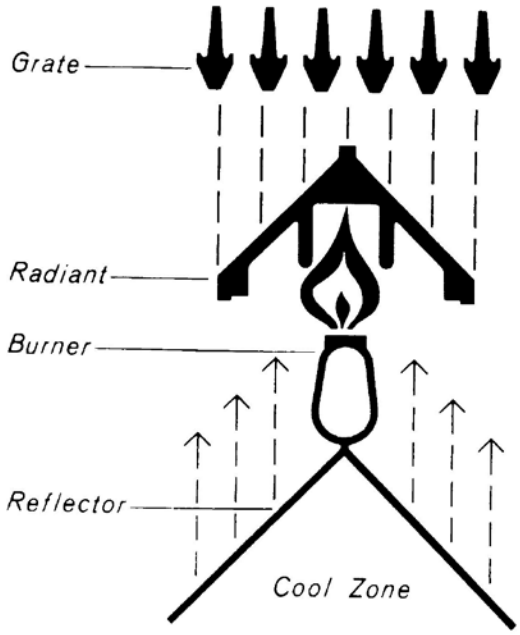
## 6.3 Technology

### 6.3.1 Standard Technology

Under-fired broiler design is relatively simple. The technology typically incorporates high-input atmospheric gas burners, using either metal shields or ceramic briquettes to diffuse their heat (see Figure 91). A heavy-duty grate, which maintains a surface temperature of 600°F (315°C) or more, is used to cook the food product. Under-fired gas broilers typically use two burners per foot of grate width, rated at 15,000 Btu/h per burner or more. This translates to an energy input of at least 90,000 Btu/h for a three-foot broiler. Virtually all commercial broilers employ

continuous standing pilots to light the burners. Standard under-fired broilers use one standing pilot for every two burners, or one pilot per linear foot. A typical three-foot under-fired broiler containing three standing pilot lights may consume between 1,500 and 3,500 Btu/h for the pilots alone.

**Figure 91: Under-Fired Broiler Heater Source**




Source: Vulcan-Hart Company

Broilers do not yet offer temperature feedback to the operator, often leading to arbitrary adjustment of the burners and over-firing the appliance (hotter than necessary operating temperatures). Any unnecessary increase in broiler temperature translates to increased appliance energy load, increased HVAC load due to additional heat gain to the surrounding space, and (in most cases) increased operator discomfort.

#### *6.3.1.1 Ventilation Considerations*

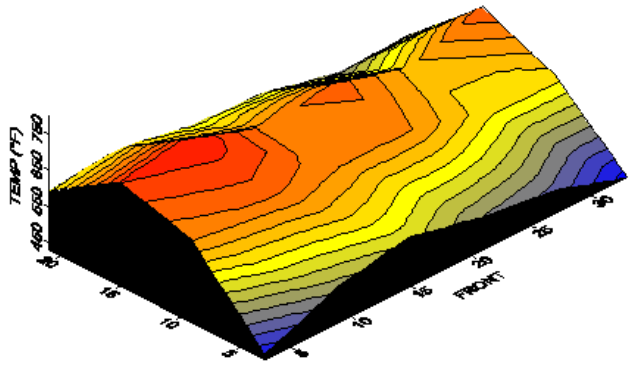
Under-fired broilers present a challenge for kitchen ventilation due to the nature of their particulate emissions and extreme thermal plumes. Even within a diverse cook line, an under-fired broiler will drive the ventilation requirements for acceptable capture and containment of cooking effluent. An inherent characteristic of under-fired broilers is the fact that even during non-cooking periods, the thermal plume generated can challenge a hood's ability to capture and contain the effluent—almost as severely as when the broiler is cooking food product under fully-loaded conditions. While other types of appliances offer opportunities to reduce ventilation rates during non-cooking periods, under-fired broilers are not as amenable. The FSTC Commercial Kitchen Ventilation lab has reported that the minimum capture and containment rates for an under-fired broiler are 480 cfm/ft (linear foot of the kitchen hood) while cooking, and 360 cfm/ft while idling beneath a five-foot wall canopy hood.

#### *6.3.1.2 Energy and Temperature Performance*

Understanding the energy performance of standard broilers involves the discussion of several key topics—including operating and idle energy rates, preheating, and temperature uniformity. Since broilers are not thermostatically controlled and manufacturers have established input rates based on peak production (i.e., high broiling temperatures that minimize cook time), they typically consume energy throughout the day at a rate that is close to their maximum input. Unlike other appliances that consume less energy to maintain a set temperature once the food load is removed, the end of a broiler cooking event does not automatically return the broiler to an idle (non-cooking) state. Furthermore, because it is partially concealed beneath the grid and/or coals, the visibility of a broiler's flame does not remind the operator to turn the broiler off between loads.

Many standard under-fired broilers show a substantial temperature drop towards the front of the cooking zone. They commonly exhibit a difference of 200°F (93°C) or more between the hot spot in the center and the cold spot along the edges of the cooking grate (Figure 92). In practice, this temperature difference can be used to the operator's advantage. An experienced cook will place more delicate items such as chicken or shrimp on the cooler areas of the broiler, and use the hottest spots for heavier items, such as steaks or chops. However, this large temperature variation can be a disadvantage for operations that use a broiler for batch cooking, where larger quantities of uniform food products are being prepared in a short amount of time.

**Figure 92: Temperature Uniformity Plot for Three-foot Wide Standard Under-Fired Broiler**




Source: FNi

### 6.3.2 Advanced Technology

#### *6.3.2.1 Lidded Broiler Design*

FSTC studies performed on conveyor broilers and under-fired broilers suggested that the addition of a lid into the design of an under-fired broiler would improve overall appliance efficiency, while simultaneously improving kitchen ventilation system efficiency, operator comfort, and satisfaction. There are many appliance performance parameters that would improve with the use of a lid, including a reduced idle energy rate, faster cook times, and increased cooking-energy efficiency.

Testing at the FSTC showed that idle rates can be reduced by adding a lid element to an under-fired broiler. The closed lid would also retain radiant heat more effectively in the cooking zone of the under-fired broiler. Heat would be applied radiantly, as in a standard non-convection oven, in addition to conductively from the grill. Similar to the conveyor broiler, which has a semi enclosed cavity, production capacity would be increased and cook times reduced if cooking with the lid down. When a lid is added, the under-fired broiler would not suffer the same radiant heat losses that conveyor broilers do because the cavity would be completely enclosed. It is possible that the improved heat transfer to the food product would make it feasible to reduce the maximum energy input to the burners (by use of thermostatic controls) and still achieve the desired cooked product. In this way, a reduction in the cooking energy rate is expected.

#### *6.3.2.2 Improved Burner Design*

Simple improvements in burner design and heat shields (radiants) can also improve cooking-energy efficiency rates. Infrared (IR) burners are an advanced burner type that has been successfully applied to commercial under-fired broilers. Several manufacturers currently offer models using infrared burners. FSTC testing of these broilers as documented *Commercial Gas Under-fired Broiler Technology Overview* showed a great deal of improvement over standard atmospheric burners. These models achieved an average cooking-energy efficiency increase by 44 percent, when compared with a typical cooking-energy efficiency of 30 percent for standard-efficiency models. Another advantage of IR burners is that heat is distributed much more evenly across the heated surface.

#### *6.3.2.3 Ventilation Considerations*

Reducing the cooking energy rate is important to the overall system efficiency—not only in terms of appliance gas consumption, but also when examining the impact of the appliance on the kitchen space. A broiler that operates at a lower average cooking energy rate would radiate less heat to the kitchen space, thereby improving operator comfort and reducing the broiler's impact on the commercial kitchen exhaust system. While these side benefits could result in additional energy savings, especially in combination with demand-ventilation systems installed in the facility, the advantage may not be as tangible to the average operator without advanced ventilation systems that include variable frequency drives on the fan motors.

The prototype advanced broiler featured in this report, Figure 93, incorporates some of the advanced features described, including thermostatic control and ceramic infrared burner design. The most unique feature of this prototype was that it incorporated a lid that may be used during idle periods, and potentially during cooking.

**Figure 93: Lidded Under-Fired Broiler Prototype**

Photo Credit: FNi

## 6.4 In-lab Testing and Results

### 6.4.1 ASTM Testing of Advanced Unit

For in-lab testing, FSTC researches applied ASTM standard F1695-03: *Standard Test Method for Performance of Under-fired Broilers* when determining broiler input rate, temperature distribution, preheat duration and energy consumption, idle energy rate, cooking-energy efficiency, pilot energy rate, and electric (control) energy consumption.

#### *6.4.1.1 Input Rate Test*

The test broiler input rate was measured with all controls set to full input. The energy rate was measured at 88,500 Btu/h.

#### *6.4.1.2 Temperature Distribution*

Broiler grate temperature was measured using ¼-inch thick, 5¼-inch diameter steel disks with a thermocouple tack-welded to the center of one side. The test was conducted with 24 steel disks, as shown in Figure 94, evenly distributed across the grate. Controls were set to full input, and the lid was left open during testing. The burners did not cycle during this test. The resulting temperatures are shown in Figure 95, Figure 96 and Figure 97.

**Figure 94: Temperature Uniformity Test on a Generic Broiler**

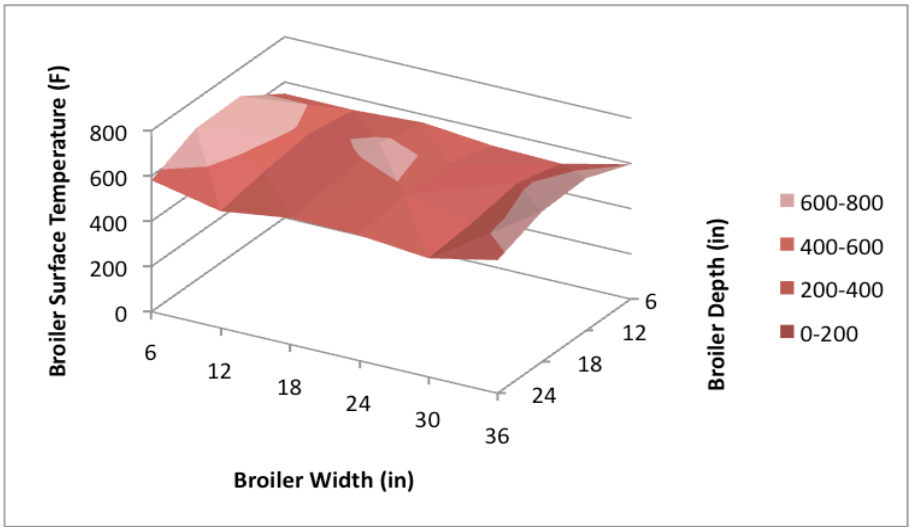
Photo Credit: FNi

**Figure 95: Temperature Uniformity for an Infrared Broiler**

| | | | | | |
|---|---|---|---|---|---|
| 581 | 516 | 558 | 554 | 524 | 588 |
| 672 | 557 | 581 | 596 | 544 | 664 |
| 676 | 583 | 612 | 591 | 579 | 673 |
| 549 | 548 | 565 | 535 | 527 | 596 |

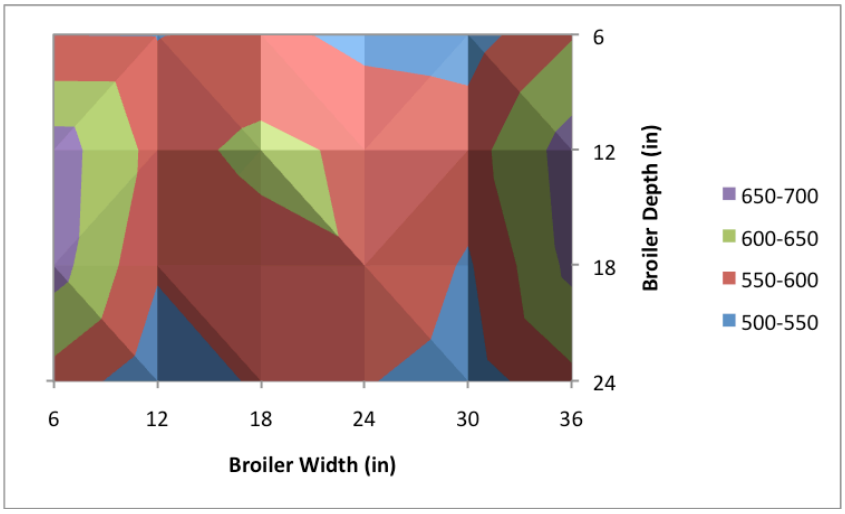
Source: FNi

**Figure 96: Detailed 3-D Temperature Uniformity for an Infrared Broiler**




Source: FNi

**Figure 97: Detailed 2-D Temperature Uniformity for an Infrared Broiler**




Source: FNi

The uniformity test resulted in only a 160°F (70°C) temperature difference between the coldest disc at 516°F (269°C) and hottest one at 676°F (358°C) after the broiler was stabilized.

#### *6.4.1.3 Preheat Test*

Using three steel disks (one per linear foot), and beginning from a standing (room temperature) start, time and energy were monitored while the broiler preheated. Preheat was judged complete when the last disk reached a temperature of 500°F (260°C). The burners did not cycle off during the lid-up or the lid-down preheat test.

With the lid up, the broiler preheated in 16.2 min, while consuming 25,600 Btu of energy. With the lid down, the broiler preheated in 12.0 min, while consuming 19,180 Btu of energy.

#### *6.4.1.4 Cooking-Energy Efficiency*

Using the steel disks, the broiler controls were adjusted so the disks were as close to 600°F (315°C) as possible. After removing the disks, the broiler was stabilized for one hour. The cooking tests used 24, ⅓-lb, 80/20 hamburger patties that were stabilized to 40°F (5°C) in a refrigerator. Hamburger patty cook time was determined to give finished patties an average final temperature of 170°F (77°C). A full test run consisted of two stabilization loads followed by three test loads with one-minute unload/scrape time between loads. This test was repeated two additional times to give three data points, and the energy efficiency was calculated according to the following (simplified) equation, Where energy efficiency is the ratio of energy added to the food and total energy supplied to the appliance during cooking:

$$Energy\ Efficiency = \frac{Energy\ Imparted\ to\ Food\ (btu)}{Energy\ Consumed\ by\ Broiler\ (btu)}$$

With the lid up and the thermostat adjusted to its maximum setting of 500°F, the cook time was 6.75 minutes. The burners occasionally cycled off for a short period when the patties were removed from the broiler. Energy efficiency was 44.7 ± 0.7 percent. The cooking energy rate was 60,830 Btu/h, and the production capacity was 62.7 ± 0.6 lb/h.

With the lid down, the cook time shortened to 6.0 minutes. The burners cycled off slightly longer than during the lid-up test—typically when the burgers were removed. Energy efficiency was 52.9 ± 1.3 percent (an increase of 8.2 percent over cooking with the lid up). The cooking energy rate was 57,570 Btu/h, and the production capacity was 69.5 ± 0.1 lb/h (cook time decreased 10.8 percent over cooking with the lid up). Burner flare ups, when cooking with the lid down, caused by the burger grease hitting the burner resulted in an artificially high temperature detected by the thermostat which then turned off the burners.

#### *6.4.1.5 Idle Energy Rate*

The broiler was monitored while unloaded at the 600°F (315°C) calibration used for the cooking tests. With the lid up and the thermostat adjusted to its maximum setting of 500°F (260°C), the idle energy rate was 65,110 Btu/h. The burners did not cycle off during this test. With the lid down, the burners cycled on and off. The lid-down idle energy rate was 53,860 Btu/h (a 17.3 percent energy rate decrease over idling with the lid up). A third test was conducted with the lid down and the thermostat set to 350°F (177°C). The energy rate for this test was 34,380 Btu/h.

#### 6.4.1.6 Pilot Energy Rate

This measured the energy consumption of the standing pilots for an eight-hour period, with all controls set to "off". During the monitoring period, the pilots consumed 2,960 Btu/h.

#### 6.4.1.7 Electric Energy Consumption

Whenever the broiler is turned on by the main on/off switch, it consumes a small, constant amount of electricity—about 4.5 Watts.

### 6.4.2 Energy Efficiency Comparison of Standard and Advanced Units

The goal of lab testing was to validate appliance performance by applying ASTM F1695. To determine the energy efficiency of under-fired broilers, the ASTM test method specifies cooking tests that use ⅓-pound hamburger patties as the food product. Table 31 lists the cooking-energy efficiencies of a series of three-foot gas under-fired broilers tested in accordance with the ASTM test method. Broilers #1 – #6 represent conventional designs and broilers #7 and #8 represent advanced (infrared burner) designs. The heavy-load cooking test was performed without a lid for the broilers with advanced burners. While most broilers can achieve substantially higher operating temperatures, all the broilers were adjusted to operate at 600°F (315°C) for the cooking tests. The advanced designs had an average cooking-energy efficiency of 43.5 percent versus standard designs at 30.3 percent. This demonstrates a relative 44 percent efficiency improvement (13.2 percent absolute).

**Table 31: Three-Foot Under-Fired Broiler Energy Performance Testing Results**

| Test Broiler | Rated Input (Btu/h) | Cooking Energy Rate (Btu/h)* | Heavy-load Cooking-Energy Efficiency (%) | Production Capacity (lb/h) |
|---|---|---|---|---|
| 1 | 120,000 | 72,500 | 32% | 57 |
| 2 | 105,000 | 78,300 | 31% | 58 |
| 3 | 105,000 | 64,400 | 28% | 46 |
| 4 | 87,000 | 57,200 | 34% | 48 |
| 5 | 105,000 | 82,400 | 29% | 58 |
| 6 | 105,000 | 83,400 | 28% | 56 |
| 7 | 105,000 | 64,600 | 41% | 66 |
| 8 | 105,000 | 54,200 | 46% | 63 |

*Cooking energy rate represents the energy consumption rate required to maintain 600°F (315°C) in the cooking zone.

Source: FNi

These cooking-energy efficiencies were determined from cooking discrete (heavy) loads of hamburger patties. However, the real-world (in kitchen) efficiency drops dramatically as the energy consumed by the broiler during periods of non-cooking (idle) is factored into the denominator of the energy efficiency equation. For example, a gas under-fired broiler used to cook 100 pounds of food over an eight-hour period consumed 600,000 Btu of energy as referenced in *Cooking Appliance Performance Report*. Based on average of 300 Btu per pound of food cooked, the total energy actually delivered to the food product over the eight-hour period would be approximately 30,000 Btu. This translates to a real-world energy utilization efficiency of only 5 percent because the rest of the time is usually spent in idle mode. It is clear that a

tremendous opportunity to improve overall appliance energy efficiency exists in developing new broiler designs and usage patterns.

Production capacity indicates the maximum amount of food (by weight) that can be cooked on a broiler in a given amount of time. Since the ASTM test method uses hamburger patties for the test product, production capacity is the weight, in pounds, of hamburger patties that can be cooked by the broiler in one hour (lb/h). This number is dependent on the size of the broiler and the length of the cook time. Table 31 shows the range in production capacities for three-foot under-fired broilers. Comparing the production capacity of advanced burner designs in Table 31(units 7 and 8) to the conventional burners (units 1-6), we see a 20 percent improvement with infrared burners, which translate to faster cook times.

In addition to reducing heat gain to the kitchen space, covering the broiler with a lid will reduce the rate that energy is consumed by the broiler while still maintaining a hot cooking grate. Testing at the FSTC has shown that, when calibrated to 600°F (315°C), an under-fired broiler will realize a reduction of over 17 percent in its idle energy consumption rate (from 65,110 Btu/h to 53,860 Btu/h) by simply covering the broiler grate with an improvised lid during non-cooking periods. The tests further showed a heat gain reduction of 27 percent (from 6,000 to 4,400 Btu/h) when the broiler was covered. An ASHRAE research paper found a conventional un-lidded broiler (one with a non-infrared burner) operating at an idle input rate of 73,900 Btu/h to have a radiant heat gain of 9,000 Btu/h (*Revised Heat Gain Rates from Typical Commercial Cooking Appliances, ASHRAE Research Project 1362*). This would result in a 51 percent heat gain reduction switching from a conventional un-lidded broiler to the IR burner prototype idling with the lid closed. Thus, a lidded broiler calibrated to 600°F (315°C) can maintain that temperature while using much less energy *and* radiating less heat to the kitchen. The reduced idle energy rate could also be used in conjunction with a demand ventilation control system to reduce the exhaust airflow during non-cooking periods, thereby increasing energy savings even further.

## 6.5 Field Testing

### 6.5.1 Field Test Plan

#### *6.5.1.1 Site Monitoring Instrumentation and Procedures*

The instrumentation package that was used for field testing of the under-fired broiler included a diaphragm-type positive displacement gas meter with a one-pulse/$ft^3$ output (Figure 98). A data logger was used to log at a one-minute interval and process and store cumulative gas consumption from the meter's pulse outputs.

**Figure 98: Field Monitoring Gas Meter Connected to a Data Logger in the Lab and in the Field**

Photos Credit: FNi

Broiler operation hours were determined by calculating an hourly input rate using a ten-minute moving average. Anything higher than the pilot moving average was considered hours that the appliance was on.

Cubic feet were converted into Btu using a representative heating value of 1,025 Btu/scf, a temperature correction factor of 0.98, and a pressure correction factor of 0.98.

#### *6.5.1.2 Field Monitoring Site Selection*

Four restaurants were selected for standard broiler monitoring. After the baseline daily energy usage and appliance hours of operation were metered, the standard broilers were replaced with lidded thermostatically-controlled broilers of the same size. Energy monitoring commenced on the replacement broilers for a given period of time. Broiler usage patterns and restaurant operation remained the same with the existing replacement broiler and the pre-existing standard broiler.

The four restaurants were selected based on their existing broiler usage patterns, each one of them representing different broiler uses.

**Prather Ranch American Eatery**

Prather Ranch American Eatery (Figure 99) is a takeout restaurant specializing in cooking locally sourced organic meats. Most of the product is cooked to order on a broiler—including burgers, sausages, steaks, and kabobs. The restaurant is located in a historical landmark building in San Francisco that has been converted into a series of shops and restaurants. The eatery is open seven days a week from 10 am to 7 pm on weekdays, 8 am to 6 pm on Saturday, and 11 am to 5 pm on Sunday. The restaurant usually has a steady stream of customers during lunch and dinner hours.

**Figure 99: Prather Ranch Meat Company in the Historical San Francisco Ferry Building**

Photo Credit: Tod Bedrosian

## High Tech Burrito

High Tech Burrito (Figure 100) is a quick-service restaurant specializing in cooking California inspired Mexican food. Most of the protein—steak, carne asada and chicken—was cooked on a broiler. This restaurant is a part of a small local chain of a dozen stores. It has a small dining room and outdoor seating area. A large portion of the orders are takeout. This particular store is located in a high-traffic strip mall in Alamo, a small town in the San Francisco Bay Area. The eatery is open seven days a week, from 10 am to 9 pm. The restaurant usually has a steady stream of customers during lunch and dinner hours serving between 250 and 300 customers daily.

**Figure 100: Restaurant Outdoor Seating Area**

Photo Credit FNi

### San Ramon Valley Conference Center

As part of the FSTC's evaluation of the advanced lidded broiler prototype, the unit was installed in the kitchen of the San Ramon Valley Conference Center (previously the PG&E production test kitchen). The cafeteria-style operation, whose outdoor seating area is pictured in Figure 101 below, serves between 100 and 300 meals per day and serves breakfast, lunch and dinner on weekdays. The menus differ every day, so different appliances are utilized each day.

**Figure 101: San Ramon Valley Conference Center Cafeteria Outdoor Dining Area**

Photo Credit: FNi

### Norm's Place

Norm's Place is a restaurant and bar specializing in cooking American pub food. Most of the product is cooked to order on a broiler. This establishment is famous for its burgers, which are ground in-house and cooked on the broiler. The restaurant is located in a historical downtown of Danville. The eatery is open Tuesday through Sunday from 11 am to 10 pm or later. The restaurant usually has a steady stream of customers during later hours of the day and is usually very busy after 5 pm. The dining room is shown in Figure 102.

**Figure 102: Norm's Place Bar and Dining Area Serving Happy Customers**

Photo Credit: Google Maps

## 6.5.2 Field Test Results

### *6.5.2.1 Prather Ranch American Eatery*

Baseline Results

Prather Ranch's kitchen consultant specified a conventional three-foot wide, open, under-fired broiler with non-thermostatic controls, which was installed before the restaurant opening. The maximum input of the broiler (shown in Figure 103) was 90 kBtu/h, with six adjustable 15 kBtu/h radiant burners. The gas metering equipment was installed on the standard broiler and monitoring commenced for several months. After several months of data were analyzed, 75 days were selected for the baseline monitoring from January through April. The standard broiler specifications are listed in Figure 104 below.

**Figure 103: Standard Broiler Installed in Prather Ranch's Newly-Built Kitchen**

Photo Credit: FNi

**Figure 104: Standard Broiler Specifications**

***Heavy Duty Radiant Broiler***

| MODEL NO. | WIDTH (A) | DEPTH (B) | NUMBER OF BURNERS * | TOTAL BTU | SHIP WEIGHT |
|---|---|---|---|---|---|
| RRB-12 | 12" | 29-3/4" | 1 | 15,000 | 170 Lbs. |
| RRB-18 | 18" | 29-3/4" | 3 | 45,000 | 235 Lbs. |
| RRB-24 | 24" | 29-3/4" | 4 | 60,000 | 300 Lbs. |
| RRB-30 | 30" | 29-3/4" | 5 | 75,000 | 340 Lbs. |
| RRB-36 | 36" | 29-3/4" | 6 | 90,000 | 383 Lbs. |
| RRB-48 | 48" | 29-3/4" | 8 | 120,000 | 460 Lbs. |
| RRB-60 | 60" | 29-3/4" | 10 | 150,000 | 510 Lbs. |
| RRB-72 | 72" | 29-3/4" | 12 | 180,000 | 670 Lbs. |

* Radiant Burner(s) @ 15,000 BTU/hr. each

***Heavy Duty Radiant Broiler***

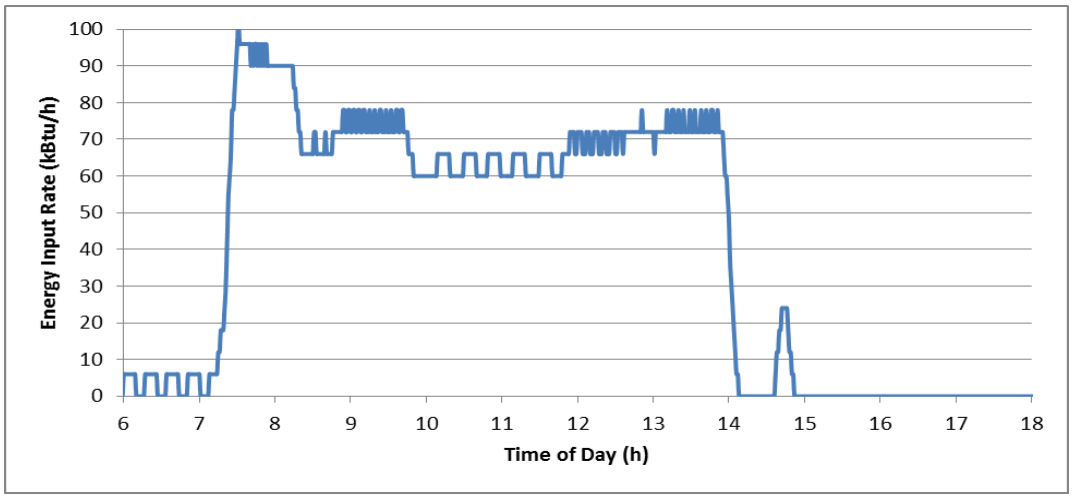
| MODEL NO. | WIDTH (A) | DEPTH (B) | NUMBER OF BURNERS * | TOTAL BTU | SHIP WEIGHT |
|---|---|---|---|---|---|
| RRB-12 | 12" | 29-3/4" | 1 | 15,000 | 170 Lbs. |
| RRB-18 | 18" | 29-3/4" | 3 | 45,000 | 235 Lbs. |
| RRB-24 | 24" | 29-3/4" | 4 | 60,000 | 300 Lbs. |
| RRB-30 | 30" | 29-3/4" | 5 | 75,000 | 340 Lbs. |
| RRB-36 | 36" | 29-3/4" | 6 | 90,000 | 383 Lbs. |
| RRB-48 | 48" | 29-3/4" | 8 | 120,000 | 460 Lbs. |
| RRB-60 | 60" | 29-3/4" | 10 | 150,000 | 510 Lbs. |
| RRB-72 | 72" | 29-3/4" | 12 | 180,000 | 670 Lbs. |

* Radiant Burner(s) @ 15,000 BTU/hr. each

Source: Royal Range of Califronia, inc.

On weekdays, the broiler was preheated around 7 am and turned off around 5 pm. The average time the broiler was on per day during the entire baseline monitoring period was 10.2 hours including weekends. Throughout the day there was minimal adjustment to the burner input rates by the user. The average input rate was 74 kBtu/h (82 percent of full input) during the restaurant's cooking hours. The broiler has a 3.5 kBtu/h standing pilot, but occasionally the staff would turn off the pilot at night. A typical weekday profile is shown in Figure 105.

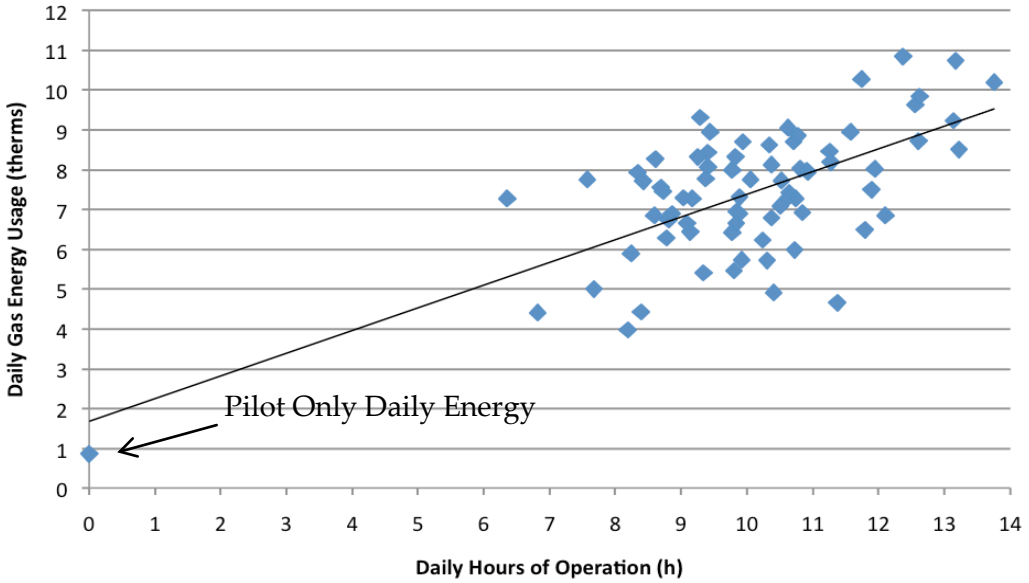
**Figure 105: Thursday January 26, Typical Standard Broiler Energy Profile at Prather Ranch**




Source: FNi

The average daily gas consumption of the standard broiler was 7.48 therms per day, averaged over 75 days of monitoring (excluding holidays). The daily energy usage ranged from 4 to 10 therms depending on the time of the week, with Friday and Saturday being the busiest days in terms of broiler operating hours. Broiler energy usage and operation hours were grouped in bin graphs shown in Figure 106 for a better understanding of day-to-day operational variation:

**Figure 106: Standard Broiler Energy Use and Hours of Operation**




Source: FNi

Replacement Results

After baseline monitoring was completed, the broiler was replaced with a lidded infrared broiler that was thermostatically controlled (shown in Figure 107). The dimensions of the replacement broiler were the same as the standard model. The lidded broiler had three adjustable 30 kBtu/h infrared burners, shown in Figure 108 with the radiant grate removed. The broiler had a user-adjustable thermostat which turned off the infrared burners once the temperature inside the lid has reached its set-point. The burners automatically engaged if the temperature dropped below this set-point.

**Figure 107: Replacement Lidded, Thermostatically-Controlled Broiler Installed on Cook Line**

Photo Credit: FNi

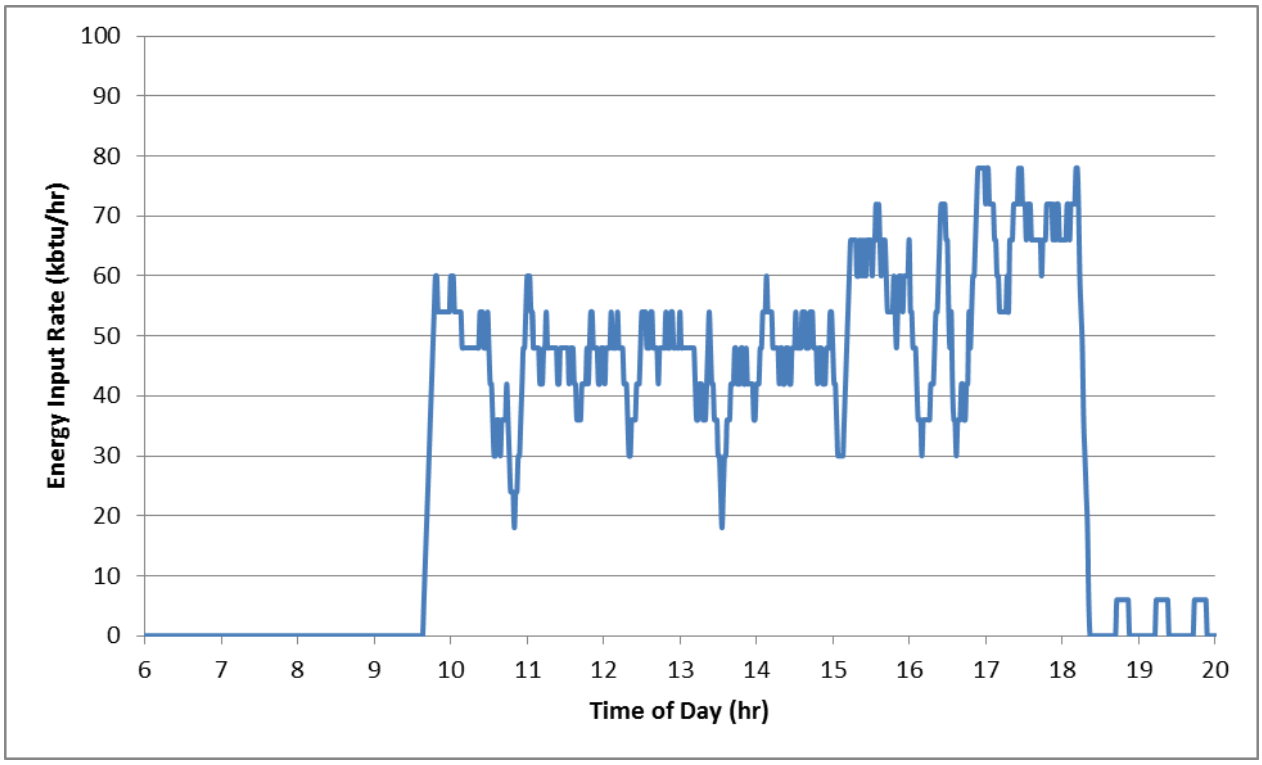
**Figure 108: Replacement Thermostatically-Controlled Broiler Infrared Burners**

Photo Credit: FNi

The kitchen staff was taught how to use the thermostatic controls and was instructed to keep the lid closed when not cooking on the broiler. All cooking was performed with the lid up. Several months of data were analyzed; 93 days were used for replacement monitoring from April through September. The average time the replacement lidded broiler was on per day during the entire monitoring period was 10.1 hours, including weekends. Throughout the day there was minimal adjustment to the burner input rates by the user, and the average input rate was 60 kBtu/h. A typical weekday profile is shown in Figure 109.

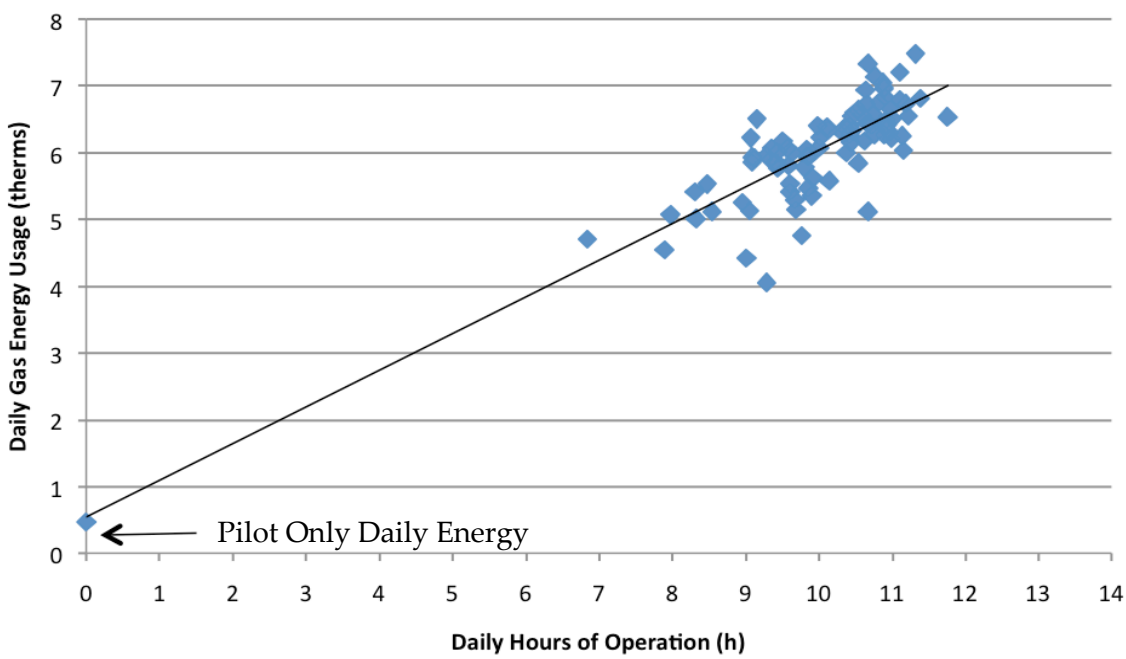
As illustrated by energy fluctuations in the plot, the broiler automatically turned its burners on and off throughout the day in response to usage of the lid. This caused the average input rate to be lower than the conventional broiler. The average daily consumption of the replacement thermostatically-controlled broiler was 6.09 therms per day, averaged over 93 days of monitoring (excluding holidays). The daily energy usage ranged from 4 to 8 therms, depending on the day of the week (Friday and Saturday being the busiest days in terms of broiler operating hours). The broiler pilot energy was 2 kBtu/h; staff sometimes turned off the pilot at night. Broiler energy use and operation hours were summarized using the scatter plots in Figure 110 to show day-to-day operational variation. Both the standard and the replacement broilers were shown to operate for the same number of hours; however the energy usage was reduced by 19 percent due to a lower average energy input rate. Closing the lid reduced the idle energy, and in a cook-to-order restaurant scenario such as this, a majority of the “on” time was spent in idle mode. The overlaid comparison graphs in Figure 111 clearly illustrate the reduced energy use when the lid was used. Figure 112 shows the regression lines taken from Figure 106and Figure 110, based on the daily operating hours and energy use.

