

Measured Impacts of High Efficiency Domestic Clothes Washers in a Community

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ABSTRACT

The U.S. market for domestic clothes washers is currently dominated by conventional vertical-axis washers that typically require approximately 40 gallons of water for each wash load. Although the current market for high efficiency clothes washers that use much less water and energy is quite small, it is growing slowly as manufacturers make machines based on tumble action, horizontal-axis designs available and as information about the performance and benefits of such machines is developed and made available to consumers.

To help build awareness of these benefits and to accelerate markets for high efficiency washers, the Department of Energy (DOE), under its **ENERGY STAR**[®] Program and in cooperation with a major manufacturer of high efficiency washers, conducted a field evaluation of high efficiency washers using Bern, Kansas as a test bed. Baseline washing machine performance data as well as consumer washing behavior were obtained from data collected on the existing machines of more than 100 participants in this instrumented study. Following a 2-month initial study period, all conventional machines were replaced by high efficiency, tumble-action washers, and the study continued for 3 months. Based on measured data from over 20,000 loads of laundry, the impact of the washer replacement on (1) individual customers' energy and water consumption, (2) customers' laundry habits and perceptions, and (3) the community's water supply and waste water systems were determined. The study, its findings, and how information from the experiment was used to improve national awareness of high efficiency clothes washer benefits are described in this paper.

Introduction

Background

Conventional domestic clothes washers use approximately 40 gallons of water to wash a typical load of clothes. This fact combined with the knowledge that, on average, most U.S. homes wash about one load a day, makes automatic clothes washers one of the highest end uses of water in today's home. About 35 billion loads of laundry are washed annually in the United States, and this activity consumes 2.6% of the total residential energy use (*Home Energy* 1996). Only a relatively small amount of energy is used by the washer to operate the motor and controls. A much larger component is the energy needed to heat the water and the energy needed to dry the washed clothes. Consequently, washers that have low hot water requirements and effective spin cycles (to remove water from the clothing, thereby reducing the energy needed by the dryer) tend to be efficient. As long as the laundry throughput (load size) is not compromised, these washers will use less water and energy.

Most clothes washers produced for the U.S. consumer are vertical axis (v-axis) washers with a central agitator (see Fig. 1). While there are variations, most v-axis washers suspend the clothes in a tub of water for washing and rinsing. However, some U.S. appliance manufacturers are beginning to produce high efficiency residential clothes washers designed for the domestic market. These machines are based on a horizontal axis or h-axis design in which the clothing is tumbled through a small bath of

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water rather than being immersed in a tub of water as is conventionally done with most washers made and sold in the United States. Estimates have shown that these machines should use about 40% of the energy needed for a conventional clothes washer and approximately 60% of the water consumed by a conventional, vertical axis washer. Further, information suggests that the high spin speed of h-axis models tends to leave the clothes with less moisture, and this reduces the time needed to dry the clothes in the dryer. Consequently, the dryer (gas or electric) consumes less energy. The extent to which these savings can be realized in a real-world field setting will have a large influence on the market for these machines.

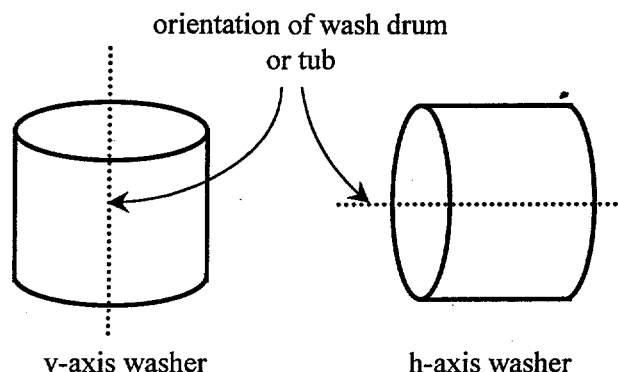


Fig. 1. Vertical and Horizontal-Axis Washer Design

High efficiency washing machines face two major challenges to wide-scale adoption by consumers—cost and awareness. The high efficiency machines do cost more than the conventional machines, which is not likely to significantly improve with increased demand. Further, few consumers are aware of the technology and its benefits in terms of cleaning performance and reduced operating cost, water use, and energy consumption.

