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Bern Clothes Washer Study Final Report

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It comes as a surprise to many that conventional domestic clothes washers use about 40 gallons of water – water weighing more than 300 pounds – to wash a load of clothes which typically may weigh only 7 pounds. This fact combined with knowledge that, on average, U.S. homes wash about one wash load each day, makes automatic clothes washers one of the highest end-uses of water in today's homes. About 35 billion loads of laundry are washed annually in the U.S. and this consumes 2.6% of the total residential energy use[1]. Only a relatively small amount of energy is used by the clothes washer itself to operate the motor and controls. A much larger component is in the energy needed to heat the water used by the washer and in the energy needed to dry clothes once they have been washed. Consequently, washers that have low hot water requirements and have effective spin cycles to remove moisture from the clothing thereby reducing the energy needed by the dryer, tend to be efficient and as long as the laundry throughput (load size) is not compromised, 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. While there are variations, most v-axis washers suspend the clothes in a tub of water for washing and rinsing. As an alternative, the horizontal axis (h-axis) washer tumbles the wash load repeatedly through a small pool of water at the bottom of the tub to produce the needed agitation. This tends to reduce the need for both hot and cold water. The h-axis washer, popular in Europe, has a very limited market share in the U.S. at present. Yet, estimates have shown that a large quantity of energy and water could be saved through the replacement of conventional v-axis washers with the h-axis design. 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 design,
- to demonstrate the findings, and
- to develop information helpful to utilities (energy and water) 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.

The small town of Bern, Kansas (population approximately 200) was selected for this project. During phase I of the study, 103 clothes washers in the town and surrounding Rural Water District were instrumented so that data on customer profiles, laundry habits, laundry throughput (loads and load weight), and energy and water consumption could be measured. Following a two-month data collection period, all of the washers were replaced by new, h-axis clothes washers, and the experiment continued for an additional three-month period. Overall, detailed data were collected and analyzed on more than 20,000 loads and nearly 70 tons of wash done by all of the participants over a wide range of real-world conditions.

Overall, it was found that the changeover to the h-axis washer reduced the average water consumption from 41.5 gallons/load to 25.8 gallons/load – a water savings of about 38%. The h-axis washer's energy consumption including washer energy and hot water energy fell by 58% due to hot water savings and the impact of a highly efficient motor in the h-axis. The remaining moisture content of damp loads removed from the h-axis washers was, on average, 7% lower than for loads removed from participants' phase I v-axis washers, and this would tend to improve the energy savings from the changeover still further.

[1] "Revolution, Not Agitation: A New Spin on Clothes Washing", *Home Energy*, Vol. 13, No. 6, November/December 1996, pp. 7-8.

The data and subsequent analyses also showed that across all loads, temperature settings, use of detergent and other additives, participants found the cleaning performance of the h-axis technology to be generally superior to their phase I v-axis washer irrespective of its age. Participants seemed to adapt easily to the h-axis design, and laundry habits (average load weights, detergent use, how loads were dried, when loads were washed during the week, wash/rinse temperatures and other factors) remained largely unchanged from phase I to phase II.

These findings demonstrate convincingly that the tumble-action technology (h-axis design) is much more energy and water-efficient than the technology present in clothes washers found in the field today. Taken together, these findings suggest that a changeover to h-axis technology delivers large savings in energy and water to the customer with an improvement in cleaning performance and utility.

ABSTRACT

The U.S. market for domestic clothes washers is currently dominated by conventional, vertical axis washers, which typically require about 40 gallons of water for each load. Although small for an individual load, the fact that 35 billion loads of laundry are washed annually in the U.S. results in a substantial quantity of water and energy use. Although much smaller, today=s market for high-efficiency clothes washers which use much less water and energy is growing albeit slowly as manufacturers are making washers based around tumble-action, horizontal axis designs available, information about their performance and benefits is being developed, and consumers are made aware of these benefits.

To help build awareness of these benefits and to accelerate markets for high-efficiency washers, DOE, under its Energy Star Program and in cooperation with Maytag Appliances, conducted a field-evaluation of high-efficiency washers using Bern, Kansas (population approximately 200) as a test bed. Baseline washer performance data as well as customer washing behavior were obtained from data collected on the existing washers of more than 100 participants in this instrumented study. Following a 2-month initial study period, all conventional washers were replaced by high-efficiency, tumble action washers, and the experiment continued for another 3-month period. 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 and are reported.

GLOSSARY

btu	British thermal unit or 3.6 million joules of energy
C/C	Temperature setting of washer set on cold water wash and cold water rinse
Cold	Cold water use of washer
CRADA	Cooperative research and development agreement
DOE	U.S. Department of Energy
Field	Field data or data collected in a “real world” setting such as a person’s home rather than in a tightly-controlled laboratory setting
gal or gals	A measure of water use in gallons. One gallon is equivalent to 3.7854 liters
Gallons/load	Gallons of water use per number of loads by the washer
gpm	Gallons per minute refers to the rate of water use (gallons) over a minute time period
H/C	Temperature setting of washer set on hot water wash and cold water rinse
H-axis	Horizontal-axis washer design in which the axis of rotation of the washer drum is horizontal to the floor on which the washer sits
Hot	Hot water use of washer
I.D.	Identification number or customer number assigned to each participant in the study
kWh	Kilowatt-hour of energy use equivalent to 3413 Btu
Lb or lbs	A pound which is a measurement of weight equal to 2.2046 kilograms
Load or load cycle or cycle	A complete wash/rinse/spin cycle of a washer or a complete cleaning of dirty clothes
ORNL	Oak Ridge National Laboratory, Oak Ridge, Tennessee, managed by Lockheed Martin Energy Research Corp. for the U.S. DOE
oz	Ounce or a unit of weight equal to one-sixteenth of a pound or approximately 28.35 grams.
Phase I	First two months of the Bern Washer Study using conventional v-axis washers
Phase II	Last three months of the Bern Washer Study using new h-axis washers
RMC	Remaining moisture content or moisture remaining in the cleaned laundry after completing the washer’s final spin cycle
RWD	Rural water district
SWS	Superwash Saturdays which were two high impact wash days conducted on June 28^{th} for phase I and September 13^{th} for phase II
Total water	Hot plus cold water use of washer combined
TUF	Temperature utilization factor which refers to the percent of loads washed at various wash/rinse washer temperature settings
V-axis	Vertical axis (conventional washer design) in which the axis of rotation of the washer agitator is vertical to the floor
W/C	Temperature setting of washer set on warm water wash and cold water rinse
W/W	Temperature setting of washer set on warm water wash and warm water rinse

1. OVERVIEW AND OBJECTIVE OF THE FIELD STUDY

Some U.S. appliance manufacturers are beginning to produce high-efficiency residential clothes washers designed for the U.S. market. These machines are based on a horizontal axis or h-axis design in which the clothing is tumbled through a small bath of 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 have about 60% of the water consumption of 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 Xgas or electric X consumes less energy. The extent to which these savings in energy and water which have been demonstrated in the laboratory, can be realized in a real-world field setting will have a large influence on the market for these machines.

Market Challenges - High-efficiency washing machines face challenges to wide-scale adoption by consumers. First, these machines tend to cost more than the conventional machines. Increased sales will foster higher production volumes and better, more efficient plant assembly line utilization, and, combined with increased competition between manufacturers for market share, will tend to reduce first costs to the consumer. However, indications from manufacturers are that a price premium for high-efficiency washers will remain even in a fully developed market. The ultimate market for high-efficiency washers will depend largely on the extent to which performance advantages of these machines can be made known to justify the higher price.

According to a survey conducted through a consortium of utilities and DOE, 17% of households who own a washing machine intend to purchase a new machine in the next two years. Of this number, only 0.4% reported that they will probably buy a horizontal-axis, high-efficiency washer in this time period. These results are not surprising in view of the fact that only 2% of the current U.S. clothes washer market is for horizontal-axis, high efficiency washers. The survey found that a major reason for consumers= not opting for the high-efficiency machine is due to awareness: consumers were simply not aware of the technology and its benefits in terms of cleaning performance, reduced operating cost, less water use, and lowered energy consumption. This lack of awareness extends from consumers shopping for a clothes washer, to electric and gas utilities who manage energy efficiency and customer service programs, and to water utilities looking at ways to encourage water conservation. The survey also showed that only 25% of respondents were aware of horizontal-axis washers in residential settings, and in focus groups held as part of the study, very few participants mentioned this type of machine when asked to describe the different types of washers currently available. Other work has confirmed that increased awareness of the benefits of high-efficiency washers is the key to transforming the market.

The Bern Washer Study – To (1) evaluate the real-world performance of h-axis washers and (2) to help bring about increased 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 (A) gathering water consumption data on the existing washing machines in Bern to establish a baseline against which the water use pattern of high-efficiency washers can be measured, and (B) switching out these washers with high-efficiency h-axis models, and (C) determining the savings in water, energy consumption and changes in laundry habits other impacts experienced by the town and its residents from a changeover to the h-axis machines.

2. HOW THE STUDY WAS CONDUCTED

The study was conducted through a CRADA between Lockheed Martin Energy Research Corporation and Maytag Appliances with additional participation by the Kansas Rural Water Association, and the U.S. Bureau of Reclamation (providing municipal water metering and on-site personnel to help monitor Bern's community water systems). The study involved:

- establishing criteria for the field test site,
- locating the site (community) which best fulfilled the criteria,
- conducting the field study, and
- reporting the findings as through this report.

Further dissemination of project results to target audiences remains an important objective.

3. INITIATING THE PROJECT

3.1. SITE SELECTION CRITERIA

It was anticipated that much of the success of the field study depended on (1) developing a set of desirable characteristics for the test site to possess, and (2) finding a site which had these characteristics and whose residents were willing to participate in the study. The principal attributes to be possessed by the town included the following:

∃ *A small size.* The available resources (funds, equipment, instrumentation and personnel) limited the number of participants in the study to about 80 to 100. This represents the number of clothes washer sites (e.g. homes) which could be instrumented and used to evaluate the performance of the existing washer as well as the h-axis model. It was also important that a large fraction of the total number of washers in the town be included in the study so that the impact of clothes washers on the entire town's water consumption and waste water generation could be evaluated. Estimates have shown that the penetration of clothes washers in homes is about 78% nationally.[2] By assuming that the chosen town would have the same penetration of clothes washers as found nationally, the selected town would need to have 100 to 130 homes and have a population in the range of 200 to 300 persons. This estimate was based on the assumption that most homeowners with washers would qualify and become participants in the study.

• *Presence of community water utilities*. An objective of the study was to determine the impact of clothes washers on municipal utilities, that is, the impact on a town's water supply and wastewater disposal systems. To meet this objective, the study needed to take place in a town which had a central water utility which metered the water sold to each customer, and a sewer system for collecting and treating waste water. While they may have a community water supply, many smaller, rural towns would tend to rely on subsurface waste disposal (septic tanks). A much smaller number of towns were expected to have centralized water and sewage disposal facilities, yet it was deemed essential that the town selected for the study have these features.

• *Presence of a water problem*. It was felt that interest and participation would be enhanced by conducting the study in a community which either had experienced a water problem or was currently plagued with a water-related problem, and to evaluate the degree to which h-axis

[2] *Appliance Magazine*, 44th Annual Report, Statistical Review, April 1997, p. 86.

washers could contribute to the solution. The communities "water problem" could have taken many forms such as: chronic seasonal droughts, inadequate waste water treatment facilities, a population growth which is outstripping the capacity of the water providers, or lack of availability of fresh water – all were candidate considerations in the site selection.

• *Participant willingness and enthusiasm*. The conventional approach to field studies of this type involves instrumentation and data collection that does not involve the participant and does not require assistance by participants. In this study, it was essential that the participants be willing to help gather the data from instrumentation placed on their washer and to provide information on each load of laundry washed. This approach was taken because the expense of distributed automatic data acquisition systems was far beyond the study's resources, and because some of the information needed for the study required input from the participants.

3.2. SITE SELECTION PROCESS

Anticipating that small, rural towns would be likely to satisfy the criteria for the study, we contacted the National Rural Water Association to get their assistance in identifying candidate sites, communities or towns. Through this association and with the assistance of other groups, we contacted all of the state rural water associations and/or state environmental agencies requesting a listing of sites, which met the criteria for the study. A list of potential sites was screened, and where information was missing, calls to the appropriate state agency or town official were made. In some cases, site visits were made. The town of Bern, Kansas was selected based on a high ranking of all of the criteria mentioned.

3.3. BERN KANSAS

Located about 75 miles west of St. Joseph, Missouri and 4 miles south from the Nebraska state line, Bern is a thriving, mostly farming community producing corn, sorghum and wheat. Figures 3.1 through 3.5 provide a view of the town, its industries, and some of the key players in the study. A survey of the town indicated that the primary occupation of 40% of the head of household is farming.

Before 1954, the residents of Bern obtained their water from individual wells. However, in 1954, Bern elected to drill several community water wells, erect a 50,000-gallon water tower and install underground water mains to serve the town. Subsequently, Bern installed three sewage treatment lagoons (cells) to handle wastewater generated by the town. Further, a Rural Water District (RWD) was formed, wells sunk and more than 70 miles of piping was installed to provide water to the residents living just outside of the city of Bern.

Periodically, Bern and the surrounding areas have experienced problems with water availability. In the mid 1980's Bern's water supply came from four, low-production, 8 gpm wells, and these wells were dropping in production. In addition, the city was interconnected with the surrounding RWD however; the district=s water supply consisting of two operating wells had an average production of 15 gpm. Water quality was very poor with high iron and manganese content. In 1988, northeast Kansas experienced severe drought conditions. The water production for the City of Bern and the RWD declined dramatically. Based on its limited water availability, the RWD and city of Bern were both identified by the State of Kansas as priorities (drought vulnerable) to obtain additional water resources. Along with this application for assistance, Bern implemented conservation practices and the RWD instituted water rationing in March 1989. The RWD increased its water rates from $1.35 to $3.00 per one-thousand gallons. To alleviate the shortage of water, several patrons of the RWD loaded water from farm ponds or hauled water from other locations to supplement their livestock water needs. To meet demand and improve water supply sources, Bern initiated a project to obtain water from neighboring Nebraska. Project costs to install 2 new wells in the neighboring state of Nebraska approximately 4 miles from any existing rural water transmission line, connecting pipeline and a booster station were estimated at $233,500. Funding came in the form of $23,800 by the City of Bern, the RWD contributed $47,600, and a neighboring community of Oneida paid $7,600. An emergency grant of $154,000 was awarded by special appropriation by the Kansas Department of Commerce & Housing. Rates were increased by the city of Bern as a result of the increased debt and need to conserve water. This was in November 1990. Monthly rates adopted then remain in force today for the residents of Bern:

Monthly Min. $8.50 for first 2000 gallons,
$2.75 per 1000 for the next 4,000 gallons,
$1.60 per 1000 for the next 6,000 gallons,
$1.40 per 1000 for all water over 12,000 gallons.

Rates in the RWD, which uses much more water per user, were increased more dramatically to curtail use:

Monthly Min. (Debt Service) is $12.50, no water,
$3.00 per 1000 gallons for all water use.

Fig. 3.1 Panorama view of Bern, Kansas (from grain elevator).

Fig. 3.2 H-axis washer with study participant Jill Meyer.

Fig. 3.3 Washer manufacturer representative: Mike Cox.

Fig. 3.4 Bern study liaison team: Betty Lortscher, Tim Krehbiel, and Diane Fitzgarrald.

The RWD subsequently reduced the rates to the following:

Monthly Min. of $12.50, no water
$2.50 per 1000 gallon for the first 10,000 gallons
$1.35 per 1000 gallons for all use over 10,000 gallons

A declining block rate such as the one found in Bern and the RWD is not unusual to find in farming communities – even ones with water availability problems.

Presently, the RWD has one well in Kansas pumping continuously and two wells in Nebraska. Present concerns are that the district has experienced some pumping of sand and turbid water from one of the new wells. A bag filter system has been installed on a trial basis. The RWD has also experienced problems with inadequate water pressure and, to alleviate these problems, has recently installed an additional storage standpipe at a cost of $90,000. The city of Bern continues to operate three wells. The city and RWD water lines, which surround the city, are tied together so that the city and RWD can share water resources if needed.

Fig. 3.5 Downtown area and local industries in Bern (grain elevator, city hall, cafe, and meat plant).

3.4. PARTICIPANT SELECTION

Information about the project, a survey form and invitation to join the project were mailed to each of the 175 homeowners in Bern and the surrounding rural water district. The residents were made aware of the project's goals of measuring the performance of high-efficiency clothes washers using the entire town as a test bed and for developing other information to determine the impact on the community of a changeover to high-efficiency clothes washers. The homeowners were told that if they were selected, they should be prepared to help collect data of each load of laundry washed during a five-month period. For the first two months, data would be collected on their current clothes washer, the washers would be changed out to the Maytag Neptune (horizontal axis) clothes washers, and data collection continued on the new washers for a three-month period. In return for their cooperation and assistance, the participants could elect to keep the new washer if they so desired.

The initial plan was to select about 90 homes with clothes washers to participate in the study. With the help of a three-person volunteer Bern Washer Study Team (see Fig. 3.4), information from applicants including laundry habits, customer profiles, types of existing washers, dryers and hot water heating systems was received and analyzed. The Bern Washer Team also coordinated and hosted a town meeting on May 27th in the Bern High School Gym to give ORNL and Maytag representatives an opportunity to meet the residents, provide details of the project and answer questions. A total of 104 participants (washer owners) elected to join the study and submitted an application in time to be included. These "participants: included 3 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.

Bern's Laundromat had six coin-operated, commercial washers and an equal number of dryers. A decision was made to collect data on three of these washers for the two-month baseline period, then to replace these with three coin-operated, commercial, h-axis washer for the balance of the study. In all other cases, the replacement washer was Maytag's domestic h-axis model. Of the 104 who joined initially, one single homeowner elected to withdraw about three weeks into the study, leaving 103 participants. Notably, all 103 completed the study.

At the initiation of the project, the participants were surveyed to gain demographic, life-style and laundry behavior information. Some of the findings from this survey included:

General information:

- The average Bern household is comprised of two adults and two children; in some cases, households have as many as 2 adults and 5 children;
- 21% of the households cited housewife/homemaker as the primary occupation of the female head of household;
- 40% of the households cited farming as the primary occupation of the male head of household;
- About 47% of the participants live in the Bern city limits; the remainder lives around Bern and is tied into the surrounding rural water district.

Laundry behavior and equipment:

- The majority of washers (71%) were located on the first floor of the home;

- The majority of washers (65%) had a fabric softener dispenser although 49% of households with the dispenser indicated that they never use it;
- The majority of washers (60%) also have a bleach dispenser; of this fraction, 48% of the participants sometimes use the dispenser, and 45% indicated that they never use the dispenser;
- 88% of the participants used an electric dryer; 11% used a gas dryer and 1% did not own a dryer; the average age of a Bern dryer is 12 years;
- 64% of the participants used propane for water heating; 36% used electricity; natural gas is not available;
- Twice as many participants use powder detergent as use liquid detergent, and 25% had both types of detergent on hand;
- The number of loads washed per week depended on the household size; estimates made by Bern residents indicated that the average Bern household washed 11 loads/week – see Fig. 3.6.

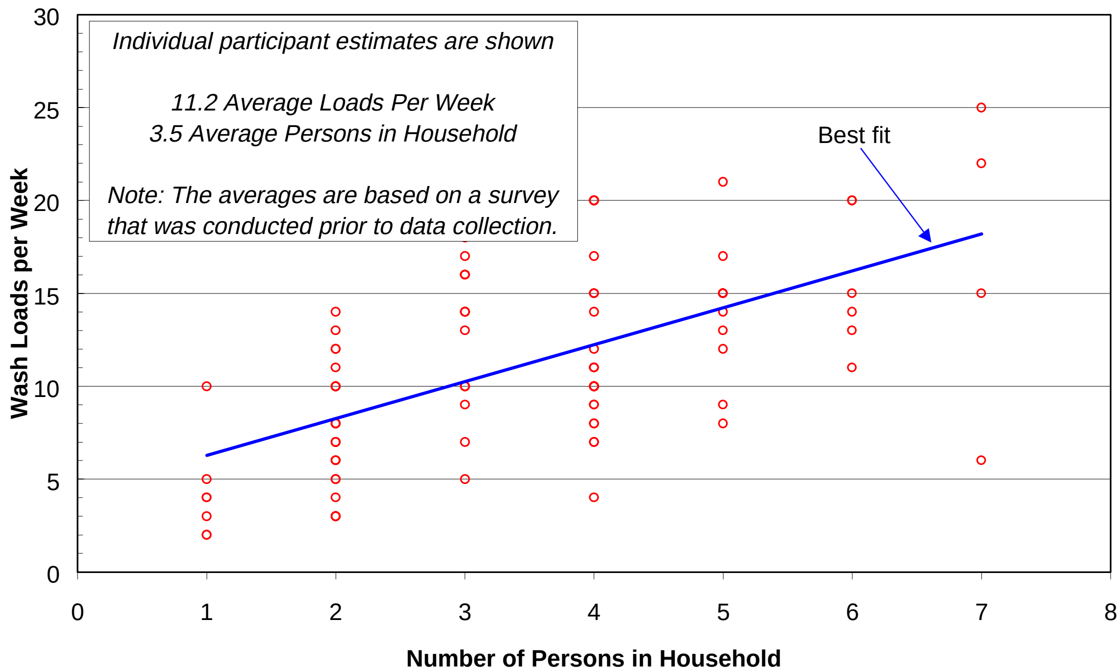


Fig. 3.6 Dependence of loads washed per week on household size (pre-study estimates).

The age and brand of clothes washer owned by the participants were also determined and compared with available information on national averages. The pie chart at the left in Fig. 3.7 shows the distribution of washer brands owned by the study participants at the outset of the project, and the pie chart at the right, shows the distribution of washer brands on a national basis[3]. The distribution of washers by brand in Bern follows the national market share for some brands, while for others, the distribution of washer brands is different. These differences may be attributed to differences between local markets in Bern and the average U.S. market as well as manufacturer/distributor retailing efforts in larger towns surrounding Bern as compared to average market conditions on a nationwide basis. Importantly, all major national brands were represented in the study, and this provided a good cross-section of vertical axis washers for comparison.

[3] *Appliance Magazine*, 44th Annual Report, Statistical Review, April 1997.

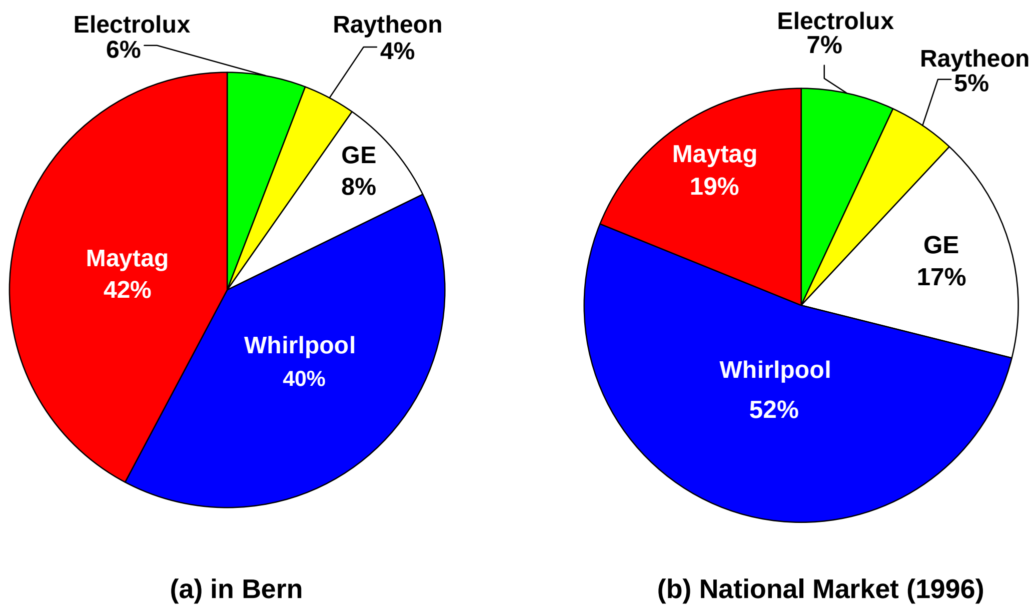


Fig. 3.7 Clothes washer market in the U.S. and in Bern.

In addition to providing brand information on their washers, the participants also indicated the age of their washers at the beginning of the study. Washer age was important to know because any changes in washing performance and energy/water consumption by replacing washers with an h-axis model would depend on the performance of the existing baseline washer. The newer the washer, the better its performance would be expected to be. Data on washing machine ages provided the information needed to calculate the saturation curve (Bern Washers) shown in Fig. 3.8. The lower curve in this figure represents Bern washers and the upper curve is the national average distribution based on a 14-year typical lifetime for washers. This figure shows the fraction of washers in Bern according to their age. For example, the age of the oldest washer in the study was 28 years; therefore 100% of the washers in Bern were 28 years old or younger. Further, about 10% of Bern's washers were 2 years old or newer (shown as the intercept on the left side in Fig. 3.8). Moreover, half (50%) of Bern's washers were no older than 8 years. The distribution of washer ages ranging to more than 28 years suggests that the true life expectancy of U.S. automatic clothes washers (point at which they are scrapped) can be much longer than the length-of-first-ownership. After the length-of-first-ownership, the old unit may be traded in, relegated to use somewhere else or scrapped. The length-of-first-ownership, characterized as the "typical lifetime" of a washer, is about 13 years[4]. If the ultimate lifetime of a washer were the same as the typical lifetime, an age distribution curve as shown by the upper line in Fig. 3.8 would be applicable. This underscores the fact that like other major U.S. appliances, clothes washers can last for a long time and that the average clothes washer in the U.S. would be a little older than what a typical lifetime estimate would otherwise suggest.