**Figure 109: Thursday June 21, Typical Replacement Broiler Energy Profile at Prather Ranch**



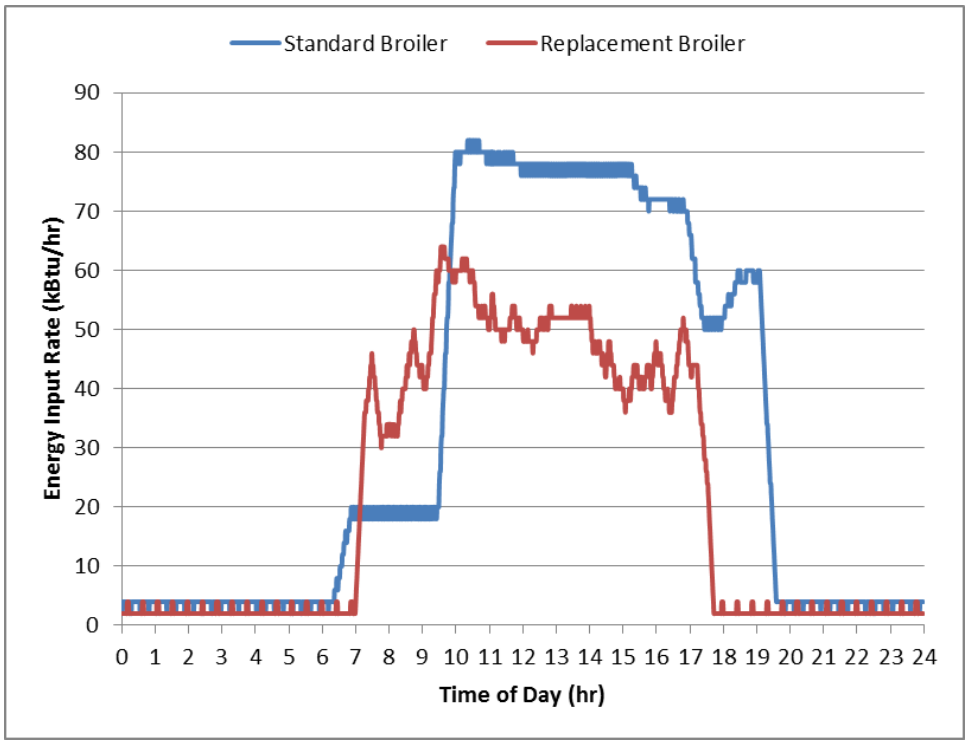

Source: FNi

**Figure 110: Replacement Broiler Energy Use and Hours of Operation**



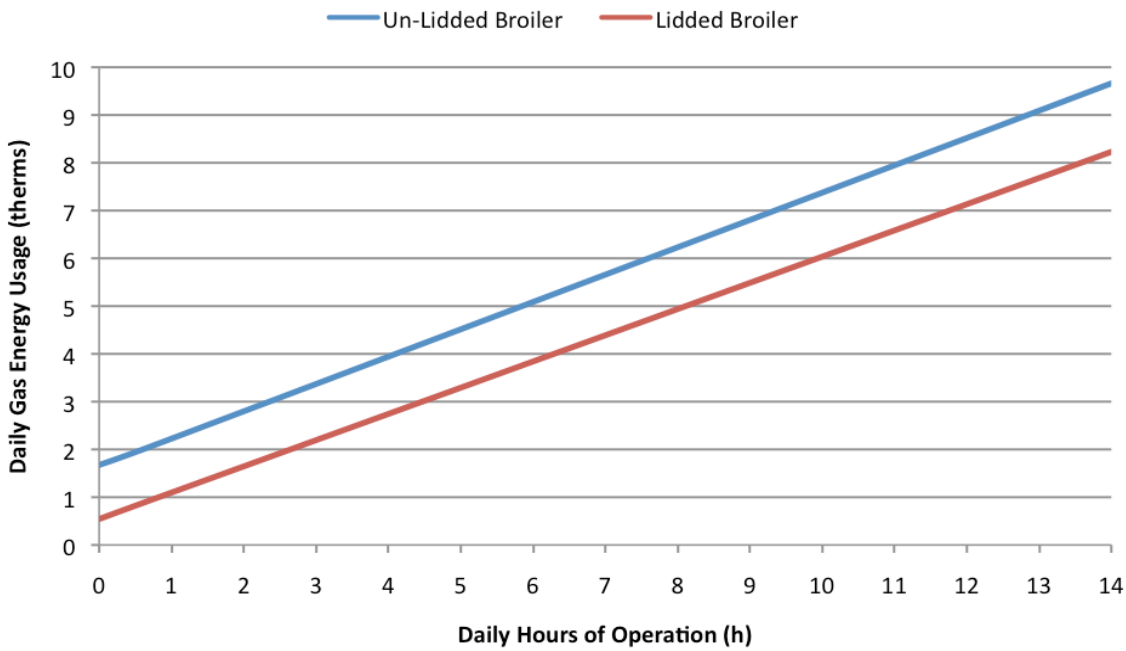

Source: FNi

**Figure 111: Standard to Replacement Broiler Energy Profile Comparison**




Source: FNi

**Figure 112: Standard to Replacement Broiler Daily Energy Regression Comparison**




Source: FNi

The slopes of both lines for the standard and replacement broiler are almost identical, meaning that the energy use is directly proportional to the hours of operation for both broiler configurations. The replacement broiler line is offset lower, showing that the daily gas energy usage was reduced by more than a therm each day regardless of the daily operating hours.

In addition to energy savings, closing the lid on the broiler improved the thermal comfort of the restaurant employees and reduced the amount of grease that entered the hood filters. After interviewing the head chef and her staff, the operating team was pleased with the improved cooking times, uniformity and reduced heat load in the kitchen. Figure 113 illustrates how operators used the replacement broiler at Prather Ranch.

**Figure 113: Operator Cooking Burger on Thermostatically-Controlled Broiler with Lid Open**

Photo Credit: FNi

### *6.5.2.2 High Tech Burrito*

Baseline Results

High Tech Burrito has been open for several years and has a mixed line of appliances. The kitchen's biggest energy consumers were the under-fired broiler and gas range. The existing broiler was at least 20 years old, according to the chain's maintenance manager. All the chain stores had the same broiler model, and the maintenance operator had replaced the broiler's burners several times. The maximum input of the broiler was 114 kBtu/h with six adjustable 19 kBtu/h standard-efficiency radiant burners. The gas metering equipment was installed on the standard broiler and the monitoring commenced for several months. After analyzing several months of data, 89 days were selected for the baseline monitoring, from August through November.

The standard broiler specifications are listed in Figure 114 below. The broiler is pictured on the line in Figure 115.

**Figure 114: Standard Broiler Specifications**

| | Specify Type of Gas: | ☐ Natural | ☐ Propane | Shipping Weight | Shipping Class | Cube (Crated) ft³/m³ |
|---|---|---|---|---|---|---|
| | Manifold Pressure: | 6.0" WC | 10.0" WC | | | |
| Models: | Burners | BTU/hr (kW) | BTU/hr (kW) | | | |
| **UF-18R** | 2 | 38,000 (11.1) | 38,000 (11.1) | 160 lbs (73 kg) | 85 | 13/.4 |
| **UF-24R** | 4 | 76,000 (22.3) | 76,000 (22.3) | 372 lbs (169 kg) | 85 | 21/.6 |
| **UF-30R** | 5 | 95,000 (27.8) | 95,000 (27.8) | 402 lbs (182 kg) | 85 | 32/.9 |
| **UF-36R** | 6 | 114,000 (33.4) | 114,000 (33.4) | 432 lbs (196 kg) | 85 | 32/.9 |
| **UF-48R** | 8 | 152,000 (44.5) | 152,000 (44.5) | 744 lbs (337 kg) | 85 | 46/1.3 |
| **UF-60R** | 10 | 190,000 (61.2) | 190,000 (61.2) | 804 lbs (364 kg) | 85 | 65/1.8 |
| **UF-72R** | 12 | 228,000 (55.7) | 228,000 (55.7) | 864 lbs (391 kg) | 85 | 65/1.8 |

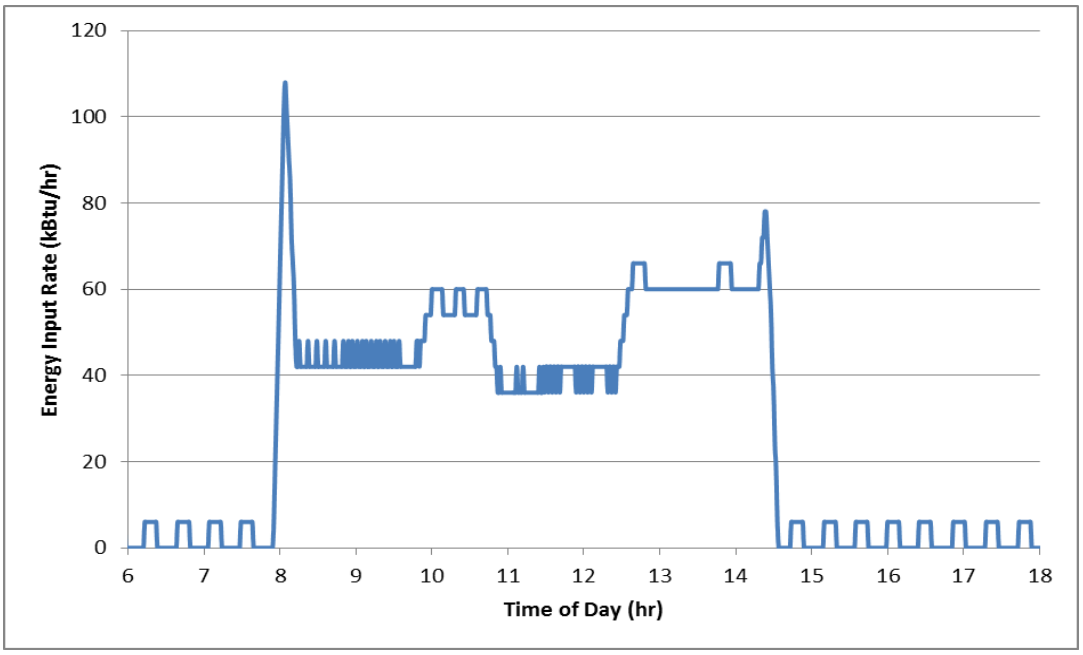
Source: Montague

**Figure 115: Standard Broiler on High Tech Burrito's Kitchen Line**

Photo Credit: FNi

On most days, the broiler was preheated around 8 am and turned off around 2 pm. The average time the broiler was on per day during the entire baseline monitoring period was 6.2 hours, including weekends. Throughout the day, there was occasional adjustment to the burner input rates by the user. The average input rate was 55 kBtu/h. A typical weekday profile is shown in Figure 116 below.

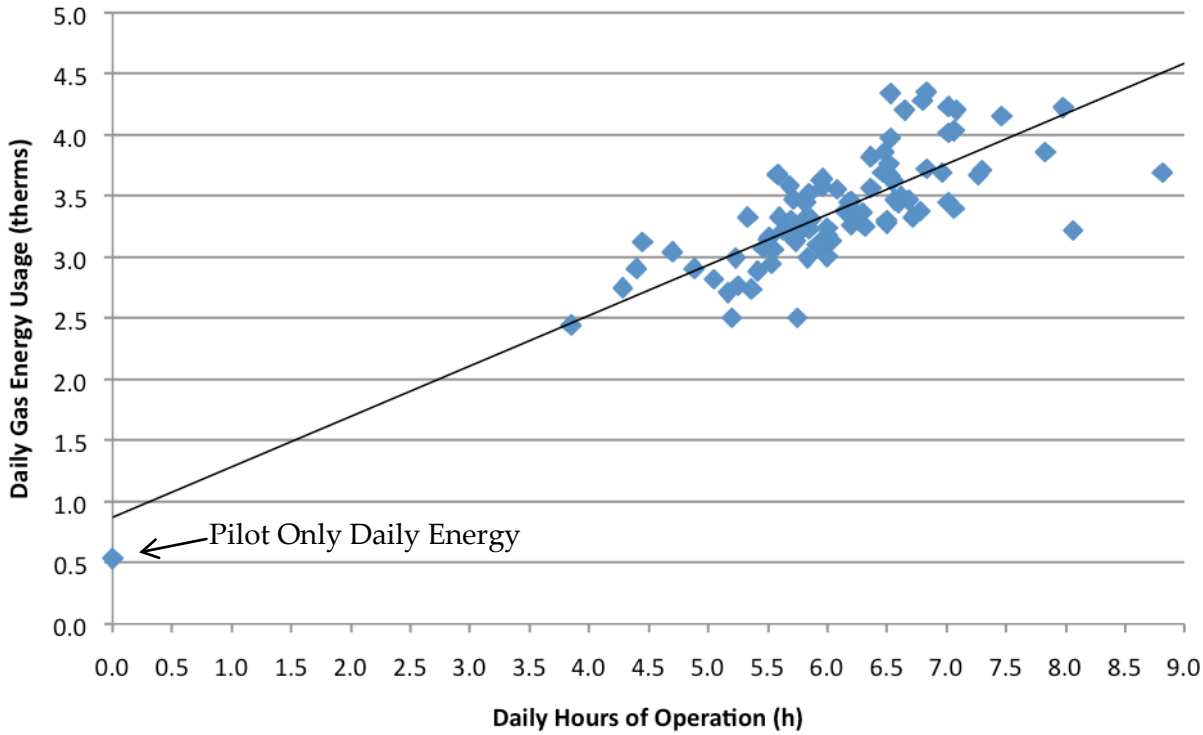
**Figure 116: Friday August 24, Typical Energy Profile of Standard Broiler at High Tech Burrito**




Source: FNi

The average daily gas consumption of the standard broiler was 3.49 therms per day, averaged over 89 days of monitoring (excluding holidays). The daily energy usage ranged from 2 to 5 therms, depending on the time of the week (Friday and Saturday being the busiest days in terms of broiler operating hours). The restaurant is a batch cooking operation, not cook-to-order, meaning the broiler is fully loaded with product several times a day and a large quantity of food is cooked in batches. This results in the user having to cook only a few batches of product per day, compared to a cook-to-order operation when the broiler is cooking small quantities of food throughout a longer day. Also, based on the graph above, the broiler is not operating near its more than 100 kBtu/h nameplate rating; the operator adjusts the input rates based on the cooking load. The broiler had a 2.2 kBtu/h standing pilot. According to the restaurant operator, this particular store goes through 140 pounds of food cooked on the broiler per day. Broiler energy usage and operation hours were plotted in Figure 117 for a better understanding of day-to-day operational variation:

**Figure 117: Standard Broiler Energy Use and Hours of Operation**




Source: FNi

Replacement Results

After completion of baseline monitoring, the broiler was replaced with a lidded infrared broiler that was thermostatically controlled (shown in Figure 118). The dimensions of the replacement broiler were the same as the standard model. The replacement broiler had three adjustable 30 kBtu/h infrared burners; shown in Figure 119 with the radiant grate removed. The broiler had a user-adjustable thermostat which turned off the infrared burners once the temperature inside the lid had reached its set-point. The burners engaged automatically if the temperature dropped below its set-point.

The kitchen staff was educated on how to use the thermostatic controls and was instructed to keep the lid closed when not cooking on the broiler. All cooking was performed with the lid up. The thermostat and input settings are shown in the illustration of the broiler (Figure 120 below).

Months of data were analyzed; 51 days were used for replacement monitoring between the months of April and September. The average time the replacement lidded broiler was on per day during the entire monitoring period was 6.7 hours including weekends. Throughout the day, there were occasional adjustments to the burner input rates by the user, and the average input rate was 54 kBtu/h. The broiler input controls were not set for a maximum input rate, as shown in Figure 120. A typical weekday profile is shown in Figure 121.

**Figure 118: Replacement Lidded Thermostatically-Controlled Broiler at High Tech Burrito**

Photo Credit: FNi

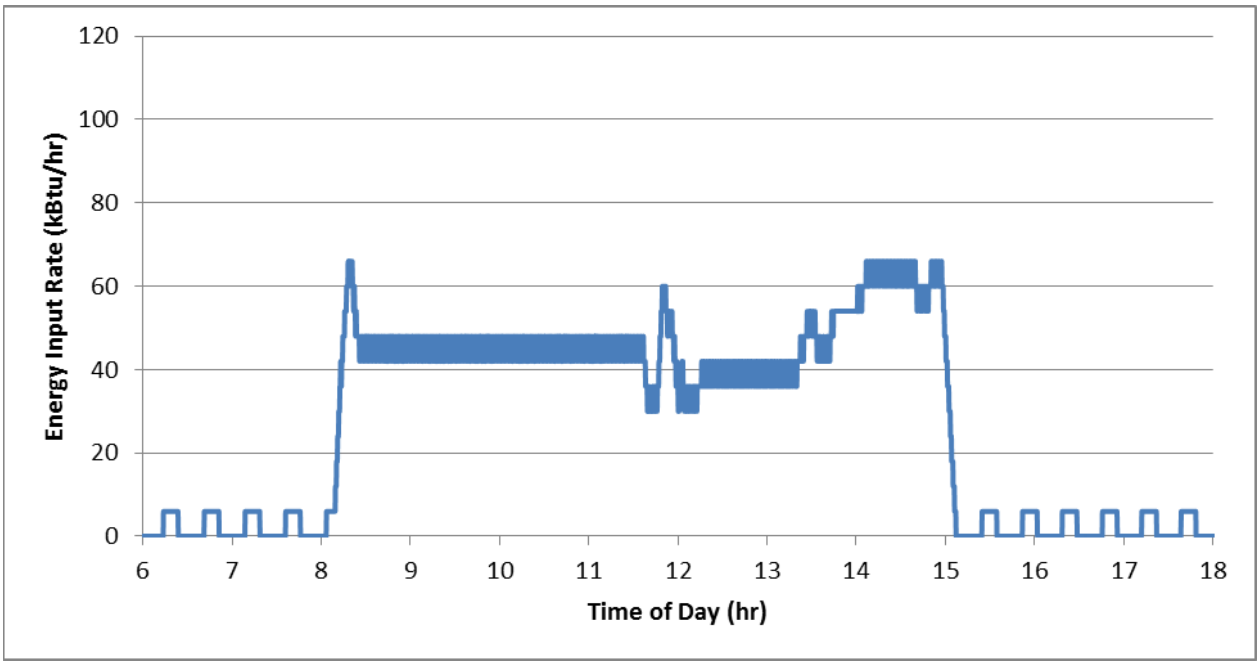
**Figure 119: Replacement Thermostatically-Controlled Broiler Infrared Burners**

Photo Credit: FNi

**Figure 120: Replacement Broiler Cook Settings**

Photo Credit: FNi

**Figure 121: Saturday March 30, Typical Replacement Broiler Energy Profile: High Tech Burrito**




Source: FNi

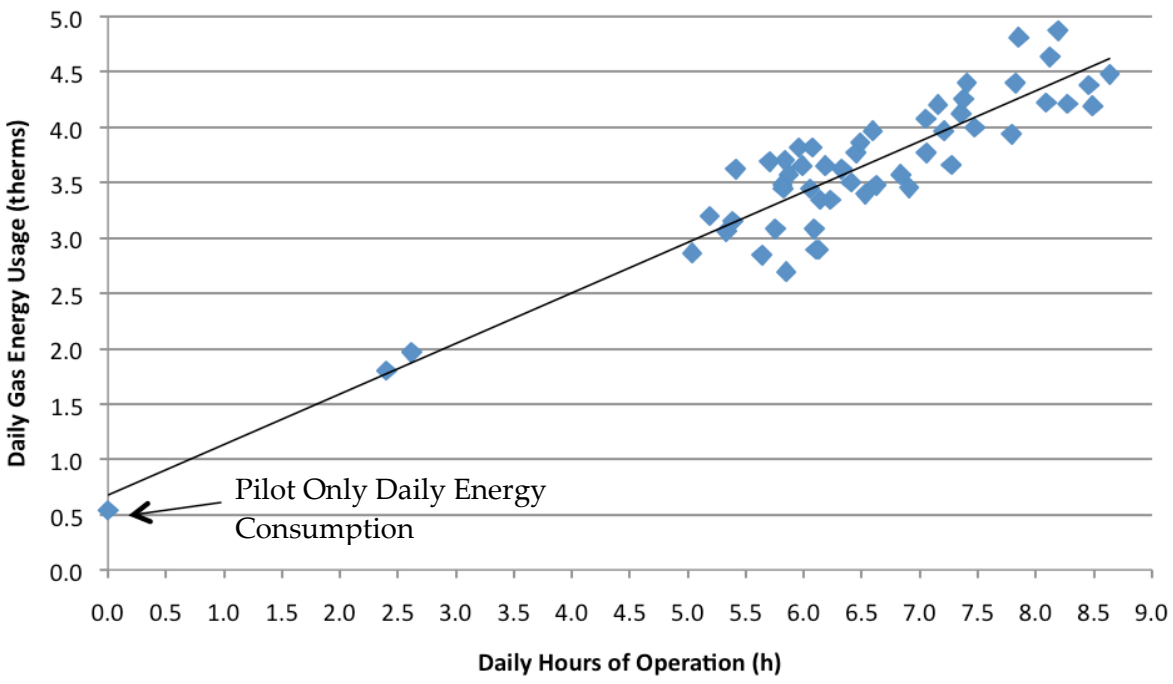
As seen from the graph, the lidded, thermostatically-controlled broiler input rate did not fluctuate much throughout the day. This means that the thermostat was not engaging. After talking to the broiler operator, it was discovered that the staff was not closing the lid on the broiler. This was mostly due to the batch cooking operation of this restaurant.

Typically broiler energy usage hours match or exceed the hours the restaurant is open, however in this situation, since the food was precooked in the earlier part of the day, the broiler was shut

off six hours before the restaurant closes (10 am – 9 pm restaurant operating hours, compared to 8 am – 3 pm broiler operation hours). According to the restaurant manager, 140 pounds of food is cooked at the restaurant per day. The broiler can fit 30 to 40 chicken breasts at a time, which is approximately 10 pounds of product. If the chicken took 10 to 15 minutes to cook, plus five minutes to prep and unload the next batch, 140 pounds of chicken would have taken over four hours to cook. Cooking beef on the broiler usually takes longer than chicken, so this would have increased the broiler operating time. If the broiler was on for only six hours a day and four to five hours were spent cooking, this left very little time for idle operation when no food was being cooked.

All the cooking on the replacement broiler was done with the lid up, so the staff either did not close the lid the rest of the time or closed the lid for a short period of time which minimized energy savings with thermostatic, lidded broiler technology. The average daily consumption of the lidded, thermostatically-controlled broiler was 3.59 therms per day, averaged over 51 days of monitoring (excluding holidays). The daily energy usage ranged from 2 to 5 therms, depending on the time of the week (Friday and Saturday being the busiest days in terms of broiler operating hours). Broiler energy use and operating hours were summarized using the scatter plots in Figure 122 to show day-to-day operational variation.

**Figure 122: Replacement Broiler Energy Use and Hours of Operation**



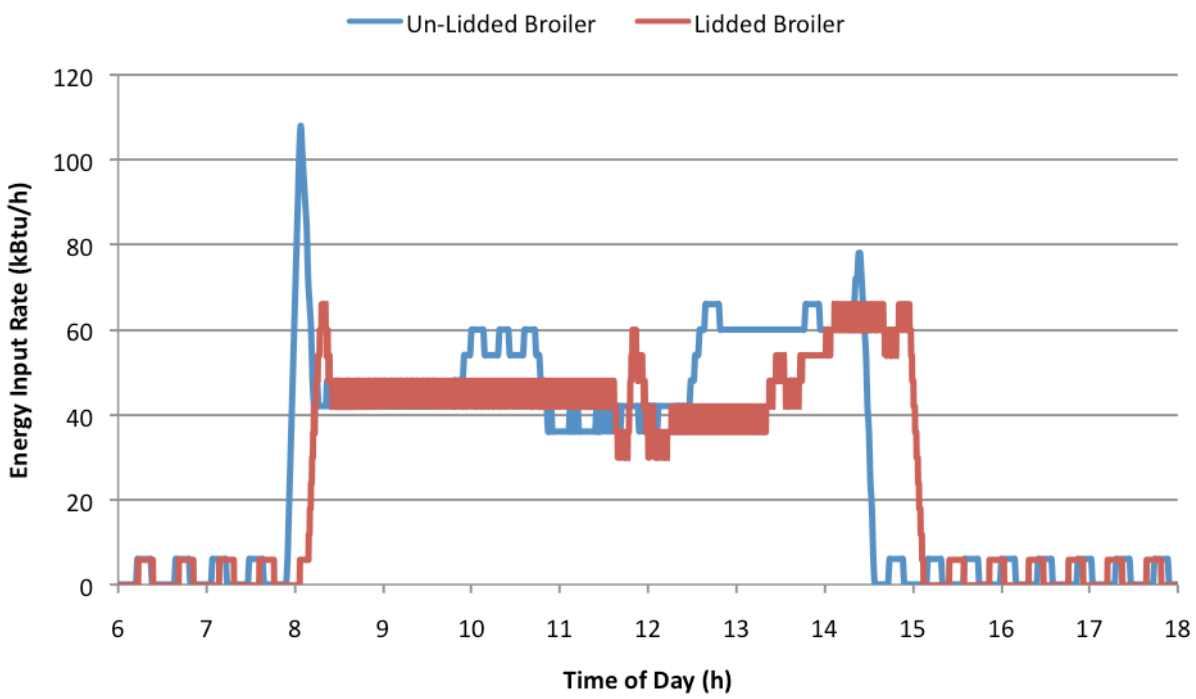

Source: FNi

Both the standard and the replacement broilers were operating for the almost same number of hours. The replacement broiler was used half an hour a day longer, due to a slight increase of customers during springtime, according to the restaurant manager. The manager also stated that the restaurant usually goes through 33 percent more customers during that time. Overall,

the replacement broiler did not show energy savings over the standard broiler. This is largely due to the batch cooking operation of the restaurant where the lid was not used by the operator and the lower cooking rate of the standard broiler. Comparing the two daily energy profiles in Figure 123, it is evident that both broilers were used in a similar fashion without the use of the lid.

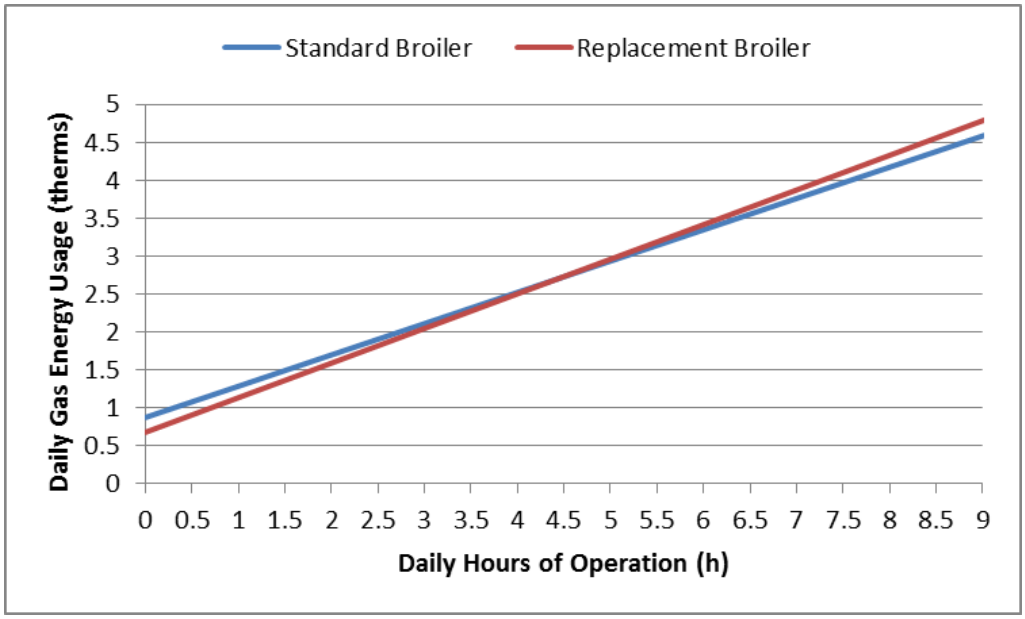
Figure 124 shows the regression lines taken from Figure 117 and Figure 122 based on the daily operating hours and energy usage. The slopes of both lines for the lidded and un-lidded broiler are almost identical, meaning that the energy use is directly proportional to the hours of operation for both broiler configurations. This proves once again that unless the lid is used, a thermostatic broiler will perform very similarly to a conventional un-lidded broiler. After interviewing the chef and her staff, the broiler operator was pleased with the improved cooking times and uniformity, despite the lack energy savings in this particular restaurant. Figure 125 illustrates how operators used the lidded broiler at High Tech Burrito.

**Figure 123: Standard to Replacement Broiler Energy Profile Comparison**




Source: FNi

**Figure 124: Standard to Replacement Broiler Daily Energy Regression Comparison**




Source: FNi

**Figure 125: Operator Cooking Chicken on Replacement Broiler with Lid Open**

Photo Credit: FNi

### *6.5.2.3 San Ramon Valley Conference Center*

Baseline Results

The cafeteria at the San Ramon Valley Conference center has been in operation for over 25 years, and the broiler monitored was installed at the restaurant's opening. The maximum input of the broiler was 105 kBtu/h, with six adjustable 17 kBtu/h radiant burners. The gas metering equipment was installed on the standard broiler and the monitoring commenced for two weeks. The standard broiler specifications are listed in Figure 126 below. A photo of the standard broiler is shown in Figure 127.

**Figure 126: Standard Pre-Existing Broiler Specifications**

| MODEL | # BURNERS | # DRIP TRAYS | TOTAL BTU/HR NATURAL GAS | TOTAL BTU/HR LP GAS | APPROX SHIP WT (LB/KG) |
|---|---|---|---|---|---|
| VACB25 | 4 | 1 | 68,000 | 64,000 | 290/131 |
| VACB36 | 6 | 1 | 102,000 | 96,000 | 370/167 |
| VACB47 | 8 | 2 | 136,000 | 128,000 | 450/203 |
| VACB60 | 11 | 2 | 187,000 | 176,000 | 500/225 |
| VACB72 | 13 | 2 | 221,000 | 208,000 | 580/263 |

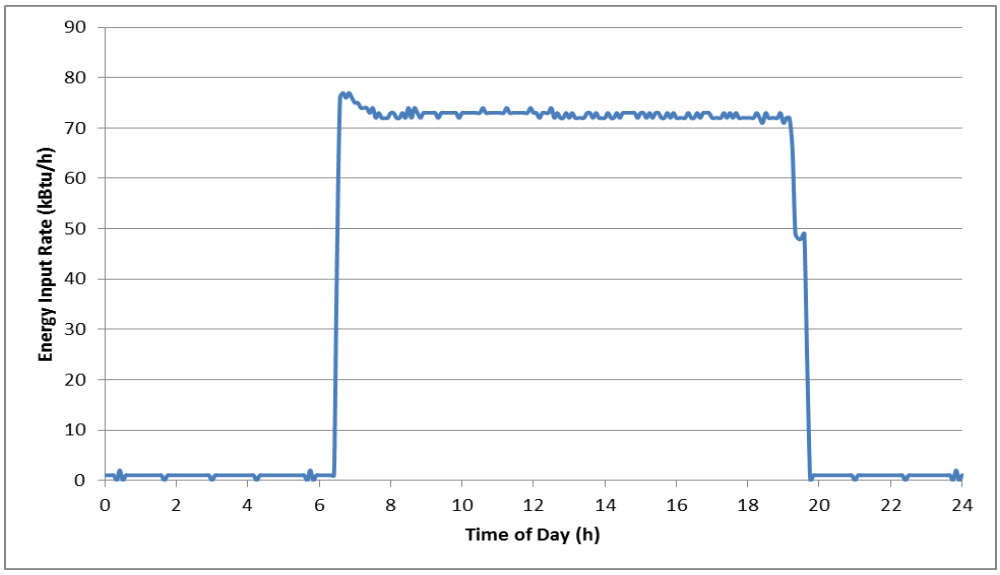
Source: Vulcan-Hart Company

**Figure 127: Standard Pre-Existing Broiler in the SRVCC Kitchen**

Photo Credit: FNi

On Monday through Thursday, the broiler was preheated around 6 am and turned off around 8 pm. Friday was a half-day operation, and the cafeteria was closed on Saturday and Sunday. The average time the broiler was on per day during the entire monitoring period was 13.4 hours, excluding Fridays and weekends. Throughout the day broiler knobs were not adjusted, and the average input rate was 86 kBtu/h. The broiler has a 2 kBtu/h standing pilot (the staff did not turn off the pilot at night). A typical weekday profile is shown in Figure 128.

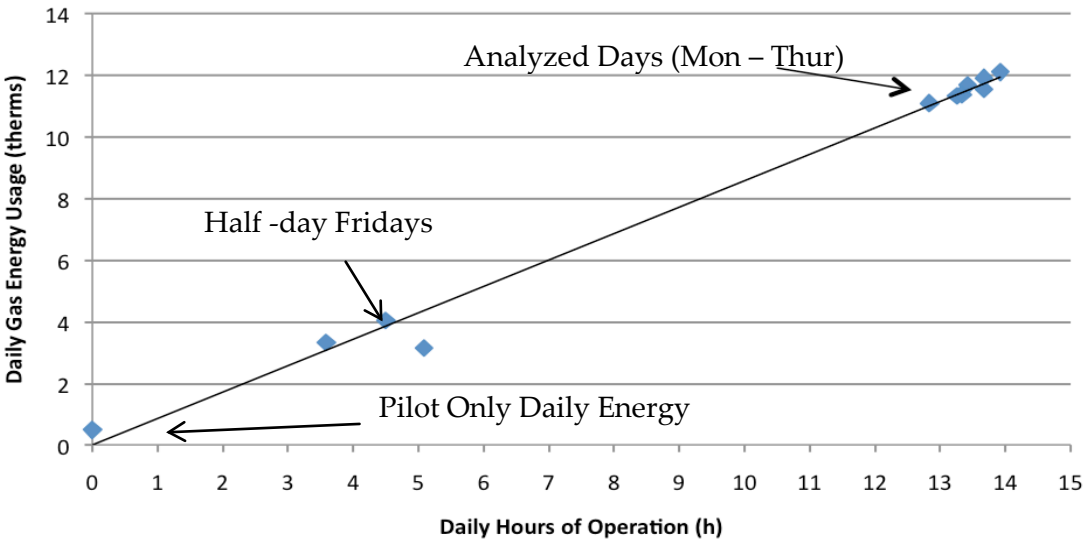
**Figure 128: Tuesday December 1, Typical Energy Profile of Standard Broiler at SRVCC**




Source: FNi

The average daily gas consumption of the un-lidded broiler was 11.6 therms per day averaged over seven days of monitoring (excluding Fridays and weekends). The daily energy usage was fairly consistent, ranging from 11 to 12 therms depending on the time of the week. Broiler energy use and operation hours were summarized using the scatter plot in Figure 129 to show day-to-day operational variation.

**Figure 129: Standard Broiler Energy Use and Hours of Operation**




Source: FNi

Replacement Results

After baseline monitoring was completed, the broiler was replaced with a lidded infrared broiler that was thermostatically controlled (shown in Figure 130). The dimensions of the replacement broiler were the same as the standard model. The lidded broiler had three adjustable 30 kBtu/h infrared burners; shown in Figure 131 with the radiant grate removed. The broiler had a user-adjustable thermostat which turned off the infrared burners once the temperature inside the lid has reached its set-point. The burners automatically engaged if the temperature dropped below this set-point.

The kitchen staff was taught how to use the thermostatic controls, and was instructed to keep the lid closed when not cooking on the broiler. All cooking was performed with the lid up. A week of data was analyzed. The average time the replacement lidded broiler was on per day during the entire monitoring period was 13.08 hours (excluding Fridays and weekends).

**Figure 130: Replacement Broiler Installed on SRVCC Line**

Photo Credit: FNi

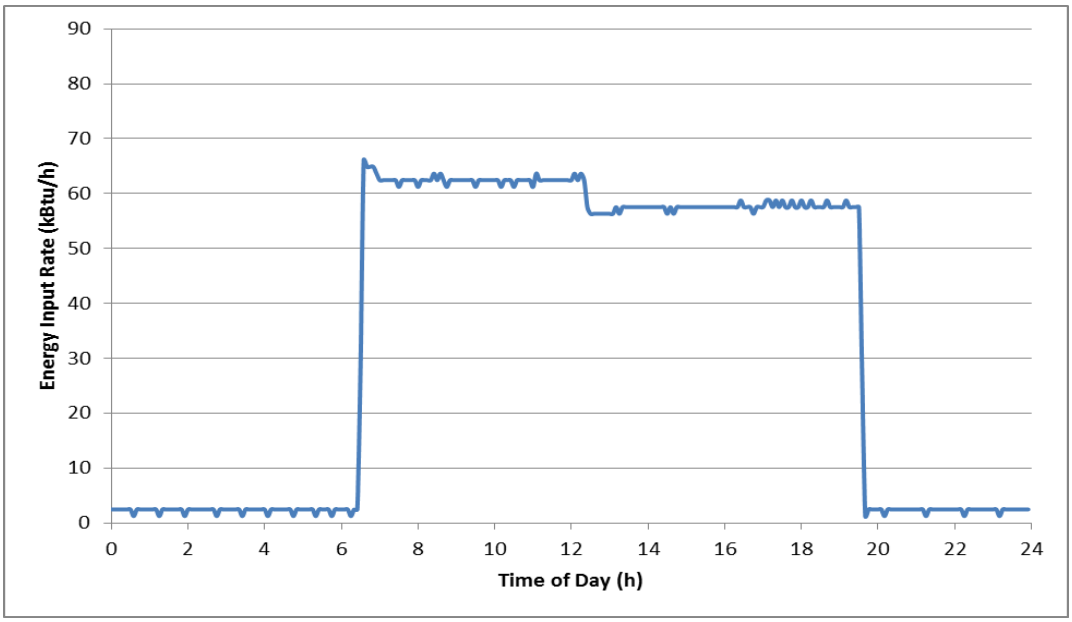
**Figure 131: Replacement Thermostatically-Controlled Broiler Infrared Burners**

Photo Credit: FNi

Throughout the day, there was minimal adjustment to the burner input rates by the user. The average input rate was 65 kBtu/h. A typical weekday profile is shown in Figure 132.

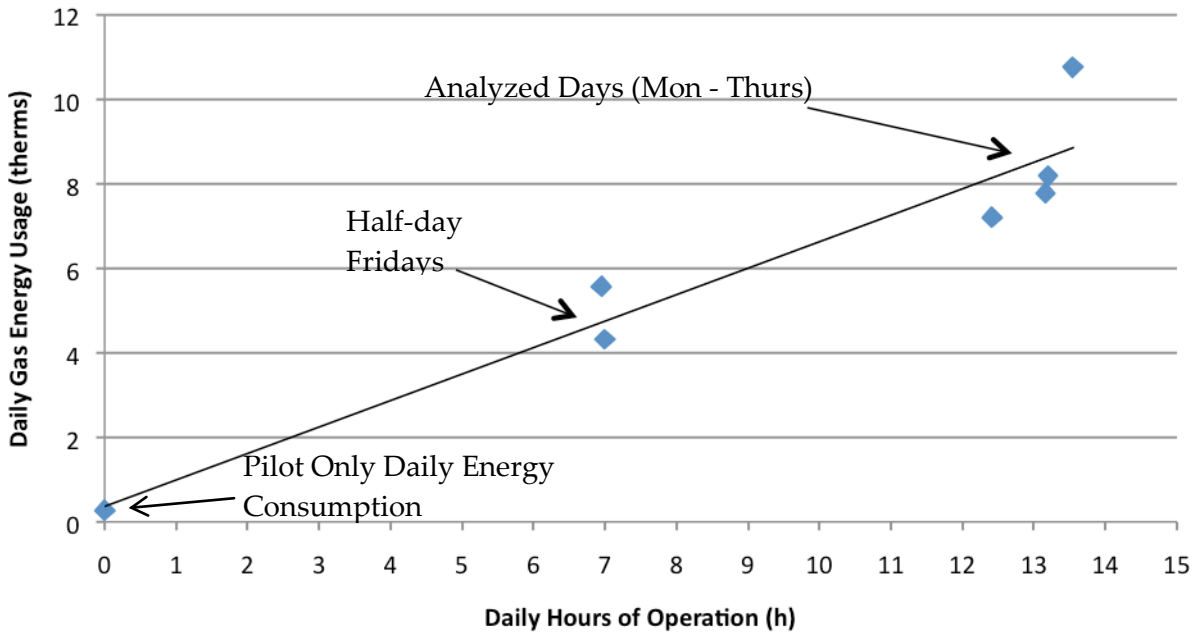
Using the lid caused the average input rate of the thermostatically-controlled broiler to be lower than the conventional broiler. The average daily consumption of the replacement thermostatically-controlled broiler was 8.48 therms per day averaged over 4 days of monitoring (excluding Fridays and weekends). The daily energy usage ranged from 7 to 10 therms depending on the time of the week. The broiler pilot energy was 2 kBtu/h; staff did not turn off the pilot at night. Broiler energy usage and operation hours were summarized using the scatter plot in Figure 133 to show day-to-day operational variation.