Scope

Given this background, the objectives of this project were to:

- evaluate the energy and water savings of high efficiency, h-axis washers in a community which has been converted to the new washer design,
- demonstrate the water and energy savings and other findings, and
- develop information helpful to utilities and others with an eye towards moving the current clothes washer market to higher efficiency options.

This project is a key element under the DOE **ENERGY STAR**[®] market transformation program.

Methodology

To evaluate the real-world performance of h-axis washers and increase awareness of the benefits of h-axis washers, a small town, Bern, Kansas, was located and used as a test bed for

evaluating the performance and acceptability of h-axis washers. The 5-month study consisted of the following:

- (A) gathering water consumption data on the existing v-axis washing machines in Bern to establish a baseline against which the water use pattern of high efficiency h-axis washers can be measured,
- (B) switching out these washers with high efficiency h-axis models, and
- (C) determining the savings in water and energy consumption, changes in laundry habits, and other impacts experienced by the town and its residents from a changeover to the h-axis machines.

It was anticipated that much of the success of the field study depended upon (1) developing a set of desirable characteristics for the test site and (2) finding a site that possessed these characteristics. These characteristics included the following: small size, presence of community water utilities, experience with community water problems, and participant willingness and enthusiasm. The town of Bern, Kansas, was selected based on a high ranking of all of the criteria mentioned above. The town is a mostly farming community located 75 miles west of St. Joseph, Missouri, and 4 miles south of the Nebraska state line.

With the help of a three-person volunteer team from Bern, information from potential study participants including laundry habits, customer profiles, types of existing washers, dryers and hot water heating systems was assembled and analyzed. A total of 104 participants (washer owners) elected to join the study and submitted an application in time to be included. These "participants" included three washers in Bern's local Laundromat, one washer in the Bern High School, one in Bern's vet clinic and one in Bern's meat plant. All of those electing to join the study (1) had a water meter and purchased water either from the city of Bern or from the rural water district, (2) currently had a clothes washer, and (3) were sufficiently interested in the study to commit to a 5-month data collection period.

Some of the general information about the participants and their laundry behavior and equipment is outlined below.

- The average Bern household is comprised of two adults and two children; however, some families have as many as two adults and five children.
- 88% of the participants use an electric dryer, 11% use a gas dryer and 1% do not own a dryer. The average age of a Bern dryer is 12 years.
- 64% of the participants use propane for water heating, and 36% use electricity. (Natural gas is not available.)
- The number of loads washed per week depends on the household size. Estimates by the residents indicated that the average household washes 11 loads each week.

A central objective of the field study was to determine the impacts of replacing existing, conventional washers with high efficiency, horizontal-axis (h-axis) washers. There are a number of potential impacts that a replacement h-axis washer could have, including changes in the following:

- ☐ water consumption and its effect on the customer and water/sewer utility;
- ☐ energy consumption of the washer itself and in the amount of hot water used;
- ☐ load weights (i.e., for the same "throughput" of laundry, the weight of each load determines the number of loads of wash needed to be done);

- ❑ detergent use and patterns;
- ❑ the "dryness" of loads removed from the washer. The ability of the washer to extract water in the final spin affects the energy needed by the dryer;
- ❑ customer satisfaction as related to cleaning/drying performance; and
- ❑ customer laundry habits.

The experimental design included individually metering the participant's conventional v-axis washers and recording data from this instrumentation as well as from participants on each load of laundry that they washed for a 2-month period (phase I of the project). Following phase I, all of the participants' washers were replaced by the high efficiency, h-axis washer, the instrumentation reinstalled, and the experiment continued for a 3-month period (phase II of the project). The changes in performance, laundry patterns, participant satisfaction and other potential impacts listed above were determined by comparing phase I and phase II data. In addition, the influence that clothes washers had on Bern's water supply and waste water generation for two days of heavy washing – one Saturday during phase I and the other during phase II was determined.

The following describes the equipment and instrumentation used in this study.

Water Meters. Two water meters, accurate to $\sim 1/200$ of a gallon and modified to have digital readouts at washer height, were installed on each washer in the project. One measured the hot water consumption and the other the cold. Participants simply recorded the readings from the hot and cold readouts after each load of laundry was completed, and the conversion of these readings into gallons of water was done during the data analysis phase of the project. Each meter at floor level also had the conventional analog register from which cumulative hot and cold water consumption could be determined. These registers were read periodically by project staff and used to check digital readout recordings made by participants.