[4] *Appliance Magazine*, Appliance Life Expectancy/Replacement Picture, September 1997, p. 85.

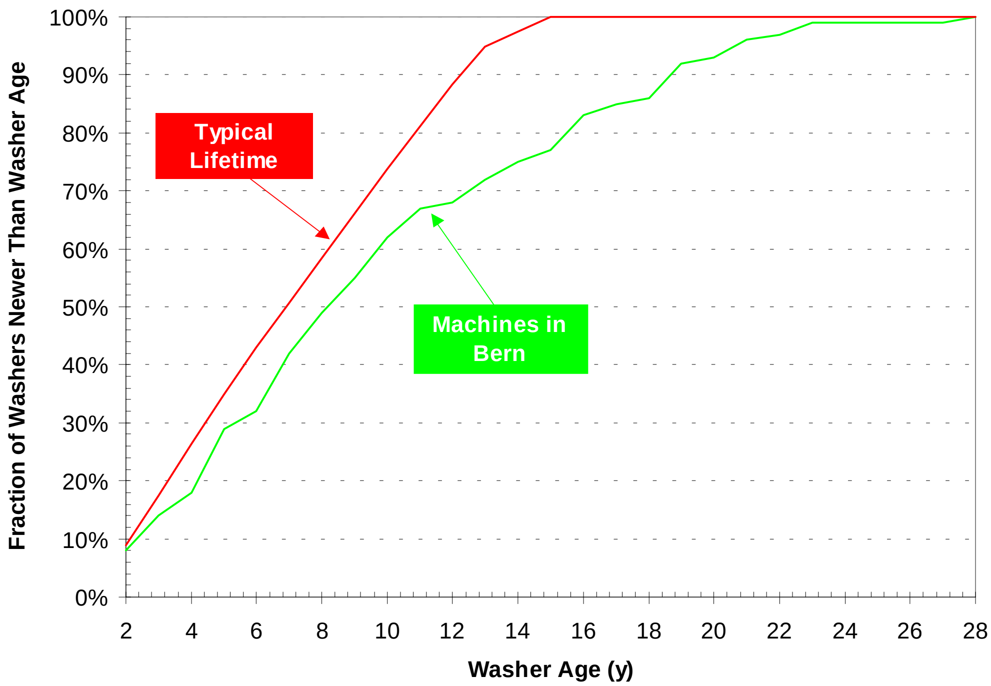


Fig. 3.8 Typical clothes washer ages.

3.5. EXPERIMENTAL DESIGN

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 water consumption and its effect on the customer and water/sewer utility;
- Changes in energy consumption of the washer itself and in the amount of hot water used;
- Changes in load weights. For the same "throughput" of laundry, the weight of each load determines the number of loads of wash needed to be done;
- Changes in detergent use and patterns;
- Changes in 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;
- Changes in customer satisfaction as related to cleaning/drying performance;
- Changes in customary laundry habits.

The experimental design included individually metering the participant's conventional washers and recording data from this instrumentation as well as from participants on each load of laundry that they washed for a two-month period (phase I of the project). Following phase I, all of the participant's washers were replaced by the high-efficiency, h-axis washer, the instrumentation reinstalled, and the experiment continued for a three-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 during phase I and the other during phase II was determined.

3.5.1. Instrumentation

Water Meters - Two water meters were installed on each washer in the project – one to measure the hot water consumption and the other for the cold. These meters (Badger Model 50) had been modified and adapted to work with a remote digital readout. The meter modification detailed in Appendix I, provided the readout with a measurement precision of almost 1/200 of a gallon. 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 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 for weighing wash loads. For most of the study, the scales with a measurement precision of ±1 oz., were used twice for each load: first, for obtaining the pre-wash weight of each load and a second time for determining the post-wash load weight which was the weight of the load after washing but before drying. All recorded weights included the weight of the clothes and the laundry basket. As part of the analysis, load weights were determined by subtracting the weight of the basket from recorded weights.

Laundry Basket - Each participant was given a standard laundry basket to use for weighing the loads. This simplified determination of load weights across the participants.

Measuring Cup - Each participant was given a standard detergent cup to meter detergent use for each load. As before, participants recorded detergent use on individual load data sheets.

Temperature Measurements - Water meters were installed on each washer during the first week of the study, and at this time, hot and cold water temperatures were carefully measured by the installation team and used in the analysis for both phases of the study. These temperatures were measured once again during the changeover to the h-axis washer.

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. Sample data sheets for phase I and phase II of the study are shown in Fig. 3.9 The two sheets are quite similar; they differ only in the "Settings" sections where the phase II settings are based on the controls for the Maytag Neptune model h-axis washer. Item 1 consisted of the date and time that a load was washed so that information on laundry habits could be determined. In items 2 and 8, participants recorded pre-wash and post-wash weights to provide information on load weights and residual moisture. In items 3, 4, 5, 6 and 11, participants recorded information characterizing the load, describing washer settings, detergent use and indicating how the load would be dried. In item 7, participants recorded numbers from the digital displays connected to the two water meters on their washers. Finally, in items 9 and

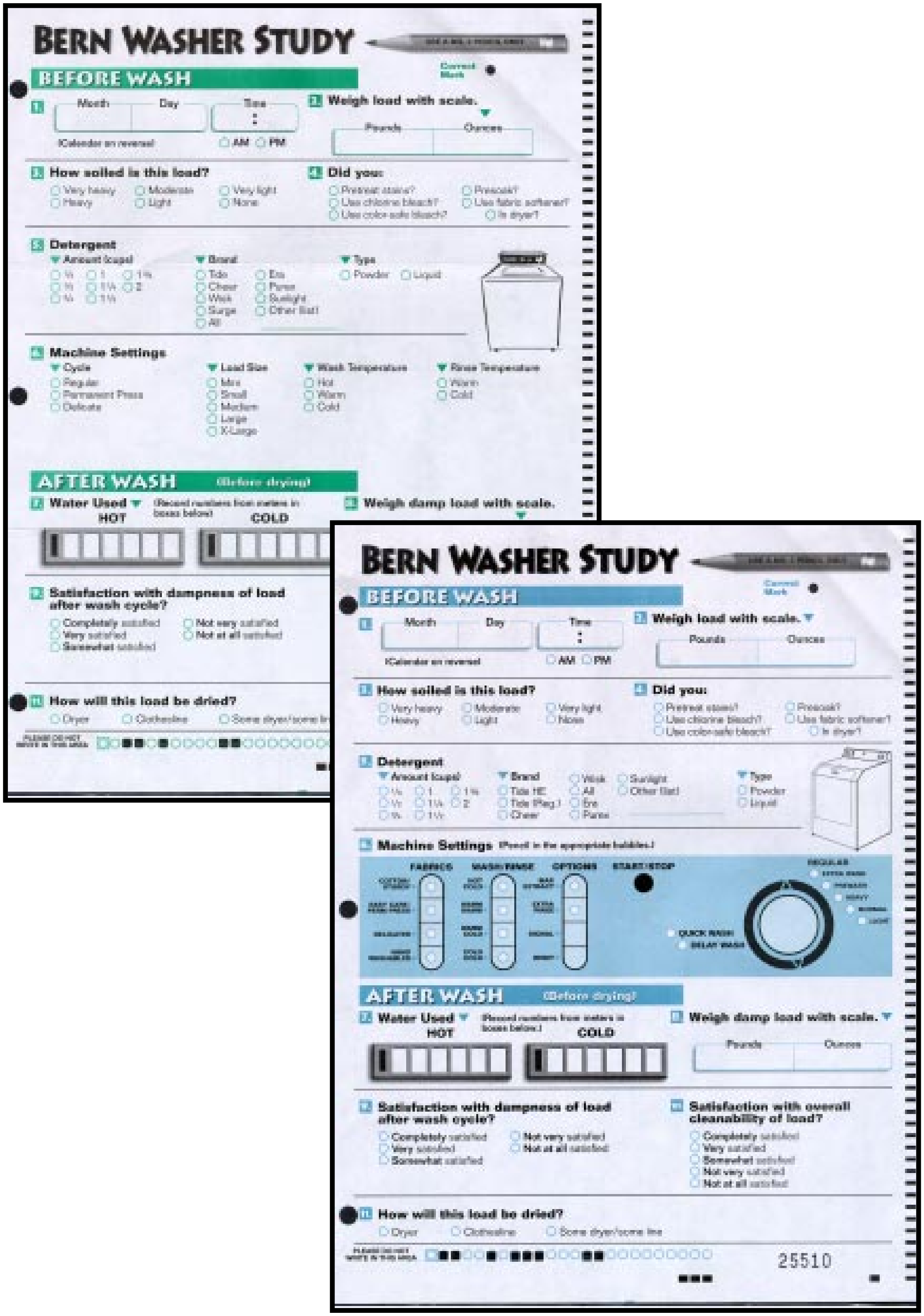


Fig. 3.9 Data sheets for phase I (in background) and II (in foreground) of the study. Hidden area of phase I datasheet is identical to corresponding area in phase II datasheet.

10, participants could indicate satisfaction with the dampness and cleanliness of the load after washing.

3.5.1.Schedule

The schedule for the study is given in Table 3.5.2.

Table 3.5.2 Project Schedule for Bern Study.

	Project Schedule
May 23, 1997	Selection and notification of study participants in Bern
May 28	Town meeting – Bern High School Gym
June 2 - 6	Installation of instrumentation on current washers; distribution of notebooks; initiation of phase I data collection
June 27	Installation of metering on Bern water tanks and wastewater treatment lagoons to measure community water use/disposal patterns on the following day
June 28	First “Superwash” Saturday – a day when participants concentrated their washing into a window of 10:00 a.m. to 4:00 p.m. to determine the impacts of a heavy washday on the community’s water use.
July 28 – August 1	Removal of current washer; Neptune washer installation; re-installation of instrumentation; initiation of phase II data collection
September 13	Second “SuperWash” Saturday; a repeat of the first SWS so that changes in community water use could be determined and compared with impacts from first SWS. Also, announcement of preliminary findings on energy/water consumption found at that point in the study.
October 31 - November 4	Removal of instrumentation
November 4 – December 31	Data analysis
January 15, 1998	Final study draft report completed; to be followed by published final report

Recognizing that the key element of the project was continued interest and participation by the people of and surrounding Bern, an aggressive schedule was set for the project so that the data could be collected quickly and analyses conducted. At intervals during both phases, individually tailored reports, citing results from each participant in the study, were prepared and sent to each participant as one way of providing relevant and important feedback to participants. A sample of one of these reports is provided in Appendix B.

3.6. DATA COLLECTION AND ANALYSIS PROCEDURE

The overall approach to data collection and analysis was to create database tables of project information and link these databases according to information queries. The information in these tables included recorded experimental information, detailed participant information, information about phase I washer characteristics and other information which were recorded on the data sheets and submitted to Oak Ridge National Laboratory (ORNL) for analysis. These individual tables of information were joined together as needed for analysis and for reporting results to individual participants. The key to the approach lay in the development of a normalized database in which all tables of information and data were linked through a single parameter, a unique number assigned to each datasheet.

The tools used to build the databases and to process data from the study included Microsoft Access 97 and Microsoft Excel 97. Access is a relational database management system that provides features for importing data and for creating tables, queries, forms and reports. In Access, data are represented as a table (a matrix of data in rows and columns). Access provides a number of routines for operating on the data such as queries, macros, visual Basic modules, forms and reports. Queries and reports were the two main components used in the study. The queries could be either created in a graphical view or by writing Sequential Query Language (SQL) statements. Queries were used to filter, sort, and screen the data from the study as well as to perform calculations such as sum and average the data. Access was linked to Excel as needed to perform histograms, create full-page graphics and to perform calculations which otherwise would have required extensive programming using Access. An example of this flexibility was the use of Excel to create pre-wash water meter readings from the ending water meter readings of the prior washer cycle. The ability to do this eliminated the need for participants to record the readings from both water meters twice in a single load.

At the outset of the study, each participant was assigned a unique number or I.D., and a database of participant information and I.D. code was prepared. Second, on every data sheet for the project was printed a unique five-digit code which had been lithographed at the lower right-hand corner of the form. As sets of these blank data sheets were periodically distributed to participants, ORNL kept track of the lithocodes assigned to each participant as well as the lithocodes on datasheets returned by each participant for analysis. Although Fig. 3.9 shows the front page of typical datasheets, there was a reverse side where the cumulative gallons of water as read from the register of each water meter could be entered. This was done twice (beginning and end) for each phase of the study. The datasheets have bubbles, which were shaded in, and blank boxes for handwritten data entries. The bubbled entries limit the data to discrete values. For example, in item 5, detergent use, the amount of detergent in a cycle could be specified in ¼-cup increments up to 2 cups. Examples of handwritten data fields are date, time and load weights.

Each of the phase I data records consisted of 21 data fields. Each of the phase II data records originally consisted of 21 data fields, but this was further subdivided into 26 separate fields because of the possibility of more than one selection in some categories. As the project proceeded, every couple of weeks or so, participants mailed completed data sheets to ORNL for analysis. Once received, the lithocodes were logged and checked to ensure that they had been correctly assigned to a participant. The data sheets were subsequently delivered to the Tennessee State Testing & Evaluation Center where an optical scanner read them and the handwritten data were entered by a keypunch operator. As records were read and prepared, State Testing also assigned a sequence number to each data record as it was entered into the scanner. A software program, which was prepared especially for the study, was used to assemble the recorded data into an Excel spreadsheet file and e-mailed to ORNL for analysis.

Once received by ORNL, the data were converted into comma-delimited files that could be imported into Access. The Access import engine provided the ability to create a specification file for comma delimited files. The specification file assigned a data type for each data field: either as date/time, text or number, and specification files were created once for the phase I data records and once for the phase II records. Further work automated this process so that as more and more data were received through periodic mailings from participants, and pre-processed by State Testing & Evaluation, the specification file automatically assigned the correct data type to each field in a record as the data records were imported into Access.

Some of the tables of data and information also contained a listing of participant number. Other tables, e.g. the body of data produced by the participants as they washed clothes throughout phases I and II also contained a column listing the lithocodes for each data record. The tables, which allowed all of the information to be tied together, were the lithocode/participant I.D. table and the sequence number/participant I.D. table. Using the later table gave the fastest response to queries.

Summarizing, the overall process for assembling a database of information for the study consisted of the following six steps:

- Data entry by the Bern participants on pre-formatted data sheets;
- Optical scanning of the data sheets supplemented by keyboard entries to generate a data table;
- Formatting and importing the data table into Excel;
- Conversion of the spreadsheet to comma-delimited ASCII file;
- Importing this file into Access;
- Creating SQL queries to assign data records to participants;
- Creating SQL queries to sort, filter and screen all data and to perform calculations and analyses needed to address the study objectives.

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 report.

The integrity and quality of the data collected from the Bern participants during both phases I and II of the study is discussed in Appendix C.

4. OVERALL FINDINGS AND IMPACTS

The tumble-action principle of the h-axis washer and design of the h-axis washer based on this principle 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. These impacts include, for example, changes in average load sizes and weights, changes in detergent use patterns, changes in energy and water consumption, changes in cleaning performance and changes in the post-wash moisture content of loads. In the following sections of this report, we examine first some of the overall impacts and findings between phases I and II of the study, and second, a more detailed examination of the influence of individual parameter differences on these overall results.

4.1. IMPACTS ON LOAD SIZE

The size of loads washed with each cycle can be an important measure of the "throughput" of laundry because it can determine the number of loads washed by a customer. More loads take more time and can consume more energy and water than fewer loads. This is particularly the case on laundry days when loads are done one after another. Its volume or its weight or perhaps some combination of the two could characterize the size of a load of laundry. Although the weight of any wash load and its volume are linked, the relation between the two depends on the type of clothing in the load, e.g. a laundry basket full of cotton towels, sweatshirts, bedding, etc. may weigh more than one filled with permanent-press shirts or delicates. A participant's lifestyle would likely determine the type of clothing worn and washed most often, and over the course of the study, the lifestyles for most of the participants remained fixed. This meant that load weights used in the study, were a good indicator of load size.

Participants measured and recorded load weights for each load washed during phases I and II. Fig. 4.1 shows the distribution of these loads in 2-pound increments up to 14 pounds and all loads which weighed more than 14 pounds (relatively small number).

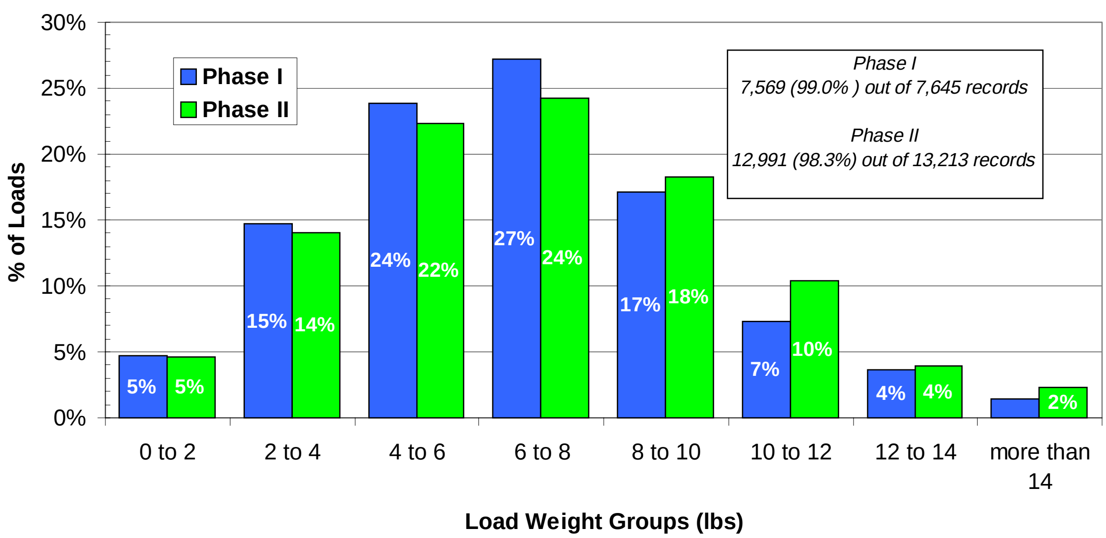


Fig. 4.1. Distribution of load weights in Phase I and II.

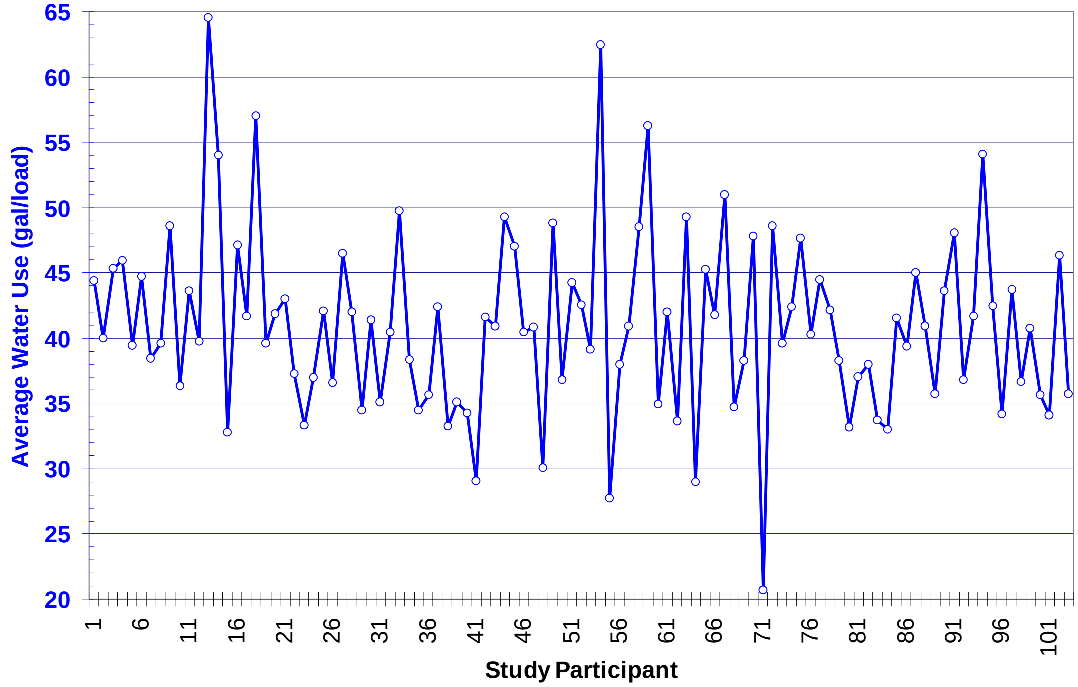
In phases I and II, most of the loads weighed between 6 and 8 pounds, and about as many loads weighed less than 2 pounds as weighed more than 14 pounds. Across all washers and participants, the average load weight in phase I was 6.65 pounds and the average for loads done in phase II was 6.98 pounds. Interestingly, Fig. 4.1 shows that a larger fraction of loads were done by the phase I washers in each load category less than 8 pounds than were done by the phase II washers in those same load weight categories. During phase II and as the summer progressed into the fall, participants tended to wash heavier loads (those weighing more than 8 pounds) more often than they did in phase I. These results are based on average pre-wash weight measurements from 7,523 loads (50,035 pounds) of laundry done in phase I and 12,759 loads (89,063 pounds) done in phase II.

We found that as the study progressed, the average load weight increased slightly for each week of the study and throughout both phases at a rate of about 0.04 lb/load per week. Consequently, the average load weight for the first two months of the study (phase I) is a little smaller than the average load weight for the last three months of the study (phase II). The finding that the average load weight tended to increase throughout the study suggests that the increase in average load weight between the two phases is not necessarily due to the type of washer. Instead, it appears to be timing related and results from differences in the type of laundry being washed by the participants as the study progressed through the Summer and into the Fall. Measurable changes up or down in laundry "throughput" (weight per load) as a result of washer type were not found.

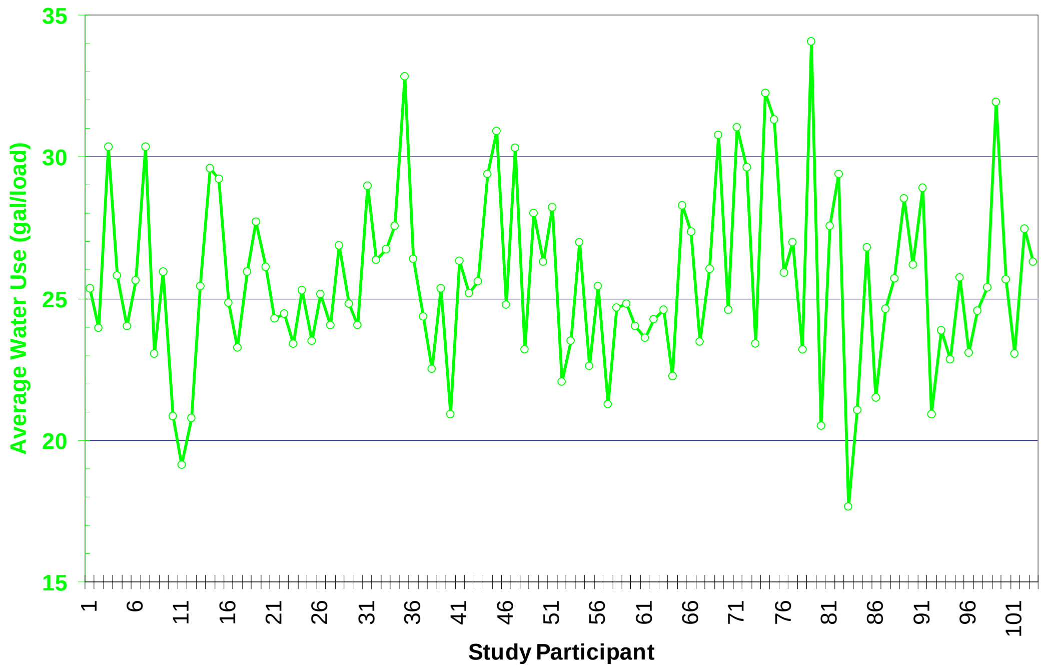
4.2. WATER CONSUMPTION

The water consumed by each washer in both phases of the study was determined through individual, positive displacement (nutating disk) water meters applied to the hot and cold water lines to each clothes washer. After each load was washed, the digital display affixed to each meter was read and recorded by each participant. These readings simply indicated "counts", and during the data analysis phase of the study, these "counts" were converted to gallons through a conversion factor. The water consumed during one cycle was determined during analysis by subtracting the meter reading from the prior wash cycle from the reading for the current wash cycle. In each case, the difference in meter readings was converted into gallons of water.

Figure 4.2 shows the average water (hot and cold) consumption during phase I and II for each individual participant in the study. A count of the water use over all participants in 1 gallon bin groupings (such as 0 to 1 gallon) yields the distribution curves for phase I and II shown in Figure 4.3. In phase I, the average total water use ranged from about 18 gallons to more than 60 gallons per load with an average of 41.5 gallons/load. In phase II, the total water consumption ranged from 17 gallons/load to about 37 gallons/load with an average of 25.8 gallons/load. Across all study participants, this represents an average per load water savings of 15.7 gallons, or 37.8%.



(a) Phase I.



(b) Phase II.

Fig. 4.2 Average water consumption by participant for phases I and II.

