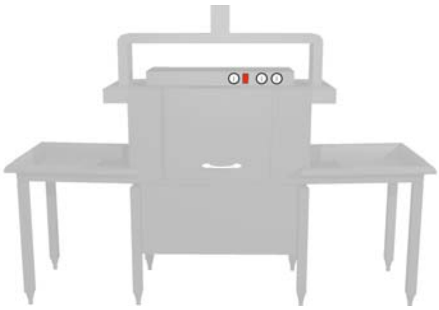
Design Guide

Improving Efficiency of Rack Conveyor Dishwashers

Water, Energy and Chemical Savings



The information presented is applicable to new construction and dishmachine replacement. The target audience consists of kitchen designers, mechanical engineers, code officials, foodservice operators, and property managers.

This guide reviews the fundamentals of ware washing and considers design constraints common to all food service operations. It presents conveyor dishwasher sizing guidelines and details the steps necessary for proper dishroom design. The guide provides water and energy savings results of high-efficiency and best-in-class units versus conventional models based on field monitoring. It is a supplemental guideline that complements current design practices and codes.

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Introduction

This document guides the reader to use innovative strategies to reduce the water, energy, and chemical waste inherent to running a rack-conveyor dishwasher. It accomplishes this by describing conventional dishwashers in relation to their specification, operation, and maintenance practices and discussing their operating costs, namely, energy and water costs. It focuses on common shortcomings of old dishwashers related to improper specification and sizing, machine malfunctions, and water waste practices. Advanced technologies provide major improvements on old technologies, especially when the dishmachines are properly selected and commissioned along with properly trained dishroom and maintenance staff. Finally, it goes further to present a design path for savings which will be applicable for both new dishroom designs and for retrofit projects, and will motivate replacement of old and particularly wasteful machines.

Background

A restaurant could theoretically wash and sanitize all of its dishes by hand in a three-compartment sink and meet health codes, but this is not practical in most full-service restaurants and cafeterias due to time and space constraints. Dishwashers are important workhorses that significantly reduce labor time and the need for a large inventory of wares by rapidly washing and sanitizing wares and returning them for reuse. From an operational standpoint, the main function of a dishwasher is to lessen a labor and materials bottleneck to keep the restaurant moving!

Figure 1. Multi-tank rack-conveyor dishwasher in operation.

Glossary of Abbreviations, Conversions and Terms

Abbreviations
FSTC – Food Service Technology Center
HCF (or CCF) – 100 cubic feet
gpm – gallons per minute
gpr – gallons per rack

Conversions
1 Therm = 100 kBtu = 100,000 Btu
1 HCF = 748 gallons

Terms
British thermal unit (Btu) is the energy required to raise the temperature of 1 lb of water 1°F.

Installed cost encompasses capital, labor and installation cost of a project or the final cost installed.

kWh or *kilowatt-hour* is used to express the energy delivered or used and is the product of power in kilowatts multiplied by time in hours.

Throughput is the number of racks a dishwasher can wash per hour.

Therm is a unit of heat energy that is used for converting a volume of gas to its heat equivalent to calculate the actual energy use.

Large Dishrooms

Full-service restaurants may need to wash hundreds of patrons' worth of dishes in as little as an hour, and a rack conveyor dishwasher is necessary to meet this level of demand (Figure 1). Large dishrooms are set up so dirty dishes are scrapped of food debris and dropped off to be racked and pre-rinsed prior to loading into the dishwasher. Pre-rinse operations in large dishrooms may be more extensive, consisting of scrappers and troughs. Rack conveyors have a motorized system designed to push racks at a selected speed through the washing and rinsing zones in the cavity. The optional pre-wash portions of conveyor dishwashers are designed to remove solid and stuck-on debris from wares before they enter the wash portion, in order to ensure the efficacy of the wash, and to save on detergent from less tank water change outs. In the wash tank, the soiled wares are washed, which gets rid of any residual food debris and oils. The powered and final rinse cycles are designed to remove the residual detergent and sanitize wares before the rack exits the other side of the cavity. Every step in the process adds heat to raise the internal temperature of the wares for an effective wash and sanitizing final rinse as illustrated in Figure 2 with a high-temperature dishwasher. Dishmachines use one of two methods for sanitation. High-temperature (high temp) rinse machines use 180°F rinse water to kill all microbes, and low-temperature (low temp) rinse machines use a chemical sanitizing solution at a lower temperature rinse. High temp machines generally use more energy, but less water and chemicals than low temp machines.

