INNOVATIVE CONSERVATION PROGRAM
Metropolitan Water District of Southern California

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Conveyor Dishwasher Performance Field Evaluation Report

FSTC Report Number: P20004-R0
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Prepared by:
Amin Delagah
Fisher-Nickel, Inc.

Contributors:
Angelo Karas, Rodney Davis, David Zabrowski
Fisher-Nickel, Inc.

Prepared for:

Pacific Gas & Electric Company
Customer Energy Efficiency Programs
San Francisco, California

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Test Sites:
The Claremont Hotel, Facebook, Google, Stanford

Food Service Technology Center Background

The information in this report is based on data generated at the Pacific Gas and Electric Company (PG&E) Food Service Technology Center (FSTC). Dedicated to the advancement of the foodservice industry, The FSTC is the industry leader in commercial kitchen energy efficiency and appliance performance testing. Operated by Fisher-Nickel, inc., the FSTC has developed over 40 Standard Test Methods for evaluating commercial kitchen appliance and system performance.

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Acknowledgments

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FSTC Contact Information

Amin Delagah
Project Engineer
(925) 866-5265
adelagah@fishnick.com

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Revision History

Revision Num.	Date	Description	Author(s)
0	December 2015	Draft Report	Amin Delagah

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Executive Summary

Project Summary

Conveyor dishwashers are one of the largest consumers of water and energy in a large commercial food service operation. Previous monitoring has shown that there is an opportunity to reduce the gas, electricity and water use of older legacy dishwashers by at least half. The objective of this field study was to monitor the water and energy use of existing rack and flight conveyor dishwashers and when applicable, monitor the replacement high-efficiency unit installed in large commercial kitchens. The purpose of this project was to demonstrate and document the energy and water savings and economic benefits of replacing an old inefficient dishwasher with a new efficient or best-in-class dishwasher and to devise a comprehensive program to sustain operating savings throughout the lifespan of the equipment. To achieve this, the data was normalized between the dishwashers to show comparative savings and staff operating and maintenance practices were investigated to provide insight into optimal machine operation.

Background

Prior to this project, the Pacific Gas & Electric Company's Food Service Technology Center (FSTC) operated by Fisher-Nickel Inc. had the opportunity to monitor several older conveyor dishwashers in the field to assess the energy and water savings that could be achieved by replacing existing machines with modern energy efficient models in support of the utility's calculated incentive program. While this work had provided a clear business case for replacement, the FSTC team realized that many of the dishwashers that were monitored were not operating to their design specifications. Many operating and maintenance shortcomings associated with these large machines were brought to light that demanded further study. Another key finding of these earlier studies was that a significant portion of daily water consumption was related to tank filling operations, which was contrary to standard practices for estimating water consumption of dishwashers. Commercial foodservice industry and efficiency professionals had been basing the water and energy use of a conveyor dishwasher on the unit's rated rinse flow rate. The additional hot water associated with the numerous daily tank fills accounted for significantly greater hot water use than would be estimated by rinse water consumption alone. The water intensity of conveyor machines makes these appliances the largest single use of water and energy in a commercial kitchen.

This first-of-its-kind research project examined the complexity of conveyor dishwashers in depth, benchmarking water and energy use of old dishwashers operating in facilities and identifying strategies to sustain the savings potential of high-efficiency machines. This research goes further to study the factors that lead to inefficient or efficient operation of dishwashers and washing and sanitizing performance. It is expected that this research project will demonstrate that water and energy use of old conveyor dishwashers can be reduced by at least half through a replacement program with high-efficiency models.

The catalyst for this study was receiving funding from Metropolitan Water District's 2013 Innovative Conservation Grant Program and co-funding from Pacific Gas and Electric Company. All work was performed by Fisher-Nickel Inc.

Process

The research process involved identification of suitable field sites that employed a range of older conventional and newer high-efficiency conveyor dishwashers in various sizes ranging from a 44-inch rack conveyor to 120-inch flight conveyor machine. The field study was conducted on nine dishwashers spanning seven sites, including commercial kitchens at The Claremont Hotel, Stanford University Cafeteria, and cafes at Facebook and Google from May 2014 to June 2015. In most cases, the dishwashers were monitored and characterized as found, irrespective of the condition of the machine. Data, including rinse and fill water use, rinse flow rate, dishwasher and booster heater energy use, and rinse time, was collected at five second intervals and stored with a time stamp in the memory of the data acquisition system (DAQ). Overall, over 70 measured or calculated parameters were analyzed to identify the most important parameters to use to normalize the results for each dishwasher for a fair comparison of other dishwashers in its classification.

Findings and Conclusions

Summary data from the nine dishwashers monitored for this field project were added to nine other dishwashers previously monitored by FSTC in the last five years to supplement the number of dishwashers in this analysis. For each dishwasher, the data was quantified for water and energy use per hour of rinse operation. The conveyor dishwashers were classified into four groups including conventional rack, high-efficiency rack, conventional flight and high-efficiency flight machines to derive savings estimates from replacing older machines with high-efficiency replacements. Tables ES-1 and ES-2 summarize the normalized water and energy consumption for the twelve rack conveyor and six flight type conveyor dishwashers, respectively.

Table ES-1. Measured water and energy use per hour of rinse operation for rack-conveyor dishwashers

	Dishwasher Make and Model	Measured Water Use Per Hour of Rinse Operation (gph)	Measured Energy Use Per Hour of Rinse Operation (Btu/h)
1	Stero SCT-44CS	730	N/A
2	Ecolab ET44	542	692,977
3	Ecolab EC44	235	N/A
4	Stero SCT-44	363	714,978
5	Stero SCT-66S	389	N/A
6	Stero SCT-66S	416	658,194
7	Stero SCT-86S	2194	2,259,192
8	Stero SCT-108S	667	1,504,373
9	Jackson Crew66	135	350,834
10	Hobart CL64E	367	770,499
11	Hobart CLPS86ER	243	401,493
12	Hobart CLPS86ER	301	603,262
	AVG. Conventional Conveyor	692	1,549,961
	AVG. High-Efficiency Conveyor	261	531,522

Table ES-2. Measured water and energy use per hour of rinse operation for flight-conveyor dishwashers

	Dishwasher Make and Model	Measured Water Use Per Hour of Rinse Operation (gph)	Measured Energy Use Per Hour of Rinse Operation (Btu/h)
13	Stero STPCW	605	1,232,775
14	Stero STPCW	1277	703,333
15	Stero STPCW	1770	2,748,224
16	Stero STPCW-ER	823	1,023,582
17	Hobart FT 1000ER	232	595,852
18	Hobart FT 1000ER	303	696,841
	AVG. Conventional Conveyor	1119	1,426,978
	AVG. High-Efficiency Conveyor	267	646,346

The normalized results from 18 sites showed at least 60% reduction in water and energy use by replacing old conveyor dishwashers with new high-efficiency models. Specifically, the water use of the average conventional rack conveyor, at 692 gallons per hour of rinse operation, was reduced by more than 60% when replaced by an average high-efficiency unit, using 261 gallons per hour. Similarly, the energy use was reduced by more than 65% from approximately 1,550,000 Btu/h to 530,000 Btu/h of rinse operation.

The water savings from flight conveyor dishwashers was even greater – representing a reduction of 75%. Water use of the average conventional rack conveyor, at 1,119 gallons per hour of rinse operation, was reduced to 267 gallons for the average high-efficiency unit. Similarly, the energy consumption was reduced by 55% from approximately 1,430,000 Btu/h to 645,000 Btu/h of rinse operation. There is a strong business case to make the switch in all cases, as long as there was minimal fuel switching involved from removing a dishwasher that was primarily heated with natural gas to one heated by electricity.

Old inefficient conveyor dishwashers were replaced with ENERGY STAR qualified high-efficiency models at four sites. The average cost savings per site based on average California utility rates was approximately $22,000 per year. In each case, the cost savings were driven by the substantial reduction in water use.

The research showed that old conveyor dishwashers consume two to three times more water than was predicted based on the rated rinse flow and tank volume specifications. High-efficiency conveyor dishwashers used 70% to 85% more than the rated specifications. The new machines operated more closely in line with the specifications than older machines as they benefited from advanced features that mitigated water waste during tank filling. The results also showed that the rated rinse water flow rate by itself only accounted for a quarter to less than half of the measured real world water use (Table ES-3). Projections based on rinse flow rate specifications alone would not accurately characterize the water use of a particular machine.

Table ES-3. Comparison of specified hourly rinse flow rate to measured water use per hour of rinse operation.

Dishwasher Type	Specified Rinse Flow Rate (gph)	Measured Water Use Per Hour of Rinse Operation (gph)	Specified Rinse as a Percentage of Measured Water Use
AVG. Conventional Rack Conveyor	274	692	40%
AVG. High-Efficiency Rack Conveyor	119	261	46%
AVG. Conventional Flight Conveyor	277	1119	25%
AVG. High-Efficiency Flight Conveyor	58	267	22%

A significant finding was that the majority of conveyor dishwashers installed in facilities are not set up to wash and rinse medium to large back of the house wares without incurring substantially higher water use during operation. Most conveyor dishwashers are designed to wash front of the house cups, glasses and dishes, with the larger back of house wares providing a challenge for the machine. Some of the overspray issues caused by washing large wares could be mitigated with the specification of taller cavity machines and incorporating specialized racks for washing sheet pans and other flat wares at an angle that allows water to drain back into the correct tank instead of horizontally spraying through the machine.

Benchmarking water and energy use through sub-metering of the dishwasher when the unit is performing well and staff is fully trained is a critical tool to incorporate to establish the baseline energy and water use of the machine. Without a benchmark to indicate water performance, the standard “fix” is to increase hot water and chemical use to ensure cleaning and sanitization performance. In extreme cases, poor maintenance can lead to real world water use that is as much as 10 times higher than the specifications for water consumption per hour of rinse operation. Benchmarking allows for easy comparison of multiple foodservice operations and allows management to keep each operation running efficiently as it is easy to check in on the dishroom annually to gauge the performance of the dishwashing operation.

Recommendations

Field monitoring of commercial conveyor dishwashers has identified opportunities to reduce water and energy consumption in commercial dishrooms. In some instances, significant savings can be achieved through the retro-commissioning of existing machines to return the machines to their designed specifications. Greater savings can be achieved by replacing older machines with the latest generation of energy efficient machines, but at a high investment on the part of the operator. While incentives can offset the installed cost of a new machine, an effective conveyor dishwasher program would need to include retro-commissioning to make a significant impact on the market. A two-pronged approach would ensure that both older and newer machines are operating properly and help to sustain the investment in water and energy savings. A pilot dishwasher program would also help to promote the replacement of older machines by identifying the most appropriate candidates. The experiences gained from the pilot project will aid in incorporating more permanent programs that can be expanded throughout the state.

While the dishwasher is responsible for the final cleaning and sanitization of the dishes, the work starts at the pre-rinse station. While codes have mandated a maximum flow rate of 1.6 gpm for pre-rinse spray valves installed in front of a commercial dishwasher, the larger facilities employ more water intensive measures for pre-rinsing dishes that can greatly exceed the intended water consumption and potentially match or exceed that of the dishwasher. Some of the reasons for this is that kitchen staff are often disconnected from the operating costs of running the dishroom and with no sub-metering, there is little to connect dishroom behavior to the overall building water use. The FSTC team has identified at least 5 types of pre-rinse equipment that can be used individually or in combination to effectively accomplish the task of prewashing dishes and other wares. A comprehensive study on dishroom operation is recommended to individually monitor the conveyor dishwasher and pre-rinse operations separately to identify the savings potential from the best pre-rinse devices and operating practices.

Comprehensive policies to encourage sub-metering the water consumption of conveyor dishwashers in existing or new facilities would go a long way to support ongoing efforts to reduce commercial building water and energy use. Additional incentives should be provided for high-efficiency smart dishwashers that minimize water and energy use while having integrated water and energy meters and logging and communications hardware to engage operators and managers on the performance of the unit. While the technology for machines to meter water and energy use is available, few manufacturers have incorporated this capability. A dishwasher sub-metering initiative could integrate with a wider program offering an annual free checkup of the dishwasher and assessment by a 3rd-party. They may provide employee operation and maintenance training to facility staff through the use of videos or onsite visits.

The majority of conveyor machines installed in facilities are designed for front of the house wares, such as dishes, glass ware and eating utensils. As more and more facilities direct their back of the house wares such as pans and trays, the machines are being challenged to accommodate large wares that can impact water use. In addition, many machines were found to be oversized relative to the operation. Too much emphasis has been placed on conveyor speed and rack capacity in the design phase. Without sufficient staff to operate the machines, there is little to be gained by the higher throughput machines. In fact, every facility in this study would benefit from a commercial dishwasher design guide that covers selection and sizing of conveyor dishwashers, best practices for operation and maintenance of the dishwasher, benchmarking tools and calculations for estimating the maximum hot water demand for a machine. The commercial dishwasher design guide could also benefit health departments and plan checkers by providing the resources to evaluate designs.

There is also a need to fund additional field monitoring projects on high-efficiency dishwashers just entering the market that utilize 2^{nd}-generation heat recovery systems, such as drain water heat recovery. Quantifying the water and energy use of these emerging technologies can support future incentive programs and provide a solid foundation to enhance the ENERGY STAR specifications for commercial dishwashers. As more and more dishwasher manufacturers continue to add models with integrated heat recovery systems, third-party research is needed to validate real world savings potential of their designs.

Abstract

Conveyor dishwashers are the single most water and energy intensive appliance operating in commercial kitchens. Prior research was in this area was limited, thus it was not possible to draw any strong conclusions especially with the savings potential of associated with replacing older machines with new high-efficiency models. This field research project was devised to document comprehensive water and energy use data, along with operating characteristics, for a wide array of facilities to fully understand the workings of conveyor dishwashers. Models selected for monitoring ranged from the smallest rack conveyor to the largest flight type conveyor machines. The results for all these machines were normalized for water and energy use per hour of rinse operation to provide a level comparison from facility to facility. This highlighted a substantial savings opportunity to that could be achieved by replacing older conventional dishwashers with new energy-efficient models. After analyzing several dishwasher replacement projects, the value of sub-metering dishwashers has become apparent as a tool for commissioning and benchmarking the water and energy use of the machine. The major recommendations are to conduct a follow-up research project that includes monitoring the energy and water use of conveyor dishwasher in conjunction with pre-rinse operations. In addition, a pilot retro-commissioning and replacement program would yield significant water and energy savings per site and support the development of a commercial dishwasher design guide. Lastly, funding to keep up with the energy and water savings potential of the latest generation dishwashers with advanced heat recovery systems is needed, which would also support future enhancements to the ENERGY STAR specifications.

Keywords: commercial dishwasher, conveyor dishwasher, rack conveyor, flight conveyor, rackless conveyor, ware washers, dishmachine, dishroom, restaurant, food service, commercial kitchens, energy savings, heat recovery, water savings, booster heater

Introduction

Background

In the last five years, the dishwasher market has evolved significantly towards utilization of advanced technologies, and there now exists a significant opportunity to increase the adoption rate of high-efficiency dishwashers in market, similar to what has been done with pre-rinse spray valves in the dishroom. It has been observed through informal field monitoring studies that the principal metric of rinse flow rate does not accurately characterize the overall water and energy use of conveyor dishwashers. While rinse flow rate has become an expedient surrogate for dishwasher efficiency, researchers at the Food Service Technology Center (FSTC) have position that the stock of conveyor dishwasher can consume considerable more water and energy that would be attributed to their rated rinse water usage.

Conveyor rack or flight dishwashers use the most energy and water per hour of operation for a single appliance in a commercial kitchen. Previous unpublished monitoring projects by FSTC have shown that hot water use of an old rack conveyor dishwasher can account for up to 75% of the total use in the restaurant. Recent findings have shown that not only are these existing conveyors consuming large volumes of hot water for the rinse and tank fill operations, but also that staff operating practices and insufficient maintenance are greatly adding to the water waste. While the overall impact of proper commissioning and usage has been discussed in various forums, until now, there has been no comprehensive study to compare the actual water usage to the dish machine's nameplate rating.

This research project was selected to benchmark water and energy use of old dishwashers operating in facilities and quantify the savings potential of high-efficiency machines. This research goes further to study the factors that lead to inefficient or efficient operation of dishwashers and washing and sanitizing performance. It is expected that this research project will demonstrate that water and energy use of old conveyor dishwashers can be reduced by at least half through a replacement program with high-efficiency models.

This project was made possible by funds from The Metropolitan Water District of Southern California (MET) Innovative Conservation Program (ICP) and Pacific Gas and Electric Company (PG&E).

Conveyor Dishwasher Types and Sizing Implications

Flight Type conveyor dishwashers are the largest-size class of conveyor type dish machines sold on the market for commercial kitchens and are typically used in large hotels, universities, hospitals, in-flight catering and other high-volume applications. The majority of flight conveyors are rackless conveyors where most wares like dishes and preparation ware are typically loaded directly on the pegs of the conveyor rather than loaded on to a rack first (Figure 1). Certain items like cups and utensils are still loaded on to racks before entering the flight conveyor to minimize damage and for easy handling. The upside of flight conveyors is that they can handle a very high throughput of wares (Flight Type machines are typically rated for 10,000 to 20,000 dishes per hour) and usually incorporate a re-circulating prewash, wash, and rinse sections with a fresh water final rinse and an optional blower dryer. The downside of flight conveyors is they are expensive to purchase and install, they take up a very large space (14 to 26 feet in length), are loud, have very high energy input requirements and use a large volume of hot water regardless of the throughput through the machine. Some older flight conveyor models have no mechanism to sense if or where there are wares being placed on the conveyor, and therefore to make sure that everything gets washed, rinsed and sanitized, the conveyor runs at full throttle—continually using a fresh water rinse and rinse aid chemicals while engaging all the water pumps, even if there are no wares passing through the chamber. Other machines have some type of mechanical sensor used to initiate the fresh-water rinse, but as the machine ages, a good portion of the sensors observed in the field are no longer in working order causing the machine to be constantly rinsing anytime the conveyor belt is operating.

Figure 1: Rackless feature of flight conveyor

Rack conveyor machines move standard 20 x 20-inch racks through the wash and rinse sections and are offered in two classifications: single-tank units and multi-tank units. Single-tank conveyors have one wash tank and typically utilize a second section for the fresh water rinse; these features are typical of a 44-inch conveyor. Larger single-tank conveyors may include a prewash section and/or an auxiliary rinse section(s), and unit lengths can range up to 76 inches. Single-tank conveyors are more popular due to their compactness and lower purchase costs. Multi-tank conveyors incorporate one or more wash tanks and one or more pumped rinse tanks and an extra section for the fresh water rinse. The length of these conveyor machines typically range from 64 to 86 inches. These units are found in very large restaurants, commercial cafeterias and other facilities. The majority of conveyor dishwashers use hot water at 180°F or above to sanitize dishes, while there are a significant number of low temperature models that use chemical sanitizers and directly use the incoming hot water supply typically set at 140°F.

Savings Opportunities

The primary water and energy reduction strategy is based on a rinse flow rate reduction from a dishwasher replacement project with a high-efficiency unit. Reductions are possible with the addition of multiple rinse stages to maximize coverage and heating of the wares while reducing the fresh water rinse. Conventional models utilize a high flow fresh water rinse in the 3 to 5 gpm range to remove soap and residual food debris from plates. Many advanced models available today are capable of removing soap and debris by first utilizing a recirculated primary rinse followed up with a minimal 1 and 2 gpm fresh water sanitizing rinse. The secondary reduction strategies involve improving operational practices to reduce the number of racks washed or rinse time, right sizing the dishwasher and reducing tank water waste by limiting over spray.

In addition to reducing the amount of fresh water used to rinse the dishes, manufacturers have employed technologies such as dishwasher cavity insulation, advanced door seals, advanced controls and waste heat recovery technologies. Exhaust-air heat recovery (EAHR) is a fairly mature technology that uses the waste steam to preheat incoming cold water for the sanitizing rinse, thereby reducing the energy load on the building's domestic hot water supply. In this process, cold water passes through copper pipes while a fan extracts steam and forces it through thin aluminum plates. The steam condenses on the cold fins and the latent heat is transferred to the 50 to 70°F cold incoming water elevating it to 110 to 130°F at which point is further heated by the booster heater to sanitizing temperatures between 180 to 195°F.

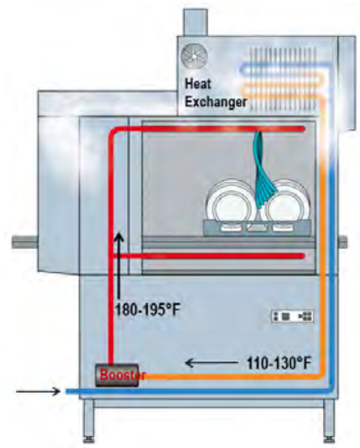

Figure 2: Exhaust-air heat recovery

Photo Credit: Winterhalter

Dishwasher Market

The segments of the food service sector that utilize conveyor dishwashers are large commercial kitchens found in medium to large full-service restaurants, commercial cafeterias, hospitals, hotels with dining facilities, nursing homes, colleges, universities, K-12 central kitchens, and correctional facilities.

Purpose

The goal of this project was to develop a more accurate commercial dishwasher water and energy use estimate that could provide the foundation on which to base utility incentives, 3rd-party dishwasher retro-commissioning and replacement programs, market transformation initiatives and water heater sizing guidelines.

Objectives and Scope

The objective of this project was to characterize the water and energy use of conveyor dishwashers installed in commercial and institutional food service facilities and to estimate the benefits associated with the replacement of existing machines with high efficiency models that minimize hot water use and utilize innovative technologies. In each site, the monitoring team analyzed staff operations and identified opportunities to reduce the operating time or water waste through best management practices, where applicable.

The scope of this project included the selection of a range of field sites representing different scales of operation, from restaurants to institutional facilities. The purpose in each test site was to measure the total water and energy use of the conveyor dishwasher and to estimate the operating cost—including water/sewer, gas, and electricity. For the sites in which a dishwasher replacement occurred, the FSTC research team provided analysis to support the development of a calculated incentive based on the estimated energy and water savings associated with the new machine. A comparison between the rated and real-world water use of different machines provided the framework for developing best practices and retro commissioning strategies for the optimal operation of modern dishwashing equipment.

The measured water and energy consumption of both conventional and high efficiency models could be used to develop a more precise calculation of the savings potential for sites outside the scope of this study.

Project Limitations

Conveyor dishwashers are very diverse in many aspects including the types and sizes of products on the market, energy sources available for water heating, premium options, types of wares washed, operating practices, and maintenance procedures. There are many more variations between monitored dishwashers than there are field studies. Thus, it is a challenge to normalize the data between machines, especially related to financial comparisons. This project was able to draw more conclusive conclusions on water use and limited ones on energy cost. A “like for like” replacement is of dishwashers is rare and this complicates energy savings estimates and the development of energy rebates; it is much more straight forward with the water related estimates.

Methodology

Instrumentation Setup

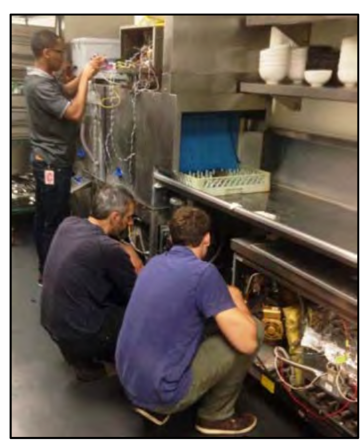

Figure 3: Installing instrumentation on a rack conveyor with booster heater

The FSTC team installed instrumentation and data logging equipment in the test sites to measure and record the energy and water use of each dishwasher (Figure 3). Commercial-grade water meters were placed on all water inlets to the dishwasher. Gas meters were used if the dishwasher used natural gas directly to heat the internal tanks or booster heater. Electrical energy metering equipment was to measure electricity use of the dishwasher, tank heater(s) and booster heater. The setup included temperature sensors placed at key water pipes entering and exiting the dishwasher to provide additional insight the operation of the dishwasher, to estimate energy use at the water heater and to calculate booster efficiency. Additional tank temperature metering was installed on some units to better understand the functionality of the dishwasher and to check if any malfunctions were present.

The gas, electricity and water meters provided pulse outputs (per unit of measure) to the data acquisition system (DAQ) also known as a datalogger. The on/off sensors send state change information to the DAQ's pulse input channels. The temperature sensors send voltage information to the analog input channels where the DAQ converts the voltage reading to a temperature measurement. All data was logged at a five-second intervals and stored with a time stamp in the memory of the DAQ corresponding.

For the water lines, the welded or twisted thermocouple wire junction was affixed to the outer copper pipe walls, and the interface was treated with heat-sink compound, wrapped with electrical tape, and covered with foam pipe insulation. Tank temperature thermocouples were either affixed to the outside tank walls in a similar fashion or inserted directly into the tanks.

Each machine involved monitoring about a dozen different data points characterize its performance and operating time for its various functions and truly understand the operation of the dishwasher.

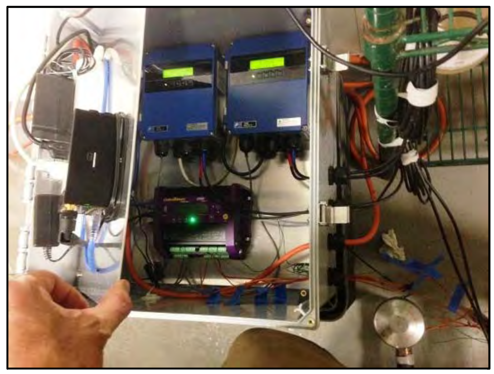

Figure 4: Large enclosure equipped with two water meters, datalogger and cell modem

Various sizes of instrumentation enclosure assemblies were used for this monitoring project, all consisting of water-proof enclosures that contained the relevant pieces of data acquisition equipment that were wired to all the instrumentation connected to the dishwashers. The following instrumentation specifications include pictures of the instrumentation at various locations where the instrumentation was installed.

Instrumentation Specifications

Temperature Sensors

Thermocouple Wire: Therm-X Class-1 Type-T Teflon extension wire, model number TT(f)-T-24 PFA, tolerance of ±1.8°F or 0.75%, sensor temperature range of -330 to 650°F (Figure 5). www.thermx.com

Figure 5: Thermocouple wire

Gas Meters

American Meter Company Elster BK-G4 Diaphragm type meter with 1 pulse/ft^3 output, flows from 1.4 ft^3/h to 200 ft^3/h, working temperature of -4 to 140°F (Figure 6).

Figure 6: Diaphragm gas meter

Water Meters

5/8" Badger Recordall M25 Industrial disc meter with 198.4 pulses/gal output, accuracy ±1.5% of reading, flow range of 0.5 to 30 gpm, cold water meter. www.badgermeter.com

5/8" Badger Recordall M25 Industrial disc meter with 198.4 pulses/gal output, accuracy ±1.5% of reading, flow range of 1 to 30 gpm, hot water meter.

Fuji FSV IP66 ultrasonic meter, can measure pressurized sections of water piping from 0.5" to 4" pipe diameter, FLD-2 compact–type detector, accuracy ±1% of rate (Figure 7). www.fujielectric.com

Figure 7: Ultrasonic meter

1/2" Seametrics SEB single-jet turbine meter with 550 pulses/gal output, accuracy 1% of full scale, flow range of 0.2 to 10 gpm, maximum temperature of 185°F.

1/2" Omega Engineering FTB4607 single-jet turbine meter with 75.7 pulses/gal output, accuracy 1% of full scale, flow range of 0.2 to 11 gpm, maximum temperature of 190°F (Figure 8).

Figure 8: Single-jet meter

Power Metering

Continental Control Systems WattNode Pulse electric energy meter, single- and three-phase, Wh pulse output (Figure 9). www.ccontrolsys.com

Figure 9: WattNode Pulse

Dent Instruments standard and mini hinged split-core current transformers, low voltage 0.333 Vac out, 5 to 1300 A, accuracy ±1%.

www.dentinstruments.com

Continental Control Systems standard and mini hinged split-core current transformers, low voltage 0.333 Vac out, 5 to 250 A, accuracy ±1%. www.ccontrolsys.com

Figure 10: DataTaker DT-80

Dataloggers

DataTaker DT80 Series 2 or 3, configured to record at five-second intervals, capable of logging from ten isolated thermocouple inputs and eight pulse counter inputs (Figure 10). www.datataker.com

Data Collection

In most cases, the dishwashers were monitored and characterized as found, irrespective of the condition of the machine. Depending on the machine type and heating energy type (gas or electric), the sites required varying types and levels of instrumentation to measure the total energy and water use of the machine.

At each dishwasher, researchers monitored the cold and hot water supplies to the machine to support the sanitizing rinse, tank fill and tempering water use. Energy use of the booster heater, tank heaters, blower dryers and dishwasher conveyor motors pumps and controls were instrumented and monitored to meet the objectives of this project. In cases where the gas use of a tank heater or booster heater could not be directly measured, an on/off state sensor was used on the gas solenoids to provide a surrogate measurement. In these situations, gas use was calculated by measuring the solenoid "on" time and multiplying it by the nameplate gas input rate with the assumption that the nameplate input rate was reasonably close to the actual input rate.

The water temperature was measured at key locations to gauge the performance of the hot water system internal or external to the dishwasher. The temperature of the supply water pipe(s) were measured, which may include one to three separate pipes, depending on the configuration of the machine. The most common configuration included a 130-150°F tank fill and/or booster inlet pipe along with a 180°F rinse pipe. The booster heater outlet water temperature was monitored at a point just before the fresh water rinse arm (to measure the true final rinse temperature). In some applications, temperature sensors were applied to several or all water tanks and to the common drain line from the machine. Variations in dishwasher models and equipment installations occasionally affected the ability to directly measure water or energy use at specific points mentioned. In a few situations, best efforts were made to analyze the remaining dataset to estimate usage when direct measurement of water or electricity use was not readily possible.