Weighing Scale. Each participant was given a scale with a precision of ± 1 oz for obtaining the pre- and post-wash (but before drying) weight of each load.

Laundry Basket. Each participant was given a standard laundry basket to use for weighing the loads. This tare weight was later subtracted from the weight readings in the data analysis.

Measuring Cup. Each participant was given a standard graduated detergent cup to use for each load.

Temperature Measurements. At the beginning of phase I when water meters were first installed and at the end of phase I and beginning and end of phase II, hot and cold water temperatures at the washer were carefully measured by the installation team and used in the analysis for both phases of the study.

Washer Energy Consumption. The electrical energy consumption (kWh required to operate a washer's motor and controls for a cycle) of most of the original phase I washers in the study was determined from available data based on brand and model number. In those cases where a washer was too old and energy consumption information was unknown, washer energy consumption was taken to be the average of the washer energy consumption of the remaining phase I washers. This provided a conservative (lower energy use) estimate for the older washers. The average washer energy consumption from prior field experiments on the h-axis washer was used in phase II of the Bern Study.

Data Sheets/Notebook. Finally, each participant in the project was given a notebook containing data sheets to be filled out – one for each load of laundry, and a set of instructions for data entry and managing the notebook. Each data sheet contained a unique serial number to help manage the data and to track data from individual participants. A slightly different data sheet format was provided for phase I versus phase II to account for differences in control options for the types of machines.

Analysis was then performed on data from these measurements. The overall process for assembling a database of information for the study consisted of the following seven steps:

1. data entry by the Bern participants on the pre-formatted data sheets;
2. optical scanning of the data sheets supplemented by keyboard entries to generate a data table;
3. formatting and importing the data table into a spreadsheet or a field- and record-delimited file;
4. importing the spreadsheet or field/record-delimited file into a database program;
5. creating sequential query language (SQL) queries in the database program to assign data records to participants;
6. creating SQL queries to sort, filter, and screen all data and to perform calculations and analyses needed to address the study objectives; and
7. plotting overall and individual participant results.

Based on this process, data from over 7,000 washer loads in phase I and over 13,000 loads in phase II were analyzed to address the objectives of the study, and the results are reported in the next section of this paper.

Results

The tumble-action principle of the h-axis washer represents a major design change from the conventional, v-axis washers. Therefore, it was reasonable to expect that in the Bern Study, there could be significant impacts resulting from a changeover from conventional, v-axis washers to the h-axis design.

Several factors did not vary from phase I to phase II. These factors included load size or throughput, detergent consumption, use of other additives, laundry habits, and drying habits. Most of these factors are determined by individual preference rather than the laundering method.

There was some change between phase I and II in the wash settings chosen. Hot water was used for the wash cycle more often in phase II, and warm water was used for washing more frequently in phase I. The improvements in cleaning satisfaction during phase II are certainly worth noting and the difference in cleaning performance for either the phase I or II washers between these different wash settings was insignificant and would not explain this improvement. The most significant change occurred in the fraction of loads in which the participants were "completely satisfied" with cleaning. This fraction rose from 15% in phase I to 45% in phase II.

Energy and Water Consumption

As anticipated, water and energy consumption decreased significantly with the use of the h-axis washers. The energy included that used by the washer motor and controls (machine energy) and the thermal energy needed for heating the water in the water heater. The decreased water consumption also yielded a decrease in the amount of wastewater produced. Figure 2 illustrates the changes in water and energy consumption.