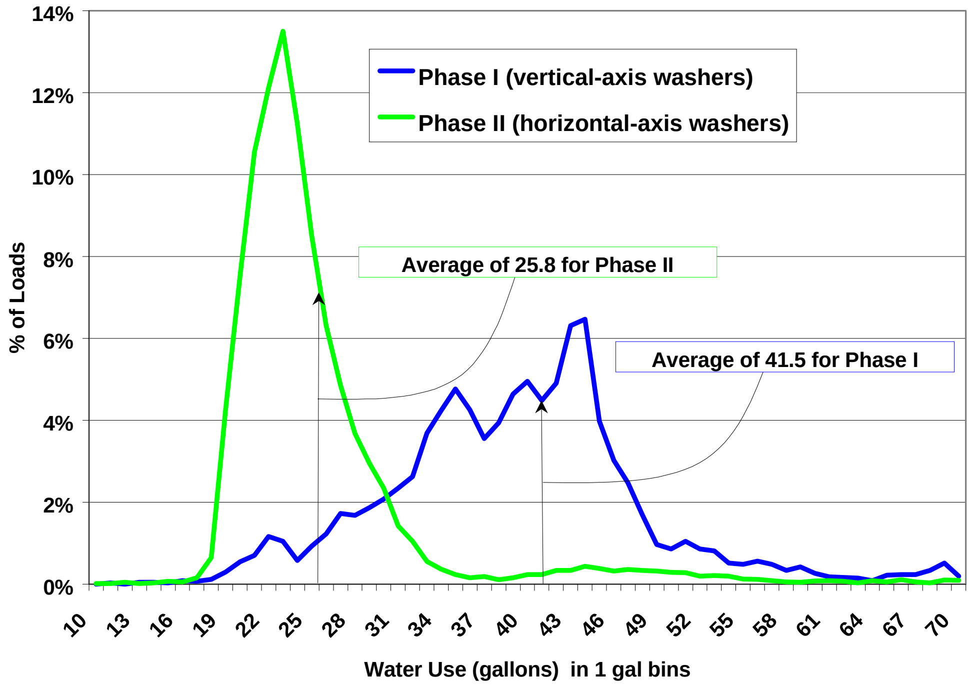


Fig. 4.3 Distribution of water use in phases I and II.

4.3. ENERGY CONSUMPTION

Washers consume energy through two main mechanisms: first, energy is needed to produce hot water used by the washer, and second, the washer itself uses energy to operate the motor and controls. In this analysis, the hot water energy was taken to be the thermal energy in the hot water used by the washer. This energy was determined by measuring the temperature of the hot and cold water (see Appendix D) at a sink or faucet after the water had run for a time so that the temperatures were stable. This was done on three separate visits to each participant during the progress of the experiment. The hot and cold water temperatures were entered into a spreadsheet to be included in the analyses. The amount of hot water consumed was measured by the water meters described earlier, and based on the volume of hot water consumed and the temperature difference between the hot and cold water, the energy content of the hot water to the washer was determined (Btu/gallon). It should be noted that although this procedure puts the energy contained in hot water on a consistent footing to compare washer performance, it understates the actual amount of energy purchased by the participants to heat the water used by these washers. From the survey administered to participants at the outset of the project, 64% of the participants heated water using propane and the rest used electricity. By applying national averages for the efficiency of water heaters[5] (52% for gas/propane and 85% for electric), ignoring any heat losses from the hot water distribution piping in homes and standby losses, it can be shown that only about 64% of the energy purchased for water heating actually ends up as hot water.

A comparison of the average total energy (hot water and washer) consumption of the phase I washers and the energy consumption of phase II washers on an individual participant basis is shown in Fig. 4.4. A count of the energy use over all participants in 0.1 kWh bin groupings (such

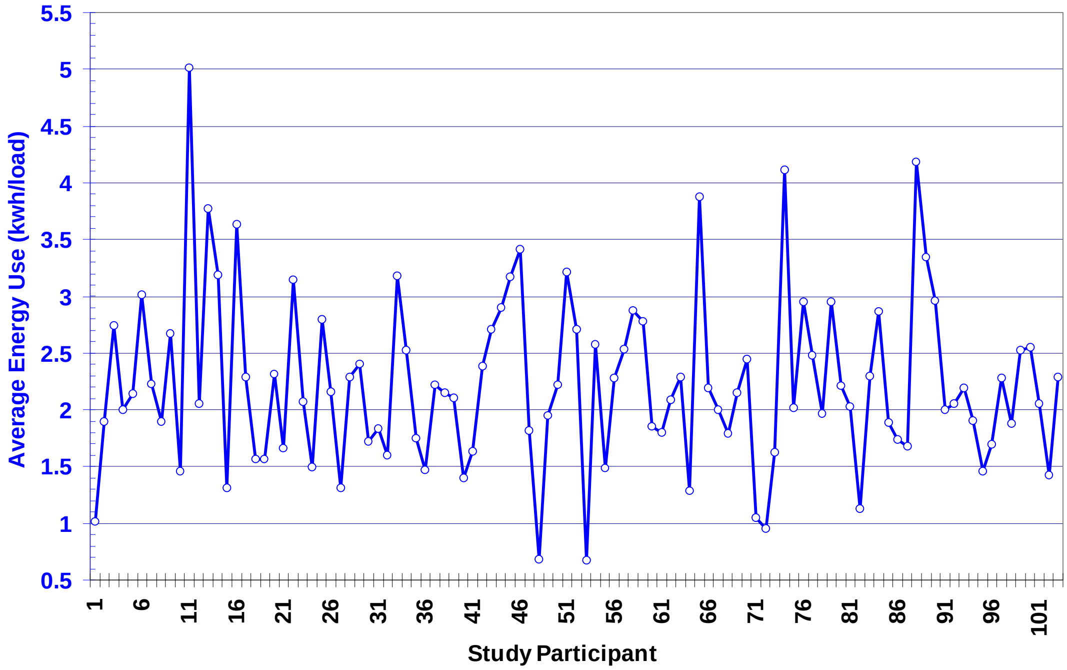
[5] BTS Core Databook, version 2, U.S. Department of Energy, Office of Building Technology, State and Community Programs. For copy or information, contact Bill Zwack, 301/588-9387.

as 0 to 0.1 kWh) yields the distribution curves for phase I and II shown in Figure 4.5. In every case, the phase II washer used less total energy than the phase I washer, and in some cases, the savings were dramatic. One must keep in mind that the phase I washers in Bern spanned the gamut from washers which were fairly new and relatively efficient, to ones which were much older and probably less efficient. Moreover, the phase I water and energy consumption information (Figs 4.3 and 4.5) shows the large variability in the water and energy and water consumption among the population of washers in Bern. Some of this variability was due to the washer, while the rest of the variability was due to different settings used by each participant.

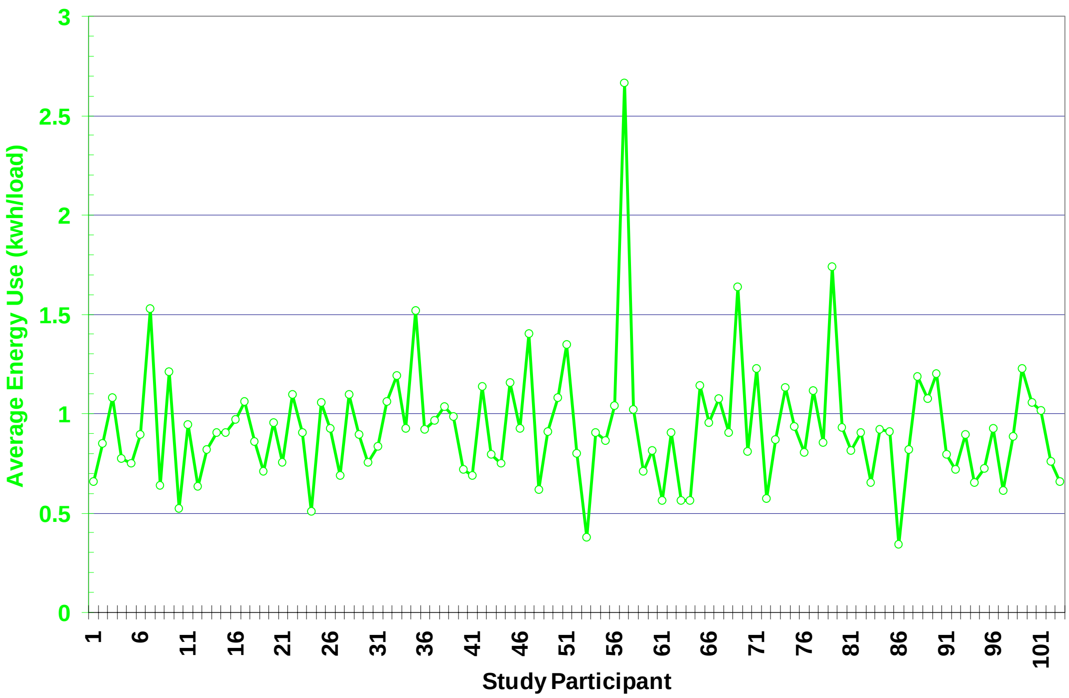
From the complete dataset taken during phase I and II on loads, load weight and hot/cold water consumption, the impact of the replacement of all participants' vertical-axis phase I washers by the phase II h-axis washers was determined, and the findings are shown in Table 4.1. As can be seen from Entry 1 in the table, there were a total of 7,645 datasheet records received from participants during phase I and 13,213 datasheets received in phase II. From a review/analysis of these sheets, we determined the number of loads washed by participants (Entry 2). The difference between these two numbers of records represents occasions when participants provided information other than load data such as readings from water meter registers that were made periodically during the study as a check on the information from the digital readouts. Entries 3, 4, 5 and 6 show totals on water consumption and laundry weight. Averages were based only on the number of datasheets where information was provided and the information appeared reasonable. For example, of the 13,130 loads done in phase II, participants provided load weight on 12,759 of these loads (97% response rate). Consequently, the total load weight divided by the number of reported load counts yielded the average load weight shown in Entry 8. This same procedure of data normalization according to the counts received rather than the total number of records was used to determine averages for hot and cold water consumption as well as for the remaining analyses to be described later in this report. Overall, solid information on load weights (pre- and post-wash) and hot/cold water readings were provided on data sheets for at least 92% of the time.

These results show that, on average, the h-axis washer used 62.2% of the water used by the v-axis washer, and this yielded total water savings of 37.8%. Moreover, the average h-axis washer consumed 42.4% of the energy used by a typical v-axis washer in the study, resulting in energy savings of 57.6%. These results as well as the distribution of energy consumption are shown in Fig. 4.6.

With both washers, the majority share of the energy consumed is the energy needed to heat water. Therefore, a reduction in hot water consumption directly has a direct and beneficial effect of reducing overall energy consumption. Table 4.1 shows that the hot water consumption of the h-axis washer is less than half of the hot water energy used by the average v-axis washer in the study. This finding supplemented by a 50% reduction in washer energy consumption work together to provide the energy savings shown in Fig. 4.6.



(a) Phase I.



(b) Phase II.

Fig. 4.4 Average washer energy use by participant for phases I and II.

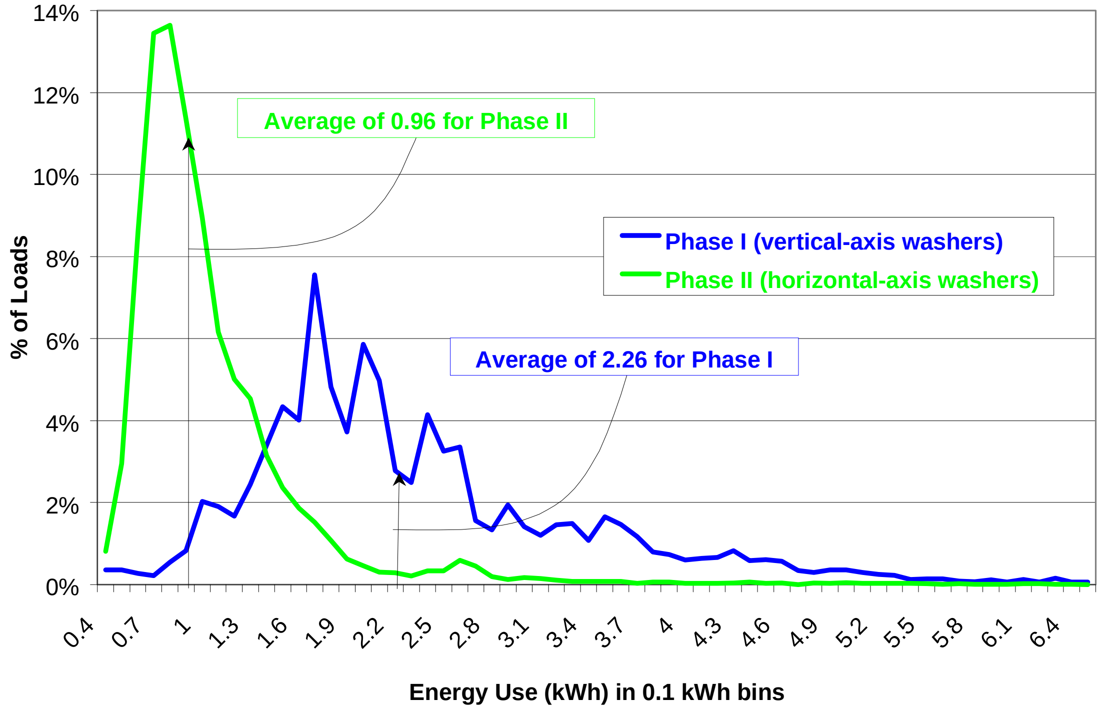
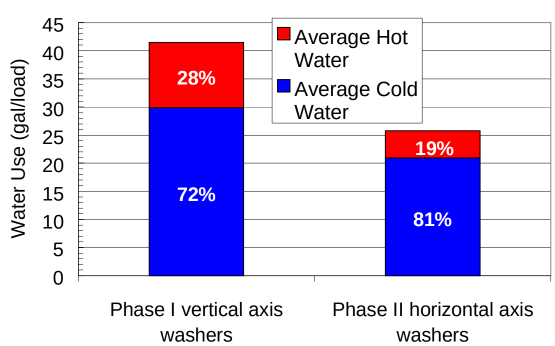
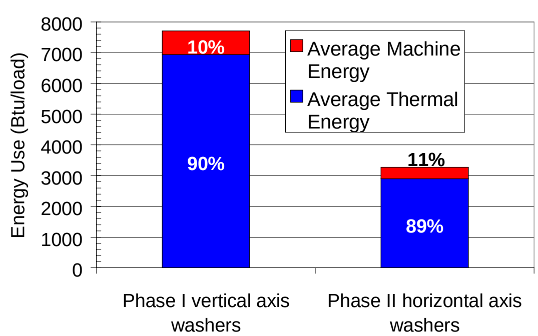


Fig. 4.5 Distribution of energy use in phase I and II.



(a) Average hot and cold water consumption.



(b) Average energy consumption.

Fig. 4.6 Average water and energy consumed by phase I and II washers.

Table 4.1 Average Energy and Water Consumption in Phases I and II.

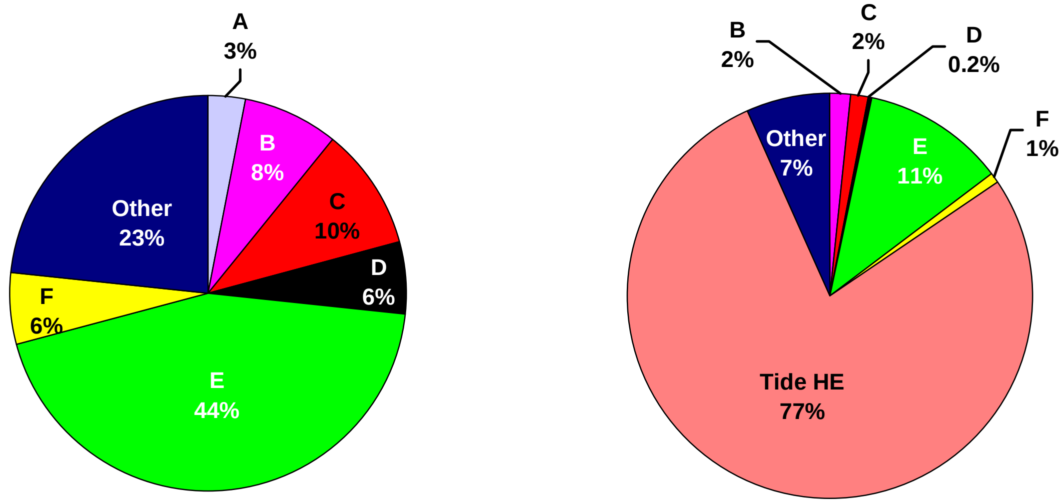
#	Calculation	Units	Phase I		Phase II	
			Data	Records	Data	Records
1	Total Records		7645	7645	13213	13213
2	Number of Loads		7633	7633	13130	13130
3	Total Hot Water Use	gallons	81405	7033	58000	12011
4	Total Cold Water Use	gallons	209286	7002	250462	11950
5	Total Water Use	gallons	290691		308462	
6	Total Laundry Weight	pounds	50035	7523	89063	12759
7	No. of Participants Reporting		103		103	
8	Average Load Weight	lb/load	6.65		6.98	
9	Number of wash days	days	61		105	
10	Average Hot Water Temperature Difference*	°F	72		72	
11	Average Washer Energy Use	kWh/load	0.23		0.11	
12	Average Hot Water Use	gallons/load	11.57		4.83	
13	Average Cold Water Use	gallons/load	29.89		20.96	
14	Average Total Water Use	gallons/load	41.46		25.79	
15	Average Total Energy Use	Btu/load	7710		3272	
16	Average load/day per Participant	loads/day	1.21		1.21	
	% Water Savings**				37.8	
	% Energy Savings**				57.6	

**The temperature differences for each participant are given in Appendix D.*
***Comparison of items 14 and 15, respectively, for water and energy.*

4.4. DETERGENT USE AND CONSUMPTION

Changes in detergent use by participants were also evaluated in the study. The survey conducted at the beginning of the study determined the distribution of detergent brands used by the participants, and as the study progressed, participants used the measuring cup which was provided as part of the experimental equipment to measure and record the amount of detergent used with each load. Participants were noted to use varying amounts of detergents to complete their wash. Cases were found where participants used as much as 2 cups of detergent to wash small loads. However, the average detergent use for the phase I washers was about a ½ cup/load.

A heavy concentration of ordinary detergent may not be desired for an h-axis washer because of the high degree of tumbling present that can lead to oversudsing. There are three ways in which any tendency for oversudsing can be minimized. One approach would be for the h-axis washer to be designed to sense any oversudsing condition and to alter its cycle, perhaps using an extra rinse, to eliminate it. The Maytag Neptune washer used in phase II of the study was designed to detect and handle problems with oversudsing. However, this may cause the washer to use more water than would ordinarily be used. The second approach would be to use a low-sudsing detergent. The market for low-sudsing detergents is anticipated to grow as h-axis washers gain market share and the demand for low sudsing detergents grows. In conjunction with the phase II part of the study, participants were allowed to continue to use their customary brand and type of detergent in the new, h-axis washer, or they could use a new detergent formulated expressly for use in tumble action washers. This formulation, Tide HE (high-efficiency) was provided free to those participants who were interested. Figure 4.7 indicates the distribution of detergent brands A-F used in phase I of the study and how the participants responded in phase II to the availability of the new detergent, Tide HE. Clearly, many of the participants took advantage of the new detergent; however, there was also a substantial number who elected to continue to use the brand to which they were accustomed.



(a) Phase I **(b) Phase II**

Fig. 4.7 Distribution of detergent brands A-F and Tide HE in phases I and II.

The amount of detergent used by participants depended on the individual, the weight of the wash load and there were some differences as well between phases I and II. Figure 4.8 shows the distribution of loads for both phases according to the amount of detergent used with each load. Since the smallest division on the laundry cup was ¼ cup, detergent use in ¼ cup increments was used to produce this figure. It can be seen that about 30% of loads were washed using ¼ cup of detergent and that about 80% of all loads were washed using ½ cup of detergent or less. In phase II, participants tended to favor using ½ cup of detergent rather than ¼ or ¾ cup, whereas in phase I, the distinction is less sharp. Surprisingly, there were some (albeit few) loads washed using 2 cups of detergent.

The relation between detergent concentration (cups of detergent relative to load size) and the distribution of loads is shown in Fig. 4.9. As expected, this histogram is similar in shape to the one in Fig. 4.8. The most frequently found detergent concentration in phase I ranged from 0.06 to 0.08 cups of detergent per pound of load weight. With the phase II washer, the most frequently used detergent concentration was somewhat less at 0.04 to 0.06 cups/pound. One of the more interesting points from this Figure is the fact that that detergent concentration varied fivefold across about 80% of all wash loads. These differences are reflective of the individual washing habits of each of the participants (some use less, some more detergent for a given load size).

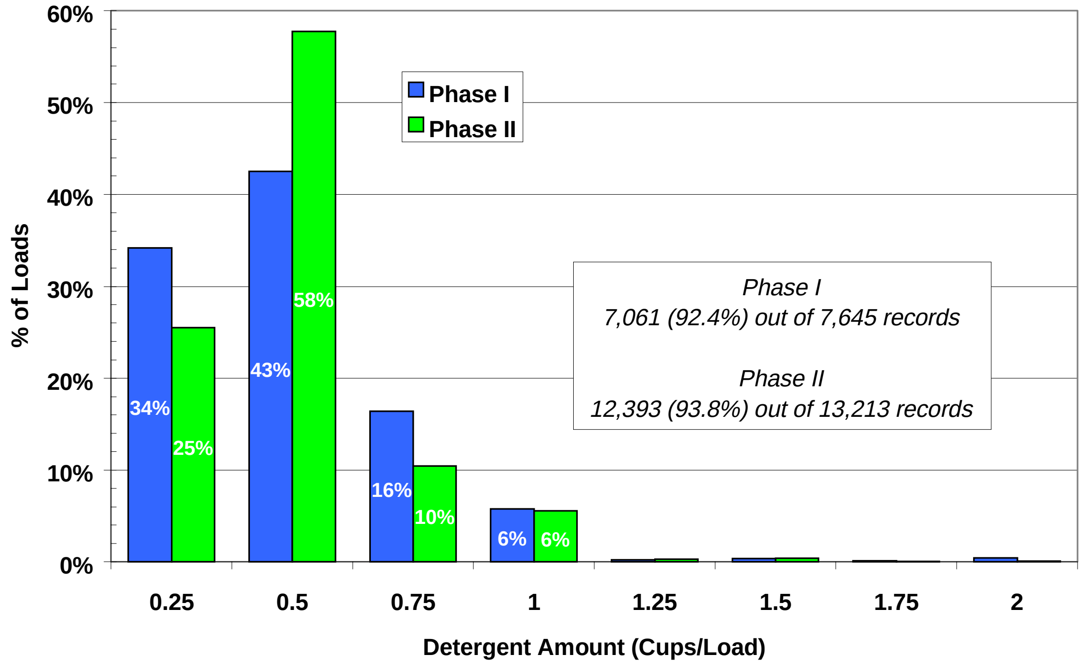


Fig. 4.8 Detergent use by load.

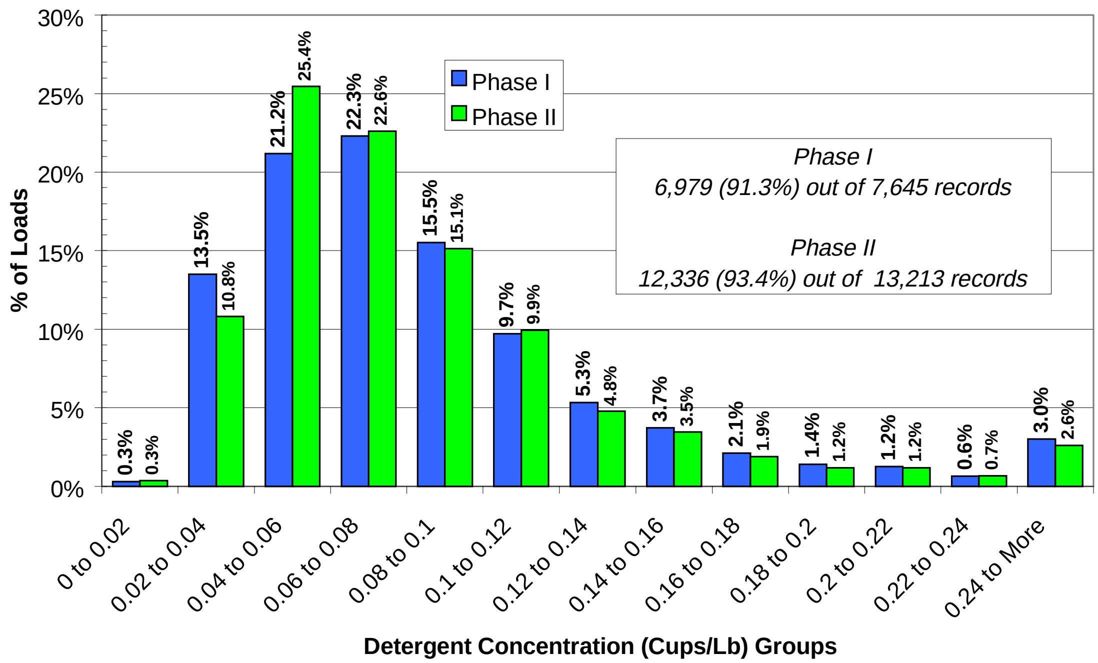


Fig. 4.9 Changes in detergent concentration.