Data Analysis

The data was measured and recorded in 5-second intervals provide sufficient detail on the operation of the dishwasher. The measured data was analyzed to draw out dishwasher operating information that was key to comparing dishwashers and identifying performance attributes of each machine. The following parameters in the outline were tabulated on spreadsheets, but only some of these parameters were important enough to discuss and analyze in this report. Some of the parameters are defined in the glossary including the methodology for calculating certain parameters:

- Operating time (h)
    - Booster operating time
    - Cold water flow time

- Dishwasher operating span
    - Dishwasher operating time
    - Hot water flow time
    - Rinse flow time
    - Tank fill flow time
    - Tank top off flow time
    - Total water flow time
- Water flow rate (gpm, gph)
    - Cold water flow rate
    - Hot water flow rate
    - Rinse flow rate
    - Maximum hourly hot water demand
    - Overall flow rate
    - Peak flow rate
    - Tank fill flow rate
    - Tank top off flow rate
- Tank fill information
    - Fills per hour of rinse (fills/h_rinse)
    - Gallons per fill (gal/fill)
    - Number of tank fills
- Mass-weighted (during flow periods) water temperature (°F)
    - Booster inlet temperature
    - Cold supply temperature
    - Drain temperature
    - Heat exchanger inlet
    - Heat exchanger outlet
    - Hot supply temperature
    - Rinse supply temperature
    - Tank fill temperature
- Average (during flow periods) tank water temperature (°F)
    - Dual rinse tank temperature
    - Powered rinse tank water temperature
    - Scrapper tank water temperature
    - Wash tank water temperature
    - Water heater or boiler outlet temperature
    - Water heater temperature rise (heater outlet T – average annual cold water supplyT)
- Water use (gal)
    - Annual water use
    - Cold water tempering
    - Cold water use
    - Daily water use
    - Hot water use
    - Pre-rinse water use
    - Rinse water use
    - Tank fill water use
    - Tank top off water use
    - Total water use
    - Water waste
- Electricity use (kWh)
    - Annual electricity use
    - Booster heater use

- Dishwasher use (water pumps, controls, optional blower dryer)
  - Tank heater use (wash tank, rinse tank, and/or auxiliary tank)
  - Total daily electricity use
- Gas use (therms)
  - Annual gas use
  - Booster heater use
  - Tank heater use (wash tank, rinse tank)
  - Total daily gas use
  - Water heater or boiler use
- Misc. parameters
  - Booster and heat exchanger efficiency (heat exchanger energy in – booster energy out)
  - Booster heater efficiency ((booster energy in – booster energy out)
  - Demand charge ($/kW)
  - Electricity cost ($/kWh)
  - Energy use per 1,000 square feet (btu/1000 ft^2)
  - Energy use per hour rinse operation (Btu/h_rinse)
  - Energy use per meal (Btu/meal)
  - Energy use per seat (Btu/seat)
  - Natural gas cost ($/therm)
  - Pre-rinse water use per hour of rinse (gal/h_rinse)
  - Probable contribution to peak demand (kW)
  - Total annual cost ($/year)
  - Total energy use (Btu/d)
  - Water and sewer cost ($/HCF)
  - Water use per hour of rinse operation (gal/h_rinse)
  - Water use per meal (gal/meal)
  - Water use per seat (gal/seat)
  - Water use per 1,000 square feet (gal/1000 ft^2)

Reporting

The following section characterizes daily operation of the dishwasher and displays the average daily water use profile. For each test site, the facility was characterized by the type of food-service facility, operating days and hours, type of dishwasher and booster heater, dishwasher make and model, and dishwasher specifications. The monitoring period and total monitoring days for each dishwasher was logged along with measurement points for the dishwasher monitored. A spreadsheet of daily monitoring results is provided in the appendices. The file size for each site’s data set is very large since data was being logged in 5-second intervals, thus it was not feasible to provide anything more than daily totals and averages.

The dishwasher operation and maintenance was also highlighted. Challenges faced by the FSTC field team during the monitoring period are included in the information for each site, along with irregular performance issues of the dishwasher. Additional water use profiles were included to illustrate poor practices or operation of advanced machines, as appropriate. The measured and calculated results are discussed along with a data summary table. If applicable, the replacement energy efficient dishwasher will be equally characterized and results provided on the same summary table. The final section discusses the lessons learned and summarizes any notable takeaways.

The summary of results section focuses on the outcomes from the collective analysis of dishwashers at all sites. A key portion of the analysis compares the rated dishwasher water use to the measured water use. To strengthen the comparison between rated and actual water use, results from nine other FSTC monitoring sites have been included to supplement the number of dishwashers in this analysis. The data from the nine additional sites utilized the same monitoring and analysis methodology as nine machines monitored under the scope of this study.

Results

In total, the project characterized the energy and water consumption for nine dishwashers in the field, with the added bonus of monitoring for pre-rinse operations in three facilities. The presentation of the results begins with the existing rack conveyor dishwashers monitored at four Google cafés followed by monitoring of the preexisting and replacement rack conveyor machines at Stanford's Wilbur Hall dining facility. Subsequently, the results from the preexisting and replacement flight conveyors at Facebook's Epic Café are covered. Finally, the results for the existing flight conveyor in the main kitchen at the Claremont Hotel and Spa are discussed.

Google Cafes

Figure 11: Baadal Dining Room

Photo Credit: Yelp

Four café dishrooms on the Google main campus where chosen to study two conventional and two high-efficiency dishwashers. The particular sites were chosen based on the ease of instrumentation installation and because they provided a good opportunity to compare multiple low-efficiency and high-efficiency dishwashers across facilities with similar operating and maintenance practices. Altogether, the four sites provided some site diversity to this project as the first site Café Baadal was representative of a fine-dining restaurant (Figure 11), Backyard café was representative of a fast-casual restaurant , and Heritage and Masa cafés were representative of small and large cafeteria style dining facilities respectively.

In characterizing the four sites together, three sites used natural-gas-fired tank and booster heaters. It is less common to encounter the use of natural gas as a fuel source to heat water for the booster heater and wash tank heaters due to the additional maintenance required especially in hard water areas, but the cost savings versus using electricity is very attractive, even though the equivalent gas-fired heaters are much larger in size.

Google Café Baadal

Site Overview

Figure 12: Google Café Baadal indian fare

Photo Credit: SFGATE

This Indian restaurant serves lunch only, with family-style meals during the work week (Figure 12). It is a fine dining establishment that accepts reservations. The café uses a 2007 Stero SCT-66S high-temperature dishwasher, equipped with natural-gas-fired tank and external booster heaters and has a rated rinse water use of 290 gph or 4.8 gpm (Figure 13). This unit has a scrapper tank (a.k.a. pre-rinse tank) and wash tank.

Monitoring Period

Figure 13: Baadal dishwasher with gas booster

The dishwasher was monitored from August 25th to October 9th, 2014 for a total of 33 operating days. The monitoring data compiled for each work day are shown in Appendix A.

Measurement Points

The hot water usage was measured separately at the booster heater inlet to determine the rinse water fraction, and at the dishwasher tank fill supply line for the tank fill water fraction. Due to the piping and space limitations, it was not possible to monitor and log the scrapper water fill directly, but a manual measurement of the scrapper tank fill water flow rate was performed, and an auxiliary thermocouple to sense scrapper fill periods was used as a proxy to calculate scrapper fill total daily water use. Temperatures were also measured at the inlet and outlet of the booster heater. The on/off state of the tank and booster heaters gas solenoids were monitored, and gas use was calculated by assuming the nameplate gas input rate specifications and integrating over recorded on-time. The electricity use of the water pump motors, conveyor belt and controls was also measured.

Challenges

Figure 14: Calibration of water meter

Through the calibration process (Figure 14), it was found that the rinse flow rate of 2.1 gpm was significantly less than the manufacturer's specification of 4.8 gpm. After two weeks of initial monitoring, the water pressure was increased to 20 psi as indicated on the rinse pressure gauge, which helped increase the rinse flow rate, but not significantly. A flow rate of 3.4 gpm was achieved, which is still 30% below the manufacturer's specification. A final five-week monitoring period commenced after this adjustment.

Even with the lower rinse flow rate, the overall water use was still significantly higher than anticipated, which was later discovered to be due to the water consumed for filling the scrapper tank. Being that the scrapper fill water was not being directly measured, initially, it was thought that by counting the number of fills in the wash tank through data analysis, the scrapper wash tank fill could be readily estimated using manufacturer's scrapper tank volume specifications. On the second visit to the site, trial runs using racks with sheet pans revealed much greater scrapper water use than first assumed. After closer observation, it was recognized that a significant loss of hot water was occurring through overspray on the loading side of the machine, especially when sheet pans were washed (Figure 15). The high water velocity of the overspray bouncing off the bottom of the pans and various other bulky wares was causing high volumes of water to exit the machine into the pre-rinse sink and down its drain—in part due to the backward slope of the feed table away from the dishwasher and towards the pre-rinse sink. This caused the scrapper tank water level to drop and therefore continually refill to top off the tank and maintain the tank water level. These tank top-offs are also known as maintenance fills.

Figure 15: Scrapper tank overspray

Average Daily Water Use Profile

The overall average water use of the dishwasher during the monitoring period was 1319 gallons per day (gal/d). Representative of this average, the total hot water use on September 11th, 2014 was 1272 gallons. This daily water use profile is shown in Figure 16. Looking closely at the plot, there was a scrapper and wash tank fill at roughly 6:50 AM, and wash tank top-offs at 8:40 AM. The wash tank fill and top-off volume totaled 55 gallons and occurred at a flow rate of approximately 20 gpm. The scrapper tank top-off occurred more frequently throughout the day and totaled 365 gallons with a flow rate of 16 gpm. Rinse water flowed at 3.7 gpm and totaled 815 gallons.

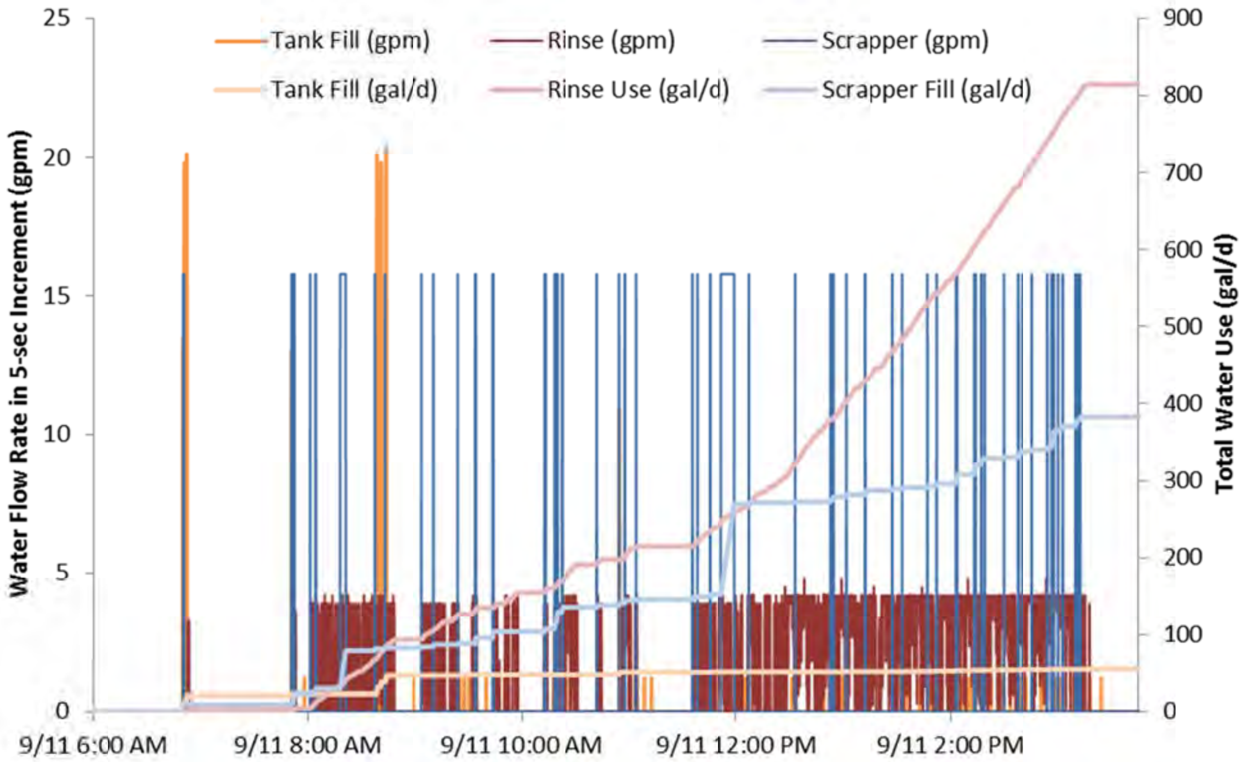

Figure 16. Café Baadal plot of daily water flow rates and total use

Results

The monitored data were analyzed to deliver the following results in Table 1. The rinse water use at 701 gal/d was slightly more than the cumulative scrapper and wash tank fill and top-off of 618 gal/d. There was an average of 2.4 tank fills per day with an average fill amount of 32.5 gallons for the scrapper and tank, which is close to the manufacturer specifications of 36 gallons per fill operation.

The average rinse flow rate was measured at 3.7 gpm over the monitoring period, which is below the specifications at 4.8 gpm. The real world dishwasher peak hot water flow rates are also important to help with sizing of the centralized water heater. In this case, the peak flow rate in a 10-second increment was 28.9 gpm, which is information that is used for sizing tankless water heaters. The majority of facilities that install conveyor dishwashers utilize a centralized storage water heater or boiler with storage tank where the key sizing parameter is the maximum hourly hot water demand. The max demand in this scenario is elevated at 1,033 gph since the overspray at the scrapper tank was excessive at instances where washing a large number of sheet pans can activate a lengthy tank fill operation. Water use per hour of rinse operation is a new flow rate parameter that originated during this project. It allows for accounting for the total water use of the dishwasher and goes further to normalize this value to per hour of rinse operation to allow for an equal comparison with other conveyor dishwashers. The dishwasher water use per hour of rinse operation is 416 gph.

Table 1. Google Baadal data summary

	Existing Stero
Daily Water Use	
Scrapper Tank Water Use (gal/d)	506
Wash Tank Fill and Top-off Water Use (gal/d)	112
Rinse Water Use (gal/d)	701
Number of Fills per day	2.4
Gallons per Fill	32.5
Total Water Use (gal/d)	1319
Flow Rates	
Rinse Flow Rate (gpm)	3.7
Peak Flow Rate (gpm)	28.9
Maximum Hourly Hot Water Demand (gph)	1033
Water Use Per Hour of Rinse (gph)	416
Water Temperatures	
Estimated Boiler Outlet Temperature (°F)	155
Scrapper Tank Fill Temperature (°F)	145
Tank Fill Water Temperature (°F)	145
Booster Inlet Temperature (°F)	144
Booster Outlet Temperature (°F)	190
Drain Temperature (°F)	138
Flow Time and Hours of Use	
Rinse Flow Time (h)	3.2
Dishwasher Operating Time (h)	5.5
Dishwasher Operating Span (h)	8.2
Energy Use, Booster Efficiency and Peak Demand	
Estimated Boiler Energy (therms/d)	14.1
Wash Tank Heater Energy (therms/d)	2.4
Booster Heater Energy (therms/d)	3.9
Total Gas Energy (therms/d)	20.4
Gas Booster Efficiency	69%
Dishwasher Electrical Energy (kWh/d)	15.2
Probable Contribution to Peak Demand (kW)	1.9
Total Energy Use (Btu/d)	2,088,128
Dishwasher Energy Use Per Hour of Rinse (Btu/h)	658,194

The average rinse time of 3.2 hours was extrapolated from the water flow data. The average dishwasher operating time of 5.5 hours was extrapolated from the energy monitoring of the gas booster heater and electricity use of the conveyor. The daily rinse flow time is plotted on the left axis and the total hot water use on the right axis in Figure 17. The plot shows that the rinse time and water use track each other well and there are minor fluctuations in total hot water use from a day to day operation. The largest fluctuations occurred during the first and fourth week where water use on the Monday was around 1,000 gal/d and by Thursday it approached 1,600 gal/d.

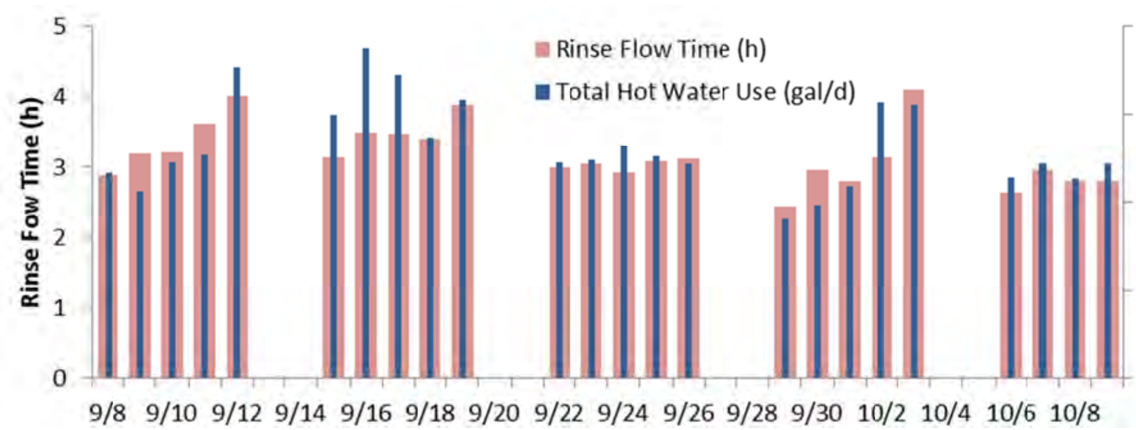

Figure 17. Café Baadal plot of daily rinse flow time and total hot water use

The total daily gas use required to operate the dishwasher was 20.4 therms. The majority of this gas energy, 14.1 therms, was used to heat cold water at the boiler to a nominal 155°F while a smaller portion, was used to increase the hot water temperature through the booster and to maintain wash tank temperature at 145°F. The central boiler outlet temperature was estimated to be a nominal 10°F higher than the delivered temperature to factor for heat losses through the piping. The average annual cold water temperature was estimated at 65°F, which translates to a temperature rise of 90°F through the water heater. The external booster heater operated with an average efficiency of 69% to heat hot water from 144°F to 190°F. Electricity was only used to power the dishwasher controls, pumps and motors, and totaled 15.2 kWh/d. To estimate the probable contribution to peak demand, the average electricity use is divided by the operating span of the dishwasher from when it is turned on to when it is turned off. The resulting estimated value is 1.9 kW, which was used to calculate a monthly peak demand charge associated with the dishwasher. Finally, by converting the electricity use data to a common energy unit of Btu/h, the total energy use of the dishwasher is calculated at 2,088,128 Btu/d.

Lessons Learned

The biggest surprise was the intensity of overspray exiting the scrapper section of the dishwasher when washing large wares like sheet pans. Either the use of sheet pan racks designed to hold the pans vertically or replacement of this dishwasher with another with a taller cavity and/or a longer length could significantly reduce the water waste associated with the overspray. The other lesson learned was that the operator or maintenance professional cannot always depend on the pressure gauge to

Figure 18: Original pressure gauge setting of 18 psi

establish proper rinse flow. In this case, with a gauge reading of 18 psi (Figure 18), which was within the target pressure range, the rinse flow rate was only 44% of the specified rate. Either an inaccurate gauge reading high or a restriction in the rinse flow stream could have caused the discrepancy.

Google Backyard Café

Site Overview

Figure 19: Backyard Cafe

Photo Credit: FourSquare

This BBQ-inspired café serves breakfast and lunch during the work week (Figure 19). It uses a 2005 Stero SCT-44 high-temperature dishwasher with a natural-gas-fired tank and external booster heaters and has a rated rinse water use of 290 gph or 4.8 gpm (Figure 20).

Monitoring Period

Figure 20: Backyard Dishwasher

The dishwasher was monitored from August 22nd to October 9th, 2014 for a total of 47 days of which 34 were operating days. The monitoring data summary split for each work day is shown in Appendix B.

Measurement Points

Figure 21: Mechanical meter installation on inlet to booster

The water use was measured at a single hot water supply to the dishwasher (Figure 21) and accounted for water use through the booster heater for rinse water, and for the tank fill water through a connection branching to the dishwasher. Temperature was measured at the inlet and outlet of the booster heater and at the drain. The gas solenoid on/off state was monitored to estimate gas use by assuming the nameplate gas input rates specifications for the tank and booster heaters and integrating that rate over recorded on time. The electricity use of the water pump motors, conveyor belt and controls was also measured.

Challenges

Figure 22: Overspray on inlet side slopping to pre-rinse sink

Gathering energy data for this dishwasher was troublesome due to instrumentation connection issues. Only one week of usable electrical energy data was gathered, but because the machine used gas-fired heaters, the electrical energy use was minimal (and consistent with the similar machines in other monitoring projects), so the average daily electricity use was confidently extrapolated from operating time data. Similarly, only one week of wash tank heater gas use data was

gathered, but the average tank heater gas use was extrapolated by correlating gas use to water consumption and operating time. Similar to the Baadal dishwasher, although to a much lesser degree, there was a tendency for water to overspray out of the dishwasher and onto the feed table and then down the pre-rinse sink drain (Figure 22).

Average Daily Water Use Profile

The total hot water use was 1010 gallons on September 26th, 2014; the water use profile for this date is shown in Figure 23. This day's water use total is representative of the overall average of 1053 gal/d. The wash tank fill (17 gal) and tank top offs (342 gal) totaled 359 gal at an average flow rate of 9.7 gpm. Rinse water flowed at a rate of 4.8 gpm and totaled 651 gallons for the day. Looking closely at the plot, there was one wash tank fill at 7:00 AM and subsequent wash tank top-offs throughout the rest of the day.

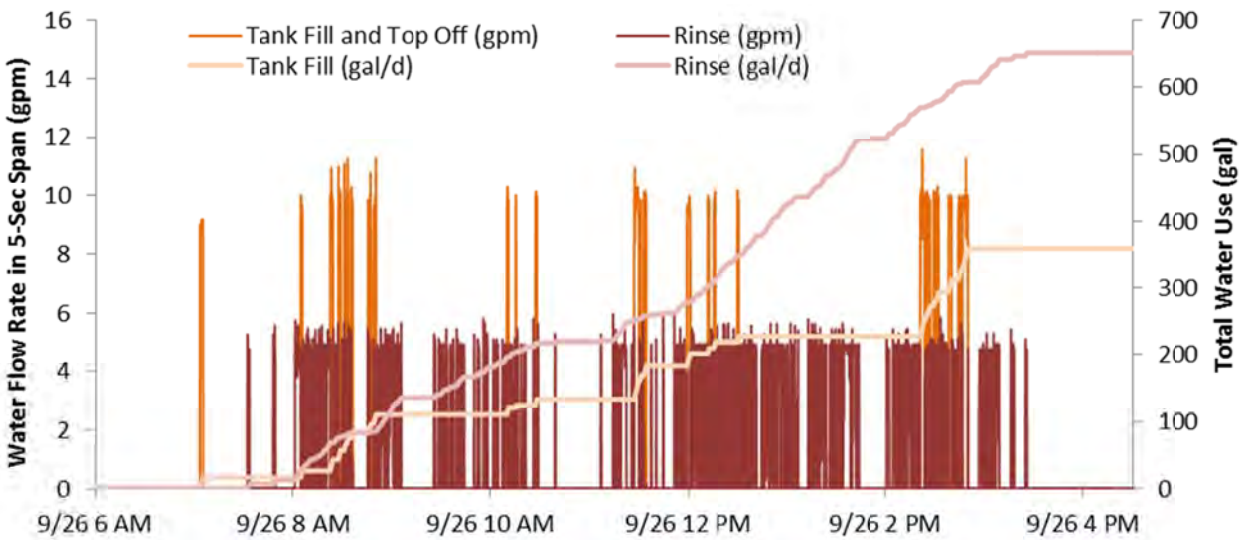

Figure 23. Backyard Café daily water flow rates and total use

Results

The monitoring data were analyzed to deliver the following results in Table 2. The rinse water use of 846 gal/d was four times more than the wash tank fill and top off of 207 gal/d. There was significantly less overspray on this 44"-rack conveyor compared to the prior 66"-rack conveyor of the same vintage and manufacturer. There was one wash tank fill per day with an average fill volume of 16 gallons, which is close to the 20-gallon-tank specification.

The average rinse flow rate measured at 4.8 gpm matched the specifications exactly. The water use per hour of rinse operation at 345 gph was close to the manufacturer's specifications for hourly rinse flow rate at 290 gph and is a good indicator that the machine is operating efficiently as well as being used efficiently.

Table 2. Google Backyard data summary

	Existing Stero
Daily Water Use	
Wash Tank Fill and Top-off Water Use (gal/d)	207
Rinse Water Use (gal/d)	846
Number of Fills per day	1.0
Gallons per Fill	16.0
Total Water Use (gal/d)	1053
Flow Rates	
Rinse Flow Rate (gpm)	4.8
Peak Flow Rate (gpm)	11.1
Maximum Hourly Hot Water Demand (gph)	345
Water Use Per Hour of Rinse (gph)	363
Water Temperatures	
Estimated Boiler Outlet Temperature (°F)	160
Tank Fill Water Temperature (°F)	151
Booster Inlet Temperature (°F)	151
Booster Outlet Temperature (°F)	184
Drain Temperature (°F)	142
Flow Time and Hours of Use	
Rinse Flow Time (h)	2.9
Dishwasher Operating Time (h)	4.1
Dishwasher Operating Span (h)	8.8
Energy Use, Booster Efficiency and Peak Demand	
Estimated Boiler Energy (therms/d)	11.7
Wash Tank Heater Energy (therms/d)	2.8
Booster Heater Energy (therms/d)	5.9
Total Gas Energy (therms/d)	20.4
Dishwasher Electrical Energy (kWh/d)	9.8
Probable Contribution to Peak Demand (kW)	1.1
Total Energy Use (Btu/d)	2,073,438
Dishwasher Energy Use Per Hour of Rinse (Btu/h)	714,978

The average sanitizing rinse time was 2.9 hours. The conveyor run time was 4.1 hours, or roughly half of the dishwasher operating span from the initial fill at approximately 7 AM to shutdown at 3:30 PM. The plot in Figure 24 shows six weeks of dishwasher operation. The rinse time and total water use track each other well and there are moderate fluctuations in total hot water use and rinse time from a day to day or sometimes weekly basis.

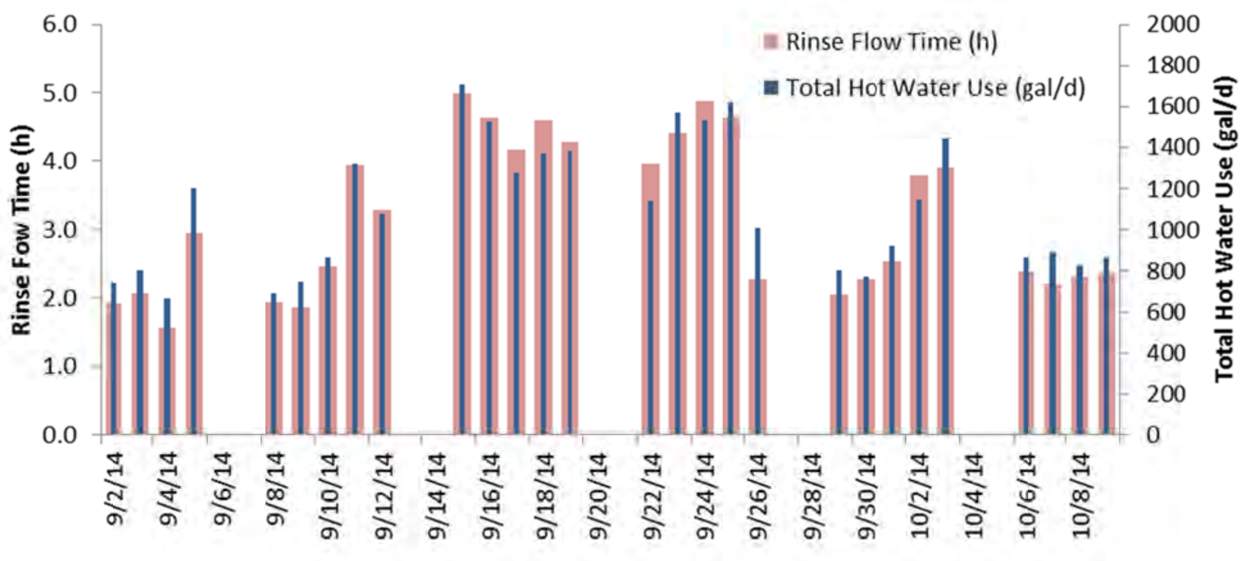

Figure 24. Backyard Café plot of daily rinse flow time and total hot water use

The total daily gas use required to operate the dishwasher was 20.4 therms. Approximately half of this gas energy, 11.7 therms, was used to heat cold water at the boiler to a nominal 160°F while a smaller portion, was used to increase the hot water temperature through the booster and to maintain wash tank temperature at 151°F. The same methodology as Café Baadal was used to estimate the temperature rise at the central boiler and calculate the estimated gas use. The external booster heater heated hot water from 151°F to 184°F. Being that this dishwasher and booster are heated with natural gas, electricity is only used to power the dishwasher controls, pumps and motors, which totaled 9.8 kWh/d. The probable contribution to peak demand was 1.1 kW. The total energy use of the dishwasher was calculated at 2,073,438 Btu/d, which is very close to the dishwasher monitored at Café Baadal.

Lessons Learned

Upon witnessing the overspray and resultant water waste at two sites, some sheet pan racks (designed to hold pans vertically) were brought in to test their performance (Figure 25). Testing at the Backyard Café confirmed that the dedicated use of sheet pan racks instead of running the pans flat on conventional racks could significantly cut down the water waste associated with overspray

Figure 25: Sheet pan rack demo

Overall, albeit being an older, inefficient machine, the unit performed to specification with regards to energy use, water temperatures and water flow rate even nine years after installation.

Google Heritage Café

Overview

Figure 26: Heritage dishwasher and pre-rinse sink

This small cafeteria serves American style fare until 8 PM. Their niche is serving brunch all day during the work week. The café uses a Hobart CL-64E high-temperature dishwasher equipped with natural gas fired wash tank and powered-rinse tank heaters and an external natural gas fired booster heater (Figure 26). The machine has a rated rinse water use of 132 gph or 2.2 gpm.

Monitoring Period

Monitoring equipment was installed on the dishwasher in late November, but successful data gathering of all monitoring points started on January 26th to March 10th, 2015 for a total of 46 days in which 31 days where operating days. The monitoring data daily summaries are shown in Appendix C.

Measurement Points

This machine is designed with a single water inlet connection that is supplied from the booster heater, meaning that all the water used by the dishwasher, including the fresh water rinse and tank fill, is first heated by the booster heater (instead of using a separate hot water supply for the tank fill). In this arrangement, one water meter was able to measure the total water use, and the data was easily filtered to disaggregate rinse and fill activities. Temperature was measured at the inlet and outlet of the booster heater, and at the drain. Rinse and wash tanks temperatures were measured to provide further insight into the workings of the machine. The on/off state of the gas solenoid of the wash tank heater, rinse tank heater and booster heater was monitored. The electricity use of the water pump motors, conveyor belt and controls was also measured.

Pre Rinse Monitoring

Figure 27: Pre-rinse station

This site was one of three sites where the pre-rinse station was sub-metered. This site was selected as it utilized a scrapper, which had not previously been studied by FSTC. Water was used for the 2.5 gpm pre-rinse spray valve, the scrapper and by the degreaser solution dispenser in Figure 27. The scrapper works by passing large volumes of water in a waterfall effect over the rack or individual wares and reuses the water continuously while typically adding 2 gpm of fresh water into the mix.

We had initially assumed that the hot water used for the degreaser solution to pre-soak utensils in the rectangular tub in Figure 27 would be minor. But on occasions, the degreaser solution hose line was redirected to the scrapper basin (Figure 28) and was a contributor to the overall water waste. When it was redirected, it was on continuously during the dishwashing period for the purpose of adding heat to the scrapper water. The pre-rinse sprayer was used on demand using tempered water, whereas the scrapper was on continuously using cold water during the meal period and sometimes operating unattended.

Figure 28: Hot water hose used to heat cold scrapper water

Challenges

There were operating inconsistencies of the booster heater in both remembering to switch the booster heater ON during operating hours and turning it OFF during closing hours. Furthermore on one occasion there was an apparent malfunction as the switch was found in the ON position while the booster heater was not working. In total, the booster heater was turned completely OFF or was only operating for part of the day on a total of 13 days out of the total of 31 and exhibited an average outlet temperature of 147°F as compared to the 184°F with the booster on. For the purposes of this report and better comparison with other dishwashers, the daily booster heater energy use data was normalized for the non-conforming days.