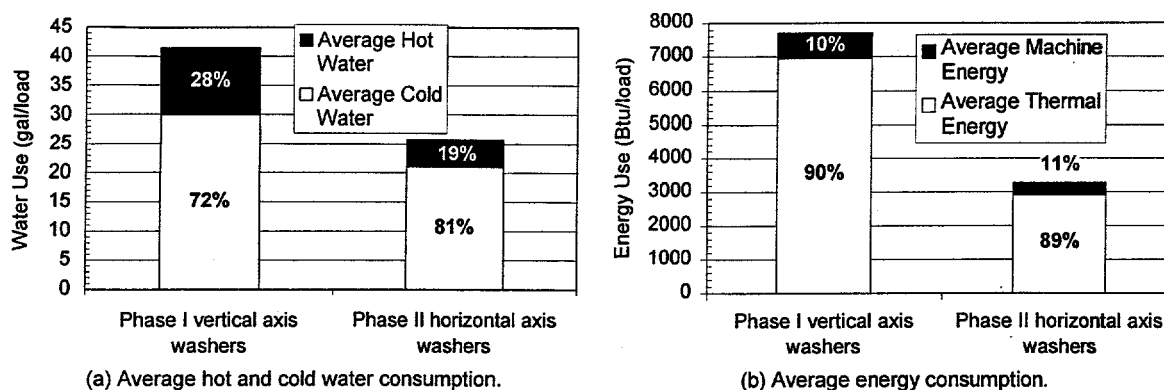


Fig. 2. Average water and energy consumed by phase I and II washers.

In phase I, the average total water use ranged from ~18 gallons to more than 60 gallons per load, with an average of 41.5 gallons per load (29.9 for cold and 11.6 for hot). As seen in the figure, the percentage of cold and hot water on average was 72% and 28% of the water use per load, respectively. For any given wash load, the percentage of hot and cold will vary depending on the wash/rinse and load settings used by the customer. In phase II, the total water consumption ranged from 17 to approximately 37 gallons/load, with an average of 25.8 gallons per load (21 for cold and 4.8 for hot). The percentage of cold and hot water used is given in the figure. Across all study participants, this represents an average per load water savings of 15.7 gallons or 37.8%.

Two SuperWash Saturdays (SWSs) were held during this study. On these days, the participants saved their laundry during the week and performed the bulk of their washing between 10:00 a.m. and 4:00 p.m. to more accurately assess the effects on the community's water supply and waste water generation. The results from these days correlate with the savings projected above. During the first SWS, the phase I washers consumed 20,454 gallons of water. During the second SWS, an equal number of phase II, h-axis washers used 13,091 gallons of water—a 36% reduction in overall washer water consumption.

With both washers, the majority of energy consumption is from the energy needed to heat the water. The percentage of machine versus thermal energy used by phase I and II washers is shown in the above figure. The average h-axis washer consumed 42.4% of the energy used by a typical v-axis washer—an energy savings of 57.6%.

Load- Settings and Washer Water Use

An important factor that affected the amount of water used by participants was the load setting of the washer that determines the amount of water used by the washer for each wash load. This is an important issue for the phase I (v-axis) washer since the level is set manually for each wash load. If the setting is higher than necessary for a load, water is wasted and the washer operates less efficiently. If the setting is too low, then cleaning performance and rinsing may be compromised. In many cases, the phase I v-axis washers were capable of being set at one of five different load settings ranging from mini to extra-large. The Phase II h-axis washer did not have a manual load setting but instead automatically regulated the amount of water used for each wash.

Overall for all participants, the average water use (in gallons) for the different load settings in phase I were: 28.5 for mini, 30.5 for small, 37.3 for medium, 43.5 for large, and 46.1 for extra large. In comparison, the phase II washers used on average 25.8 gallons per wash load. Also, it was

determined that most of the wash loads performed in phase I were at the higher load settings. Over 87 % of the loads were washed at the medium, large, and extra-large settings of the washer.

Cleaning Performance

There were five categories from which the participants could choose to indicate cleaning satisfaction: completely, very, somewhat, not very, and not at all satisfied. Apparently, there was noted improvement in satisfaction levels from the changeover to the phase II washer. On average, participants were at least "very satisfied" with 70% of the loads washed in Phase I and 96% of the loads washed in Phase II with the h-axis washers. The largest improvement was found in the "completely satisfied" category in which the fraction of loads meeting this level increased nearly three-fold.

There are, of course, several factors that could affect the participants' level of satisfaction with washer performance. These include the initial soil level, use of bleach and other additives, initial washer age, temperature settings, and type of detergent. Most of these factors remained relatively constant in both phases of the study. It is interesting to note, however, that the use by some of the participants of a detergent formulated specifically for these high efficiency h-axis washers did not have much impact (either negative or positive) on the participants' level of satisfaction.

Of all of the factors discussed above, the vintage of the phase I washer merits further discussion. Each participant in the study judged cleaning performance based on their experience with their original phase I washer. It seems reasonable to anticipate that participants with older phase I washers would see more cleaning improvement with a phase II washer than would participants whose original washer was newer. That is, the newer the washer, the better its cleaning performance would likely be and the less of an impact the phase II washer would make on cleaning. Since the phase I washers ranged in age from almost new to more than 20-years old, a participant's judgement of the relative improvement in cleaning by changing to the phase II washer could be significantly affected by the original washer.