**Figure 132: Tuesday November 18, Typical Energy Profile of Replacement Broiler at SRVCC**




Source: FNi

**Figure 133: Replacement Broiler Energy Use and Hours of Operation**

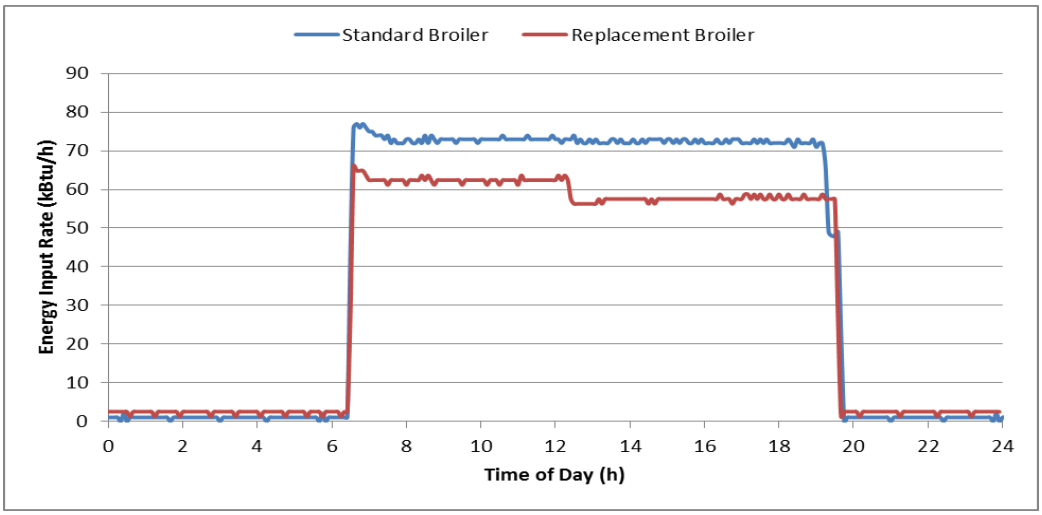



Source: FNi

Both the standard and the lidded broilers were shown to operate for the same number of hours; however the energy usage was reduced by 26 percent due to a lower average energy input rate. Closing the lid reduced the idle energy, and in a cafeteria scenario such as this, a majority of the

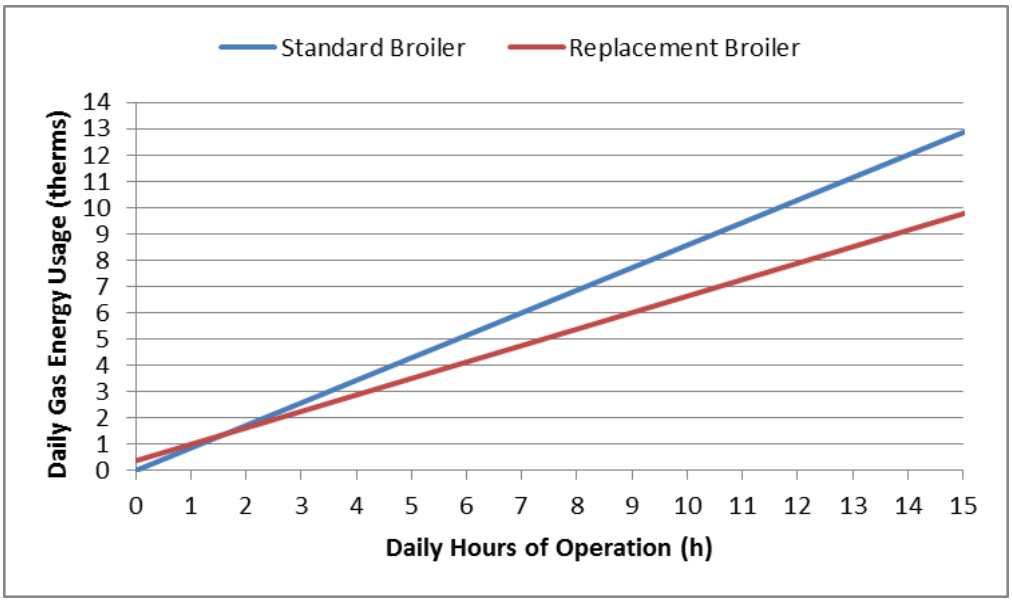
"on" time is spent in idle mode, because the broiler is preheated every day at the same time regardless how much food is cooked on it that day. The overlaid comparison graphs in Figure 134 clearly illustrate the reduced energy use when the lid was used. Figure 135 shows the regression lines taken from Figure 129 and Figure 133 based on the daily operating hours and energy usage.

**Figure 134: Standard to Replacement Broiler Energy Profile Comparison**




Source: FNi

**Figure 135: Standard to Replacement Broiler Daily Energy Regression Comparison**




Source: FNi

The slope of the standard broiler is steeper than the replacement broiler, meaning that the energy use is proportional to the hours of operation for both broiler configurations. The steeper

slope also indicates that the standard broiler will use more energy per hour than the replacement, while achieving same or better cooking results.

While observing the service, FSTC researchers noted the thermostat control was set to maximum, and the lid was down while the broiler idled. The individual knobs were set to approximately three-quarters open. The broiler was not cycling during idle in this condition.

When a food item was prepared, cooking occurred with the lid down. The cooks indicated a decrease in both cook-time and radiant heat from the broiler with the lid down. They also stated that cooking with the lid down was preferred, but they would cook with the lid up when they were busy.

The service observed by the FSTC researchers was considered slow. The only food product being cooked was frozen hamburger patties, and the rate of orders only required one or two burgers cooking at one time. Staff indicated that the broiler had been used to 'mark' chicken before the lunch service, and that it performed this task well. A comment was made about hot and cold spots, but that once they were able to "learn" the broiler, it was not an issue.

After interviewing the chef and the staff about the broiler replacement, the following was found: The overall impression of the cooks was that there was no strong case either for or against a broiler with a lid. They stated that it took a few services to get used to using the lid and the broiler's hot and cold spots, but after that it was "fine". They found the lid easy to use and the handle never became too hot to operate with bare hands. They felt a slight decrease in cook time and a definite decrease in radiant heat were both positives.

The only anecdote about the lid involved a cook opening the lid with his left arm while simultaneously flipping a hamburger patty with his right arm. The hamburger patty was directly underneath his grip on the handle, so the ensuing flare-up caused a burn on his forearm. His comment was along the lines of, "It's a kitchen, and you get burns. I won't make that mistake again".

Cafeteria staff stated it was odd that the rear of the broiler grate was the coolest spot. They were used to having the cool spot at the front of the broiler, and said they now had to reach across the hottest sections to reach the coolest section. Again, they stated that it was not an issue once they cooked on the broiler for a period of time.

The final comments were that the fast preheat time was impressive. The standard broiler took nearly half an hour to heat up, where the infrared unit was ready in less than ten minutes. Cleaning the hood was a problem, with the baked on grease becoming too difficult to remove and making the outside of the lid a bit unsightly against the rest of the clean kitchen. This was a concern because the broiler was in full view of customers moving along the ordering line.

#### *6.5.2.4 Norm's Place*

Baseline Results

The restaurant's kitchen consultant specified a several-decades-old conventional three-foot wide, open under-fired broiler with non-thermostatic controls, shown in Figure 136. The

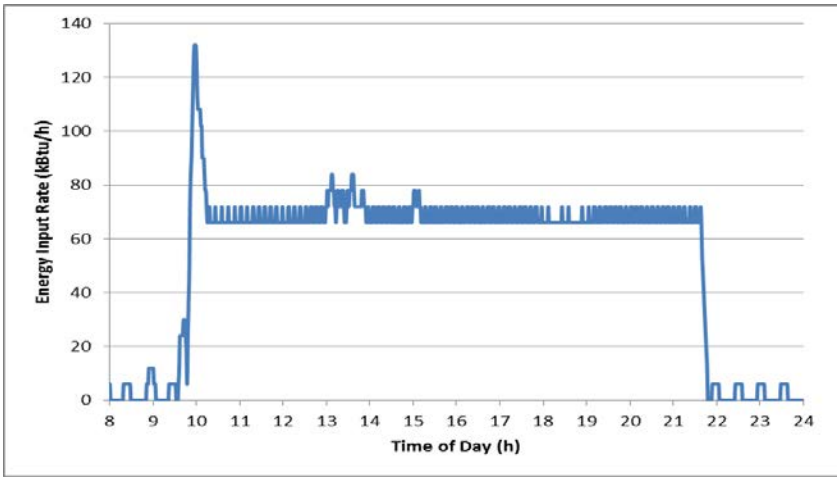
maximum input of the broiler was 120 kBtu/h with six adjustable 20 kBtu/h radiant burners. The gas metering equipment was installed on the standard broiler, and the monitoring commenced for several months. After several months of data were analyzed, 58 days were analyzed for the baseline monitoring from February through April.

On weekdays, the broiler was preheated around 10 am and turned off around 10 pm. The average time the broiler was on per day during the entire baseline monitoring period was 12.8 hours, including weekends. Throughout the day there was minimal adjustment to the burner input rates by the user, and the average input rate was 74 kBtu/h. The broiler had a 1.9 kBtu/h standing pilot and the staff did not turn off the pilot at night. A typical weekday profile is shown in Figure 137.

**Figure 136: Standard Broiler at Norm's Place**

Photo Credit: FNi

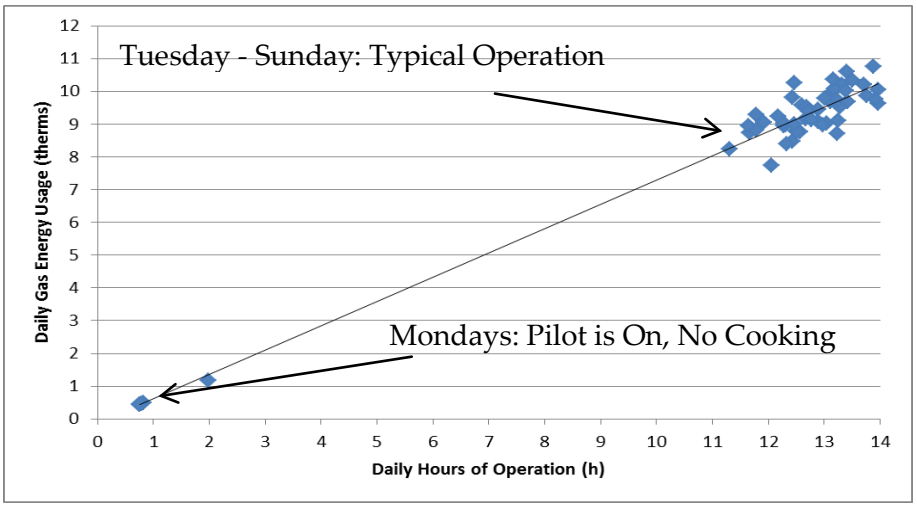
**Figure 137: Thursday Feb. 28, Typical Energy Profile of Standard Broiler at Norm's Place**




Source: FNi

The average daily gas consumption of the standard broiler was 9.44 therms per day, averaged over 50 days of monitoring (excluding holidays and Mondays). Daily energy use was fairly consistent and ranged from 7 to 11 therms, depending on the time of the week (Friday and Saturday being the busiest days in terms of broiler operating hours). Broiler energy use and operating hours were summarized using the scatter plots in Figure 138 to show day-to-day operational variation.

**Figure 138: Standard Broiler Energy Use and Hours of Operation**




Source: FNi

Replacement Results

The replacement broiler delivery was delayed by the manufacturer and had not yet been installed at the test site at the time this report was written. The picture of the replacement broiler is shown in Figure 139. Norm's replacement broiler is planned to be replaced by the lidded thermostatically-controlled broiler several months after this report is published.

The initial broiler operation is very consistent, and the operator does not turn down the broiler throughout the restaurant's long hours of operation. These criteria make this site a perfect candidate for a lidded broiler replacement. The average savings from the lidded broiler discussed in sections 6.1.4 Project Outcomes and 6.1.5 Conclusions was 23 percent.

Projecting these savings to this site, while assuming the operator will be using the lid during the idle operation times, should result in a daily gas energy consumption of 7.27 therms per day. Projected energy savings are 2.2 therms per day of operation.

**Figure 139: Replacement Broiler Waiting to be Installed at Norm's Place**

Photo Credit: FNi

### 6.5.3 Summary of Results and Discussion

The four restaurants were selected based on their existing broiler usage patterns. Each site represented a different sector in foodservice with different broiler usage patterns.

The first restaurant—Prather Ranch, a cook-to-order restaurant—utilized the broiler to cook small quantities of food several times a day for an average duration of 10 hours a day, achieving 19 percent energy savings when switching to the replacement broiler.

The second restaurant—High Tech Burrito, a batch-cooking quick-service chain restaurant—utilizes the broiler to cook large quantities of food continuously for a short period during the day for an average duration of six hours a day. The batch operation of High Tech burrito did not allow the broiler to idle because all the time was spent cooking with the lid up. Failure to use the lid by the restaurant operators resulted in no gas savings at this restaurant location.

The third restaurant—the San Ramon Valley Conference Center, a cafeteria-style restaurant—utilized the broiler to cook batch quantity of food depending on the varying weekly menu for an average duration of 13 hours a day achieving 26 percent energy savings when switching to the replacement broiler. Such energy savings were achieved at this location due to the majority of the broiler operating time being spent in idle, during which the closed lid greatly reduced the energy consumption.

The fourth restaurant—Norm's Place, an American pub—utilized the broiler to cook large quantities of food during lunch and dinner. Long hours of operation of the bar force the operator to have the broiler on throughout the day, but the majority of the food is cooked during shorter hours of lunch and dinner, causing most of the time spent in idle operation mode for the broiler. This made Norm's a perfect candidate for the replacement broiler, which will be installed after this report is published.

Table 32 below shows the energy impact of the lidded broiler at each replacement location.

**Table 32: Lidded Broiler Replacement Energy Impacts and Monitored Restaurant Locations**

| Location | Operation | Hours Broiler is On, Pre – Post (h) | Un-Lidded Broiler Daily Energy Consumption (therms) | Lidded Broiler Daily Energy Consumption (therms) | Energy Savings |
|---|---|---|---|---|---|
| Prather Ranch | Cook-to-order | 10.2 – 10.1 | 7.48 | 6.09 | 19 percent |
| High Tech Burrito | High Batch Cooking, no idle | 6.2 – 6.7 | 3.49 | 3.59 | None * |
| SRVCC Cafeteria | Batch Cooking, long idle | 13.4 – 13.1 | 11.57 | 8.48 | 26 percent |
| Norm's Place | Cook-to-order | 12.8 | 9.48 | 7.27 (projected) | 23 percent (projected) |

*The lid was not used as food was batch-cooked in a continuous manner for relatively short periods of time with little to no periods of idle operation.

Source: FNi

The energy use and savings from a lidded broiler depends on the restaurant operation and the willingness of the restaurant staff to close the lid. Average gas energy savings from the lidded broiler was 15 percent across these various restaurant cooking scenarios.

## 6.6 Conclusion and Recommendations

### 6.6.1 Conclusion

In a 2010 PIER report by Fisher-Nickel, inc. on *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment*, it was estimated that 42,000 under-fired broilers were in operation in California commercial kitchens. With most under-fired broilers operating at a baseline efficiency of approximately 30 percent, the estimated annual gas use was 122 million therms in California.

Cooking efficiency of under-fired broilers can be dramatically increased by using advanced infrared burners and cooking with the lid down. While many traditional restaurant operators will be reluctant to cook with the lid down, it has the potential to almost double the cooking

efficiency, as described in section 6.1.5 Conclusions of this report. The biggest energy saving with a lidded broiler, however, is reduced idle energy rates when the lid is down and the thermostat engaged.

In section 6.5.2.2 High Tech Burrito, the site study proved that unless the lid is closed, the lidded broiler will not result in energy savings because it will operate like a conventional non-thermostatically-controlled broiler. The other two site studies where idle operation takes most of the day and the user was consistently closing the lid resulted in 23 percent savings between the two sites. Naturally, there are going to be certain sites that will benefit the most from the use of the lidded broiler. The San Ramon Valley Conference Center (described in section6.5.2.3 San Ramon Valley Conference Center), which has long operating hours and consequently long idle times, was a great candidate for the lidded broiler replacement. Norm's, whose operating hours are similar to the SRVCC, will be a prime location for monitoring once the lidded broiler is installed. Sizable energy savings could be realized once comparable restaurants are identified.

The principal contributor to energy savings for the under-fired broiler was the thermostatic control system which would bring the broiler to a set point when the lid was closed before turning off the burners. The incremental cost of this technology was approximately $850. Taking into account that a standard under-fired broiler in California uses approximately 5700 therms per year. The reported energy savings due to this technology was approximately 23 percent. Pricing the natural gas at 0.70 dollars per therm, potential savings are approximately $918. Therefore the payback period would be less than a year, which is a significant factor in regards to market penetration.

As stated earlier, there are potentially 42,000 under-fired broilers in California. Based on our study of the four restaurants, average daily energy usage of the standard broiler is 8.0 therms. At a 50 percent market penetration if an estimated 21,000 standard-efficiency broilers, with an average energy consumption of 8 therms per day, operated with the 23 percent savings gained through the use of the lidded broiler technology, an annual savings of 14 million therms could be possible. This translates to a saving of 9.8 million dollars for the California food service industry using EIA values of 10.21 therms/MCF and 7.13 dollars/MCF of natural gas (EIA 2013).

### 6.6.2 Recommendations

Broiler efficiency has remained the same for decades. However, more and more manufacturers have recently started to sell infrared broilers. Several companies have experimented with lidded prototypes, and the prototype described in this report could benefit from a few more improvements. For large scale market adoption, the lidded broiler concept will need to be refined and promoted by the manufacturers.

Several comments from the restaurant operators who cooked on the broiler daily are described at the end of Section 6.5.2.3 San Ramon Valley Conference Center. A major concern is that the lid is still quite heavy and the user can get burned on it if not careful. A lid handle extension could decrease the lifting effort if installed in the right place.

Often times only a small part of the broiler is utilized during cooking while the rest of the cooking surface is emitting tremendous amounts of waste heat. This problem can be solved

with a split lid where the operator can cook only on half of the cooking surface, while the thermostat under the cover of the other part maintains a lower input rate. This would also encourage the user to cook some products, such as bone-in chicken, with the lid down and simultaneously have the opportunity to cook other products, such as burgers, with the lid open. Another possible improvement could be a double-walled lid, with an air gap acting as an extra insulator for the lid.

The lidded broiler had a standing pilot that consumed the same amount of energy as the conventional broiler. This pilot energy can be greatly reduced by having an automatic pilot ignition system.

Since an under-fired broiler requires some of the highest ventilation rates of all commercial kitchen appliances, a demand controlled ventilation system could be paired with the lid. Opening the lid can simply trigger the vent fan to increase speed without the use of any complicated optics.

It may be feasible to incorporate a two-stage burner system gas valve as an alternative to the thermostat. This may provide more consistent operation, as flare-ups sometimes caused the thermostat to shut off the burners. The burners needed to stay on at all times when the food was being cooked with the lid open.

Overall, there are great potential savings with the lidded broiler in restaurants that have their units idling for a long time. As more restaurant users and manufacturers become aware of the lidded broiler technology that they have been familiar with for decades, they will start adopting this technology and start improving on it as they get more feedback from the customers.

# CHAPTER 7: Over-Fired Broilers

## 7.1 Summary

### 7.1.1 Introduction

Over-fired broilers are available in three primary grades: high production upright broilers, and medium duty salamander broilers and light-duty cheese melters. All categories apply heat to the food from above and produce much less smoke and flame than their under-fired counterparts. Over-fired broilers range in size and ability from those that are used to broil thick steaks in quantity to those intended for melting cheese and/or browning/finishing food. The radiant heat in an over-fired broiler is generated with gas infrared burners or gas radiants. Some manufacturers use powered burners that force premixed gas and air through a ceramic infrared burner. The Gas Technology Institute (GTI) has identified solutions to raising the energy efficiency and lowering the standby consumption in a previous CEC project (#500-05-011). As a part of this project, GTI has designed a radiant burner, for the over-fired broiler, that uses a sealed flame and heat recovery through a recuperator to improve efficiency. However, this project ended without the broilers reaching the full development status required for the market introduction to occur. In a mature market, over-fired broiler energy consumption can be reduced by 0.7 million therms, assuming a modest market penetration rate of 20 percent is achieved, saving California customers 0.49 million dollars annually.

Salamanders are medium-duty as their input range slightly overlaps that of both upright broilers and cheese melters, and they are designed to fit above a range top on a back shelf. The broiling cavity can be as wide as an upright's but not as deep, typically 12 inches instead of 24 inches deep. Salamanders generally have a lower input rate to match their smaller size, and deliver slightly less energy to each square foot of the grid. They are intended to prepare the same range of foods as a high-input upright broiler, but at lower volume and without occupying floor or counter space.

In the 2010 PIER report by Fisher-Nickel inc. *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment*, it was estimated that there are approximately 24,433 salamanders in California consuming an estimated 11.7 million therms.

### 7.1.2 Purpose

The purpose of this report was to identify new technologies that could improve over-fired broiler energy efficiency and performance. The goal was to validate a targeted 17 percent energy-efficiency gain when using advanced design equipment.

### 7.1.3 Project Objectives

The objectives of the salamander over-fired broiler field study were to:

- Characterize the daily use profiles of salamanders in commercial restaurants.

- Analyze and identify usage patterns for salamanders and project energy-saving potential.
- Design and develop new concept prototype for a commercial over-fired broiler which is both energy efficient and robust.
- Recommend future improvements to further over-fired broiler energy efficiency.

### 7.1.4 Project Outcomes

A flat panel radiant burner concept was derived from GTI technology on the Gas-Fired GlowTube burner for process heating applications and then applied to the over-fired broiler concept. The goal was to improve the broiler's performance including improving the heating surface temperature uniformity, increasing thermal efficiency, and reducing emissions. The burner was fabricated based on the GTI design.

The burner failed to ignite during initial testing and several designs were made to improve performance. After the team completed the modifications to the burner, compressed air provided sufficient combustion air supply and spacers made the air and combustion chamber passages more uniform. The team was able to ignite the burner with its own automatic ignition system at the turnaround region by using gas flow rate around 60 SCFH and the air flow at 780 SCFH. The firing rate varied after successful ignition, from a very low (5 SCFH) up to the full fire rate and the combustion was stable for the whole range. Temperature distribution inside the combustion chamber was not uniform, which could be seen from the bottom radiant surface color difference.

After the test, the team disassembled the flat panel burner. Several sheets of metal were warped and distorted from the combustion heat, and some soot was discovered around the screw holes close to the gas chamber. The temperature distribution and combustion inside the flat panel burner were highly inconsistent as observed in the color difference of the radiant surfaces.

The conclusions of the test are that ignition remains a challenge in this design and burner body warping and distortion is a major problem even for the 1.6mm thick wall tubular shape GlowTube burner. Steps can be taken to make the flame longer and a lower temperature can be used to ensure a more uniform heat distribution, but the metal thickness (and weight) would have to be increased to withstand the combustion heat without distortion. Air and fuel distribution were problematic for the current design even after the team's modifications. A better design is also needed to lower the air side pressure. A clear path for this design to work properly with simple modifications is not apparent and is beyond the scope of work for the project.

Supplementing the concept development, two baseline test sites were located for the field test in the San Francisco Bay Area. Test site one, a casual dining restaurant called Sunrise Bistro, is located in Walnut Creek and offers breakfast, lunch, and dinner service. Test site two, Artisan Bistro, is a fine dining restaurant located in Lafayette offering lunch and dinner.

Both sites employed regular use of a salamander broiler and showed the same consumption rate of 59 kBtu/h after six to eight weeks of field monitoring. Average daily gas use and average daily hours of use illustrated in Table 33 shows very similar usage profiles.

**Table 33: Summary of Results**

| Site | Sunrise Bistro | Artisan Bistro |
|---|---|---|
| Average Daily Gas Use (therms) | 2.03 | 2.84 |
| Average Daily Hours of Use | 3.4 | 4.8 |
| Average Consumption Rate (kBtu/h) | 59 | 59 |

Source: GTI

Major findings of the field data showed that salamander broilers have flat usage profiles and are not modulated often during operation, if at all. Because of the lack of controls in current models, incorporating demand use sensors to reduce total gas consumption could improve efficiency in future models.

Previous research in PIER project 505-06-028, *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment*, indicates there are approximately 24,433 units of salamander broilers consuming an estimated 11.7 million therms in California. By improving salamander efficiencies by ten percent can yield a potential category savings of 1.17 million therms at 100 percent market penetration.

### 7.1.5 Recommendations

It is recommended that energy-saving features, such as a demand sensor used to cycle the unit on or off as food is loaded or unloaded, be incorporated into salamanders. A demand sensor could be a pressure switch that is tripped when product is placed within the salamander. Improved unit construction through better insulation can further increase the efficiency of a salamander by minimizing heat loss through the unit. A range-top field study, *Commercial Gas Range Field Study*, was performed as part of CEC project 500-09-044, which showed an annual consumption of 16.6 million therms of gas for open-top ranges. When the impact of the sites in this range study are compared with the annual 11.7 million therms for salamanders across the state, it shows that salamanders have as significant an energy footprint as ranges, and that it is worth continuing to examine improvements in salamander design.

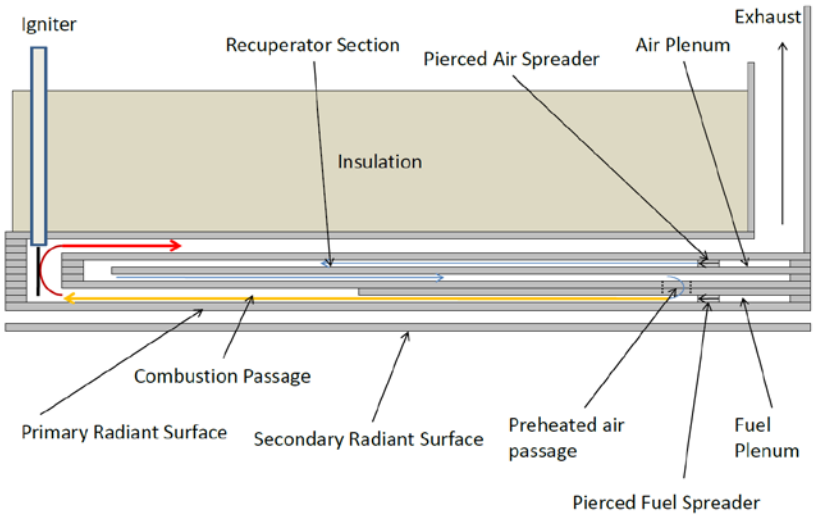
## 7.2 Background

The flat panel radiant burner concept was derived from the GTI Gas-Fired GlowTube for process heating applications.

Figure 140 and Figure 141 show the concept design envisioned for the flat panel radiant burner. The main goal was to improve the broiler's performance. This included improving the heating surface temperature uniformity, increasing thermal efficiency, and reducing emissions. The burner was fabricated by Royal and tested by both Royal and Montague. Both experienced

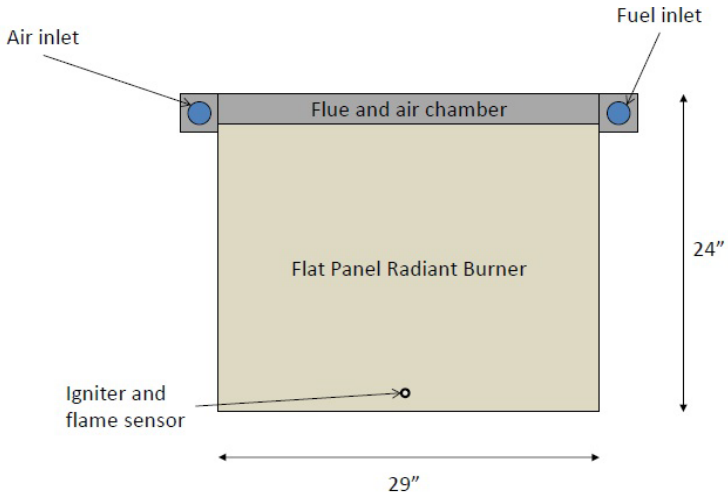
issues with flame ignition and stability and were unable to maintain a uniform flame. Eventually it was decided to ship the unit to GTI for further testing and evaluation.

**Figure 140: The Schematic of the Flat Panel Radiant Burner Concept**




Source: GTI

**Figure 141: Top View of the Flat Panel Radiant Burner**




Source: GTI

## 7.3 GTI Lab Test Setup

The flat panel radiant burner-based broiler prototype was delivered to GTI in October 2012, and was set up at GTI's lab for testing as shown in Figure 142. The air was supplied by a blower and the natural gas flow was controlled by a solenoid valve, which responded to signals from the automatic ignition system (Fenwal, Model number: 35-705506-015) and the flame sensor. The full firing rate for this first prototype was 100,000 Btu/h, which is the most commonly used firing rate for a broiler. The detailed dimensions of this prototype broiler were measured at GTI

and documented. There was not much deviation from Linck's first design. The automatic ignition system was designed to ignite the fuel/air mixture at the burner turnaround, and the flame sensor was located side by side with the igniter. Figure 142 shows the top view of the flat panel burner, with the igniter/flame sensor, the air inlet, and the fuel inlet.

**Figure 142: Test Setup at GTI for the Flat Panel Radiant Burner Prototype**

Photo Credit: GTI

In the initial testing, the most problematic area was burner ignition issues. This meant that no further performance test could be executed until the design could be modified. Figure 143 shows the electric arcing generated from the ignition system when the team first tested each component of the system to prove their individual performance. Although not very powerful, the igniter looks fine and works properly.

**Figure 143: Electric Arcing and the Flame Sensor from the Automatic Ignition System**

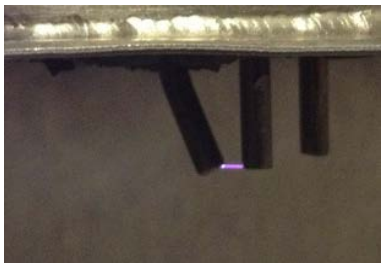


Photo Credit: GTI

After many failed attempts to ignite the burner, the team disassembled the burner to investigate what was causing the burner to malfunction. The team found the following reasons that could have contributed to the ignition failure issue:

- The air flow rate delivered by the blower was too low.
- The team ascertained from the burner's exhaust slot that the air flow distribution was highly inconsistent.
- The combustion chamber was not sealed well which left many leaks.

After the diagnosis of the ignition failure, the following modifications were made:

- The team hooked up compressed air as the air supply instead of the supplied blower (Dayton PSC 1TDN7), which could only supply max 1,000 SCFH Air at 0.5 "WC pressure head as specified. The air flow rate requirement at the full firing rate was 1,230 SCFH at 5 percent stack $O_2$. By using compressed air, the team discovered the air side pressure drop through the flat panel burner was 2.3"WC at air flow rate 1,230 SCFH. Therefore, this kind of blower was inadequate for this high pressure drop burner design. In the future, either a more powerful air blower will be needed, or the air side flow passage must be enlarged to decrease the pressure drop. Air and gas flow meters were installed to measure the air and gas flow rates, a pressure gauge was used to measure the natural gas delivery pressure, and a monometer was put in place to measure the air side pressure.
- The inconsistent air distribution for the burner was mainly caused by the varying narrow air passages constructed by the thin sheet metals for both the air supply passage and the combustion chamber passage. Therefore eight spacers at the combustion chamber turnover and eight spacers inside the chamber were installed to maintain more even spacing of the passages (see Figure 144). Ten spacers were also welded at the air preheat chamber outlet to keep a more uniform air flow path, as shown in Figure 145. These modifications greatly improved the air distribution uniformity, and alleviated the issue caused by sheet metal distortion under hot combustion conditions.

**Figure 144: Burner Combustion Chamber Before and After the Modification**

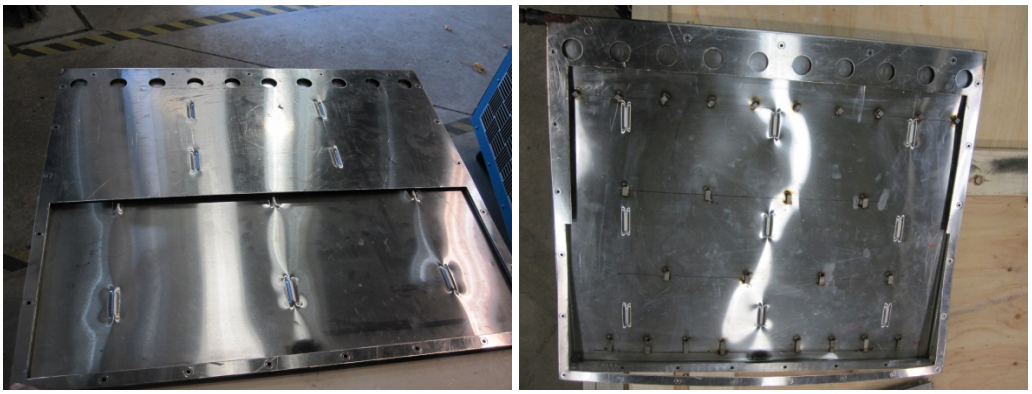


Photo Credit: GTI

**Figure 145: Air Chamber Outlet Modification with Ten Spacers**

Photo Credit: GTI

- To improve the flame stability and ignition, an 8mm x 8mm x 8mm flame holder was placed 70mm downstream of each single gas jet, as shown in Figure 146.

**Figure 146: Photo of the Gas Jet, Preheated Air Passage, and the Flame Holder**

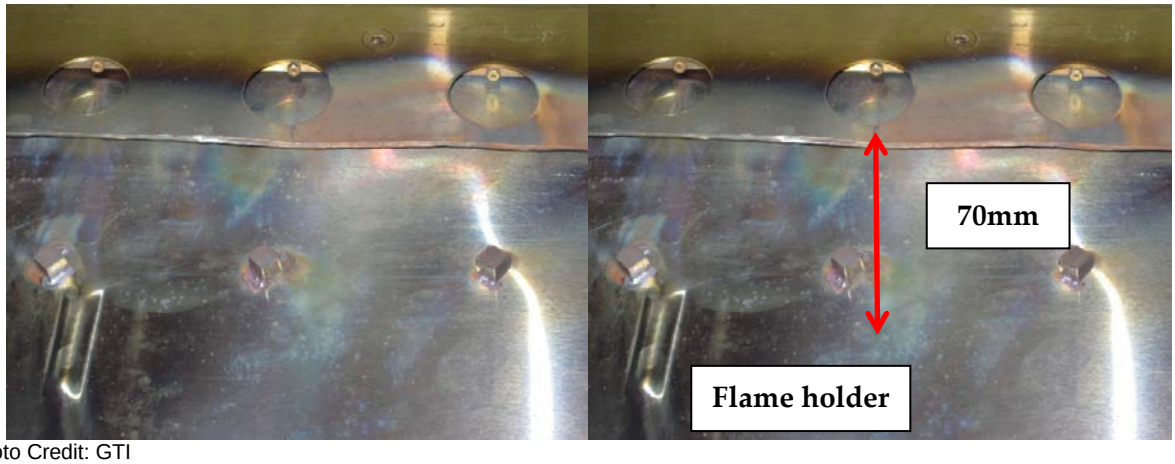



Photo Credit: GTI

- High temperature gaskets were put around the combustion chamber to prevent leaks.

After the modification, the flat panel radiant burner lab test was set up as shown in Figure 147.

**Figure 147: Modified Flat Panel Radiant Burner Lab Setup**

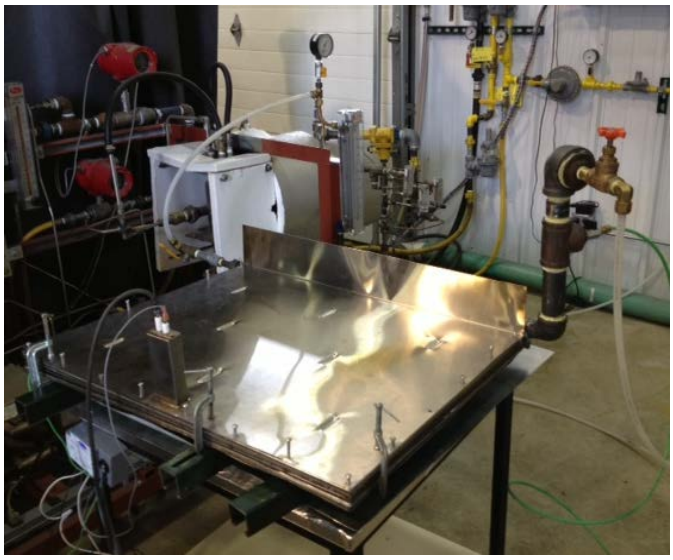


Photo Credit: GTI

## 7.4 In-Lab Test Results

### 7.4.1 Before Modifications--Torch Ignition Test Results

After the team failed to ignite the burner with its automatic ignition system, a propane torch to ignite the burner at its outlet. The purpose of the testing was to check the gas and air flow uniformity, while also ascertaining whether the flame could propagate back to the gas orifice in the combustion chamber. As shown in Figure 148, the flames stayed at the burner outlet. The yellow flames indicated that there was insufficient air supplied by the blower, and the flame could not propagate back to the combustion chamber. This was due to the lack of air as well as poor air/fuel distribution.

**Figure 148: Burner Flame Stays Outside**

Photo Credit: GTI

Next, the team opened up the burner, ignited the burner with the torch without the forced air supply at the gas orifices to see the gas distribution, natural flow rates varied from 20 SCFH to 100 SCFH. As shown in Figure 149, at lower gas flow rates, the gas distribution was relatively

uniform; but at higher gas flow rates, there was very poor distribution. The team discovered that gas not only came out from the gas orifices, but it also leaked in the gas supply chamber.

**Figure 149: Diffusion Flames Without Forced Air Supply**

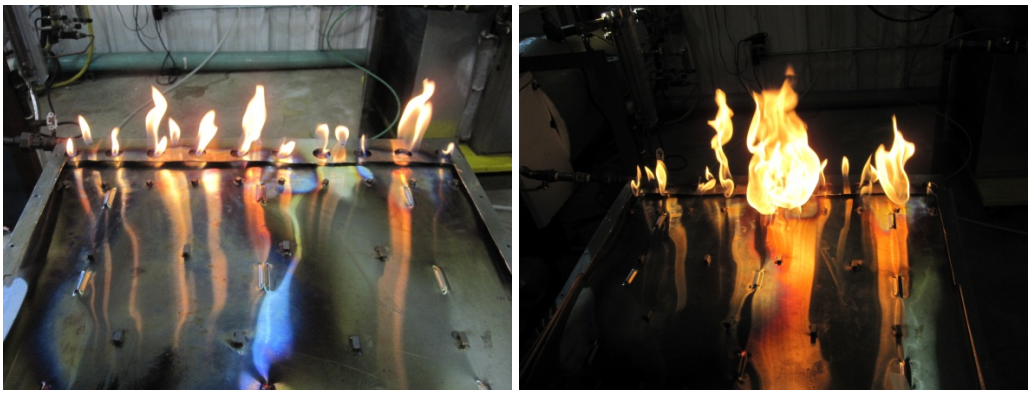


Photo Credit: GTI

### 7.4.2 After Modifications

After the team completed the modifications to the burner, compressed air provided sufficient combustion air supply and spacers made the air and combustion chamber passages more uniform. The team was able to ignite the burner with its own automatic ignition system at the turnaround region by using gas flow rate around 60 SCFH and the air flow at 780 SCFH. The firing rate varied after successful ignition, from very low (5 SCFH) up to the full fire rate and the combustion was stable for the whole range. Figure 150 shows the laminar flame inside the combustion chamber through the gap caused by the thermal expansion. Figure 151 shows the primary radiant surface glowing red several minutes after ignition and the flames are relatively short. Temperature distribution inside the combustion chamber was not uniform, which could be seen from the bottom radiant surface color difference.

After the test, the team disassembled the flat panel burner. Several sheets of metal were warped and distorted from the combustion heat, and some soot was discovered around the screw holes close to the gas chamber (see Figure 152). The temperature distribution and combustion inside the flat panel burner were highly inconsistent as observed by the color difference of the radiant surfaces.

**Figure 150: Observed Flames Through the Burner Gap Caused By Burner Distortion**

Photo Credit: GTI

**Figure 151: Bottom Primary Radiant Surface Glows Locally, Nonuniform Temperature**

Photo Credit: GTI

**Figure 152: Burner Sheet Metal Distortion and Color Change After Several Tests**

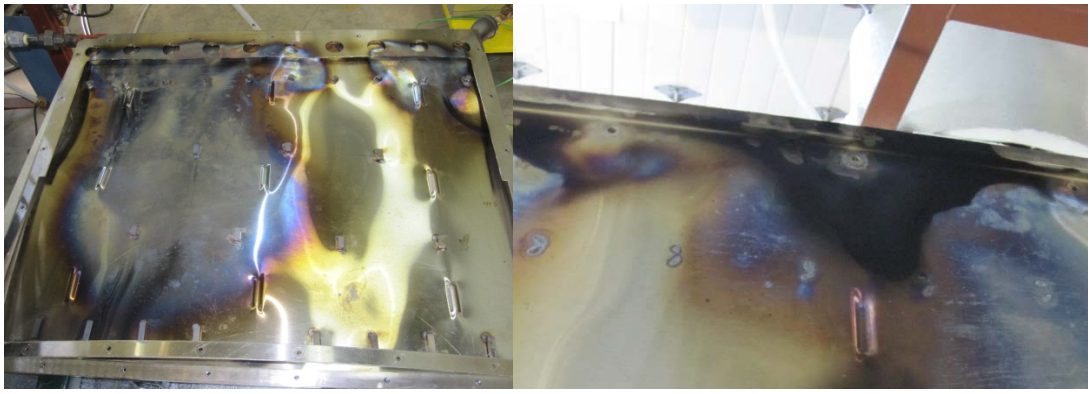


Photo Credit: GTI

### 7.4.3 In Lab Test Summary

As observed with the GlowTube, ignition remains a challenge and burner body warping and distortion is a major problem even for the 1.6 mm thick wall tubular shape GlowTube burner. The same issues were observed with the flat panel design. Steps can be taken to make the flame longer and a lower temperature can be used to ensure a more uniform heat distribution, but the sheet metal material used was too thin to withstand the combustion heat without distortion. Thicker metal sheets are needed for the combustion chamber construction, but that may cause a weight issue with the over-fired broiler. Air and fuel distribution were problematic for the current design even after the team's modifications. A better design is also needed to lower the air side pressure. A clear path for this design to work properly with simple modifications does not yet exist. Major redesign work, outside the scope of this project, needs to be undertaken to achieve the goal set for this flat panel broiler.