This particular site utilized sheet pan racks for washing flat objects like cutting boards, lids and sheet pans (Figure 29). This measure greatly reduces the water and energy use of the dishwasher as multiple objects can be washed on the same rack, and the angle in which the spray heads hit the wares minimizes overspray leaving the machine out table. This practice was great to observe, but operating consistency is still needed as on another occasion sheet pans were washed the conventional way horizontally placed on a rack.

Figure 29: Conventional washing of sheet pans (top) vs. efficient washing of sheet pans (bottom)

There was a three day period starting in the afternoon of February 3rd until closing of operation on February 5th where the dishwasher was malfunctioning (Figure 30). For the first 2.5 days, it appears that the rinse activation lever was stuck in the on position, which is caused the fresh water rinse to operate anytime the conveyor was running. From 9:30 PM to 10:40 PM, it appears that the drain was left open as the tank fill was continuously activated until the machine is shut down for the night. On average, on the three affected days, the water use doubled from an average of 1262 gallons on an average day to 2503 gallons. The energy use increased as well, with an 83% increase in gas use and a 55% increase in dishwasher electricity use. The booster inlet and outlet temperature graphically show the nearly continuous rinse flow operation until the prolonged tank fill operation beginning at 9:30 PM.

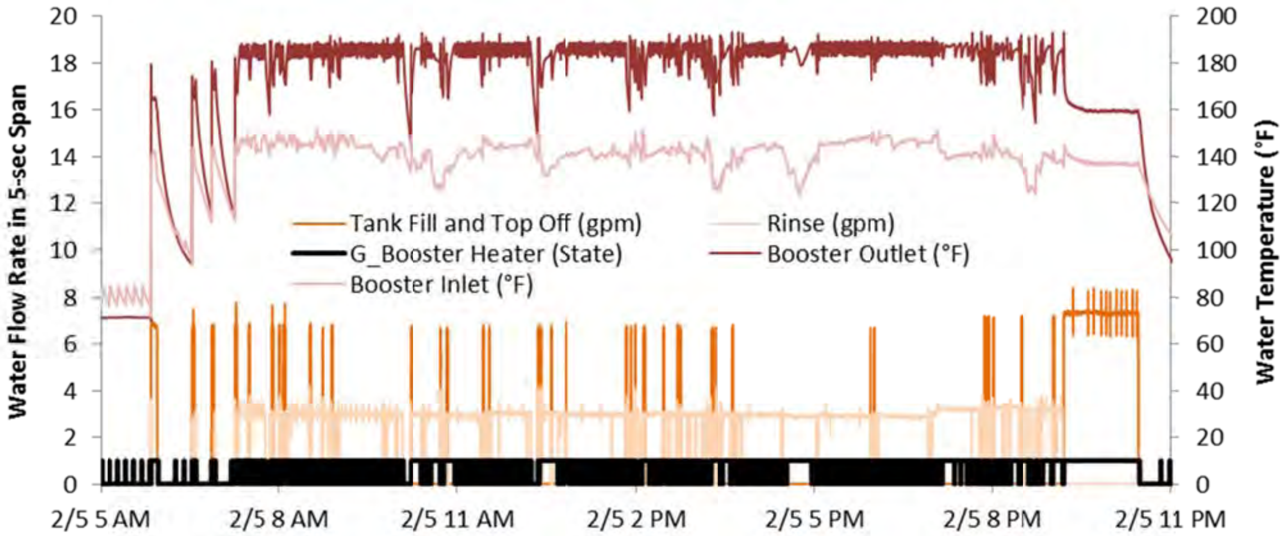

Figure 30: Dishwasher rinse and fill problems

Average Daily Water Use Profile

The total hot water use was 1380 gallons on February 12th, 2015, The water use total is representative of the overall average of 1382 gallons per day (gal/d). This daily water use profile for this date is shown in Figure 31. Looking closely at the plot, there was one rinse and wash tank fill at roughly 6 AM totaling 42 gallons and wash tank top-offs the rest of the way, shown in dark orange. The wash tank fill and top-off totaled 801 gallons at a water flow rate of 6.8 gpm. The rinse flow rate was 3.0 gpm for a total water use of 579 gallons. Overall, the dishwasher is used pretty continuously from the morning breakfast to the evening dinner period, which is consistent with its all-day breakfast themed operation.

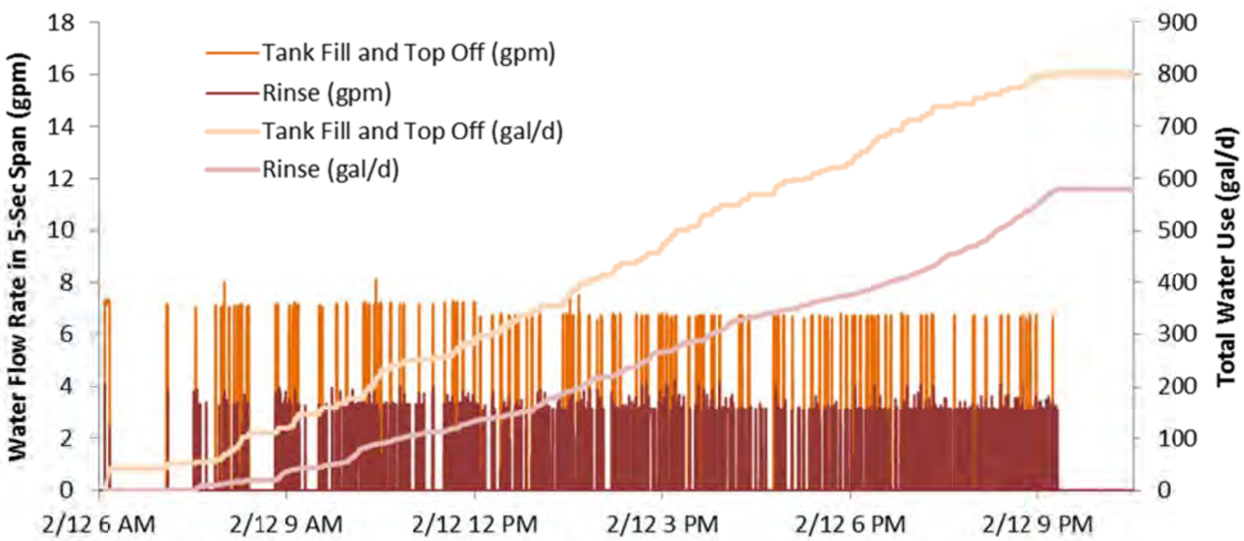

Figure 31. Heritage Café daily water flow rates and total use

Results

The monitored data was analyzed to deliver the following average results in Table 3. The rinse water use at 659 gal/d was comparable to the tank fills and top off operations at 723 gal/d. There was one tank fill per day with an average fill of 61 gallons. This exceeds the specified wash and rinse tank volume at 45 gallons. On 1/3 of the days analyzed for tank fills, either the drains where not closed prior to starting a fill operation or there was a cleaning function that elevated the average fill to 95 gal/d. The average dishwasher water use at 1,382 gal/d was greatly overshadowed by the pre-rinse water use at 3,145 gal/d.

Table 3. Google Heritage data summary

	Existing Hobart
Daily Water Use	
Wash Tank Fill and Top-off Water Use (gal/d)	723
Rinse Water Use (gal/d)	659
Number of Fills per day	1.0
Gallons per Fill	61
Total Dishwasher Water Use (gal/d)	1,382
Total Pre-Rinse Operation Water Use (gal/d)	3,145
Flow Rates	
Rinse Flow Rate (gpm)	2.9
Peak Flow Rate (gpm)	7.8
Maximum Hourly Hot Water Demand (gph)	349
Water Use Per Hour of Rinse (gph)	367
Pre-Rinse Water Use Per Hour of Rinse (gph)	835
Water Temperatures	
Estimated Boiler Outlet Temperature (°F)	155
Tank Fill Water Temperature (°F)	143
Booster Inlet Temperature (°F)	143
Booster Outlet Temperature (°F)	184
Drain Temperature (°F)	147
Flow Time and Hours of Use	
Rinse Flow Time (h)	3.8
Dishwasher Operating Time (h)	8.3
Dishwasher Operating Span (h)	13.6
Energy Use, Booster Efficiency and Peak Demand	
Estimated Boiler Energy (therms/d)	14.8
Wash and Rinse Tank Heater Energy (therms/d)	7.1
Booster Heater Energy (therms/d)	6.2
Total Gas Energy (therms/d)	28.1
Gas Booster Efficiency	76%
Dishwasher Electrical Energy (kWh/d)	28.0
Probable Contribution to Peak Demand (kW)	2.1
Total Energy Use (Btu/d)	2,901,730
Dishwasher Energy Use Per Hour of Rinse (Btu/h)	770,499

The rinse flow rate measured at 2.9 gpm is above the specifications at 2.2 gpm. The peak flow rate was reasonably low at 7.8 gpm. The water use per hour of rinse operation at 367 gph was almost three times the manufacturer's specifications for hourly rinse flow rate. This unit was not operating efficiently due to the water waste from tank top offs and elevated rinse flow rate. The pre-rinse water use per hour of dishwasher rinse operation was extremely high at 835 gph.

The average daily rinse time was 3.8 hours. The conveyor daily run time was 8.3 hours and operating span was calculated at 13.6 hours. The plot in Figure 32 shows six weeks of dishwasher rinse time and total water use. Except for the second week where there was a rinse and fill malfunction, the rest of the weeks have relatively moderate rinse flow time and water use. Fridays are notably slow days.

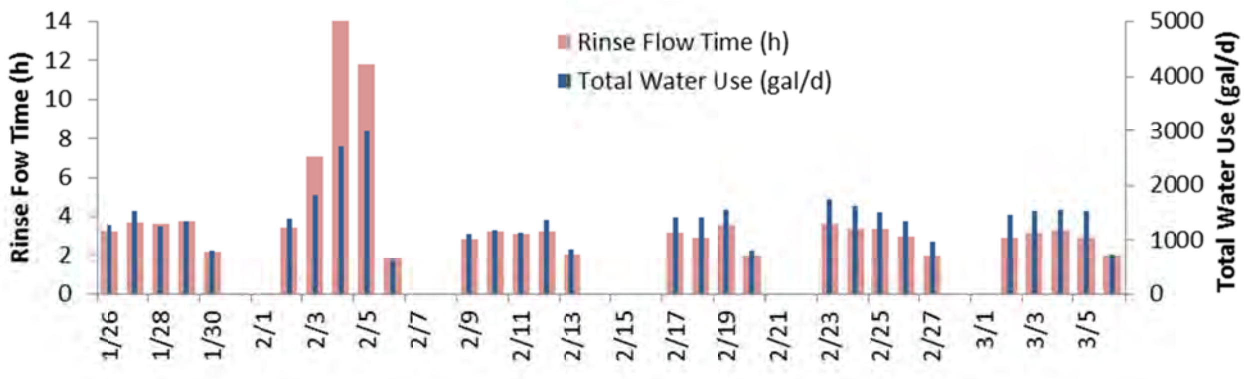

Figure 32. Heritage Café plot of daily rinse flow time and total hot water use

This dishwasher is predominately run by natural gas, which is responsible for 100% of its water heating needs. The total daily gas use required to operate the dishwasher was 28.1 therms. Approximately half of this was used to heat cold water at the boiler to a nominal 155°F while approximately a quarter was used to increase the hot water temperature through the booster and another quarter to maintain wash and rinse tank temperatures. The external booster heater heated hot water from 143°F to 184°F. The external booster heater has an average operating efficiency of 76%. Being that this dishwasher and booster are heated with natural gas, electricity is only used to power the dishwasher controls, pumps and motors, which totaled 28.0 kWh/d. The probable contribution to peak demand was 2.1 kW. The total energy use of the dishwasher was calculated at 2,901,730 Btu/d. The dishwasher energy use per hour of rinse operation was 770,499 Btu/h.

Lessons Learned

The biggest surprise was that only one daily tank fill operation was satisfactory for the dishwasher operation that spanned over 13 hours. Although sheet pan racks where present in the dishroom, we are unsure to what extent they reduced the tank top off needs of the machine since they were not consistently used and more importantly tank fills and top offs accounted to more than half of the total daily water use.

Google Masa Café

Site Overview

Figure 33: Masa Café dining room

Photo Credit: Yelp

This large cafeteria serves Mexican fare from 8 AM to 5:30 PM (Figure 33) covering the breakfast and lunch meal periods during the work week and lunch and dinner periods on the weekend. The café uses a Hobart CLPS-86ER high-temperature dishwasher with an integrated EAHR device (Figure 34). The unit has an integrated electric booster heater and electric tank heaters. The rated rinse water use is 133 gph or 2.2 gpm. This unit has a scrapper tank, a wash tank and a rinse tank. Our understanding of how the unit works prior to testing was that the unit uses a hot water supply for tank fills and top offs and cold water supply that is pre-heated (after passing through the heat exchanger and booster heater) for rinse operation. This dishwasher was the most complex and also the most efficient dishwasher amongst the four Google sites monitored.

Figure 34: Masa Café dishwasher

Monitoring Period

Successful data gathering started on November 21st, 2014 and continued until March 10th, 2015. Excluding the days when the café was closed, data was gathered for 93 days in which the first 62 days were used for calculating average daily use. The monitored data and calculated parameters for each work day are shown in Appendix D.

Measurement Points

Electricity use was measured to the unit at two main feed supply points, separating the booster heater use and dishwasher use. Dishwasher electricity use includes the operation of the wash and rinse tank heaters, water pump motors, conveyor belt and controls. Two Badger meters where used to measure the hot and cold water entering the dishwasher. Temperature was measured to the inlet and outlet of the booster heater, the incoming cold water and at the drain. Tank temperatures were measured at the rinse, wash, and scrapper tanks to provide further insight into the workings of the machine.

Figure 35: Pre-rinse station

Pre Rinse Monitoring

This pre-rinse station was selected for monitoring as it had installed the same components of a pre-rinse spray valve and scrapper (Figure 35) as the Heritage site. At this site, staff training and commitment to minimize water use was taken seriously by dishroom staff and the Executive Chef who had begun his career in commercial kitchens in the dishroom. Water was only used by the 1.15 gpm spray valve and the scrapper was not used. Using the industrial hose that was intended for cleaning the floors was outlawed by management for rinsing wares.

Challenges

During the last 31 days of monitoring, the recorded cold water usage of the dishwasher reduced drastically, with speculation that either the cold water supply to the machine was nearly shut off or for some other reason the dishwasher was operating outside normal specifications. Thus this data was omitted from the results below. Also, December 17th was the last day that the drain water temperature sensor was reading correctly, for the remainder of the test period, the sensor was disconnected from the drain pipe.

Average Daily Water Use Profile

The representative average day water use profile is shown in Figure 36, totaling 1,330 gallons. The hot and cold water use measured was roughly equal. There was one rinse and wash tank fill at 8 AM totaling 177 gallons which is more than the manufacturer's specification of 68 gallons. Overall, the dishwasher is used almost continuously from the morning breakfast to the evening cleanup with a few lulls during the day.

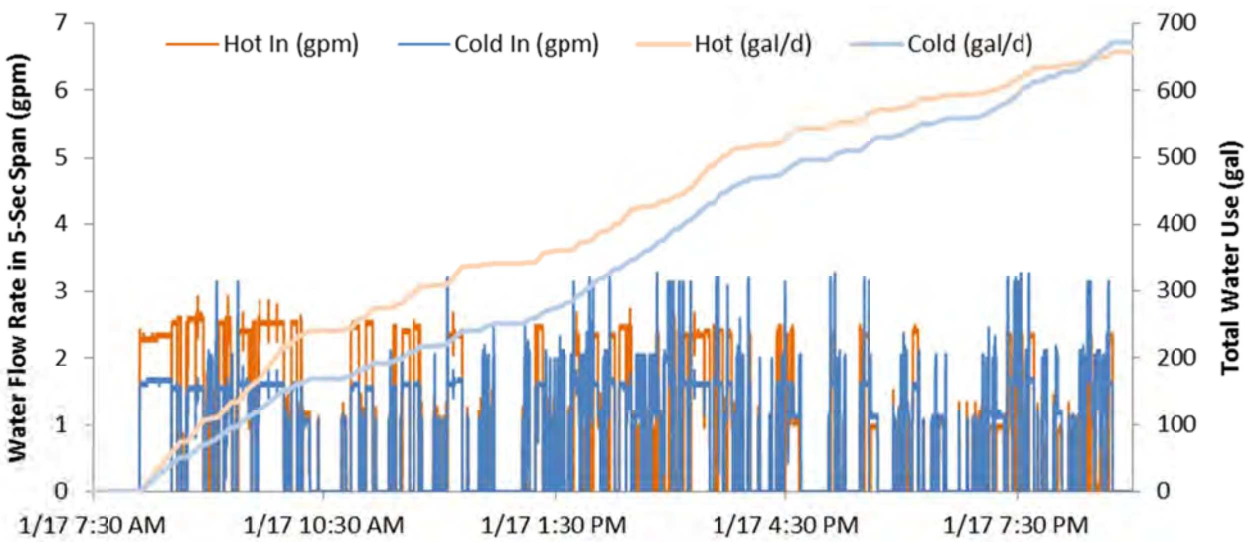

Figure 36. Masa Café daily water flow rates and total use

Results

Table 4. Google Masa data summary

	Existing Hobart
Daily Water Use	
Hot Water Use (gal/d)	655
Cold Water Use (gal/d)	670
Wash Tank Fill and Top-off Water Use (gal/d)	473
Rinse Water Use (gal/d)	852
Number of Fills per day	1.0
Gallons per Fill	67.5
Total Dishwasher Water Use (gal/d)	1,325
Total Pre-Rinse Operation Water Use (gal/d)	75
Flow Rates	
Hot Water Flow Rate (gpm)	1.7
Cold Water Flow Rate (gpm)	1.5
Rinse Flow Rate (gpm)	2.4
Peak Flow Rate (gpm)	18.7
Maximum Hourly Hot Water Demand (gph)	150
Dishwasher Water Use Per Hour of Rinse (gph)	243
Pre-Rinse Water Use Per Hour of Rinse (gph)	14
Water Temperatures	
Estimated Boiler Outlet Temperature (°F)	140
Hot Inlet (°F)	128
Cold Inlet (°F)	65
Heat Exchanger Inlet Temperature (°F)	93
Booster Outlet Temperature (°F)	182
Rinse Tank (°F)	158
Wash Tank (°F)	155
Scrapper Tank (°F)	139
Drain Temperature (°F)	131
Flow Time and Hours of Use	
Rinse Flow Time (h)	5.4
Dishwasher Operating Time (h)	10.8
Dishwasher Operating Span (h)	12.7
Energy Use, Booster Efficiency and Peak Demand	
Estimated Boiler Energy (therms/d)	5.8
Wash and Rinse Tank Heater and Dishwasher Electricity Use (kWh/d)	268
Booster Heater Energy (kWh/d)	201
Total Electricity Use (kWh/d)	469
Electric Booster Efficiency with Heat Exchanger	93%
Probable Contribution to Peak Demand (kW)	37.1
Total Energy Use (Btu/d)	2,184,750
Dishwasher Energy Use Per Hour of Rinse (Btu/h)	401,493

On an average day, there were 655 gallons of hot water and 670 gallons of cold water used to operate this dishwasher. The rinse water use at 852 gal/d was more than the tank fill and top off water use of 473 gal/d in Table 4. This means that there was less overspray occurring with this dishwasher versus the prior units monitored which were all smaller and had less physical separation between tanks. There was only one tank fill per day at the start of the day with an average of 67.5 gallons, which meets the manufacturers specifications for wash and rinse tank volume. The average pre-rinse spray valve water use at 75 gal/d was very low and almost negligible to the dishwasher average daily water use.


Figure 37: Rinse pressure gauge reading at 17.5 psi

The unit utilizes hot water and cold water simultaneously at average flow rates of 1.7 gpm and 1.5 gpm, respectively. The simultaneous and relatively even flow rate of hot and cold water for filling and rinsing operations for this dishwasher with integrated heat recovery was surprising. The working assumption was prior to monitoring this dishwasher that hot water would be used mainly for tank fills while cold water would be predominately used for the rinse operation when the heat exchanger has warmed up. The rinse flow rate measured at 2.4 gpm is not far off the manufacturer’s specifications at 2.2 gpm. The correlating rinse pressure at the gauge was 17.5 psi (Figure 37), which is lower than recommended industry setting of 20 psi.

The peak flow rate which is used for sizing tankless heaters was 18.7 gpm and the maximum hourly hot water demand was 150 gph for sizing storage heaters. The water use per hour of rinse operation at 243 gph was reasonable since it included tank fill operations for its calculation. The pre-rinse water use per hour of dishwasher rinse operation was extremely low at 14 gph.

The analysis of this heat recovery machine was more complicated versus conventional dishwashers due to the simultaneous hot and cold water use operations. The average daily rinse time was calculated at 5.4 hours. The conveyor daily run time was 10.8 hours and operating span was 12.7 hours with only two hours of idle time, calculated as the difference between run time and operating span. The dishwasher is utilized very well with minimal idle time. The plot in Figure 38 shows six weeks of dishwasher rinse time and total water use plotted on the two vertical axes. The dishwasher had some major malfunctions on February 13th through the 15th in what appears to be an open drain or partially blocked drain. When the conveyor dishwasher was in operation, the machine was actively filling the tanks throughout the work day. The rest of the weeks were relatively moderate with respect to total daily water use with reductions in water use and rinse time between the work week and weekend periods.

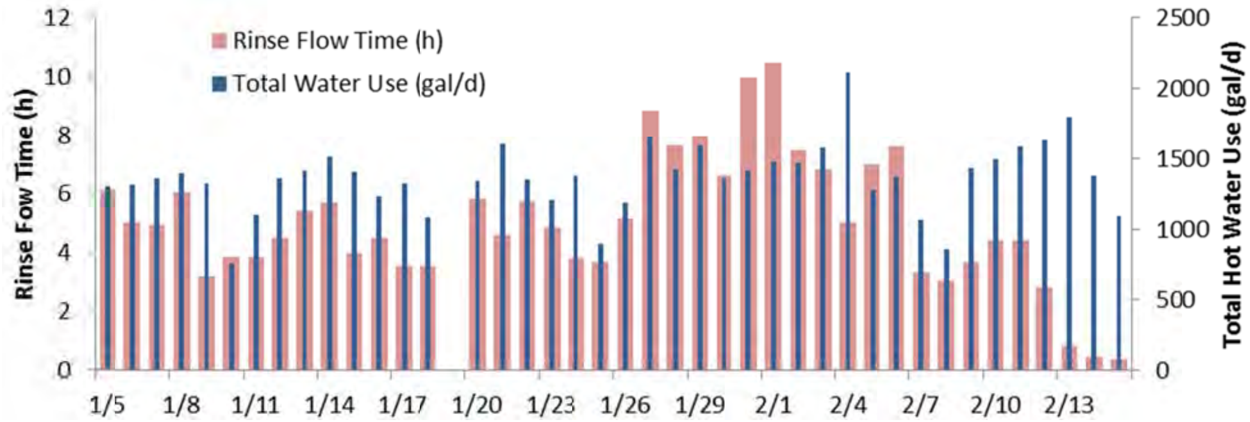

Figure 38. Masa Café plot of daily rinse flow time and total hot water use

The hot water demand at the dishwasher requires the use of 5.8 therms/d of natural gas to heat water at the boiler to approximately 140°F. The average hot water supply temperature delivered to the dishwasher was 128°F. The hot water mixes with cold water to reach the inlet of the heat recovery device at 93°F. The water is preheated in the heat exchanger before reaching the booster heater where it is heated to an average temperature of 182°F using 201 kWh/d of electricity. The dishwasher used an additional 268 kWh/d to power the controls, pumps, motors, and maintain the water temperatures in the rinse tank (158°F) and wash tank (150°F). The internal booster heater and heat exchanger combine for an average operating efficiency of 93%. The probable contribution to peak demand was 37.1 kW. The total energy use of the dishwasher was calculated at 2,184,750 Btu/d. The daily energy use is divided by the average hours of rinse operation resulting in a normalized energy use rate of 401,493 Btu/h.

Lessons Learned

Figure 39: Long unloading table with auto conveyor shut off on right edge

It was surprising that a significant amount of hot water was supplied to the heat exchanger during normal operation, which reduced the effectiveness of the EAHR device.

This site also had the most efficient pre-rinse operations of the four Google sites visited. They consistently used sheet pan racks and had long tables on the entrance and exit ends of the machine in which they utilized well by running continuous racks back to back. The dishroom had installed conveyor shut off switches shown in Figure 39 that reduces wear and tear on the machine and racks as well as improving the efficiency of the conveyor dishwashing operation to some extent.

Figure 40: Conveyor jam caused by sheet pan rack loading

Although sheet pan racks where used, we quickly realized that during high-speed dishwashing operations, it is easy to dislodge a sheet pan or two from its rack and have it obstruct the dishwasher conveyor process thus causing the machine to be shut down and manually corrected (Figure 40). Sheet pan racks are designed for specific dishwashers and using a generic sheet pan rack depending on the angle of racking or sheet pan pitch can cause obstructions when passing through the cavity. It is recommended that a taller dishwasher cavity be specified if planning to wash large wares and making sure that the correct sheet pan racks are purchased. Additionally, the one side open ended design of a sheet pan rack makes it easier for the racks to get dislodged (Figure 41.


Figure 41: Open ended design of sheet pan rack

Stanford Wilbur Café (Original Dishwasher)

Site Overview

The size of this kitchen and dining area is 22,000 square feet with a total of 650 seats, serving an average of 1,300 meals per day. On average, 230 meals are served for breakfast, 550 for lunch and 575 for dinner. Operating hours are from 7:30 AM to 7 PM, for 7 days a week while students are attending classes.

The original dishwasher used in this café was a 2001 Stero SCT-108S high-temperature dishwasher (Figure 42) with a rated throughput of 309 racks per hour. Its rated rinse water use is 272 gph or 4.5 gpm. This was a steam heated model utilizing a centralized steam boiler to provide direct steam to the tank heaters and to indirectly heat water through a heat exchanger for the final rinse operation. This was the largest rack conveyor tested during this study, and included a scrapper tank, a wash tank and a rinse tank. The initial observations during the first site audit was that the dishroom was very hot and steamy—even with 3 fans in operation (Figure 43). After a visual check of the elevated rinse and tank temperatures, the usage of a steam distribution system and the layout of the dishwashing tables. It was immediately apparent that this would be a great site to monitor an old inefficient dishwasher.

Figure 42: Wilbur Café original dishwasher

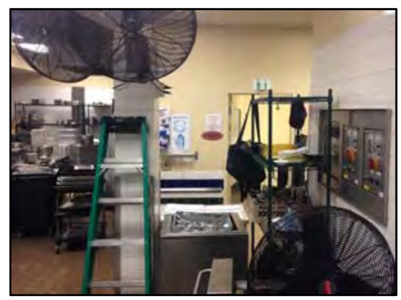

Figure 43: Steamy dishroom with 3 fans

Monitoring Period

Initially the research team found it very difficult to gain access to this dishwasher for monitoring. After 6 months of helping Stanford make the case for upgrading this unit to a new high-efficiency model, access was finally provided only 2 weeks prior to its replacement. Still, one of the goals of this project was do a pre- and post- dishwasher retrofit study whenever possible, so it was decided that although it was going to be a short monitoring window, the savings data would be very valuable. Data gathering started on November 30th, 2014 and continued until December 12th, 2015 when the students were let out for winter break. Data was gathered for a total of 13 days. The monitored data and calculated parameters for each work day are shown in Appendix E.

Measurement Points

Electricity use in this case was monitored to measure the minimal electric functions of running the conveyor motor, water pumps and controls. Two Fuji ultrasonic flow meters were used to measure the tank fill and rinse lines leading to the dishwasher. Temperature was measured at these fill and rinse lines as well as at the drain. Tank temperatures were also measured at the powered rinse, wash, and scrapper tanks. The gas use associated with the steam-heated tanks, booster heater, and water supply was estimated (further discussed below).

Challenges

The installation of monitoring equipment on this steam based system was very challenging in several respects. First, the steam entering the kitchen goes through a steam to hot water heat exchanger whereby domestic hot water is blended to condense the steam, providing hot water at 180°F or higher for the sanitizing rinse. Due to either the setting or age of the heat exchanger, the outlet rinse water contained a mixture of hot water and steam which occasionally caused the temperature sensors to read excessively elevated rinse temperatures. In response, any temperature readings above 208°F were readjusted down to 208°F while any temperature below this threshold was left unchanged. As part of our instrumentation calibration process, we uncovered that the dishwasher auto fill function was not working consistently due to worn out relay switches (Figure 44). The switches only sometimes triggered the wash tank fill solenoid valve to open in order to fill it while simultaneously filling the scrapper and rinse tanks. Consequently, a manual fill of all three tanks was required to ensure that the tanks were full.

Figure 44: Tank fill relay switch

In Figure 42 on the left there is a hard 90 degree corner on the dish table that requires a staff member to manually dislodge the rack after it has been rinsed (the original motor and drive roller system designed to move the racks had long since failed). Otherwise the rack could not travel further, thereby causing a backup of racks through the machine. The excessive wear and tear from this had caused many of the racks in the dishwasher to wear out prematurely (Figure 45) causing them to not advance through the dishwasher until a following rack in good working order pushes the worn rack through the machine.

Figure 45: Rack wear and tear

Average Daily Water Use Profile

Total hot water use on December 7th, 2014 was 1,515 gallons, representative of the overall daily average of 1,372 gal/d. The water use profile for this date is shown in Figure 46. Looking closely at the plot shows three tank fills: one at roughly 6:50 AM, another at 8:25 AM, and the last one at 4:18. The rest of the flows shown in dark orange are tank top offs.

Judging by the rinse flow rate profile in dark red, the dishwasher is used periodically for the morning breakfast period while continuous dishwashing sessions only occur during the lunch and dinner periods. The plot also reveals three abnormally lengthy rinse periods, illustrated by the hollow sections in the rinse flow at approximately 1:30 PM and prior to and after 6 PM. Anecdotally, these periods may be attributed to a rack continuously triggering the rinse sensor while stalled out in the machine.