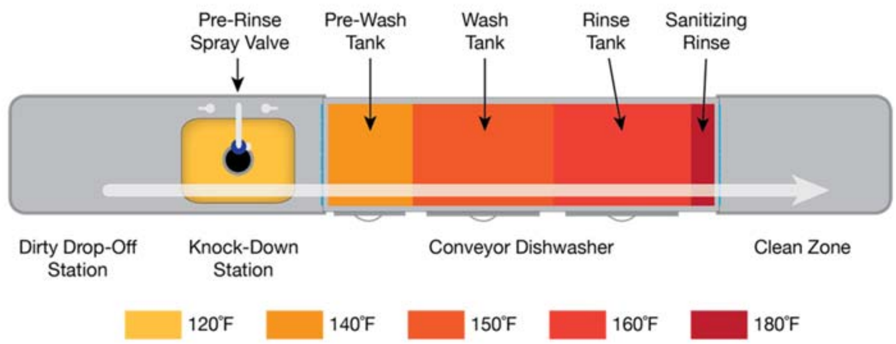

Figure 2. Pathway of wares through a conveyor dishwasher.

The smallest dishmachines have cavities that are 44 or 54 inches in length and only have wash tanks with powered wash arms and a sanitizing rinse zone where potable water is used for the final rinse. Larger models may have a pre-wash tank. Other options include a powered rinse tank, which primarily increases the maximum throughput of the dishmachine, and post-rinse blower dryers to save time on drying dishes and unloading. The largest machines are up to 120 inches in length.

Figure 3. Average California utility rates for restaurants.

Benefits and Drawbacks

180°F High Temp

- ☑ *Best dishwashing performance,*
- ☑ *Reduces the need to inspect and rewash wares*
- ☑ *Uses heat to sanitize wares, thus they dry faster and are ready for use*
- ☑ *Lower water and sewer costs*
- ☒ Typically requires a booster heater and an exhaust hood
- ☒ Higher purchase cost
- ☒ Requires more power increasing installation cost and demand charges
- ☒ Higher energy use

140°F Low Temp

- ☑ *Lowest purchase, lease and installation cost*
- ☑ *Doesn't produce as much steam or heat in the dishroom*
- ☒ *Hard time removing greasy residue, lipstick and hard stains*
- ☒ *Can damage flatware, plastics, aluminum, silver, steel, and alloys*
- ☒ *Use of chlorine may affect sewage system and environment*
- ☒ *Requires regular attention to monitor sanitizer concentration*
- ☒ *Higher dependency on water heater and distribution system*
- ☒ *Sanitizers can prevent beer from foaming a head, and can diminish the flavor profile of wine and beers*

Annual Operating Costs

A conveyor dishmachine is one of the largest users of water and energy in a restaurant. Utility costs are rising faster than inflation, which means that utility bills will play an increasingly important role in the overall cost of operating a restaurant. Table 1 compares the utility costs of various rack conveyor dishmachines for an average medium to large sized full-service restaurant. The three types of units commonly found include a low temperature unit with electric tank heater, high-temperature unit with electric tank and booster heaters and high-temperature unit with gas tank and booster heaters.

Table 1. Typical 44-inch rack conveyor utility costs for a restaurant.

Type	Water Use (gal/d)	Electricity Use (kWh/d)	Gas Use (therms/d)	Water and Sewer Cost	Electricity Cost	Gas Cost	Annual Utility Cost
Low Temp*	2400	150	24.3	$12,230	$9,910	$9,690	$31,830
High Temp Electric**	2400	330	24.3	$12,230	$21,800	$9,690	$43,720
High Temp Gas***	2400	20	35.7	$12,230	$1,320	$14,260	$27,810

*With electric tank heat, **With electric tank heat and booster heater, ***With gas tank heat and booster heater

Table 1 is an estimation based on field monitoring of conventional rack conveyors (Delagah 2015). Although the utility costs of low-temp conveyors are lower than an electric-heated high-temp unit, most rack conveyors operate at a high temperature due to their significant performance benefits which are detailed in the caption to the left. With existing energy prices, a gas-heated high-temp unit is comparable in operating cost to a low-temp unit because heating water using electricity costs four times more than heating with gas. Generally, electric heated dishwashers have been preferred due to their added reliability and space saving benefits.