## 7.5 Field Testing

### 7.5.1 Field Test Plan

#### *7.5.1.1 Site Monitoring Instrumentation and Procedures*

The instrumentation package used for field data collection of the salamander ovens consisted of a diaphragm-type positive displacement gas meter with a one pulse/ft$^3$ output as shown in Figure 153. A data logger was used to log at a 60-second interval and store cumulative pulse output data from the gas meters as shown in Figure 154.

**Figure 153: Typical Instrumentation Setup**

Photo Credit: FNi

**Figure 154: Data Logger**

Photo Credit: FNi

### *7.5.1.2 Field Monitoring Site Selection*

Two test sites were located for the field test in the San Francisco Bay Area. Test site one, a casual dining restaurant called Sunrise Bistro, is located in Walnut Creek and offers breakfast, lunch, and dinner service. Test site two, Artisan Bistro, is a fine dining restaurant located in Lafayette offering lunch and dinner.

**Sunrise Bistro**

Sunrise Bistro is a casual-dining restaurant located in Walnut Creek, California with a 100-seat dining room and a 20-seat outdoor patio. The restaurant operates seven days a week, serving breakfast, lunch, and dinner Monday through Saturday, and breakfast and lunch on Sunday. The restaurant has two kitchens, with one servicing the dining room and the other servicing the catering operations. Monitoring was performed on the dining room salamander unit. The dining room salamander was a 20 kBtu/h-rated input unit, part of a six-burner range integrated into one piece, as shown in Figure 155. The salamander had an infinite heat control valve used to control the size of the flame.

**Figure 155: Salamander at Sunrise Bistro**

Photo Credit: FNi

**Artisan Bistro**

Artisan Bistro is a fine dining restaurant located in Lafayette California with a 40-seat dining room and a 6-seat bar. The restaurant is open for dinner Tuesday thru Sunday, and offers lunch Tuesday through Friday and brunch on the weekends. The restaurant has a small kitchen with the salamander mounted on the wall above the French top range and the fryer (Figure 156). The salamander is a 32 kBtu/h-rated input unit with infrared burners and a ceramic stone mounted in the bottom to help retain heat in the unit.

**Figure 156: Salamander at Artisan Bistro**

Photo Credit: FNi

## 7.5.2 Field Test Results

### *7.5.2.1 Sunrise Bistro*

The salamander servicing Sunrise Bistro's dining room, which had a rated input rate of 20 kBtu/h, was monitored for a total of eight weeks. Daily gas consumption, hours on, and hourly Btu consumption rate for the eight-week monitoring period at Sunrise Bistro are shown in Table 34, Table 35, and Table 36, respectively. The Btu/h energy consumption results in Table 34 shows very consistent salamander use, and the daily usage profile in Figure 157 illustrates a relatively flat profile during hours of operation, indicating that the salamander was not cycled on and off between uses. Instead, the salamander was turned on at the start of the dining service and left running until the end of the day. The salamander had a rated input rate of 20 kBtu/h.

**Table 34: Sunrise Bistro Results—Daily Energy Consumption**

| Btu/Day | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Week 1** | **Week 2** | **Week 3** | **Week 4** | **Week 5** | **Week 6** | **Week 7** | **Week 8** | | |
| Mon | | 154,552 | 173,256 | 168,334 | 220,508 | 213,617 | 210,664 | 202,788 | max | 300,245 |
| Tue | | 158,490 | 164,396 | 156,521 | 212,633 | 218,539 | 212,633 | 217,555 | min | 138,802 |
| Wed | 300,245 | 217,555 | 221,492 | 214,601 | 225,430 | 220,508 | 218,539 | | avg | 203,311 |
| Thur | 219,523 | 228,383 | 224,445 | 217,555 | 216,570 | 187,038 | 222,477 | | | |
| Fri | 217,555 | 239,212 | 222,477 | 210,664 | 217,555 | 226,414 | 186,053 | | | |
| Sat | 228,383 | 224,445 | 202,788 | 222,477 | 209,679 | 210,664 | 214,601 | | | |
| Sun | 148,646 | 153,568 | 153,568 | 158,490 | 197,866 | 138,802 | 159,474 | | | |

Source: FNi

**Table 35: Sunrise Bistro Results—Salamander Hours of Operation**

| Hours On | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Week 1** | **Week 2** | **Week 3** | **Week 4** | **Week 5** | **Week 6** | **Week 7** | **Week 8** | | |
| Mon | | 8.0 | 12.7 | 9.4 | 13.8 | 13.5 | 13.8 | 13.0 | max | 18.4 |
| Tue | | 11.0 | 9.8 | 9.6 | 13.3 | 14.4 | 13.8 | 14.0 | min | 7.1 |
| Wed | 18.4 | 14.8 | 14.3 | 13.4 | 15.2 | 14.4 | 14.5 | | avg | 12.5 |
| Thur | 13.4 | 13.5 | 13.5 | 13.5 | 13.7 | 10.5 | 14.4 | | | |
| Fri | 12.9 | 15.2 | 13.6 | 13.3 | 13.7 | 14.6 | 11.0 | | | |
| Sat | 14.0 | 13.9 | 12.7 | 13.9 | 13.8 | 13.0 | 13.5 | | | |
| Sun | 7.5 | 8.3 | 8.1 | 8.5 | 8.0 | 7.1 | 8.8 | | | |

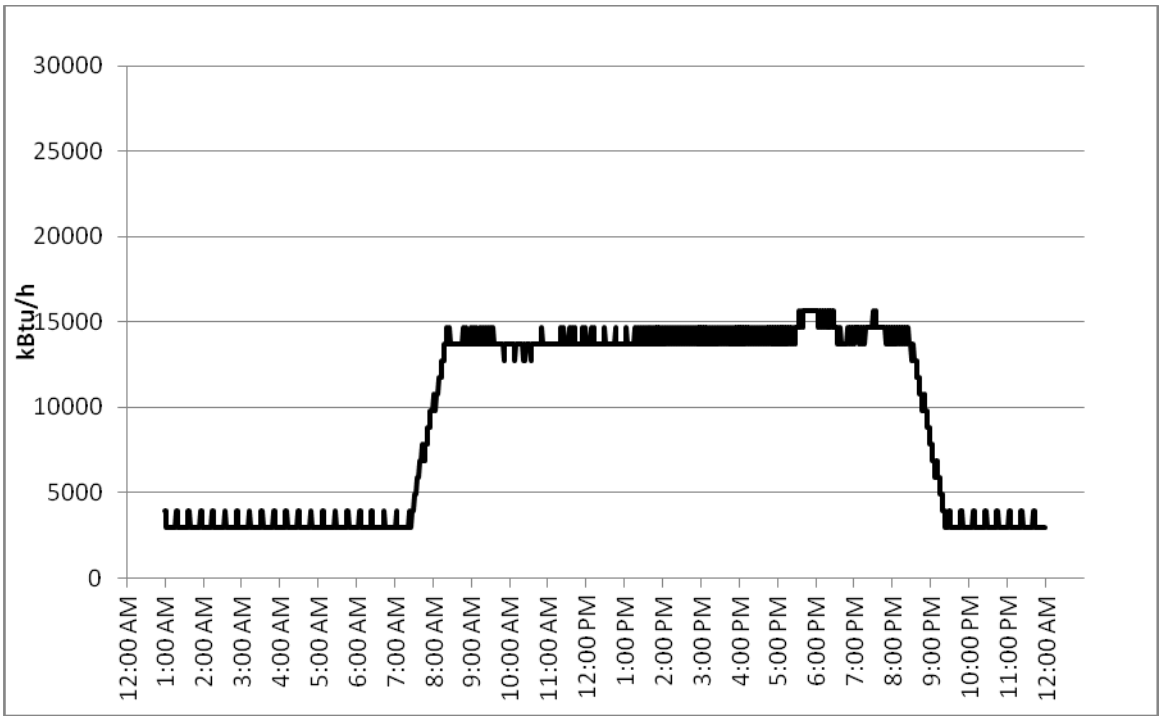
Source: FNi

**Table 36: Sunrise Bistro Results—Hourly Energy Consumption Rate**

| Btu/h | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 | Week 7 | Week 8 | | |
| Mon | | 19,279 | 13,660 | 17,876 | 15,921 | 15,804 | 15,302 | 15,559 | | |
| Tue | | 14,408 | 16,775 | 16,304 | 16,007 | 15,124 | 15,408 | 15,595 | max | 24,889 |
| Wed | 16,362 | 14,683 | 15,543 | 15,975 | 14,864 | 15,313 | 15,072 | | min | 14,408 |
| Thur | 16,342 | 16,855 | 16,667 | 16,115 | 15,789 | 17,757 | 15,450 | | avg | 16,560 |
| Fri | 16,821 | 15,686 | 16,339 | 15,800 | 15,861 | 15,526 | 16,940 | | | |
| Sat | 16,352 | 16,205 | 15,926 | 16,025 | 15,158 | 16,163 | 15,838 | | | |
| Sun | 19,952 | 18,428 | 18,959 | 18,609 | 24,889 | 19,504 | 18,122 | | | |

Source: FNi

**Figure 157: Daily Salamander Profile at Sunrise Bistro**




Source: FNi

### *7.5.2.2 Artisan Bistro*

Artisan Bistro was monitored for about six weeks. Their salamander had a rated input rate of 32 kBtu/h. Daily gas consumption, hours on, and hourly Btu consumption rate for the eight-week monitoring period at Artisan Bistro are shown in Tables 37, 38, and 39, respectively. Similar to Sunrise Bistro, the salamander showed very consistent hourly energy rate profiles, indicating that the appliance was not turned off during dining service until the end of the day. However, the operator at Artisan Bistro was more aware of energy use; the daily profile in Figure 158 shows the salamander was turned off between lunch and dinner. The salamander had a rated input rate of 32 kBtu/h.

**Table 37: Artisan Bistro Results—Daily Energy Consumption**

| Btu/Day | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Week 1** | **Week 2** | **Week 3** | **Week 4** | **Week 5** | **Week 6** | **Week 7** | | |
| Mon | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Min | 165,381 |
| Tue | 298,276 | 318,949 | 313,042 | 324,855 | 193,929 | 208,695 | 206,726 | Max | 342,575 |
| Wed | 247,087 | 297,292 | 329,777 | 308,120 | 329,777 | 187,038 | | Avg | 284,122 |
| Thur | 329,777 | 310,089 | 321,902 | 216,570 | 254,962 | 262,837 | | | |
| Fri | 337,653 | 332,731 | 322,886 | 252,009 | 258,900 | 277,604 | | | |
| Sat | 342,575 | 325,840 | 339,621 | 270,713 | 287,448 | 293,354 | | | |
| Sun | 311,074 | 288,432 | 317,964 | 252,009 | 276,619 | 165,381 | | | |

Source: FNi

**Table 38: Artisan Bistro Results—Salamander Hours of Operation**

| Hours | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mon | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | Min | 5.5 |
| Tue | 10.3 | 10.8 | 10.7 | 11.4 | 6.8 | 7.0 | 7.0 | Max | 11.8 |
| Wed | 9.2 | 10.4 | 11.2 | 10.3 | 11.2 | 6.3 | | Avg | 9.8 |
| Thur | 11.8 | 10.5 | 11.0 | 7.3 | 8.9 | 8.9 | | | |
| Fri | 11.6 | 11.2 | 11.0 | 8.9 | 9.2 | 9.8 | | | |
| Sat | 11.8 | 11.2 | 11.6 | 9.3 | 9.8 | 10.3 | | | |
| Sun | 11.2 | 9.9 | 11.0 | 8.9 | 9.5 | 5.5 | | | |

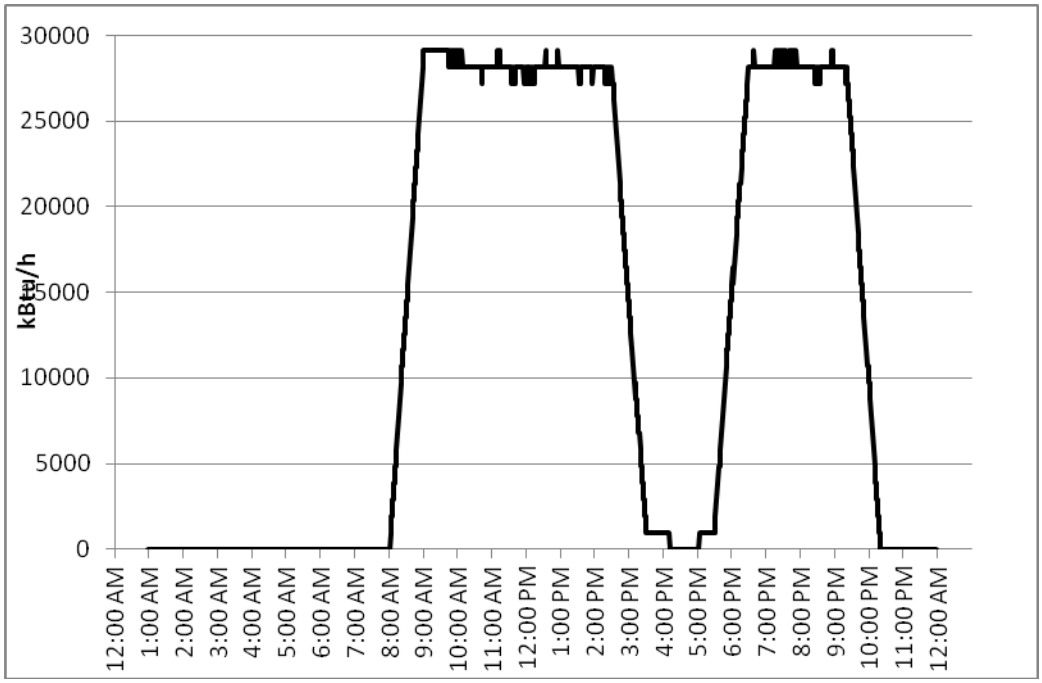
Source: FNi

**Table 39: Artisan Bistro Results—Hourly Energy Consumption Rate**

| Btu/h | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mon | | | | | | | | Min | 26,906 |
| Tue | 29,006 | 29,396 | 29,256 | 28,413 | 28,730 | 29,672 | 29,603 | Max | 30,012 |
| Wed | 26,906 | 28,632 | 29,532 | 30,012 | 29,357 | 29,610 | | Avg | 29,011 |
| Thur | 28,026 | 29,674 | 29,353 | 29,667 | 28,755 | 29,422 | | | |
| Fri | 29,150 | 29,752 | 29,265 | 28,210 | 28,244 | 28,424 | | | |
| Sat | 28,991 | 29,136 | 29,152 | 29,214 | 29,331 | 28,435 | | | |
| Sun | 27,899 | 29,135 | 28,819 | 28,369 | 29,067 | 29,798 | | | |

Source: FNi

**Figure 158: Daily Salamander Profile at Artisan Bistro**




Source: FNi

### 7.5.3 Summary of Results and Discussion

Both sites showed the broilers operating at a fairly constant rate over long operating hours. The first site exhibited a duty cycle of 83 percent for the salamander broiler over a 12.5-hour typical operating day. The second site exhibited a duty cycle of 90 percent for the salamander broiler

over a 9.6-hour typical operating day. Average daily gas use and average daily hours of use illustrated in Table 40 shows very similar usage profiles.

**Table 40: Summary of Results**

| Site | Sunrise Bistro | Artisan Bistro |
|---|---|---|
| Average Daily Gas Use (therms) | 2.03 | 2.84 |
| Average Daily Hours of Use | 12.5 | 9.8 |
| Average Consumption Rate (kBtu/h) | 16.6 | 29.0 |

Source: FNi

## 7.6 Conclusions and Recommendations

### 7.6.1 Conclusions

This project had successfully characterized energy use of salamanders. Salamanders used at both sites showed consistent profiles, indicating they typically operate in a fully "on" or "off" mode, not modulated like the burner on an open-top gas range.

Major findings of the field data showed that salamander broilers have flat usage profiles and are not modulated often during operation, if at all. Because of the lack of controls in current models, incorporating demand use sensors to reduce total gas consumption could improve efficiency in future models.

Previous research in PIER project 505-06-028, *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment*, indicates there are approximately 24,433 units of salamander broilers consuming an estimated 11.7 million therms in California. By improving salamander efficiencies by ten percent can yield a potential category savings of 1.17 million therms assuming 100 percent market penetration. This correlates to saving 0.82 million dollars annually.

### 7.6.2 Recommendations

It is recommended that energy-saving features, such as a demand sensor used to cycle the unit on or off as food is loaded or unloaded, be incorporated into salamanders. A demand sensor could be a pressure switch that is tripped when product is placed within the salamander. Improved unit construction through better insulation can further increase the efficiency of a salamander by minimizing heat loss through the unit. A range-top field study, *Commercial Gas Range Field Study*, was performed as part of CEC project 500-09-044, which showed an annual consumption of 16.6 million therms of gas for open-top ranges. When the impact of the sites in this range study are compared with the annual 11.7 million therms for salamanders across the state, it shows that salamanders have as significant an energy footprint as ranges, and that it is worth continuing to examine improvements in salamander design.

# CHAPTER 8:
# Commercial Water Heaters

## 8.1 Introduction

### 8.1.1 Background

Despite the large operating cost associated with the service of hot water in commercial facilities and the number of facilities that can benefit from energy efficiency measures, there has been little motivation to develop and promote high-efficiency, gas-fired water heating equipment and systems. There is immense potential to increase the overall system operating efficiency of hot water systems in the commercial sector. Water heaters installed in commercial facilities operate at reduced efficiencies for a variety of reasons, many of which were explored, and are connected to inefficient distribution systems.

Water heating in commercial installations, particularly process intensive facilities such as commercial foodservice, represents a significant gas load in California. A California Public Utilities Commission Study in 2000 estimated natural gas usage in commercial facilities at 2,100 million therms annually with 38 percent of the gas used for water heating. This equates to 800 million therms annually for water heating (CPUC 2003). Similarly, the FSTC estimated an annual gas load of 620 million therms in segments of the commercial sector with moderate to high hot water load for this report. These segments include: bar and taverns, coffee and specialty stores, quick and full service restaurants, schools, supermarkets, cafeterias, hotels, casinos, hospitals, colleges and universities, correctional facilities, personal care services, office buildings, nursing and residential care, laundry facilities, and hotels without foodservice.

In the report, characterizing hot water use in commercial kitchens, restaurants are estimated to use for water heating (Delagah 2010 p.35). In 2013, FSTC updated this estimate for restaurants from recent field monitoring research and showed an increase in annual gas load at 320 million therms. This is based on the average daily hot water use estimate in full-service restaurants being increased from 2000 to 2500 gallons per day and in quick-service restaurants, the average daily temperature rise was increased from 70 to 75°F for an increase from 2010 estimates of 58 and 2 million therms, respectively.

After researching and field monitoring of hot water systems in foodservice facilities for the last decade, FSTC saw the need to quantity savings from a large array of energy efficiency measures, and more importantly study heat losses from various distribution systems. Coincidently, the PG&E Applied Technology Services (ATS) was conducting similar testing at the Residential Water Heater Laboratory with great success. The idea arose to develop a the PG&E Commercial Water Heating Laboratory (CWHL) to test various heaters in combination with various distribution systems and quantify performance for various commercial applications. The build out of the CWHL for this project was modeled after the design of an actual hot water system in a quick service restaurant.

### 8.1.2 Assessment Objectives

The objective of this laboratory testing initiative was the investigation of a laboratory protocol to better predict the performance and energy use of commercial water heaters (in the field) and evaluate the efficiency potential of high-efficiency (condensing) tank-type and tankless commercial water heaters. This included comparisons of water heater system performance using real world draw profiles with and without some typical retro-commissioning (RCx) modifications, along with understanding the impact on water heater efficiency through preheating of inlet water (for example, from a solar system). The goal of this testing program was be to increase knowledge with respect to real world efficiencies of commercial water heaters, the implication of preheating incoming water on system efficiency, and retrofit opportunities in support of utility customer energy efficiency programs developed for commercial water heating systems. More specifically, the goal of this PIER study was to:

1. Stimulate the purchase of high-efficiency (condensing) water heaters for both retrofit and new construction.
2. Secure energy savings through a water heater RCx initiative including operational flue-damper, insulation, and optimizing distribution.
3. Promote emerging waste energy recovery technologies (e.g., refrigerant heat recovery) and solar for preheating domestic hot water. Of particular relevance, is the impact that preheating the incoming water will have on the performance of high-efficiency water heaters.
4. Expand on best practice guidelines for designing and operating water heating systems in commercial foodservice.
5. Obtain at least a 15 percent savings in energy consumption in comparison to traditional technology.

## 8.2 Field Monitoring

The purpose of this field study was to generate real-world, daily hot water flow test profiles for a quick-service restaurant (QSR) with a recirculation system. A representative daily flow profile from the field testing of the water heater was identified. It was then analyzed alongside flow data gathered from hot water using fixtures to develop individual end-use profiles for sinks and equipment that correspond with the test points in the laboratory. The flow rates at these test points in the laboratory were setup to mimic six key fixtures found in quick-service and full-service restaurants and included: the 3-compartment sink, mop sink faucet/hose bib, kitchen hand sink, lavatory sink, dishwasher and pre-rinse spray valve. This repeatable test profile was used subsequently to test and compare various water heater technologies and distribution system architectures in the laboratory.

For this QSR test profile, data from four key hot water use components (3-compartment sink, hand sinks, mop sink faucet/hose bib, and lavatory sinks) were isolated to generate a 500 gallon 24-hour test profile.

### 8.2.1 Site-Monitoring Instrumentation and Procedures

The instrumentation package that was used for field testing of the hot water heater included two diaphragm type gas meters multi-jet water meter installed on the cold water supply line and thermocouple temperature probes located at the water heater inlet, outlet and hot water return piping. A central data logger was used to log at a 5-second interval and process and store average temperature and cumulative water and gas consumption.

End use monitoring at selected sinks and equipment provided distinct hot water use profiles that were overlaid on to the water heater hot water load profile in order to provide hot water use profiles at each distinct hot water end use fixture. The measured and disaggregated hot water end-use profiles were analyzed to develop a custom profile that was used for testing at the CWHL in subsequent tasks.

Water Heater Measurement points:

- Inlet water temperature
- Outlet water temperature
- Hot water return temperature
- Hot water flow
- Gas consumption

Water Heater Instrumentation:

- Thermocouple Wire: Therm-X Class 1 Type T beaded wire (Tolerance ±0.5°F (±0.5°C) or 0.4 percent) were affixed to the outer copper pipe walls and the interface treated with heat-sink compound, wrapped with electrical tape and covered with foam pipe insulation
- Gas meter: Elster BK-G4 Diaphragm type gas meter with 1 pulse/$ft^3$ output, flows from 1.4 $ft^3$/h to 200 $ft^3$/h
- Water meter: ¾" Omega FTB8007A-PR multi-jet meter with 1 pulse/gal output, accuracy is 1.5 percent of reading, flow range of 0.22 to 22 gpm
- Data logger: DataTaker DT80 configured to record thermocouple and flow meter inputs at 5-second intervals

End Use Sink or Equipment Measurement points:

- Hot water inlet temperature
- Hot water flow

End Use Sink or Equipment Instrumentation:

- Thermistor temperature sensors enclosed in a brass assembly were installed inside the brass pipe
- Water meter (hand washing sinks and pressure washer): 3/8"Gems FT-110 Turbine meter with 8300 pulse/gal output, accuracy 3 percent of reading, flow range of 0.26 to 4 gpm

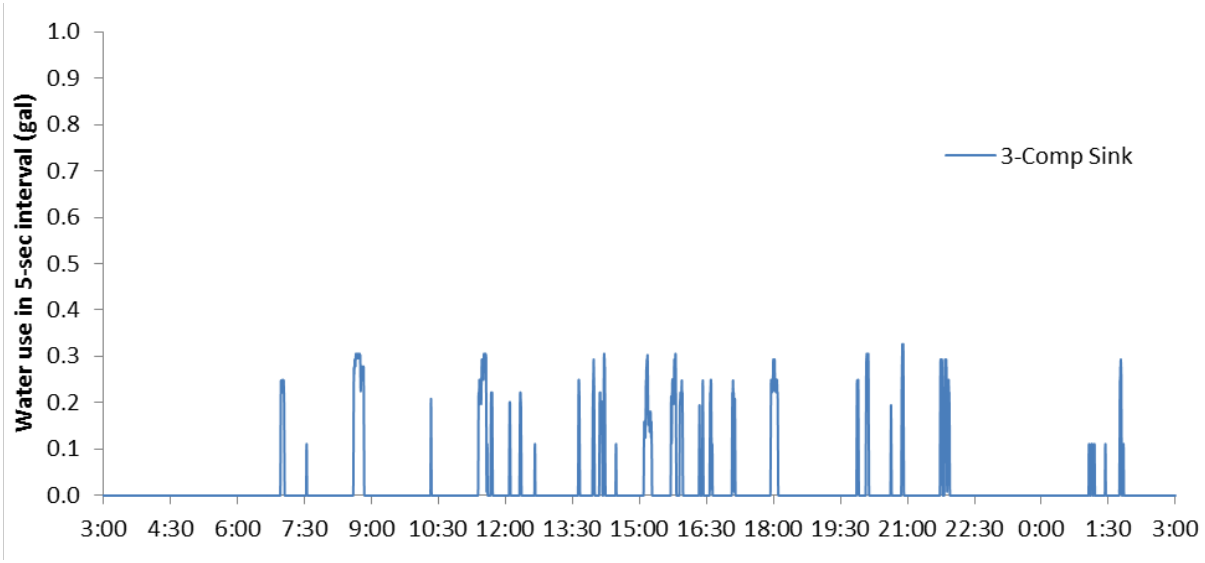
- Water meter (3-compartment sink or Power soak sink): ¾" Minol Minomess 130 multi-jet turbine meter with 1 pulse/gal output, accuracy 1.5 percent of reading, flow range of 0.25 to 22 gpm
- Data logger (each sink or appliance): Pace Scientific XR5-SE-M configured to record thermocouple and flow meter inputs at 5-second intervals

### 8.2.2 Hot Water Flow Test Profile Development

The hot water flow profile for February 8th, 2011 was selected out of six days where the entire hot water system was monitored at the end-use faucets. Water use was measured and logged at the water heater, 3-compartment sink, 2-compartment sink, preparation sink, 3 lavatory sinks, two hand sinks and hose bib. The only location that was not monitored in the actual restaurant was the mop sink. The mop sink hot water use profile was developed by plotting the hot water use profile at the water heater and the combined end-use profiles at the faucets. Any major water use events on the water profile that did not align with the totalized end-use profile where assigned to the mop sink. End-use monitoring at every location was not amenable to the restaurant representative and not practical at the mop sink.

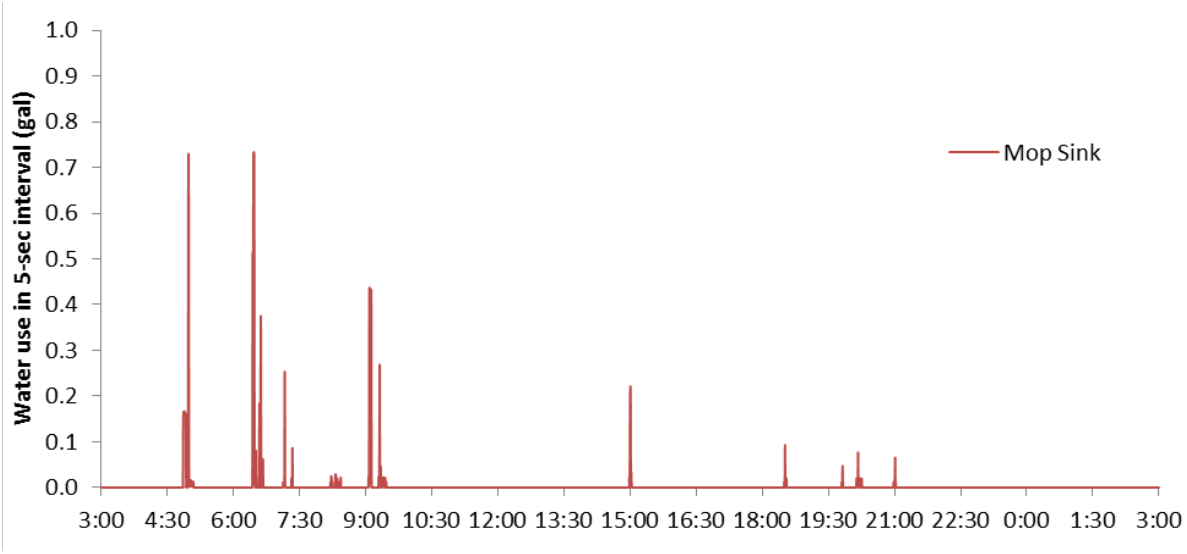
From the monitored data four individual hot water use profiles were developed. The flow profiles are highlighted in Figure 159 to Figure 162 for the 3-compartment sink, mop sink, total of three lavatory sinks and two kitchen hand sinks, respectively.

**Figure 159: Water Use Profile at the 3-Compartment Sink**



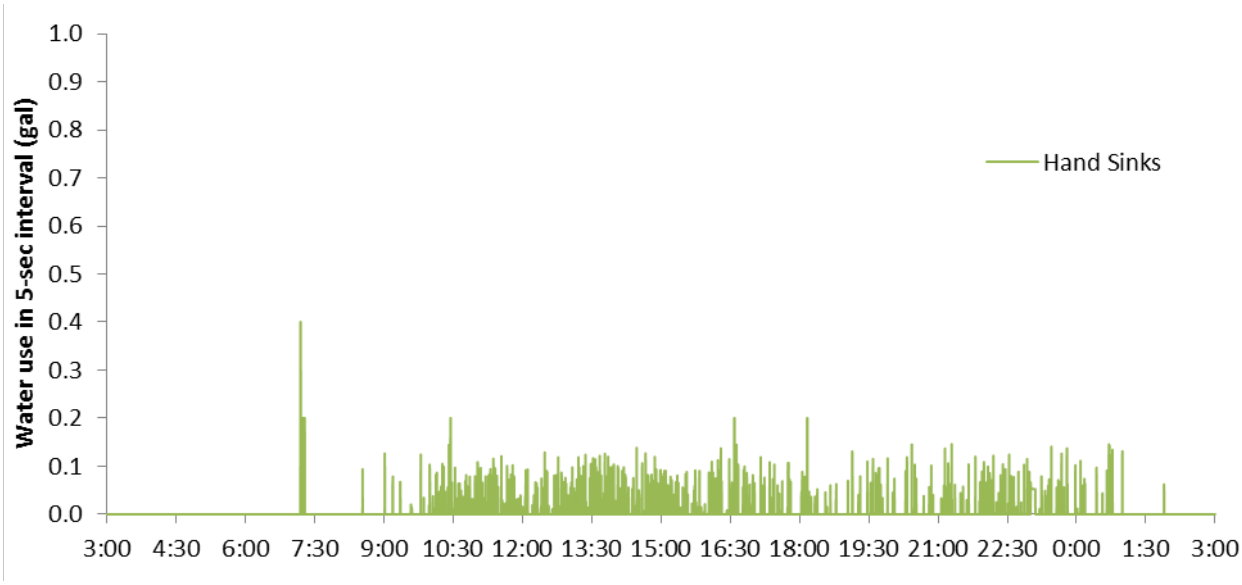

Source: FNi

**Figure 160: Water Use Profile at the Mop Sink**



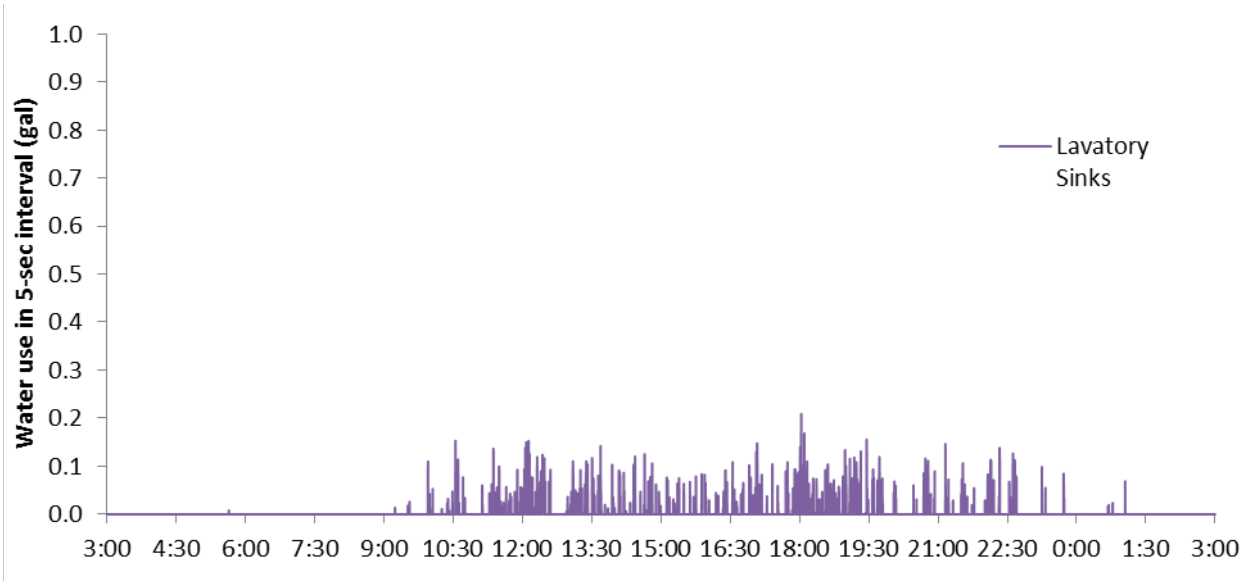

Source: FNi

**Figure 161: Combined Water Use Profile at the Hand Sinks**




Source: FNi

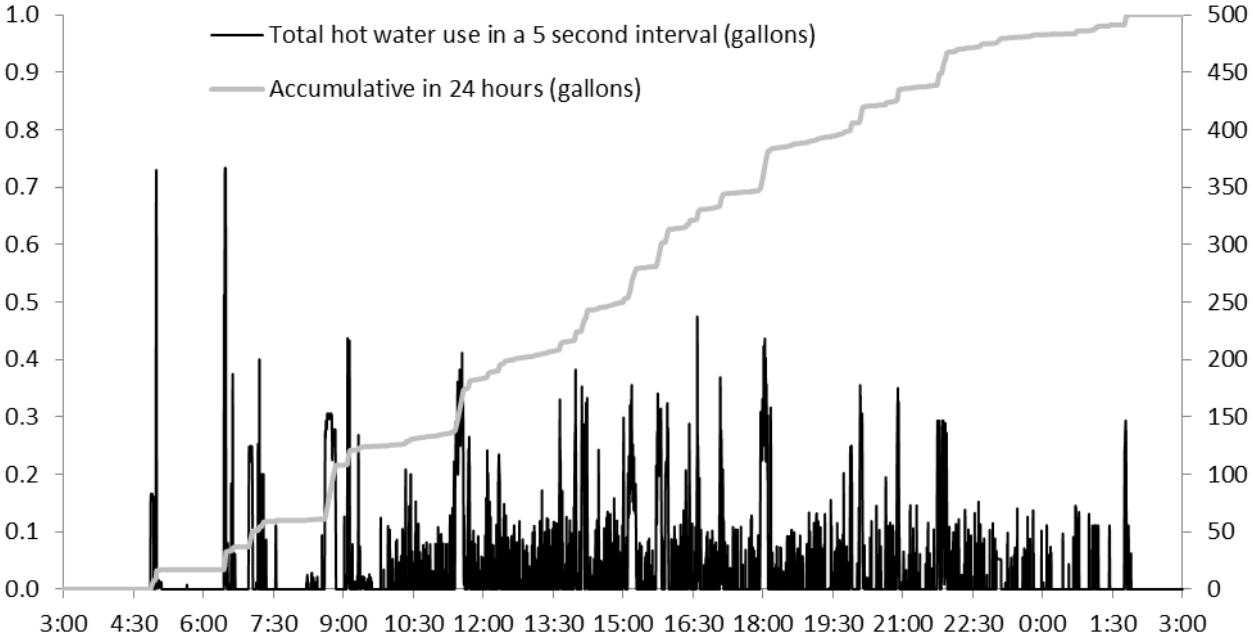
**Figure 162: Combined Water Use Profile at the Lavatory Sinks**




Source: FNi

Data from field testing at the four fixture types correspond to fixtures simulated in the lab for the QSR test. All QSRs have these four common sinks utilized in their facility. Combining the four daily water use profiles together in one plot yielded a total daily hot water use of 500 gallons (Figure 163). Previous field monitoring data has shown that 500 gallons is consistent with average daily hot water use in several quick-service restaurants (Karas, A. 2007).

**Figure 163: Real-World Draw Profile from Field Monitoring**

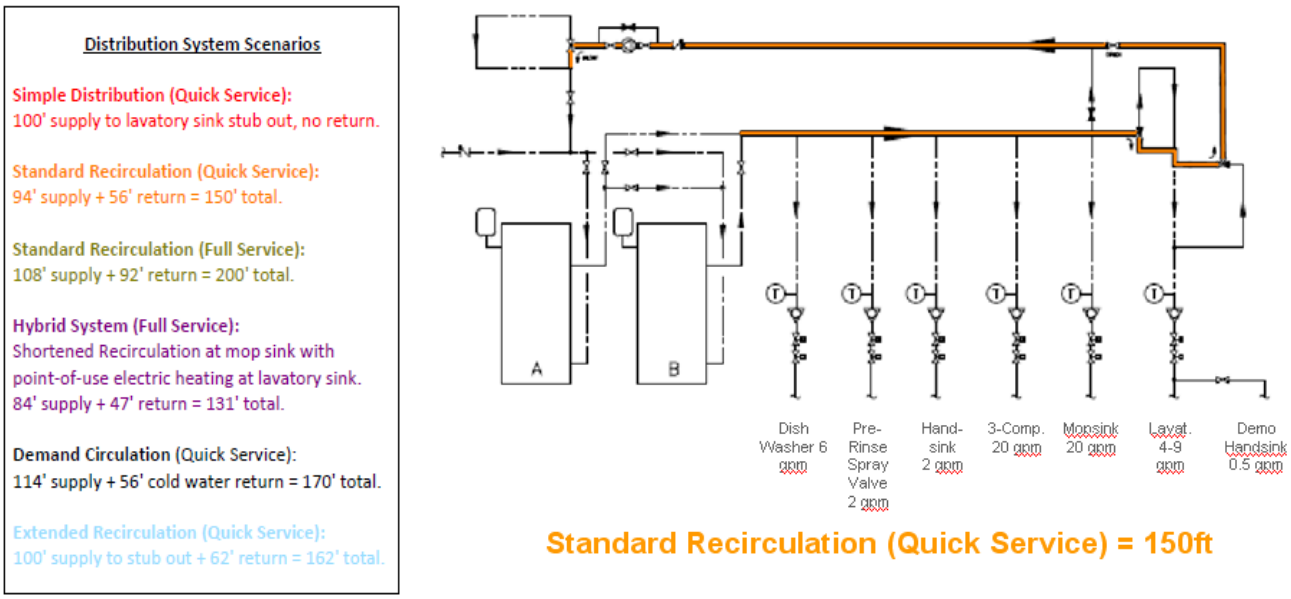



Source: FNi

## 8.3 Laboratory Configuration

The CWHL was configured to mimic up to six restaurant hot water distribution system scenarios as outlined in Figure 164. The simulated fixtures were at designated lengths down the hot water supply line to mimic what is commonly found in real world restaurant configurations. The test apparatus integrated up to four water heaters that can be plumbed in series or in parallel. All 24-hour draw profile tests were performed using the standard recirculation distribution system arrangement to simulate performance impacts of various retrofit and retro commissioning measures on a typical QSR hot water system.

**Figure 164: Distribution System Scenarios and Schematic for Standard Recirculation) Distribution Configuration**




Source: PG&E ATS

### 8.3.1 Equipment Under Test

The following list includes the water heaters that were used for testing. The technologies were selected to compare both standard and high-efficiency tankless and tank-type water heaters. Each was expected to perform differently when challenged by the standardized hot water load profile due to the dissimilar components and variance in rated thermal efficiency (TE). Both tankless units were actually residential models that could be used in a commercial application. Note that both tankless units have flow rate limitations, and that in a restaurant application both units may need to be installed in parallel with another water heater to achieve the required peak flow.

- **HEATER 1:** High Efficiency Tank: A. O. Smith Cyclone Xi, Model #:BTH 199 100, 100 gallon, 199,900 Btu/h input, 95 percent TE
- **HEATER 2:** Standard-Efficiency Tank: A.O. Smith Master-Fit, Model #:BTR 197 118, 100 gallon, 199,000 Btu/h input, 80 percent TE

- **HEATER 3:** High Efficiency Tankless: Takagi Flash T-H1, 199,000 Btu/h input, 92 percent EF
- **HEATER 4:** Standard-Efficiency Tankless: Rinnai R94LSi, M/N REU-VA2535FFUD-UC, 199,000 Btu/h input, 82 percent Energy Factor

### 8.3.2 Test Apparatus

The PG&E Water Heating Laboratory in San Ramon was expanded to accommodate testing of commercial water heating systems with the capability of evaluating both the water heating equipment and the hot water distribution loop. The commercial water heating test apparatus was designed to meet the test conditions as defined by ANSI Standard 118.1-2008, and to simulate operation under real world conditions as seen in the foodservice industry, more specifically, quick-service and full-service restaurants.