4.5. IMPACTS ON USE OF OTHER ADDITIVES

In addition to detergent use, there are a variety of additives which can be used to help launder clothes. Heavily soiled clothing can be pretreated with a stain removal agent, bleach in solid or liquid form can be used to oxidize stains and improve brightness, and fabric softeners can also be used in the final rinse or in the dryer. Study participants used none of these additives in approximately 30% of all loads washed, and there was no significant difference in non-use between phases I and II. Chlorine bleach was used for about 5% of all loads, and color-safe bleach was used for about 5% of all loads, and there was little difference in use of bleach between phases. A fabric softener was used for about 60% of the loads on phase II and for as many as 43% of loads in phase I. It remains unclear as to why there is this difference in fabric softener use. It may be attributed to the availability of a dispenser on all of the phase II washers to automatically dispense softener at the appropriate time in the system, whereas an automatic dispenser would likely be present on a smaller number of phase I washers due to their age. For the most part, differences in how wash additives were used were more a function of habits and customs of the individual participants and less a function of the phase of the study.

4.6. IMPACTS ON LAUNDRY HABITS

The wash cycle of the h-axis washer is a little longer than the wash cycle for a typical v-axis washer. To determine whether this made much difference in when participants washed loads, we analyzed the distribution of loads according to day of the week. If the somewhat longer cycle times made much of a difference, it might be seen through this distribution. Saturdays followed by Mondays as shown in Fig. 4.10 continued to be the days of the week when most loads were washed. Although slightly fewer loads were washed on Saturdays and slightly more loads were washed on Sundays during phase II than during phase I, there does not appear to be an indication that phase II washing had to be continued into days of the week when fewer loads would ordinarily have been done. Tuesday through Thursdays continued to be light laundry days during both phases of the study.

4.7. IMPACTS ON WASHER SETTINGS

The phase I as well as the phase II clothes washers had the ability to set the water temperature used during the wash and rinse cycles. In both study phases, participants continued to set these temperatures according to their customary laundry habits and custom, and to record setting information on the load datasheets. From these data, temperature utilization factors (TUFs) were determined as shown in Fig. 4.11. The wash/rinse temperature settings (H = hot, W = warm, C = cold) are shown along the horizontal axis, and the fraction of loads washed by participants using each of these settings is shown at the left. The TUFs used in both phases of the study were close to the TUFs defined and used in the DOE Test Procedure for rating clothes washers and shown in the figure for comparison. Most of the wash load cycles were done using W/C temperature settings, and about 94% of the loads were rinsed in cold water. In the DOE Test Procedure[6], the combined TUFs for cold water wash is 82%. Apparently, the participants were generally more conserving of hot water and washed a larger fraction of the loads in warm water. Based on the fact that farming is a principal vocation in Bern, it is reasonable to expect that warm water rinses would be used to the extent shown. Hot water was used for the wash cycle more often in phase II than in phase I, and warm water was used for washing more frequently in phase I than in phase II.

[6] *Federal Register, Rules and Regulations,* Vol. 62, No. 166, August 27, 1997. p. 45507

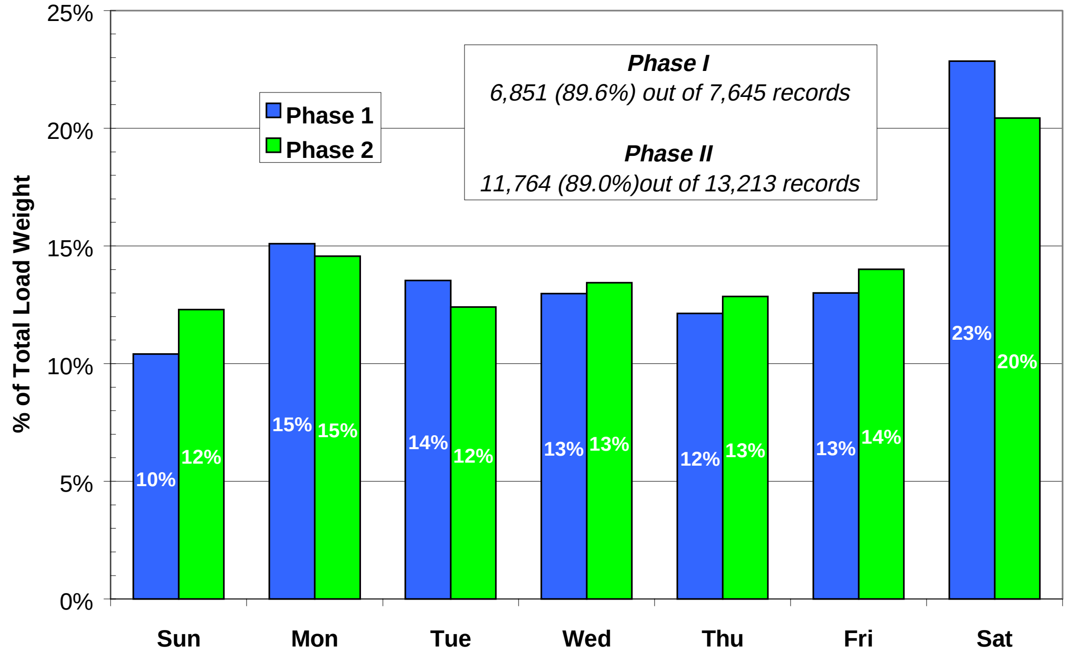


Fig. 4.10 Distribution of wash loads through the week.

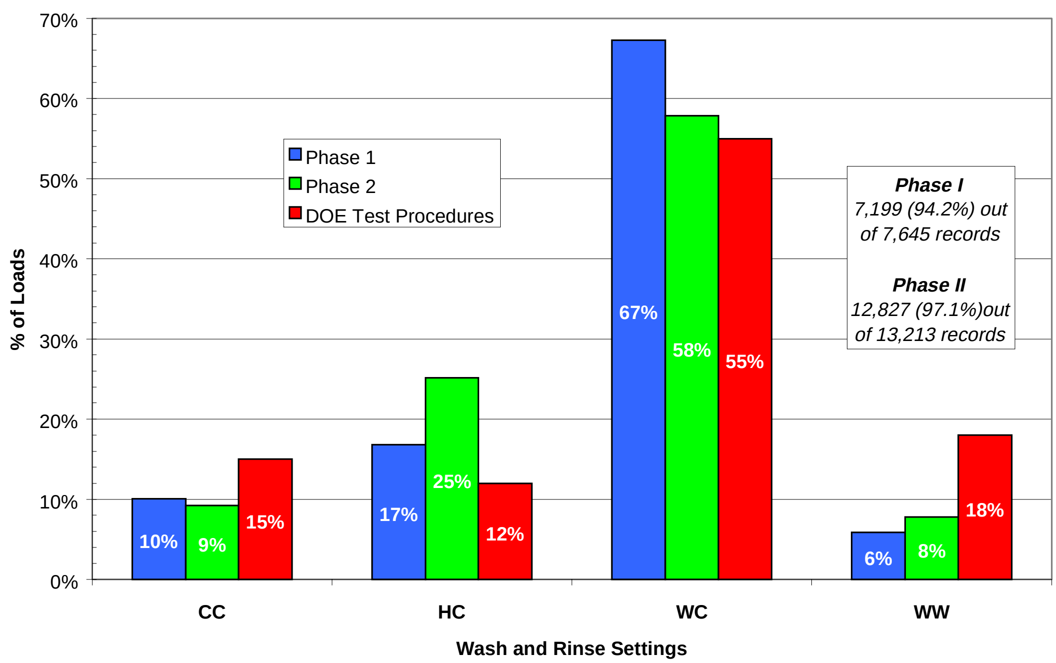


Fig. 4.11 Temperature utilization factors for phases I and II.

4.8. CLEANING PERFORMANCE

From a customer's perspective, the cleaning performance of a clothes washer is paramount among the other attributes. In general, customers are unwilling to compromise cleaning performance in exchange for savings in energy and water or for added features on a washer. As washer technologies and qualities have improved and markets have remained competitive, customers have come to expect a high degree of cleaning performance from any washer purchased. In the study, the issue of cleaning performance was evaluated by participants based on visual inspection of laundry loads removed from the washers. Visual inspection of loads to judge how well the load was cleaned is a useful tool for determining "cleanability" particularly since it is based on the experience, familiarity with individual articles of clothing and laundry habits of each of the individual participants. Moreover, the 5-month duration of the study including both phases made it likely that a participant would likely wash the same articles a number of times and would be aware of any substantive changes in cleaning. The "cleanabilty" index used in the study was indicative of participants' reaction to the overall cleanliness of each load without reference to individual cleaning features such as stain type and removal, brightness, soil removal, and other specific measures.

With each load washed, participants were requested to indicate their satisfaction with the cleaning performance of the washer on a scale of five choices ranging from "Completely satisfied" to Not at all satisfied." The results for phase I and for phase II are shown in Fig. 4.12. These results are based on information on the datasheets received (94% response rate for phase I and 93% for phase II). Overall, it appears that participants were at least reasonably satisfied with their washers' performance in phase I as well as in phase II. There were, however, significant improvements in cleaning satisfaction levels as participants moved to the phase II washer. The most significant change is in the fraction of loads in which participants were "completely satisfied." This fraction rose from 15% in phase I to 45% in phase II. Moreover, the fraction of loads in which participants were "somewhat satisfied" decreased. Dissatisfaction with cleaning performance (generally indicated by participants either "not very" or "not at all" satisfied) was not seen very often in either phase I or in phase II. It appears that the differences shown in Fig. 4.12 are significant between the two phases. These results show that, in general, the overall satisfaction level for the entire population of participants in the cleaning performance of their washers increased significantly as a result of the changeover to the phase II washer. Details on the relative influence of factors such as the phase I washer vintage on cleaning satisfaction are given in Section 5.2.

4.9. IMPACTS ON LOAD DAMPNESS

In a manner similar to the data gathered on cleaning performance, participants were asked to indicate how satisfied they were with how dry the loads felt as they were removed from the washer at the conclusion of a wash cycle. An indication of "not at all satisfied" would mean that at the end of the wash cycle, the load was much wetter than anticipated indicating that the spin cycle was not as effective as participants believed it should have been. The dryness of a load after washing also affects the energy used for the final drying process. If a load with a low moisture level is placed into a dryer, less energy would be needed to dry the load and the drying time would be shortened. This is the usual case particularly if the dryer is controlled by a sensor which detects either the moisture or temperature of the air exiting the dryer. Information on satisfaction with load dampness was submitted for 94% of the total records reported in the study, and the overall results are shown in Fig. 4.13. Apparently, there was noted improvement in satisfaction levels from the changeover to the phase II washer. The largest improvement was found in the category "completely satisfied" in which the fraction of loads meeting this satisfaction level increased nearly five-fold. Noticeably too was the reduction in the number of loads in the category "somewhat satisfied." In both phases, although more markedly in phase I, there were loads for which participants expressed some degree of dissatisfaction with dampness.

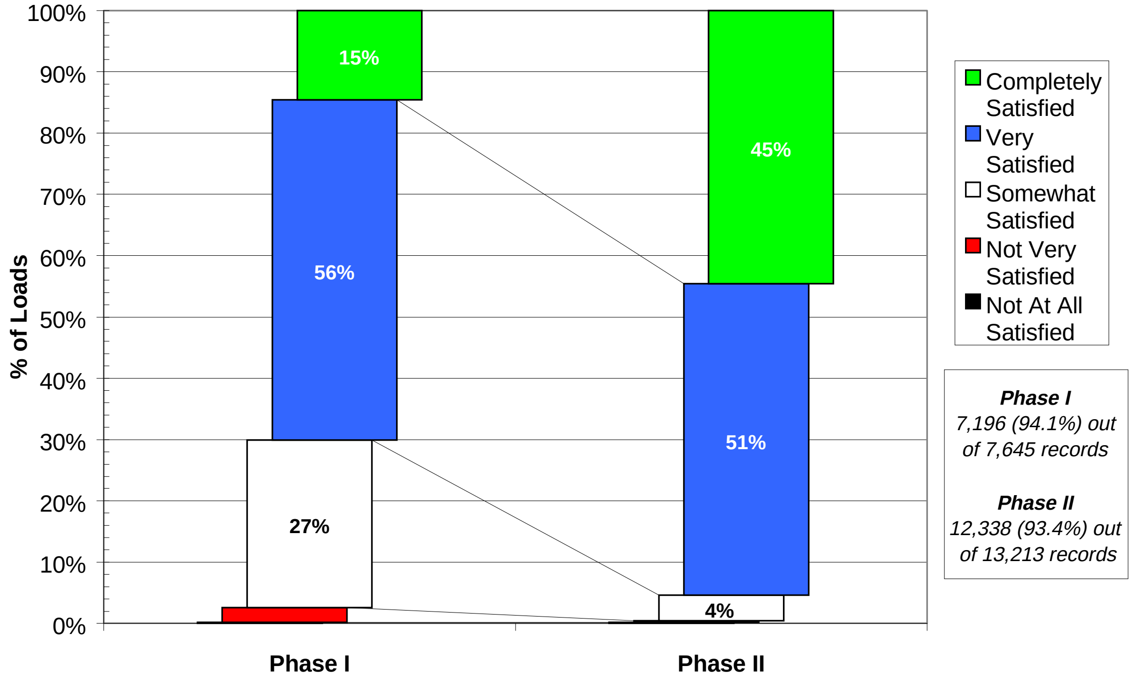


Fig. 4.12 Overall satisfaction with cleaning performance.

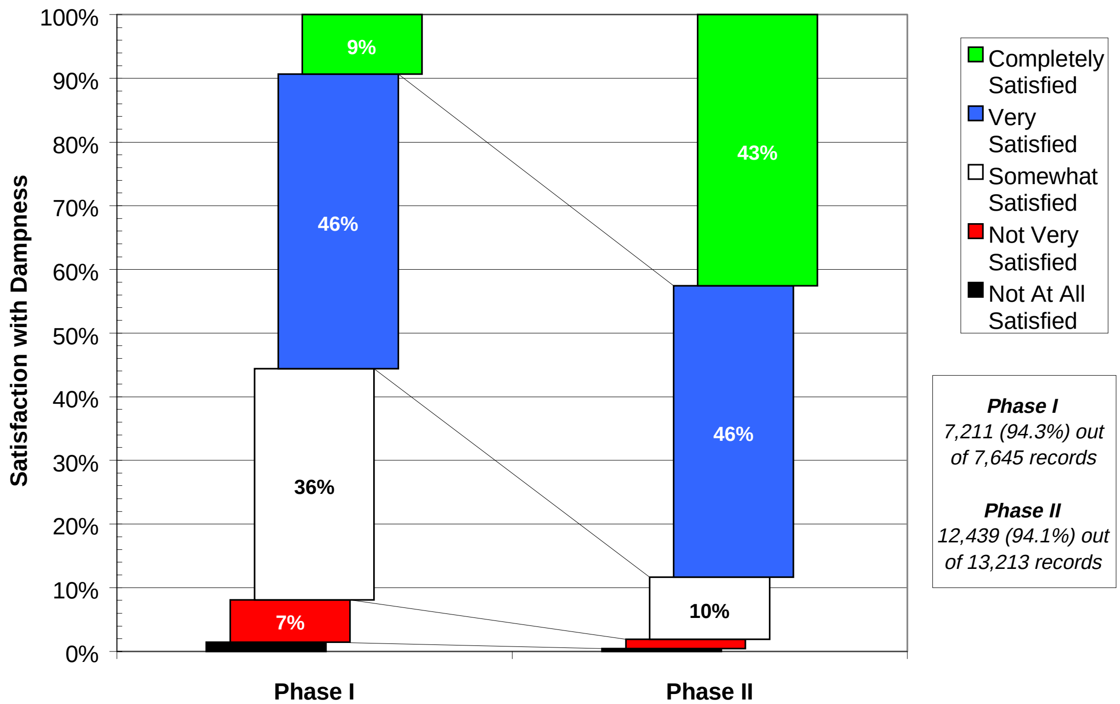


Fig. 4.13 Overall satisfaction with dampness.

4.10. IMPACTS ON DRYING HABITS

Dryer energy consumption was not measured in the study; however, after each wash, participants indicated how each load would be dried, whether in the dryer, on a clothesline or some of each. The distribution of loads and how they were to be dried is shown in Fig. 4.14. About 70% of all loads washed during phase I and II were dried at least partially in the dryer. About 20% were dried only on the clothesline, and there were no significant differences between phases I and II. Based on this information, the customary habits of participants did not change as a result of the changeover to the h-axis washer. This information could be useful in determining any savings in dryer energy consumption if there were differences in the remaining moisture content (RMC) between the v-axis and h-axis washers. Since the dryer was not used at all for about 18–26% of the loads depending on the study phase, any savings due to lower RMC should be lowered by that same decrement.

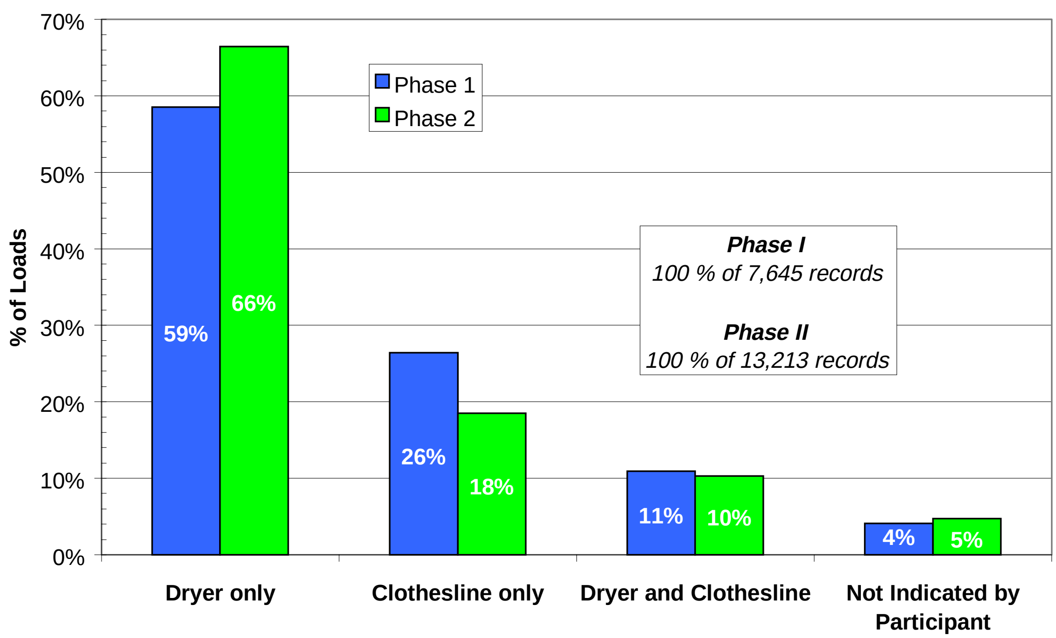


Fig. 4.14 How loads were dried.

4.11. MUNICIPAL UTILITY IMPACTS

The water used by clothes washers comes from the same source as all of the drinking water to a house. After each wash/rinse cycle, most of the water that is used ends up going down the drain; only the small portion bound up in the wet clothes passes into the air during the drying process. Consequently, the amount of water used by clothes washers has an impact on the service providing the water to washers as well as the service for treating an equal amount of wastewater from the washer. In the study, the systems for supplying water and disposing of waste water were different depending on whether a participant lived in Bern proper or in the region which surrounds the city. Both water and sewer services are provided to residents who live in the town. Water is provided from a few community wells, some far away. One large (50,000-gallon) water tower located inside the city limits is used to provide most of the capacity needed by the town. This tower, shown in Fig. 4.15 has also served Bern faithfully as a landmark since its erection in 1953.

Wastewater from the city is carried through underground sewer lines to a wastewater treatment facility at the edge of town. This facility consists of a small number of lagoons that allow evaporation of water and biological breakdown of wastes.

In the area surrounding Bern itself, water comes to residents in two ways: through their individual wells and/or through the community water supply system or Rural Water District (RWD). The RWD consists of distributed water piping to each of the homes in the District along with two standpipes (one shown in Fig. 4.16 to maintain adequate water pressure at critical points in the water distribution system.

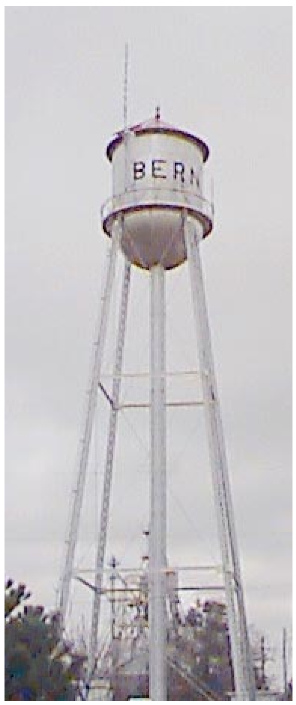


Fig. 4.15 Bern's 50,000-gallon tank.

Figure 4.16 Rural Water District standpipe (Nemaha County).

Wastewater from residents of the RWD is treated with individual septic systems as are common throughout much of the rural areas of the nation. Many households located in the RWD used individual wells to meet agricultural and farming water needs and used the water from the RWD for domestic needs such as clothes washing. For a household in the RWD to qualify as a participant in the study, it was required that its domestic water be provided through the RWD utility.

The impacts of clothes washers on the water utilities (supply and wastewater) in and around Bern were evaluated through two "Superwash Saturdays." The first Superwash Saturday (SWS) was conducted on June 28, 1997, when the original washers were still in place, and the second SWS was held on September 13, 1997, with the h-axis washers up and operating. The objective on both occasions was to measure the delivery flowrate water to the city and to the RWD, and the wastewater flowrate from the city throughout the day. These data, combined with information from the datasheets filled out by participants would allow the impacts of clothes washing on the community's water infrastructures to be determined. On each Saturday, valves on the water piping in Bern and the RWD were used to stop the water flow to Bern's water tower, and to isolate water flow to both standpipes in the RWDs so that water input could be determined. The water discharge from each tank was determined by monitoring the water level inside the tank as it dropped throughout the day. Tank water levels were measured indirectly through use of pressure transducers that had been installed in the water lines at the base of each water tower. The water pressure at the location of the transducer is directly proportional to the height of the water in the tank. The amount of water discharged from the tank over any time interval was determined from changes in pressure sensed by the transducer over this same time interval and the diameter of the tank. Based on this procedure, the volume of water supplied to the city of Bern as well as to the RWD was determined throughout the day on each of the SWSs.

The flowrate of wastewater from Bern was determined through instrumentation that was installed at the lagoon. This instrumentation consisted of a sensor to measure the height of wastewater upstream and downstream of a v-notch weir through which wastewater flowed just before emptying into the lagoon. The difference in height at these two points is proportional to the volume flowrate of water passing through the weir. This instrumentation was connected to a battery-powered datalogger, and data on the rate of wastewater generation on both SWSs were collected and compared with the rate of fresh water consumption of the city of Bern.

There were two main objectives of the SWS concept. The first was to determine the impacts that clothes washers have on water utilities as compared with all of the other water uses present in households. The idea was to encourage participants to postpone most of their week's washing until Saturday when many loads would be done signifying a large wash day. The second objective of the Superwash concept was to determine the differences in water consumption of the collection of washers between phases I and II. This gives an idea of the impact that a large-scale changeover to h-axis washers can have on a community's water utilities.

The impact of a heavy wash day on the Bern's water supply and wastewater disposal system from the first SWS is shown in Fig. 4.17. On this day, data on water flow from Bern's water tank and wastewater flow into the lagoon began to be collected about 9:30 a.m. The figure shows that over the day about 16,000 gallons of water were used and discharged down the drains of the residents of the city. The total flows to the lagoon and from the water tank were about the same, and this indicates that there was no outside watering done. The source of noise in the signal from the city water tank beginning about 2:00 p.m. is unknown. The collective water consumption of the metered clothes washers in the city has been added to this plot as shown in the Figure. Although some participants started loads early in the morning, most began about the time that utility water data collection began. Figure 4.17 shows the clothes washer water consumption with a beginning time of 9:30 a.m. It can be seen that over the day, the 48 v-axis washers in the city used about 18-20% of the total water used by the town. Moreover, these washers accounted for the same fraction of total wastewater generated by the town. It should be pointed out that Saturdays are normally heavy wash days already and that participants were encouraged to concentrate their week's laundry on the 6/28/97 SWS. Records show that on that day, study participants who lived inside Bern washed 164 loads of clothes weighing 1,027 pounds using 72 cups of detergent.

Similar information was obtained for the water consumed by the surrounding RWD and the loads of clothes done by washers located in the rural water district. This information was used to supplement the information developed for the city to arrive at the total impact of SWS on the community. This summary information, shown in Figure 4.18 indicates that the city and RWD together used 55,000 gallons of water, and that clothes washers, based on measurements from the 103 individual washers, used about 12,000 gallons of water (22% of the total). During that time, all 103 participants in the study washed 503 loads weighing 3,336 pounds with 225 cups of detergent. On average, participants in the rural water district washed 68% of the total number of loads done that day.