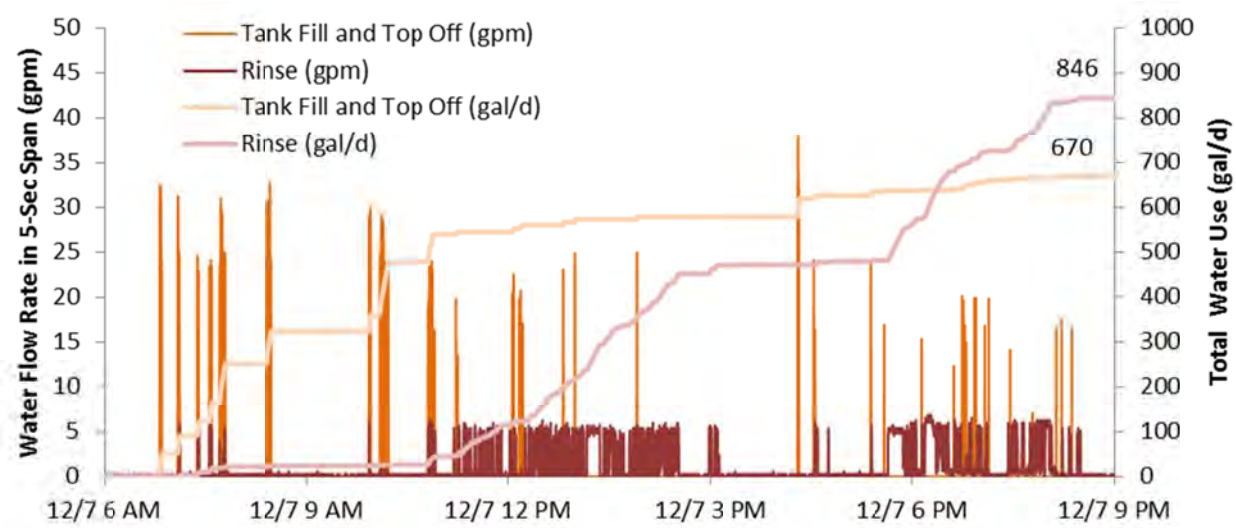

Figure 46. Wilbur Cafe December 7th water flow rates and average daily water use graph

The maximum daily water use profile occurred on December 2nd and is shown in Figure 47. On this day 2,738 gallons were used for the tank fill and top off while only 595 gallons were used for the rinse. There were two tank fill sessions at 10 AM and 7 PM where water waste from the fill operation totaled roughly 2,500 gallons.

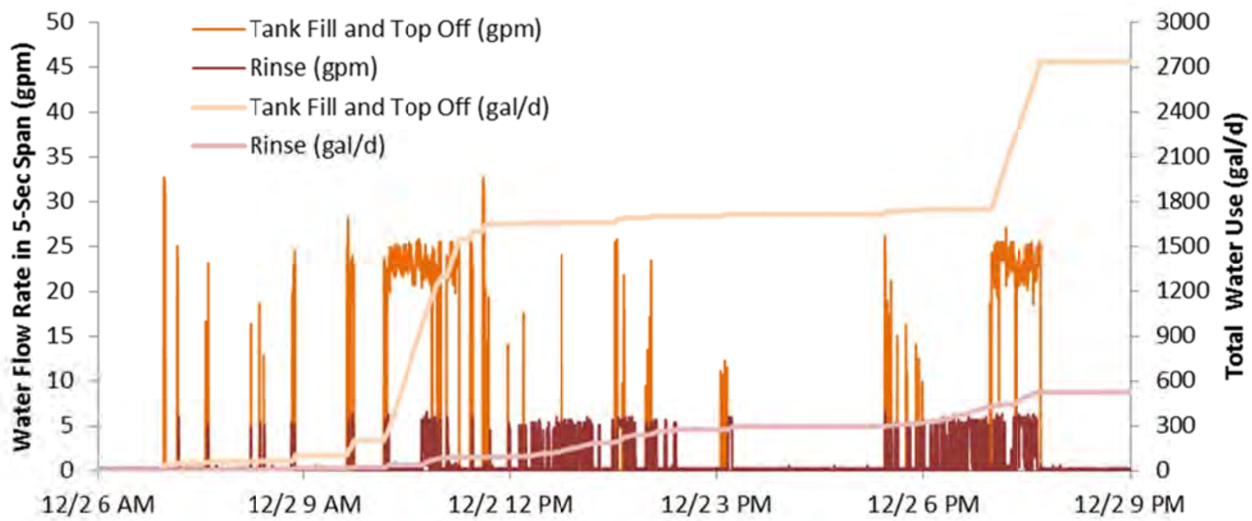

Figure 47. Wilbur Cafe December 2nd water flow rates and maximum daily water use graph

The normal daily water use profile without any water waste events occurred on December 6th in Figure 48. On this day 192 gallons were used for the tank fill and top off and 601 gallons were used for the rinse.

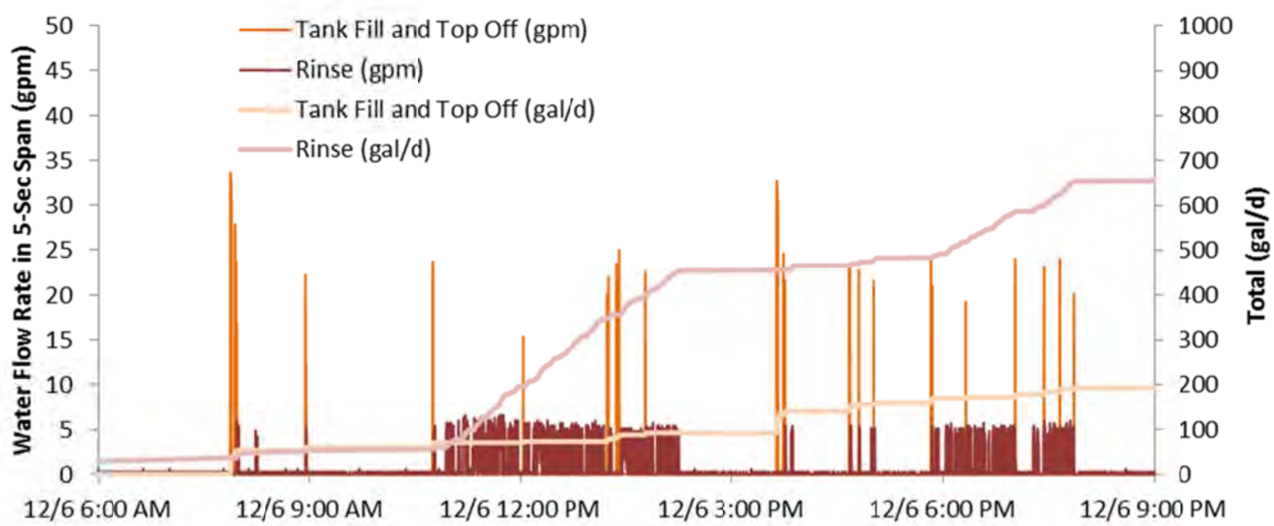

Figure 48. Wilbur Cafe December 2nd water flow rates and maximum daily water use graph

Results

Monitored data was analyzed to deliver the results in Table 5 for the existing and new dishwashers, and the savings from replacement. With the original dishwasher on an average day, there were 125 gallons used for tank fills, 586 gallons used for tank top offs, and 660 gallons used for rinsing. The tank and maintenance fills accounted for more than half of the total water use on an average day due to the significant water waste calculated at 484 gal/d. There were two tank fills per day averaging 37 gallons. This total corresponds with the automatic fill of the scrapper and rinse tanks (15 and 24 gal, respectively), assuming that the wash tank is filled manually. The average daily total water use for this lightly utilized machine was 1,372 gal/d. The average total daily industrial spray valve water use was 1,282 gallons from the three hoses used in the dishroom for pre-rinsing wares which is high considering the mild use of the dishroom.

The measured rinse flow rate of 5.3 gpm is 15% above the manufacturer's specifications of 4.5 gpm. For water heater sizing purposes, the peak flow rate was measured at 35.4 gpm and the maximum hourly hot water demand was 1,424 gph. The hourly demand is inflated since operating practices periodically lead to large periods of hot water waste. The dishwasher water use per hour of rinse operation at 667 gph was also elevated. The pre-rinse water use per hour of dishwasher rinse operation was extremely high at 623 gph.

Table 5 Stanford data summary

	Original Stero	*Replacement Hobart*	*Savings*
Daily Energy Use and Booster Efficiency			
Hot Water (gal/d)		334	
Cold Water (gal/d)		294	
Rinse Use (gal/d)	661	319	342
Tank Fill and Top Off (gal/d)	711	309	402
Tank Fills (gal/d)	125	235	
Top Off (gal/d)	586	74	
Number of Fills	2.0	2.0	
Gallons Per Fill	37	111	
Water Waste (gal/d)	484	95	389
Total Dishwasher Water Use (gal/d)	1,372	628	744
Total Pre-Rinse Water Use (gal/d)	1,282		
Average Flow Rates			
Hot Water (gpm)		3.4	
Cold Water (gpm)		1.7	
Rinse Flow Rate (gpm)	5.3	2.5	2.8
Peak Flow Rate (gpm)	35.4	5.9	29.5
Maximum Hourly Hot Water Demand (gph)	1424	314	1110
Dishwasher Water Use Per Hour of Rinse (gph)	667	301	366
Pre-Rinse Water Use Per Hour of Rinse (gph)	623		
Water Temperatures			
Estimated Boiler Outlet (°F)	212	145	
Hot During Flow (°F)		120	
Cold During Flow (°F)		66	
Heat Exchanger Inlet During Flow (°F)		79	
Rinse During Flow (°F)	194		
Fill During Flow (°F)	123		
Rinse Tank (°F)	148	161	

Wash Tank (°F)	167	162	
Scrapper Tank (°F)	151	133	
Drain (°F)	142	124	
Flow Time and Hours of Use			
Rinse Flow Time (h)	2.1	2.1	
Dishwasher Operating Time (h)	5.1	8.5	
Dishwasher Operating Span (h)	12.7	13.1	
Energy Use, Booster Efficiency and Peak Demand			
Total Gas Use (therms/d)	30.2	3.2	27.0
Dishwasher Energy (kWh/d)	21	191*	
Booster Energy (kWh/d)		85	
Total Electricity Use (kWh/d)	21	276	-255
Electric Booster Efficiency with Heat Exchanger		102%	
Probable Contribution to Peak Demand (kW)	1.7	21.2	-19.5
Total Energy Use (Btu/d)	3,095,860	1,260,150	1,835,710
Dishwasher Energy Use Per Hour of Rinse (Btu/h)	1,504,373	603,262	901,111
Facility Parameters			
Water Use Per 1000 Square Feet (gal/1000ft^2)	62.3	28.6	
Water Use Per Seat (gal/seat)	2.1	1.0	
Water Use Per Meal (gal/meal)	1.1	0.5	
Energy Use Per 1000 Square Feet (Btu/1000ft^2)	140,721	57,279	
Energy Use Per Seat (Btu/seat)	4,763	1,939	
Energy Use Per Meal (Btu/meal)	2,381	969	
Annual Operating Costs			
Water and Sewer Cost[2]	$6,693	$3,065	$3,628
Gas Cost[3]	$11,037	$1,160	$9,877
Electricity Cost[4]	$1,303	$17,138	-$15,835
Demand Charge[5]	$283	$3,618	-$3,335
Total Annual Cost	$19,316	$24,981	-$5,665

[1]With Electric Tank Heat, [2]$10/HCF (Weighted mean of restaurant water and sewer costs for 8 largest California cities), [3]$1/therm (PG&E 2015 small commercial gas rates), [4]$0.17/kWh (PG&E 2015 Avg. A-10 & E-19 commercial electricity rates), [5]$19/kW (PG&E 2015 Avg. A-10 & E-19 commercial electricity rates)

With a length of 108" and a rinse time of 2.1 hours, this dishwasher is greatly oversized considering the average demand on the dishwasher and the short operating hours (shown on the earlier flow profile plots). The rinse flow time was the lowest in the group, while this rack-conveyor dishwasher is the largest in the group. It is assumed that this value is artificially low since racks were observed passing through the rinse cavity without activating the fresh water rinse. The dishwasher operating time of 5.1 hours for three meal periods is less than two hours per meal period. The total dishwasher operating span of 12.7 hours indicates lengthy idling between meal periods. The operating time and operating span when compared to the rinse time illustrates the overall underutilization of the dishwasher.

The plot in Figure 49 shows a period of two weeks where dishwasher rinse time and total water use were analyzed together. The dishwasher had some major malfunctions on December 1st through the 3rd in what appears to be occasions where the drain was left open during tank filling or rinse operation. The rest of the days were pretty moderate for rinse time and total water use. Both these parameters track each other well for the remaining ten days where the machine was operating normally.

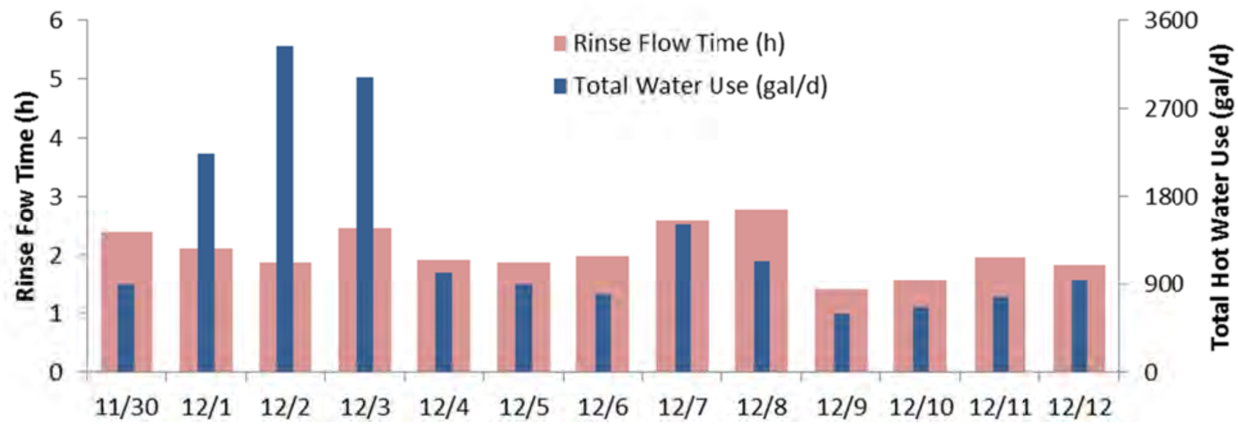

Figure 49. Wilbur Café plot of daily rinse flow time and total hot water use on original dishwasher

This dishwasher is predominately run by natural gas as the steam output from the centralized boiler on campus is directly injected into the tank heaters to maintain temperature and utilized by the heat exchanger for the sanitizing rinse. The operating efficiency at which natural gas is used to generate steam, distribute it and convert it to domestic hot water was estimated to be 50% for the calculation of gas use. The hot water demand at the dishwasher requires the use of an estimated 30.2 therms/d of natural gas to heat water, distribute it to the dishwasher, and maintain rinse tank (148°F) and wash tank (167°F) water temperatures. It appears that the steam injectors were not working to heat the rinse tank, thus relying on the elevated fresh water rinse temperature to keep it hot. The average hot water supply temperature delivered to the dishwasher was 123°F for the fill and 194°F for the rinse. Electricity use was measured to power the dishwasher controls, pumps and motors to an average daily total of 21 kWh/d. The probable contribution to peak demand was a low 1.7 kW. The total energy use of the dishwasher was calculated at 3,095,860 Btu/d. The daily energy use is divided by the average hours of rinse operation resulting in a normalized energy use rate of 1,504,373 Btu/h.

Figure 50: Temperature gauge readings on dishwasher during rinse operation

This dishwasher operated at the highest elevated temperatures seen thus far-- all temperature gauge readings exceeded manufacturer's minimum specifications by 15 to 20°F (Figure 50) during the initial site visit. The elevated water temperatures and the uninsulated steam heat exchanger that was radiating heat into the room contributed to a hot and steamy dishroom. The average scrapper tank temperature at 151°F was elevated since the cold water supply to the scrapper tank was disconnected. Scrapper tank temperatures should normally be in the 110°F range. The purpose of the scrapper tank is to use warm water to knock down food debris, however if the water temperature is too high certain types of food debris can get baked onto the dishes.

Lessons Learned

The biggest lesson learned about this dishwasher and more so the overall dishroom is that it fits the mold for absolute inefficiency on all accounts: equipment specification, operation and maintenance, and dishroom design. To start, the cafeteria dishroom design relies on automatic mechanical operations that inevitably break down, and in doing so makes the rest of the sanitation process more inefficient. Originally, the design relied on a cafeteria tray delivery system to a trough-based pre-rinse system, with rack advancing systems on both ends of the machine. The trough based system is now broken or no longer used, thus it is being supplemented by three industrial hoses with pre-rinse sprayers operating at 5-7 gpm (Figure 51). Moving along the warewashing assembly, the rack advance system works well on the entrance but is restricted on the other end due to a broken rack advance feature, causing a bottleneck for the racks moving through the hard 90° turn. The dishwasher is oversized and poorly maintained by engineering/maintenance staff, although it was one of the cleanest machines studied. Lastly, the heat loss from the uninsulated heat exchanger next to the dishwasher, coupled with the elevated water temperatures delivered to the machine by the steam distribution system made the room very uncomfortable to work in while being a major contributor to energy waste.

Figure 51: Dishroom pictures from left (dishwasher outlet) to right (pre-rinse station)

Stanford Wilbur Café (Replacement Dishwasher)

Site Overview

Over the winter holidays, Stanford replaced older Stero conveyor dishwashers in three cafeterias. At Wilbur Café, a Hobart CLPS-86ER was installed (Figure 52). It is a heat recovery unit that also has an electric internal booster heater and electric tank heaters. The electrical service was upgraded to accommodate this additional load. The rated rinse water use is 133 gph or 2.2 gpm. The internal water connections with these advanced dishwashers with heat recovery are very extensive (Figure 53). The benefits of the new unit include the steam removal system, insulated doors and door seal system, which combined and with the elimination of the steam heat exchanger system made for a comfortable work environment even without the room fans running. Additional features of the high-efficiency dishwasher include a door actuated drain closure system, vent fan control, energy saver mode, and integrated booster heater.

Figure 52: Replacement Hobart dishwasher

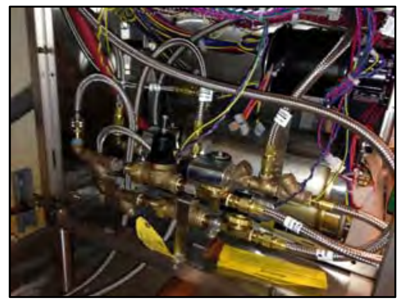

Figure 53: Hobart dishwasher internals

Monitoring Period

Data collection started on January 10th, 2015 and continued until April 28th, 2015. During the initial period until February 26, the dishwasher was operated as commissioned, except for a period from January 23rd to February 4th where the dishwasher was monitored with the hot water turned off. Upon preliminary data analysis it was observed that the machine was not operating efficiently as it was using excessive amounts of hot water instead of a higher fraction of cold water (heat recovered). It was communicated with Stanford and Hobart that the machine didn't appear to be working well. We are unsure if any adjustments were made by Hobart technicians, but the dishwasher started performing as designed on February 27th until March 10th. On Wednesday March 11th the cold water was turned off for testing purposes and remained off for the rest of the monitoring period. Overall the dishwasher was monitored for a total of 101 days, in which the 12 days where the machine was operating properly were used for calculating average daily use. The monitored data and calculated parameters for each work day are shown in Appendix F for all test conditions listed below:

1. Originally installed dishwasher (Energy recovery system not performing)
2. Recommissioned dishwasher (energy recovery system working as designed)
3. Highest efficiency operation (cold water supply only)
4. Lowest efficiency operation (hot water supply only)

Measurement Points

The same instrumentation setup was used for both the original and replacement dishwasher, with the addition of one electric meter. Electricity use was measured at two points for the booster heater and dishwasher independently using the energy meter instrumentation shown in Figure 54. Two Fuji ultrasonic meters (one transducer shown in Figure 55) where used to measure the hot and cold water entering the dishwasher. Temperature was measured at the incoming hot and cold water supplies, at the inlet and outlet of the booster heater, and at the drain (hot water and drain temperature sensor locations displayed in Figure A). Tank temperatures were measured at the rinse, wash, and scrapper tanks.

Figure 54: Electricity metering instrumentation

Figure 55: One water meter and two temperature sensor locations

The two major functions of the dishwasher in washing and rinsing wares and dumping and filling the tanks were shown graphically in Figure 56. Washing and rinsing and tank top off operations continue until about 2:10 PM. At this point, hot and cold water flow stops and the drain temperature was elevated to around 165°F in purple which was the tank dump operation. At 2:15 PM the tank fill was initiated and the cycle starts again.

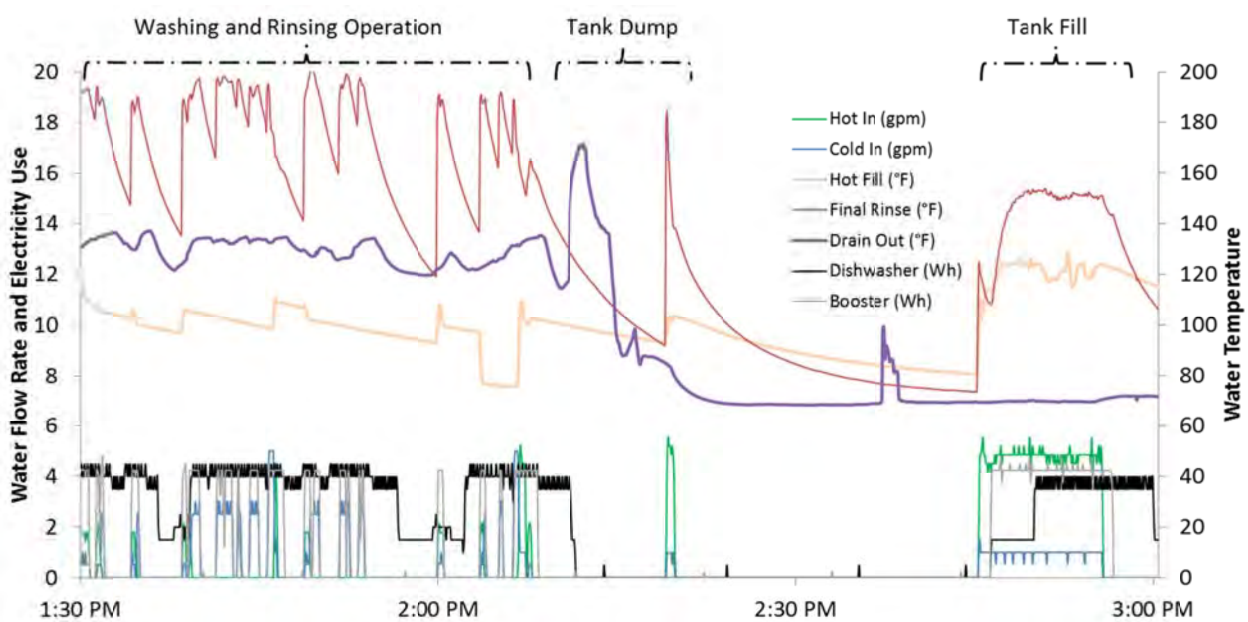

Figure 56: Visual plot of dishwasher rinse and tank dump and fill functions

Challenges

The biggest challenge faced after analyzed the preliminary data on the new dishwasher was to confirm with the manufacturer's technicians on whether the dishwasher was commissioned correctly. Early observations in the dishroom spotted that the exhaust ventilation system for the dishwasher was off and that the energy recovery system on the dishwasher was not receiving cold water for correct operation. The data leads us to think that this machine was not commissioned properly after installation, but the unit was fixed and working correctly later in the monitoring period after we contacted the technicians. FSTC worked with Stanford to monitor the dishwasher under four test configurations to learn more about the unit. Except for the normal test configuration, discussion of the data for the various test configurations is outside the scope of this report, but the data is provided in Appendix F.

Average Daily Water Use Profile

The total hot water use was 611 gallons on February 10th, 2015; the water use profile is shown in Figure 57. The water use total is representative of the overall average of 628 gal/d. There was one tank fill at roughly 7 AM totaling 66 gallons which is very close to the manufacturer's specification of 68 gallons. The hot and cold water use totaled 474 and 137 gallons. The dishwasher is not heavily used until 10:30, but then it is continuously used until 8 PM except for a break after the lunch period. It appears that the period after lunch, the drain may have been left open from roughly 3 PM to 5 PM, judging by the flow profile shown and constant elevated drain temperature in the data for this period.

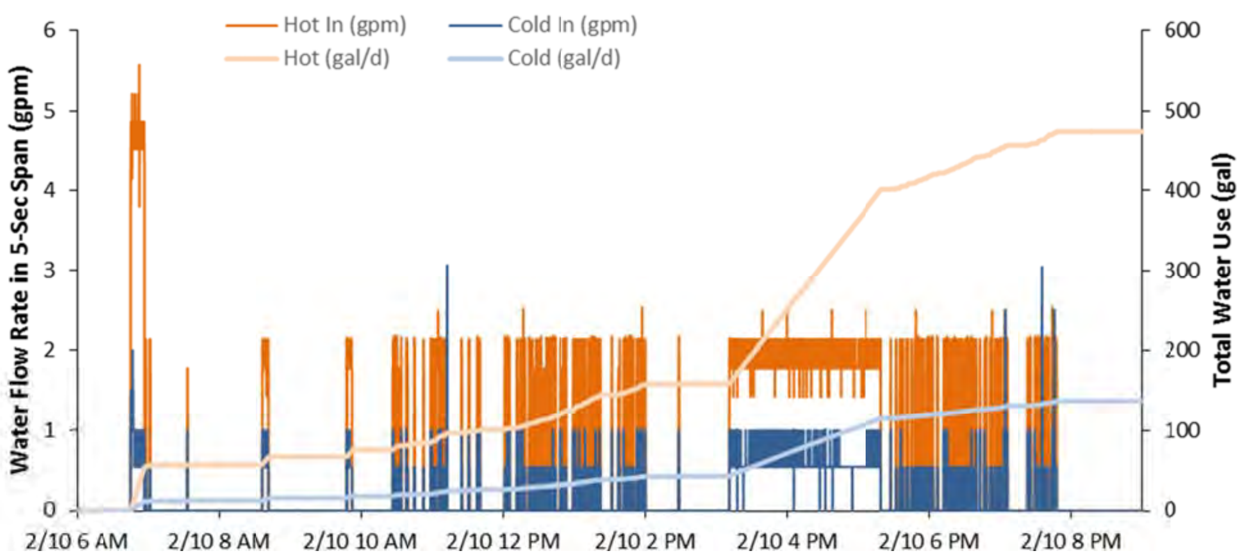

Figure 57. Wilbur Cafe representative average daily water flow rates and total use

As mentioned earlier, there may have been a second commissioning of the dishwasher on February 27th in Figure 58. At approximately 1 PM, the hot and cold water flow profile completely changes from a constant hot and cold rinse water flow profile to a variable rinse flow profile. These changes are better illustrated in Figure 59 for February 28th. After a morning fill prior to 8 AM, the unit is idle until close to 10:30 AM. When the unit starts up for rinse operation, the dishwasher is cold and it takes time to generate the steam required for the heat exchanger to be effective. Thus, the dishwasher senses this and starts the rinse operation by utilizing hot water through the booster heater. At approximately a half hour later, the heat exchanger is warmed up and the dishwasher cuts down on the hot water use while increasing the cold water flow rate through the heat exchanger and booster. This continues until the rinse operation is over at 3 PM and the tanks are emptied. A very large tank fill using 460 gallons is initiated which could have included a dishwasher cleaning step or an example of the tank drain being left open. Then the same rinse process starts again at 4 PM. If the additional water use of the second tank fill is factored out in excess of the rated tank volume, then the cold water use throughout the day would have exceeded the hot water use.

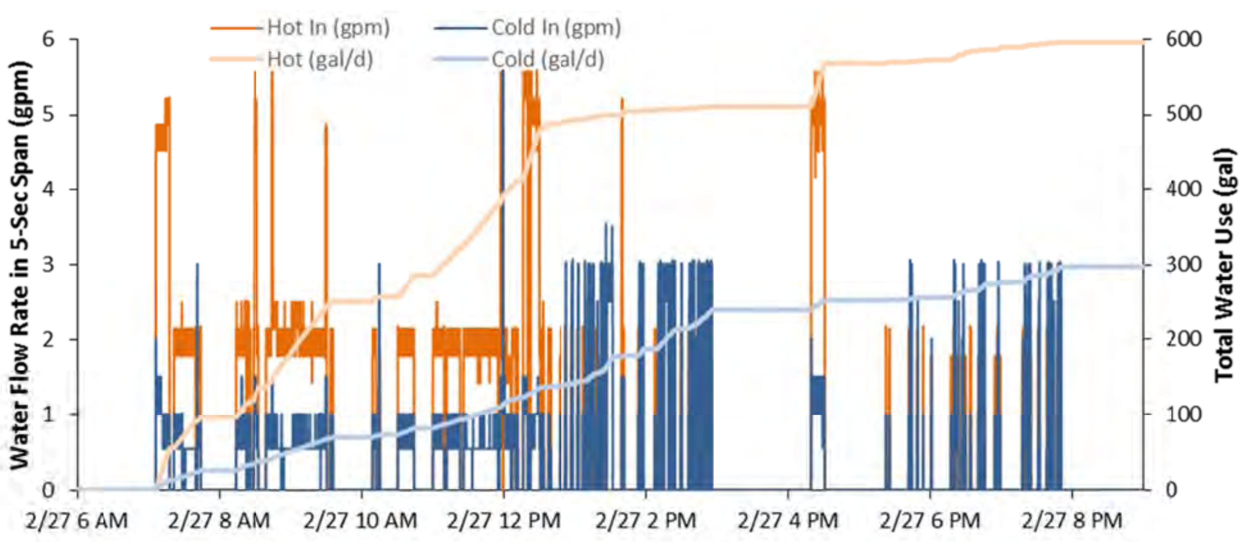

Figure 58. Wilbur Cafe Feb 27 1 PM adjustment to dishwasher resulting in change in flow rate profile

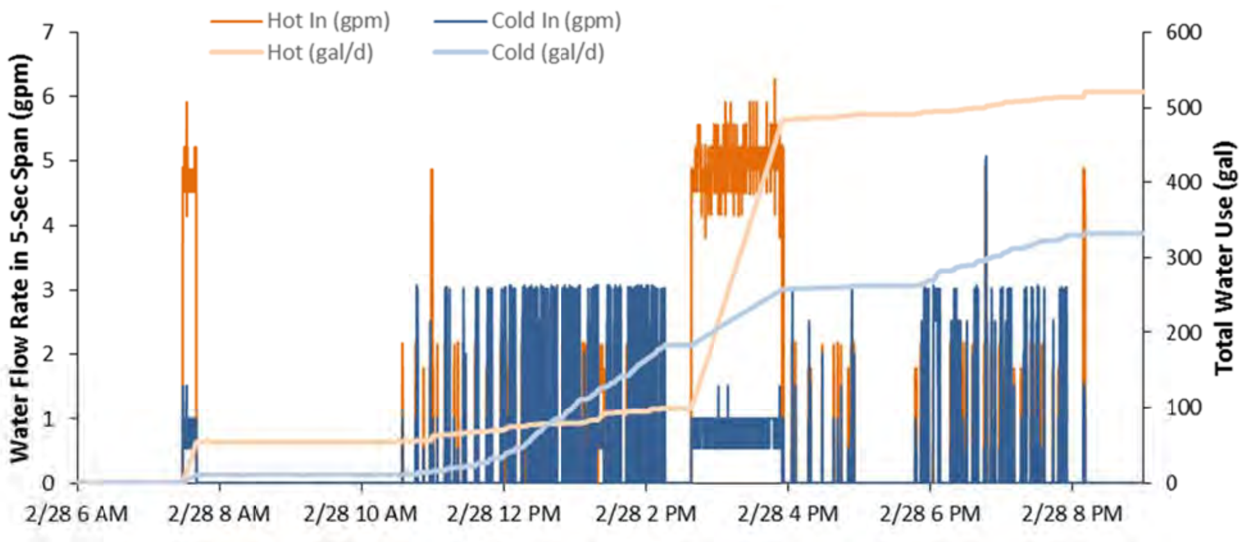

Figure 59. Wilbur Cafe Feb 28 normal flow rate profile

Results

The monitored data for the replacement dishwasher was analyzed on a daily basis in Appendix F. The average use data is displayed in four rows signifying the four test conditions and test periods. Only the results from the recommissioned test condition is displayed in the body of the report in Table 5.