In order to simulate real world conditions, the test apparatus was essentially an operational and fully instrumented hot water distribution system with simulated fixtures and a recirculation loop. The test apparatus included flexibility in distribution lengths, paths, and fixtures, in order to represent a greater assortment of restaurant water heating systems and to evaluate options for energy efficiency improvements. The design of the test apparatus included input from restaurant plumbing experts in order to lay out a system with realistic plumbing sizing, lengths, and location of fixtures downstream from the water heaters. The fixture flow rates were set with an adjustable flow control valve. In order to simulate a hot water draw, a solenoid valve was opened at that fixture and the water flows at the set flow rate. Draw profiles are programmable as described further in the sections below.

For the purposes of this test while utilizing the real world profile, the distribution system was set to simulate the standard QSR recirculation loop, except where noted. Also, all tests were conducted with pipe insulation, except where noted. The fixture flow rates were adjusted to match the average hot water flow rates of each fixture as determined by the real world draw profile defined in Figure 163.

### 8.3.3 Measurements and Instrumentation

Measurements taken were mostly those required by the ANSI test standard, and includes measurements necessary to calculate the energy removed in a hot water draw (flow and temperatures in and out of the tanks and at fixtures), the energy consumed by the water heater (gas and electric energy input), the energy consumed by the recirculation pump, the change in stored energy in the tank (tank temperatures), and the ambient conditions (air temperature, humidity, and pressure). For the complete list of measurements and accuracy used as guidelines for instrumentation, reference ASHRAE Standard 118.1-2003 Section 6.1.

#### *8.3.3.1 Instrument Calibration*

Prior to testing, all of the resistance temperature detectors (RTDs) were calibrated against a laboratory standard temperature sensor in an ice bath (32°F, 0°C), and a gallium melting point cell (85.6°F, 30°C). Upon completion of testing, RTD temperature probe calibration were verified against a laboratory standard temperature sensor in an ice bath and an isothermal block at 110°F (43°C) and 190°F (88°C) (Figure 165). The range of calibration temperatures was selected

to bind all temperatures seen by each probe during the course of testing. Pressure sensors were calibrated using a dead weight tester before and after testing, Figure 166. After testing was complete, a ½″ Coriolis flow standard was used to calibrate each water flow meter used in the system.

**Figure 165: Isothermal Temperature Block Used for RTD Probe Calibration**

Photo Credit: PG&E ATS

**Figure 166: Ametek PKII Dead Weight Pressure Calibration Standard**

Photo Credit: PG&E ATS

#### *8.3.3.2 Data Processing and Measurement Uncertainty*

An uncertainty analysis was performed on each of the measurement parameters used to establish water heater thermal efficiency. Sources of error, such as repeatability of pretest vs. post-test calibrations and error due to fluctuating test data are accounted for in all temperature, pressure and water flow parameters.

#### *8.3.3.3 Repeatability of Calibrations (pre vs. post test calibration)*

Some drift in measurement may have occurred during the course of testing between pre and post calibrations. In order to account for the impact of this drift on the overall uncertainty, precision and bias errors were quantified. The equation below provides the calculation of precision error resulting from repeatability in calibration of instrumentation:

$$\text{Repeatability of Calibrations (Precision Error)} = \frac{SEE}{\sqrt{\sum CalibrationPts}}$$

Where:

SEE = Standard Error of Estimate of a correction curve fit to the calibration data

CalibrationPts = Number of calibration points performed on instrumentation

The equation below provides the fossilized bias error resulting from repeatability in calibration of instrumentation:

$$\text{Calibration Uncertainty} = \sqrt{\left(\frac{SEE}{\sqrt{\sum CalibrationPts}} * t\right)^2 + (CalBias)^2}$$

Where:

SEE = Standard Error of Estimate

CalibrationPts = (Summed) calibration points performed on instrumentation

t = Student t degrees of freedom in pre and post-test calibration data

CalBias = Bias error introduced by instrument calibration, including uncertainty in standards themselves as well as the applied calibration offsets.

#### *8.3.3.4 Error Due to Fluctuating Test Data*

Uncertainty is introduced to the measured parameter by fluctuation of data between one measurement and the next. The impact of these precision errors from one measurement to the next on the total uncertainty can be reduced by taking more data points. The equation below provides the calculation of precision error resulting test data fluctuations:

$$\text{Error Due to Fluctuating Test Data (Precision Error)} = \frac{\sigma}{\sqrt{\sum DataPts}}$$

Where:

$\sigma$ = Standard deviation in test data

DataPts = (Summed) test data measurements

The square root of the sum of individual uncertainty components above were taken to determine the total uncertainty in the measured parameter.

### 8.3.4 Data Acquisition and Controls

The instrumentation was connected to multiple rack-mounted Compact FieldPoint modules from National Instruments, depending on the signal type. The signal conditioning modules included different units for RTDs, thermocouples, voltage and pulse count (water and gas meters) inputs, plus both analog and digital output modules for the mixing valve and solenoid valves, respectively. Each rack included an Ethernet communications module that enabled the system to be accessed from anywhere on the local area network.

A local computer connected to the local area network ran a program written in National Instrument's LabVIEW graphical programming language. This program was developed to read all the measurement devices, display the readings and additional calculated values on screen, and save the data to disk for later analysis, as well as control the water draws and inlet temperature. The system was programmed such that the water draws could be automated over a 24-hour period. The scan rate for sampling from the FieldPoint modules and updating the screen was set at 2 Hz, although the internal scan rate of the modules was 10 Hz.

The frequency at which data was averaged and recorded to disk meets specifications defined by ANSI standard. In addition, the logging interval can be set to depend on the status of the water heater. During a water draw, readings can be recorded at the highest frequency; typically 5 seconds, but can be set faster if more resolution was desired. During the real world profile tests, the data may be logged at a slower rate during periods when the water heater is on standby or there are no draws taking place.

### 8.3.5 Operation

A user interface built in LabVIEW was designed for the test operator to visually monitor the test apparatus. The user interface integrates both manual and automatic controls where a draw profile script is programmed to automatically run on the system. Only one draw profile script was necessary for this testing for running the real world hot water draw profile, described further below. The thermal efficiency test was better done on a manual basis.

The simulated fixtures consisted of a drop from the hot water distribution line, RTD for temperature measurement, turbine flow meter, a solenoid valve, and a flow control valve. The flow control valve was set to the average real world flow rate for the assigned fixture by manual adjustment and while monitoring the flow rate. For example, from the fixture data compiled in section 8.2, the mop sink had a hot water flow rate average of 0.9 gpm which would be applied to the fifth fixture down the hot water supply line. When a draw on the mop sink is programmed, the solenoid valve opens for the duration of the draw and the flow control valve

maintains the set flow rate. The total gallons for each draw will vary slightly from the provided profile, but the 24-hour total is nearly equal.

## 8.4 Laboratory Test Methodology

Laboratory testing was conducted after the field monitoring study to gather a real world profile to be used in laboratory testing. The laboratory testing evaluated the performance of commercial water heating systems under various configurations and was broken into three separate tasks. The results of the first laboratory testing task, 4.2, defined the baseline performance for comparison to the performance results from Tasks 4.3 and 4.4. Testing evaluated water heater performance using both ANSI Standard 118.1-2008 thermal efficiency test and a real world profile for 24-hour hot water usage as described further in the sections that follow.

### 8.4.1 Laboratory Testing and Comparison of Thermal Efficiency

The goal of Task 4.2, was to test four water heaters using both the ANSI Z21.10.3/CSA 4.3-2004 test procedures and a real world hot water use profile to compare thermal and system distribution efficiency results. Water heater thermal efficiency was measured and analyzed by calculating the energy output of the hot water heater, divided by the energy consumption of the water heater. The hot water distribution system delivery efficiency was measured and analyzed by calculating energy out of the system as delivered by the fixtures, divided by energy in described in the analysis section below. The data was collected using the test apparatus and automated data acquisition system and controls as described in the Laboratory Configuration section above. Analysis of the data is described in the Analysis section.

Task 4.2 General Test Conditions

ANSI Thermal Efficiency Test

- 70°F (21°C) Inlet Water Temperature
- 140°F (60°C) Outlet Water Temperature
- Maintain Maximum Firing (Or Max Possible Firing)
- Allow System to Reach Steady State (i.e. Constant Tank Temperature)

ANSI Standby Loss Test

- Maintain Room Temperature to 70°F (21°C)
- Set Water Heater to 140°F (60°C)
- Allow No Mass to Flow Through Heater

24-Hour Draw Profile – Real World QSR Draw Profile

- With the System Recirculation Pump Running and Insulated Distribution Lines
    - Set Water Heater to 140°F (60°C)
    - Set Fixture Flow Rates to Total Approx. 500 Gallons Delivered
- Without The System Recirculation Pump Running and Insulated Distribution Lines

- Set Water Heater to 140°F (60°C)
- Set Fixture Flow Rates to Total Approx. 500 Gallons Delivered

The test conditions for Task 4.2 are summarized in Table 41 and the complete Task 4.2 testing matrix is shown in Table 42.

**Table 41: Task 4.2 Test Condition Description**

| Task 4.2 Test Conditions | | | |
|---|---|---|---|
| Condition # | Test Condition Description | Distribution System Insulation | Recirculation |
| 1 | ANSI Thermal Efficiency | n/a | n/a |
| 2 | ANSI Standby Loss | n/a | n/a |
| 3 | 24-Hour Draw Profile (QSR Profile) | Fully Insulated | Yes |
| 4 | 24-Hour Draw Profile (QSR Profile) | Fully Insulated | No |

Source: PG&E ATS

**Table 42: All Tests Included in Task 4.2**

| Test I.D. | Heater # | Task | Test Condition | Inlet Temp, °F (°C) | Outlet Temp, °F (°C) | Run # |
|---|---|---|---|---|---|---|
| **1.4.2.1.70.140** | 1 | 4.2 | 1 | 70 (20) | 140 (60) | ALL |
| **1.4.2.2.X.140.1** | 1 | 4.2 | 2 | X | 140 (60) | 1 |
| **1.4.2.2.X.140.2** | 1 | 4.2 | 2 | X | 140 (60) | 2 |
| **1.4.2.2.X.140.3** | 1 | 4.2 | 2 | X | 140 (60) | 3 |
| **1.4.2.3.X.140.1** | 1 | 4.2 | 3 | X | 140 (60) | 1 |
| **1.4.2.3.X.140.2** | 1 | 4.2 | 3 | X | 140 (60) | 2 |
| **1.4.2.4.X.140.1** | 1 | 4.2 | 4 | X | 140 (60) | 1 |
| **2.4.2.1.70.140** | 2 | 4.2 | 1 | 70 (20) | 140 (60) | ALL |
| **2.4.2.2.X.140.1** | 2 | 4.2 | 2 | X | 140 (60) | 1 |
| **2.4.2.2.X.140.2** | 2 | 4.2 | 2 | X | 140 (60) | 2 |
| **2.4.2.3.X.140.1** | 2 | 4.2 | 3 | X | 140 (60) | 1 |
| **2.4.2.3.X.140.2** | 2 | 4.2 | 3 | X | 140 (60) | 2 |
| **2.4.2.4.X.140.1** | 2 | 4.2 | 4 | X | 140 (60) | 1 |
| **2.4.2.4.X.140.2** | 2 | 4.2 | 4 | X | 140 (60) | 2 |
| **3.4.2.1.70.140** | 3 | 4.2 | 1 | 70 (20) | 140 (60) | ALL |
| **3.4.2.3.X.140.1** | 3 | 4.2 | 3 | X | 140 (60) | 1 |
| **3.4.2.3.X.140.2** | 3 | 4.2 | 3 | X | 140 (60) | 2 |
| **3.4.2.4.X.149.1** | 3 | 4.2 | 4 | X | 140 (60) | 1 |
| **4.4.2.1.70.140** | 4 | 4.2 | 1 | 70 (20) | 140 (60) | ALL |
| **4.4.2.3.X.140.1** | 4 | 4.2 | 3 | X | 140 (60) | 1 |
| **4.4.2.3.X.140.2** | 4 | 4.2 | 3 | X | 140 (60) | 2 |

| Test I.D. | Heater # | Task | Test Condition | Inlet Temp, °F (°C) | Outlet Temp, °F (°C) | Run # |
|---|---|---|---|---|---|---|
| **4.4.2.4.X.140.1** | 4 | 4.2 | 4 | X | 140 (60) | 1 |
| **4.4.2.4.X.140.2** | 4 | 4.2 | 4 | X | 140 (60) | 2 |

*ALL indicates one or more consecutive 30 min. thermal efficiency tests within the same Test I.D.

Source: PG&E ATS

### 8.4.2 Energy Savings through Retro-Commissioning and Retrofit

The goal of Task 4.3 was to apply retro-commissioning (RCx) and retrofit measures to the QSR distribution system in the laboratory and evaluate the energy efficiency improvements of each measure. Some retrofit measures were combined for some of the tests. Results from testing were used to estimate energy efficiency improvements expected by each RCx and retrofit option. In addition, lab results were compared to results described in the field study report "*Energy Saving Potential for Commercial Water Heating through Retro-Commissioning*" by the FSTC (Karas 2008). Special attention and additional inquiry were applied to the RCx measures found to be inconsistent in the field study and adjustments will be made to the system in order to optimize energy savings from the retrofit measure. The RCx and retrofit measures that were tested are identified below along with notes for investigation:

Task 4.3 General Test Conditions

Overall Comments

- Each test underwent a consistent 24-hour draw profile (QSR Profile).
- System delivery efficiency was calculated for each of the conditions listed below.
- All tests were performed on the standard-efficiency tank-type water heater.
- Heater temperature set point was 140°F (60°C), unless specified otherwise.
- Room temperature was to be maintained to 70°F (21°C).
- Recirculation was used for every test, unless controlled (timeclock, aquastat) or otherwise specified.

Disable Flue Damper

- The flue damper remained in the open position throughout the duration of the test.

Time Clock

- The recirculation loop was modified to be controlled with a time clock based on operation hours. The pump turned off at 1:30 am and on at 6:30 am.

Aquastat

- The recirculation pump was modified to be controlled by an aquastat.
- The aquastat temperature sensor was placed in the same location and orientation for each test, just upstream of the water heater inlet.

- The dead band of the aquastat was set to 10°F (8°C), with the temperature set to shut off the recirculation pump at 135°F (57°C) (temperature sensor is placed on the surface of the return line, internal pipe temperature may vary).

Point of Use Water Heaters

- The distribution system was be modified to not allow hot water flow to the lavatory sink to simulate a point of use water heater using cold water to meet the demand of the lavatory sink.
- Previous testing conducted at the FSTC yielded point of use water heater efficiency results to be used in calculation of overall system efficiency under this configuration.
- Energy delivery to the lavatory sink from task 4.2 testing on heater #2 was used to establish point of use heater output energy requirements.

Pipe Insulation

- No Insulation--Pipe insulation was completely removed from the test apparatus for this test to measure efficiency reduction.
- Partial Insulation - Test began with removal of insulation on lengths of pipe typically inaccessible in retrofit situations to identify added benefit to partially insulating the system where accessible.
- Full Insulation – Insulation covered all distribution piping.

160°F (70°C) Setpoint

- Test was performed at a temperature setpoint of 160°F (70°C). Some commercial kitchens try to compensate for undersized water heaters, poorly designed distribution systems or underperforming dishwashers by raising the thermostat setpoint.

Recirculation Pump Operation

- Tests were performed with and without recirculation of water through the distribution system to analyze the impacts on system performance.

The test conditions for Task 4.3 are summarized in Table 43 and the complete Task 4.3 testing matrix is shown in Table 44. Hot water distribution system delivery efficiency was measured and analyzed by calculating energy out of the system as delivered by the fixtures, divided by energy in described in the analysis section below. The data was collected using the test apparatus and automated data acquisition system and controls as described in the Laboratory Configuration section above.

**Table 43: Task 4.3 Test Condition Description**

| Task 4.3 Test Conditions | | | |
|---|---|---|---|
| Condition # | Test Condition Description | Distribution System Insulation | Recirculation |
| 6 | Disable Flue Damper | Fully Insulated | Yes |
| 7 | Timeclock | Fully Insulated | Varies |

| | | | |
|---|---|---|---|
| 8 | Aquastat | Fully Insulated | Varies |
| 9 | Point of Use - Lavatory Sink | Fully Insulated | Yes |
| 10 | Disable Flue Damper | Not Insulated | Yes |
| 11 | Timeclock | Not Insulated | Varies |
| 12 | Aquastat | Not Insulated | Varies |
| 13 | Point of Use-- Lavatory Sink | Not Insulated | Yes |
| 14 | Partial Insulation | Partially Insulated | Yes |
| 15 | No RCx Measure - w/ Recirculation | Not Insulated | Yes |
| 16 | 160°F (70°C) Temperature Setpoint | Not Insulated | Yes |
| 17 | No RCx Measure - w/o Recirculation | Not Insulated | No |

Source: PG&E ATS

**Table 44: All Tests Included in Task 4.3**

| Test I.D. | Heater # | Task | Test Condition | Inlet Temp | Outlet Temp, °F (°C) | Run # |
|---|---|---|---|---|---|---|
| **2.4.3.6.X.140.1** | 2 | 4.3 | 6 | X | 140 (60) | 1 |
| **2.4.3.6.X.140.2** | 2 | 4.3 | 6 | X | 140 (60) | 2 |
| **2.4.3.7.X.140.1** | 2 | 4.3 | 7 | X | 140 (60) | 1 |
| **2.4.3.7.X.140.2** | 2 | 4.3 | 7 | X | 140 (60) | 2 |
| **2.4.3.8.X.140.1** | 2 | 4.3 | 8 | X | 140 (60) | 1 |
| **2.4.3.8.X.140.2** | 2 | 4.3 | 8 | X | 140 (60) | 2 |
| **2.4.3.9.X.140.1** | 2 | 4.3 | 9 | X | 140 (60) | 1 |
| **2.4.3.10.X.140.1** | 2 | 4.3 | 10 | X | 140 (60) | 1 |
| **2.4.3.10.X.140.2** | 2 | 4.3 | 10 | X | 140 (60) | 2 |
| **2.4.3.11.X.140.1** | 2 | 4.3 | 11 | X | 140 (60) | 1 |
| **2.4.3.11.X.140.2** | 2 | 4.3 | 11 | X | 140 (60) | 2 |
| **2.4.3.12.X.140.1** | 2 | 4.3 | 12 | X | 140 (60) | 1 |
| **2.4.3.12.X.140.2** | 2 | 4.3 | 12 | X | 140 (60) | 2 |
| **2.4.3.13.X.140.1** | 2 | 4.3 | 13 | X | 140 (60) | 1 |
| **2.4.3.14.X.X.1** | 2 | 4.3 | 14 | X | 140 (60) | 1 |
| **2.4.3.14.X.X.2** | 2 | 4.3 | 14 | X | 140 (60) | 2 |
| **2.4.3.15.X.X.1** | 2 | 4.3 | 15 | X | 140 (60) | 1 |
| **2.4.3.15.X.X.2** | 2 | 4.3 | 15 | X | 140 (60) | 2 |
| **2.4.3.16.X.X.1** | 2 | 4.3 | 16 | X | 140 (60) | 1 |
| **2.4.3.16.X.X.2** | 2 | 4.3 | 16 | X | 140 (60) | 2 |
| **2.4.3.17.X.X.1** | 2 | 4.3 | 17 | X | 140 (60) | 1 |
| **2.4.3.17.X.X.2** | 2 | 4.3 | 17 | X | 140 (60) | 2 |

Source: PG&E ATS

### 8.4.3 Impact of Preheating Water on Thermal Efficiency

The goal of this task, 4.4, was to investigate the impact on the water heater TE when using preheated water as the supply to the tank (such as from a heat recovery or solar system). The ANSI thermal efficiency tests were run on all four of the water heater test units with varying inlet water supply temperatures to determine the effect on water heater performance. The same preheat temperatures were applied while repeating the real world profile on all four test units. In order to identify any venting-related issues caused by warm return water temperatures, the exhaust temperatures were monitored.

For most tests, the supply water to the water heater was maintained using the supply water tempering system. However, for purposes of this test, at high water supply inlet temperatures and higher resulting water heater outlet flow rates, the water tempering system did not have the capacity to maintain a stable inlet temperature. In order to provide a constant inlet water temperature to the unit under test, the test apparatus used supplemental heat from additional water heaters available in the lab. Table 45 lists the testing matrix for Task 4.4.

### 8.4.4 Test Plan

**Table 45: All Tests Included in Task 4.4**

| Test I.D. | Heater # | Task | Test Condition | Inlet Temp, °F (°C) | Outlet Temp, °F (°C) | Run # |
|---|---|---|---|---|---|---|
| 1.4.4.1.80.140 | 1 | 4.4 | 1 | 80 (27) | 140 (60) | ALL |
| 1.4.4.1.90.140 | 1 | 4.4 | 1 | 90 (32) | 140 (60) | ALL |
| 1.4.4.1.100.140 | 1 | 4.4 | 1 | 100 (38) | 140 (60) | ALL |
| 3.4.4.1.80.140 | 3 | 4.4 | 1 | 80 (27) | 140 (60) | ALL |
| 3.4.4.1.90.140 | 3 | 4.4 | 1 | 90 (32) | 140 (60) | ALL |
| 3.4.4.1.100.140 | 3 | 4.4 | 1 | 100 (38) | 140 (60) | ALL |
| 3.4.4.1.110.140 | 3 | 4.4 | 1 | 110 (43) | 140 (60) | ALL |
| 3.4.4.1.120.140 | 3 | 4.4 | 1 | 120 (49) | 140 (60) | ALL |
| 3.4.4.1.130.140 | 3 | 4.4 | 1 | 130 (54) | 140 (60) | ALL |

Source: PG&E ATS

## 8.5 Analysis

### 8.5.1 Water Heater Thermal Efficiency

To calculate the water heater TE for the unit under test, the following equation will be used per ANSI standard:

$$E_t = \frac{K * W * (\theta_2 - \theta_1)}{Q * C * H + E_c}$$

Where:

K = 1.000 Btu/lbm°F

W = total weight of water heated, lbs.

$\theta_1$ = average temperature of supply water, °F

$\theta_2$ = average temperature of outlet water, °F

Q = total gas consumption metered, $ft^3$

C = correction applied to higher heating value (HHV) when measured at non-standard conditions

H = total higher heating value of gas, $Btu/ft^3$

Ec = electrical consumption of water heater, in appropriate units

Results from both ANSI and preheat thermal efficiency tests will be presented with measurement uncertainty.

### 8.5.2 Water Heater Standby Loss

To calculate the ANSI water heater standby loss for the unit under test, the following equation will be used per ANSI standard:

$$S = \left[ \left[ \frac{C * Q * H + E_c}{K * W * \Delta T_3 * t} \right] - \left[ \frac{\Delta T_4}{\Delta T_3 * t * \frac{E_t}{100}} \right] \right] * 100$$

Where:

K = 1.000 Btu/lbmF

W = total weight of water heated, lbs.

Q = total gas consumption metered, actual $ft^3$

C = correction applied to HHV when measured at non-standard conditions

H = total heating value of gas, Btu/ $ft^3$.

Ec = electrical consumption of water heater

$t$ = test duration (hours)

$\Delta T_3$ = difference between the average value of the mean tank temperature and the average value of the ambient air temperature, °F

$\Delta T_4$ = difference between the final and initial mean tank temperature, °F

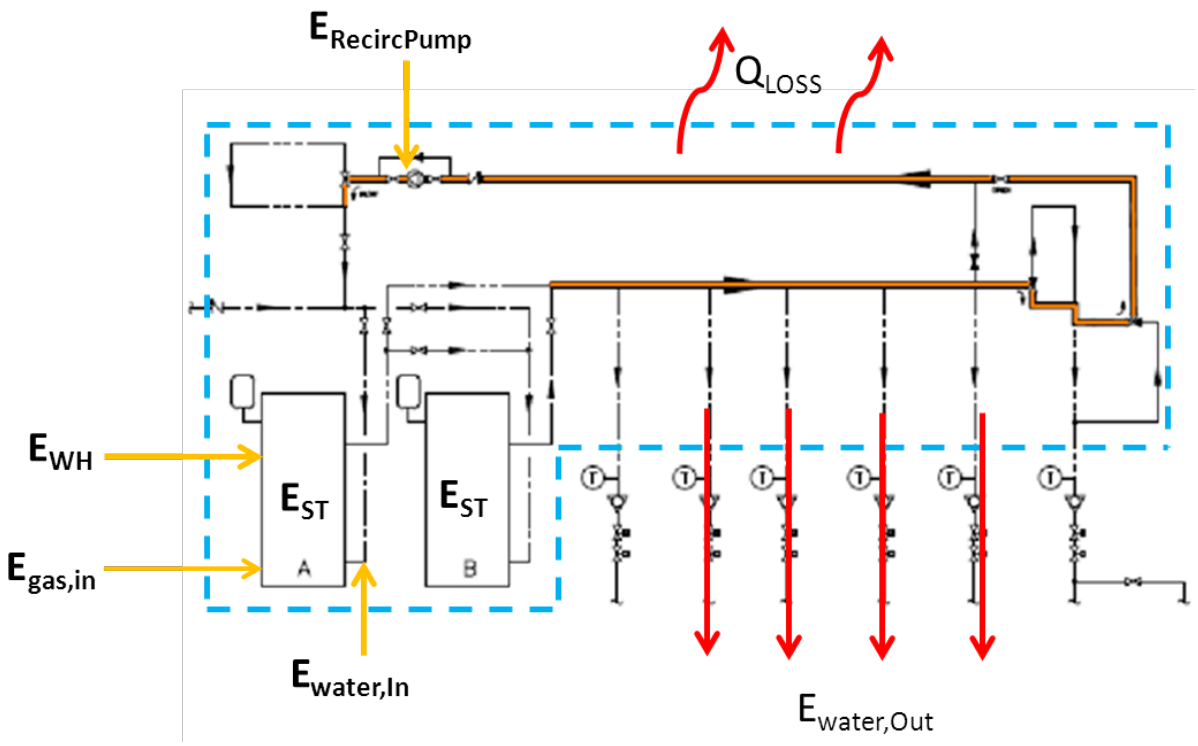
$E_t$ = thermal efficiency as determined under ANSI Method of Test for Measuring Thermal Efficiency.

Standby loss results are also displayed in units of Btu/hr.

### 8.5.3 Hot Water System Delivery Efficiency

System delivery efficiency was defined as the total amount of heat energy transferred to the water passing through the system divided by the total energy input to the system. In Figure 167, the boundaries of the control volume are identified, along with the energy entering the control volume, leaving the control volume and stored in the control volume. The system extends all the way to the point of use for each fixture.

**Figure 167: System Control Volume Boundary Definition Used for Establishing System Operating Efficiency. (Energy Storage Only Taken into Account When Testing Tank-Type Water Heaters)**




Source: PG&E ATS

More specifically, system delivery efficiency was defined as the amount of energy required to heat a volume of water by a measured temperature rise (the temperature difference between the end-use fixtures and the cold supply inlet) divided by the summation of natural gas energy input and auxiliary electrical energy input during a 24-hour test. Auxiliary electric energy input consisted of energy required to run the hot water heater as well as the distribution system recirculation pump, if running.

#### *8.5.3.1 Calculation of System Delivery Efficiency*

System delivery efficiency was calculated for each 24-hour real world draw profile test. The units used in this analysis are listed below:

- Volume: Water (gallons), Gas ($ft^3$)
- Density: ($lbm/ft^3$)
- Temperature: (°F)

- Pressure: Gas (inches $H_2O$), Atmospheric (psia)
- Specific Heat (Btu/lbm °F)
- Energy (Btu)
- Higher Heating Value (Btu/ft$^3$)

For 24-hour real world draw profile tests where hot water is supplied to tankless water heaters, system delivery efficiency was calculated using the following formula:

$$\eta_{\cdot DELIVERY-TEST-TANKLESS} = \frac{E_{out,Lavatory} + E_{out,HandSink} + E_{out,3CompSink} + E_{out,MopSink} - E_{in,CityWater}}{\left(Volume_{gas,std} * HHV_{gas}\right) + E_{aux}}$$

System energy storage was taken into account for tank-type water heater system delivery efficiency. For 24-hour real world draw profile tests where hot water is supplied to tank-type water heaters, system delivery efficiency was calculated using the following formula:

$$\eta_{\cdot DELIVERY-TEST-TANK-TYPE} = \frac{O.E._{\cdot TEST} + \Delta E_{Storage}}{I.E._{\cdot TEST}}$$

Where:

$O.E._{\cdot TEST}$ = Total system energy output during each test

$\Delta E_{Storage}$ = System energy storage difference between the beginning and end of each test

$I.E._{\cdot TEST}$ = Total system energy input during each test

#### *8.5.3.2 Output Energy Calculations*

Output energy was calculated as the difference in energy content of the water leaving and entering the system.

$$O.E._{\cdot TEST} = E_{out,Lavatory} + E_{out,HandSink} + E_{out,3CompSink} + E_{out,MopSink} - E_{in,CityWater}$$

Where:

$E_{out,Lavatory}$ = Energy content of water delivered to the lavatory sink

$E_{out,HandSink}$ = Energy content of water delivered to the hand sink

$E_{out,3CompSink}$ = Energy content of water delivered to the 3 comp sink

$E_{out,MopSink}$ = Energy content of water delivered to the mop sink

$E_{in,CityWater}$ = Energy content of city water entering the system

#### 8.5.3.3 Energy Content of Water Leaving the System

The energy content of water leaving the system at each individual fixture throughout 24-Hour draw profile was calculated as follows:

$$E_{out,HandSink} = \rho_{waterHandSink} * V_{delivered,HandSink} * c_{p,Water} * T_{delivered,HandSink}$$

Energy output from each fixture was calculated individually based on temperature and volumetric flow measurements at each fixture. Water temperature at each fixture was used to calculate density of water and energy content, averaged during a simulated draw event. The total delivery volume of each 24-hour draw profile was calculated as follows:

$$V_{delivered,Total} = V_{delivered,Lavatory} + V_{delivered,HandSink} + V_{delivered,MopSink} + V_{delivered,3CompSink}$$

#### 8.5.3.4 Energy Content of Water Entering the System

The energy content of city water entering the system throughout the 24-hour draw profile was calculated as follows:

$$E_{in,CityWater} = \rho_{CityWater} * V_{delivered,Total} * c_{p,Water} * T_{inlet,CityWater}$$

Where:

$\rho_{water,i}$ = Water density unique to each fixture, calculated using the temperature at each respective fixture

$V_{delivered,i}$ = Delivered volume of water at each respective fixture

$T_{delivered,i}$ = Water temperature at the Tee of each respective fixture

Energy content of the incoming water was calculated based on temperature at the system inlet, and the sum of volumetric flow from all fixtures.

#### 8.5.3.5 Storage Energy Calculations (Tank-Type Heaters)

Energy content of the water within the storage tank, in the defined system control volume, changed between the beginning and end of each test. Factoring in the chance in stored energy using the mean tank temperature allowed for differences in this energy storage to be accounted for to enable a better test to test system performance comparison. The calculation of stored energy content difference in the system between the beginning and end of each 24-hour draw profile was calculated as follows:

$$\Delta E_{Storage} = 100 * V_{\tan k} * \rho_{water} * (\theta_E - \theta_S)$$

Where:

$V_{tank}$ = Storage Tank Volume

$\rho_{water}$ = Water density, calculated using the mean tank temperature

$\theta_S$ = Mean tank temperature at the beginning of the test

$\theta_E$ = Mean tank temperature at the end of the test

$\Delta E_{Storage}$ = Change in energy content of the water heater storage tank between the beginning and end of each test

#### *8.5.3.6 Input Energy Calculations*

Total system energy input during a 24-hour real world draw profile test included chemical energy in entering natural gas and electrical energy supplied to the water heater and recirculation pump, if used. That calculation follows:

$$I.E._{TEST} = \left(Volume_{gas,std} * HHV_{gas}\right) + E_{aux}$$

Where:

$$V_{gas,STD} = V_{gas,ACT} * \left(\frac{460+60}{460+T_{gas}}\right) * \left(\frac{\left(p_{gas} * .036\right) + p_{atm}}{14.73}\right)$$ = Standard cubic feet of natural gas

$V_{gas,ACT}$ = Actual cubic feet of gas delivered to the water heater

$T_{gas}$ = Natural gas compensation temperature, taken at the natural gas volume meter

$p_{gas}$ = Natural gas compensation pressure, taken at the natural gas volume meter

$p_{atm}$ = Atmospheric pressure

#### *8.5.3.7 Point of Use Water Heating*

Point of use water heating was simulated on the lavatory sink using results from a study performed by the FSTC (Allen, D. 2011 p.19). The efficiency of the point of use heater in this study was determined to be 90 percent. Two separate system delivery efficiencies are calculated for this measure, named point of use delivery efficiency A and B. Point of use system delivery efficiency A factors in a site to source energy conversion loss resulting from using electricity as the energy source instead of gas. Point of use system delivery efficiency B does not factor in a site-to-source energy conversion loss. A site-to-source conversion factor of 3.34 is used for these analyses (Energy Star 2011 p.10). The total system energy input during each point of use 24-hour draw profile test was calculated as follows:

$$IE_{TESTPOU} = \left(Volume_{gas,std} * HHV_{gas}\right) + E_{aux} + \left(S.S. * \frac{OE_{lavatory}}{\eta_{reisi\tan ceheater}}\right)$$

Where:

$E_{aux}$ = Electric energy entering the system

$S.S.$ = Site to source energy conversion, addressing fuel-switching

$OE_{lavatory}$ = Energy delivered to the lavatory sink

$\eta_{reisi\tan ceheater}$ = Efficiency of the electric resistance heater

#### *8.5.3.8 Normalization of 24-Hour System Efficiency Test due to Variations in Delivery*

Each 24-hour test was setup with the intention of delivering 500 gallons of hot water total. However, each individual test varied in the total quantity of water delivered. If system delivery efficiency was intended for use of comparing performance one system arrangement to another (insulation, recirculation, RCx measures etc.) this difference in the total quantity of water delivered in each test requires a normalization to be made to the system operating efficiency for proper comparison between tests. A system efficiency curve describing the relationship between system efficiency and volume delivered is discussed in a later section.

As discussed previously, system operating efficiency was defined as the energy increase in water delivered at the fixtures divided by the total energy input into the system. Heat loss from the distribution system between tests where the temperature setpoint of the water heater was consistent will be similar. If the total gallons of hot water delivered between tests varied, the total energy output of the test varied, but the energy required to maintain temperature and compensate for heat loss in the distribution system remained. If the total gallons delivered in the same test are lower in the first 24 hour run than the second 24 hour run and consistent system heat loss was assumed, the system operating efficiency was lower in the first test. Test data was normalized for variations in total gallons of water delivered to a standard test condition where 500 gallons of water were delivered.

For the purposes of normalizing test data for comparison, heat loss from the distribution system, or system energy input at zero system energy output, were measured under the following conditions:

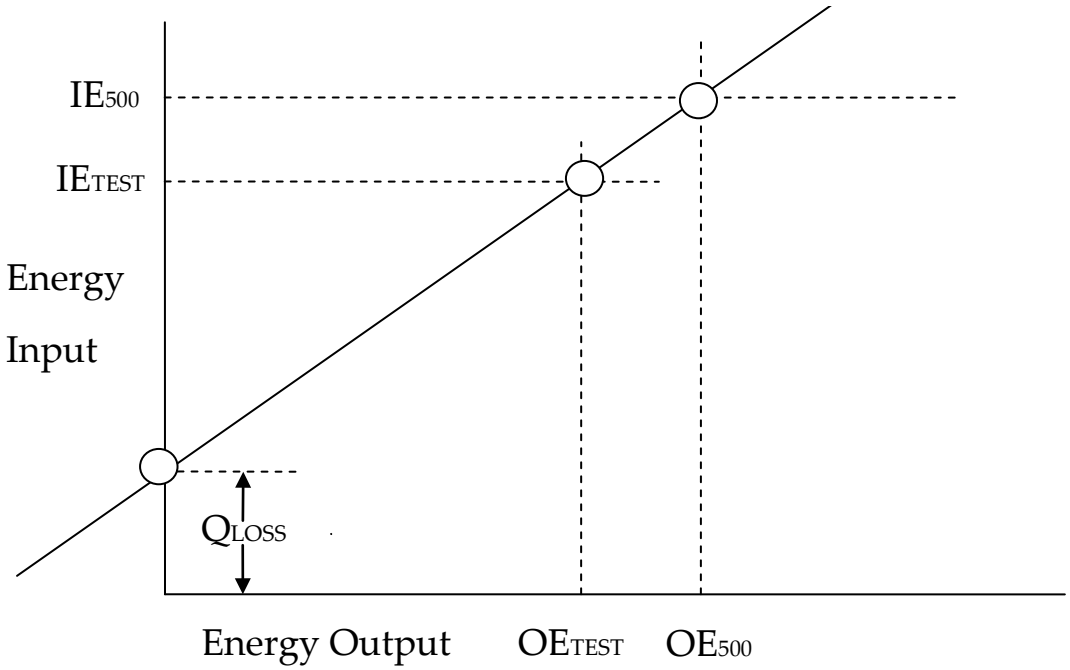
- Condition 1 - 140°F (60°C) Water Heater Temperature Setpoint with insulation
- Condition 2 - 140°F (60°C) Water Heater Temperature Setpoint without partial insulation
- Condition 3 - 140°F (60°C) Water Heater Temperature Setpoint without insulation
- Condition 4 - 160°F (70°C) Water Heater Temperature without insulation

System energy input at zero system energy output results are summarized in the appendix.

#### *8.5.3.9 Graphical Representation of System Operating Efficiency Normalization*

An illustration of the performance of the system is included in Figure 168. The relationship between energy input and output of the system was assumed linear with total gallons delivered per test for the purposes of normalizing system operating efficiency. This relationship between system energy input and output can be established using a point-slope formula for a line. The intersection of the y-axis can be considered the energy required to maintain system temperature at zero output, with energy input increasing from there as a function of increasing output.

**Figure 168: Normalization of 24-Hour Real World Profile Test Variations in Total Gallons Delivered**




Source: PG&E ATS

Along the System Performance Line, the following equation is assumed:

$$Input_{system} = m * Output_{system} + Q_{LOSS}$$

Where:

$Input_{system}$ = Total energy input into the system during each 24-hour test

$Output_{system}$ = Total system energy output during each 24-hour test

$Q_{LOSS}$ = Total energy required to maintain system temperature at zero energy output, determined through measuring system input under this condition.

Assumptions and Equations used for Normalizing Test Data to 500 gallons

System Output – 500 Gallon Equivalent 24-Hour Draw Profile Test

Assuming that System Output is proportional to total gallons delivered, the following equation can be used to establish system output were 500 gallons of water is to be delivered.

$$OE_{500} = OE_{TEST} * \frac{500}{V_{TEST}}$$

Where:

$OE_{500}$ = Calculated equivalent output of a 24-hour draw profile test with 500 gallons of delivered water

$OE_{TEST}$ = Measured system output during a 24-hour draw profile test

$V_{TEST}$ = Actual gallons of water delivered during each 24-hour draw profile test

#### *8.5.3.10 System Input/Output Line Slope*

The slope of the system performance line is calculated as follows:

$$m = \frac{IE_{TEST} - Q_{LOSS}}{OE_{TEST}}$$

Where:

$IE_{TEST}$ = Measured system input during a 24-hour draw profile test

$Q_{LOSS}$ = System heat loss based on temperature setpoint and insulation level

System Input – 500 Gallon Equivalent 24-Hour Draw Profile Test

System input (normalized) at a 500 gallon equivalent 24-hour draw profile test can be calculated using the point slope formula below.

$$IE_{500} = m * OE_{500} + Q_{LOSS}$$

#### *8.5.3.11 Normalized System Delivery Efficiency – 500 Gallon Equivalent 24-Hour Draw Profile Test*

Given the equations for system input, output and the slope of the input/output line, the normalized system delivery efficiency can be calculated.

$$\eta_{NORMALIZEDSYSTEM} = \frac{OE_{500}}{IE_{500}} = \frac{\left(OE_{TEST} * \frac{500}{V_{TEST}}\right)}{\left(\frac{IE_{TEST} - Q_{LOSS}}{OE_{TEST}}\right) * \left(\frac{OE_{TEST} * 500}{V_{TEST}}\right) + Q_{LOSS}}$$

#### *8.5.3.12 Normalized System Delivery Efficiency – Point of Use Lavatory Sink Heating - 500 Gallon Equivalent 24-Hour Draw Profile Test*

The Calculation of total system energy input of a point of use measure 24-hour draw profile test is as follows:

$$IE_{TESTPOU} = \left(Volume_{gas,std} * HHV_{gas}\right) + E_{aux} + \left(S.S. * \frac{OE_{lavatory}}{\eta_{reisi\tan ceheater}}\right)$$

Where:

$S.S.$ = Electric site to source energy conversion constant.