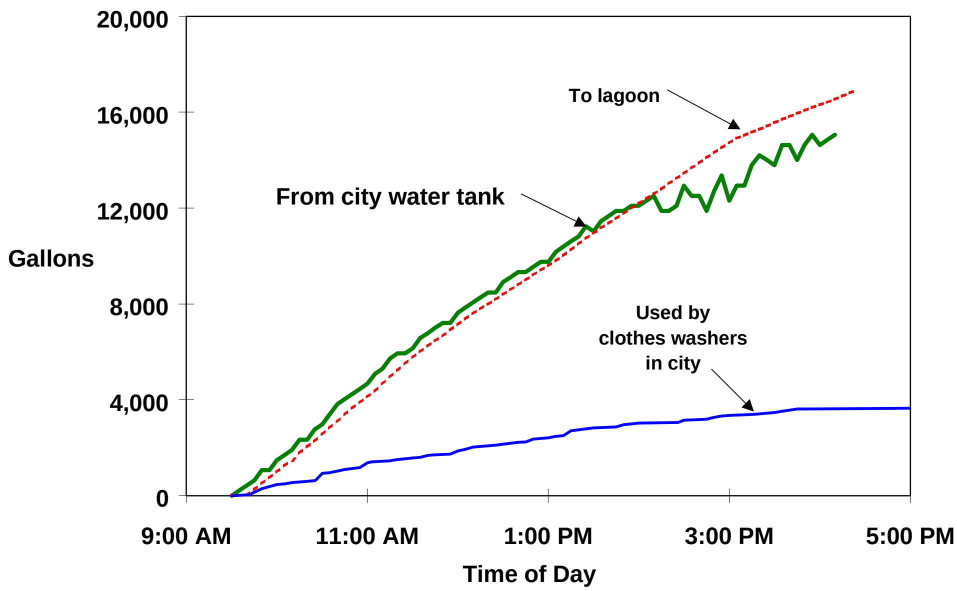


Fig. 4.17 Water utilization in Bern during first Superwash Saturday, 6/28/97 for phase I washers.

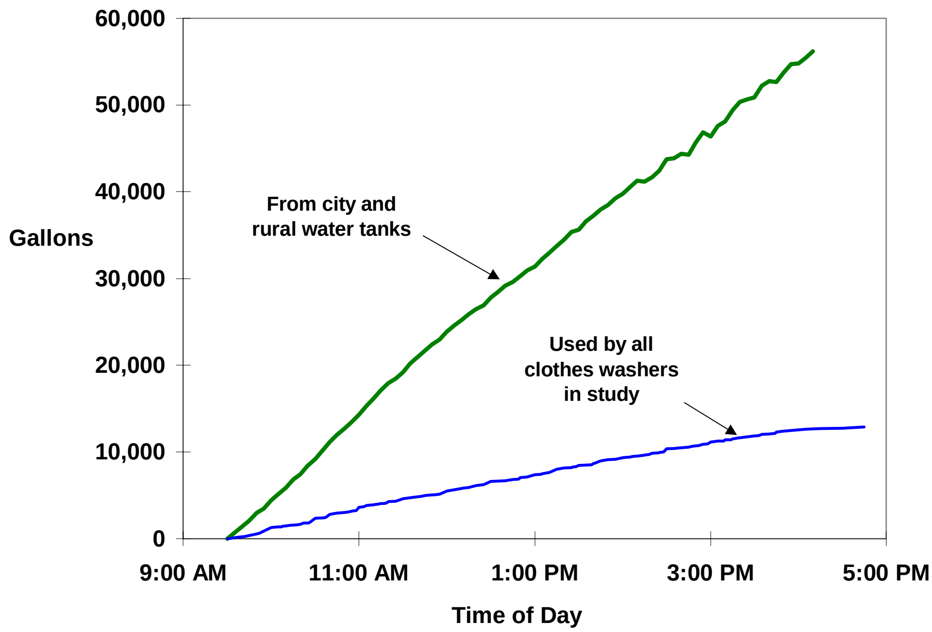


Fig. 4.18 Water utilization in Bern and RWD during first Superwash Saturday, 6/28/97 for phase I washers.

It can be concluded from this analysis that on a heavy laundry day (e.g. 6/28/97 for Bern), a community like Bern could be expected to use 18 – 22% of its total water consumption in clothes washing. The fraction of wastewater generated by clothes washers would be at least this much –

perhaps much higher depending on the amount of water used outside the house for watering or washing the car.

On September 13, 1997 after the h-axis washers had been installed and phase II of the study was well underway, a second SWS was held. The technique and approach were identical to the ones used for the first SWS with all systems instrumented as before. The purpose of this test was to gather the data needed to compare the water consumption of the phase I washers in the first SWS to the consumption of the phase II, h-axis washers. During the second SWS, all of the study participants (city and RWD) washed 516 loads and 3,666 pounds of clothing using 251 cups of detergent. This represents only small increases (2.6% more loads, 9.9% more pounds of wash, 11% more detergent) over what was seen during the SWS conducted in phase I. Comparing data from the two Superwash days indicates that there were differences in the proportion of loads done by city washers as compared to all of the loads washed. On the first SWS, 32% of all loads were washed in the city whereas on the second SWS, 40% of all loads done were washed in the city. The major change, however, between the two SWS periods, as shown in Figure 4.19, was found in the total amount of water needed by washers during those two similar days. In this figure, the cumulative water consumption of all washers for all loads of wash done in each SWS is plotted as a function of the time of day. 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. Apparently, on both days, the wash day started early and ended late for some although most of the loads were done in the period 7:00 a.m. till 4:00 p.m. A town picnic was held the afternoon of 9/13, and the impact of this picnic on washing behavior can be seen as many of the participants and picnic-goers attended to washing chores earlier in the day than they did for the first SWS.

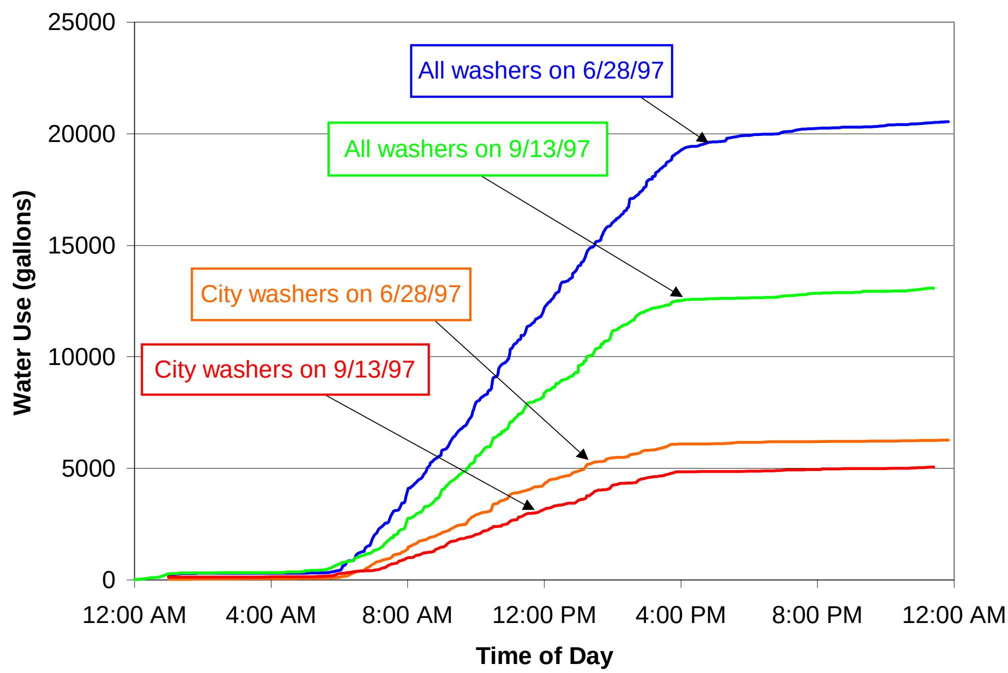


Figure 4.19 Collective water consumption of participants' washers during both SWSs.

5. ANALYSES OF FINDINGS AND IMPACTS

In this study, phase I washers spanning a range of ages, brands, and features were replaced by a single type, brand and model washer (Maytag's h-axis Neptune model). The impacts reported in the previous sections of this report were based on the "average" phase I washer in the Bern Study. This "average" washer was found to be about 8 years old, to consume 11.6 gallons of hot water and 29.9 gallons of cold water per load, and to have the other average characteristics shown in Table 4.1. In this section of the report, we analyzed relationships between several of the parameters to determine their influence on the findings. Although there are a number of analyses that could be conducted from information provided in the study, we chose to perform a limited number of analyses. These analyses were designed to answer some key questions posed in the study as well as to evaluate some performance-related issues associated with the h-axis washer such as:

- How does water savings depend on the load size?
- How does the cleaning performance (cleanability) depend on the age of the phase I baseline washer?
- What were the impacts of using the conventional detergent vs. the high-efficiency detergent in the h-axis washer?
- Other than the washer itself, how did other factors affect the cleaning performance?

In the following sections, we explore some of these questions.

5.1. WATER CONSUMPTION

The amount of water consumed by a washer is determined by a number of factors as shown in Fig. 5.1. Some of these factors are fixed and depend on the design of the washer itself while others depend on how the washer is used and operated by customers.

- *Machine*. Three principal characteristics of a washer affect its water consumption, and these include the type of washer (v-axis or h-axis), the age of the washer (older washers may be less water-efficient than newer ones), and the washer settings used by customers.

- *Load*. The load type and size affects the water consumption of a washer. Many v-axis washers have a load size setting (switch or knob) that can be used to regulate the water level inside the tub. It is not clear how many actually use this switch to adjust their water use with load size. However, there is also the chance that small loads could be washed using a large load-size setting, and this would require more water to be used than is necessary. These washers also have a water level sensor that controls the level of water in the tub for the washing and deep rinse cycles. Since clothes tend to displace water in the tub of a v-axis washer during a fill cycle, the water needed to reach each water level setting depends on the size and makeup of the load in the tub. The h-axis washer is designed to operate without using a switch for setting the washer according to load size, i.e. the washer regulates the amount of water needed to wash and rinse each load – less water for smaller loads and more water for larger ones. Therefore, for both types of washer, v- or h-axis, load size should affect water consumption.

- *Detergent*. The type and amount of detergent can affect a washer's water consumption. The vigorous tumbling action of the h-axis washer can cause oversudsing if too much of a conventional, high sudsing detergent is used. The Neptune was designed to sense any oversudsing condition, and if found would automatically call for extra water to eliminate the condition as part of a suds management protocol. The extent to which extra water was required depends on the amount of detergent that participants used for each load and the type of detergent: their normal brand or the low sudsing Tide HE.

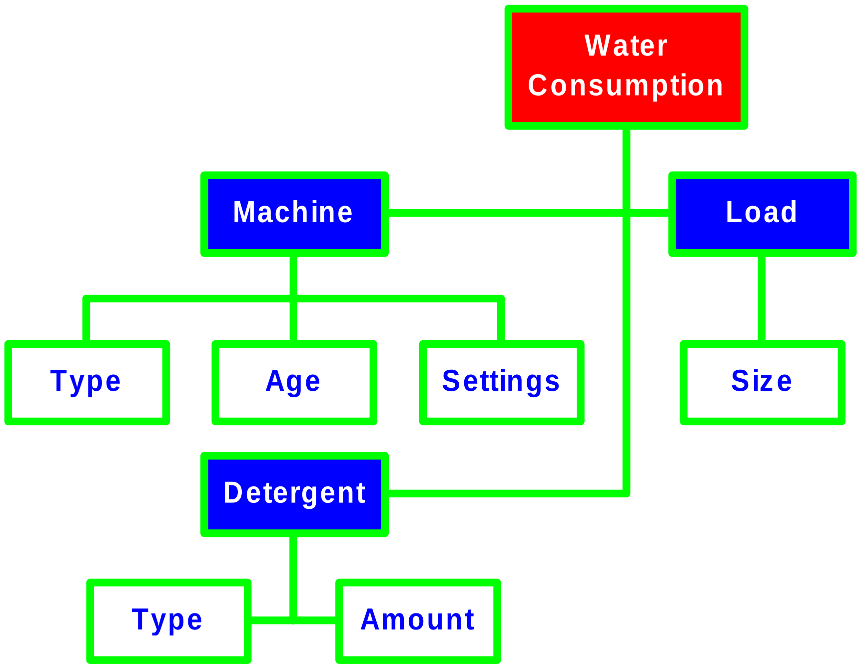


Fig. 5.1 Washing factors that determine water consumption

In a prior section of this report (Section 4), we looked at the influence of washer type on water consumption. We found that the v-axis washers of phase I tended to use more water (on average 15 gallons more) than the h-axis washers of phase II. In the current section of this report, we explore the two remaining factors (load size and detergent type/amount) to determine how they affect water consumption. Throughout both phases of the study, participants washed loads ranging in size from a pound or so to much larger weights. From these data, relations between load weight and water consumption per unit load weight were developed by performing a statistical analysis (best fit) of the load weight/water consumption data. The results of this analysis are shown in Fig. 5.2. The trends for phase I and II are similar showing that as load weight increases, the ratio of water consumption to load weight decreases. This means that both types of washers, h-axis and v-axis tend to use water more efficiently at higher load weights. Across the load weights shown, the h-axis model used less water per pound of load than did the v-axis model and this relative improvement in performance increases with load weight. The notes on the curves for the h-axis and v-axis washers shows the equations developed for a single-parameter fit of water consumption to load weight. The notes further indicate that much of the water consumption for either washer can be explained by this single parameter model.

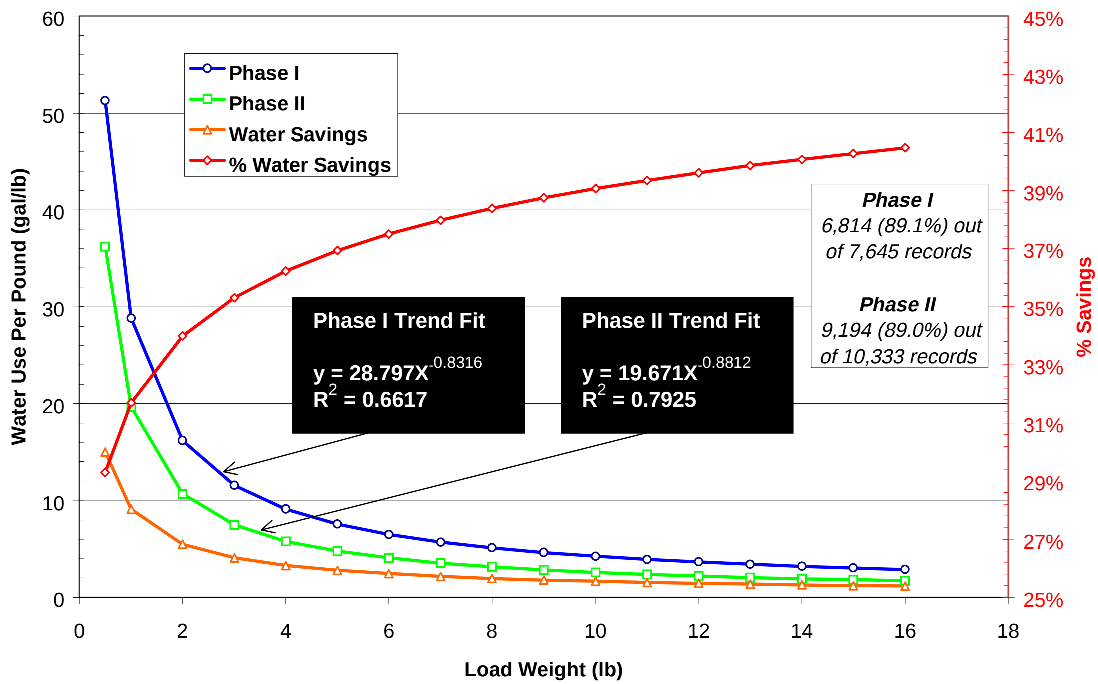


Fig. 5.2 Impact of load weight on water consumption and savings produced.

Based on data from the study, we explored relationships between detergent type/amount and water consumption, and the results of this investigation are shown in Fig. 5.3.

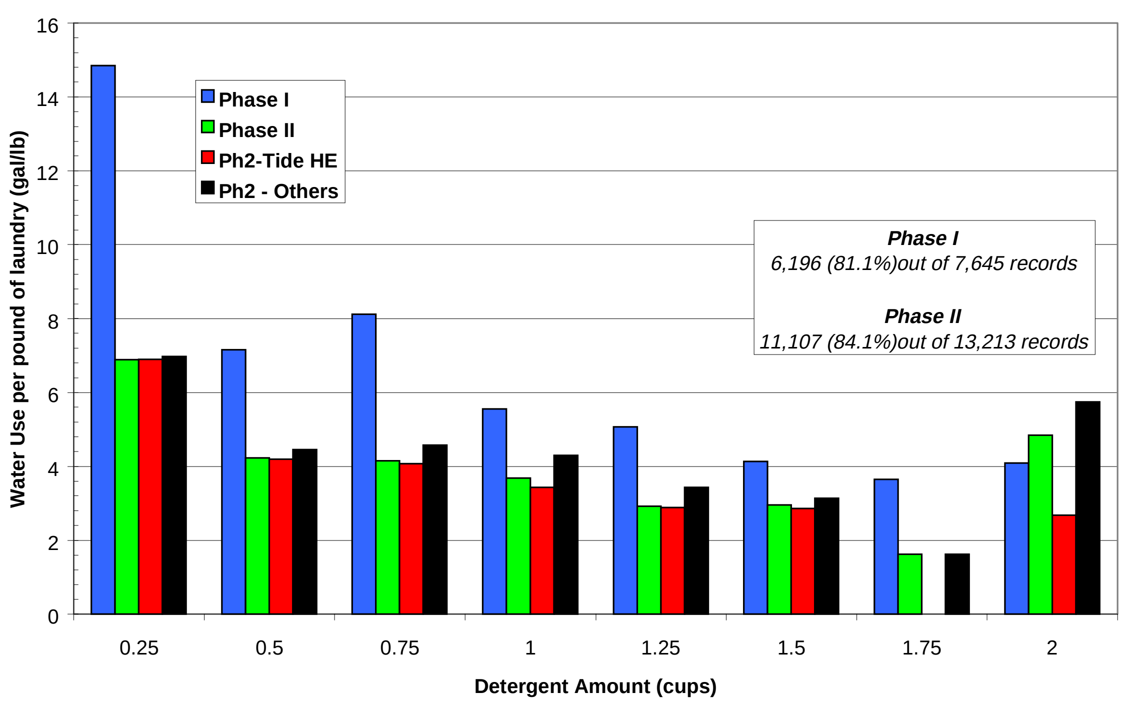


Fig. 5.3 Impact of detergent type/concentration on average water use.

In Fig. 5.3, there are four relations shown: one for the phase I washers, the second for all of the phase II washers without regard for the type of detergent used, the third for phase II washers in which participants elected to use the low-sudsing (Tide HE) detergent provided, and the fourth bar for phase II participants who chose to continue to use their conventional detergent (others). The phase I and phase II bars simply reiterate the finding that the v-axis washers used more water per pound of wash than did the h-axis washer, and that participants would likely increase the amount of detergent as load size increases. In the remaining two bars, differences in water consumption between participants who used the low sudsing detergent and ones who continued to use their customary brands (others) are shown. Interestingly, with each detergent concentration in phase II, water consumption was consistently larger for the customary, conventional detergent than for the Tide HE detergent. This suggests that the low sudsing detergent provides a benefit in reducing the amount of water used. There was little benefit seen for loads that used ¼ cup of detergent and somewhat greater benefits with higher detergent amounts. This is to be expected since low concentrations of either type of detergent would not lead to an oversudsing condition. The absence of a bar at the 1-¾ cup level simply indicates that no loads at that Tide HE concentration were done and reported.

5.2. CLEANING PERFORMANCE

There are a number of factors that can affect the cleaning performance of a washer and customer satisfaction with cleaning as shown in Fig. 5.4. While many of these factors are identical to ones identified previously, there are additional ones that affect customers' perception of the cleaning performance of a washer.

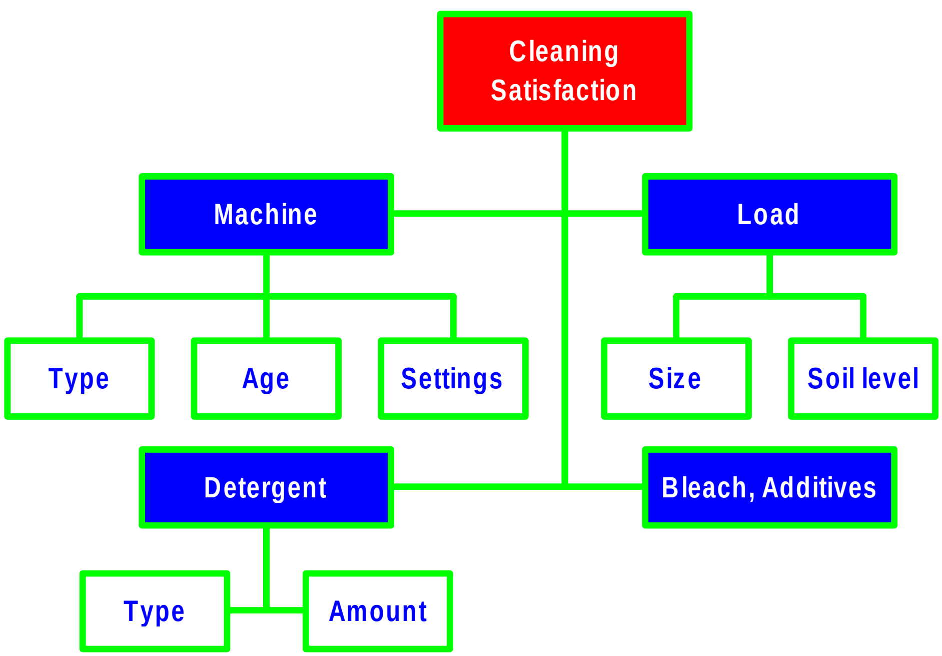


Fig. 5.4 Washing factors that affect customer's satisfaction.

The initial soil level of loads before washing, the use of bleach and other additives, the temperature settings used on the washer, the amount and type of detergent used can each affect cleaning performance as well as the washer itself. Therefore, it was important to distinguish differences in cleaning performance as a result of the changeover to the new h-axis washer from differences that could be attributed to these other factors.

- *Initial soil level*. How clean a load appears when removed from a washer depends to some extent on the initial soil level of the load going into the washer. We assumed that over the extended period of the study and the large number of loads analyzed (more than 20,000), the average soil level in a typical load and the distribution of loads at any initial soil level would be uniform. Some loads were probably quite soiled before washing, some less so, but on average and across all participants, the initial soil levels were taken to be consistent between phases of the study.

- *Bleach use*. Bleach and other additives can affect the appearance of loads removed from the washer and a customer's perception of cleaning performance. From the loads studied and analyzed, there were no significant changes in the use of bleach. About 10% of the loads in each phase were washed using bleach.

- *Effects of Washer Age*. 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 who's original washer was newer. It is reasonable to assume that: 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 as shown in Fig. 5.5 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 washer 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 is seen to increase with increasing age (the 25 to- 27-year old category notwithstanding where there was only one washer).

  Figure 5.6 shows the cleaning satisfaction reported by participants who had replaced their phase I washer of the vintage shown with the h-axis model. A comparison of these two figures (Fig. 5.5 and Fig. 5.6) indicates that in each age range, cleaning satisfaction increased with the changeover to the h-axis model. The improvement in satisfaction was especially notable to participants who had phase I washers more than 15 years old.

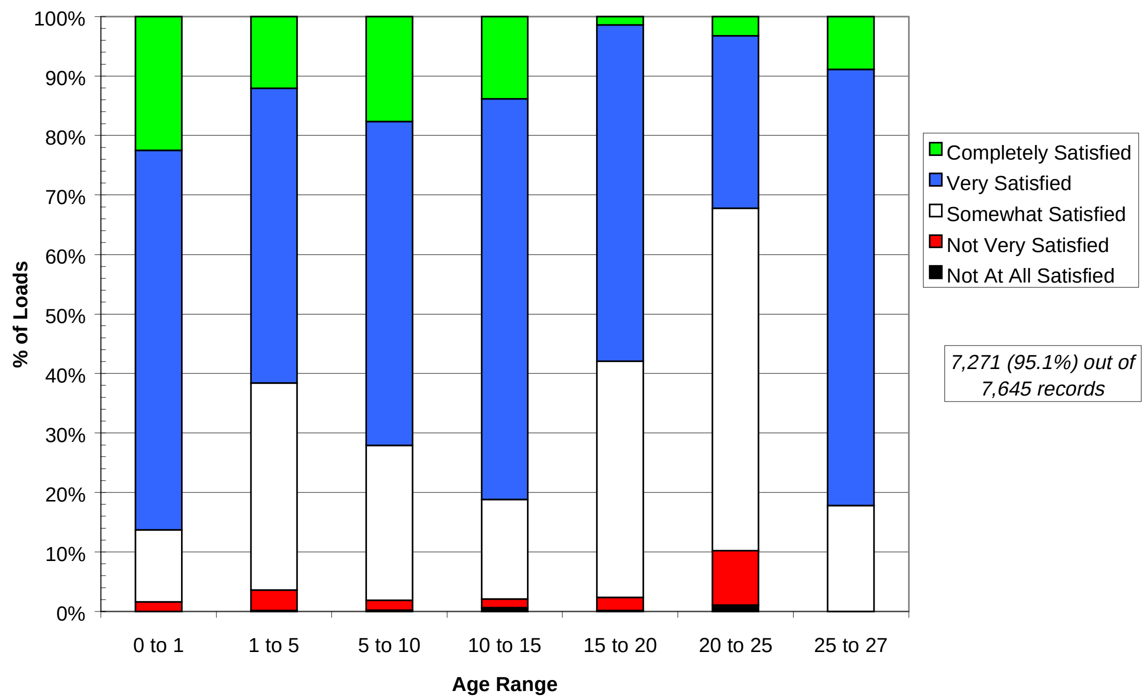


Fig. 5.5 Dependence of cleaning satisfaction of phase 1 machine on its vintage.