The ratio of daily hot and cold water use of approximately 3:1on the newly installed machine was unexpected. After the unit was recommissioned the ratio of hot to cold water use was close to 1:1 with an average water use of 628 gallons per day. Also, the daily water use for tank fill and top off operation at 309 gallons was close to the rinse water use at 319 gallons. On average there was two tank fills per day using 111 gallons per fill. Tank fill water waste contributed to 95 gallons of water use per day, but this value might also include dishwasher auto clean or manual descale operations which could not be isolated from the data, if they occured.

The rinse flow rate calculated at 2.5 gpm is slightly higher than the rated 2.2 gpm. The maximum hot water flow rate in a 10-second period is 5.9 gpm and the maximum hourly hot water demand is 314 gph for sizing tankless and storage heaters, respectively. The dishwasher water use per hour of rinse operation at 301 gph was roughly half, compared to the prior dishwasher or existing pre-rinse operation.

The rinse flow time at 2.1 hours is low for the size of the cafeteria and extent of operation but consistent with the operation of the original dishwasher. The dishwasher operating time is 8.5 hours and the operating span is 13.1 hours. The 4:1 ratio of dishwasher operating time to rinse flow time and 6:1 ratio between operating span and rinse time illustrate that the majority of the time during the dishwashers operating day, the machine is either idling or conveyor is running without the sanitizing rinse operation.

The plot in Figure 60 shows a period of a month where dishwasher rinse flow time and total water use were compared on a daily basis. On nine occasions or roughly 30% of the days, the total water use greatly exceeds the rinse time due to water waste activities on that day. With the first half of February and March, the rinse time is moderate at approximately two hours, but the second half of February the rinse time increases to roughly six hours per day.

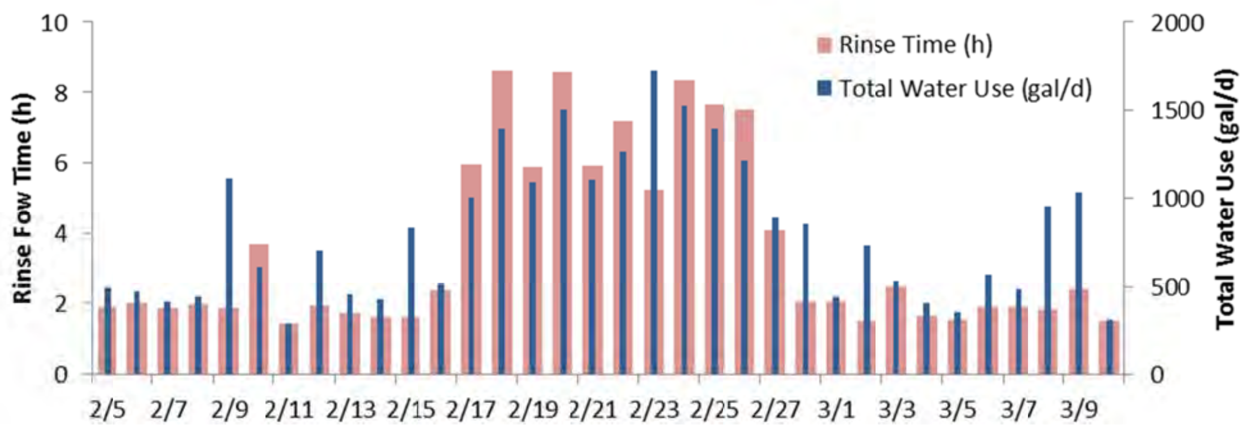

Figure 60. Wilbur Café plot of daily rinse flow time and total hot water use on replacement dishwasher

The average inlet hot water temperature to the dishwasher was 120°F after the facility switched from a centralized campus steam system to a centralized hot water system during the dishwasher replacement period. Although switching from a steam to domestic hot water system was a good step, there are still significant pipe heat losses from the extensive centralized campus hot water distribution system. In order to estimate the boiler outlet temperature to later calculate energy use at the boiler, the temperature loss through the distribution pipes need to be estimated. One way to do this is to analyze the highest hot water using day where distribution pipe temperature losses are minimized. This occurred on March 15th, where over 2000 gallons of water waste contributed to the daily hot water use of 2,550 gallons, driving up the hot water supply temperature to the dishwasher to 134°F, which is 14°F higher than the average temperature. Thus, it is estimated that the outlet temperature of the boiler is a nominal 10°F higher temperature at 145° Also estimating that the average annual cold water temperature to the water heater is 65°F results in the calculation for temperature rise through the centralized water heater of 80°F.

The 120°F hot and 66°F cold water supply temperatures were mixed to yield a heat exchanger inlet temperature of 79°F. The combination of the heat recovery device and booster heater elevates the water temperature to 193°F for the sanitizing rinse. The water temperature cascades through the dishwasher from the sanitizing rinse temperature to the powered rink tank with an average temperature of 158°F. Then the water cascades to the wash tank at 150°F, scrapper tank at 139°F, and down the drain at 131°F. The water temperatures listed are within normal operating range.

This dishwasher is predominately run by electricity as it heats the two onboard tank heaters and booster heater. Electricity is also used to power the dishwasher controls, pumps and motors. In total the dishwasher uses an average of 276 kWh/d in the recommissioned test case. In the original test case 5.7 therms/d are used to heat water at the boiler, this is reduced to 3.2 kWh/d in the recommissioned test case. Since it would be difficult to normalize the data due to the large fluctuations in water waste on a daily basis, we will focus on two critical outcomes. One is that gas used at the boiler can be significantly reduced or eliminated with the recommissioned or cold water only test scenarios. The second is that the heat exchanger is much more effective thus improving the combined heat exchanger and booster heater operating efficiency from 87% in the original case to 102% when using more cold water for the rinse operation in the recommissioned case, or 133% when using only cold water. The probable contribution to peak demand for this dishwasher is 21.2 kW. The total average daily energy use of the dishwasher was calculated at 1,260,150 Btu/d with a normalized hourly energy use rate of 603,262 Btu/h. Both these values are approximately a 60% reduction versus the original machine.

Cost and Payback

The direct water and energy savings from dishwasher replacement was calculated in Table 5 along with cost savings information. The facility was very happy with the new dishwasher and the staff were able to work in a comfortable dishroom. The facility was not able to experience overall operating cost savings from this project due to fuel switching from a 100% gas heated dishwasher to a primarily electric heated dishwasher. Even though the facility reduced water and energy use by over 50%, it was not able to overcome the added expense of using electricity over natural gas. The facilities annual operating cost increased from $19,316 to $24,981 for an added annual cost of $5,665 to operate the new dishwasher. This calculated cost savings does not factor in savings from reducing the chemical use in the replacement dishwasher. There is no payback for this project.

Facility Parameters

For this facility we were able to calculate the daily water and energy use of the dishwasher with respect to the size of the facility, per seat and per meal in Table 5. The results are very site specific at this time as data like this is only available for a few sites so it would be difficult to draw any wider conclusions. These parameters can be used as a benchmarking tool for the campus. The water use per 1000 square feet of floor space was reduced from 62.3 to 28.6 gallons. The water use per seat (in the dining room) was originally 2.1 gallons and is now 1.0 gallon. The water use per meal was reduced similarly from 1.1 gallons to 0.5 gallons. The original dishwasher used 140,721 Btu/d per 1000 square feet and this was reduced to 57,279 Btu/d. Similar reductions occurred with energy use per seat and per meal. The pre-rinse water and energy use could easily be added to this and if the water and energy use for the 3-compartment sink was quantified, then the total water and energy use of the dishroom could be calculated.

Lessons Learned

Although it wasn’t fully discussed in this report, a lot of time was spent analyzing the data from the four test configurations. The takeaway was that proper commissioning of an advanced dishwasher is critical to the success of the project in realizing the energy savings associated. Both the Masa Café and Wilbur Café heat recovery dishwashers were not properly commissioned. The Masa Café continues to operate inefficiently, while we were able to intervene to recommission the dishwasher at Wilbur Hall.

In conversations with the manufacturer’s technicians, FSTC learned that the techs are not trained on how to commission the heat recovery based dishwashers in their lineup, which is a bigger problem. The tech interviewed mentioned that the only aspects of the machine they check is the rinse pressure and temperature, tank temperatures and basic operation of the machine. They don’t have the tools to measure the ratio of hot and cold water or other parameters that would indicate if the machine’s heat recovery system is working properly.

Properly training staff on the working of the new dishwasher was also very limited and ineffective as the staff, perhaps unaware how to use the dishwasher to its fullest, had continued with some wasteful practices with tank filling and on occasion rinse operation. Proper training and retraining of staff is necessary and should be built in to the project plan at the time of installation. In most situations a quick one time training session of a portion of the staff occurs that does not benefit the facility in the long term.

Facebook Epic Café (Original Dishwasher)

Site Overview

This large cafeteria is open from 8 AM to 8 PM during the work week and covers the breakfast, lunch and dinner meal periods (Figure 61). The dining and kitchen facility covers an area of 28,800 square feet with 470 seats in the interior (Figure 62) and 430 seats in the exterior and serves an average of 10,000 meals per day. Lighter operation of the dishwasher occurs during the weekends as staff members are still working onsite on maintenance and cleanup tasks. During the work week, the facility also washes wares from an estimated 10 small food service facilities on campus.

Figure 61: Epic Café Outdoor Seating

Figure 62. Epic Cafe dining room panoramic

The preexisting dishwasher was a 2008 Stero STPCW-ER-20 high-temperature dishwasher with electric tank and booster heaters (Figure 63). The rinse water consumption was rated at an efficient 98 gallons per hour. The unit measured 20 ft. in length and included a 36-gallon scrapper tank and 47-gallon wash and rinse tanks.

Figure 63: Epic Café original dishwasher

The initial observations during the first site audit of this dishroom were that this was a very high-throughput dishwasher operated by multiple staff members while they carried out supplementary tasks. This facility utilized a drainwater tempering device to attempt to keep the exiting temperature below 110°F— a special circumstance since the facility drain level is below that of the main sanitary sewer system and requires that the wastewater be pumped vertically up to the main sewer level. High dishwasher drain temperatures in the past routinely had resulted in seized water pumps, therefore causing problems for this and other facilities on campus.

Measurement Points

Electricity use was measured for the booster heater and dishwasher independently. Two ultrasonic meters where used to measure the hot and cold water entering the dishwasher. Temperature was measured on the dishwasher cold and hot water supply lines, at the outlet of the booster heater and at the drain.

Monitoring Period

Data collection started on May 4th, 2014 and continued until May 7th when a break occurred until June 22nd when comprehensive monitoring restarted and continued until September 12th. Data was gathered for a total of 57 days. The monitored data summary and results for each work day are shown in Appendix G.

Challenges

This was a high traffic dishroom, and it was quickly realized after losing data for over a month that all of the instrumentation would need to be fastened very securely and with the instrumentation enclosure situated so it would not be moved thus dislodging any connected wiring and causing further data gaps (Figure 64). However, between July 5th and 24th, one temperature sensor did get dislodged and an estimate was made for the missing data based on the average temperature rise observed on a daily basis with in the remaining dataset.

Figure 64: Instrumentation box (lower right)

Daily Water Use Profiles

The total hot water use was 5,784 gallons on July 16th, 2014 and the profile is shown in Figure 65. The water use total is representative of the overall average of 5,749 gal/d. Looking at the plot, there were three tank fills at roughly 6:30 AM, 5:30 PM, and 10:00 PM. The rest of the flows shown in dark orange above 5 gpm are tank top offs and rinse flows combined. When the rinse is activated only, it is differentiated by the shaded sections in dark orange at below 4 gpm. Looking at the plot, the prior nights work finishes after midnight and operation restarts in the morning at 6:30 AM. The dishwasher usage is continuous until about 4 PM at which point there is lighter use until 8 PM when nightly cleanup begins.

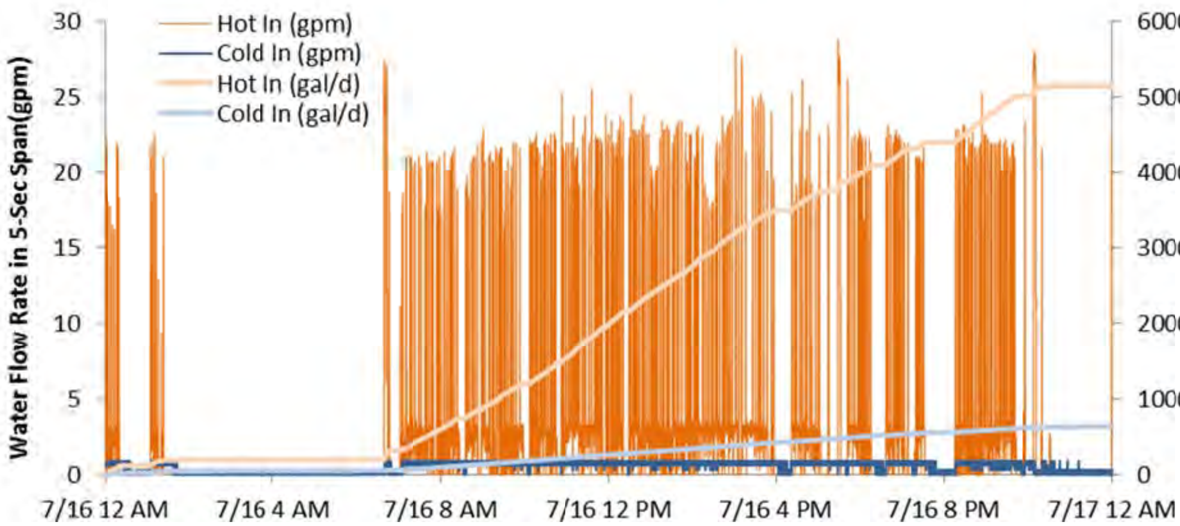

Figure 65. Epic Cafe July 16th water flow rates and average daily water use graph

The maximum daily water use profile occurred on June 26th and is shown in Figure 66. On this day 13,253 gallons of water were used with only a small portion at 538 gallons used for cold water tempering. There were three tank fill events. The average daily and maximum water use profiles look very different in the hot water use flow profile. It appears that a drain is left partially or fully open possibly due to food debris. For the entire day, whenever the dishwasher is in operation, the rinse and tank top off operations are occurring simultaneously at approximately 18 gpm. The sections on the plot where there are hallow white portions illustrate continuous water flow periods. This adds up to around 6,500 gallons of water waste between the average and maximum water use day. It appears from the data set that this drain malfunction was occurring from the beginning of the monitoring period on May 5th until June 26th before it was fixed after FSTC brought it to their attention. Due to the gap in monitoring, only 8 days of flow data with the drain malfunction were captured and included in the average daily use analysis.

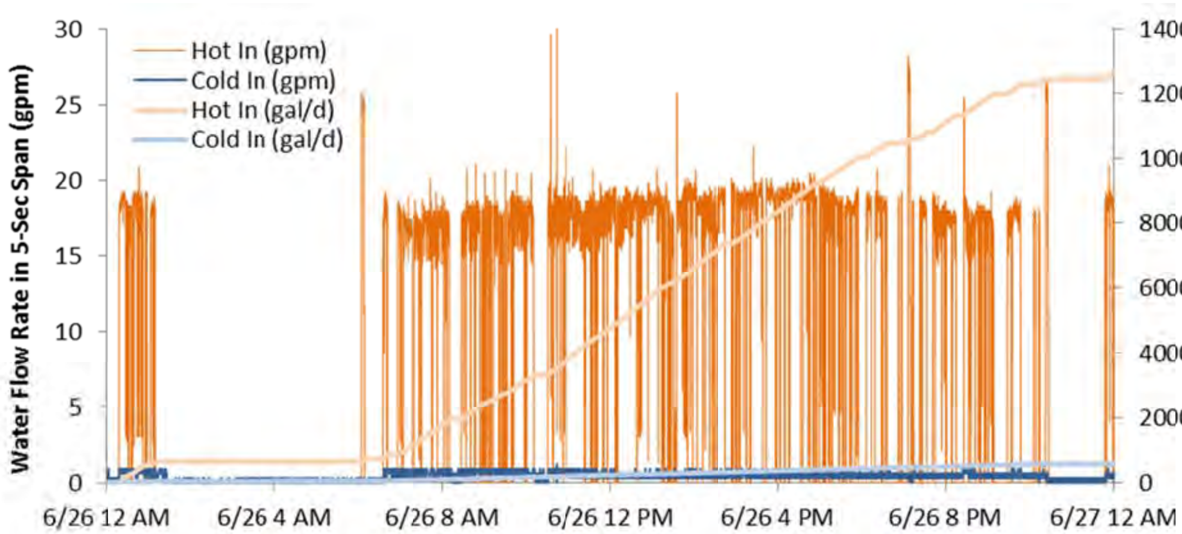

Figure 66. Epic Cafe June 26th water flow rates and maximum daily water use graph

Results

The monitored data for the original dishwasher was analyzed to deliver the following results in the first column in Table 6. On an average day, there were 327 gallons used for tank fills, 3,415 gallons used for tank top offs, 1,296 gallons used for rinsing, and 618 gallons of cold water used for tempering the wastewater. The tank and maintenance fills accounted for a majority of the water used on a typical day. There was 3.2 tank fills per day with an average fill of 100 gallons. The total water use for this machine was 5,656 gal/d.


Figure 67: Rinse pressure at 30 psi during operation

The rinse flow rate measured at 3.2 gpm is twice that of the specified 1.6 gpm flow rate. One of the culprits leading to the higher rinse flow rate was the rinse pressure observed during operation at 30 psi in Figure 67. For water heater sizing purposes, the peak flow rate was measured at 36.6 gpm and the maximum hourly hot water demand was 987 gph, which is high driven by routine periods were there was hot water waste. The dishwasher water use per hour of rinse operation at 823 gph was also elevated.

Table 6. Facebook original and replacement dishwasher data summary

	Original Stero	*Replacement Hobart*	*Savings*
Daily Energy Use and Booster Efficiency			
Hot Water (gal/d)	5,038	1,130	
Cold Water (gal/d)	618	727	
Rinse Use (gal/d)	1,296	548	748
Tank Fill and Top Off (gal/d)	3,742	1,077	2,665
Tank Fills (gal/d)	327	424	
Top Off (gal/d)	3,415	653	
Number of Fills	3.2	3.4	
Gallons Per Fill	100	126	
Total Water Use (gal/d)	5,656	1,857	3,799
Average Flow Rates			
Hot Water (gpm)	12.2	10.6	
Cold Water (gpm)	0.9	5.2	
Rinse Flow Rate (gpm)	3.2	1.2	2.0
Peak Flow Rate (gpm)	36.6	16.8	19.8
Maximum Hourly Hot Water Demand (gph)	987	234	753
Water Use Per Hour of Rinse Operation (gph)	823	232	592
Water Temperatures			
Estimated Boiler Outlet (°F)	145	145	
Hot During Flow (°F)	134	137	
Cold During Flow (°F)	68	70	
Booster Inlet During Flow (°F)		127	
Rinse During Flow (°F)	172	181	
Power Rinse Tank (°F)		174	

Rinse Tank (°F)		169	
Wash Tank (°F)		164	
Scrapper Tank (°F)		144	
Drain (°F)	115	119	
Flow Time and Hours of Use			
Hot Flow Time (h)	7.1	1.8	
Cold Flow Time (h)	11.6	2.3	
Rinse Flow Time (h)	6.9	7.0	
Dishwasher Operating Time (h)	8.6	11.0	
Dishwasher Operating Span (h)	16.3	14.3	
Energy Use, Booster Efficiency and Peak Demand			
Total Gas Use (therms/d)	48.0	10.0	38.0
Dishwasher Energy (kWh/d)	398	875.5[1]	
Booster Energy (kWh/d)	256	55.5	
Total Electricity Use (kWh/d)	654	931	-262.9
Electric Booster Efficiency	61%	123%[2]	
Probable Contribution to Peak Demand (kW)	41.1	64.9	-23.8
Total Energy Use (Btu/d)	7,031,270	4,176,572	2,854,698
Dishwasher Energy Use Per Hour of Rinse (Btu/h)	1,023,582	595,852	427,731
Facility Parameters			
Water Use Per 1000 Square Feet (gal/1000ft^2)	196	64	
Water Use Per Seat (gal/seat)	6.2	2.1	
Water Use Per Meal (gal/meal)	0.6	0.2	
Energy Use Per 1000 Square Feet (Btu/1000ft^2)	244,130	145,015	
Energy Use Per Seat (Btu/seat)	7,769	4,615	
Energy Use Per Meal (Btu/meal)	703	418	
Annual Operating Costs			
Water and Sewer Cost[3]	$24,586	$7,930	$16,656
Gas Cost[4]	$17,515	$3,650	$13,865
Electricity Cost[5]	$40,601	$57,769	-$17,167
Demand Charge[6]	$6,882	$11,097	-$4,215
Total Annual Cost	$89,585	$80,445	$9,140

[1]Replacement dishwasher has optional blower dryers installed, [2]With free energy contribution of heat exchanger,
[3]$10/HCF (Weighted mean of restaurant water and sewer costs for 8 largest California cities),
[4]$1/therm (PG&E 2015 small commercial gas rates), [5]$0.17/kWh (PG&E 2015 Avg. A-10 & E-19 commercial electricity rates),
[6]$19/kW (PG&E 2015 Avg. A-10 & E-19 commercial electricity rates)

Figure 68: Tempering controls set at 87°F

The cold water is used for tempering at a low flow rate and water continues to flow until the drain water temperature drop down to the 87°F setpoint on the tempering controls (Figure 68). Due to the capped 1 gpm flow rates for cold water tempering, the drain temperature spikes during tank dump operation or situations where the drain is left open accidently during operation.

There is a large rinse demand on the dishwasher based on a rinse time of 6.9 hours. The dishwasher operating time of 8.6 hours is not too far from the rinse flow time thus the takeaway is that the machine has very little idle time throughout the use period. The operating span is 16.3 hours to cover the three meal periods and cleanup wares from this cafe and many offsite kitchens on campus.

The plot in Figure 69 shows five weeks of dishwasher operation. The rinse time and total water use were plotted on the two vertical axes. The rinse flow time and total daily water use was pretty moderate from Monday's to Thursday's, but it appears that Fridays are notably slow days. There was a large fall off in use and operating hours on the weekends where the dishwasher was probably cleaned and miscellaneous wares where washed through the machine. Overall the rinse time closely tracks the total water use, which signifies that there were no outlier practices that significantly contributed to water waste.

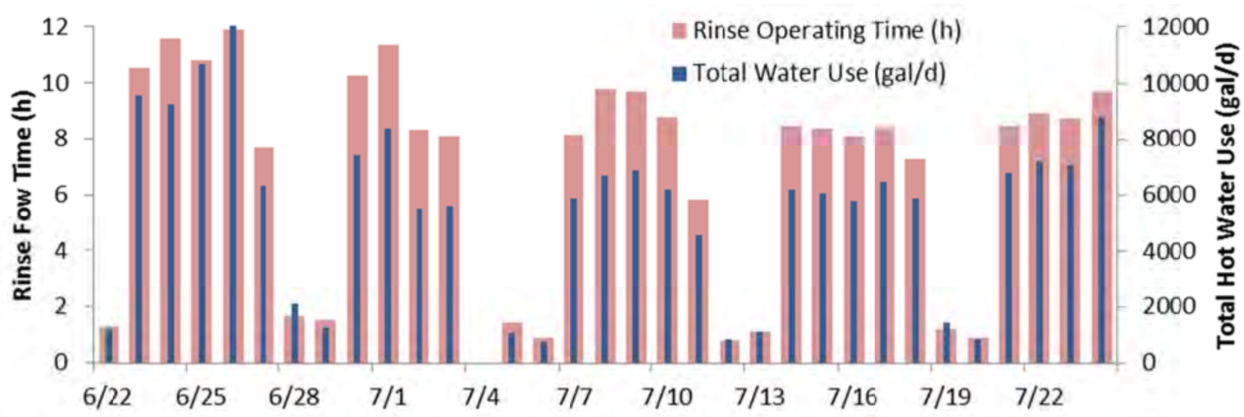

Figure 69. Epic Café plot of daily rinse flow time and total hot water use of original dishwasher

This dishwasher uses a large amount of natural gas and electricity to operate the machine. The average daily gas use at the boiler is estimated at 48 therms to deliver hot water to the dishwasher at an average temperature of 134°F. This is lower but expected since there is no insulation on the piping leading to the dishwasher. This puts an additional load on the booster heater to try to heat twice the volume of water and achieve an additional 5°F rinse to reach a minimum sanitation temperature of 180°F. The booster heater used 256 kWh/d to heat the rinse water to an average temperature of 172°F. The dishwasher uses an additional 398 kWh for a total of 654 kWh/d.

The electric booster heater operating efficiency of 61% is lower than normal but this value accounts for all the idle heat losses from the un-insulated pipes leading to and from the booster. On the weekends, the heat losses from the booster sitting at idle drive the operating efficiency down to a range of 15% to 50%. During the work week the operating efficiency ranges from 45% to 75%. The probable contribution to peak demand for this dishwasher was estimated at 41.1 kW. The total energy use of the dishwasher was calculated at 7,031,270 Btu/d. The dishwasher energy use per hour of rinse operation was 770,499 Btu/h.

Lessons Learned

These large flight machines are commonly found not holding rinse specifications and their overall water use in this case is greatly increased by the lack of maintenance by a trained internal or external technician. From elevated rinse pressure, drains left open or clogged in the open position, broken rinse fingers (Figure 70) and to missing strip curtains (Figure 71), there is a considerable amount of maintenance issues that cause the dishwasher to perform poorly. A continuous maintenance program and employee training program needs to be in place to operate these large machines to close to specifications.

Figure 70: Broken rinse sensor fingers

There were some positives to this monitoring project. This was the first large conveyor that was correctly sized for the operation. They also utilized plenty of operating staff working in coordination to run this large dishwasher productively. Their passive tray drop off window and manual hand scrapping of food waste combined with a row of three high efficiency pre-rinse sprayers were an efficient and reliable pre-rinse combination. It shows that minimizing hardware for the pre-rinse (Figure 72), even a high foot-traffic dishroom is efficient and reliable versus the automated pre-rinse system at the much lower throughput Wilbur dishroom. The Facebook dishroom did have a trough based scrapper system that we did not see being utilized.

Figure 71: Missing strip curtains

Figure 72: Dining tray drop off window

Facebook Epic Café (Replacement Dishwasher)

Site Overview

In Spring of 2015, Facebook went ahead and replaced the dishwasher with a high efficiency model with integrated heat recovery. The Hobart FT1000 ER was installed and monitoring commenced on May 4th 2015. The unit has an electric internal booster heater and tank heaters. The rated rinse water use is 58 gph or 1 gpm (Figure 73).

Figure 73: Replacement Hobart dishwasher

The water and electrical connections with these advanced dishwashers with heat recovery are extensive. The features and benefits of the new unit include the steam removal system, insulated doors and door seal system, an automatic soil removal system, auto clean and descaling functions, vent fan control, energy saver mode, pumped rinse system, and integrated booster heater.

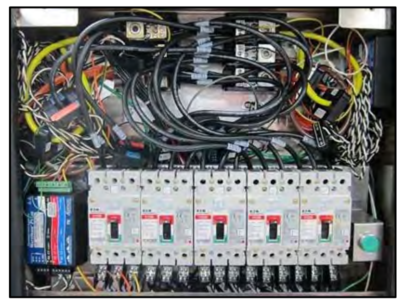

Figure 74: Power meter instrumentation installed in subpanel

Measurement Points

The same monitoring setup was used for both the original and replacement dishwasher. Electricity use to the unit was measured at three points using the power meter instrumentation shown in Figure 74. This included the two, 480V 3-phase connections to the machine that operate the dishwasher heaters, controls and motors and an additional meter for monitoring the booster heater separately. Two ultrasonic meters where used to measure the hot and cold water entering the dishwasher. Temperature was measured on the incoming cold and hot water line, to the inlet and outlet of the booster heater and at the drain. Tank temperatures were measured at the powered rinse, wash, and scrapper tanks (Figure 75).

Figure 75: Temperature sensor affixed to tank

Monitoring Period

Data logging started on May 4th, 2015 and continued until June 21st. Data was gathered for a total of 49 days, but because there was a continuous 0.5 gpm water leak discovered during the initial monitoring, only the remaining 20 leak free days were used in the data analysis. The leak was fixed after FSTC staff communicated the issue

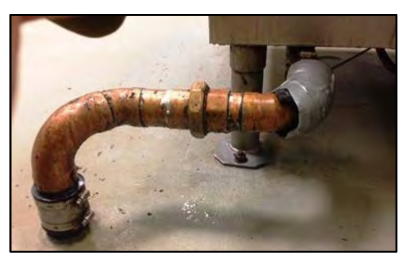

Figure 76: Copper drain pipe

with management. With this facility, since the drain line is closed (Figure 76), there was no way to see visually if there was a leak or major malfunction that is causing water to be wasted down the drain. The monitoring data daily summaries are shown in Appendix H.

Challenges

This was the most complex dishwasher we had monitored to date and it took a long time to install and commission our instrumentation and analyze the data. It was more difficult to separate out the electricity used by the individual major components inside the machine through data analysis than initially thought. We were able to measure total use and separate out the booster heater use, but it is unclear what amount of energy was used on the blower dryer heater, which is an optional feature on this model. Interestingly, the dishroom staff members were unhappy with the blower dryer operation as it didn't do a good job of drying wares, and mostly just added extra heat to the space. The staff still had to manually dry the appearance-critical wares for the most part.

Daily Water Use Profiles

The total water use on June 12th, 2015 was 1,965 gallons, shown in Figure 77. This water use profile is representative of the average total water use for the machine was 1,857 gal/d. Looking closely at the plot, there were five tank fills with an approximate flow rate of 14 gpm that totaled 424 gallons in the day. The rest of the flows in dark orange are tank top offs at an average flow rate of 8.5 gpm. Looking at the cold water flow rate plot, the flow rates at around 4 gpm are associated with the rinse operation. Flow rates at 8 gpm are associated with the water tempering function that is activated during when the tank is drained.