$\eta_{reisi\tan ceheater}$ = Efficiency of electric point of use water heater used at lavatory sink.

$OE_{TESTPOU}$ = Defined consistently with $OE_{TEST}$, with the exception being that output energy and volume delivered at the lavatory sink is estimated as the output of the lavatory sink and delivered volume for a standard 24-hour base case test with recirculation and with or without insulation respectively. Point of use tests performed with an insulated system use base case 24-hour lavatory energy output and delivered volume and tests without insulation use a non-insulated system base case 24-hour to represent lavatory energy output and delivered volume requirements.

#### *8.5.3.13 Normalized System Delivery Efficiency – Timeclock/No Recirculation - 500 Gallon*

The calculation of a normalized system delivery efficiency of an equivalent timeclock/no recirculation measure 500 gallon 24-hour draw profile test is as follows:

$$\eta_{NORMALIZEDSYSTEM} = \frac{OE_{500}}{IE_{500}} = \frac{\left(OE_{TEST} * \frac{500}{V_{TEST}}\right)}{\left(\frac{IE_{TEST} - Q_{LOSS}}{OE_{TEST}}\right) * \left(\frac{OE_{TEST} * 500}{V_{TEST}}\right) + Q_{LOSS} * \frac{24 - H_{TC}}{24}}$$

Where:

$H_{TC}$ = Hours that the timeclock shuts down the circulation pump.

For the purposes of this analysis, it was assumed that the hours when the timeclock had shut down recirculation eliminated distribution system heat loss during that time, as there is little to no flow requirement during that time. The same assumption was made about system heat loss when a recirculation pump was not being used at all during a 24-hour draw profile test. If a 24-hour draw profile test was ran right at 500 gallons total delivered, this assumption has no impact on the normalized system efficiency. As the actual total gallons delivered deviate further from 500, the inaccuracies in this assumption play a larger role impacting the normalized system operating efficiency.

#### *8.5.3.14 24-Hour Draw Profile Test System Delivery Efficiency Curve*

The calculation of 24 hour draw profile system output energy at a specific delivery volume on the system performance line is as follows:

$$OE_{CURVE} = OE_{TEST} * \frac{V_{CURVE}}{V_{TEST}}$$

$OE_{TEST}$ = Measured system output during a 24-hour draw profile test

$V_{CURVE}$ = 24-hour total delivery volume where the system delivery efficiency is desired to be calculated

$V_{TEST}$ = Actual gallons of water delivered during each 24-hour draw profile test

The calculation of the 24 hour draw profile system input energy at a specific delivery volume on the system performance line is as follows:

$$IE_{CURVE} = OE_{CURVE} * m + Q_{LOSS}$$

With System output and input calculated at the specified 24-hour delivery volume where the system operating efficiency is desired to be determined, the system operating efficiency can be calculated. Selecting various delivery volumes in a range, with individual system operating efficiencies calculated can provide enough data to perform a curve fit of the system operating efficiency as a function of total volume delivered in 24 hours.

The calculation of the system performance line slope for a 24-hour draw profile system input energy at a specific delivery volume on the system performance line is as follows:

$$\eta_{CURVE} = \frac{OE_{CURVE}}{IE_{CURVE}}$$

## 8.6 Results

### 8.6.1 Water Heater Thermal Efficiency

Table 46 summarizes the results of the ANSI thermal efficiency tests on the four water heaters including uncertainty measurements for each heater.

**Table 46: ANSI Thermal Efficiency Results with Measurement Uncertainty**

| Heater # | Heater Type | Thermal Efficiency (%) | 95 % Conf. Uncertainty (% T.E.) |
|---|---|---|---|
| **1** | High-Efficiency Tank-Type | 93.36 | 2.23 |
| **2** | Standard-Efficiency Tank-Type | 80.36 | 2.14 |
| **3** | High-Efficiency Tankless | 91.01 | 1.12 |
| **4** | Standard-Efficiency Tankless | 83.36 | 2.78 |

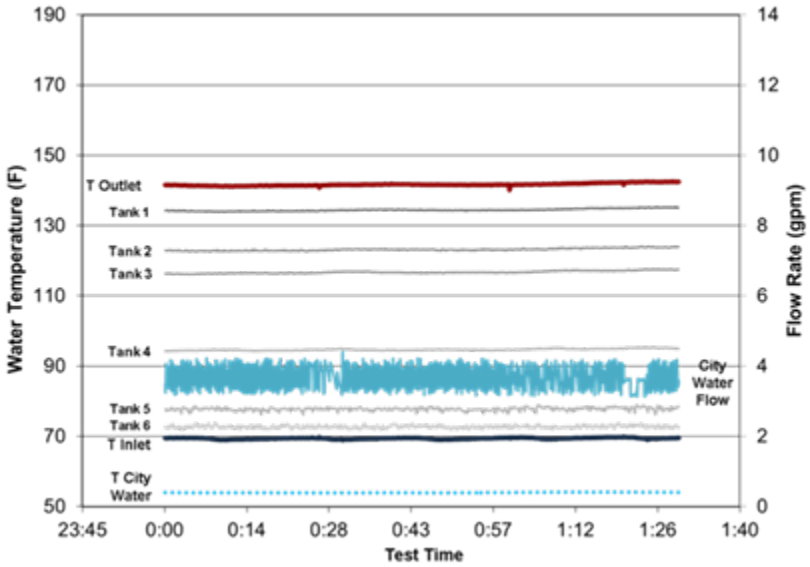
Source: PG&E ATS

#### *8.6.1.1 Task 4.2 Thermal Efficiency Discussion*

High-efficiency condensing heaters #1 and #3 performed superior to standard-efficiency non-condensing heaters #2 and #4 under ANSI thermal efficiency test conditions. Heater 1, which is fired from the top of the tank, demonstrated significant stratification within the tank during the course of the thermal efficiency test compared to standard-efficiency non-condensing tank-type

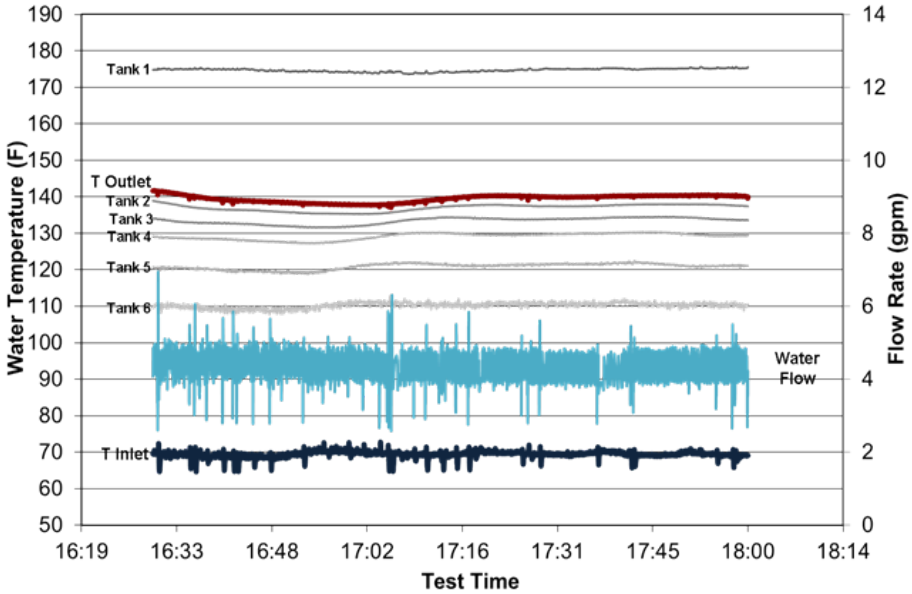
heater #2. Internal tank temperatures in heater #1 are as low as 70°F (21°C) at the bottom of the tank in Figure 169, compared to heater #2 which utilized a burner that fires from the bottom, and has a lower tank temperature of 110°F (43°C) in Figure 170.

**Figure 169: High-Efficiency Condensing Tank-Type Heater—ANSI Thermal Efficiency Test**




Source: PG&E ATS

**Figure 170: Standard-Efficiency Non-Condensing Tank-Type Heater - ANSI Thermal Efficiency Test Summary of Results**




Source: PG&E ATS

As demonstrated in Figure 169 and Figure 170, internal tank temperatures throughout testing maintained within about 5°F (2.8°C). Stored energy over the course of the test was factored out of the resulting thermal efficiency in an effort to mitigate any concern about total stored energy content during each test.

Thermal efficiency of the high-efficiency condensing tankless heater #3 exceeded the thermal efficiency of the standard-efficiency non-condensing tankless heater #4 by more than 7.6 percentage points. This difference is less than the improvement in efficiency of heater #1 over heater #2, which is 13 percentage points more efficient than its comparable standard-efficiency unit. The standard-efficiency tankless heater #4 has a thermal efficiency 3 percentage points greater than the standard-efficiency tank-type heater, while the efficiency of the tank-type condensing heater #1 exceeds the efficiency of the tankless by 2.35 percentage points.

The firing rate of each water heater can vary widely at full fire under ANSI thermal efficiency test conditions. Heater #4 appeared to modulate its output based on its operating condition, and may have not been operating a full fire throughout the test. A summary of the firing rates during the ANSI thermal efficiency tests is presented in Table 47.

**Table 47: ANSI Thermal Efficiency Results – Firing Rate During Test**

| Heater # | Heater Type | Firing Rate (Btu/h) |
|---|---|---|
| **1** | High-Efficiency Tank-Type | 174,817 |
| **2** | Standard-Efficiency Tank-Type | 189,658 |
| **3** | High-Efficiency Tankless | 191,899 |
| **4** | Standard-Efficiency Tankless | 167,583 |

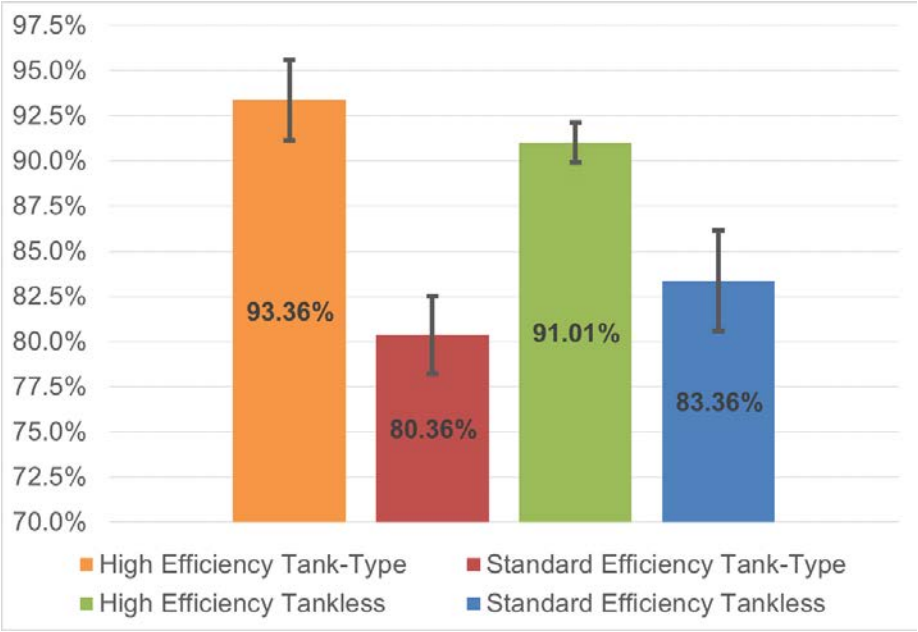
Source: PG&E ATS

#### *8.6.1.2 Uncertainty in Thermal Efficiency*

Uncertainty in measurement was established for each test based on limitations in bias and precision of the instruments used to calculate thermal efficiency of each heater. Significant sources of uncertainty include bias in the water flow rate measurement through the heater, natural gas volumetric flow rate and natural gas higher heating value.

Figure 171 compares the results of the ANSI thermal efficiency tests and test uncertainties. All thermal efficiency test results are documented in the appendices. Included in the more detailed results is a sensitivity analysis of each measurement parameter used to establish thermal efficiency. All uncertainty values are reported with 95 percent confidence.

**Figure 171: ANSI Thermal Efficiency Test Summary of Results with Error Bars**




Source: PG&E ATS

### 8.6.2 Water Heater Standby Loss

Table 48 summarizes the results of the ANSI standby tests on the four water heaters. Standby loss of the high-efficiency tank-type heater was less than half of the standby loss of the standard-efficiency tank-type heater.

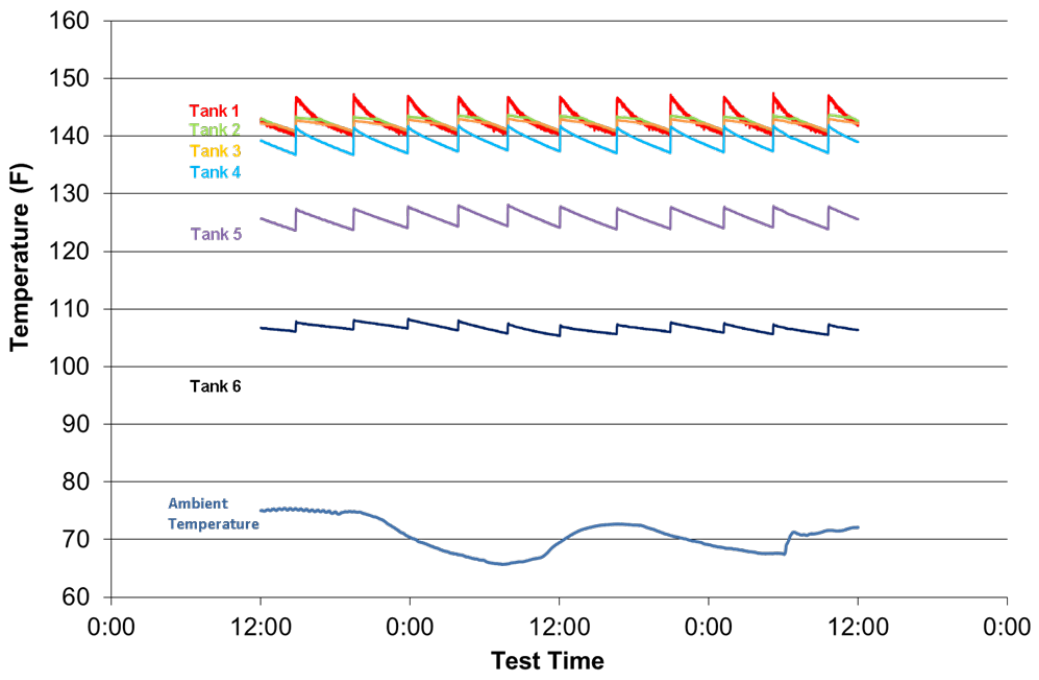
**Table 48: ANSI Standby Loss Results**

| Heater # | Heater Type | Standby Loss (%) | Standby Loss (Btu/h) |
|---|---|---|---|
| **1** | High Efficiency Tank-Type | 1.28 | 670.0 |
| **2** | Standard-Efficiency Tank-Type | 2.58 | 1,654.0 |
| **3** | High-Efficiency Tankless | n/a | n/a |
| **4** | Standard-Efficiency Tankless | n/a | n/a |

Source: PG&E ATS

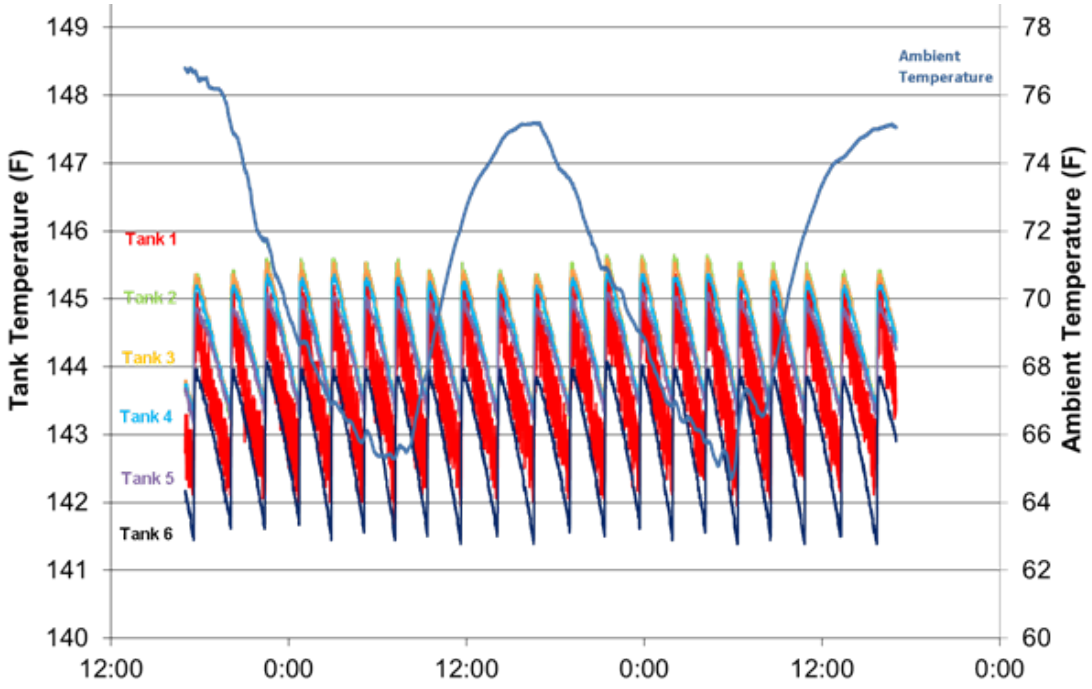
Throughout the test, the high-efficiency heater had significant stratification within the tank, with a 30°F (17°C) change in temperature from the top and bottom of the tank in Figure 172. The stratification within the tank of the standard-efficiency heater #2 in Figure 173 was almost nonexistent at any given time. It averaged about 1.5°F (1°C) higher at the top of the tank versus the bottom of the tank throughout this two-day test.

**Figure 172: Test 1.4.2.2.X.140.2 Results: High-Efficiency Tank-Type Water Heater—ANSI Standby Test**




Source: PG&E ATS

**Figure 173: Test 2.4.2.2.X.140.2 Results: Standard-Efficiency Tank-Type Water Heater—ANSI Standby Test**




Source: PG&E ATS

### 8.6.3 Hot Water System Delivery Efficiency

Table 49 summarizes the results of the system delivery efficiency test for each heater type with and without the operation of the continuous recirculation system. The first column list the system delivery efficiency and the four following columns list the hot water delivery temperature at each sink to quantify hot water delivery performance for each operating condition.

**Table 49: System Delivery Efficiency and Fixture Temperatures—24-Hour Draw Profile**

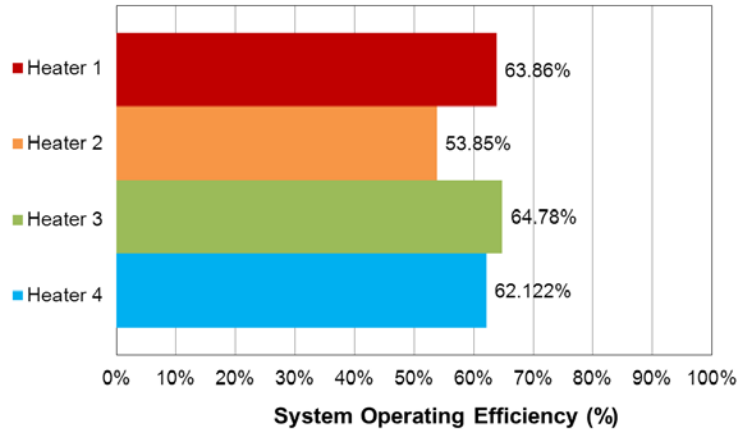
| Operating Condition | System Delivery Efficiency | $T_{DELIVERED}$ Hand Sink (°F) | $T_{DELIVERED}$ 3 Comp Sink (°F) | $T_{DELIVERED}$ Mop Sink (°F) | $T_{DELIVERED}$ Lavatory Sink (°F) |
|---|---|---|---|---|---|
| **Heater 1 - High Efficiency Tank-Type** | | | | | |
| w/ Recirc | 63.86% | 132.25 | 137.89 | 136.85 | 124.91 |
| w/o Recirc | 78.12% | 130.19 | 138.59 | 126.34 | 120.19 |
| (w/ - w/o Recirc) | -14.27% | 2.06 | -0.71 | 10.51 | 4.72 |
| **Heater 2 - Standard Efficiency Tank-Type** | | | | | |
| w/ Recirc | 53.85% | 134.82 | 141.77 | 140.83 | 132.23 |
| w/o Recirc | 63.25% | 133.59 | 143.45 | 131.93 | 128.31 |
| (w/ - w/o Recirc) | -9.40% | 1.23 | -1.67 | 8.90 | 3.92 |
| **Heater 3 - High Efficiency Tankless** | | | | | |
| w/ Recirc | 64.78% | 125.69 | 133.36 | 132.36 | 121.60 |
| w/o Recirc | X | 70.75 | 68.51 | 67.51 | 70.57 |
| (w/ - w/o Recirc) | X | X | X | X | X |
| **Heater 4 - Standard Efficiency Tankless** | | | | | |
| w/ Recirc | 62.122% | 128.04 | 134.36 | 133.36 | 124.29 |
| w/o Recirc | 61.446% | 110.62 | 112.05 | 111.05 | 111.01 |
| (w/ - w/o Recirc) | 0.675% | 17.42 | 22.31 | 22.31 | 13.29 |

Source: PG&E ATS

#### *8.6.3.1 System Delivery Efficiency Results—24-Hour Draw Profile—With Pipe Insulation*

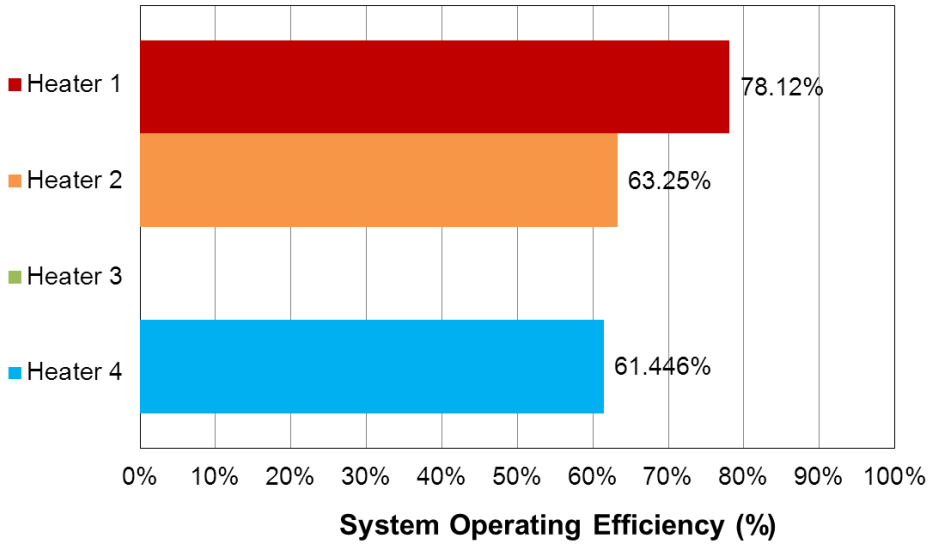
Maximum system delivery efficiency for an insulated system with use of a recirculation pump was achieved with the high-efficiency condensing tankless heater. Minimum system delivery efficiency was found to occur when using the standard-efficiency tank-type heater. The high-efficiency tank-type heater and both the high-efficiency and standard efficiency tankless units performed within 3 percentage points of each other in Figure 174.

**Figure 174: Results: System Delivery Efficiency by Heater Type – With Recirculation and Insulation**




Source: PG&E ATS

**Figure 175: Results: System Delivery Efficiency by Heater Type—Without Recirculation, With Insulation**



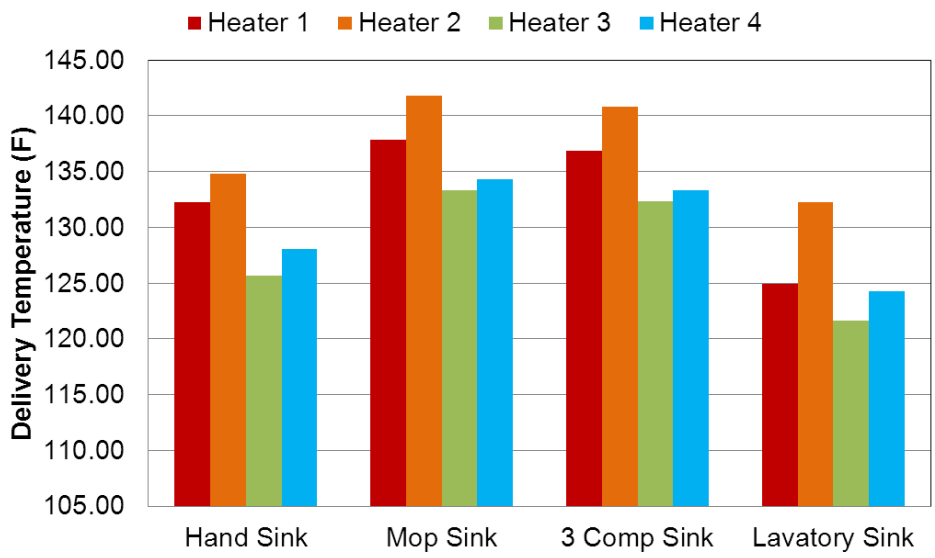

Source: PG&E ATS

Maximum system delivery efficiency for an insulated system without use of a recirculation pump was achieved with the high-efficiency condensing tank-type heater. Minimum system delivery efficiency was found to occur when using the standard-efficiency tankless heater. The spread in system delivery efficiency is much more pronounced without continuous recirculation in Figure 175, as the system with the high-efficiency tank-type heater is 15 percent more efficient than the next most efficient system, the standard-efficiency tank-type heater. The high-efficiency tankless heater did not fire with any draws without use of the recirculation pump, so its performance could not be determined.

### *8.6.3.2 Average Delivery Temperature—24-Hour Draw Profile*

Average hot water delivery temperature during flow periods at each sink is a good measure of hot water delivery performance. In Figure176, both tank-type water heaters delivered hot water to the sink with continuous recirculation and pipe insulation at 5°F to 10°F (3°C to 6°C) higher temperature than the tankless heaters. Hot water at a slightly higher water temperature was delivered to all four sinks with the standard-efficiency units versus condensing models. Maximum delivery temperature was achieved by standard-efficiency tank-type heater #2 in a system using a recirculation pump, with the minimum delivery temperature achieved by the high-efficiency tankless heater #3.

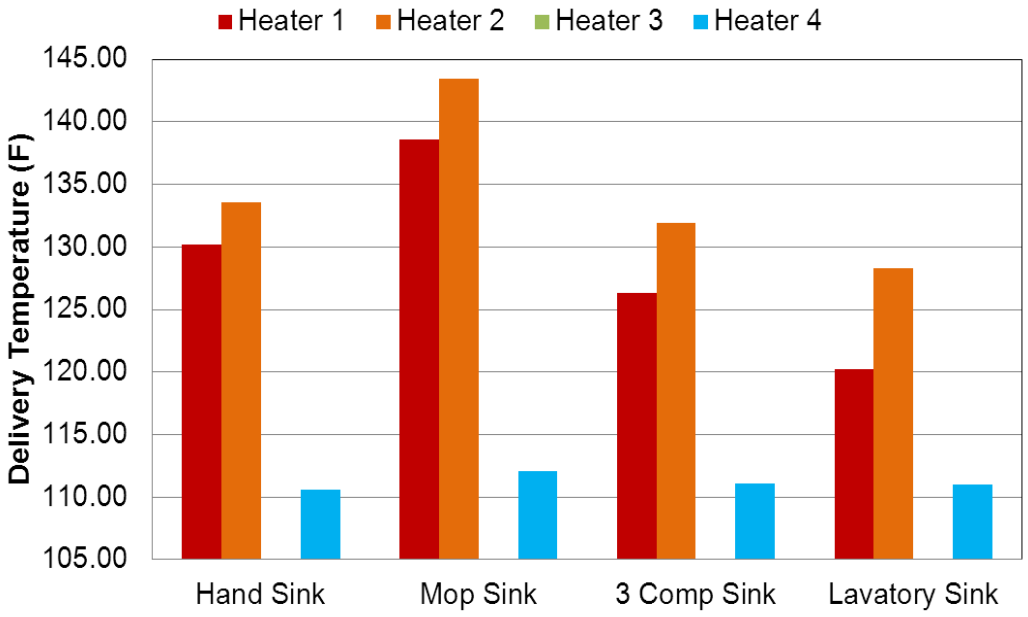
**Figure 176: Results: Delivery Temperature by Heater Type—With Recirculation and Insulation**




Source: PG&E ATS

Average hot water delivery temperature of the individual heaters in a system without recirculation and with insulation showed contrasts with hot water delivery performance of storage and tankless water heaters in Figure 177. Average delivered temperatures from the standard-efficiency tankless heater at the four sinks were between 10°F (6°C) and 30°F (12°C) lower than both tank-type heaters at all fixtures. A reduction of 0 to 5°F (0 to 3°C) in average delivery temperature was observed between the storage water heaters in the continuous recirculation and no recirculation tests. In a system without a recirculation pump, average maximum delivery temperature was achieved with a standard-efficiency tank-type heater; though the average delivered temperature decreased at every fixture but the mop sink. Mop sink draws are extended and less frequent, while hand, 3 comp and lavatory sink draws are frequent and shorter in duration. No gas usage was measured while testing the high-efficiency tankless heater without the use of a recirculation pump.

**Figure 177: Results: Delivery Temperature by Heater Type—Without Recirculation, With Insulation**

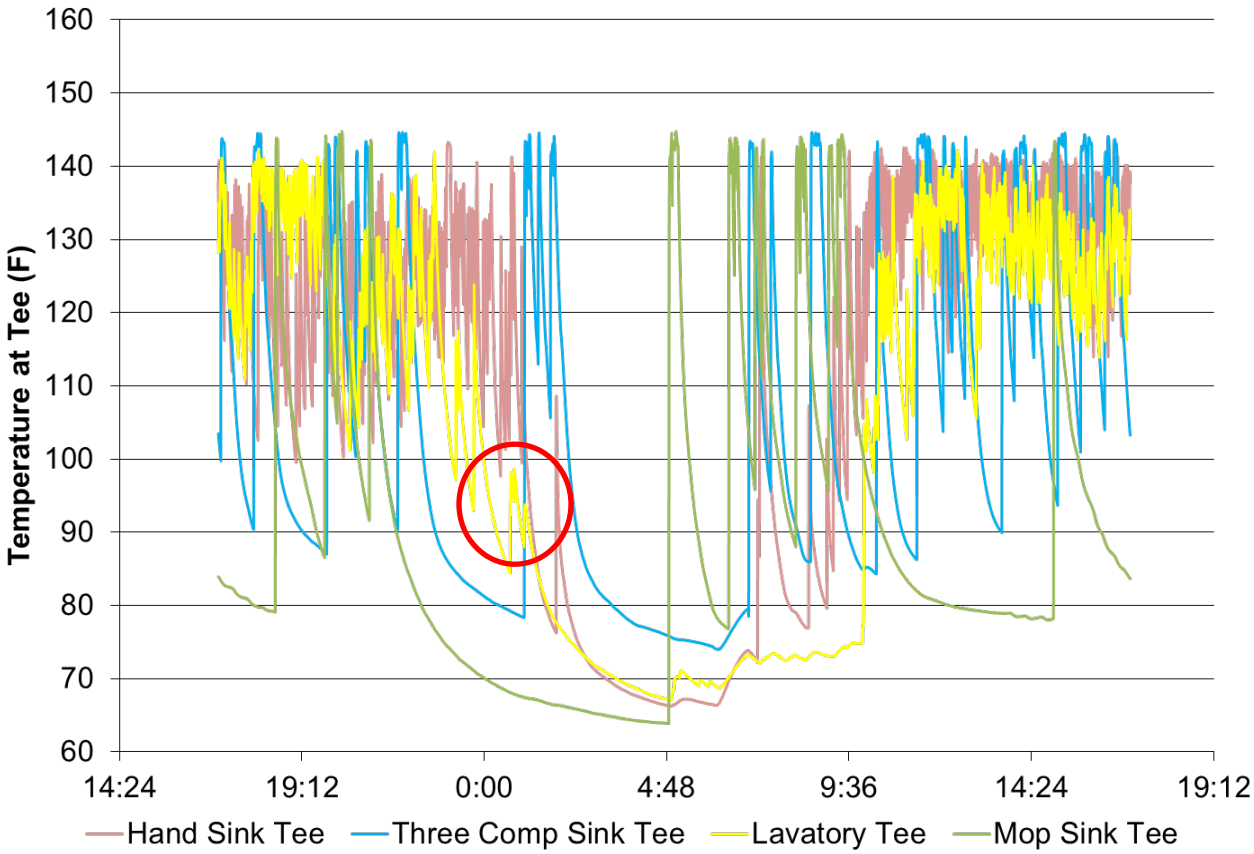



Source: PG&E ATS

### *8.6.3.3 Instantaneous Delivery Temperature – 24-Hour Draw Profile—With Recirculation*

Figure 178 includes the instantaneous temperature at each fixture in a system using the standard-efficiency tank-type water heater with recirculation. The circled area includes a draw from the lavatory sink during a period of light system usage where the temperature at the fixture did not exceed 100°F (38°C). Overall, the hot water delivery performance to all sinks was adequate in this system configuration.

**Figure 178: Test 2.4.2.3.X.140.1 Results: Standard-Efficiency Tank-Type Water Heater—QSR Profile Test—With Recirculation—Temperature at Fixtures**



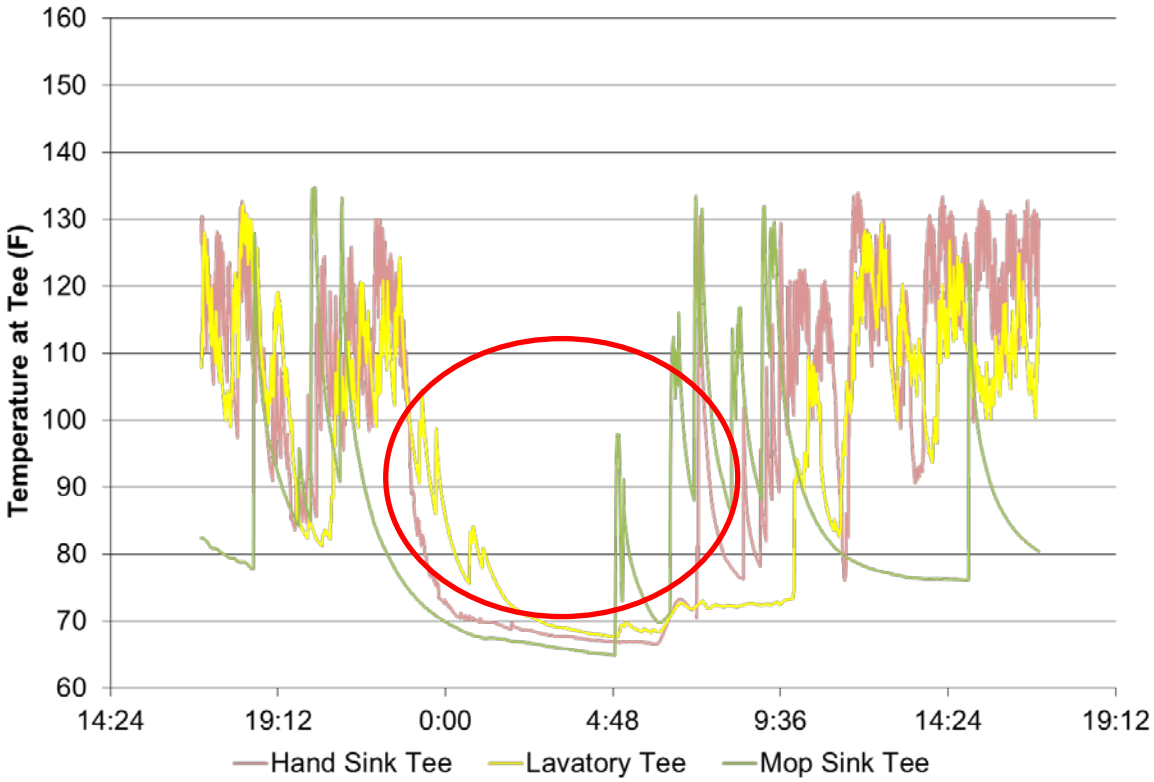

Source: PG&E ATS

*8.6.3.4 Instantaneous Delivery Temperature—24-Hour Draw Profile—Without Recirculation*

In Figure 179, with the standard-efficiency tankless heater in a system without recirculation, the temperature at the lavatory and mop sink both remained below 100°F (38°C) during a series of draws in the profile. Similar to the behavior of the delivery temperatures in a system with a standard-efficiency tank-type water heater, temperatures are below 100°F (38°C) during periods of low water usage.

All test results are included in the appendices. These results include instantaneous temperature one fixture at a time with delivery flow rates on the same plot.

**Figure 179: Test 4.4.2.4.X.140.1 Results: Standard-Efficiency Tankless Water Heater—QSR Profile Test—Without Recirculation—Temperature at Fixtures**




Source: PG&E ATS

## 8.6.4 Delivery Efficiency—Energy Savings through Retro-Commissioning and Retrofit

### *8.6.4.1 System Delivery Efficiency Results—24-Hour Draw Profile—With Insulated Distribution System*

In Table 50, maximum system delivery efficiency was achieved when using an aquastat to control the system recirculation pump, though significant test to test performance variations exist when using the aquastat. A reliable improvement in system delivery efficiency resulted from the installation and use of the timeclock. During periods when the restaurant was not in operation, between 1:30 am and 6:30 am, the timeclock turned off the recirculation pump. This resulted in an improvement of system delivery efficiency of almost 3 percent. Repair or retrofit of a flue damper resulted in an improvement in system delivery efficiency of 5 percent. For this particular system configuration, point of use heating at the lavatory sink resulted in a significant drop of about 8.4 percent system delivery efficiency when factoring in site to source energy. When looking at the partially insulated piping case, the hot water delivery temperature at all sinks declined significantly.

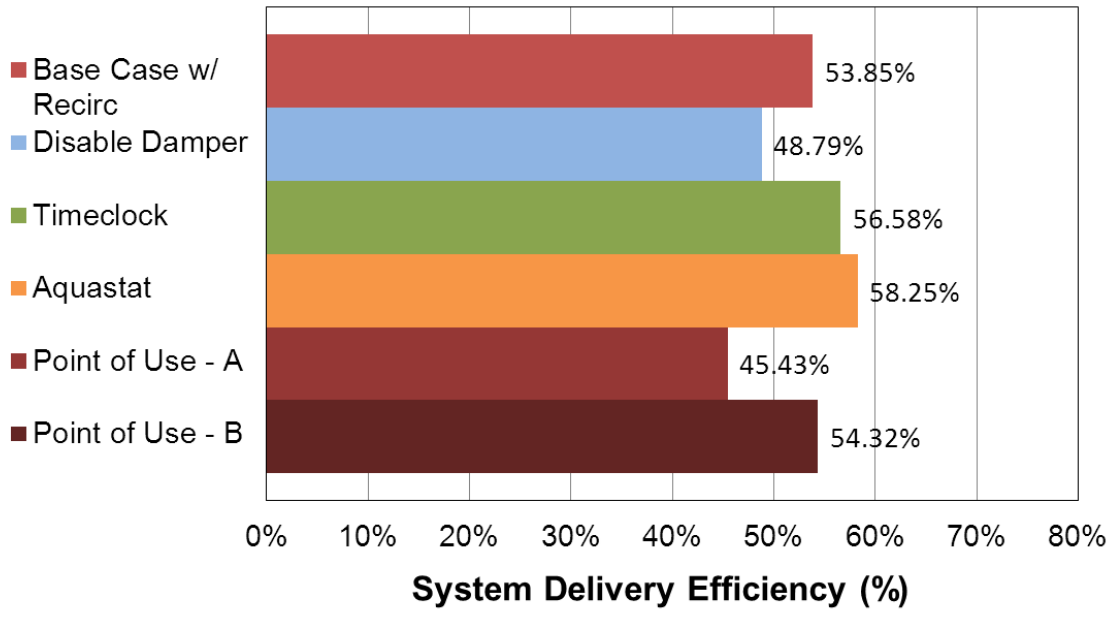
**Table 50: Results—System Delivery Efficiency and RCx Measures—Insulated Distribution System**

| With Insulated Distribution System | | | | | | |
|---|---|---|---|---|---|---|
| Base Case | System Delivery Efficiency | $T_{DELIVERED}$ Hand Sink (°F) | $T_{DELIVERED}$ 3 Comp Sink (°F) | $T_{DELIVERED}$ Mop Sink (°F) | $T_{DELIVERED}$ Lavatory Sink (°F) | Difference in S.D.E. vs. w/ Recirc w/ Insulation |
| w/o Recirc | 63.25% | 133.59 | 143.45 | 131.93 | 128.31 | 9.40% |
| w/ Recirc | 53.85% | 134.82 | 141.77 | 140.83 | 132.23 | X |
| RCx Measure | | | | | | |
| Disable Damper | 48.79% | 134.69 | 141.79 | 140.72 | 130.52 | -5.05% |
| Timeclock | 56.58% | 134.50 | 141.46 | 139.84 | 131.11 | 2.73% |
| Aquastat | 58.25% | 133.24 | 141.07 | 139.46 | 130.32 | 4.41% |
| Point of Use - A | 45.43% | 134.37 | 141.66 | 140.75 | 132.25 | -8.42% |
| Point of Use - B | 54.32% | 134.37 | 141.66 | 140.75 | 132.25 | 0.47% |
| 160F Setpoint | X | X | X | X | X | X |
| Partially Insulated Distribution System | | | | | | |
| w/ Recirc | 48.65% | 123.22 | 134.84 | 134.63 | 113.78 | -5.19% |

Source: PG&E ATS

Figure 180 summarizes portions of the retro-commissioning measures in Table 46 with fully insulated piping to show the percentage increase or decrease in system delivery efficiency.