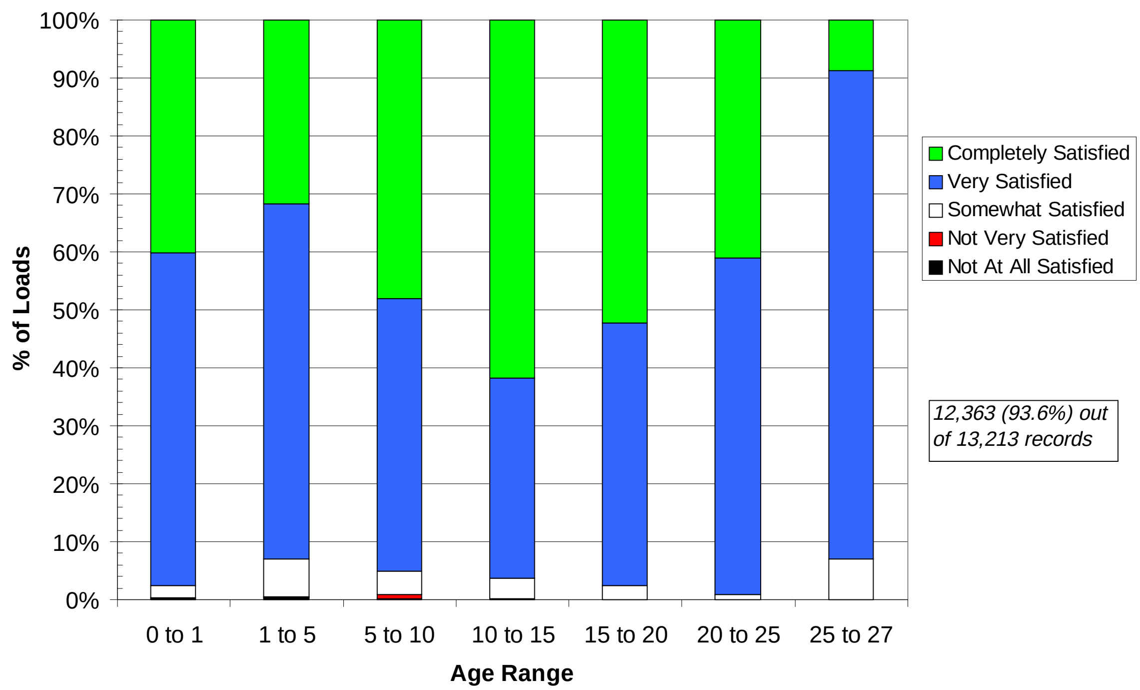
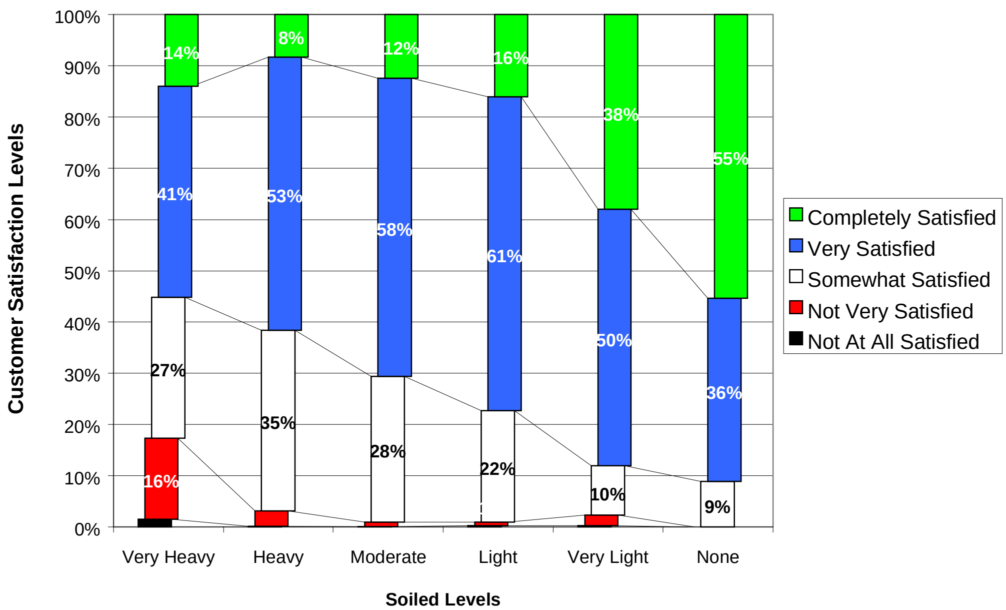


Fig. 5.6 Dependence of cleaning satisfaction of phase II washer based on experience with phase I washer (by vintage).

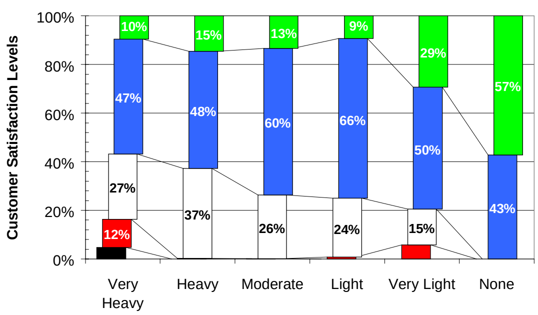
- *Effect of Temperature Settings*. Wash and rinse temperatures can affect the cleaning performance of a washer. Participants were asked to indicate how they set the wash and rinse temperatures for their washers as they washed clothes. In most of the washers, a hot, warm or cold wash temperature could be selected, and a warm or cold rinse temperature could be selected. In addition, participants were asked to characterize the soil level of each wash load prior to washing. As can be seen in the datasheet, soil levels of Very Heavy, Heavy, Moderate, Light, Very Light and None were the selections available. Participants simply selected the initial soil level from among these choices for each load of wash. The information was collected for both phases of the study, and the results shown are in Fig. 5.7 for phase I and in Fig. 5.8 for phase II. The top of each figure shows how participants characterized the pre-wash soil level of all wash loads without regard to a particular wash/rinse temperature setting; that is, all temperature selections were used. In phase I (Fig. 5.7), participants' satisfaction with cleaning performance followed the expected trend: participants were more satisfied with a washer's cleaning performance for lightly soiled loads than for heavily soiled ones. They were very (or completely) satisfied for more than 90% of all loads, which were very lightly soiled, and 55% for loads, which were very heavily soiled at the outset. The four charts at the bottom of Fig. 5.7 indicate how these satisfaction levels varied according to wash/rinse temperature settings. As before, cleaning satisfaction tended to be according to the initial soil level of the load.

  The results of initial soil loading and wash/rinse temperatures for the phase II h-axis washer are shown in Fig. 5.8. Without regard for temperature setting (top of the Figure), participants were at least very satisfied with 90% or better of all loads across all initial soil levels. For lightly soiled loads, the satisfaction level is about 98%. The four charts at the bottom of the figure show how cleaning performance depends on the wash/rinse temperature selections. Over all temperature setting combinations and all initial soil levels, participants' assessment of the overall cleaning performance of the h-axis washer was superior to their phase I washer.

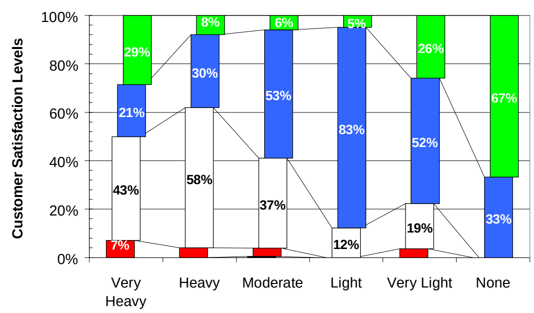
- *Effect of High Efficiency Detergent*. During phase II of the study, participants had the option of continuing to use their conventional detergent, or using Tide HE, which had been formulated expressly for use in h-axis clothes washers. About 80% of all phase II loads were done using the HE detergent. To test the contribution that the new HE detergent had on cleaning performance, we separated datasheets received in phase II according to those loads washed with Tide HE and those washed using participants' customary brand/type of detergent. The results of this analysis are shown in Fig. 5.9. Also, the satisfaction responses for those loads for which there wasn't a detergent brand identified or more than one entry was given are shown in the figure as the category "none or more than one specified". All, participants appeared to be very satisfied with the cleaning performance of both types of detergents. In the case of Tide HE, participants were at a minimum very satisfied with 96% of all loads that they washed using this low-sudsing detergent, whereas with the conventional detergent, 92% of all loads delivered this same satisfaction level. These results are based on data from 11,483 loads. No detergent use or more than one detergent type was reported for a much smaller sample size as shown in Fig. 5.9.



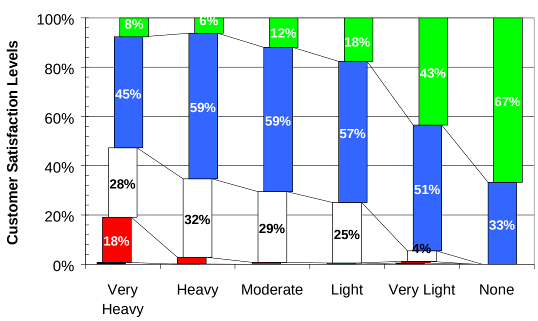
(a) All washer temperature settings.



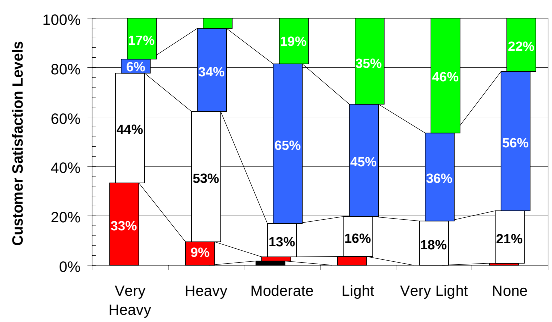
(b) Hot/Cold temperature setting.



(c) Warm/Warm temperature setting.

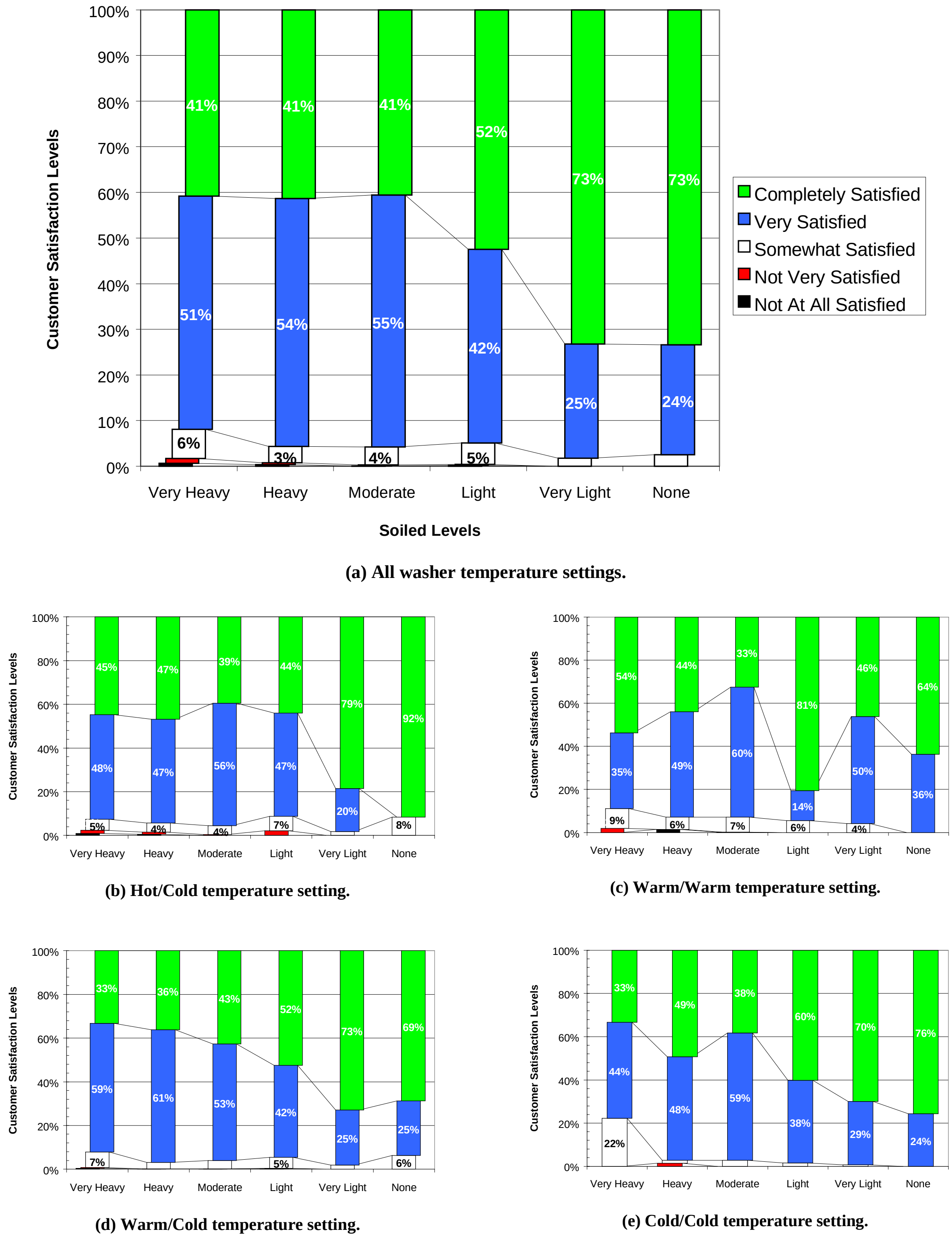


(d) Warm/Cold temperature setting.



(e) Cold/Cold temperature setting.

Fig. 5.7 Relative cleaning performance of phase I washers versus initial soiled level of laundry.



(a) All washer temperature settings.

(b) Hot/Cold temperature setting.

(c) Warm/Warm temperature setting.

(d) Warm/Cold temperature setting.

(e) Cold/Cold temperature setting.

Fig. 5.8 Relative cleaning performance of phase II washers versus initial soiled level of laundry.

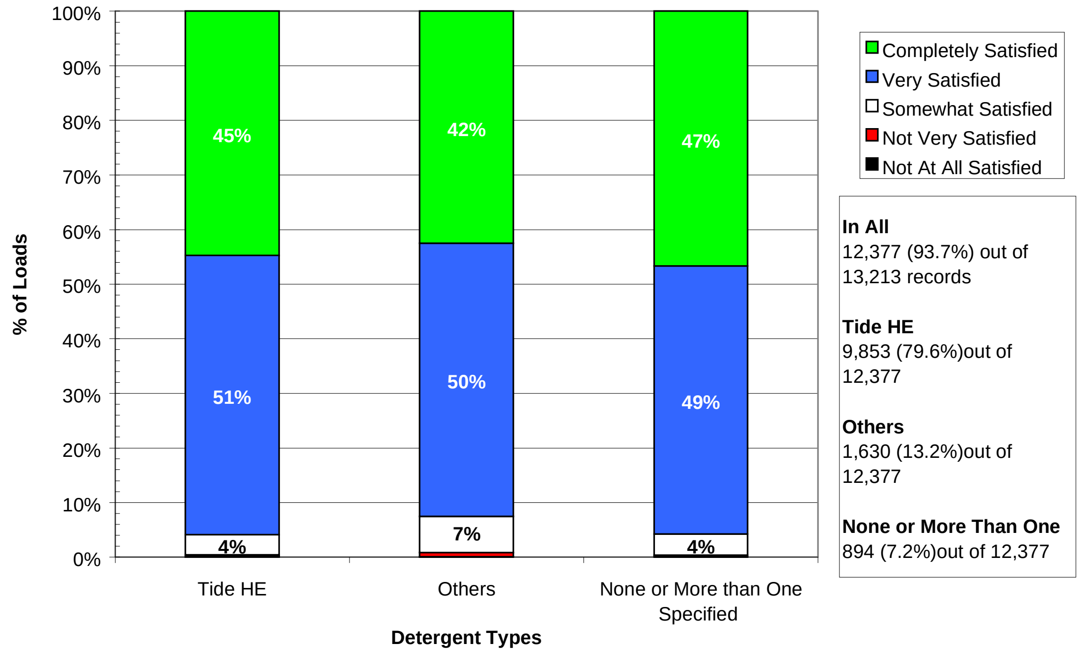


Fig. 5.9 Dependence of cleaning satisfaction on detergent in phase II.

Finally, the data on cleanability was examined to determine effects stemming from familiarity with the phase II washer. The data records were separated according to time-of-ownership for the h-axis washer, and cleaning satisfaction levels were compared as shown in Fig. 5.10. Over a 3-month period starting from when phase II washers were first installed, participants were at least reasonably satisfied with about 95% of the loads done during that period. Most evident is the increase in overall satisfaction level shown by the significant and consistent increase in the number of loads for which participants were completely satisfied. These results suggest that (1) participants became more experienced with the h-axis washer and increasingly were able to obtain excellent performance from it, and (2) improved cleaning of the same articles of clothing through repeated washings over this time period became more evident.

5.3. MOISTURE REMOVAL PERFORMANCE

Satisfaction with how dry loads appeared at the conclusion of the wash cycle is affected by most of the same factors as satisfaction with cleaning performance as shown in Fig. 5.11. One major determinant of the remaining moisture content (RMC) in a load is load weight. Therefore, it would be anticipated that with higher load weights, participants would tend to be less satisfied with the level of dampness. To test this assertion, the loads done in phase II were segregated according to load weight as shown in Fig. 5.12, and the level of dampness satisfaction (fraction of loads with satisfaction levels applied) was determined. Overall, dampness satisfaction followed the expected trend, that participants' were noted to be less satisfied as load weight increased. Fig. 5.13 shows the results for the same weight categories for phase I, and it appears that there is some improvement in the level "complete" satisfaction for load weights in the 15-20-pound load weight range.

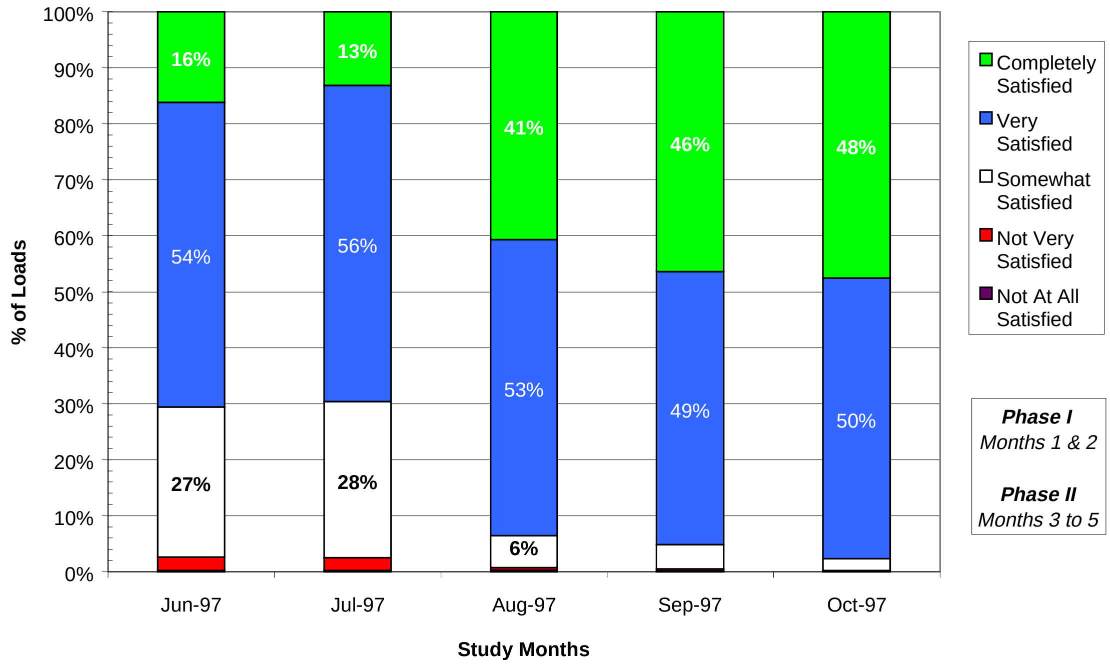


Fig. 5.10 Changes in satisfaction with cleaning performance of phase I and II washers.

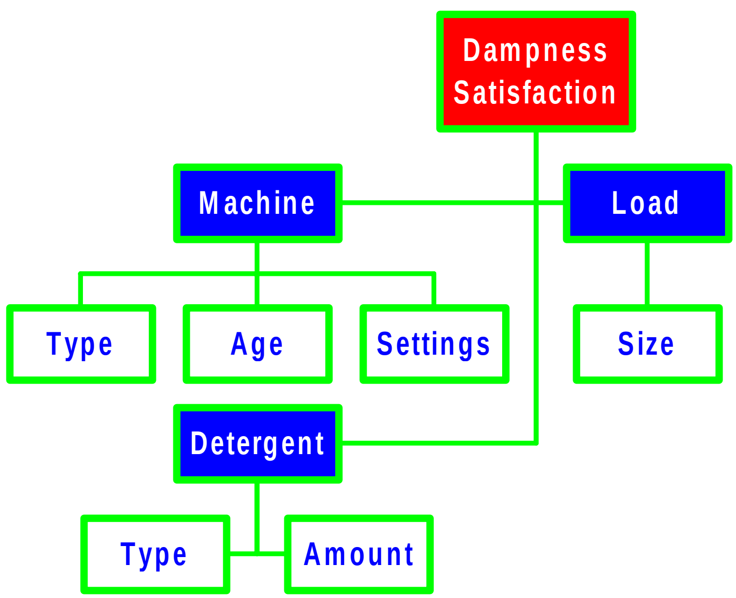


Fig. 5.11 Washing factors that affect customer's dampness satisfaction.

The h-axis washer used in the study had a switch on the operating panel that would increase the speed and duration of the spin cycle to wring more moisture from the clothing. Participants used this max extract (maximum extraction) feature for about 62% of all loads and an extra rinse feature for about 4% of all loads washed in phase II. Fig. 5.14 shows the effects that these washer features had on the dampness satisfaction index. There seems to be little in terms of a trend except for the point that participants' satisfaction levels were lower where the extra rinse alone was used. Beyond this, there were only minor differences in satisfaction levels.

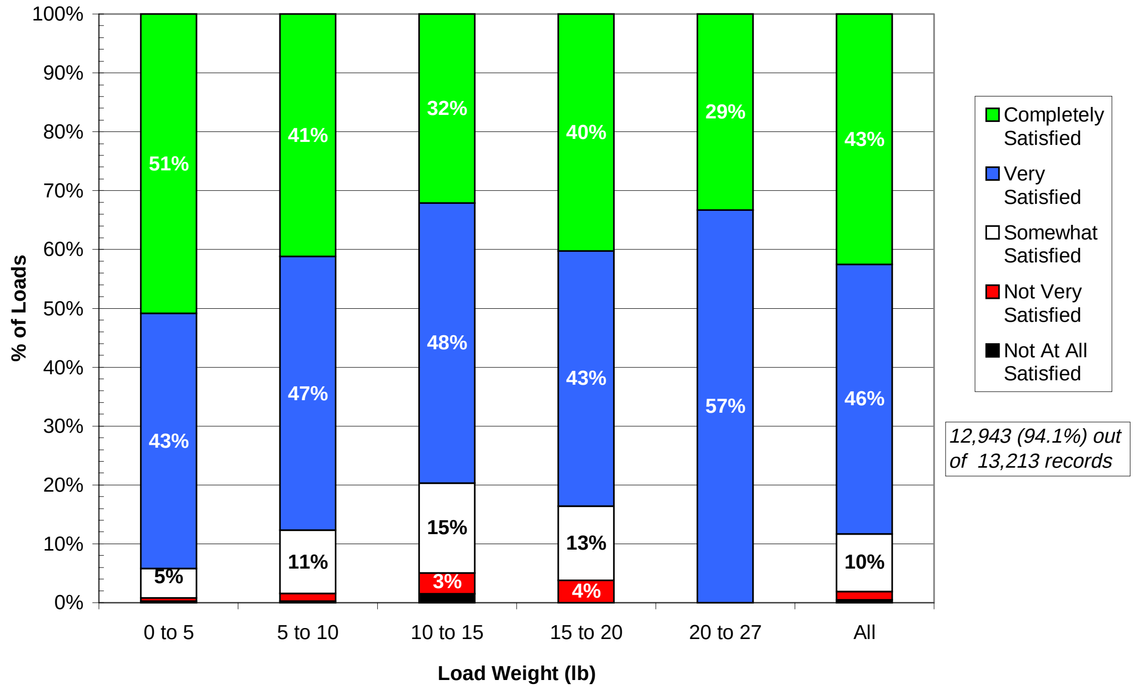


Fig. 5.12 Dependence of dampness satisfaction with load weight for phase II.