To test this assumption and to establish a basis for conclusions on washer cleaning performance, we segregated phase I washers according to vintage and determined cleaning satisfaction levels as before. While there was some variability in the results, the younger the phase I washer, the higher the satisfaction with its cleaning performance. This is especially evident with the phase I washers which were "brand new" (1 year old or newer) as compared to older washers. As would be expected, participants with brand new washers were at least "very satisfied" most of the time (about 86% of loads washed). For older washers, the dissatisfaction level generally increased with increasing age. Next the phase II washers were segregated by the vintage of the original phase I washers to determine the change in cleaning satisfaction. In all vintage categories, such as 1 year old and less, the level of at least "very satisfied" increased to 90% or better. The greatest changes in satisfaction occurred for the oldest phase I machines.

Moisture removal performance was also examined in both phases. The ability of a washer to remove moisture in the final spin is characterized by the remaining moisture content, or RMC, which is the quotient of the weight of moisture remaining in a load to the dry weight of the load. Lower RMCs (more moisture removed by the washer) are desirable from the standpoint of reduced dryer energy consumption although energy use by the dryer (either gas or electric) was not measured in this study. A high-speed final spin in all washers is used to remove moisture from the load and to reduce the RMC. The Phase II h-axis washers came with a switch that allowed the user to select between two final spin

speeds: a normal one and a higher one. At the customer's option, the higher spin speed could be used for maximum moisture extraction (max extract).

In the study, a field RMC was determined by weighing each load prior to washing and before drying. Three sets of RMC data were prepared based on (1) Phase I loads, (2) Phase II loads without the max extract feature activated, and (3) Phase II loads with max extract enabled. Trend fits of the RMC data as functions of dry load (or prewash) weight are shown in Fig. 3. With increasing load weight, the RMC for all machines and settings decreased as shown. The average weight of a load for each phase of the study was about 7 pounds, and this leads to a Phase II RMC of about 0.5 and a Phase I RMC somewhat higher. The benefit of the max extract (high speed final spin) for the Phase II washer is evident.