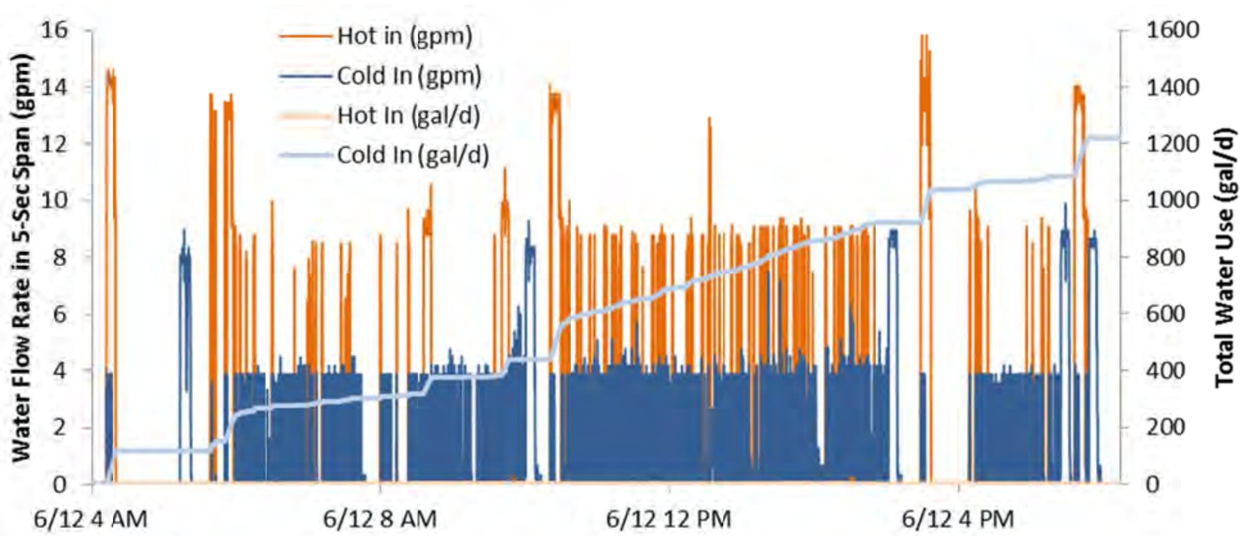

Figure 77. Epic Cafe July 16th water flow rates and average daily water use graph

Advanced flight dishwashers have a unique rinse water use profile compared to conventional machines. The tank dump and fill operations were similar. Looking at Figure 78, the tanks continue to drain at 10:30 to 10:37 AM, at which time cold water use at an elevated flow rate of 8 gpm is tempering the outgoing wastewater. At 10:50, the tank fill cycle begins which involves using mostly hot water for a 10 minute period at flow rates approaching 14 gpm. At approximately 11 AM, the rinse cycle is activated and the cold water fills the tank in short bursts at approximately 4 gpm and continues this process approximately every 70 seconds to keep the rinse cycle going. This flight dishwasher does not use continuously flowing water at a standard 20 psi for the rinse operation. Instead it fills a small tank with cold water and when rinse water is requested, it uses a water pump that regulates the flow of water to send the cold water through the heat exchanger to be preheated and into the booster prior to passing through the rinse arms. The remaining bursts of hot water at below 9 gpm are maintenance fills of the tanks during wash and rinse operations. From the Booster In temperature profile, at the beginning of the rinse operation, the heat exchanger starts to heat up thus transferring more heat into the incoming cold water line from 90°F water at 11 AM to 130°F water 13 minutes later.

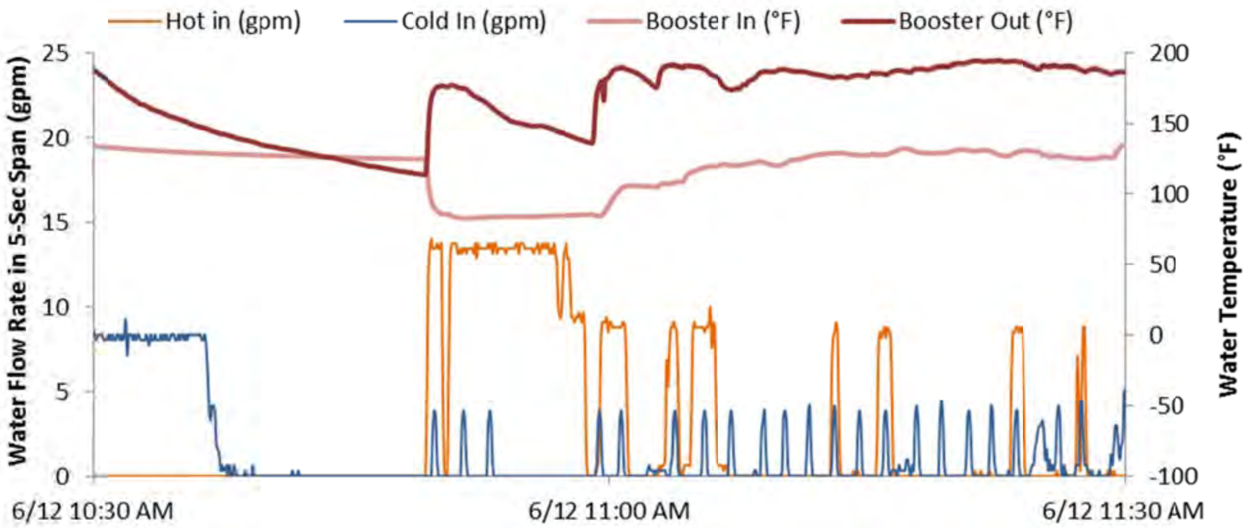

Figure 78. Epic Cafe June 26th close up of water flow rates and temperatures for the wash and rinse cycles

Results

The monitored data for the replacement dishwasher was analyzed to deliver the following results in the second column in Table 6. On an average day, there were 424 gallons used for tank fills, 653 gallons used for tank top offs, and 548 gallons used for rinsing and 232 gallons of cold water used for tempering the wastewater. The tank and maintenance fills accounted for a majority of the water used on an average day. There was 3.4 tank fill per day with an average fill of 126 gallons which corresponds with the 130 gallon capacity of the tanks. The total water use for this heavily utilized machine was 1,857 gal/d.

The rinse flow rate was normalized over the entire rinse flow time to be a fair comparison with conventional flight dishwashers yielding a constant flow rate equivalency of 1.2 gpm which is close to the original specifications of 1.0 gpm. For water heater sizing purposes, the peak flow rate was measured at 16.8 gpm and the maximum hourly hot water demand was 234 gph, which is reasonable. The dishwasher water use per hour of rinse operation at 232 gph was elevated.

The key cold water flow time parameters are a tempering time of a half hour and rinse time of 1.8 hours, which when normalized for continuous sanitizing rinse time equates to 7 hours. The dishwasher operating time is 11.0 hours which is significantly higher than the rinse flow time. This is mainly due to the fact that this dishwasher has blower dryers installed that continue to operate even if the conveyor belt has stopped. The operating span for this dishwasher is 14.3 hours to cover the three meal periods and cleanup.

The plot in Figure 79 shows three weeks of dishwasher operation after the drain malfunction was fixed on June 1st. The rinse flow time and total daily water use were pretty moderate from Monday's to Thursday's, but it appears that Fridays are notably slow days. There was a large fall off in use and operating hours on the weekends where the dishwasher was probably cleaned and miscellaneous wares where washed through the machine. Overall the rinse time closely tracks the total water use, which signifies that there were no outlier practices that significantly contributed to water waste except for June 19th when the drain was left open at 6:30 pm which consumed 1231 gallons of water.

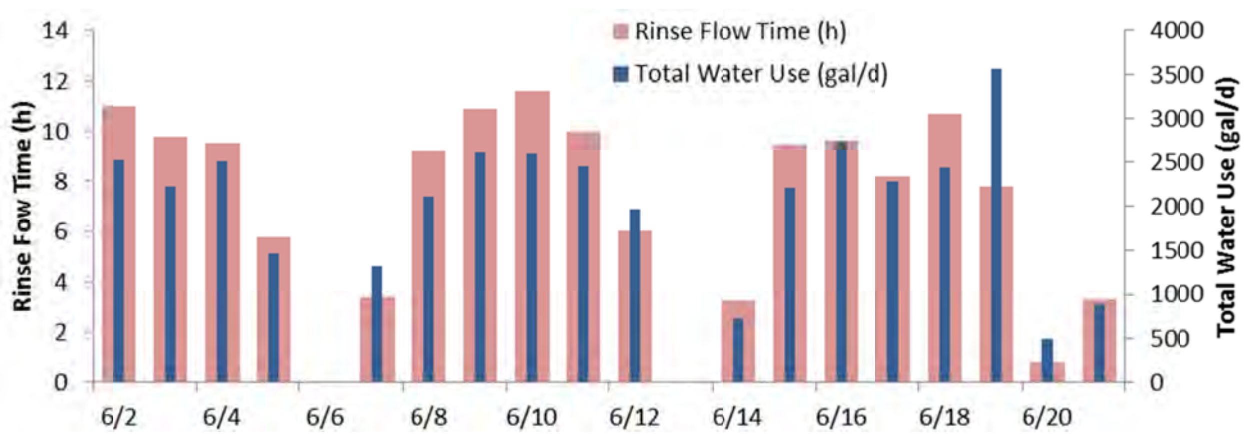

Figure 79. Epic Café plot of daily rinse flow time and total hot water use of replacement dishwasher

This facilities boiler uses an estimated 10 therms/d to supply the dishwasher with 137°F water, which is a huge savings over the original dishwasher since hot water is used for tank filling operations only. The hot and cold water are mixed and arrive at the booster heater at a temperature of 127°F after being preheated in the heat exchanger. The large reduction in rinse flow rate combined with the heat recovery device minimize the electricity use at the integrated booster heater to 55.5 kWh/d to heat the rinse water to 181°F. The dishwasher electricity use is higher than anticipated at 875.5 kWh/d. This includes the electricity used to operate then tank water heaters, air heaters, blower dryer fans, water pumps, and remaining functions. The average tank temperatures were normal ranging from 174°F at the dual rinse tank and reduced down to 144°F in the scrapper tank. The cold water tempered the drain temperature to 119°F.

To calculate the efficiency of the booster heater, the contribution of the free heat from the heat recovery device is included. This effectively increases the efficiency to 123% since heat output of the heat recovery device and booster heater combination is larger than the heat input of the booster heater. The probable contribution to peak demand for this dishwasher is higher at 64.9 kW due to the added functions of this machine including the blower dryer and soil removal system. The total energy use of the dishwasher was calculated at 4,176,572 Btu/d. The dishwasher energy use per hour of rinse operation was 595,852 Btu/h.

Lessons Learned

This dishwasher is amongst the most advanced commercial dishwashers on the market which significantly reduced the hot water load requirements of the facilities water heater. Thus if this machine was installed in a new facility, the centralized hot water system could be simplified and sized down. Unfortunately, with all the advancements, some of the optional features on this dishwasher that use additional energy don't perform as well as anticipated for this dishroom.

Considerable number of break downs occurred where servicing was required in the first six months of operating this machine. Due to the high tech sensors installed on this machine, it easily got fouled up when staff ran prohibited or unconventional wares like kitchen exhaust ventilation grease filters through the unit. This unit has an automatic soil removal system installed on the front end to theoretically act as a manual pre-rinse of the wares to remove food debris before the wares enter the scrapper tank. Staff mentioned that this dishwasher was very sensitive to food debris. Previously with the Stero dishwasher, they would not manually rinse the salad bowls, but with the new unit they do now and the residual lettuce causes problems with the operation of the dishwasher (Figure 80). Anecdotally, a dishroom staff member mentioned that the new unit requires 30% more manual pre-rinse work.

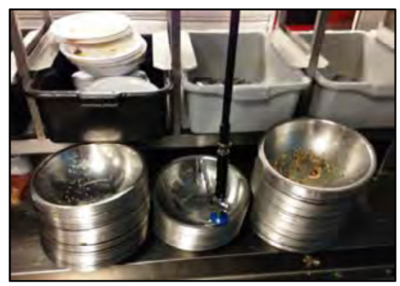

Figure 80: Stacked salad bowls

Figure 81: Kitchen prep wares

This was our first opportunity to see the performance of blower dryers installed on flight dishwashers. In this facility, the dishroom staff member commented that 70% of the wares are back of the house preparation wares (examples are shown in Figure 81) and only 30% are front of the house plates, cups and utensils. The blower dryer have a lot of trouble drying non metal or ceramic wares. The water can be visually seen on these salad bar trays in Figure 82. The bigger observation we made was that the blower dryer fan seldom turns off and it takes a minimum 30 seconds for the blower dryer heater to turn off when the conveyor is not running. Thus for an operation such as this, the blower dryer fan and heater are on practically continuously using a significant amount of energy in the process with marginal labor savings.

Figure 82: Wet wares exiting the blower dryer

Claremont Hotel

Site Overview

The Claremont Hotel, Club and Spa began operation 100 years ago in 1915. One of the early postcards of the hotel is shown in Figure 83. This hotel operates three restaurants, the Bayview Café, The Paragon Restaurant and Bar, and Meritage at the Claremont. The main kitchen and dishroom serve a variety of functions including service for the Meritage at the Claremont, in-room meals and banquet functions. The Meritage serves an American-themed menu (Figure 84) and is open for the breakfast and dinner meal periods except for Sunday when they are open for breakfast and brunch meal periods.

Figure 83: Claremont Hotel Post Card

Photo Credit: Alamedainfo.com

Figure 84: Meritage at the Claremont

Photo Credit: MeritageClaremont.com

The nameplate was missing on this dishwasher, but it is estimated that the unit is 20 years old and is one of the older Stero STPCW series machines that is rated at 336 gallons of rinse water use per hour. The unit uses steam heat for all its water heating functions (Figure 85). Information such as the number of seats or square footage was not gathered for this facility because it was unclear which portion of the wares was being cleaned for the restaurant or another hotel function.

The initial observations during the dishroom site audit were that this dishwasher was underutilized (i.e. not heavily loaded with wares and not used for long durations), not in the best of shape and ready for replacement. This facility utilized a water temperature tempering to introduce cold water to maintain the scrapper tank and drain temperatures at 120°F and 110°F respectively. The steam boiler and distribution system was old and leaking and was mainly operating to produce steam to run the dishwasher. The hotel reached out to the FSTC with interest in making a business case for replacing the entire steam heating system for the kitchen including the end-use equipment such as the dishwasher, steam cooker, proofer and steam tables.

Figure 85: Steam Heated Flight Dishwasher

Measurement Points

The gas used at the steam boiler was not measured, but it was estimated based on the water volume and temperature of the hot water used for the rinse and fill functions. The gas use for the steam injected into the tanks for maintaining water temperatures was also estimated. The electricity use of the water pump motors, conveyor belt and controls was measured at the dishwasher. Two ultrasonic meters where used to measure the rinse and fill water entering the dishwasher (Figure 86). The cold water flow rate was spot metered prior to removing the instrumentation. The fixed cold fill flow rate and fill flow time was used to calculate the daily water use. The cold tempering flow time was estimated based on a change in temperature from ambient to cold water supply temperature at the cold water fill spout.

Figure 86: Instrumentation box and ultrasonic water meter transducers

The monitoring box, coil of orange temperature sensors wires and transducers for measuring water use are shown in Figure 87. Temperature was measured on the hot fill, rinse, cold tempering, and drain water lines. Also tank water temperatures where measured at the powered rinse and wash tanks.

Figure 87: Instrumentation box and ultrasonic water meter transducers

Monitoring Period

Monitoring started on September 16th, 2014 and continued until February 11th, 2015. Data was collected for a total of 133 days with gaps between several dates in October where data was lost due to disruptions in supply power to the instrumentation box. Summary data for each work day are shown in Appendix I.

Challenges

There were numerous monitoring challenges with this site due to the age of the machine and its steam-based heating system. Many components on the dishwasher were not working properly including the automatic tank fill operation, steam leakage into one or two wash tanks (which elevated the tank temperatures) and the heat exchanger to maintain fill and rinse temperatures was not keeping up. Also, the blower dryer was no longer operational. It took a while to familiarize with the unique operations of this dishwasher and unlock all of the problems to help with making adjustments to our monitoring plan and latter analysis of results.

Daily Water Use Profiles

On an average day, the flight conveyor used 6,018 gal/d. The water use profile on December 2nd, 2014 shown in Figure 88 is representative of the average water use day profile with a total water use of 5,983 gallons. Looking closely at the plot, there was four tank fills at flow rates around 21 gpm totaling 154 gallons, 397 gallons, 1,803 gallons, and 387 gallons, respectively. Only the morning tank fill operation was close to the manufacturer's specifications for total volume of 130 gallons. Water waste due to the manual filling practice accounted for 2,254 gallons. The rest of the flows shown in dark orange below 20 gpm are tank top offs (192 gallons) and misc. low flow fills (19 gallons). When the rinse is activated, it is differentiated by the shaded sections in dark red totaling 1,437 gallons at 9 gpm. The scrapper tank is filled with cold water to mix with the hot water that cascades into the tank to temper it. Cold water shown in light blue flows in unison with the rinse flow periods at close to 14 gpm for a total of 1,743 gallons. The facility only serves breakfast on Mondays thus the Tuesday dishwashing shift doesn't get going until 9 AM. For the rest of the day, the dishwasher is used sparingly until the dinner meal period when there is two large rinse periods from 5:30 to 9 PM before tapering off until midnight.

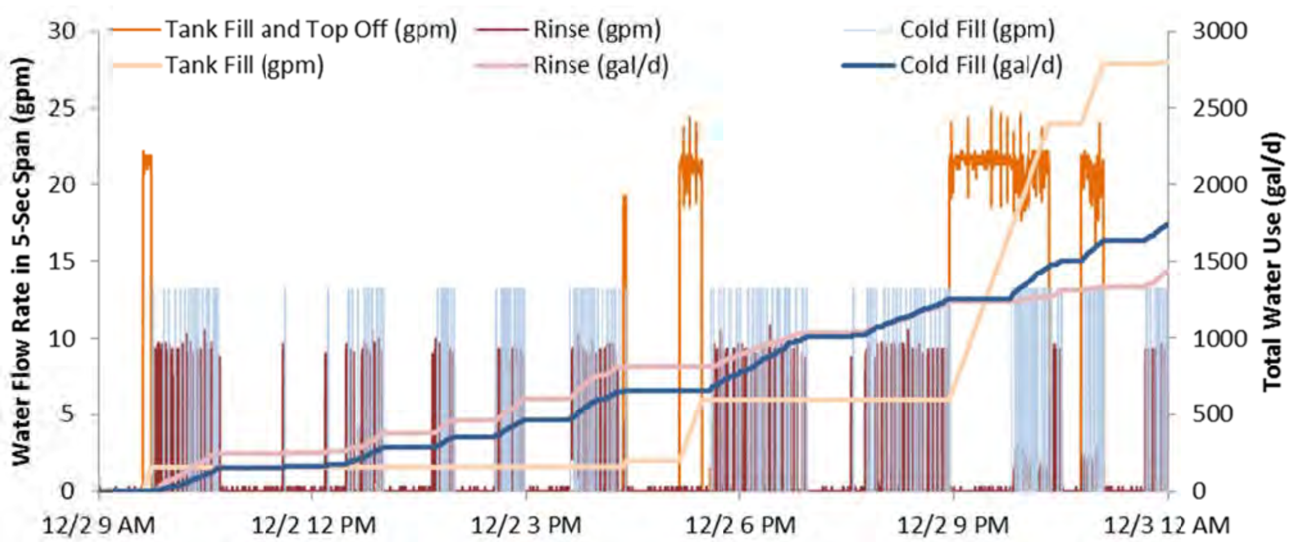

Figure 88. Claremont average water flow profile

The third largest daily water use day occurred on December 8th and the profile is shown in Figure 89. The dishwasher consumed 10,618 gallons of water with 2,482 gallons used for the rinse operation, 548 gallons for productive tank fills, 619 gallons for tank top offs and 4,916 gallons wasted throughout the day during the manual tank overfilling operation. The largest water waste period occurs at around 9 PM when the manual fill operation is deployed for a 4 hour period totaling 4,740 gallons down the drain.

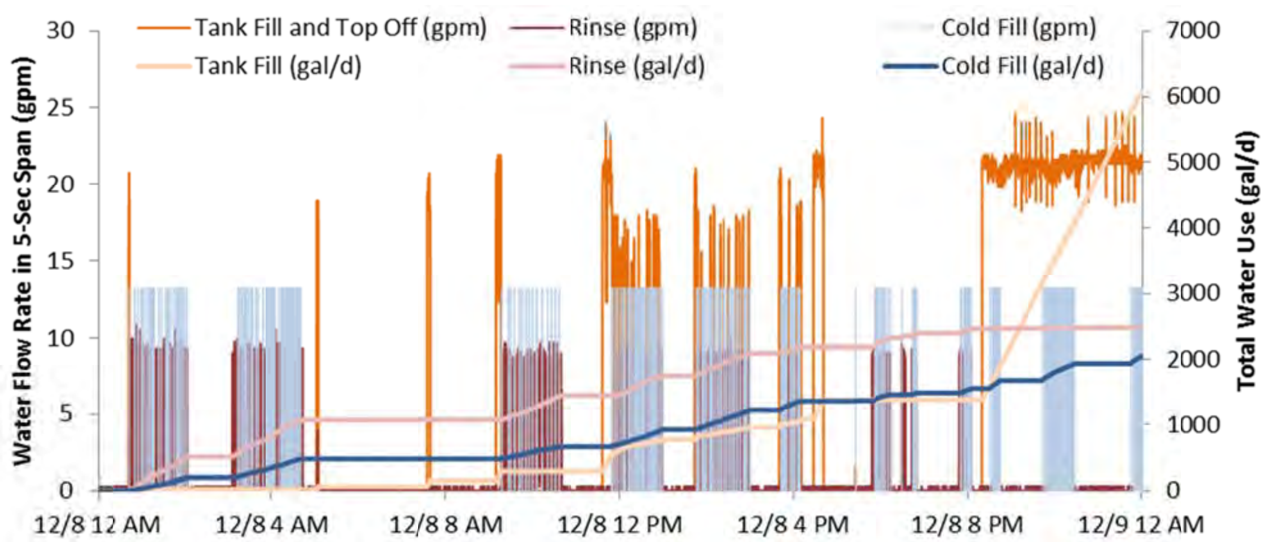

Figure 89. Claremont low water flow profile

The water flow profile on October 31st is an example of a day where tank fill water is not wasted in all four tank fill operations shown in Figure 90. On this day 4,065 gallons are used with 1,602 gallons used for the rinse operation, 548 gallons used for tank fills, 190 gallons for tank top offs, 1,715 gallons used for tempering. This clearly illustrates that precise operations can override maintenance issues if staff are trained at a high level, but it is very difficult to do consistently day after day. It is best to stay on top of the maintenance as much as possible to leave to leave very little room for operators to have a need to use manual override functions.

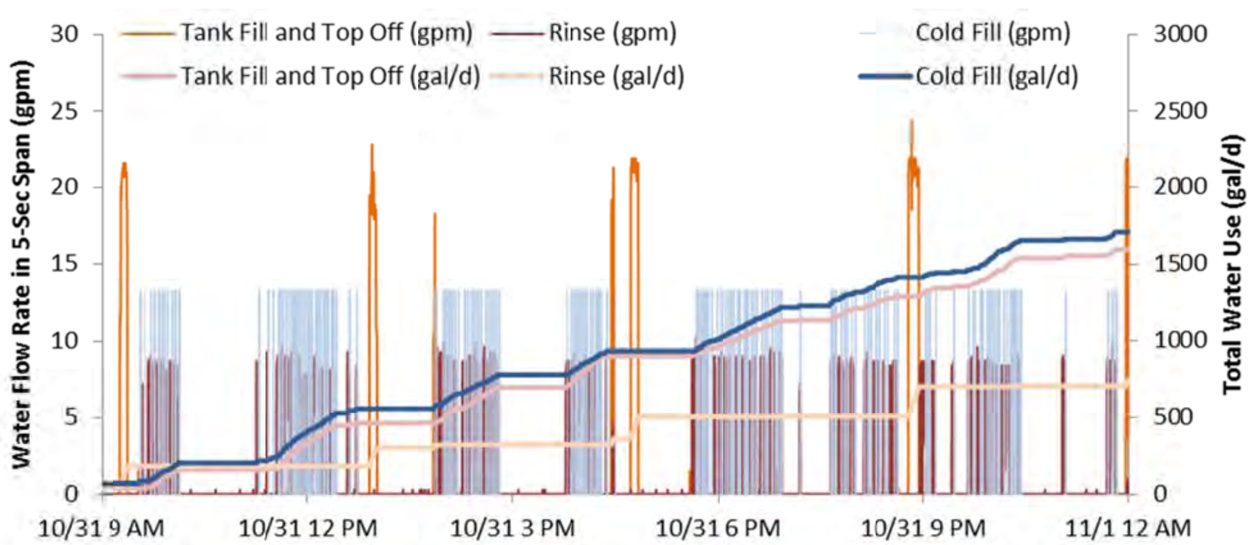

Figure 90. Claremont low water flow profile

Results

The monitored data was analyzed to deliver the following results in Table 7.

Table 7. Claremont data summary

	Original Stero
Daily Energy Use and Booster Efficiency	
Hot Water (gal/d)	4,389
Cold Water (gal/d)	1,629
Rinse Use (gal/d)	1,761
Tank Fill and Top Off (gal/d)	2,628
Tank Fills (gal/d)	2,314
Top Off (gal/d)	314
Number of Fills	4.9
Gallons Per Fill	477
Water Waste (gal/d)	1,608
Total Water Use (gal/d)	6,018
Average Flow Rates	
Hot Water (gpm)	20.8
Cold Water (gpm)	13.3
Rinse Flow Rate (gpm)	8.6
Peak Flow Rate (gpm)	23.9
Maximum Hourly Hot Water Demand (gph)	1,307
Water Use Per Hour of Rinse Operation (gph)	1,770
Water Temperatures	
Estimated Boiler Outlet (°F)	212
Rinse During Flow (°F)	156
Fill During Flow (°F)	127
Rinse Tank (°F)	135
Wash Tank (°F)	133
Drain (°F)	113
Flow Time and Hours of Use	
Rinse Flow Time (h)	3.4
Dishwasher Operating Time (h)	7.7
Dishwasher Operating Span (h)	15.5
Energy Use, Booster Efficiency and Peak Demand	
Total Gas Use (therms/d)	92.4
Dishwasher Energy (kWh/d)	33
Probable Contribution to Peak Demand (kW)	2.2
Total Energy Use (Btu/d)	9,343,961
Dishwasher Energy Use Per Hour of Rinse (Btu/h)	2,748,224

On an average day, there were 6,018 gallons of water used by this flight dishwasher. Cold water used for scrapper tank tempering accounts for 1,629 gallons. Hot water use totaled 4,389 gallons, with the majority at 2,628 gallons used for tank filling and top off operations, whereas 1,761 gallons are used for the sanitizing rinse operation. The major reason why tank filling operations surpassed the rinse operation is because the manual auto-fill operation by staff was causing 1,608 gallons of water waste per day. Only 706 gallons of tank fill water was used for effective tank fills. A portion of the dataset was analyzed on a daily basis to compare water waste versus useful tank fills in Figure 91. There are significant fluctuations from day to day as different dishroom staff members have different manual techniques that they use for the tank fill operation. The daily water waste over this period fluctuated from 0 to 4,916 gallons per day. In summary, the dishwasher averaged 4.9 tank fill and dump operations per day with an average fill of 477 gallons which is 3.5 times more than the equipment specifications.

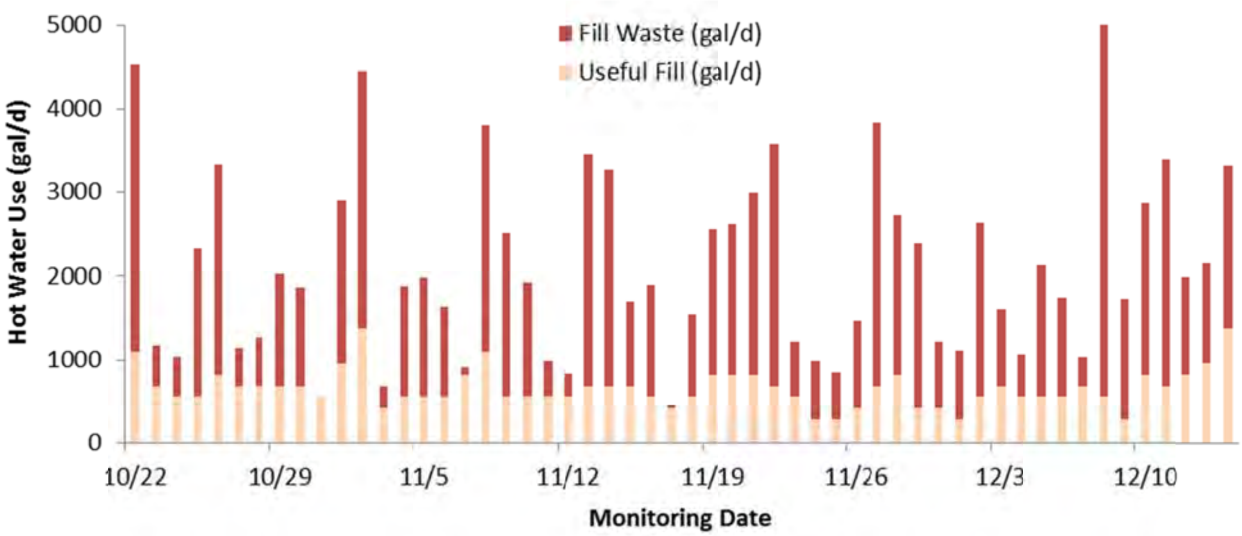

Figure 91. Useful Fill Versus Fill Waste

The rinse water use is 8.6 gpm which is 1.5 times over the manufacturer’s specifications at 5.6 gpm. For water heater sizing purposes, the peak hot water flow rate was measured at 23.9 gpm and the maximum hourly hot water demand was 1,307 gph, which is high, driven by wasteful tank fills. The dishwasher water use per hour of rinse operation at 1,770 gph was the highest documented for a flight machine.

Collectively, the water temperatures listed for the sanitizing rinse and tank fill operations, and wash and rinse tanks are approximately 25°F below normal operating range. This is a major performance problem stemming from the old steam to hot water heat exchanger. The heat exchanger due to its age and the elevated tank fill and rinse flow rates cannot keep up to maintain sanitizing rinse temperatures at 180°F or above, or typical tank fill temperatures at 140°F -150°F on a short term basis. The rinse water temperature quickly drops from 175°F to 153°F on the rinse line at the start of operation at 12:45 AM on Figure 92. The tank fill flow line maintains a tank fill temperature below 130°F where 150°F hot water temperature is required (NSF 2004).