Chemical costs to wash, sanitize and dry (rinse aid) wares range from $8,000 to $16,000 per year. They are omitted from this table because they are highly variable and dependent on the chemical distributor and negotiated pricing for low-temp or high-temp chemicals. Additionally, the energy use in operating a dedicated dishwasher ventilation system is omitted from this analysis. Some of the operating assumptions for the conventional-rack conveyor in Table 1 are a 5 gpm rinse flow rate with 5 hours of operation and a 15 gpm for tank fill and tank top off operations for 1 hour.

Dishwasher Sizing Guidelines

Dishwashing in a door-type or under-counter machine is constrained by the machine's limited throughput of 30 to 60 racks per hour. During lunch or dinner peak periods, door-type dishwashers cannot keep up with demand in medium to large restaurants. Most rack conveyors are rated at 200 to 300 racks per hour to satisfy peak dishroom loads, but it is commonly known in the industry that an experienced operator can only load 90 racks per hour. This labor bottleneck is much narrower than the dishwasher's rated maximum throughput, rendering the performance rating of rack conveyors moot. Dishwashing with a rack conveyor machine is typically space and labor-constrained. The units are typically placed next to a wall so loading can only occur from one face of the machine, which limits the number of staff to one on the load side and one on the unload side during operation. The largest conveyors are rackless and are better known as flight-type units. These are usually reserved for large cafeterias, hotels and catering operations. Table 2 shows typical sizing guidelines provided by manufacturers and dishroom designers for selecting the appropriate type of dishwasher for your facility.

Table 2. Dishwasher selection criteria.

Meals Per Hour	Dishwasher Type	Intended Use
Up to 50	Undercounter	Mixed bar and dining wares
50 to 250	Single-tank door type	Mixed dining and preparation wares
250 to 400	Single-tank rack conveyor	Mixed bar and dining wares
400 to 750	Double-tank rack conveyor	Mixed dining and preparation wares
750+	Double-tank flight conveyor	Mixed dining and preparation wares

Unfortunately, this is a simplistic approach, which doesn't take into account washing large wares like sheet pans for food preparation and the number of wares per meal, which vary greatly depending on the restaurant. It is common to find a 44-inch conveyor shoehorned into a small dishroom in a busy restaurant with 6 hours of rinse use. It is also common to find a large flight conveyor in a lightly used cafeteria that only sees 3 hours of rinse use.

The manufacturer's rated throughput of the machine in racks per hour is a metric that is useless to the dishroom designer for two major reasons. First, the rated throughput is based entirely on the maximum conveyor speed. Machines rarely operate at the maximum speed due to logistic constraints. Second, the rated throughputs for almost all modern conveyor dishwashers would require two to three times the staff to load and unload the machine at capacity.

Design Path for Savings: A Loads and Labor Perspective

Commercial dishrooms face two major challenges: they are typically over-equipped and undersized. A common strategy for overcoming the space requirements is to design higher volume equipment to overcome the space shortages. While this strategy can appear to work on paper, it fails to account for the additional labor and table space required to work the higher-volume machines. The added complexity of the type of wares being processed presents further challenges to a comprehensive dishroom design. It is important to correctly size the machine and dirty (loading) and clean (unloading) tables to accommodate the anticipated use and staffing plan.

Step 1: Designers should first identify the type of wares that need to be washed. Front-of-house wares such as plates, mugs, glassware and silverware and back-of-house wares such as cutting boards, large bowls, sheet pans, and cookware are inherently different. Back-of-house wares require a taller dishwasher cavity so sheet pan racks can be passed through. Selecting a lengthier cavity provides better separation between the wash and rinse tanks to minimize overspray.

Step 2: The number of racks which need to be washed and available number of staff members in the peak period must be identified. The main constraint here is at any given time, there must be enough clean wares to prepare and serve a meal.

Step 3: The dishwasher needs to have enough space on either side for people to work and for efficient batch loading of racks. As a general rule, each staff member will need at least 5 feet of table space to work in.

Step 4: Design the scrapping and pre-rinse station to utilize a pre-rinse sink with efficient pre-rinse sprayer and deep strainer basket. Avoid disposers, scrappers, and troughs that are less reliable, prone to misuse and have higher installation, maintenance, staff training and operating costs.