**Figure 180: Results—System Delivery Efficiency and RCx Measures—Insulated Distribution System**




Source: PG&E ATS

### *8.6.4.2 System Delivery Efficiency Results—24-Hour Draw Profile—Without Insulated Distribution System*

In Table 51, maximum system delivery efficiency again was achieved when using an aquastat to control the system recirculation pump in a non-insulated system. Installation of a timeclock also resulted in the second best system delivery efficiency improvement. Repair or retrofit of a flue damper resulted in an improvement in system delivery efficiency of almost 4 percent, similar to the 5 percent improvement above the base case seen in a system in an insulated system. For this particular system configuration, point of use heating at the lavatory sink again resulted in a significant drop of about 7 percent system delivery efficiency when factoring in site to source energy. System delivery efficiency was not significantly impacted by raising the temperature setpoint on the heater to 160°F (70°C).

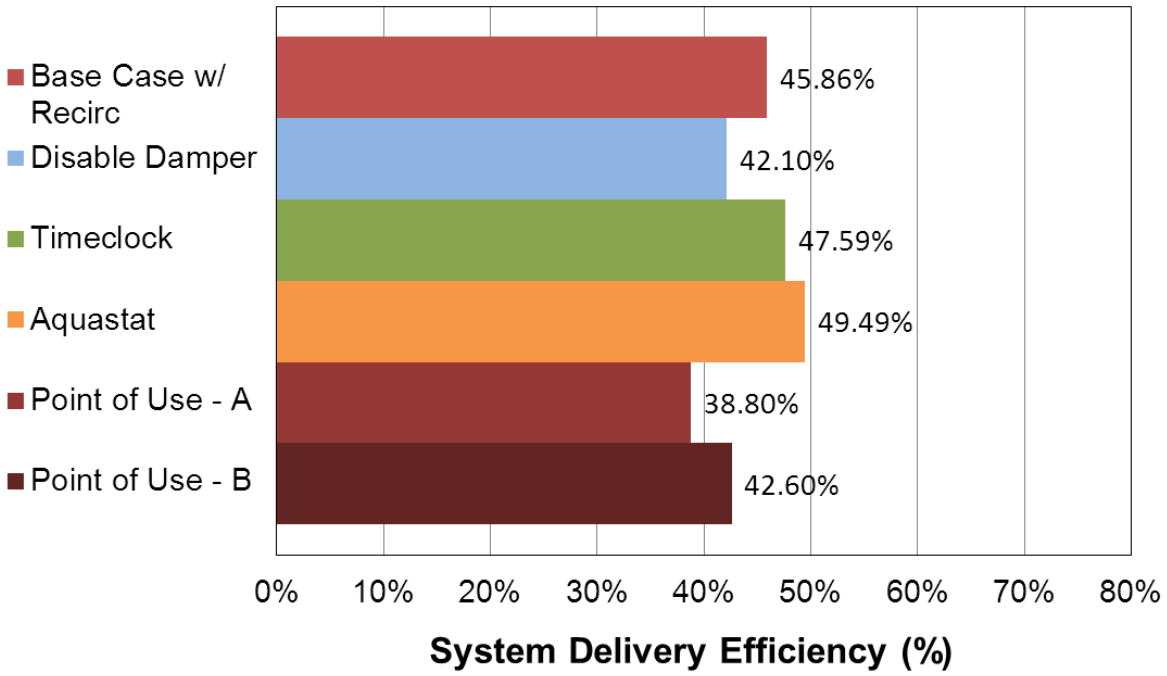
**Table 51: Results—System Delivery Efficiency and RCx Measures—Non-Insulated Distribution System**

| Without Insulated Distribution System | | | | | | | |
|---|---|---|---|---|---|---|---|
| Base Case | System Delivery Efficiency | $T_{DELIVERED}$ Hand Sink (°F) | $T_{DELIVERED}$ 3 Comp Sink (°F) | $T_{DELIVERED}$ Mop Sink (°F) | $T_{DELIVERED}$ Lavatory Sink (°F) | Difference in S.D.E. vs. w/ Recirc w/o Insulation | Difference in S.D.E. vs. w/ Recirc w/ Insulation |
| w/o Recirc | 54.17% | 123.22 | 132.67 | 127.83 | 110.33 | 8.31% | 0.32% |
| w/ Recirc | 45.86% | 123.21 | 134.35 | 134.75 | 113.47 | X | -7.99% |
| RCx Measure | | | | | | | |
| Disable Damper | 42.10% | 123.09 | 134.52 | 134.74 | 113.59 | -3.76% | -11.75% |
| Timeclock | 47.59% | 126.50 | 134.31 | 133.16 | 121.04 | 1.73% | -6.26% |
| Aquastat | 49.49% | 125.22 | 134.18 | 131.73 | 120.10 | 3.63% | -4.36% |
| Point of Use - A | 38.80% | 124.16 | 134.49 | 134.77 | 113.65 | -7.05% | -15.04% |
| Point of Use - B | 42.60% | 124.16 | 134.49 | 134.77 | 113.65 | -3.26% | -11.25% |
| 160F Setpoint | 45.35% | 142.98 | 152.39 | 152.81 | 135.36 | -0.51% | -8.50% |

Source: PG&E ATS

Figure 181 summarizes portions of the retro-commissioning measures in Table 47 with no insulation on the distribution system to show the percentage increase or decrease in system delivery efficiency versus the base case. There was an 8 percent drop in system delivery efficiency when moving from the base case system with insulation to the system without insulation when comparing Figure 180 and Figure 181.

**Figure 181: Results—System Delivery Efficiency and RCx Measures—Non-Insulated Distribution System**




Source: PG&E ATS

*8.6.4.3 System Delivery Efficiency Results—24-Hour Draw Profile—Disable Flue Damper*

In Table 52, comparing performance of insulated distribution systems, disabling the flue damper resulted in a 5 percent reduction in absolute system delivery efficiency without impacting fixture delivery temperature. Removing insulation further dropped absolute system delivery efficiency to 11.75 percent less than an insulated distribution system and properly functioning flue damper.

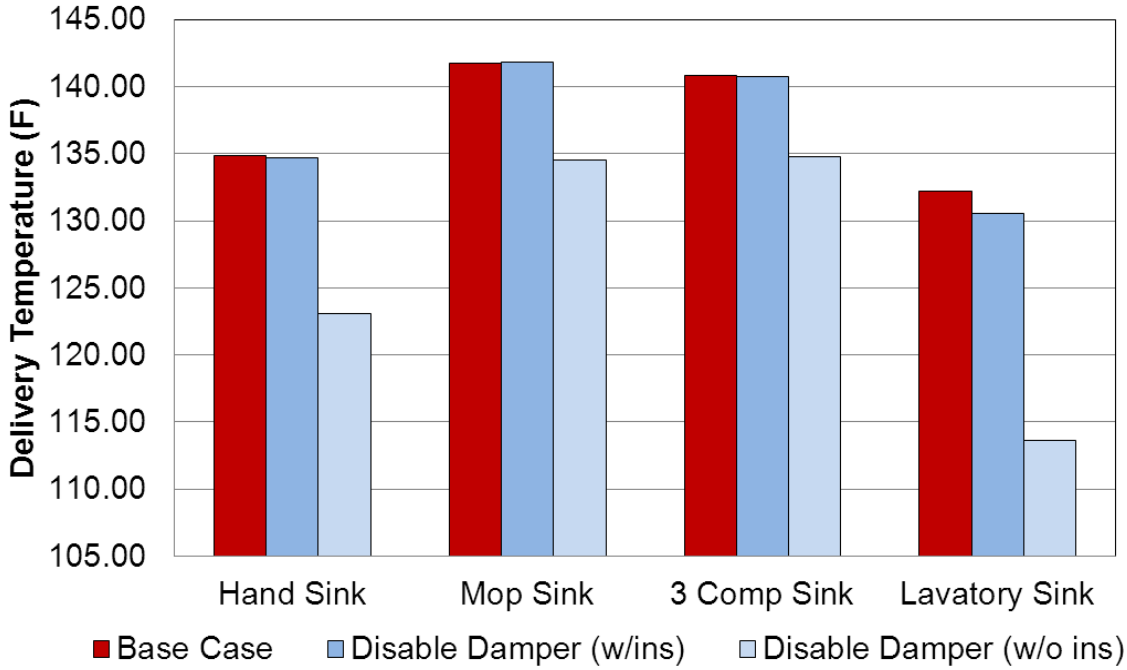
**Table 52: Results—24-Hour Draw Profile—Disable Flue Damper**

| RCx Measure: Disable Flue Damper | | | | | | |
|---|---|---|---|---|---|---|
| Test Condition | System Delivery Efficiency | $T_{DELIVERED}$ Hand Sink (°F) | $T_{DELIVERED}$ 3 Comp Sink (°F) | $T_{DELIVERED}$ Mop Sink (°F) | $T_{DELIVERED}$ Lavatory Sink (°F) | % Change in S.D.E. vs. w/ Recirc w/ Insulation |
| Base Case w/ Recirc | 53.85% | 134.82 | 141.77 | 140.83 | 132.23 | X |
| Disable Damper (w/ins) | 48.79% | 134.69 | 141.79 | 140.72 | 130.52 | -5.05% |
| Disable Damper (w/o ins) | 42.10% | 123.09 | 134.52 | 134.74 | 113.59 | -11.75% |

Source: PG&E ATS

In Figure 182, there was again a significant reduction in hot water delivery temperature in the test without insulation. Otherwise, delivery temperatures were not affected significantly versus the base case.

**Figure 182: Results—System Delivery Efficiency—Disable Flue Damper**




Source: PG&E ATS

### *8.6.4.4 System Delivery Efficiency Results – 24-Hour Draw Profile—Install Timeclock*

In Table 53, comparing performance of insulated distribution systems, installing a timeclock to stop the recirculation pump between 1:30 am and 6:30 am resulted in a 2.73 percent improvement in terms of absolute system delivery efficiency without impacting fixture delivery temperature. Removing insulation further dropped system performance to 6.26 percent less than an insulated distribution system and without an installed timeclock, but about 2 percent better than the 45.9 percent system delivery efficiency of an uninsulated system without an installed timeclock.

**Table 53: Results—24-Hour Draw Profile—Timeclock**

| RCx Measure: Timeclock | | | | | | |
|---|---|---|---|---|---|---|
| Test Condition | System Delivery Efficiency | $T_{DELIVERED}$ Hand Sink (°F) | $T_{DELIVERED}$ 3 Comp Sink (°F) | $T_{DELIVERED}$ Mop Sink (°F) | $T_{DELIVERED}$ Lavatory Sink (°F) | % Change in S.D.E. vs. w/ Recirc w/ Insulation |
| Base Case w/ Recirc | 53.85% | 134.82 | 141.77 | 140.83 | 132.23 | X |
| Timeclock (w/ins) | 56.58% | 134.50 | 141.46 | 139.84 | 131.11 | 2.73% |
| Timeclock (w/o ins) | 47.59% | 126.50 | 134.31 | 133.16 | 121.04 | -6.26% |

Source: PG&E ATS

### *8.6.4.5 System Delivery Efficiency Results——24-Hour Draw Profile—Install Aquastat*

In Table 54, individual 24-hour test runs performed using an aquastat to control the recirculation pump resulted in 58.83 percent and 57.67 percent system delivery efficiency, averaging 58.25 percent system delivery efficiency for an insulated system. This is an

improvement of between 4 percent and 5 percent absolute system delivery efficiency with little change in delivery temperature.

For tests on an uninsulated system, use of the aquastat yielded system delivery efficiencies of 47.46 percent and 51.52 percent, averaging to 49.49 percent. The system delivery efficiency of an uninsulated system is 45.9 percent, with the aquastat improving this efficiency between 1.5 percent and almost 6 percent, a wide test to test variation in performance.

The aquastat installation in the field yielded inconsistent results in all three installations and did not result in overall savings due to a resulting increase in water heater outlet temperature.

**Table 54: Results – 24-Hour Draw Profile – Aquastat**

| RCx Measure: Aquastat | | | | | | |
|---|---|---|---|---|---|---|
| Test Condition | System Delivery Efficiency | $T_{DELIVERED}$ Hand Sink (°F) | $T_{DELIVERED}$ 3 Comp Sink (°F) | $T_{DELIVERED}$ Mop Sink (°F) | $T_{DELIVERED}$ Lavatory Sink (°F) | % Change in S.D.E. vs. w/ Recirc w/ Insulation |
| Base Case w/ Recirc | 53.85% | 134.82 | 141.77 | 140.83 | 132.23 | X |
| Aquastat (w/ins) | 58.25% | 133.24 | 141.07 | 139.46 | 130.32 | 4.41% |
| Aquastat (w/o ins) | 49.49% | 125.22 | 134.18 | 131.73 | 120.10 | -4.36% |

Source: PG&E ATS

*8.6.4.6 System Delivery Efficiency Results——24-Hour Draw Profile—Point of Use Lavatory Sink Heating*

In Table 55 and Table 56, with these particular system arrangements, no improvement in performance was estimated if point of use heating were used for the lavatory sink, whether or not site to source energy conversion was applied to calculate system delivery efficiency.

**Table 55: Results—24-Hour Draw Profile—Point of Use—Site-to-Source Energy Conversion**

| RCx Measure: Point of Use - A (With Site to Source) | | | | | | |
|---|---|---|---|---|---|---|
| Test Condition | System Delivery Efficiency | $T_{DELIVERED}$ Hand Sink (°F) | $T_{DELIVERED}$ 3 Comp Sink (°F) | $T_{DELIVERED}$ Mop Sink (°F) | $T_{DELIVERED}$ Lavatory Sink (°F) | % Change in S.D.E. vs. w/ Recirc w/ Insulation |
| Base Case w/ Recirc | 53.85% | 134.82 | 141.77 | 140.83 | 132.23 | X |
| Point of Use (w/ins) | 45.43% | 134.37 | 141.66 | 140.75 | 132.25 | -8.42% |
| Point of Use (w/o ins) | 38.80% | 124.16 | 134.49 | 134.77 | 113.65 | -15.04% |

Source: PG&E ATS

**Table 56: Results—24-Hour Draw Profile—Point-of-Use—No Site-to-Source Energy Conversion**

| RCx Measure: Point of Use - B (Without Site to Source) | | | | | | |
|---|---|---|---|---|---|---|
| Test Condition | System Delivery Efficiency | $T_{DELIVERED}$ Hand Sink (°F) | $T_{DELIVERED}$ 3 Comp Sink (°F) | $T_{DELIVERED}$ Mop Sink (°F) | $T_{DELIVERED}$ Lavatory Sink (°F) | % Change in S.D.E. vs. w/ Recirc w/ Insulation |
| Base Case w/ Recirc | 53.85% | 134.82 | 141.77 | 140.83 | 132.23 | X |
| Point of Use (w/ins) | 54.32% | 134.37 | 141.66 | 140.75 | 132.25 | 0.47% |
| Point of Use (w/o ins) | 42.60% | 124.16 | 134.49 | 134.77 | 113.65 | -11.25% |

Source: PG&E ATS

### *8.6.4.7 System Delivery Efficiency Results—24-hour Draw Profile—Insulate Distribution System*

In Table 57, insulation of the distribution system increased absolute system delivery efficiency by 8 percent, a reduction change in total energy usage of 17.4 percent. Fixture delivery temperature also improved by over 15°F (8°C) at the lavatory sink and at least 5°F (3°C) at all other fixtures.

Partial distribution system insulation was applied to the water heater supply line up to the main distribution loop, and resulted in an improvement in system delivery efficiency of almost 3 percent compared to a system with no insulation. There was a significant reduction in hot water delivery temperature in the test without insulation or with partial insulation.

**Table 57: Results—24-Hour Draw Profile—Insulate Distribution System**

| RCx Measure: System Insulation | | | | | | |
|---|---|---|---|---|---|---|
| Test Condition | System Delivery Efficiency | $T_{DELIVERED}$ Hand Sink (°F) | $T_{DELIVERED}$ 3 Comp Sink (°F) | $T_{DELIVERED}$ Mop Sink (°F) | $T_{DELIVERED}$ Lavatory Sink (°F) | % Change in S.D.E. vs. w/ Recirc w/ Insulation |
| With Insulation | 53.85% | 134.82 | 141.77 | 140.83 | 132.23 | X |
| With Partial Insulation | 48.65% | 123.22 | 134.84 | 134.63 | 113.78 | -10.67% |
| With No Insulation | 45.86% | 123.21 | 134.35 | 134.75 | 113.47 | -17.42% |

Source: PG&E ATS

### *8.6.4.8 System Delivery Efficiency Curves—24-hour Draw Profile—Retro-commissioning and Retrofit*

In Table 58, the results from the retro-commissioning testing are compared to the base case. An equation is developed for each base case and RCx measure to show the relationship between system input, system output, and heat loss. This equation may be used for future modeling studies of commercial hot water systems.

**Table 58: System Delivery Efficiency Curve Development—Establishing System Line**

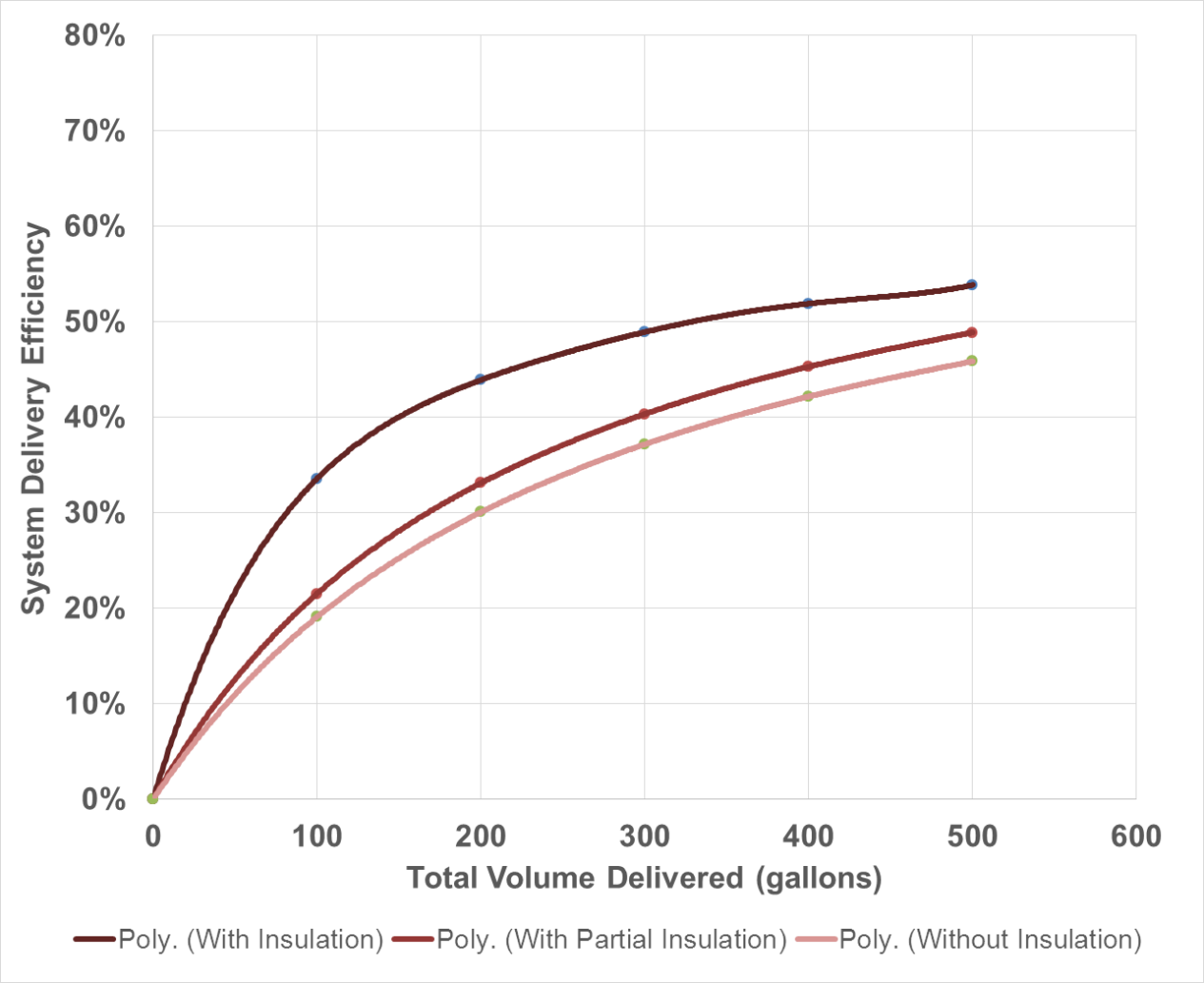
| Input vs. Output Line - With Insulated Distribution System | | | | | |
|---|---|---|---|---|---|
| Base Case | System Input (Btu) y | m | System Output( Btu) x | Heat Loss (Btu) b | Volume Delivered (gallons) |
| w/o Recirc | 454200 | 1.43 | 285697 | 45322 | 476 |
| w/ Recirc | 486401 | 1.58 | 259551 | 77149 | 472 |
| RCx Measure | | | | | |
| Disable Damper | 558452 | 1.78 | 270320 | 77149 | 471 |
| Timeclock | 459175 | 1.55 | 257030 | 61076 | 460 |
| Aquastat | 450268 | 1.44 | 258333 | 77149 | 456 |
| Point of Use - A | 539579 | 1.87 | 246682 | 77149 | 458 |
| Point of Use - B | 450769 | 1.51 | 246682 | 77149 | 458 |
| 160F Setpoint | X | X | X | X | X |
| Partially Insulated Distribution System | | | | | |
| w/ Recirc | 429354 | 1.40 | 200489 | 149440 | 436 |
| Without Insulated Distribution System | | | | | |
| w/o Recirc | 470114 | 1.40 | 251685 | 117468 | 519 |
| w/ Recirc | 439055 | 1.42 | 191081 | 168280 | 434 |
| RCx Measure | | | | | |
| Disable Damper | 506031 | 1.65 | 205139 | 168280 | 444 |
| Timeclock | 474451 | 1.53 | 223483 | 133222 | 478 |
| Aquastat | 468139 | 1.31 | 229003 | 168288 | 482 |
| Point of Use - A | 449504 | 1.69 | 166246 | 168280 | 400 |
| Point of Use - B | 411303 | 1.46 | 166246 | 168280 | 400 |
| 160F Setpoint | 682366 | 1.38 | 306623 | 260433 | 488 |

Source: PG&E ATS

### *8.6.4.9 System Delivery Efficiency Curves—24-Hour Draw Profile—Distribution System Insulation Impacts*

Figure 183 plots the system delivery efficiency curves of the base continuous recirculation case with full, partial and no pipe insulation test scenarios. It shows that there are significant system delivery efficiency improvements when insulation is added, especially in the full-insulation case.

**Figure 183: Results—System Delivery Efficiency Curves—Distribution System Insulation Impacts**



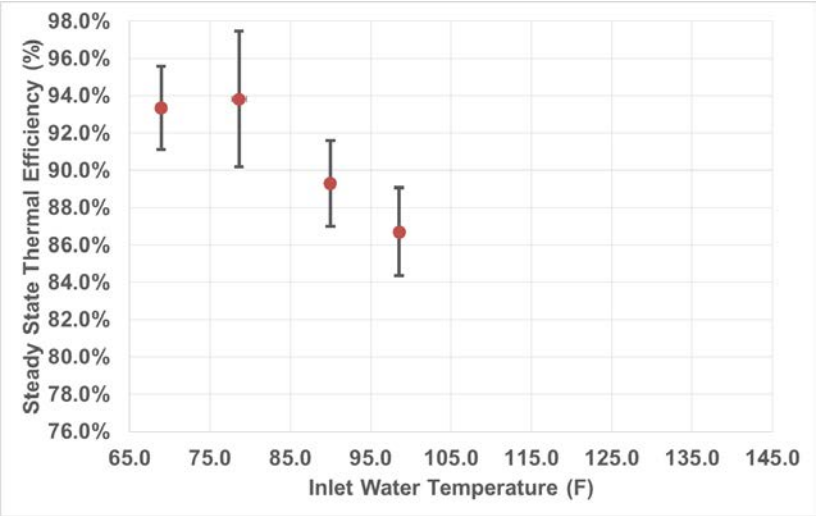

Source: PG&E ATS

## 8.6.5 Impact of Preheating Water on Thermal Efficiency

### *8.6.5.1 Condensing Tank-Type Water Heater*

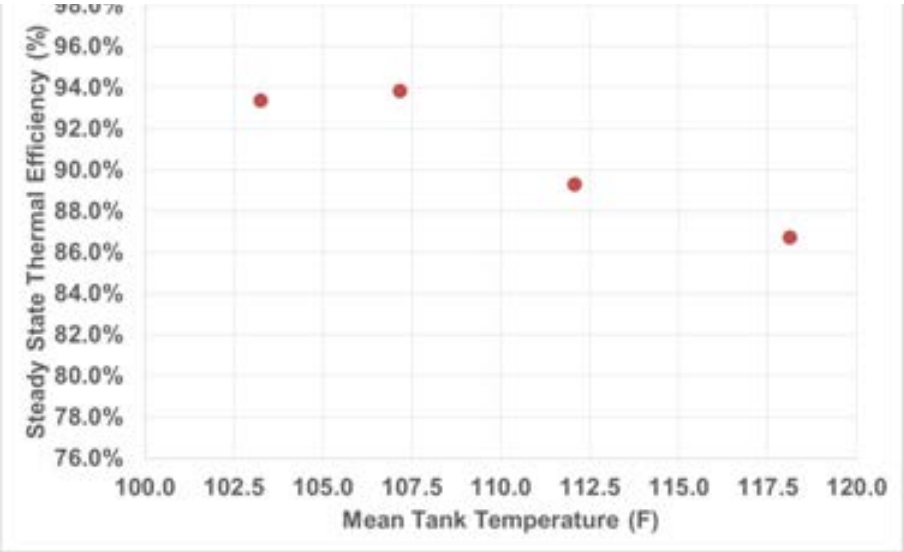
In Figure 184, thermal efficiency of the high-efficiency tank-type water heater dropped significantly between an inlet water temperature of 80°F (27°C) and 90°F (32°C). A drop in thermal efficiency continued as the inlet water temperature approached 100°F (38°C). The same trend is apparent between mean tank temperature and water heater thermal efficiency in Figure 185.

**Figure 184: Results—High-Efficiency Tank-Type Heater—Thermal Efficiency and Tank Inlet Water Temperature**




Source: PG&E ATS

**Figure 185: Results—High-Efficiency Tank-Type Heater—Thermal Efficiency and Mean Tank Temperature**



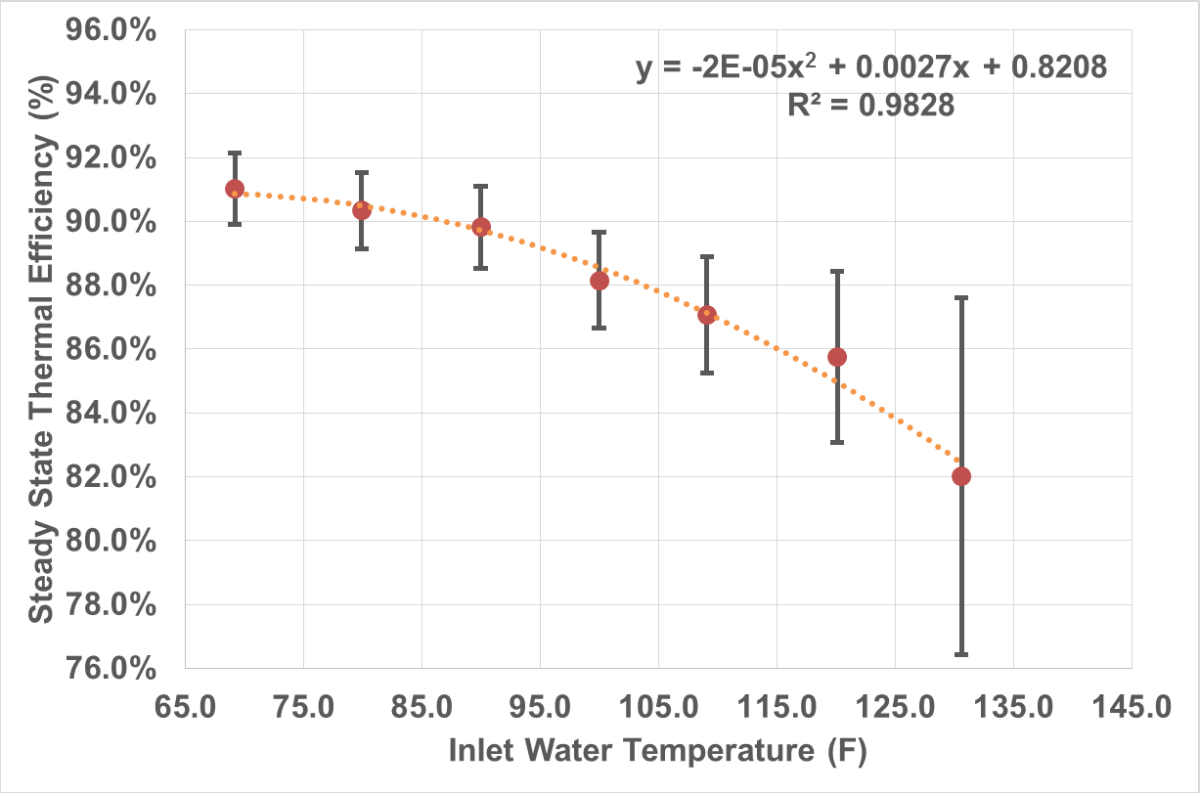

Source: PG&E ATS

### *8.6.5.2 Condensing Tankless Water Heater Thermal Efficiency*

In Figure 186, the thermal efficiency of the condensing tankless heater continued a steady decline with increasing inlet water temperature. At an inlet temperature of 90°F (32°C), the

thermal efficiency fell below 90 percent and continued to decline until it had lost all condensing operation at an inlet temperature of 130°F (55°C).

**Figure 186: Results—High-Efficiency Tankless Heater—Thermal Efficiency and Tank Inlet Water Temperature**

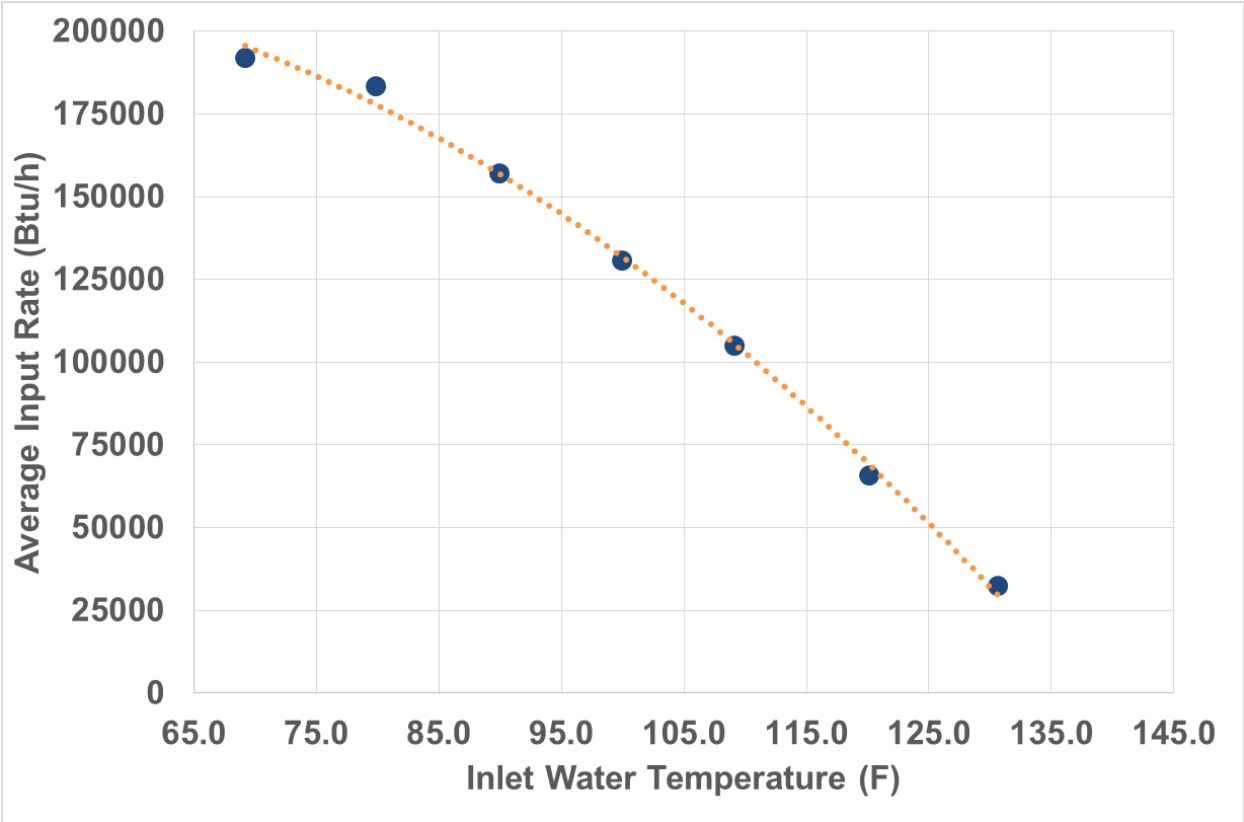



Source: PG&E ATS

### *8.6.5.3 Condensing Tankless Water Heater Input Rate and Inlet Water Temperature*

In Figure 187, the input rate of the high-efficiency tankless water heater adjusted automatically as inlet water temperature changed with the various preheat test conditions. Thus, output of this water heater is also dependent upon operating inlet water temperature.

**Figure 187: Results—High-Efficiency Tankless Heater—Input Rate and Tank Inlet Water Temperature**




Source: PG&E ATS

### 8.6.6 Information Dissemination Summary

FSTC and ATS collaborated to educate the industry on the results of this project. In the last few years, presentations have been delivered to the research and utility community regarding the objectives of this project. The findings of the commercial hot water system laboratory report will be distributed to a wide array of stakeholders, including manufacturers, energy efficiency professionals, utilities, regulatory bodies (plumbing codes, food safety regulations, building codes, energy efficiency codes), engineering societies, conference attendees, both independent and chain operators, hot water system designers and plumbing professionals. The information dissemination plan relies heavily on educating the public on best design practices while highlighting existing high-efficiency products and energy efficient components. The goal was to communicate the benefits of optimized hot water system design and the various energy efficient options to educate the client on concepts that yield energy savings for their application.

#### *8.6.6.1 Information Dissemination Program*

Various methods will be used to educate the industry, including speaking engagements, publications, meetings, partnerships and demonstrations from the commencement of this project in 2011. The team routinely host seminars at the FSTC and at other California investor-owned utilities and present at various technical conferences and engagements. Information

from this project will be disseminated through publishing reports, writing articles and being quoted in publications. The results from the laboratory testing will be influential in updating foodservice hot water system design guides (Fisher-Nickel, inc. 2010) and existing engineering hot water system design handbooks, and maintaining the Fisher-Nickel, inc. website. Additionally, the team will conduct design consultations and energy efficiency audits with restaurateurs, co-ordinate with ATS to host field trips and walkthroughs of the hot water system laboratory, and meet with manufacturers and service providers. Important outcomes of the project will be communicated with NGO's, government organizations, professional and industrial trade organizations.

#### *8.6.6.2 Information Dissemination Plan*

The information dissemination plan consists of five types of outreach. The team educates through delivering presentations, developing website resources and publications, meetings with stakeholders, forging partnerships, and hosting demonstrations. Details on each outreach path were provided in the Interim Report titled, *Information Dissemination Plan* submitted to the CEC (Delagah A. 2013), which includes the quantification of the level of effort.

### 8.6.7 Summary of Laboratory Test Results

#### *8.6.7.1 Water Heater Thermal Efficiency*

- Under the conditions outlined the ANSI Standard, the tank-type condensing water heater offered the highest thermal efficiency.
    - Stratification within the tank provides a low temperature medium to recover latent energy contained in the exhaust gas.
- Under the conditions outlined the ANSI Standard, the standard-efficiency tankless water heater was more efficient than the standard-efficiency tank-type water heater.
- Under the conditions outlined the ANSI Standard, the thermal efficiency of the condensing tankless unit exceeded the thermal efficiency of both standard-efficiency tank-type heaters, but was less efficient than the tank-type condensing water heater.

#### *8.6.7.2 Water Heater Standby Loss*

- Standby loss of a high-efficiency tank-type water heater is half that of a standard-efficiency tank-type water heater.
    - Due to the stratification in a high-efficiency tank-type water heater, the average tank temperature is reduced compared to a standard-efficiency tank-type water heater.
- Tankless water heaters consume very little electric energy and no gas in standby.

#### *8.6.7.3 Hot Water System Delivery Efficiency*

- Depending on the application, condensing tank-type water heaters operating in insulated systems with no recirculation offered great system delivery efficiency.
    - Eliminating recirculation through the condensing tank-type water heater allowed for stratification within the tank, enabling sufficient temperature difference for latent heat capture from exhaust gases.

- Operating a high-efficiency water heater, tank-type or tankless, with recirculation will reduce the system delivery efficiency (the amount depending on the temperature of recirculation).

#### *8.6.7.4 Hot Water System Delivery Efficiency – Energy Savings through Retro Commissioning and Retrofit*

- Insulation of the water heater distribution system generally improved its overall performance
    - Less input energy was required to meet fixture demand.
    - Delivery temperature increased under most circumstances.
- For applicable water heaters, bringing a flue damper back into service reduces input energy, but make no difference in delivery temperature.
- For applications where recirculation is not needed during specific times of the day, a timeclock can reduce input energy requirement by reducing system heat loss.
- Installation of an aquastat for controlling a system recirculation pump appears to result in an improvement of system delivery efficiency, but the actual improvement varied from test to test.
    - If the aquastat does nothing that impacts the control of hot water temperature within the water heater it will at least reduce distribution system losses.
    - The performance of this device and subsequently the performance of the hot water system are dependent upon how the device is setup.
- Point of use heaters are not well suited for systems like the one under test in this effort, as removing the end use did nothing to reduce distribution system losses.
    - If an extended length of pipe exists between the point of use, and distribution system heat loss can be reduced, point of use heaters may be a great option for saving energy.
    - Site to source energy usage should be considered, along with the cost of electrical energy vs. gas energy.

#### *8.6.7.5 Impact of Preheating Water on Thermal Efficiency*

- Thermal efficiency degrades with the increase in entering water temperature, especially above 90°F, for both high-efficiency tank-type and tankless water heaters.
    - System designers should take into account this impact of entering water temperature on system performance.
    - Tankless water heaters may limit output with increasing entering water temperature, while tank-type heaters will not modulate in this way unless designed to do so.

## 8.7 Conclusions and Recommendations

### 8.7.1 Conclusions

Condensing tank-type water heaters operating in systems with no recirculation offered the best system delivery efficiency. When a recirculation pump was in use, the system delivery efficiency maintained constant for all types of tankless and tank-type heaters, with the exception of the standard-efficiency tank-type heater, which performed worse than the rest. Adding insulation to the distribution system increased the system delivery efficiency and delivery temperature at the fixtures. For systems where preheating of incoming water is being performed, heater efficiency was found to decrease rapidly with entering water temperatures exceeding 90°F (48°C).

This project was a significant undertaking, involving the development of a 500 gallon daily hot water use profile from field testing and adapting the data for laboratory testing to mimic real world hot water system operation in commercial facilities. The design and build out of the laboratory and commissioning the testing apparatus were complex tasks, but allowed for the first phase of testing at this new laboratory. The testing produced results that will guide energy efficiency policy, incentives and education programs for the short and medium term. One outstanding accomplishment from laboratory testing was the capability to test various water heaters with differing distribution system configurations and measure system efficiency at the point of use fixtures. This type of laboratory testing of commercial facilities has never been done, where details and results of testing are made available to the public.