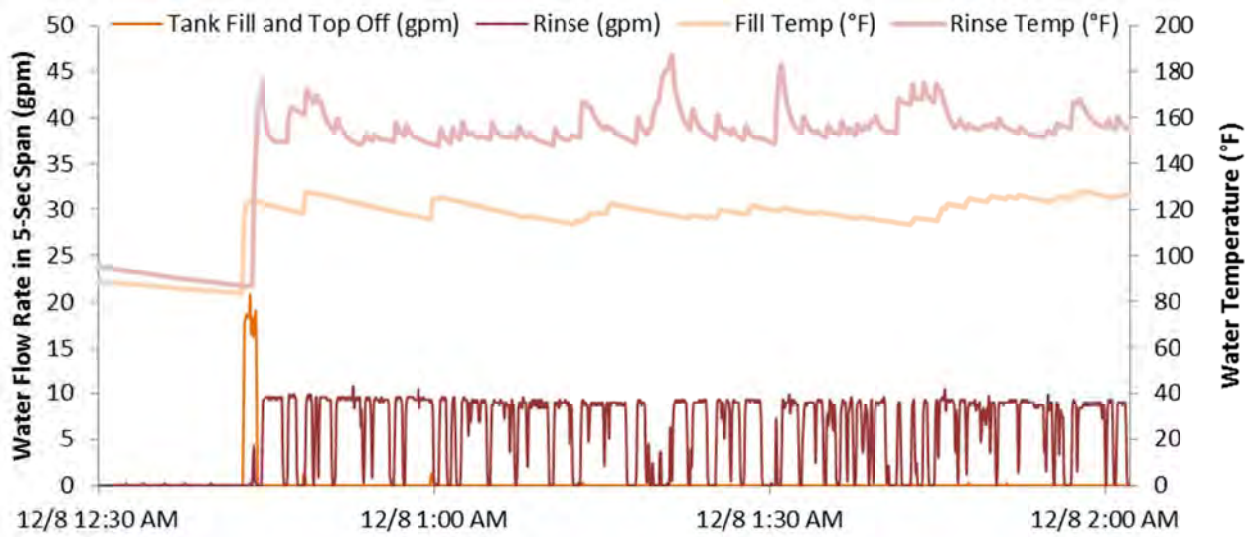

Figure 92. Claremont rinse and fill temperature comparison

Some flow times exceeded expectations, including 1.8 hours of tank fill time and 2 hours of cold fill time versus the surprising low rinse time of 3.4 hours per day. The ratio between rinse time to dishwasher operating time of 7.7 hours to operating span of 15.5 hours per day is 1:2:4, which is representative of a low throughput dishroom. At 3.4 hours of rinse time, this very large dishwasher is underutilized. This dishwasher required more tank fill operations (1.5 fills per hour of rinse) than other machines monitored due to fouling of the wash and rinse water.

The plot in Figure 93 shows six weeks of dishwasher operation. The rinse flow time and total daily water use do not track each other and both fluctuate considerably from day to day depending on hotel functions. What was consistent on most days was significant water waste which is illustrated by all the days where the total water use bar extends past the rinse flow time bar. The few days where water waste was minimal where on November 7th, 12th and 17th when the bars where graphically to the same level.

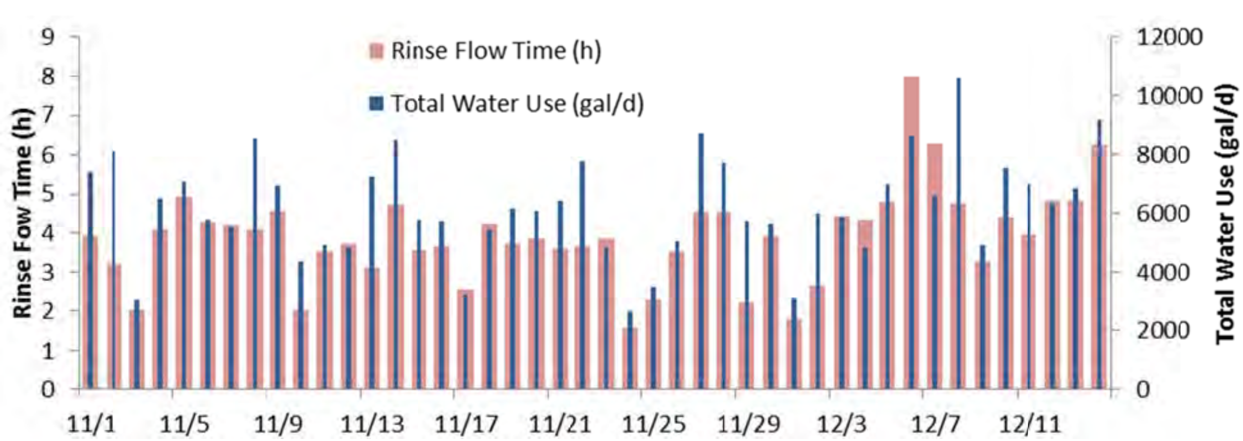

Figure 93. Claremont plot of daily rinse flow time and total hot water use of original dishwasher

The facility was not interested in sizing down from a flight conveyor to a large rack conveyor as they were focused on maintaining a large dishwashing capability for special events. After 133 days of monitoring, there were only three days where the rinse flow time exceeded 6 hours per day and the maximum daily rinse time of 8.0 hours occurred on Saturday December 6th.

This dishwasher uses a large amount of natural gas to operate the machine. The gas use at the steam and hot water boilers are estimated at 92.4 therms per day with approximately half the gas used to maintain tank temperatures. The other 46 therms are split in half between gas used for the fill operation and gas used for the rinse operation. The dishwasher uses 33 kWh per day with a probable contribution to peak demand of 2.2 kW.

Lessons Learned

This monitoring project was very challenging due to the diversity of measuring points, the age of the equipment and the amount of troubleshooting required to understand how the unit was operating. This dishwasher represents an extreme case when contrasting real world use versus specifications to determine the dishwasher performance. This dishwasher monitoring project in particular helped in our understanding of dishwasher productivity and how to quantify it based on rinse water use or rinse operating time. This was a key step to help normalize the data for comparison with other dishwashers. In doing so, this defines all other dishwashing practices such as tank filling, tank top offs or cold water tempering as forms of waste since additional resources are used, but no work is completed.

These large flight machines are commonly found not holding rinse specifications due to a number of factors including the limited capabilities of internal maintenance staff or external technicians to verify usage. In this case, the chemical supply company was contacted to try to fix problems on the dishwasher as some of the problems were leading to excessive chemical cleaner use.

The biggest lesson learned from monitoring this dishwasher was that as maintenance with the machine gets limited, malfunctions become a mainstay, and the operator has to adjust practices to operate the machine sufficiently, which results in wasteful practices. A continuous maintenance program and employee training program needs to be in place to operate these large machines to specifications.

Otherwise it can get costly and use a lot of resources. The best example of this is that the auto tank fill function on the dishwasher was only filling two of the three tanks. The operator would be required to hold the button down for approximately 4 minutes to manually override the system to allow for the third tank to get filled. In doing so, it would cause the other two tanks to overflow sending clean water down the drain. The staff learned to compensate by

Figure 94: Sharpie manual overfill

developing their own version of an autofill so they would not have to be burdened by the manual procedure. They used a Sharpie dry erase marker in Figure 94 to depress the autofill button and parked a drying and storing rack next to it so they can move on to the next task, sometimes forgetting about it. Unfortunately, this "sharpie fill" was on average using 510 gallons of potable water.

Other notable problems with this dishwasher include water leaks, poor cleaning performance and the strip curtains requiring replacement (Figure 95). Missing or short strip curtains may cause the mixing of rinse and wash water or wash and scrapper water contaminating or diluting individual tanks or causing overfills in one tank and water loss in another. The blower dryer was not working, causing the two dishroom staff members to stop or slow operation to dry wares. Holes in the rackless conveyor were causing small wares to fall in (Figure 96). Time was lost in trying to fetch them before they can cause damage to the conveyor. Also, broken pegs were creating spaces where plates couldn't be racked creating rack loading inefficiency.

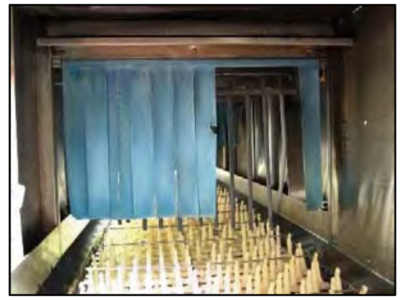

Figure 95: Missing and short strip curtains

Figure 96: Holes in rackless conveyor

There were some positives results derived from this monitoring project. After FSTC provided the staff with the results and a business case for replacement, the hotel retrofit team was able to gain approval for a dishwasher replacement project and steam boiler elimination (Figure 97).

Figure 97: Steam boiler

Summary of Results and Discussion

Conveyor Dishwasher Field Monitoring Dataset

Summary data from the nine dishwashers monitored for this field project (in **bold**) were added to nine other dishwashers monitored by FSTC in the last five years to enhance the dataset of dishwashers to analyze for this report. The 18 sites are listed below with information on the type of facility and dishwasher monitored. The conveyor rack dishwashers are listed in Table 8 and flight dishwashers in Table 9.

Table 8. List of field monitored rack-conveyor dishwashers

	Facility	Facility Type	Rack Conveyor Type	Dishwasher Make and Model
1	Genentech B4 Café	Commercial Cafeteria	Low-Temp Existing	Stero SCT-44CS
2	Tadich Grill	Fine Dining Restaurant	High-Temp Original	Ecolab ET44
3	Tadich Grill	Fine Dining Restaurant	High-Temp New	Ecolab EC44
4	**Google Backyard Café**	**Commercial Cafeteria**	**High-Temp Existing**	**Stero SCT-44**
5	Fish Market	Full-Service Restaurant	High-Temp Existing	Stero SCT-66S
6	**Google Café Baadal**	**Commercial Cafeteria**	**High-Temp Existing**	**Stero SCT-66S**
7	Lafayette Hotel	Hotel Kitchen	High-Temp Existing	Stero SCT-86S
8	**Stanford Wilbur Hall**	**School Cafeteria**	**High-Temp Original**	**Stero SCT-108S**
9	Hilton Hotel	Hotel Kitchen	High-Temp New	Jackson Crew66
10	**Google Heritage Café**	**Commercial Cafeteria**	**High-Temp Existing**	**Hobart CL64E**
11	**Google Masa Café**	**Commercial Cafeteria**	**High-Temp Existing**	**Hobart CLPS86ER**
12	**Stanford Wilbur Hall**	**School Cafeteria**	**High-Temp New**	**Hobart CLPS86ER**

Table 9. List of field monitored flight-conveyor dishwashers

	Facility	Facility Type	Rack Conveyor Type	Dishwasher Make and Model
13	Marriott Hotel San Jose	Hotel Kitchen	High-Temp Flight Original	Stero STPCW
14	Hilton Hotel	Hotel Kitchen	High-Temp Flight Original	Stero STPCW
15	**Claremont Hotel**	**Hotel Kitchen**	**High-Temp Flight Original**	**Stero STPCW**
16	**Facebook Epic Cafe**	**Commercial Cafeteria**	**High-Temp Flight Original**	**Stero STPCW-ER**
17	**Facebook Epic Cafe**	**Commercial Cafeteria**	**High-Temp Flight New**	**Hobart FT1000 ER + BD**
18	Marriott Hotel San Jose	Hotel Kitchen	High-Temp Flight New	Hobart FT1000 ER

Dishwasher Water Use Analysis

Dishwasher manufacturers list two primary water parameters on the product specification sheets for conveyor dishwashers: fresh water rinse flow rate and total (wash and rinse) tank capacity. The rinse flow rate is typically stated in gallons per hour, whereas the tank fill volume for all the tanks is listed in gallons. It is a common practice to use these parameters to estimate and maximum hourly hot water use for both sizing the hot water supply to the dishwasher and to project the daily water and energy use of the dishwasher, based on nominal assumptions. One of the goals of this project was to investigate the validity in using the manufacturer’s specifications on rinse water use as a proxy for estimating the total water and energy use of the machine. It is of further interest to determine if the use of the specified rinse water consumption is a valid surrogate for identifying energy and water efficient conveyor dishwashers.

One check on the validity of using rinse flow rate for the practices mentioned is to compare the measured total water use of a dishwasher per hour of rinse operation to the manufacturer’s specification on total water use of dishwashers for an hour of rinse operation. The spec. total water use is a combination of the rated rinse flow rate and the water used to fill the tank(s). The average daily hours of rinse operation was divided by the average daily tank fills for each dishwasher to calculate the water use contribution of tank fills per hour of rinse operation in Table 10 for rack conveyors and Table 11 for flight conveyors. The average number of tank fills per hour of rinse for the four types of conveyor dishwashers are fairly close to each other ranging from 0.59 to 0.67 tank fills per hour of rinse. The data for all 18 dishwashers were averaged to 0.65 tank fills per hour of rinse operation. Thus, the spec. total water use is equal to the specified hourly rinse flow rate plus the specified tank(s) capacity of each dishwasher multiplied by a factor of 0.65.

To better understand the parameter of the dishwasher total water use per hour of rinse operation, it requires conceptualizing the ideal conveyor dishwashing operation. In an ideal operation, the fresh water used for sanitizing rinse would be cascaded through all the chambers in the dishwasher and reused prior to being rejected to the drain, without any other fresh water use requirements during the warewashing process. Thus, the remainder of all the other activities in the dishwasher that consume fresh water but do not add value or do work would be attributed to waste. Using this approach, an ideal case would only consume water through the rinse arms and would not require any additional water flow associated with tank filling, tank top off, drain or scrapper tank tempering, or cleaning and descaling operations. These would all be included as a secondary use of the rinse water. This metric of actual total water use per hour of rinse operation normalizes the data for each site for comparison of all sites and provides a better understanding of true water use for each hour of work done by the dishwasher.

The results in Table 10 for rack conveyors show that the real world rinse water use was on average 11% higher than the rated flow rate for conventional dishwashers and 18% higher that the rated rinse flow rate for higher efficiency machines. Outliers on the high side include dishwasher #2, #7 and #10. Outliers on the low side include dishwasher #6 where the rinse pressure was well below the standard 20 psi due to a faulty gauge. The average specified rinse flow rate reduction between high efficiency (119 gph) and standard machines (274 gph) at 57% was consistent with the actual rinse water reduction of 54% between high-efficiency (140 gph) and standard (304 gph) machines.

Table 10. Model specifications vs. actual water use for rack-conveyor dishwashers

	Dishwasher Make and Model	Specified Rinse Flow Rate (gph)	Actual Rinse Flow Rate (gph)	Average Tank Fills Per Hour of Rinse	Total Rinse and Fill Based on Specs. (gph)	Total Water Use Per Hour of Rinse Operation (gph)
1	Stero SCT-44CS	315	244	0.35	328	730
2	Ecolab ET44	290	524	0.84	303	542
3	Ecolab EC44	223	215	0.73	236	235
4	Stero SCT-44	290	288	0.34	303	363
5	Stero SCT-66S	290	328	0.69	311	389
6	Stero SCT-66S	290	221	0.76	311	416
7	Stero SCT-86S	226	289	0.65	259	2194
8	Stero SCT-108S	309	319	0.97	311	667
9	Jackson Crew66	78	89	0.95	111	135
10	Hobart CL64E	132	172	0.27	161	367
11	Hobart CLPS86ER	132	147	0.20	176	243
12	Hobart CLPS86ER	132	152	0.96	176	301
	AVG. Conventional Conveyor	274	304	0.67	295	692
	AVG. High-Efficiency Conveyor	119	140	0.59	156	261

The spec. total water use is a combination of the rated rinse flow rate and the water used for tank filling. The average daily hours of rinse operation was divided by the average daily tank fills for each dishwasher to calculate the water use contribution of tank fills per hour of rinse operation in Table 10 for rack conveyors and Table 11 for flight conveyors. The average number of tank fills per hour of rinse for the four types of conveyor dishwashers are fairly close to each other ranging from 0.59 to 0.67 tank fills per hour of rinse. The data for all 18 dishwashers were averaged to 0.65 tank fills per hour of rinse operation. Thus, the spec. total water use is equal to the specified hourly rinse flow rate plus the specified tank(s) capacity of each dishwasher multiplied by a factor of 0.65.

For the rack conveyors monitored, the spec. total water use was 295 gph and 156 gph for the conventional and high-efficiency dishwashers, respectively. The average total monitored water use per hour of rinse was 692 gph for the conventional dishwashers and 261 gph for the high-efficiency units. Conventional rack conveyors at the eight sites used 134% more water than what is assumed based on the model specifications. High-efficiency rack conveyors at four sites used 67% more water than the model specifications. The results showed that model specifications were a crude way to estimate real world water use.

The results also showed that by switching from a conventional to high-efficiency conveyor dishwasher, the average operator would see a 47% reduction in water use based on rated specs. The measured savings based on the sites monitored showed a 62% reduction, from 692 gph to 261 gph. This was due in part to the relative condition of the baseline machines, which were found to be worn and operating less efficiently. The average values for spec. vs. actual rinse flow rate and spec. total water use vs. actual total water use per hour of rinse operation were plotted for conveyor dishwashers in Figure 98.

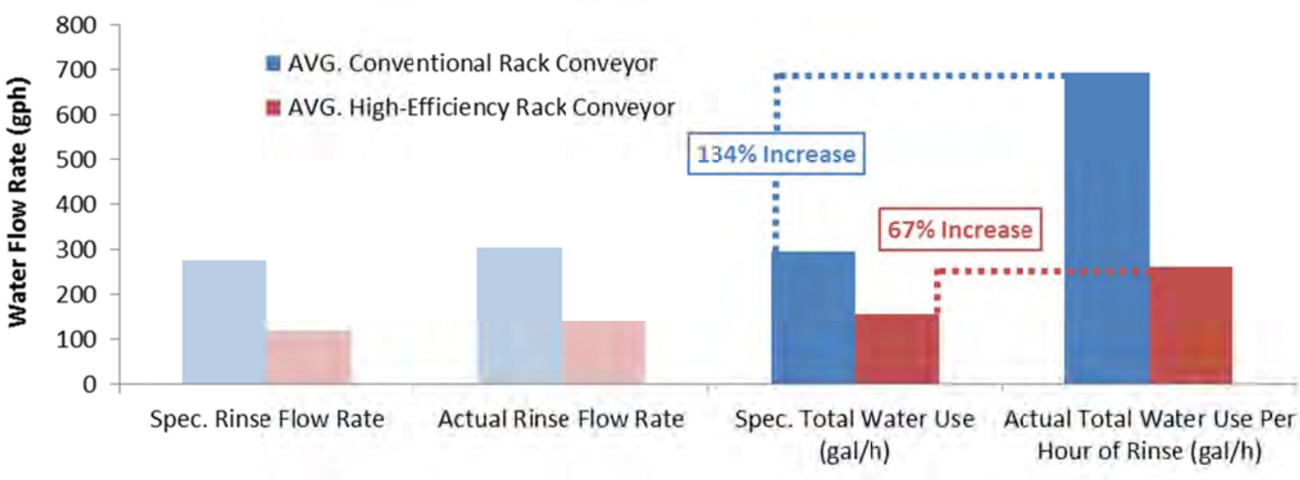

Figure 98. Spec. vs. actual rack conveyor rinse flow rate and total water use comparison

The results in Table 11 for flight conveyor dishwashers showed that the real world rinse water use was on average 30% greater than the specified flow rate for conventional dishwashers and 15% higher than spec for the high-efficiency machines. The measured rinse flow rate of dishwasher #16 at 189 gph was almost twice the specified flow rate of 98 gph. This dishwasher is an outlier compared to the other five flight dishwashers that were monitored. Some plausible reasons for the large difference may be a combination of factors such as elevated rinse water pressure and worn out nozzles on the rinse arm. The average specified rinse flow rate reduction between standard (277 gph) and high efficiency machines (58 gph) at 79% was consistent with the actual rinse water reduction of 81% between and standard (359 gph) high-efficiency (67 gph) machines.

Table 11. Model specifications vs. actual water use for flight-conveyor dishwashers

	Dishwasher Make and Model	Specified Rinse Flow Rate (gph)	Actual Rinse Flow Rate (gph)	Average Tank Fills Per Hour of Rinse	Total Rinse and Fill Based on Specs. (gph)	Total Water Use Per Hour of Rinse Operation (gph)
13	Stero STPCW	336	372	0.48	420	605
14	Stero STPCW	336	357	0.29	420	1277
15	Stero STPCW	336	516	1.43	183	1770
16	Stero STPCW-ER	98	189	0.46	163	823
17	Hobart FT1000 HR	58	71	0.49	145	232
18	Hobart FT1000 HR	58	63	0.83	145	303
	AVG. Conventional Conveyor	277	359	0.66	361	1119
	AVG. High-Efficiency Conveyor	58	67	0.66	145	267

For the flight conveyor dishwashers monitored versus rack conveyor models, there was an even larger change in spec hourly water use vs. total monitored hourly water use. The average values for spec. vs. actual rinse flow rate and spec. total water use vs. actual total water use per hour of rinse operation were plotted for flight dishwashers in Figure 99. Average total water use per hour rinse of 1119 gph for conventional conveyor dishwashers was a 210% increase over the spec. hourly water use for rinse and fill operation. With high-efficiency machines, there was an 84% increase from the spec total water use at 145 gph to the actual total water use per hour of rinse at 267 gph.

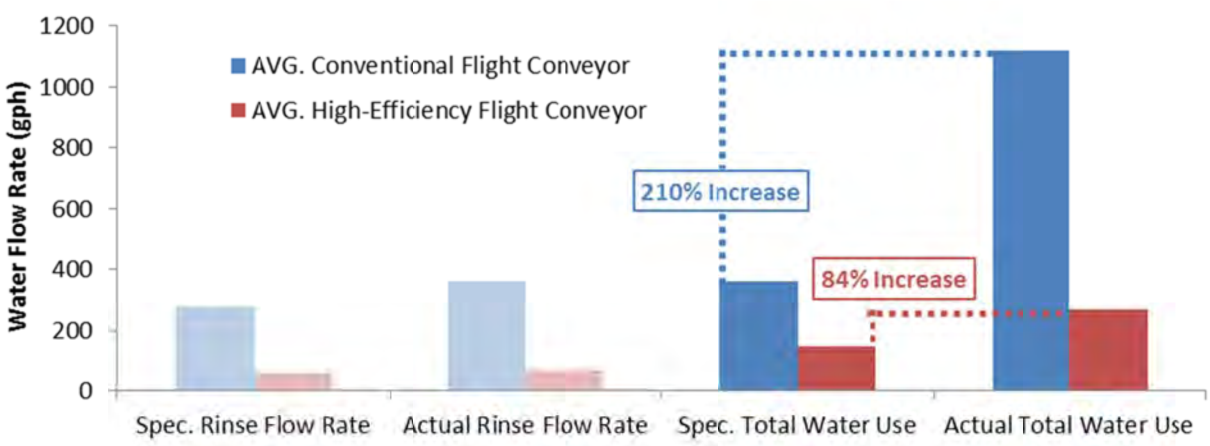

Figure 99. Spec. vs. actual flight conveyor rinse flow rate and total water use comparison

When comparing conventional to high efficiency models, the spec. total water use per hour of rinse was 361 gph and 145 gph, or a 60% reduction on paper. The real world reduction was larger, 76%, due to the significantly higher actual water use of the baseline machines. The main reason why the water reduction percentage between conventional and high efficiency machines was greater in the real world application versus the specification is that the conventional machines tested had many more years of field service and some machines showed more wear and tear in addition to having malfunctions with the machine that had not been noticed or fixed.

Energy and Water Efficiency Policy Considerations

Currently water and energy efficiency professionals use rated rinse flow rate as a proxy for water and energy savings of conveyor dishwashers for voluntary programs such as ENERGY STAR, the USGBC LEED program and various green construction codes. As this approach does not consider the impact of tank fill and top off water use or drain water tempering, the overall water consumption for conveyor machines is underestimated. This disparity between rated and real world water use led the research team to investigate alternate metrics for comparing the overall water use of these machines. Similarly, any metric found to be effective for accurately estimating water use would also be effective for estimating dishwasher energy use, since a large proportion of energy use is dependent on the water use of a conveyor dishwasher.

The data from Tables 10 and 11 were further refined in Table 12 to compare the specified rinse water use of conventional and high-efficiency rack and flight conveyor dishwashers to the measured water use per hour of rinse operation. The results showed that there is no consistent correlation between the manufacturer's specifications to the real world water use, with individual results ranging from 22% to 46% for each category. Although the rinse divided by total use comparison is more closely aligned when isolated to rack conveyors (40% to 46%) and flight conveyors (22% to 25%), this is more of an anomaly since the data range for the four classifications of dishwashers is much wider when reviewing the results for each dishwasher. Ultimately, the specified rinse flow rate is not a good proxy of real water use when it only accounts for approximately a quarter to one-half of the total real world use.

Table 12. Specified rinse flow rate vs. real world water use

Dishwasher Type	Specified Rinse Flow Rate (gph)	Measured Water Use Per Hour of Rinse Operation (gph)	Specified Rinse as a Percentage of Measured Water Use	Data Range (Rinse/Total)
AVG. Conventional Rack Conveyor	274	692	40%	10% - 95%
AVG. High-Efficiency Rack Conveyor	119	261	46%	36% - 58%
AVG. Conventional Flight Conveyor	277	1119	25%	12% - 56%
AVG. High-Efficiency Flight Conveyor	58	267	22%	19% - 25%

Peak Hot Water Flow Rate Analysis

Peak hot water flow rate information of the dishwasher is an important parameter to consider when designing the domestic hot water supply for a facility. Maximum instantaneous flow rates are particularly critical for effective sizing of tankless water heaters (Delagah, 2013). For this study, the parameter of peak flow averaged over a 10 second period and expressed in gpm was selected to represent the maximum instantaneous flow rate. A conveyor dishwasher's peak flow rate can occur during the tank filling operation or during the rinse operation when a tank top off operation is occurring. Both cases are instances where the hot water supply pipe valve is fully open. Thus the peak flow rate is dependent on the diameter of the supply pipe and supply water pressure. Peak flow rates for each of the dishwashers are shown in Table 13 for rack conveyors and in Table 14 for flight conveyors. The average peak flow rate for conventional rack dishwashers was 19 gpm, but ranged from 5 to 35 gpm. The average peak flow rate for high efficiency dishwashers is 11 gpm with a range from 6 to 19 gpm. Similarly, the average peak flow rate for conventional flight conveyor dishwashers was 24 gpm (ranging from 8 to 37 gpm). The peak flow rate for high-efficiency flight conveyors was 18 gpm (ranging from 17 to 19 gpm).

Table 13. Model spec. rinse flow rate vs. maximum hourly demand for rack-conveyor dishwashers

	Dishwasher Make and Model	Peak Hot Water Flow Rate (gpm)	Maximum Hourly Hot Water Demand (gph)	Spec. Rinse Flow Rate (gph)	Increase in Max. Hourly Demand vs. Spec Rinse	Comments on Observed Maximum Hourly Water Demand
1	Stero SCT-44CS	20	495	315	57%	Major water overspray
2	Ecolab ET44	5	141	290	-51%	Tank fills through rinse arm, thus at a lower flow rate
3	Ecolab EC44	13	226	223	1%	Normal operation
4	Stero SCT-44	11	345	290	19%	Normal operation with minor water overspray
5	Stero SCT-66S	16	445	290	53%	Major water overspray
6	Stero SCT-66S	29	1033	290	256%	Extreme overspray
7	Stero SCT-86S	27	1412	226	526%	Tank fill malfunction
8	Stero SCT-108S	35	1424	270	427%	Tank fill malfunction
9	Jackson Crew66	12	89	78	14%	Normal operation
10	Hobart CL64E	8	349	132	165%	Major water overspray
11	Hobart CLPS86ER	19	150	132	13%	Normal operation
12	Hobart CLPS86ER	6	314	132	138%	Tank fill operator error
	AVG. Conventional Conveyor	19	690	274	151%	
	AVG. High-Efficiency Conveyor	11	225	119	90%	

Table 14. Model spec. rinse flow rate vs. maximum hourly demand for flight-conveyor dishwashers

	Dishwasher Make and Model	Peak Hot Water Flow (gpm)	Maximum Hourly Hot Water Demand (gph)	Spec. Rinse Flow Rate (gph)	Increase in Max. Hourly Demand vs. Spec Rinse	Comments on Observed Maximum Hourly Water Demand
13	Stero STPCW	28	1059	336	215%	Major water overspray
14	Stero STPCW	8	424	336	26%	Normal operation
15	Stero STPCW	24	1307	336	289%	Tank fill malfunction
16	Stero STPCW-ER	37	987	98	903%	Major water overspray & drain valve blockage
17	Hobart FT 1000 Energy Recovery	17	234	58	302%	Minor water overspray and normal tank fill
18	Hobart FT 1000 Energy Recovery	19	345	58	492%	Minor water overspray and normal tank fill
	AVG. Conventional Conveyor	24	944	277	241%	
	AVG. High-Efficiency Conveyor	18	289	58	397%	

The commercial kitchen designer or engineer in charge of sizing the centralized storage water heater or boiler for a facility uses sizing guidelines that estimate the maximum hourly hot water demand in gph for each end use. Currently, this practice involves using each particular county's health department sizing guidelines for various sinks and equipment. For the conveyor dishwasher, the reference source is the published maximum hourly rinse use data, acting as proxy for maximum hourly demand. This practice assumes that the maximum hourly water use of a conveyor dishwasher occurs during the rinse operation only with no other hot water using operations by the dishwasher. Water use profiles for the sites monitored has shown that a conveyor dishwasher's maximum hourly water use typically occurs either during a tank filling operation, machine malfunction, human error event, or automated processes such as an auto clean feature. The data presented in Table 13 and 14, and Figure 100 seeks to compare the spec. maximum hourly rinse use to measured overall maximum hourly demand to demonstrate the large discrepancy between them.

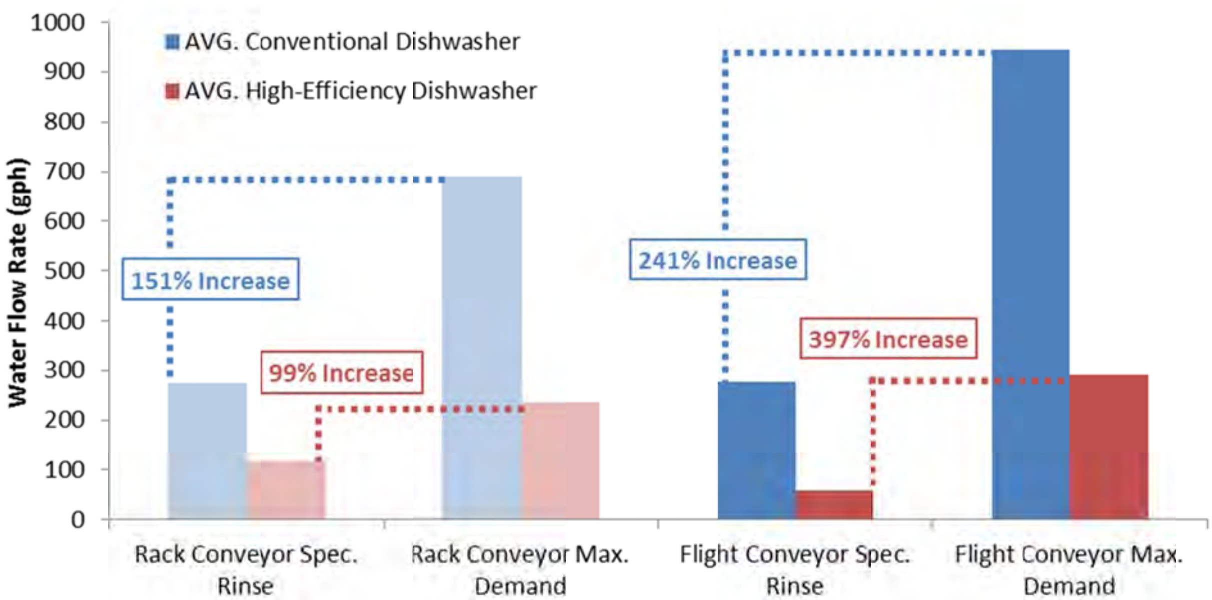

Figure 100. Spec. rinse vs. measured maximum hot water demand comparison for rack and flight machines

The comparison between the maximum hourly hot water demand and the rated maximum hourly rinse consumption in Table 13 show that for an average conventional rack dishwasher, the maximum hourly hot water demand is 126% greater than the rated rinse flow rate. For high-efficiency rack dishwashers the maximum demand is 90% greater. The discrepancy is even greater with flight dishwashers. The maximum hourly hot water demand for conventional machines is 241% greater than the rated maximum hourly rinse use and 397% greater for high efficiency units. The reason for the higher discrepancy with flight dishwashers is that they typically have lower final rinse flow rates than rack conveyors while using three to four times the water volume for tank fill operations. Thus, the water heater installed in a real world application to support a conveyor dishwasher is vulnerable to not being able to maintain the thermostat setpoint as the real world maximum hourly demand associated with the dishwasher greatly exceeds the design rinse flow rate in the majority of sites, thereby leading to poor performance.