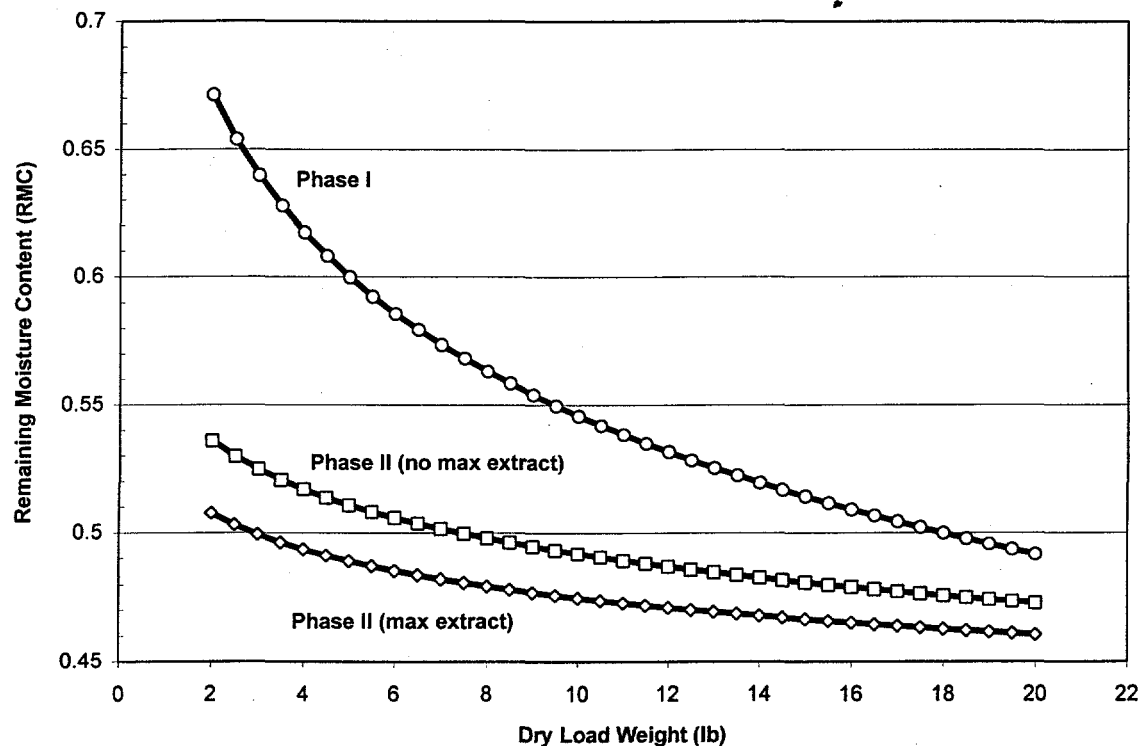


Fig. 3. Dependence of remaining moisture content on load weight.

Economic Savings and Payback

Although improved washing performance is a benefit, only energy and water savings were used to perform an economic analysis. The value of energy and water savings depends on the cost of these utilities. Although Bern has experienced water availability problems in the past, their water rates are low (\$2.50 to \$2.75/1000 gallons), and there is no charge for wastewater treatment. Water cost savings would amount to less than \$20/year based on measured water savings of 130 gallons/week through replacement of the v-axis machine with the h-axis model. Clearly, there are many areas in the United States where water/wastewater in particular are much higher than in Bern; consequently, savings in water costs would be much higher. In Boston, for example, water and sewer rates are about \$7.35 for the first 1000 gallons of water and the h-axis machine could save about \$50/year in water/sewer costs. Some Bern residents have electric resistance storage water heaters, and assuming an efficiency of 85%,

the h-axis washers would produce energy savings of about \$67/year at a rate of \$0.0849/kWh (DOE 1998).

Based on the energy/water savings, the simple payback for the h-axis washer can range from 4 years for an h-axis washer with a \$400 cost premium to much less, depending on the cost premium and comparative performance (in terms of energy and water savings) of the washer as well as the local electric and water rates. There can be significant differences in the cost of h-axis machines, and there is growing interest on the part of utilities in providing incentives to help grow markets for high-efficiency washers.

Conclusions

The results of this study indicate that v-axis washers, on average, use over 40 gallons of water and over 7,700 Btu or 2.25 kWh of end-use energy per load of wash and that h-axis washers provide close to 38% water and 58% energy savings over these v-axis washers. Based on these averages, close to 1.4 trillion gallons of water and 270 trillion Btu of energy are used by these v-axis washers annually nationwide. Complete replacement of these washers with h-axis washers could save over 500 billion gallons of water and over 150 trillion Btu of energy annually. This would yield a national water cost savings of \$1.25 billion at the water rate of \$2.5/1000 gals/month and over \$3.7 billion in energy savings at the average 1997 electric rate of \$0.0849/kWh.

Customer laundry patterns such as days of the week when laundry is done, detergent use, how loads are dried, and use of additives did not change in the switchover to the h-axis model. In addition, customers made minor changes in their washer's wash/rinse temperature settings between study phases: 9% more loads were washed using a W/C temperature setting and 9% less loads were washed using a H/C temperature setting in phase II than in phase I.

The study showed that, on average, participants' overall satisfaction with the cleaning performance of the h-axis washer over their original v-axis washer was much improved. Although there was a slight difference in the wash temperatures used by the phase II versus the phase I washer, the difference did not contribute to the increased cleaning performance since there was insignificant differences between the cleaning performance of the phase I washer for the H/C and W/C wash/rinse settings. The same was true for the phase II washer.

The fraction of loads in which participants were "completely satisfied" with the cleaning performance increased threefold from 15 to 45% in the changeover from the average v-axis washer to the h-axis washer in the study. In cases where v-axis washers that were 1-year old or newer (13 washers in this group) were replaced by the h-axis washer, the improvement in cleaning performance was notable: the number of loads in which participants were completely or very satisfied rose from 86% to 97% of all loads washed for that vintage of washer. There was only a marginal improvement in cleaning satisfaction as a result of the use of the high efficiency detergent over the conventional detergent in phase II of the study. With either type detergent, participants appeared to be well pleased.