While the results from the laboratory are encouraging, higher efficiency hot water systems must be economically viable for the owner/operator of the facility for effective penetration. Based on the results for system operating efficiency in Figure 175, an average operator in California of a 500 gallon per day quick-service restaurant will save 320 therms annually by installing a high-efficiency condensing storage water heater instead of a standard efficiency unit. This is calculated using an inlet water temperature of 65°F and an outlet temperature of 135°F for a 70°F temperature rise.

The incremental cost difference for the purchase and installation of a condensing heater over the base unit varies between $200 and $1400 depending on the size of the unit installed. The installed cost of a 70 gallon standard efficiency unit with a 120,000 Btu/h input rating is estimated at $5,540 versus $5,740 for a 50 gallon high efficiency unit with a 100,000 Btu/h burner rating. The installed cost of a 100 gallon standard efficiency unit with a 199,000 Btu/h input rating is estimated at $6,800 versus $8,200 for a high efficiency heater. In either case, the heater pays back within the working life of the unit for this application.

Distribution systems on the other hand are more complex and it is difficult to quantify the installed cost or energy savings as each conventional distribution system is unique for each facility and a handful of optimization strategies are available to choose from to optimize the system. Material and labor costs for standard versus optimized distribution systems would offset in many cases. Getting designers, engineers and regulators on board with designing and approving unconventional distribution systems is a big challenge.

### 8.7.2 Recommendations

#### *8.7.2.1 Laboratory Research*

The overarching recommendation is to expand research on heater and system performance under conditions not explored within the scope this effort. ANSI efficiency testing can be expanded to include new water heater technologies suitable for commercial facilities including hybrid (combination of mini-storage and tankless heater technologies) water heaters and tankless heaters operated in a boiler style configuration by utilizing a large volume storage tank to manage peak volume flows and recirculation systems. Impacts of recirculation through the water heater on thermal efficiency should also be explored with the control volume drawn around the heater itself to quantify real world heater operating efficiency. The distribution system configurations in the laboratory can be expanded by adding a demand circulation scenario and recirculation line lengthened from 200 to 400 feet to better represent distribution systems in medium sized full-service restaurants. Full-service restaurants are a great candidate for testing as major problems with performance are common in larger restaurants with dishwashers and the energy savings potential is much greater by optimizing the system (Fisher, D. 2007), (Delagah, A. 2010). Research can be expanded to test scenarios that improve hot water delivery performance at hand sinks without increasing energy use such as reducing pipe diameter in the branch and twig piping leading to the water using equipment or sink. Upon performing this research, further recommendations can be made for incrementally improving water heater system efficiency. There are many ways to expand on the existing research in the laboratory and ATS will be meeting with stakeholders to build a roadmap for future testing.

#### *8.7.2.2 Field Demonstration and Case Study*

Off-the-shelf technologies exist in California which can greatly improve the operating efficiency, and combined with the design of optimized hot water systems will deliver much improved hot water delivery performance. Currently, these energy efficient technologies have a low penetration rate and the use of advanced distribution system architectures is negligible. Existing and future laboratory research on hot water systems at ATS will guide the development of a field-monitoring project. This demonstration project in a full-service restaurant will document existing hot water system energy use and delivery performance, and quantify hot water delivery performance improvements and energy savings associated with an optimized system. Case studies are the most effective way to educate restaurateurs, designers, plumbing professionals, regulatory organizations, and trade organizations to increase adoption of modern hot water system design practices and energy efficient technologies.

#### *8.7.2.3 Hot Water System Performance Calculator*

Ultimate goal of the proposed laboratory and field research is to develop a hot water system performance calculator. Key inputs would help to characterize the system by determining equipment and fixtures, distribution system heat loss, hot water use profile, and water heater efficiency. Hot water systems have many variables in system design that make it difficult to generalize energy saving opportunities. Certain energy efficiency measures may or may not improve performance of a particular water heating system based on differences in distribution system design, water heater efficiency, end-use equipment, pipe-insulation, etc. Previous PIER work has generated data regarding the performance of water heating systems both in the field

and in a laboratory setting. This calculator can be utilized by a wider audience including energy efficiency professionals, designers and utilities to characterize the performance of specific equipment or design options, identify retrofit opportunities specific to that system, and provide installation, operating cost, and incentive estimates. The calculator is not meant to be a precision system simulator, but rather a tool to gather enough information to identify energy efficiency measures and approximate energy savings for each measure to promote implementation.

### 8.7.3 Benefits to California

The benefits to California by utilizing the appropriate condensing water heater technology and optimized distribution systems in commercial facilities are significant. Existing system delivery efficiencies of gas-fired hot water systems in small restaurants are in the 30 to 60 percent range as shown through laboratory tests. In many commercial hot water systems, the efficiencies would be much lower and in some cases in the single digits. It is possible to significantly improve system delivery efficiencies and thus improve operating efficiency to a lesser extent in commercial facilities.

The energy savings potential in California from medium to large commercial hot water systems by utilizing best practices is estimated to be 97 million therms or 68 million dollars for gas-fired systems. This analysis is based on an 80 percent penetration rate of condensing heaters and 35 percent penetration rate of optimized distribution systems using the same methodology in the 2010 PIER report (Delagah, A. 2010) on commercial kitchens. The segments analyzed in the commercial sector were expanded from just facility types with commercial kitchens to include personal care services, office buildings, nursing and residential care, laundry facilities and hotels without food service. Many of these best practices can be adapted to many electricity-based hot water systems for additional savings. Californians could benefit in the long term with improved system performance, energy savings and lower operating costs. The goal is to have higher efficiency systems be the norm in designing new establishments and in major retrofit of existing facilities.

# CHAPTER 9:
# Technology Transfer

## 9.1 Introduction

Technology transfer plays an important role in the dissemination of the results of this research to manufacturers, the research community, and the public. The purpose of the plan is to communicate the benefits of the PIER research and results of the technology development to the manufacturer, the commercial foodservice industry, and the public through industry events, utility training, and presentations. Tech transfer to the manufacturer is an ongoing part of the product development process and is not covered in detail here. This plan encompasses trade shows, utility programs, ASTM opportunities and other mechanisms commonly used. The team will endeavor to use as many of these opportunities for technology transfer as possible.

## 9.2 Trade Shows

Manufacturers of foodservice appliances are contacted frequently at industry trade shows throughout the year. The North American Association of Food Equipment Manufacturers (NAFEM), National Restaurant Association (NRA), International Pizza Expo, are attended annually to interact with equipment manufacturers of foodservice equipment to share new technologies and encourage adaptation. Development of the prototype equipment used in this project resulted from the working relationship with manufacturers cultivated from attending such trade shows.

**Figure 188: NAFEM Trade Show**

Photo credit: NAFEM

### 9.2.1 NAFEM

The North American Association of Food Equipment Manufacturers (www.NAFEM.org) is a trade association of nearly 550 foodservice equipment and supplies manufacturers providing products for food preparation, cooking, storage and table service. The organization puts on a biennial show for an audience of about 20,000 featuring 500 plus exhibitors of food preparation,

cooking, storage, and table service. This event showcases the latest appliance technology for buyers and sellers within the food service industry.

### 9.2.2 NRA

The National Restaurant Association is the industry trade association for restaurant businesses. Membership of the NRA is approximately 500,000 restaurant businesses. An annual trade show is hosted by the NRA to gather the restaurant, foodservice, and hospitality industry together with attendance of 58,000 plus from across the world. Exhibitors of over 900 product categories are present at this event, including equipment manufacturers. New appliance technologies are exposed to a large user base including national chain restaurants where they can be implemented to collectively save energy.

### 9.2.3 International Pizza Expo

The International Pizza Expo is an annual trade show for pizza-concept restaurant owners, operators, managers, distributors, and food brokers. This trade show has been in existence for 29 years and has attendance of more than 6,900 industry professionals visiting more than 400 exhibits. The International Pizza Expo is not open to the public and is the most direct forum of interaction with conveyor oven end users, and manufacturers.

### 9.2.4 US Foods Show

The FSTC hosted a 10x10 booth at the US Foods Seminar and showcased on October 16, 2012. This showcase and seminar presentation promoted the monitoring work and ongoing technology transfer of the work done at the FSTC.

US Foods is a leading foodservice distributor in the US, with a client base that includes restaurants, healthcare, hospitality facilities, government operations, and educational institutions. Their event is heavily-attended by their customers (US Foods busses in their customers from remote locations for this daylong event). While people attend the event to learn about new products they are also hoping to find answers to questions regarding their appliance needs, food safety, packaging, etc. FSTC staff talked to 88 restaurant owners and operators at the showcase, three of whom signed up for an energy audit. Approximately 40 attendees also attended the seminar, and each seminar attendee received a Turbo Pot. Attendees were very receptive to the FSTC's participation in the event; the movement from the digital signs attracted the attention of show attendees to the showcase, and allowed FSTC staff to spend 10-15 minutes with about half of them to talk about PIER research, PG&E programs and the FSTC, and to help answer questions and offer suggestions. The US Foods Show proved to be a venue where the message of energy-efficient appliances can effectively reach the customer.

## 9.3 ASTM International

The American Society for Testing and Materials is a volunteer organization for the development of international consensus standards. Make up of each committee is a good mixture of industry professionals of different areas from the manufacturers, government, to the end user. ASTM standards are accepted internationally and referenced by EPA for the energy star certification of foodservice equipment. The foodservice technology center actively participates in ASTM by

volunteering in the F26 committee on foodservice equipment standards. At each semi-annual meeting of the F26 committee, emerging technologies such as those developed in the conveyor oven are shared amongst all parties to help foster its technology transfer.

## 9.4 Utility Programs

California investor owned utilities offer many opportunities and venues for technology transfer of PIER program. The list below identifies several of them to be used in this project.

### 9.4.1 California Joint Utility Program

Adaptation of energy saving technologies in the foodservice industry is incentivized through the California Energy Wise program. The joint effort of the California Energy Wise program is a partnership between California utilities Pacific Gas & Electric, Southern California Gas, Southern California Edison, and San Diego Gas & Electric. Quarterly executive planning council meetings are held to share information such as new technologies in each equipment category and support adaptation. Collectively the program promotes technology transfer and information dissemination through the resources of each utility by offering rebates towards efficient equipment categories and educational classes to the rate payer base to reinforce and proliferate the use of these technologies.

### 9.4.2 Energy Centers

Each of the investor owned utilities in California operate energy centers to teach their respective ratepayers and local businesses energy efficient practices. Visitors learn about the latest in energy management and efficiency technologies through classes, workshops, interactive displays, and consulting services. Together, the joint utilities reach most of the ratepayers in the state of California.

**Figure 189: IOU Energy Centers**

Source: SoCal Gas

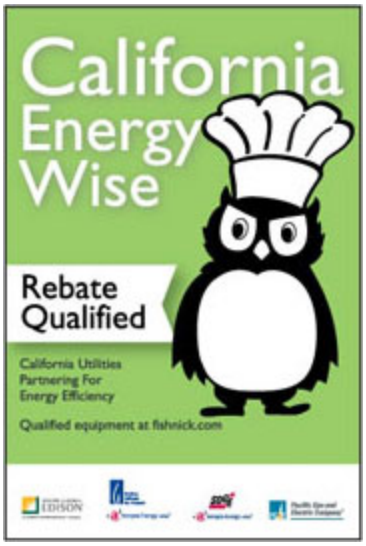
### 9.4.3 Joint Utility Energy Efficiency Seminars

Working together, the joint utility program has developed a comprehensive curriculum in food service that is taught throughout the year rotating through each energy center. The curriculum covers the spectrum from beginning to end by teaching classes about preliminary design (Efficient Lighting), to operation (Equipment Maintenance for Optimum Efficiency), and new developments in the industry (Innovative Technologies & Efficiency Rebates.)

### 9.4.4 Rebates

Under the joint utility program, food service appliances that meet energy efficiency requirements qualify for rebates. The joint utility rebate help offset the initial equipment cost while encourage the use of new efficient technologies.

**Figure 190: California IOU Energy Wise Rebates**




Source: Energy Wise website

### 9.4.5 Equipment Demos

New appliances are demonstrated at each of the utilities energy centers. Prospective buyers of new food service equipment have a chance to try out an appliance before committing to the capital investment of purchasing brand new equipment. During the demonstration the customer is educated about energy efficiency through new technology and ties back into the larger program at the FSTC. The team will look for opportunities to demonstrate all the appliances being developed in the program in utility energy centers.

## 9.5 Other Mechanisms

Other mechanisms for technology transfer will be used as much as possible in the program. Some examples follow.

### 9.5.1 Site Surveys

During a site visit, the energy analyst will examine the energy and water systems. Cooking appliances, lighting, refrigeration, exhaust ventilation, water heating, sanitation/dishwashing

and water fixtures are analyzed. A site visit report is generated to document energy saving recommendations and calculable energy saving opportunities using the latest efficient technologies.

### 9.5.2 Design Consultation

Design consultation is provided to rate payers seeking to install new or replacement appliances or equipment in their operation. Facility design and review of new construction projects is also available. Consultation drives the use of energy-efficient technologies in new kitchen design and in upgrades.

**Figure 191: Design Consultation**

Photo credit: FNi

### 9.5.3 End User Interaction

Educational classes held at the PG&E FSTC teach rate payers energy efficient practices and new technologies in food service appliances. (http://www.fishnick.com/education/seminars/events/). Attendees receive direct end user interaction from classes targeted at teaching best practices in operation (Equipment Maintenance for Optimum Efficiency), emerging technologies (Innovative Technologies & Efficiency Rebates), and ice breaking exposure to new equipment (Fryer Challenge). Large impact users with multiple locations are actively sought out to implement new equipment technologies to encourage technology transfer within respective restaurant segments. Efficient appliances with the latest technology improvements are tested and reported to the general public on fishnick.com for end users to openly access. Direct interaction with end users of conveyor ovens such as Pizza Patron in this project are used to encourage the transfer of new technologies.

### 9.5.4 Website

The FNi website (www.fishnick.com) features FSTC generated data and resources and also serves as the portal for the California statewide IOU (investor-owned utility) foodservice incentive and seminar programs. Test results of energy-efficient equipment that qualify for rebates under the joint utility program are published and tools such as life cycle cost calculators allow anyone to estimate energy usage cost between baseline appliances versus efficient models. Field studies and case studies of new technologies and energy efficient practices are available to the public to encourage further information dissemination.

**Figure 192: Food Service Technology Center Website**

Source: FSTC

## 9.6 Water Heater

### 9.6.1 Information Dissemination Summary

FSTC and ATS collaborated to educate the industry on the results of this project. In the last few years, presentations have been delivered to the research and utility community regarding the objectives of this project. Appendix F provides a summary of all the information dissemination activities relating to commercial hot water systems concluded and upcoming. The findings of the commercial hot water system laboratory report will be distributed to a wide array of stakeholders, including manufacturers, energy efficiency professionals, utilities, regulatory bodies (plumbing codes, food safety regulations, building codes, energy efficiency codes), engineering societies, conference attendees, both independent and chain operators, hot water system designers and plumbing professionals. The information dissemination plan relies heavily on educating the public on best design practices while highlighting existing high efficiency products and energy efficient components. The goal was to communicate the benefits of optimized hot water system design and the various energy efficient options to educate the client on concepts that yield energy savings for their application.

#### *9.6.1.1 Information Dissemination Program*

Various methods were used to educate the industry, including speaking engagements, publications, meetings, partnerships and demonstrations from the commencement of this project in 2011. The team routinely host seminars at the FSTC and at other California investor-owned utilities and present at various technical conferences and engagements. Information from this project was disseminated through publishing reports, writing articles and being quoted in publications. The results from the laboratory testing will be influential in updating foodservice hot water system design guides (Fisher-Nickel, inc. 2010) and existing engineering hot water system design handbooks, and maintaining the Fisher-Nickel, inc. website. Additionally, the team will conduct design consultations and energy efficiency audits with restaurateurs, co-ordinate with ATS to host field trips and walkthroughs of the hot water system laboratory, and meet with manufacturers and service providers. Important outcomes of the project will be communicated with NGO's, government organizations, professional and industrial trade organizations.

#### *9.6.1.2 Information Dissemination Plan*

The information dissemination plan consists of five types of outreach. The team educates through delivering presentations, developing website resources and publications, meetings with stakeholders, forging partnerships, and hosting demonstrations. Details on each outreach path were provided in the Interim Report titled, *Information Dissemination Plan* submitted to the CEC (Delagah A. 2013), which includes the quantification of the level of effort.

# CHAPTER 10: Conclusions and Recommendations

## 10.1 Conclusions

### 10.1.1 Conveyor Oven

There is a clear opportunity to advance state-of-the-art conveyor ovens by developing more efficient designs that maintain the functionality required by operators. This will be accomplished by decreasing the energy lost when the oven is not cooking product while still kept in a ready-to-cook or idle state through improved insulation and advanced controls. The cooking-energy efficiency of the conveyor oven will be most impacted through the development and application of advanced burner and heat exchanger designs. Through this PIER project, GTI began exploratory development of advanced conveyor ovens that reduce standby losses and improve efficiency.

There is also an opportunity for energy savings in the conveyor oven category through what is being termed by the industry as a standalone EMS specifically designed for conveyor ovens. An EMS is able to monitor and control the functions of the conveyor oven to bring the energy consumption of the appliance down during periods of inactivity. Feedback from operators at each test site indicates that peak business sales are during lunch and dinner hours, with the time between both meals representing the lightest periods. These hours of operation where the oven is predominantly in standby represent an opportunity for energy savings that can be derived from the EMS. This strategy has the potential to reduce conveyor oven energy consumption by 12 percent, based on laboratory testing and assuming that the ovens are in standby mode 30 percent of the time.

In each of the test sites, energy consumption was driven by high standby losses, evidenced by the relatively flat energy-use profile independent of cooking activity. Correct application of the EMS is crucial to achieve energy savings. In high-volume operations, such as concession stands and sporting events, there is a constant flow of customers. The constant demand from such operations would not be able to engage the energy-saving feature of the EMS and would not be the best application of this technology.

Based on previous PIER research done in project 500-06-028, *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment*, an installed base of 10,900 conveyor ovens consume an estimated 21.5 million therms in California. Current qualifying ovens under the California Energy Wise program put the highest efficiency ovens at 47 percent cooking-energy efficiency. The remaining 53 percent is energy not utilized for cooking the product; escaping through the ends of the oven, through the oven itself, and out the exhaust flue. The report also assumed a 50 percent market penetration potential for energy-efficient conveyor ovens. Field monitoring showed a savings potential ranging from 6 to 38 percent by replacing existing conveyor ovens with new energy-efficient models. The Straw Hat site represented a more typical base case in terms of existing equipment and is more representative of the savings potential for the majority of restaurants. Based on the data collected from Straw Hat Pizza, a

potential 38 percent energy reduction can be achieved by going to a new rebate-qualified conveyor oven. Reflected across the 21.5 million therms consumed and a 50 percent market penetration of energy-efficient models, a potential savings of 4.1 million therms or 2.86 million dollars is possible.

### 10.1.2 Convection Oven

Two test sites showed potential energy savings when upgrading from standard-efficiency convection ovens to ENERGY STAR® convection ovens. Additional savings were achieved for a third site when replacing an ENERGY STAR® convection oven with the best-in-class ENERGY STAR® gas convection oven. Given the longevity of convection ovens, there are many units still in operation that are old and inefficient. Tapping into this market with ENERGY STAR® convection ovens is a worthwhile effort for the operators to save energy and more importantly save money on their bill.

California has an estimated 65,000 convection ovens in service consuming an estimated 30 million therms. By adopting ENERGY STAR® convection ovens, a potential reduction of 4 million therms or 2.79 million dollars would be possible assuming a 35 percent market penetration and a 40 percent energy saving over standard ovens.

The field monitoring data also confirmed that foodservice establishments leave equipment running during operating hours without business flow affecting usage patterns. Prior to solid field monitoring data, there was no evidence to confirm whether operators turned off equipment in the middle of the day, or whether they left equipment running during operating hours. This data showed that hours of operation, not business flow, governs the daily energy consumption.

### 10.1.3 Range

The gas range is an appliance that has been around for centuries. Developments in other gas appliances like fryers, griddles and combination ovens have taken leaps over the past few decades. The technology of the gas range, however, has remained virtually unchanged during that time. This report outlines several potential range energy-saving technologies such as burner design, automatic flame shutoff, pilotless ignition, and cooking vessel design, as well as their energy impact in the lab and in the field.

The energy impact of leaving open burners with flames heating up nothing but the air around it seems very dramatic, and it has been proposed that burner shut-off technology should be developed for the range to reduce operating time without a cooking vessel. A spring-loaded burner shut-off system provided a potential solution; however it takes a great deal of attention from the operator for the mechanism to work properly under the right pressure of the cooking vessel. Most of the time chefs leave open burners during a sauté operation that is done with a lighter weight pan. Sometimes it is necessary to lift the pan in order to coat the ingredients in the cooking sauce. In both those instances the shutoff mechanism relies on the small weight of the pan to reignite the burner which has proven to be inconsistent in a lab scenario. While this technology shows promise, the current design has some challenges in replacing standard range burner technology for many types of operations.

Within the scope of this range project, a sub-study was performed in the real-world kitchen using optical flame sensor technology to analyze the actual time a burner remains open and thus quantify the energy-saving potential (or lack thereof). Combining video surveillance with the flame sensor resulted in a better understanding of how ranges are being used. After studying the data, it was found that the burners were being left on without a cooking vessel less than 3 percent of the time for the commercial kitchen being studied. It is recognized, however, that this is highly dependent on how well the staff is trained and could vary from one foodservice operation to another

Pilotless ignition is a well-established technology, operating on principle that is not much different from how cavemen lit dry grass with two flint stones. It is a technology that has become more widely adopted by the residential market than by the commercial foodservice industry. Because of the proximity tolerances of the igniter to the flame, as well as the extra wiring required, true pilotless ignition has proven to be too unreliable to be marketed on a large scale. A semi-automatic pilot ignition system was developed by one manufacturer and field tested within the scope of this research project. However, delays caused by the flame proving system were viewed as a deterrent by kitchen staff, who left the pilots burning during non-cooking times rather than diligently shutting them off and spending the extra effort to relight them. The individual pilots themselves consumed a significant amount of energy, while overall the cooking energy use of the test range was determined to be relatively low when compared to other appliances. Thus, the pilot energy use was a significant component of the total range consumption in this foodservice operation.

Thinking outside the box has caused some companies to focus on the cooking vessel rather than the range itself. Heat sink technology from the computer industry has been applied in reverse to the bottom of a cooking pot. Laboratory studies have been conducted comparing the heat-up times and efficiencies of flat bottom pots compared to finned bottom pots. The test was conducted on three different ranges and resulted in reducing water heating times by 44 percent and increasing heat-up efficiency up to 60 percent.

The high-input rated ring-burner ranges were replaced by low-input star burners and standard pots were replaced by finned Turbo Pots at a cafeteria style restaurant. This field study of upgrading to-low input burner ranges, in conjunction with finned bottom pots, led to a 33 percent reduction in energy use by the field tested ranges.

There are many energy-saving technologies for gas ranges out there. However, only a few of them have become commercially viable and practical. Developments to the passive burner design and to the cooking vessel have shown significant energy savings, while also increasing the performance of the gas range. It is up to the manufacturers to continue developing the other technologies mentioned in this report to be more durable and foolproof before the restaurant industry adopts them.

In a 2010 PIER report by Fisher-Nickel, inc. on *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment,* it was estimated that 45,000 open top gas ranges were in operation in California commercial kitchens. With most ranges operating at a baseline

efficiency of approximately 30 percent, the estimated annual gas use was 16.6 million therms in California. If 50 percent of the gas ranges in California were converted to low input burners in conjunction with finned bottom pots, this could result in an annual savings of 2.7 million therms.

### 10.1.4 Wok

Wok ranges are essential to cooking eastern dishes and are found commonly in Asian food establishments. An estimated 38,987 wok range burners currently in California currently experience an efficiency of 10 – 15 percent. In addition, each burner well uses an average of one gallon per minute of water to cool the surfaces of the appliance, resulting in an estimated 85 million gallons per year in California. The estimated energy load in California for this appliance alone is 30 million therms.

The wok range prototype examined in this study demonstrates the potential to significantly reduce water and natural gas usage in commercial foodservice establishments. With a redesigned burner, burner well, and wok pan, the 20 percent energy savings target was surpassed to achieve an efficiency of 30 percent. In addition, the wok range prototype eliminated the need for cooling water.

The field sites in this study paid an average of $5,457 per year to provide natural gas and water to the appliance. With the implementation of the prototype wok, these establishments could save approximately 74 percent on their utility bill in energy and water combined. The substantial savings potential for the wok range makes it a strong candidate for further improvements, feasibility studies, and market validation tests.

Provided the in-lab efficiency can be translated to commercial foodservice industry, California stands to reduce its natural gas use dedicated to wok ranges by 5.7 million therms per year. In addition, the need for water to cool the surfaces can be completely eliminated, saving California and estimated 85 million gallons per year. In order for this technology transfer to occur, the unit must be optimized for robustness and scalability by manufacturers. The utility and cost savings can then be assessed in the field, where restaurant operators will also have the opportunity to embrace the new technology.

### 10.1.5 Under-fired Broiler

In a 2010 PIER report by Fisher-Nickel, inc. on *Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment,* it was estimated that 42,000 under-fired broilers were in operation in California commercial kitchens. With most under-fired broilers operating at a baseline efficiency of approximately 30 percent, the estimated annual gas use was 122 million therms in California.

Cooking efficiency of under-fired broilers can be dramatically increased by using advanced infrared burners and cooking with the lid down. While many traditional restaurant operators will be reluctant to cook with the lid down, it has the potential to almost double the cooking efficiency, as described in section 6.1.5 Conclusions of this report. The biggest energy saving with a lidded broiler, however, is reduced idle energy rates when the lid is down and the thermostat engaged.

In section6.5.2.2 High Tech Burrito, the site study proved that unless the lid is closed, the lidded broiler will not result in energy savings because it will operate like a conventional non-thermostatically-controlled broiler. The other two site studies where idle operation takes most of the day and the user was consistently closing the lid resulted in 23 percent savings between the two sites. Naturally, there are going to be certain sites that will benefit the most from the use of the lidded broiler. The San Ramon Valley Conference Center, which has long operating hours and consequently long idle times, was a good candidate for the lidded broiler replacement. Norm's, whose operating hours are similar to the SRVCC, will be a prime location for monitoring once the lidded broiler is installed. Sizable energy savings could be realized once comparable restaurants are identified

As stated earlier, there are potentially 42,000 under-fired broilers in California. Based on the study of the four restaurants, average daily energy usage of the standard broiler is 8.0 therms. If 50 percent of the broilers in California were selectively switched to lidded broilers based on their hours of idle operation, this could result in 23 percent savings. Twenty-three percent savings from well-selected sites with 21,000 standard-efficiency broilers that average 9.5 therms per day and operate 364 days per year could result in an annual savings of 16.7 million therms.

### 10.1.6 Water Heater

Condensing tank-type water heaters operating in systems with no recirculation offered the best system delivery efficiency. When a recirculation pump was in use, the system delivery efficiency maintained constant for all types of tankless tank-type heaters, with the exception of the standard-efficiency tank-type heater, which performed worse than the rest. Adding insulation to the distribution system increased the system delivery efficiency and delivery temperature at the fixtures. For systems where preheating of incoming water is being performed, heater efficiency was found to decrease rapidly with entering water temperatures exceeding 90°F (32°C).

This project was a significant undertaking, involving the development of a 500-gallon daily hot water use profile from field testing and adapting the data for laboratory testing to mimic real-world hot water system operation in commercial facilities. The design and build out of the laboratory and commissioning the testing apparatus were complex tasks, but allowed for the first phase of testing at this new laboratory to be a success. The testing produced results that will guide energy efficiency policy, incentives and education programs for the short- and medium-term. One outstanding accomplishment from laboratory testing was the capability to test various water heaters and distribution system architectures and measure system efficiency at the point of use fixtures. This type of laboratory testing of commercial facilities has never been done, where details and results of testing are made available to the public.

## 10.2 Recommendations

### 10.2.1 Conveyor Oven

Feedback from equipment installers and service technicians in the field indicate more robustness in the EMS system is needed for conveyor ovens. Current EMS systems utilize a vision-based sensor placed along the ends of the conveyor to detect the presence of food

product. Field reports suggest that the feedback sensors are prone to blockage from food products such as cheese and flour, resulting in false readings that incorrectly inform the EMS to stay out of idle mode. A more robust EMS system that can withstand the vigor of commercial operation is needed to fully capture the energy savings of conveyor ovens.

The three main areas of energy loss include the end loss from the open entrance and exit of the oven, the heat loss through the oven itself (a result of low amounts of insulation), and the heat energy lost through the exhaust vent. Field data from the test sites indicated that conveyor ovens spend a majority of their time in standby/idle mode during the operating day. To increase the efficiency of the conveyor oven, it is very important to minimize these three main areas of energy loss when running in standby mode.

The field data showed that the majority of conveyor ovens operate in a light load condition. Even during cook loads, the conveyor oven is never filled to its maximum with food product. Consequently, energy loss during standby operation or between individual light product loads is large. It is recommended that more research and development be spent on reducing the energy consumption of conveyor ovens under light-load conditions.

Additional field testing should be conducted in the conveyor oven category. The data captured from this project helped to begin characterizing the energy use of conveyor ovens. However, more research is needed to completely characterize this appliance. The ultimate goal is to be able to significantly reduce the estimated 21.5 million therms consumed by conveyor ovens.

### 10.2.2 Convection Oven

When comparing convection ovens against other similar foodservice categories, there remains room for efficiency improvements. Average gas ENERGY STAR® convection ovens yield 44 to 47 percent efficiency, compared to the 50 percent to 60 percent average efficiency of other gas cooking appliances. In contrast, a combination oven which is able to operate in steam or convection mode has an efficiency of 60 percent while running in convection mode. It is recommended that further research be conducted on gas convection ovens to push the upper limit of energy-efficiency beyond the current best-in-class 54 percent and idle energy rate of 13,000 Btu/h.

Because the energy footprint of commercial ovens is so significant, it is worth investing future foodservice research towards development in increasing convection oven energy-efficiency. Further efficiency improvements can be fostered through additional research and development to extract more heat energy from combustion and retaining it within the oven. These improvements can be driven through more aggressive education and promotion of the advanced technologies via rebates for convection ovens.

### 10.2.3 Range

While there are technical issues that must be overcome before the different variations of the advanced range is a market reality, the report concluded that it was possible to create an improved range top that met the expectations of end-users and the industry alike while reducing energy use significantly. With this in hand, the energy efficiency community and gas industry needs to continue R&D work on advanced gas range concepts, focusing on developing

commercial-grade, higher-efficiency burners. Future research should continue along these paths, with emphasis on the following:

1. Development of higher efficiency burners: passive open burner technology does not have much room for improvement; however powered burners have shown energy efficiency improvement potential when properly integrated into the range as shown in the *Commercial Gas Range Top Technology Overview White Paper.*
2. Conduct more energy field monitoring of finned bottom pots in combination with different range burner types and energy inputs. While it was found that the finned bottom pots paired with low input burners yielded significant energy savings, more field studies should be performed on energy usage of finned bottom pots with high input standard ranges and stockpot ranges.
3. The pilot energy use was shown to be a significant component the total range energy use at the cafeteria test site. Reducing the energy consumption of conventional pilots and/or having single pilots for multiple burners are passive steps to pilot energy reduction. The possibility of reducing the number of pilot lights could be investigated as well as the possibility of using a single pilot for all six burners.
4. Automatic pilotless ignition technology needs to be researched and field tested. Pilotless ignition systems need to be more robust and reliable for use in a heavy-duty restaurant operation. Spark ignition times need to be reduced for the staff not to leave open burners.
5. The Turbo Pot needs to be more widely adopted by the industry and should be promoted by both energy utilities and range manufacturers to increase overall system efficiency. Stock pot ranges should be sold with finned bottom pots because they have the highest overall savings potential based on their input rate and operation time. More development work on sauté pans is warranted.
6. The California Energy Commission should consider regulations that would require pilotless ignition for all new range burners solid in California. Such regulation could be considered technology-forcing, where it would drive the manufacturers to develop more robust ignition system that has been in use in residential applications for decades.

### 10.2.4 Wok

In order for California to realize the maximum natural gas savings potential, the technology in this study must be made robust enough for commercial kitchen cooking and scalable for mass production. Although quantitative data has been collected on the prototype performance in the lab, working prototypes need to be developed and placed in various foodservice operations to assess the strength of the design, as well as the quality and consistency of the food product.

While the prototype is currently operated without water, the temperature of the range needs to be assessed for the next generation prototype. If the temperatures are too high, the operator is in danger of burns and the equipment more prone to failure. A thorough assessment of the heat transfer should be determined during the development of the next generation prototype.

Future field studies should assess the safety and monitor the input energy, water use, cook time, as well as the exact amount and type of cooking product that is used. Working with chain restaurants in this way will have the greatest impact towards gaining widespread acceptance of the new technology. In addition, the data collected in the field will substantiate the aforementioned savings claims to restaurant owners and the state of California.

### 10.2.5 Under-fired Broiler

Broiler efficiency has remained the same for decades. However, more and more manufacturers have recently started to sell infrared broilers. Several companies have experimented with lidded prototypes, and the prototype described in this report could benefit from a few more improvements. For large-scale market adoption, the lidded broiler concept will need to be refined and promoted by the manufacturers.

Several comments from the restaurant operators who cooked on the broiler daily are described at the end of each restaurants review within section 6.5.2 Field Test Results. A major concern is that the lid is still quite heavy and the user can get burned on it if not careful. A lid handle extension could decrease the lifting effort if installed in the right place.

Often times only a small part of the broiler is utilized during cooking while the rest of the cooking surface is emitting tremendous amounts of waste heat. This problem can be solved with a split lid where the operator can cook only on half of the cooking surface, while the thermostat under the cover of the other part maintains a lower input rate. This would also encourage the user to cook some products, such as bone-in chicken, with the lid down and simultaneously have the opportunity to cook other products, such as burgers, with the lid open. Another possible improvement could be a double-walled lid, with an air gap acting as an extra insulator for the lid.

The lidded broiler had a standing pilot that consumed the same amount of energy as the conventional broiler. This pilot energy can be greatly reduced by having an automatic pilot ignition system.

Since an under-fired broiler requires some of the highest ventilation rates of all commercial kitchen appliances, a demand controlled ventilation system could be paired with the lid. Opening the lid can simply trigger the vent fan to increase speed without the use of any complicated optics.

As an option for further study, it may be feasible to incorporate a two-stage burner system gas valve as an alternative to the thermostat. This may provide more consistent operation, as flare-ups sometimes caused the thermostat to shut off the burners. The burners needed to stay on at all times when the food was being cooked with the lid open.

Overall, there are great potential savings with the lidded broiler in restaurants that have their units idling for a long time. As more restaurant users and manufacturers become aware of the lidded broiler technology that they have been familiar with for decades, they will start adopting this technology and start improving on it as they get more feedback from the customers.

### 10.2.6 Water Heater

#### *10.2.6.1 Laboratory Research*

The overarching recommendation is to expand research on heater and system performance under conditions not explored within the scope this effort. ANSI efficiency testing can be expanded to include new water heater technologies suitable for commercial facilities including hybrid (combination of mini-storage and tankless heater technologies) water heaters and tankless heaters operated in a boiler style configuration by utilizing a large volume storage tank to manage peak volume flows and recirculation systems. Impacts of recirculation through the water heater on thermal efficiency should also be explored with the control volume drawn around the heater itself to quantify real world heater operating efficiency. The distribution system configurations in the laboratory can be expanded by adding a demand circulation scenario and recirculation line lengthened from 200 to 400 feet to better represent distribution systems in medium sized full-service restaurants. Full-service restaurants are a great candidate for testing as major problems with performance are common in larger restaurants with dishwashers and the energy savings potential is much greater by optimizing the system (Fisher, D. 2007), (Delagah, A. 2010). Research can be expanded to test scenarios that improve hot water delivery performance at hand sinks without increasing energy use such as reducing pipe diameter in the branch and twig piping leading to the water using equipment or sink. Upon performing this recommended research, further recommendations can be made for incrementally improving water heater system efficiency.

#### *10.2.6.2 Field Demonstration and Case Study*

Off-the-shelf technologies exist in California which can greatly improve the operating efficiency, and combined with the design of optimized hot water systems will deliver much improved hot water delivery performance. Currently, these energy efficient technologies have a low penetration rate and the use of advanced distribution system architectures is negligible. Existing and future laboratory research on hot water systems at ATS will guide the development of a field-monitoring project. This demonstration project in a full-service restaurant will document existing hot water system energy use and delivery performance, and quantify hot water delivery performance improvements and energy savings associated with an optimized system. Case studies are the most effective way to educate restaurateurs, designers, plumbing professionals, regulatory organizations, and trade organizations to increase adoption of modern hot water system design practices and energy efficient technologies.

#### *10.2.6.3 Hot Water System Performance Calculator*

Ultimate goal of the proposed laboratory and field research is to develop a hot water system performance calculator. Key inputs would help to characterize the system by determining equipment and fixtures, distribution system heat loss, hot water use profile, and water heater efficiency. Hot water systems have many variables in system design that make it difficult to generalize energy saving opportunities. Certain energy efficiency measures may or may not improve performance of a particular water heating system based on differences in distribution system design, water heater efficiency, end-use equipment, pipe-insulation, etc. Previous PIER work has generated data regarding the performance of water heating systems both in the field and in a laboratory setting. This calculator can be utilized by a wider audience including energy

efficiency professionals, designers and utilities to characterize the performance of specific equipment or design options, identify retrofit opportunities specific to that system, and provide installation, operating cost, and incentive estimates. The calculator is not meant to be a precision system simulator, but rather a tool to gather enough information to identify energy efficiency measures and approximate energy savings for each measure to promote implementation.

## 10.3 Benefits to California

In the six commercial foodservice products, the benefits to California are related to the significant efficiency improvements in this often-overlooked sector. As shown in Table 2, Benefits to the state of California include a savings of 33.4 million therms or 23.3 million dollars per year of natural gas for the products studied in this project. A reduction of approximately 0.2 million metric tonnes of CO2 greenhouse gasses would also be achieved.

The foodservice equipment technologies provide a rapid payback to the California end-users, as shown in Figure 193, below. The payback story further supports the investment in public interest R&D.

**Figure 193: Foodservice Equipment Payback**

| Appliance | Component Cost Estimate($) | Payback Period (years) |
|---|---|---|
| Convection Oven | 200 | 2.2 |
| Conveyor Oven | 300 | 0.5 |
| Open-burner Range | 100 | 0.8 |
| Wok Range | 500 to 1000 | 1.5 to 3 |
| Under-fired Broiler | 850 | 0.9 |

Source: GTI

The benefits to California by utilizing the appropriate condensing water heater technology and optimized distribution systems in commercial facilities are significant. Existing system delivery efficiencies of gas-fired hot water systems in small restaurants are in the 30 to 60 percent range as shown through laboratory tests. In many commercial hot water systems, the efficiencies would be much lower and in some cases in the single digits. It is possible to significantly improve system delivery efficiencies and thus improve operating efficiency to a lesser extent in commercial facilities. The energy savings potential in California from medium to large commercial hot water systems by utilizing best practices is estimated to be in the 100 million therms or 69.8 million dollars range for gas-fired systems. Many of these best practices can be adapted to many electricity-based hot water systems for additional savings. Californians could benefit in the long term with improved system performance, energy savings and lower operating costs. The goal is to have higher efficiency systems be the norm in designing new establishments and in major retrofit of existing facilities.

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# GLOSSARY

| | |
|---|---|
| °C | Degrees Celsius |
| °F | Degrees Fahrenheit |
| "WC | Inches of water column (pressure) |
| ATS | PG&E Applied Technology Services |
| CWHC | PG&E Commercial Water Heater Laboratory |
| ANSI | American National Standards Institute |
| ASTM | American Society for Testing and Materials |
| Btu | British thermal unit, unit of energy equal to approximately 1,055 Joules |
| CEC | California Energy Commission |
| cfm | Cubic feet per minute |
| CFS | Commercial Foodservice |
| EMS | Energy Management System |
| FNi | Fisher Nickel, Inc. |
| FSTC | Foodservice Technology Center |
| gal | Gallons |
| GTI | Gas Technology Institute |
| h | Hours |
| IOU | Investor Owned Utility |
| kBtu | Kilo or thousand British thermal units |
| lb | Pounds |
| MCF | Thousand cubic feet |
| min | Minutes |
| PAC | Project Advisory Committee |
| PG&E | Pacific Gas and Electric |
| PIER | Public Interest Energy Research |
| QSR | Quick Service Restaurant |

| | |
|---|---|
| R&D | Research and Development |
| RCx | Retrocommissioning |
| RD&D | Research, development and demonstration |
| SCFH | Standard Cubic Feet per Hour |
| SCE | Southern California Edison |
| SDG&E | San Diego Gas and Electric |
| SRVCC | San Ramon Valley Conference Center |
| TE | Thermal Efficiency |
| UTD | Utilization Technology Development |
| W | Watts, unit of power equal to 1 Joule per second |