Step 5: Consider if integrated exhaust-air heat recovery systems, heat pump water heaters or drainwater heat recovery systems are available for the length of machine in consideration. Heat recovery systems typically employ electric tank and booster heaters and make economic sense when their application eliminates the need for a dedicated exhaust ventilation system for the dishmachine and/or the need for a hot water connection to the dishwasher.

Design Path for Savings

Identify particular ware-washing needs for dining area and kitchen.

↓

Determine the number of racks that need to be washed during a peak operating period.

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Consider the number of staff working in the dishroom during a peak period.

↓

Specify long soil tables to promote efficient batch loading and long end tables reduce labor constraints.

↓

Specify a compact and reliable manual pre-rinse station.

↓

Consider the use of heat-recovery technologies prior to specifying an efficient dishmachine.

↓

Add water meter(s) and data logger to sub-meter machine.

↓

Commission the dishmachine, train staff, benchmark operations and setup maintenance and dishroom

Step 6: Specify ENERGY STAR® or best-in-class efficient equipment to save water, energy and chemicals throughout operation. Select a unit based on savings from real-world operation and user feedback instead of rated specifications.

Figure 4. Low cost wireless submetering now available offering 5-min interval metering, upload using 3G cellular network and data storage using company server (photo credit: Metron-Farnier).

Step 7: Select a dishwasher with advanced diagnostics systems that can connect in real time with the operator or maintenance staff. If water and energy submetering is not integrated, install water meter(s) to sub-meter the dishmachine and store the data using a data logger. Low-cost wireless metering is available (Figure 4). Submetering supports commissioning of new dishwashers for proper rinse flow rate and tank fill operations. It supports benchmarking water, energy and detergent use when the unit is working properly and staff is trained to efficiently operate the dishmachine. Submetering water use helps maintain proper operation by exposing machine malfunctions for the maintenance staff to address and poor operating practices which may alert the manager to retrain staff to the correct procedures.

Step 8: Commission the dishroom properly. Use manufacturer-certified installation professionals to commission and maintain the dishmachine, and ensure that no shortcuts are taken during installation of the dishwasher or its end tables. Be sure to check the final rinse arm pressure and send a load of dirty dishes through the machine before the installers leave to make sure it's operating well.

Temperature and Humidity

Dishrooms are easily the worst working environments in any food service establishment because they're hot, humid, and generally uncomfortable. This problem is much worse in dishrooms with rack and flight conveyor dishwashers because the cavities are partially open. One strategy for improving the working environment in commercial dishrooms is to reduce the heat load from the dishwasher by employing exhaust heat recovery systems. These systems capture waste steam and heat, removing it from the environment. Properly commissioned machines with integrated exhaust air heat recovery can completely eliminate excess latent heat from the environment, producing a cooler, less humid workspace.

Table 3. Hot water flow rates of low and high temperature conveyor dishwashers.

	Single-tank Conveyor	Multiple-tank Conveyor
Inefficient	> 1.4 gpr	> 1.2 gpr
Conventional	1.23 low 1.10 high	0.99 low 1.10 high
ENERGY STAR	0.79 low 0.70 high	0.54 low 0.54 high
Best in Class	0.49 low 0.35 high	0.39 low 0.28 high

Conveyor Efficiency

The rated hot water used per rack of dishes is not an effective indicator of how much energy a dishwasher will use. Nonetheless, Table 3 presents some guidelines for how much hot water each rack-conveyor type uses. It should be noted that many utilities offer point-of-sale rebates for dishwashers that meet the comprehensive ENERGY STAR criteria.

Figure 5. Overspray on soil side of conveyor due to washing sheet pans placed horizontally on the rack.

Field studies on conventional and high-efficiency rack conveyors have shown that the rated rinse only accounts for approximately 40% of total water use. Tank fills, tank top offs, operating error, and machine malfunctions account for the rest of the use (Delagah 2015, Delagah et.al. 2017). Water waste through tank top offs can be mitigated through proper specification of: the cavity height, separation between wash and rinse tanks, and specialized racks for sheet pans. The operator has to do their part in using the conveyor appropriately. The larger machines provide greater separation between wash and rinse sections. This is desirable because overspray from the wash tank can sully the rinse tank water and cause the water in the rinse tank to overflow to drain, while the reduced water level in the wash tank engages a tank top off operation. Overflow into the wash or rinse tank can increase hot water use, detergent use in the wash tank and the need to drain and refill the rinse tank. Overspray can also cause water to gush out from either side of the machine, which can be a major source of waste (Figure 5). Sheet pans, cutting boards and other flat objects should not be placed horizontally through rack conveyors.