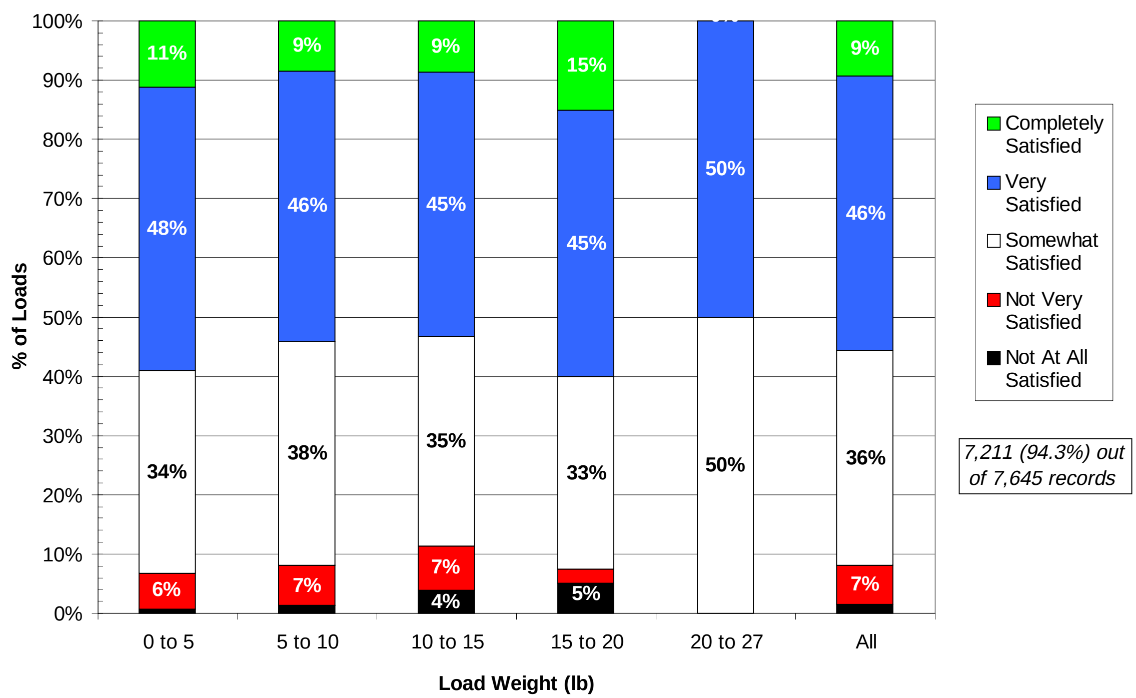


Fig. 5.13 Dependence of dampness satisfaction with load weight for phase I.

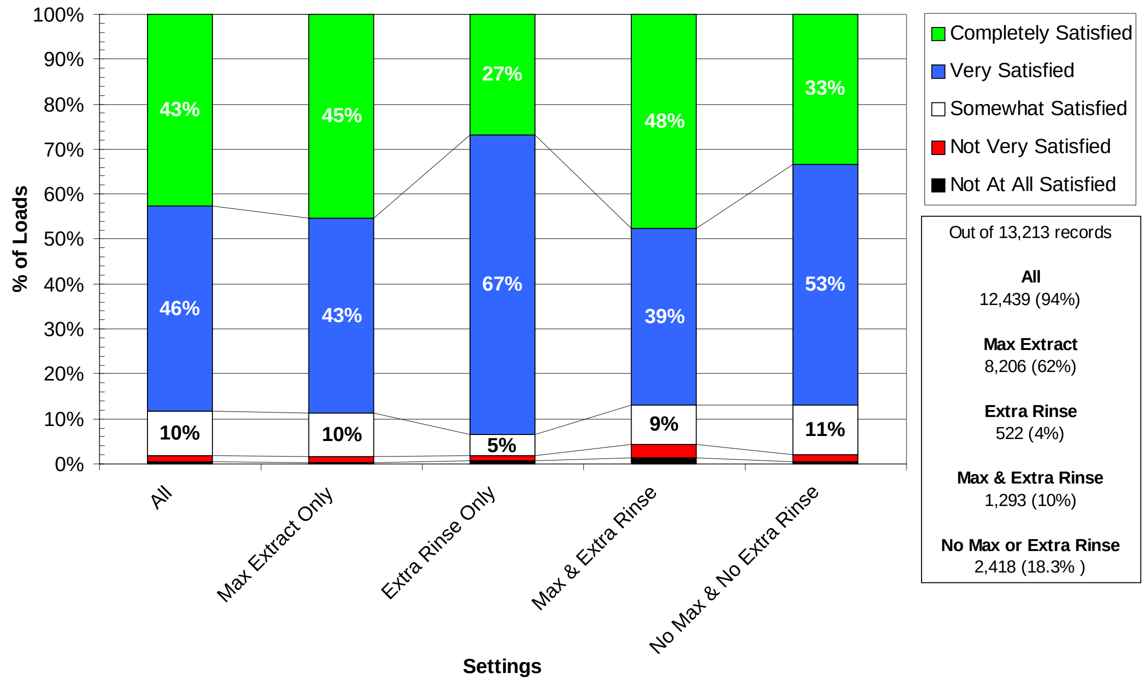


Fig. 5.14 Dependence of dampness satisfaction on max. extract and extra rinse cycles (phase II machines).

It is much more efficient to dry clothes by spinning them in a spin cycle than by using thermal energy to evaporate the moisture. Consequently, the effectiveness of the final spin in removing moisture can be important in saving dryer energy. The measure of how dry a load is after a process (e.g. final spin) is the remaining moisture content. RMC (as a fraction) is the weight of the moisture retained in a load divided by the dry weight of the same load. Lower RMCs are desirable from an energy-efficiency standpoint. From the pre-wash and post-wash load weight data, a "field" RMC value could be obtained, and this was done for phase I, and for phase II with the max extract feature enabled and without max extract. Fig. 5.15 shows the trends produced from this analysis. In phase I, RMC values ranged from about 68% for a 2-pound load to about 50% for a 20-lb load. In phase II, lower RMCs were produced by the h-axis washer operating without the max. extract feature on, and still lower RMCs with the max. extract feature on. The RMC for the class of washers in phase I was particularly sensitive to the dry load weight, and with higher load weights, both machines were able to leave loads with RMC values of 50% or less. For the 6-7 pound average load weight in phase II, the RMC of the h-axis machine using the max. extract setting was about 48%. It should be noted that these RMC values were measured in the field and were based on the condition of loads as they were prepared for washing. Laboratory measurements of RMC are based on pre-wash conditions where the clothes are bone-dry.

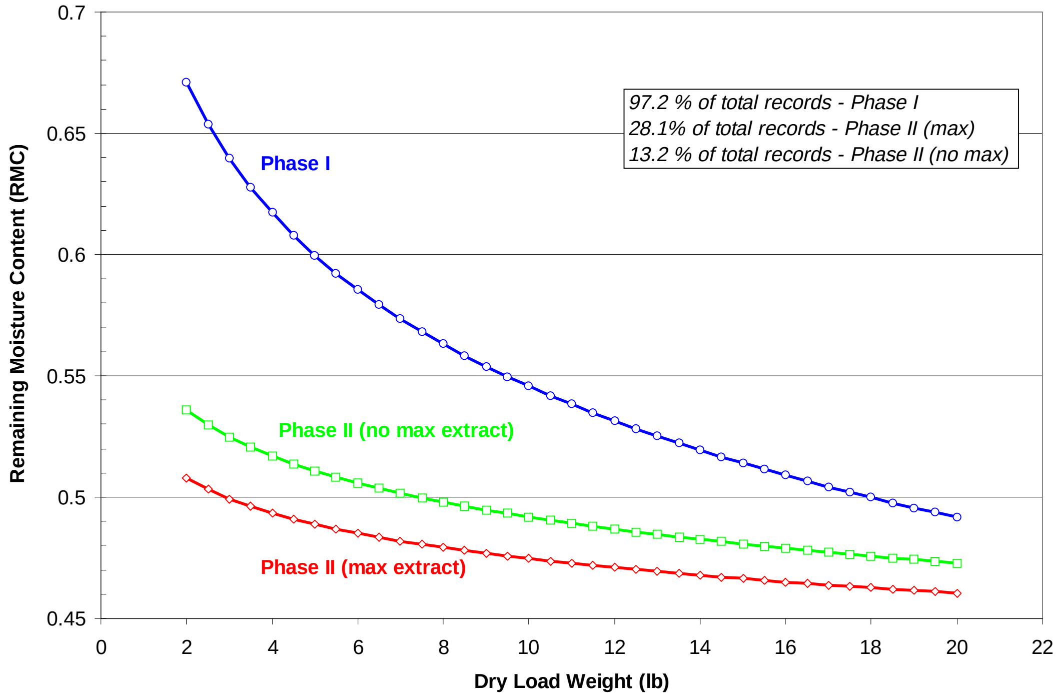


Fig. 5.15 Dependence of remaining moisture content on load weight.

6. **CONCLUSIONS**

The major impetus of this study was quantifying the water and energy savings offered by a large concentration in a community of horizontal-axis (h-axis) washers over conventional vertical-axis (v-axis) washers. Close to 35 billion loads of laundry are washed annually nationwide in the U.S consuming 2.6% of the total residential end-use energy[7]. 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 and 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.

In addition to demonstrating the h-axis washer as an extremely efficient technology, this study evaluated and quantified many of the potential impacts of a changeover to high-efficiency clothes washers. These include impacts on customer habits and behavior patterns with respect to laundering tasks, impacts on the energy and water used by customers, and impacts of washers on the utilities that supply water. Overall, the study showed that the changeover to the h-axis washer had little impact on the way in which customers washed and dried clothes. 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. 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 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. 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 much 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.

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[7] "Revolution, Not Agitation: A New Spin on Clothes Washing", *Home Energy*, Vol. 13, No. 6, November/December 1996, pp. 7-8.

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. 6.1 and 6.2 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 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 – one storage tankfull – each month. The change in energy consumption exhibits a similar trend as shown in Fig. 6.2.

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 had 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.

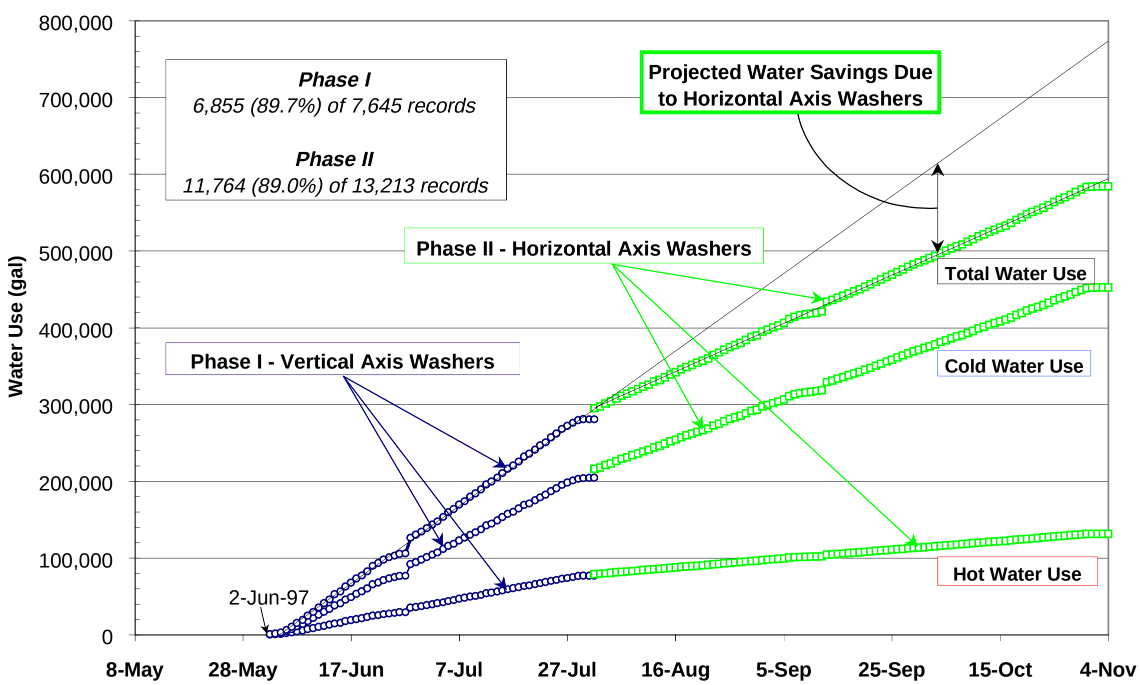


Fig. 6.1 Projected impact of washer replacement on water consumption.

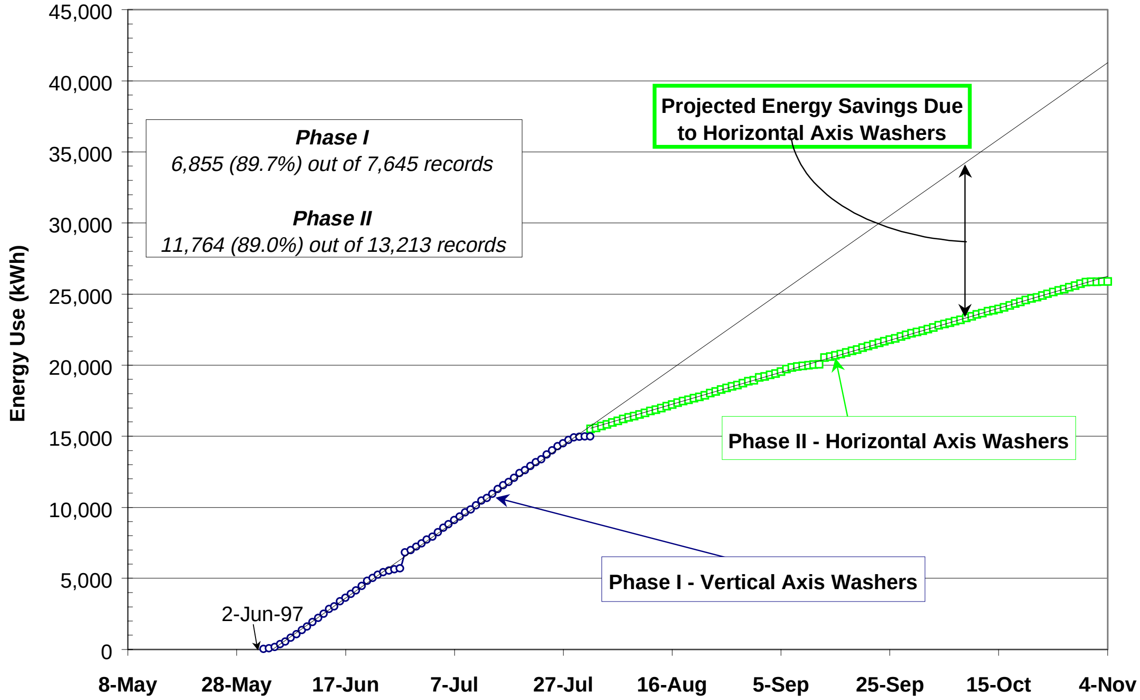


Fig. 6.2 Projected impact of washer replacement on energy consumption.

Appendix A. Water Metering for Clothes Washers

The following information – details regarding the distributed water meters used in the study – is provided to help water utilities and others who may be interested in conducting similar projects requiring end-use metering of water fixtures or appliances such as clothes washers. Described is the technique we used for adapting a conventional water meter with a remote digital readout that could be easily read by the participants with each load of laundry. This eliminated any need for the water meters to be viewable by the participants. The modification was found to be simple to implement, relatively inexpensive and retained the inherent accuracy of the water meter.

Water consumption of clothes washers in the Bern Study was determined with conventional nutating disk water meters of the type used by many water utilities for determining a customer's water consumption. Water passing through this meter causes a disk within the meter itself to nutate or wobble about a fixed axis with a frequency which is proportional to the volume flow rate of water through the meter. The nutating disk is affixed to a 4-pole permanent magnet, so that as water passes through the meter, the magnet rotates and a register on the face of the meter itself senses its rotation. We removed (temporarily) the register (as shown at the photo at the right) and installed a small reed switch on the body of the meter itself. The magnet hidden inside the bronze casing caused the reed switch to open and close four times with each nutation. Knowledge of the number of nutations per gallon of water passing through the meter (provided by the meter manufacturer) along with information concerning the four-pole magnet allowed us to develop the modified meter relationship between gallons of water passing through the meter and number of reed switch closures. For the meters chosen, 200 contact closures represented approximately one gallon of water through the meter.

The reed switch was simply connected to a battery-powered electronic counter as shown in the photo at the left. Two counters, one for the hot and one for the cold water meters, were placed into a single box and the box was placed in a convenient location in the laundry room of each participant. Participants had only to read the numerals on each electronic counter once with each laundry load, record the information on datasheets. No resetting was required, and the water consumption for each individual load could be determined from the datasheets submitted from successive loads.

Appendix B. Examples of Reports to Participants

The following pages are colorized examples of the individualized study reports sent to the 103 Bern Study participants during phases I and II of the study and at the end (comparison of phases I and II). Each report includes six graphics on the first page (first two pages in the case of the comparison report), which provide percentages on:

(1) load frequency by day of the week,
(2) load frequency by hour of the day,
(3) initial soil level of the laundry prior to washing,
(4) methods used to dry the cleaned laundry,
(5) hot water use by machine temperature setting, and
(6) cold water used by machine temperature setting.

Only the actual temperature settings used by the participant are shown for (5) and (6). Therefore, not all of the possible five temperature settings (H/C, H/W, W/W, W/C and C/C) are necessarily shown for each report.

The second page of the separate phase I and II reports and third page of the phase I and II comparison report include a summary table on the totals and averages for the loads washed by the participant. The totals include:

- number of loads or cycles washed by participant
- weight of these loads
- amount of water used
- amount of energy used (calculated from thermal and machine energy)
- amount of moisture that would have to be removed by dryer or other drying method

The averages include:

- weight of laundry or washed clothes per load cycle
- water used per load or cycle
- washer energy in kilowatt-hours used per cycle
- ratio of load weight to water use in pounds per gallon
- ratio of load weight to energy use in pounds per kilowatt-hours

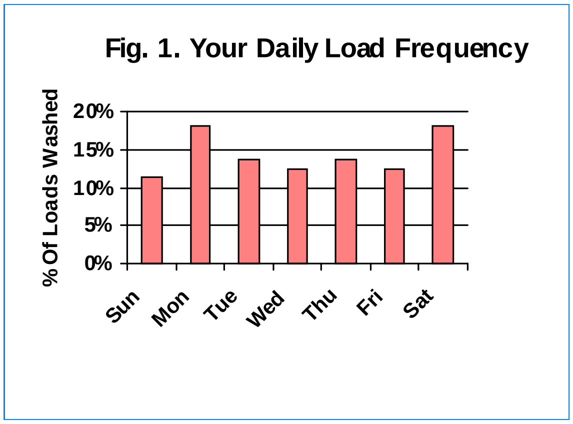
Only one report was issued to the study participants for phase I (vertical-axis washers) since most of the data was collected by the time the report was issued. Pages A.3 to A.4 provide an example of the initial report on phase I customer #1, Karen Aeschliman. Both an initial (after the first two weeks) and an interim report (after the first month) were issued to the study participants for phase II (horizontal-axis washers). Pages A.5 to A.6 provide an example of the interim report on phase II for the customer #1. Final individual reports comparing phases I and II for all of the data collected during both phases was issued along with this Bern washer study final report. Page A.7 shows the third page of the final report that was sent out comparing phases I and II. The contents of the letter that accompanied the final individual report is on pages A.8 to A.10. The letter provides a description of all the calculated values given in the comparison table of the third page of the individual report. The first two pages of the final report aren't shown since their layout is the same as the first pages of the Phase I and II reports.

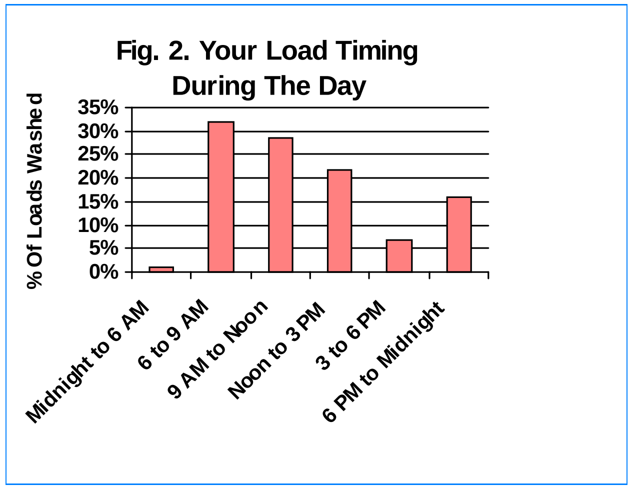
Bern Washer Study - Initial Phase 1 Results

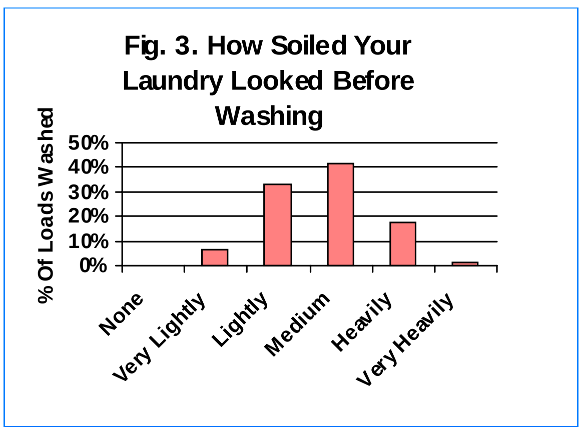
Monday, August 25, 1997

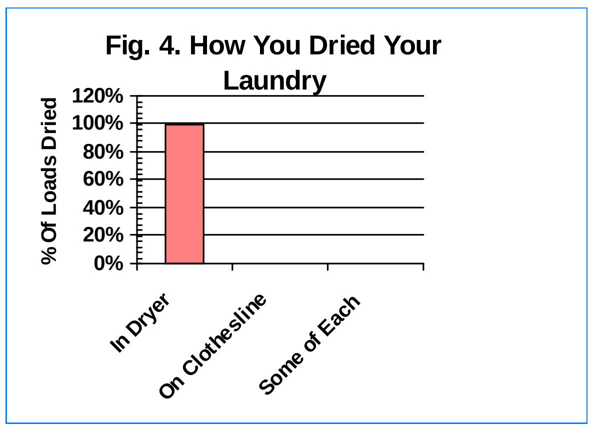
Name: Karen Aeschliman

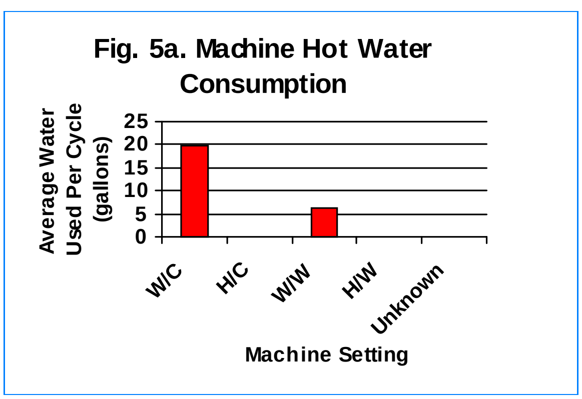
Customer Number: 1

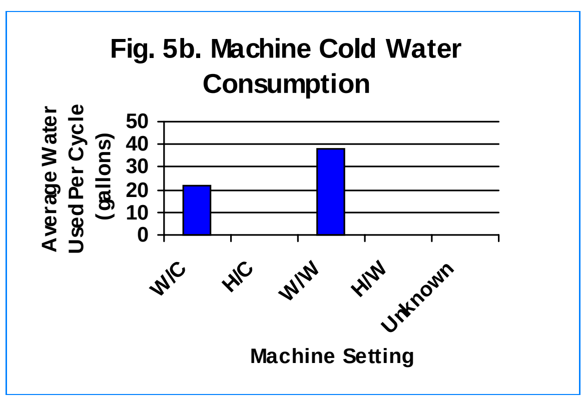












Name:	**Karen Aeschliman**
Customer Number:	**1**

Table 1. Calculations Based on Customer Data

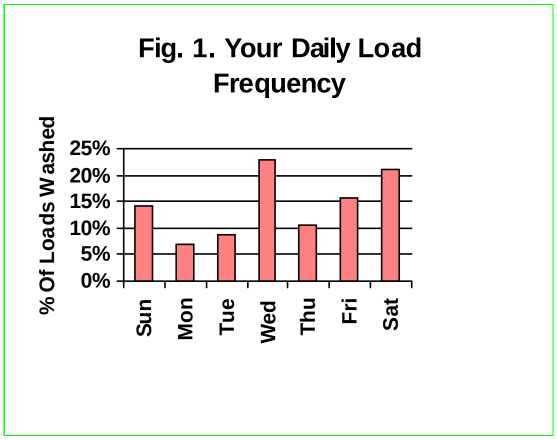
Total Number of Cycles:	88
Total Weight of all Loads (lbs):	633.28
Total amount of water used (gallons):	3906.02
Total amount of energy used (kwh):	89.03
Total amount of moisture removed by dryer (lbs):	358.56
Average weight of clothes in a cycle (lbs):	7.20
Average water used per cycle (gallons):	44.39
Average washer energy use (kwh/cycle):	1.01
Average weight of load per gallon of water used (lb/gal):	0.16
Average weight of load per kWh (lb/kWh):	7.11

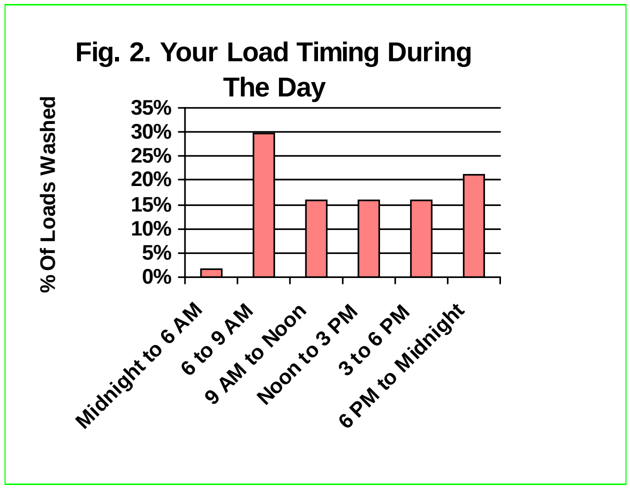
Bern Washer Study - Interim Phase 2 Results