The results from measurements of the "wetness" of loads removed from the washers were consistent in the study. Participants appeared to be more satisfied with the dryness of loads removed from the h-axis washer than from the typical, phase I v-axis washer. Participants appeared to be completely satisfied with the level of dryness in 9% of the phase I loads and 43% of the phase II, h-axis loads. This subjective measurement was corroborated by calculations of remaining moisture content which showed that the h-axis washer—particularly if aided by the high-speed spin setting—performed a better job of moisture removal for typical loads than the average v-axis washer from phase

I of the study. With higher load weights, however, the improvement (reduction) in remaining moisture content between the two washer types became less noticeable.

Major interests in the study were changes in the water and energy consumption between phases I and II. On average across all participants, the h-axis washer required only 62% of the water and 42% of the energy needed by the typical v-axis washer. The impacts of these reductions are shown in Fig. 4 and 5 where the cumulative water and energy consumption of all of the instrumented washers were measured and the results plotted.

In each Figure, the trendline showing the total water or energy that would have been consumed if the phase I washers had remained in place is shown. The presence of two SuperWash Saturdays, one in phase I and the other in phase II can be seen along with the week needed for the phase I-II transition. These savings in energy and water will continue to grow and produce benefits to the participants and the community of Bern. By converting to the h-axis washer, the 103 study participants will continue to save the community of Bern more than 50,000 gallons of water every month or over 600,000 gallons every year. Interestingly, the volume of the town's water storage tower is 50,000 gallons; consequently the town saves one tankful each month. The change in energy consumption exhibits a similar trend as shown in Fig. 5.

In summary, the Bern Washer study showed the field performance of tumble-action, h-axis washers to produce significant savings in energy and water as compared with conventional washers found in the field. The study showed that a transition to the h-axis technology did not present any extra challenges that must be overcome by customers, or that they did not have to adjust any laundry habits and patterns as a result of the replacement. Of the variables that could affect participant satisfaction, none were found to change a conclusion of superior cleaning performance and satisfaction with post-wash load dryness. The study demonstrated that large amounts of energy and water used by the conventional phase I washers in Bern are not needed to clean clothes effectively. The h-axis technology was shown to use much less water and energy than the phase I conventional washers while at the same time, was found to improve cleaning performance and produced a high level of overall customer satisfaction.