Results from real world monitoring of 13 conveyors has shown that conventional rack conveyors use 122% more water per hour of rinse operation than their theoretical value based on specifications for tank volume and rinse flow rate. ENERGY STAR units use 77% more water and a best-in-class unit uses 21% more than the theoretical value. Field results also showed that ENERGY STAR units had 54% water and 37% energy savings versus conventional units and that best-in-class units saved an additional 50% over ENERGY STAR units for a total savings of 80% in water use and 63% in energy use, versus conventional units tested. The biggest takeaway is that there is clear separation between conventional, ENERGY STAR and best-in-class rack conveyors in terms of water and energy use.

Conveyor Case Study

FSTC researchers changed out a large hotel's flight conveyor dishwasher with a best-in-class, 66-inch rack-conveyor dishwasher (Figure 6). The original flight type machine had an external gas booster heater, and the replacement rack conveyor machine had an integrated electric booster heater. The site was still able to wash dishes with the same level of speed and labor with the smaller machine with significant savings. The flight-conveyor had limited diagnostic features and could not self-diagnose that the rinse sensor fingers had dropped too low and were malfunctioning (Figure 7), thus fresh water was used for an average of nine hours of rinse operation instead of three hours per day.

Dishwasher Change Out in a Large Hotel

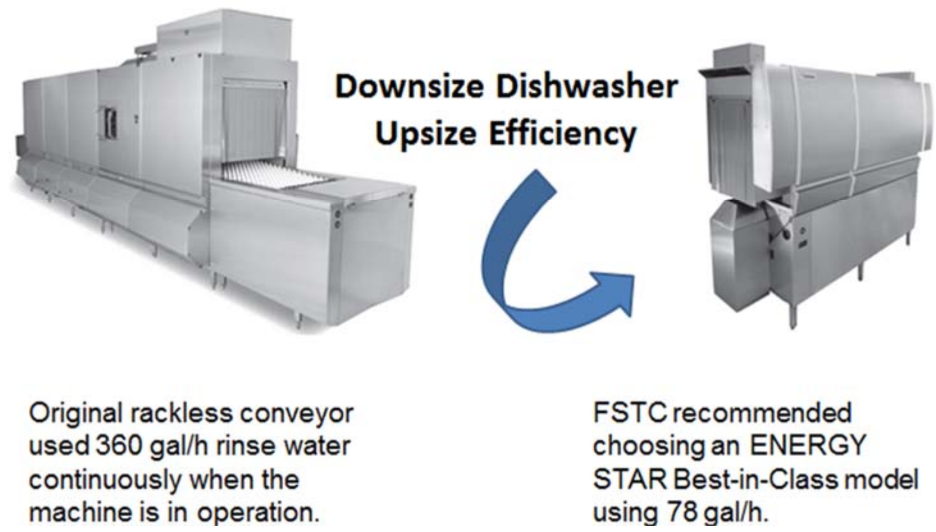

Figure 6: Dishwasher right-sizing.

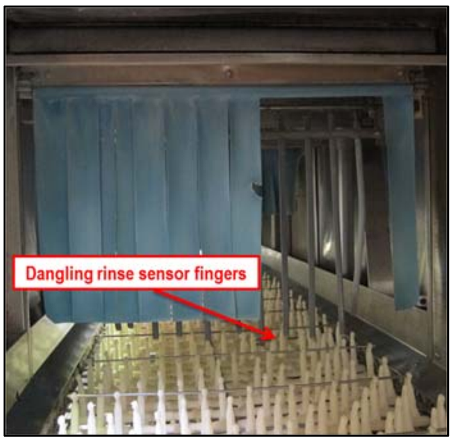

Figure 7. Rinse-sensor malfunction on original flight-conveyor dishwasher.

A payback period of less than one year was possible in this hotel where there was extreme water and gas savings of greater than 90%. (Table 4). FSTC experience has shown that in a typical dishroom, a "like for like" rack-conveyor replacement from a conventional to best-in-class unit along with savings from custom water and energy rebates in California would provide a payback period in the 2 to 3 year range.