Tables 13 and 14 are augmented with observations regarding the conditions for peak water consumption for each of the 18 monitored machines. The hourly demand of seven rack dishwashers monitored exceeded the maximum rated rinse by at least 50%. The most common problem was water overspray where maximum demand exceeded the rated rinse by 53 to 256%. Maintenance shortcomings and miscellaneous operator error also contributed to higher water use for a smaller number of machines. In these cases, the maximum hourly hot water demand exceeded rated rinse by 168 to 526%. Of the remaining rack conveyor dishwashers, four machines operated normally and one dishwasher's maximum hourly hot water demand was roughly half the rated rinse flow rate. The reason behind this was that there was not a separate hot water supply pipe installed for tank filling, thus all the hot water used by the machine for tank fill or rinse operation was pressure regulated and send through the rinse arms to fill the tank. Thus, the tank fill flow rate was equal to the rinse flow rate of 5 gpm. Since the dishwasher was not used to full capacity, the measured maximum hourly flow rate was approximately half of the maximum rinse flow rate. With flight dishwashers the same type of characterizations on the hourly hot water demand can be made.

For sizing purposes, the data shows that there was no correlation between hourly demand and rated rinse flow rate. Also, there was significant variation between maximum the hourly hot water demand between dishwashers of the same model in different installations. As a result, the dishwasher's rated rinse flow rate should not be directly used for sizing water heaters. In fact, the results indicate that the estimated hot water demand of a conveyor dishwasher is at least twice that of the maximum hourly rinse with smaller machines and up to five times the rated usage for flight units. Luckily, many designers of facilities oversize their hot water systems thus ensuring sufficient hot water supply to serve the facility. In the isolated cases where the hot water system was not sufficiently oversized based on the dishwasher specifications, the aging dishwashers had taken their toll on the hot water system and the water heater could not keep up with the demand.

Pre-Rinse Water Use Analysis

Additional monitoring of pre-rinse operations in three dishrooms showed very large variability in water use from very low to extremely high between sites. These sites were selected based on site visit observations that each site would exhibit either dramatically high or low water use, and is not representative of average pre-rinse water use. The average daily water use was divided by the average dishwasher rinse flow time to normalize the data for comparison of all sites and is summarized in Table 15. The first site at Stanford utilized three industrial spray hoses at high flow rates using 623 gph of dishwasher rinse operation. The second site was Google Heritage Café where a combination of a medium flow pre-rinse spray valve, the scrapper using 2 gpm of fresh water and misuse of hot water degreaser solution into the scrapper combined for a total use of 835 gph of rinse operation. In contrast at Google

Masa café, the high efficiency pre-rinse sprayer was exclusively used, which greatly reduced the pre-rinse water use per hour of rinse to 14 gph.

Table 15. Model specifications vs. actual water use for rack-conveyor dishwashers

Site	AVG. Daily Pre-Rinse Water Use (gph)	AVG. Daily Dishwasher Rinse Flow Time (h)	Pre-Rinse Water Use Per Hour of Rinse Operation (gph)	Dishwasher Water Use Per Hour of Rinse Operation (gph)	Total Water Use Per Hour of Rinse Operation (gph)
Stanford Wilbur Cafe	1,282	2.1	623	667	1,289
Google Heritage Cafe	3,145	3.8	835	367	1,202
Google Masa Cafe	75	5.1	14	243	257

The normalized pre-rinse water use data was combined with the normalized dishwasher water use data to calculate the total dishroom water use per hour of rinse operation for the three sites. The results showed that the total dishroom water use can vary by almost a factor of five, from 257 to 1,202 gph of rinse operation in two very similar facilities that use high efficiency dishwashers and have a scrapper and pre-rinse sprayer installed.

Energy Use Analysis

The energy use analysis is more complex than the water use analysis since there are two forms of energy being used provide hot water to the dishwashers. Many of the older dishrooms employ gas-fired water heaters to raise cold water to sanitizing rinse temperatures. Many newer machines utilize a limited amount of gas water heating from the building hot water supply, combined with localized electric heating to provide the final sanitary rinse. This shift has been caused by long term trends away from the use of central steam supply in institutional facilities to provide hot water to the dishwashers, combined with new trends to utilize waste heat recovery systems to preheat incoming water to the machines. The most common application for boosting the water temperature to the 180°F required for the final rinse is to use localized electric heaters.

On average, the eight conventional rack-conveyor dishwashers used 41.2 therms of natural gas and 72.6 kWh per day, as summarized in Table 16. The average high-efficiency machine used 10.3 therms and 238.1 kWh per day, which is a very large reduction in gas use and almost as large increase in electricity use. The same pattern is evident to a lesser extent with the flight-conveyors monitored in Table 17.

Comprehensive energy metering for dishwasher #1, #3, #5 was not completed thus energy data is left black in Table 16. It is important to note with the flight dishwashers that several of the conventional machines did not maintain the proper rinse or tank temperatures during monitoring period, thus their energy contribution would have been even larger if the data was normalized. Similarly, one of only two high-efficiency flight dishwashers monitored used an optional blower dryer not found on the original dishwasher which contributed to additional electricity use.

Table 16. Energy use analysis of rack-conveyor dishwashers

	Dishwasher Make and Model	Total Gas Use (therms/d)	Total Electricity Use (kWh/d)	Total Energy Use (Btu/d)	Rinse Flow Time (h)	Machine Energy Use Per Hour of Rinse Operation (Btu/h)
1	Stero SCT-44CS	N/A	N/A	N/A	N/A	N/A
2	Ecolab ET44	32.9	72.5	3,535,943	5.1	692,977
3	Ecolab EC44	N/A	N/A	N/A	N/A	N/A
4	Stero SCT-44	20.4	9.8	2,073,438	2.9	714,978
5	Stero SCT-66S	N/A	N/A	N/A	N/A	N/A
6	Stero SCT-66S	20.4	15.2	2,088,128	3.2	658,194
7	Stero SCT-86S	102.3	244.8	11,070,040	4.9	2,259,192
8	Stero SCT-108S	30.2	21.0	3,095,472	2.1	1,504,373
9	Jackson Crew66	4.2	179.1	1,027,969	2.9	350,834
10	Hobart CL64E	28.1	28.0	2,901,730	3.8	770,499
11	Hobart CLPS86ER	5.8	468.9	2,184,750	5.4	401,493
12	Hobart CLPS86ER	3.2	276.2	1,260,146	2.1	603,262
	AVG. Conventional Conveyor	41.2	72.6	4,372,604	3.6	1,549,961
	AVG. High-Efficiency Conveyor	10.3	238.1	1,843,649	3.5	531,522

Table 17. Energy use analysis of flight-conveyor dishwashers

	Dishwasher Make and Model	Total Gas Use (therms/d)	Total Electricity Use (kWh/d)	Total Energy Use (Btu/d)	Rinse Flow Time (h)	Machine Energy Use Per Hour of Rinse Operation (Btu/h)
13	Stero STPCW	44.1	906.0	7,501,272	6.1	1,232,775
14	Stero STPCW	50.4	397.6	6,397,899	9.1	703,333
15	Stero STPCW	92.3	33.4	9,343,961	3.4	2,748,224
16	Stero STPCW-ER	48.0	654.3	7,031,270	6.9	1,023,582
17	Hobart FT 1000 Energy Recovery	10.0	931.0	4,176,572	7.0	595,852
18	Hobart FT 1000 Energy Recovery	10.0	665.0	3,267,047	4.7	696,841
	AVG. Conventional Conveyor	58.7	497.8	7,568,600	6.4	1,426,978
	AVG. High-Efficiency Conveyor	10.0	798.0	3,721,809	5.8	646,346

The gas and electricity use in Tables 16 and 17 were combined in units of Btu/d to compare the total energy use. Dishwasher energy use per hour of rinse operation was calculated as the total energy use divided by the average daily rinse flow time. This normalized energy use per hour of rinse provides a level comparison for the 18 dishwashers. Using this analysis, conventional rack conveyors used between

650,000 to 2,250,000 Btu per hour of rinse, for an average use of roughly 1,550,000 Btu per hour of rinse. The average energy use of high-efficiency rack conveyor is roughly 530,000 Btu/rinse-h or about two-thirds less than the conventional machines. The range is much tighter as well; the most efficient units consumed 350,000 Btu/rinse-h and most consumptive units topped at 770,000 Btu/rinse-h.

Interestingly, the conventional flight conveyor dishwashers on average used 1,430,000 Btu/rinse-h, which is close to the average for a rack conveyor. The range of energy use for the conventional flight conveyors was also very similar: from 700,000 to 2,750,000 Btu/rinse-h. For the high-efficiency flight conveyors, the average use was roughly 650,000 Btu/h per hour of rinse, or about one half of the conventional models. Conveyor rack or flight dishwashers use the most energy and water per hour of operation for a single appliance in a commercial kitchen.

Dishwasher Replacement Project Cost Savings and Payback Period

During the course of this research project, a number of the sites had pre-existing machines that were eligible for replacement. These two projects, Facebook and Stanford, provided significant benefits to the operator, but did not represent a strong business case based on energy and water savings alone. Two other sites, Hilton Hotel and Marriott Hotel, exhibited substantial energy and water cost savings that justified the upgrade. Table 18 summarizes the calculated cost savings for these four projects. In each case, an old inefficient conveyor dishwasher was replaced with an ENERGY STAR qualified high-efficiency model. Annual operating cost savings are shown based on average California utility rates defined in Table 5. The large variations in operating cost savings for these projects highlight the complexity of the commercial dishwashing operation. Factors such as fuel source, machine size, energy rates, and matching load to design affect the overall cost to operate the dishwasher at a given facility. For example, switching from steam to localized electric water heating at Stanford led to an estimated increase in utility costs for the new machine, while right sizing from an oversized flight type to a correctly-sized rack conveyor machine at the Hilton resulted in a substantial decrease in operating costs. Overall, the four projects resulted in an average utility cost savings of approximately $22,000 per year. In each case, the cost savings were driven by the substantial reduction in water use.

Table 18. Annual utility savings from four dishwasher replacement project

	Water and Sewer Savings	Gas Savings	Electricity Savings	Demand Charge Savings	Total Annual Utility Savings
Hilton Hotel	$ 16,142	$14,561	$13,557	$3,068	$47,328
Marriott Hotel	$ 11,028	$8,293	$14,954	$3,236	$37,510
Stanford	$ 3,628	$9,877	-$15,835	-$3,335	-$5,665
Facebook	$ 16,656	$13,865	-$17,167	-$4,215	$9,140
Average	$ 11,864	$11,649	-$1,123	-$312	$22,078

Due to the complexity of the systems being investigated, the projected payback period of a dishwasher replacement project is dependent on a wide range of factors, including the condition of the exiting machine, fuel source, utility rates, and dishroom operation. When fuel switching is involved during dishwasher replacement by changing from natural gas to electricity for the majority of the water heating load, the payback period may be longer in regions with high electric rates and demand charges. Nonetheless, there are many older dishwashers that would be excellent replacement projects with the potential to provide overall operating cost offsets by using much less hot water while improving overall dishwashing performance.

Discussion on Procurement, Operations, Maintenance, and Commissioning of Conveyor Dishwashers

Dishwasher Sizing Considerations

The average and maximum hours of rinse operation per day are two important parameters used for correctly sizing conveyor dishwashers. Many facility operators perceive that the operating time of their machine is higher than it actually is, leading to oversizing of the new machines. Emphasis is placed on the racks per hour rating of the dishwasher, which is can be increased by specifying a larger unit. However, monitored data shows no correlation between machine size and measured rinse time (Figure 101). In general, researchers found that the average duty cycle was quite low (15%) for many of the machines, indicating that they were underutilized.

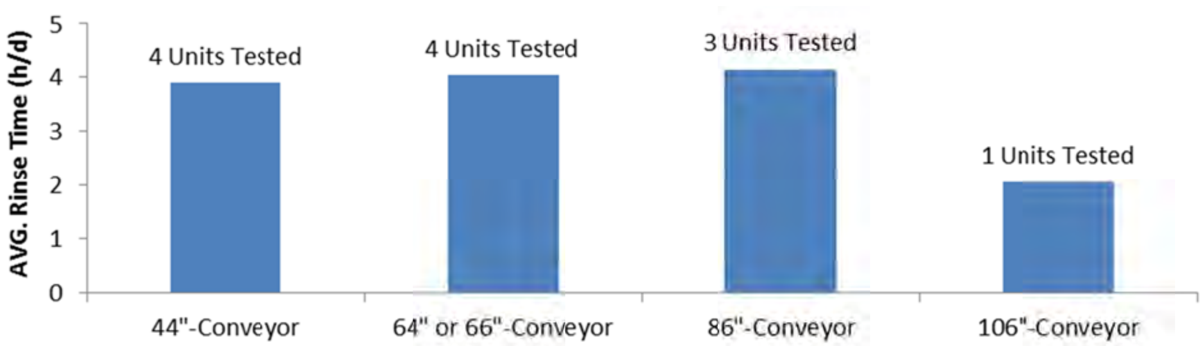

Figure 101. AVG. rinse time of various sized rack-conveyor dishwashers

Choosing a type and length of a rack-conveyor based on types of wares washed, need for scrapper, budget, and available space within the dishroom. The rack-per-hour rating of conveyor machines have little bearing on operations. Most conveyor machines are rated for between 200 and 350 racks per hour, while it has been anecdotally noted that the maximum racks that a single person can be load onto a rack-conveyor machine in an hour is 90—well short of a machine's throughput rating. In the twelve sites that were studied, roughly half operated the dishwasher with one person and the other half of the sites had two staff running the machine—one person loading and the other person unloading.

Hotels were the most concerned about the machine's ability to keep up during a peak period. Standard practice is to significantly oversize the machine to be ready for the potentially busy period that includes a large banquet, a fully booked facility, and other miscellaneous events happening simultaneously putting stress on the dishroom. In the case of the Claremont hotel, the head chef was reluctant to replace the existing flight type dishwasher with a smaller unit, even though the machine operated for an average of 3.4 hours per day in a 24-hour operation. In the 133 days that were monitored, the rinse flow time exceeded 6 hours per day three times, with a maximum operating time of 8 hours. While this data indicated that a smaller machine would provide sufficient capacity for the operation, the facility opted to replace the machine with another of equal size.

Conversely, the use of submetering as a tool to help right-size the dishwasher was effective at the Hilton Hotel. This property also used a large flight dishwasher for approximately 3 hours of rinse use per day. After reviewing the submetering results, the facility opted to down size the replacement machine to a 66"-rack conveyor. In this situation, the smaller machine provided ample capacity while resulting in significant utility cost savings.

Operations

The research showed considerable water waste related to tank fills, particularly deriving from open drain valves during fill operations. Analysis of the data at the Stanford site showed that avoidable water waste accounted for 1/3 of the total daily use. Another frequent operating condition was caused by improperly placing large wares, which exaggerated overspray and led to higher water usage. Smaller machines like 44 and 66-inch rack conveyor machines have little or no spacing between the wash and rinse zones. These designs are more prone to increased water usage caused by overspray than machines with a larger buffer zone between wash and rinse sections. As water is sprayed in to the adjacent tank, the initial tank calls for topping off, while the receiving tank sends the excess overspray to the overflow drain. This tendency can be countered by adjusting the sensitivity of the water level sensors and by properly loading wares onto the conveyor rack.

Maintenance

Proper maintenance of the machines is critical to maintaining the correct operation and water use of conveyor dishwashers. In an extreme example, an incapacitated auto tank fill led to excessive manual tank fills at the Claremont hotel. The manual fill operation contributed to an excess of 900 gallons per day, which was roughly half of the total water used for tank filling by the machine. While an extreme example, there were numerous sites where maintenance was lacking causing inadequate or excessive rinse pressure, drain malfunction, rinse sensor malfunction or inoperable auto fill function. Excessive water use due to poor maintenance was more pronounced with older dishwashers.

Commissioning of New Dishwashers

It is also important to properly commission new machines. Heat recovery systems add complexity to machine commissioning, leading to incorrect operations and subsequent performance degradation. Two heat recovery machines in this study were found to be improperly commissioned. EAHR is fairly new technology that can add complexity to the machine installation, by adding both hot and cold water feeds. One frequent challenge was ensuring the optimal balance between hot and cold feeds. It is therefore recommended that installers use meters to confirm the correct ratio of hot to cold water for the proper operation of the heat recovery device.

Benchmarking

Benchmarking the dishwasher water and energy use was not possible at all locations, due in part to the complexity of individual operations. While the number of seats may be a good metric for normalizing machine operation, additional factors need be considered. Are all meals consumed in the dining facility? What is the impact of banquet preparation? In multi-use facilities like the Claremont hotel, it was not useful to try to compare dishwasher usage to the number of seats, square footage or number of meals, as a significant part of the dishroom usage would be from some unrelated operation. The more information collected on a particular operation, the greater the potential to develop a meaningful performance metric. Table 19 shows the results for two sites, normalized per square foot, per seat and per meal. These two sites are not similar enough in operation to compare the performance metrics to each other. Accruing this data for numerous sites would provide parameters that facilities can use to compare their own facilities' dishwasher to industry averages for conventional and efficient machines.

Table 19. Benchmarking parameters for water and energy use from two dishwasher replacement projects

	Water Use Per 1000 SQ. FT. (gal/1000ft^2)	Water Use Per Seat (gal/seat)	Water Use Per Meal (gal/meal)	Energy Use Per 1000 SQ. FT. (gal/1000ft^2)	Energy Use Per Seat (gal/seat)	Energy Use Per Meal (gal/meal)
Stanford Old	62	2.1	1.1	140,721	4,763	2,381
Stanford New	29	1.0	0.5	57,279	1,939	969
Facebook Old	196	6.2	0.6	244,133	7,769	703
Facebook New	64	2.1	0.2	145,015	4,615	418

Conclusions

Previous dishwasher studies had documented baseline dishwasher use data, but offered limited information on the savings potential that can be achieved by replacing existing machines with new energy-efficient models. This study documents the energy and water use of 18 conveyor machines, in 13 different test sites, providing a solid foundation for characterizing the energy and water savings potential of these machines. The conveyor dishwashers were classified into four groups including conventional rack, high-efficiency rack, conventional flight and high-efficiency flight machines. The normalized results showed that on average water and energy use of conventional rack conveyors were reduced by more than 60% when replaced by a high-efficiency unit. The savings from flight conveyor dishwashers was even greater at more than 75% water and energy savings.

Commercial dishwashers represent significant water and energy use in a facility. Most old machines could be candidates for replacement with newer, low water using machines. As long as there is minimal fuel switching involved, there is also a strong business case for the facility to make the switch based on the value of the energy savings. The economic case is even stronger when utilities provide custom energy and water rebates for existing facilities, which would require sub-metering of both dishwashers to measure actual savings. Old inefficient conveyor dishwashers were replaced with ENERGY STAR qualified high-efficiency models at four sites. The average cost savings per site based on average California utility rates was approximately $22,000 per year. In each case, the cost savings were driven by the substantial reduction in water use.

The research showed that old conveyor dishwashers consume two to three times more water than was predicted based on the rated rinse flow and tank volume specifications. High-efficiency conveyor dishwashers used 70% to 85% more than the rated specifications. The new machines operated more closely in line with the specifications than older machines as they benefited from advanced features that mitigated water waste. The results also showed that the rinse water use only accounted for a quarter to less than half of the real world water use. Projections based on rinse specifications alone would not accurately characterize the water use of a particular machine. In fact, the estimated hot water demand of a conveyor dishwasher is on average at least twice that of the rated hourly rinse water use with smaller machines and up to five times the rated hourly rinse water use for flight-type machines.

A significant finding was that the majority of conveyor dishwashers installed in facilities are not set up to wash and rinse medium to large back of the house wares without incurring substantially higher water use during operation. Most conveyor dishwashers are designed to wash front of the house cups, glasses and dishes, with the larger back of house wares providing a challenge for the machine. Some of the overspray issues caused by washing large wares could be mitigated with the specification of taller cavity machines and incorporating specialized racks for washing sheet pans and other flat wares at an angle that allows water to drain back into the correct tank instead of horizontally spraying through the machine. In the most extreme case of exclusively washing back of the house wares through a 44-inch conveyor dishwasher, hot water use was more than double its normal operation. As more machines are used to wash back of the house wares, the challenge of correctly loading it becomes more important to ensure optimal water use.

Benchmarking water and energy use through sub-metering of the dishwasher when the unit is performing well and staff is fully trained is a critical tool to incorporate to establish the baseline energy and water use of the machine. Without a benchmark to indicate water performance, the standard "fix" is to increase hot water and chemical use to ensure cleaning and sanitization performance. In extreme cases, poor maintenance can lead to real world water use that is as much as 10 times higher than the specifications for water consumption per hour of rinse operation. None of the facilities that were monitored in the course of this study had meters to monitor water consumption of the dishwashing equipment. Without this information, maintenance can only address the problems when the chemical costs or cleaning performance becomes an issue. Without a solid preventative maintenance effort, excessive water use can go unchecked.

Recommendations

Field monitoring of commercial conveyor dishwashers has identified opportunities to reduce water and energy consumption in commercial dishrooms. In some instances, significant savings can be achieved through the retro-commissioning of existing machines to return the machines to their designed specifications. Greater savings can be achieved by replacing older machines with the latest generation of energy efficient machines, but at a high investment on the part of the operator. While incentives can offset the installed cost of a new machine, an effective conveyor dishwasher program would need to include retro-commissioning to make a significant impact on the market. A two-pronged approach would ensure that both older and newer machines are operating properly and help to sustain the investment in water and energy savings. A pilot dishwasher retro-commissioning program would also help to promote the replacement of older machines by identifying the most appropriate candidates for replacement. The experiences gained from the pilot project will aid in incorporating more permanent programs that can be expanded throughout the state.

While the dishwasher is responsible for the final cleaning and sanitization of the dishes, the work starts at the pre-rinse station. While codes have mandated a maximum flow rate of 1.6 gpm for pre-rinse spray valves installed in front of a commercial dishwasher, the larger facilities employ more water intensive measures for pre-rinsing dishes that can greatly exceed the intended water consumption and potentially match or exceed that of the dishwasher. Some of the reasons for this is that kitchen staff are often disconnected from the operating costs of running the dishroom and with no sub-metering, there is little to connect dishroom behavior to the overall building water use. The FSTC team has identified at least 5 types of pre-rinse equipment that can be used individually or in combination to effectively accomplish the task of prewashing dishes and other wares. A comprehensive study on dishroom operation is recommended to individually monitor the conveyor dishwasher and pre-rinse operations separately to identify the savings potential from the best pre-rinse devices and operating practices.

Comprehensive policies to encourage sub-metering the water consumption of conveyor dishwashers in existing or new facilities would go a long way to support ongoing efforts to reduce commercial building water and energy use. Additional incentives should be provided for high-efficiency smart dishwashers that minimize water and energy use while having integrated water and energy meters and logging and communications hardware to engage operators and managers on the performance of the unit. While the technology for machines to meter water and energy use is available, few manufacturers have incorporated this capability. A dishwasher sub-metering initiative could integrate with of a wider program offering an annual free checkup of the dishwasher and assessment by the water utility or a third-party. A 3rd party may provide employee operation and maintenance training to facility staff through the use of videos or onsite visits.

The majority of conveyor machines installed in facilities are designed for front of the house wares, such as dishes, glass ware and eating utensils. As more and more facilities direct their back of the house wares such as pans and trays, the machines are being challenged to accommodate different utensil geometries that can impact water use. In addition, many machines were found to be oversized relative to the operation. Too much emphasis has been placed on conveyor speed and rack capacity in the design phase. Without sufficient staff to operate the machines, there is little to be gained by the higher throughput machines. In fact, every facility in this study would benefit from a commercial dishwasher design guide that covers selection and sizing of conveyor dishwashers, best practices for operation and maintenance of the dishwasher, benchmarking tools and calculations for estimating the maximum hot water demand for a machine. The commercial dishwasher design guide could also benefit county health departments and plan checkers by providing the resources to evaluate designs.

There is also a need to fund additional field monitoring projects on high-efficiency dishwashers just entering the market that utilize 2nd-generation heat recovery systems, such as drain water heat recovery. Quantifying the water and energy use of these emerging technologies can support future incentive programs and provide a solid foundation to enhance the ENERGY STAR specifications for commercial dishwashers. As more and more dishwasher manufacturers continue to add models with integrated heat recovery systems, third-party research is needed to validate real world savings potential of the designs. This research would be a compliment to the proposed design guide for commercial dishwashers, serving as the basis for a phase two design guide on the application of heat recovery in commercial dishrooms.

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Glossary

Booster and heat exchanger efficiency (energy into water at HX/energy consumed by heater)

Booster and heat exchanger operating efficiency was defined as the amount of energy transferred to the daily water volume (from the measured inlet temperature at the heat exchanger to the measured outlet temperature at the booster) divided by the daily energy consumption of the booster heater. For additional information refer to the booster heater efficiency definition.

Booster heater efficiency (energy into water at booster/energy consumed by heater)

The booster heater operating efficiency is calculated by dividing the heat energy transferred to the water by the energy consumed by the booster heater. Booster heater daily operating efficiency was defined as the amount of energy transferred to the daily water volume (from the measured inlet temperature at the booster to the measured outlet temperature at the booster) divided by the daily energy consumption of the booster heater. After collecting and analyzing the data, daily operating efficiencies were calculated using the following formula:

$$\boldsymbol{Operating\ Efficiency} = \frac{\boldsymbol{Energy\ into\ Water}}{\boldsymbol{Energy\ Consumed\ by\ Heater}}$$

$$\boldsymbol{Operating\ Efficiency} = \frac{\boldsymbol{Mass_{water}[lbs]} * \Delta \boldsymbol{T_{water}}[°\mathrm{F}] * \boldsymbol{C_{p_{water}}}[\boldsymbol{Btu/(lb} * °\mathrm{F})]}{\boldsymbol{Volume_{gas}[ft^3]} * \boldsymbol{High\ Heating\ Value_{gas}}[\boldsymbol{Btu/ft^3}]}$$

In calculating these daily efficiencies, $mass\ flow_{water}$*ΔT_{water} was computed for each five-second test interval, summed over the day and then divided by gas energy. This technique eliminated the inclusion of any no-flow periods when the measured temperature in the outlet pipe would drop below the tank temperature. If this data were included in the average ΔT_{water} calculation, the efficiency would be incorrectly calculated. Reported average mass-weighted inlet and outlet temperatures were calculated by dividing the daily summed 5-second interval $mass\ flow_{water}$ * T_{water} values by the daily $mass\ flow_{water}$ total. A higher heating value of 1020 Btu/ft^3, representative of gas supply in the area was estimated and used in gas booster heater efficiency calculations.

Cold water tempering

A supply of cold water used to reduce the temperature of the dishwasher discharge to below 140°F before it enters the building sewer system to comply with local regulations.

Dishwasher operating span (h)

The total period of time that a dishwasher is operated (from the perspective of food service staff) from the time it is turned "on" to the time it is turned "off." Dishwasher operating span excludes any "off" periods between the first and last appliance operation.

Dishwasher operating time (h)

The total time in hours per day that the dishwasher conveyor was actively moving. Dishwasher operating time excludes periods that the machine was turned on but not in active use.

Input Rate

The maximum or peak rate at which an appliance consumes energy, measured during a period of continuous operation (i.e., the period of operation when all burners or elements are "on").

Maximum hourly hot water demand (gph)

The maximum combined flow rate of hot water in gallons per hour supplied to the conveyor dishwasher. Maximum hourly hot water demand includes both tank and sanitizing rinse hot water supplies.

Peak Demand (kW)

The peak demand is measured in kW and is based on the highest 15-minute interval of electric usage during the monthly billing period. Demand is calculated by recording the average power used in a 15- or 30-minute window based on the power company. The peak demand used for billing can be based on the time of day, seasonally differentiated

Probable contribution to peak demand (kW)

A dishwasher actual contribution to a building's peak demand may vary significantly depending on its usage pattern in relation to that of other electric equipment in the facility (operating schedule, appliance on time, etc.). However, it is generally known that the biggest water consuming appliance for any commercial food service is the dishwasher. Thus dishwasher water usage will be the largest contributor to overall usage and peak demand. The End-use Water Demand Profile study conducted on restaurants for the CPUC by Aquacraft documents hourly hot water demand.[i] This study conducted on seven different restaurants concludes that 24.1% of total daily use occurs during the 3-hour peak demand period between 2:00pm and 5:00pm. Therefore, it has been assumed that the probable contribution to the building's peak demand is equal to the appliance's average demand during the peak times.

$$\boldsymbol{Average\ Demand\ Peak\ Demand} = \left(\frac{kWh}{Year}\right) \times \left(\frac{days}{Year}\right) \times \left(\frac{Usage\ During\ Peak}{Total\ Daily\ Usage}\right) \div Hours$$

Rinse flow time (h)

The total time in hours per day that the dishwasher called for a hot water sanitizing rinse.

Typical Day

A selected day of energy usage based on predetermined criteria that will generate a production energy consumption profile reflecting typical production usage for a specific appliance. The typical day criteria may comprise:

- Typical day energy consumption should approximate average daily energy consumption for energy use data set.
- A specified number of appliance operations and/or cooking periods (e.g., lunch and dinner only).
- A specified range in operating hours.
- A specified mode of operation (or combination of modes) may be associated with a typical day's operation.

Appendices

Appendix A: Google Café Baadal

Appendix B: Google Backyard Café

Appendix C: Google Heritage Café

Appendix D: Google Masa Café

Appendix E: Stanford Wilbur Café (Original Dishwasher)

Appendix F: Stanford Wilbur Café (Replacement Dishwasher)

Appendix G: Facebook Epic Café (Original Dishwasher)

Appendix H: Facebook Epic Café (Replacement Dishwasher)

Appendix I: Claremont Hotel

Food Service Technology Center

Addendum: Report Certification

This certifies that the undersigned has performed equipment testing according to the methodology outlined in the report described below, and verifies that the results recorded in that report were the actual results observed.

Report: Conveyor Dishwasher Performance Field Evaluation Report

Report #: 5100131004-R0 Date published: 12/2013

File name: 13_10_04_5100131004-R0

Date sent for authorization: 12/15/2013

Tested by: ____________________ Date signed: ____________

(signature)

Amin Delagah — Engineer Level 4

(print name) (title)

FNi Authorization: ____________________ Date signed: ____________

(signature)

David Zabrowski — Director

(print name) (title)

PG&E Authorization: ____________________ Date signed: ____________

(signature)

Charlene Spoor — Senior Program Engineer

(print name) (title)