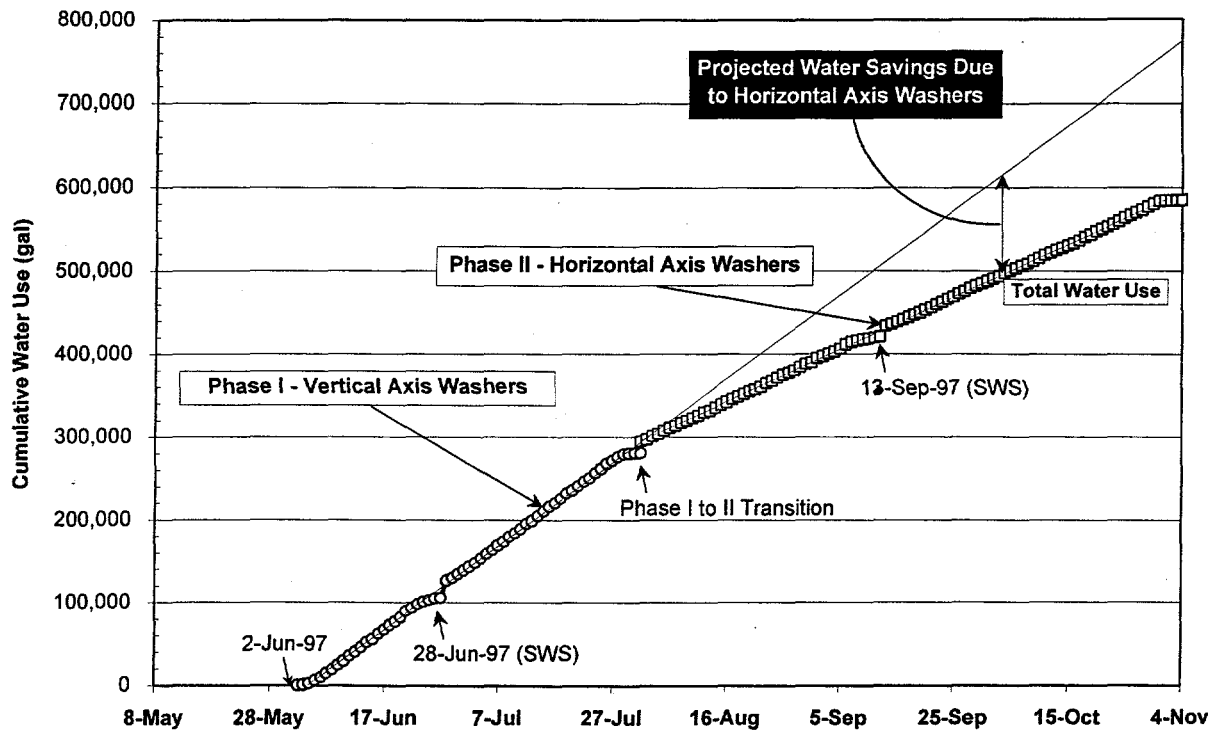


Fig. 4. Projected impact of washer replacement on water consumption.

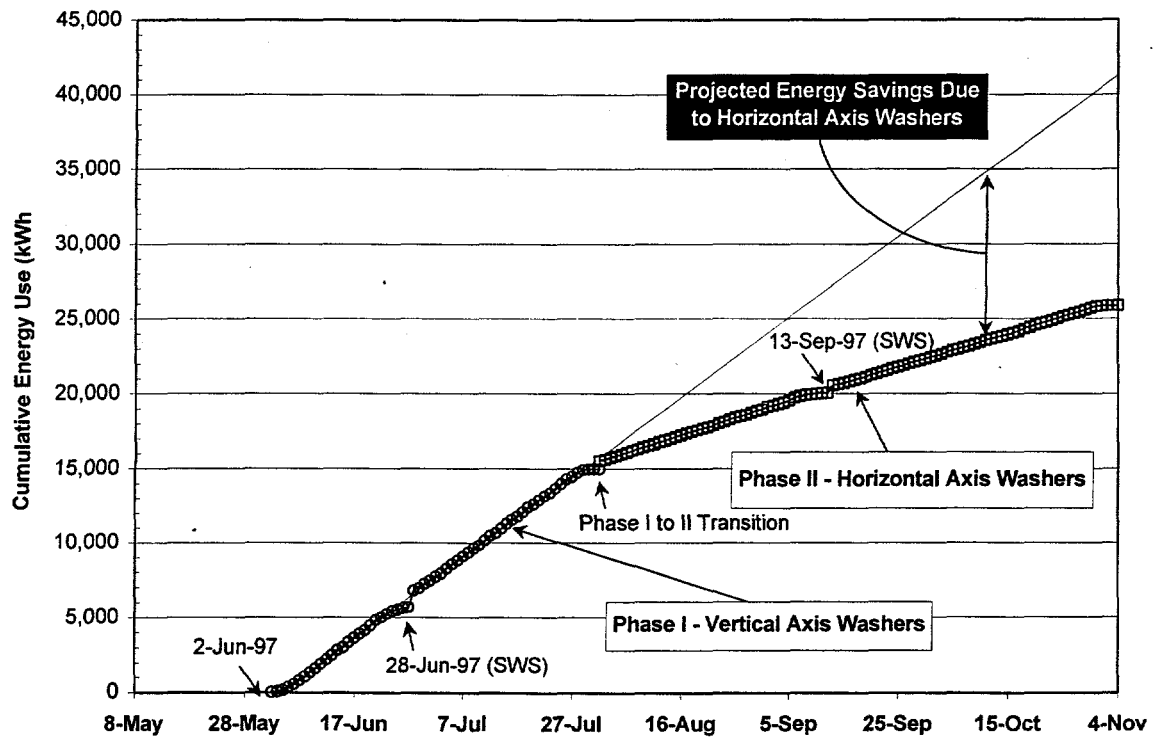


Fig 5. Projected impact of washer replacement on energy consumption.

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Additional Information

A more detailed description of the study and its results are given in a report prepared by ORNL (Tomlinson and Rizy 1998). A electronic copy is available on the internet at the DOE's **ENERGY STAR**® web site, <http://www.energystar.gov/bern.html>, or contact the authors at P.O. Box 2008, MS-6070, Oak Ridge, Tennessee, 37831, (423) 574-0291. Also, additional information on Bern and the participants is available at the web site, http://neptune.maytag.com/maytag_bern/default.asp.

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