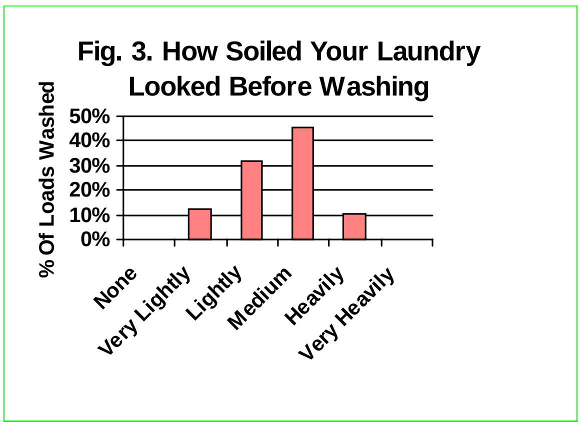
Friday, October 10, 1997

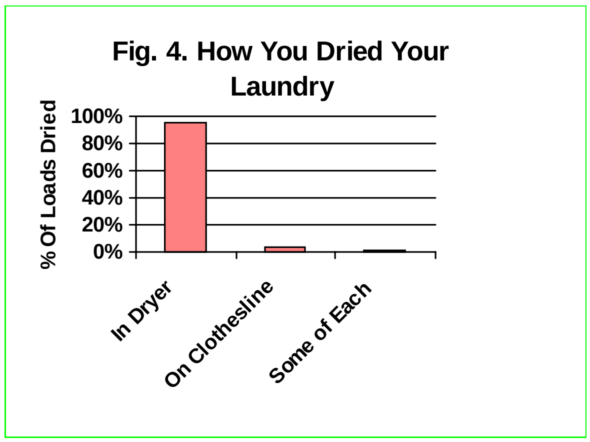
Name: **Karen Aeschliman**

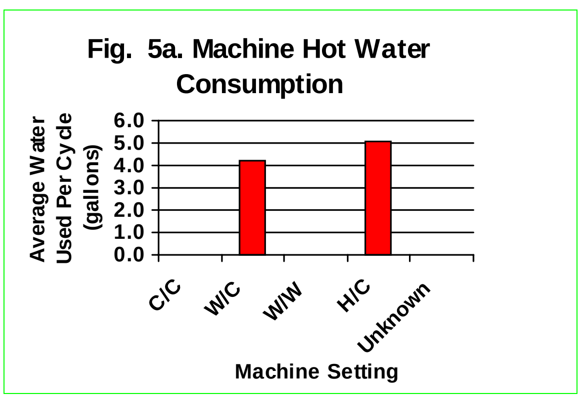
Customer Number: **1**

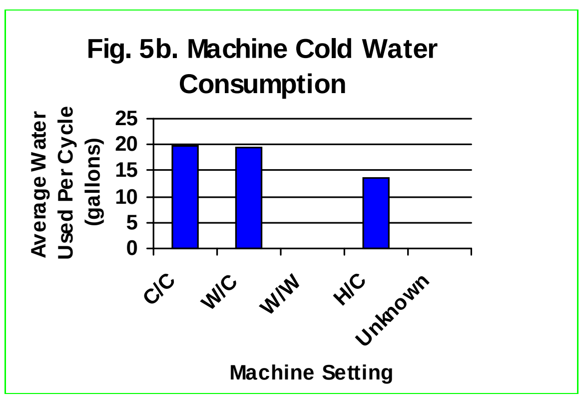












Bern Washer Study - Interim Phase 2 Results

Friday, October 10, 1997

Name:	**Karen Aeschliman**
Customer Number:	**1**

Table 1. Calculations Based on Customer Data

Total Number of Cycles:	56
Total Weight of all Loads (lbs):	358.14
Total amount of water used (gallons):	1304.08
Total amount of energy used (kwh):	34.97
Total amount of moisture removed by dryer (lbs):	203.44
Average weight of clothes in a cycle (lbs):	6.40
Average water used per cycle (gallons):	23.29
Average washer energy use (kwh/cycle):	0.62
Average weight of load per gallon of water used (lb/gal):	0.27
Average weight of load per kWh (lb/kWh):	10.24

Bern Washer Study - Comparison of Phase I and II Results

Tuesday, March 17, 1998

Name: **Karen Aeschliman**

Customer Number: **1**

	Phase I June & July 1997	*Phase II August, September, & October 1997*	*Your Savings or Difference*	*Study's Average Savings*
Water Use (gallons or gal)				
Total Hot:	594.2	656.2	62.0	
Total Cold:	3,368.7	3,232.9	135.9	
Total Hot & Cold:	3,962.9	3,889.1	73.8	
Average Hot Per Load:	6.6	4.3	2.3	6.2
Average Cold Per Load:	37.9	21.1	16.7	8.7
Average Load Hot + Cold:	44.5	25.4	19.1	14.9
Average Daily Hot + Cold:	86.2	51.9	34.3	38.7
Average Weekly Hot + Cold:	440.3	259.3	181.1	120.0
Energy Use (kilowatt-hours or kwh)				
Total Energy:	94.9	100.6	5.8	
Average Energy Per Load:	1.1	0.7	0.4	1.2
Average Daily Energy Use:	2.1	1.3	0.7	3.0
Average Weekly Energy Use:	10.5	6.7	3.8	9.9
Load Weights (pounds or lb)				
Total Weight of Loads:	667.0	1,092.1	425.1	
Average Load Weight:	7.2	6.9	0.3	
Average Daily Weight:	14.5	14.6	0.1	
Average Weekly Weight:	74.1	72.8	1.3	
Total Remaining Moisture: (wet minus dry weight)	376.8	641.8	265.0	
Average Moisture Content: (ratio [wet minus dry]/[dry])	0.6	0.6	0.0	0.1
Loads and Efficiency				
Total Number of Loads:	93	160	67	
Average lb/gal:	0.2	0.3	0.1	0.1
Average lb/kwh:	7.0	10.9	3.8	4.4

Contents of Letter to Participants enclosed with Ph I and II Comparison Report

Dear Ms. Aeschiliman,

We have completed the analysis of the data collected by you during the Bern Washer Study. Close to five months worth of data were collected during the study: two months during phase I (old vertical-axis washer) and three-months during phase II (new horizontal-axis washer). Again John Tomlinson and I wish to thank you for your participation in the study and for your diligent effort at writing data on the datasheets each time you performed a load of wash. Enclosed with this letter are two documents that provide you with the findings of the study. The first is the final Oak Ridge National Laboratory report that covers the results of all of the data and discusses the water used and saved, the energy used and saved, customer satisfaction, dampness satisfaction, and many other issues. The second is an individualized report similar to what you have received before.

Your own individual report shows how much water and energy you saved by switching from your old washer to the new washer along with other information. The first two pages of the report provide information on the use patterns for phases I and II, respectively. They show your usage patterns for the time of the day and day of the week, how soiled your clothes were before washing, how you dried your clothes, and water used with the different temperature settings of the washer. You can compare these two pages to see differences between phases I and II. The third page provides a comparison of the water and energy use, and efficiency of the old washers (phase I) versus the new washers (phase II). Each page has been colorized to better distinguish phase I (in blue) from phase II (in green) results.

With regard to the third page of the individual report, information for phases I and II is given in the first and second columns, respectively. Your savings (or average differences) provided by the new washer is given in the third column and is shown in black (or red). The savings (in black) are based on averages per load, day, week, or average efficiency and represent water or energy savings with the new washer. The differences (in red) do not necessarily represent savings and can vary from participant to participant based on the number of loads washed. Typically, these values represent differences in totals and cannot be compared to other participants. The average savings for all participants are given in the fourth column and are shown in gold. This column is included so that you can see how your savings compare with the other study participants. There are twenty-one calculations given on this page and, for easy reading, they have been broken down into four major categories of information: water use, energy use, load weights, and loads & efficiency.

Water Use

Total Hot, Total Cold, and Total Hot + Cold: The values in the first two columns show the total gallons of water (hot, cold, and hot plus cold) used during each phase of the study. The value in the third column is the difference between these two totals, which may or may not represent savings. These two values should only be compared if they are divided by the number of wash loads (shown near the end of the first two columns) performed during each phase of the study. See below.

Average Hot and Average Cold Per Load, and Average Load Hot + Cold: The values in the first two columns show the average gallons of water (hot, cold, or hot plus cold) used for each load of wash for the two phases. They were calculated by dividing the total water used (given above) by the total number of wash loads (given later). These values are good indicators of how much hot, cold, or total water was used, on average, for each load of wash. The third and fourth columns show the average gallons of water you saved and average gallons saved by all participants for each wash load. On average for all participants, the phase II washers used 6.2, 8.7, and 14.9 gallons less hot, cold, and hot plus cold water, respectively, than the phase I washers.

Average Daily Hot + Cold, Average Weekly Hot + Cold: The values in the first two columns show the average gallons of water (hot plus cold) used daily or weekly. The last two columns show your daily or weekly water savings and the average savings for all participants. On average, participants saved 38.7 and 120 gallons per day and week, respectively.

Energy Use

Total Energy: The values given in the first two columns show the total kilowatt-hours of energy (electrical energy of washer motor plus thermal energy of hot water) used during each phase of the study. The electrical energy calculation for the washer motor is based on the electrical rating of your washer. The thermal energy calculation for the hot water is based on the gallons of hot water you used and the temperature difference between the hot water and cold water faucets at the washer. As indicated above, the third column is only a difference and may or may not represent a savings.

Average Energy Per Load: The values given in the first two columns show the average kilowatt-hours of energy used for each load of wash. They were calculated by dividing the total energy used by the total number of wash loads. The third and fourth columns show your average energy savings and the average savings for all participants. On average for all participants, the phase II washers used the equivalent of 1.2 kilowatt-hours less energy than the phase I washers.

Average Daily Energy Use, Average Weekly Energy Use: The values in the first two columns show the average kilowatt-hours of energy used daily or weekly during the two phases. The last two columns show your daily or weekly energy savings and the average savings for all participants.

Load Weights

Total Weight of Loads: The values shown in the first two columns are the total weight of clothes washed by your washers during each phase of the study. These were calculated by adding all load weights before each wash. The value in the third column is the difference between these two totals, which may or may not represent a savings. The two values for phase I and II should only be compared if they are divided by the number of wash loads performed during each phase of the study. See below.

Average Load Weight: The values in the first two columns show the average load weight for the two phases. They were calculated by dividing the total weight of the laundry (given above) by the total number of wash loads (given later). The third column is the difference in average load weight between phases I and II.

Average Daily Weight, Average Weekly Weight: The values in the first two columns show the average weight of laundry washed daily or weekly. The third column shows the difference in these averages between phases I and II.

Total Remaining Moisture: The values in the first two columns show the weight of the moisture remaining in loads for the two phases of the study. It was calculated by subtracting the total weight of the laundry before washing from the total weight of the laundry after washing. This value represents the amount of water in pounds remaining in the clothes after washing. It is the amount of moisture that has to be removed from the clothes either by drying them in the dryer or out on the clothesline. The phase I and II values should only be compared if the totals are divided by the number of wash loads performed during each phase. For example, 2.0 and 2.5 pounds per load for phase I and II, respectively could be compared if the total remaining moisture is 200 and 300 pounds and the number of loads is 100 and 120 for phase I and II, respectively.

Average Moisture Content: The values in the first two columns show the average moisture content for the two phases of the study. It was calculated by summing up all the moisture contents (the value given above but divided by the total weights before washing) for every load of wash and dividing by the number of wash loads. These values have no units but provide a measure of the percent of moisture remaining in the clothes after washing. For example, if the value is 0.6 then the moisture content is 60 percent. In other words if the laundry was dry and weighed 100 pounds before washing then the laundry would be holding 60 pounds of water after washing and would weigh 160 pounds.

Loads & Efficiency

Total Number of Loads: The values shown in first two columns are the total number of wash loads based on the number of datasheets you turned in during phase I and II of the study. These values were used to calculate the averages for water use, energy use, and load weights given above.

Average lb/gal: The first two columns show the average lb/gal or pounds of laundry per gallon of water use for phases I and II of the study. The values were calculated by dividing the total weight of all the clothes washed by the total (hot plus cold) water used in each of the phases. The third and fourth column show your average lb/gal savings and the average savings for all participants. On average for all participants, the phase II washers saved 0.1 lb/gal over the phase I washers. The ratio gives you some idea of how much load weight (pounds of clothes) can be washed for every gallon of water. For example if the values are 0.1 and 0.3 for phases I and II, respectively, then 10 gallons of water will wash on average 1 and 3 pounds of clothes for phase I and II, respectively.

Average lb/kWh: The first two columns show the average lb/kWh or pounds of laundry per kilowatt-hours of energy for phases I and II. The average lb/kWh is another efficiency indicator of the phase I and II washers. The values were calculated by dividing the total weight of all the clothes washed by the total energy used in each phase. The third and fourth column show your average lb/kWh savings and the average savings for all participants. On average for all participants, the phase II washers saved 4.4 lb/kWh over the phase I washers. The ratio gives you some idea of how much load (weight) can be washed for every kilowatt-hour of energy used. For example if the values are 3.0 and 7.0 for phases I and II, respectively, then 1 kilowatt-hour will wash 3 and 7 pounds of clothes for phases I and II, respectively.

Thank you again for your participation in this important research study.

Sincerely,

John Tomlinson and D. Tom Rizy

Attachment (3-page phase I and II comparison report)

Appendix C. Data Integrity and Quality

Overall the completeness of the data was very good with any one field of information being 88% complete or better (see Table C.1) with the exception of the "did you" field which was an optional field. The quality of the data (see Tables C.2 and C.3) was also very good as well with an extremely small percentage of the data consisting of outliers (out of range values). These outliers are due to out of place (in terms of date and time) records, incomplete data, or incorrectly entered information or a combination of the three. The completeness and quality of the data is discussed more in detail below.

Completeness of Recorded Data

Part of the quality of the data is the completeness of the data records. The completeness of each data sheet or record refers to the number of nonblank entries in each data field or cell as compared to the total number of data records that was turned in. The completeness of the data set was examined by counting the number of nonblank entries for each of the possible data fields and comparing it to the total number records turned in. A total of 20,858 data sheets or records were turned in by the study participants over the five-month long data collection period of the study (two-months during phase I and three-months during phase II). Each data sheet consists of 22 to 32 individual fields or cells of data. For phase I, the maximum was 22 for a wash load without the analog readings from the faces of the water meters and 26 with the readings. For phase II, the maximum was 28 for a wash load without the analog readings and 32 with the readings. The cells of data consist of:

a) sequence number or the order in which each data sheet was scanned and entered into the database (1 field),
b) lithocode or unique id number associated with each individual data sheet (1 field),
c) date (1 field),
d) time (1 field),
e) pre-wash load weight (2 fields),
f) soiled level of pre-wash laundry (1 field),
g) "did you" or pre-wash preparations such as pretreat stains, use of bleach, presoak, use of fabric softener (1 field in phase I, 6 fields in phase II),
h) detergent amount (1 field),
i) detergent brand (1 field),
j) detergent type (1 field),
k) machine temperature, load, and cycle settings (4 fields for phase I, 5 for phase II),
l) digital hot and cold water readings (2 fields),
m) post-wash load weight (2 fields),
n) dampness satisfaction index indicated by participant (1 field),
o) cleanliness satisfaction index indicated by participant (1 field),
p) method used to dry cleaned laundry (1 field),
q) analog meter reading (4 readings)

Table C.1 shows the total number of records turned in by the study participants for each phase of the study. Also, the number of nonblank or filled-in values for each cell as well as percent of the total records that this represents is shown in this table. For example, 7585 or 99.2 % out of a total of 7645 records were filled in for the "date" field.

Table C.1 Completeness of Phase I and II Data Records.

#	Data Record	Phase (Ph) I Records		Phase (Ph) II Records	
		No.	%	No.	%
	Total Records	7645		13213	
	Records with Lithocodes	7645	100.0%	13211	100.0%
	Customers	103		103	
1	Date & Time				
	Date	7585	99.2%	13017	98.5%
	Time	7458	97.6%	12838	97.2%
2	Weigh load with scale (preweight)				
	pre-pounds	7570	99.0%	13013	98.5%
	pre-ounces	7552	98.8%	13013	98.5%
3	How Soiled is this load?	7453	97.5%	12812	97.0%
4	Did you:	3115	40.7%	9499	71.9%
5	Detergent				
	Amount	6998	91.5%	12393	93.8%
	Brand	6724	88.0%	12071	91.4%
	Type	7262	95.0%	12455	94.3%
6	Machine Settings				
	Cycle (Ph I) or Fabrics (Ph II)	7462	97.6%	12862	97.3%
	Load Size (Ph I) or Wash/Rinse (Ph II	7385	96.6%	12859	97.3%
	Wash Temperature (Ph I) or Options (Ph II)	7375	96.5%	10512	79.6%
	Rinse Temperature (Ph I) or Quick/Delay Wash (Ph II)	7379	96.5%	845	6.4%
	Regular (Ph II only)			12318	93.2%
7	Water Used				
	Hot	7444	97.4%	12894	97.6%
	Cold	7534	98.5%	12972	98.2%
8	Weigh damp load with scale (postweight)				
	Post-pounds	7535	98.6%	12930	97.9%
	Post-ounces	7508	98.2%	12929	97.9%
9	Satisfaction with dampness of load after wash cycle?	7299	95.5%	12502	94.6%
10	Satisfaction with overall cleanability of load?	7215	94.4%	12380	93.7%
11	How will this load be dried?	7319	95.7%	12586	95.3%
	Analog Readings:				
	Cold Register	207		152	
	Cold Needle	209		144	
	Hot Register	210		149	
	Hot Needle	207		141	

Overall the completeness of the data is very good at 88% or better with the exception of the “did you” field. The completeness of the “did you” field for phase I is lower than for phase II because the possibility of multiple selections was not accounted for in the data entry process for phase I. For the phase II data entry process, the field was broken down into 6 cells so that these multiple selections could be captured.

All but a few of the data records of phase I and II represent a load of wash. A small percent of them represent only the analog water readings at the beginning and end of each phase. In some cases the readings were recorded on a datasheet together with wash load data. In other cases the readings were recorded separately from a load of wash.

Integrity of Data

A second area of data quality is the reasonableness or integrity of the recorded readings and the various calculations from the recorded readings (such as water use and load weight) in each data record. A small number of the recorded readings were incorrectly entered either by the participant on the datasheet or by State Testing and Evaluation in the creation of the digital file. Many of these misentered readings showed up as values that were too small or too large. The values showed up as null (blank) values if no entry was entered for any reading. The calculations most sensitive to incorrect entries or lack of them are the water use calculations. First, the calculations depended on having both a pre- and post-reading in order to calculate the water use for the load of wash. By design, the raw data records contained only one reading which represented the digital reading after the laundry (post reading) had been washed. It was first necessary to match up post and pre-water digital readings in order to calculate water use. It was therefore necessary to create a table of pre-wash readings for each record. The pre-readings were determined by looking back at the record that occurred just prior to the current record. This required sorting of the records by both customer #, date, and by time. Thus water use, either hot or cold, was calculated by subtracting the pre-reading of this table from the post-reading of the data records for the same record. An incorrect entry for either of these values needed for sorting resulted in an outlier, a calculated value outside of the normal range of values. The weight calculations required either a recorded pound (lb) or an ounce (oz) reading in order to calculate the pre- or post-weight of the laundry. The weight calculations did not require customer #, date, and time in order to determine totals and averages. These values were only needed to sort or group the data by customer, date, and/or time.

Table C.2 and C.3 describe the quality of the data as it relates to both the water use and load weight calculations. The tables show the percent of the data records that provide reasonable calculations.

Over 85% of the data records in phase I and II were found to be of extremely good quality for water use calculations, since they fell within the 0 to 60 gallon range. Over 95% of the data records in phase I and II were found to be of extremely good quality for load weight calculations, since they fell with the 0 to 20 pounds range. Reasonableness of the calculations was determined by grouping the calculations into four groups. For the water use calculations, these are (1) less than 0 gallons, (2) 0 to 60 gallons, (3) greater than 60 gallons, and (4) not enough data to perform the calculation. For the load weight calculations, these are (1) less than 0 pounds, (2) 0 to 20 pounds, (3) greater than 20 pounds, and (4) not enough data to perform the calculation. For example, 85.9% and 91.3% of the phase I and II data records, respectively, provide water calculations that fall within the range of 0 to 60 gallons. Limits were used in the Microsoft Access queries to eliminate gross outliers. The limit of 0 to 100 gallons was used for the cold and hot water use calculations, instead of 0 to 60 gallons, which was considered to be too narrow in range. The limit of not less than 0 pounds was used for the load weight calculations. The average value calculated for the water use and load weight both without these limits and with the previously stated limits is shown on the right side of each table.

Table C.2 Quality (percent of total records) of Phase I and II Hot and Cold Water Calculations.

	% in Water Use (gal) Range				Average Water Use	
	Less than 0	0 to 60	Greater Than 60	Not Enough Data For Calculation	Limits (0 to 60)	Limits* (0 to 100)
Phase I						
Hot	9.3%	85.9%	2.1%	2.6%	11.23	11.57
Cold	3.9%	88.9%	5.8%	1.5%	28.48	29.89
Hot + Cold					39.71	41.46
Phase II						
Hot	5.6%	91.3%	1.5%	1.6%	4.77	4.83
Cold	3.6%	92.2%	3.3%	1.0%	20.38	20.96
Hot + Cold					25.15	25.79

**Limits used to calculate the total and average water use in the study. They were used to eliminate any unreasonable calculations due to incorrectly entered water readings (by participant or key punch operator) or sorting problems with readings due to incorrectly entered date or time.*

Table C.3 Quality (in percent of total records) of Phase I and II Pre-Wash and Post-Wash Weight Calculations.

	% in Weight (lb) Range				Average Load Weights	
	Less than 0	0 to 20	Greater Than 20 and Less Than 40	Not Enough Data For Calculation	No Limits	Limits (greater than 0)*
Phase I						
PreWash	0.6%	98.4%	0.03%	1.0%	6.60	6.65
PostWash	0.3%	96.0%	2.3%	1.4%	10.32	10.36
Phase II						
PreWash	0.2%	99.5%	0.1%	0.3%	6.97	6.98
PostWash	0.1%	95.8%	3.4%	0.9%	10.39	10.40

**Limits used to calculate the total and average load weights in the study. They were used to eliminate any unreasonable calculations due to incorrectly entered load weight data (by participant or keypunch operator).*

Appendix D. Individual Water Tap Temperatures and Differences at Each Washer

The water temperatures of both the hot and cold water taps (or faucets) at each participant's washer were measured at the beginning of this study. The individual water temperatures and their differences are provided in Table D.1. The average hot and cold water temperatures and difference were found to be 132.5, 62.5, and 72°F, respectively. The individual temperature differences in this Table D.1 along with the amount of hot water were used to calculate the thermal energy consumed for each load of laundry washed by each participant.

Table D.1 Hot and Cold Water Temperatures Measured at Each Participant's Washer.

		Temperature Measurements and Difference (°F)		
Participant	Customer No	Hot Water	Cold Water	Hot Minus Cold
1	1	113	60	53
2	2	146	57	89
3	3	140	60	80
4	4	125	61	64
5	5	132	62	70
6	6	136	58	78
7	7	143	60	83
8	8	124	61	63
9	9	134	57	77
10	10	132	63	69
11	11	165	60	105
12	12	111	65	46
13	13	134	61	73
14	14	112	57	55
15	15	127	65	62
16	16	129	59	70
17	17	126	62	64
18	18	124	64	60
19	19	139	63	76
20	20	148	58	90
21	21	133	68	65
22	22	137	60	77
23	23	124	60	64
24	24	134	59	75
25	25	146	61	85
26	26	143	59	84
27	27	136	56	80
28	28	141	58	83
29	29	141	61	80
30	30	119	62	57
31	31	127	65	62
32	32	120	57	63
33	33	168	57	111

Table D.1 Hot and Cold Water Temperatures Measured at Each Participant's Washer (cont.).

		Temperature Measurements and Difference (°F)		
Participant	Customer No	Hot Water	Cold Water	Hot Minus Cold
34	34	126	60	66
35	35	137	60	77
36	36	110	57	53
37	37	122	58	64
38	38	149	57	92
39	39	150	63	87
40	40	120	61	59
41	41	120	63	57
42	42	131	63	68
43	43	136	66	70
44	44	117	66	51
45	45	123	61	62
46	46	130	60	70
47	47	129	62	67
48	48	122	61	61
49	49	135	59	76
50	50	134	58	76
51	51	159	56	103
52	53	125	61	64
53	54	139	63	76
54	55	121	58	63
55	56	134	63	71
56	57	134	60	74
57	58	121	60	61
58	59	143	57	86
59	60	123	66	57
60	61	146	59	87
61	62	134	58	76
62	63	152	60	92
63	64	128	64	64
64	65	114	61	53
65	66	138	64	74
66	67	141	65	76
67	68	143	59	84
68	69	138	57	81
69	70	135	62	73
70	71	128	55	73
71	72	134	60	74
72	73	148	60	88
73	74	115	58	57

Table D.1 Hot and Cold Water Temperatures Measured at Each Participant's Washer (cont.).

		Temperature Measurements and Difference (°F)		
Participant	Customer No	**Hot Water**	**Cold Water**	**Hot Minus Cold**
74	75	121	61	60
75	76	110	61	49
76	77	141	61	80
77	78	156	66	90
78	79	134	60	74
79	80	131	60	71
80	82	134	61	73
81	83	145	61	84
82	84	122	59	63
83	85	134	61	73
84	86	134	61	73
85	87	136	55	81
86	88	147	56	91
87	89	114	60	54
88	90	150	57	93
89	91	146	60	86
90	92	140	60	80
91	93	131	61	70
92	94	125	61	64
93	95	137	59	78
94	96	118	56	62
95	97	113	59	54
96	98	131	61	70
97	99	120	60	60
98	100	137	64	73
99	101	133	58	75
100	102	135	61	74
101	103	122	60	62
102	104	120	70	50
103	105	134	61	73
average		**132.5**	**60.5**	**72**