Table 4. Conveyor Dishwasher Cost Comparison for a Hotel Kitchen.

	Original Flight Conveyor	Replacement Rack Conveyor
Water Use (HCFl)	1,807	193
Gas Use (therms)	18,400	1,521
Electricity Use (kWh)	145,132	65,383
Operating Cost	$53,300	$12,730
Annual Operating Savings		$40,560
Water, Gas and Electricity Rebates		$16,940
Total First-Year Savings	Not Including Chemical Savings	$57,500
Cost of Replacement Project		($47,300)
Payback Period (years)		.82

Emerging Technologies

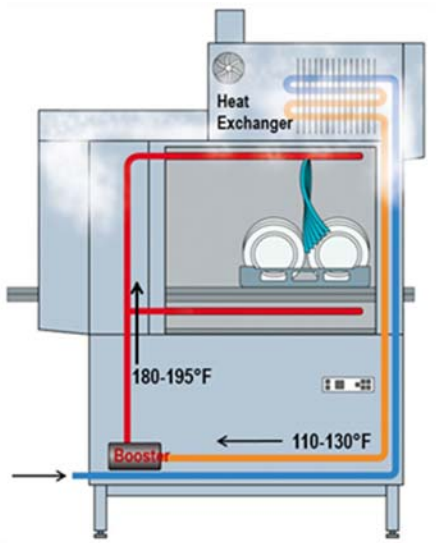

Figure 8. Rinse water heating schematic for conveyor with exhaust-heat recovery system (photo credit: Winterhalter).

New commercial dishwashers are designed to decrease operating costs by adding options like heat recovery systems, powered tank filtration, advanced diagnostics and controls, user interfaces, and auto clean and descaling program. These features reduce water, energy, and chemical use, mitigate operator errors, and also reduce maintenance and repair costs. New machines are designed to use significantly less hot water than older legacy machines, while offering improved cleaning and sanitization performance.

Exhaust heat recovery systems are effective at recovering waste heat by using a heat exchanger to condense steam and use the captured heat to preheat incoming cold water used for the rinse operation. During normal rinse operation, the machine is supplied entirely with cold water, performing all requisite heating at the point of use, and eliminating dependence on the building's domestic hot water supply (Figure 8).

Figure 9. Advanced controls and user interface (photo credit: Meiko).

Advanced controls and user interfaces add smarts to conveyor dishwashers and have become commercially available on a few units (Figure 9). These intelligent machines can limit their own operation by alerting dishroom staff that operating conditions are not ideal. They effectively force dishroom staff to address minor issues before they become major issues that can cause acute or chronic water waste events or total machine failure. For example, if the tank drain is left open after tank filling, the advanced diagnostics in the machine will not allow the dishwasher to operate in rinse mode until the alert is recognized and drain valve closed by staff.

There are several technologies such as integrated water and energy metering, wireless communications and active tank filtering (Figure 10) that if adopted from best-in-class flight conveyor dishmachines would further drive down the water, energy and chemical use of rack conveyor dishmachines.

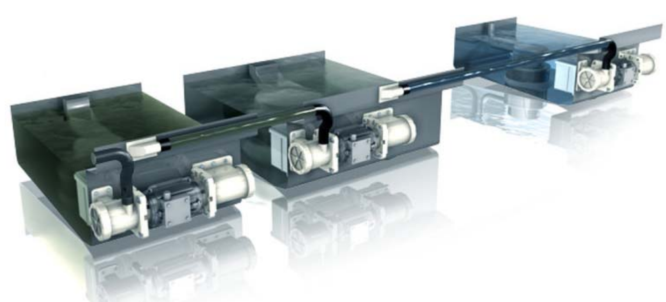

Figure 10. Active tank filtering technology (photo credit: Meiko).

Notes and Acknowledgments

References

Delagah, Amin. 2015. *Conveyor Dishwasher Performance Field Evaluation Report*. Los Angeles, CA: The Metropolitan Water District of Southern California. FSTC Report Number P20004-R0. http://bewaterwise.com/

Delagah, A., Davis, R., Slater, M., Karas, A., 2017. *Results from 20 Field Monitoring Projects on Rack and Flight Conveyor Dishwashers in Commercial Kitchens*. Atlanta, GA: ASHRAE Winter Conference Paper. www.ashrae.org

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