

Reference

NBS
Publi-
cations

NAT'L INST. OF STAND & TECH R.I.C.



A11105 087992

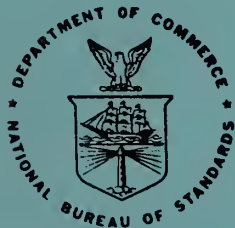
~~A11105 087992~~
NBSIR 80-2136

Energy Consumption and Usage Characteristics From Field Measurements of Residential Dishwashers, Clothes Washers and Clothes Dryers

Yui-May L. Chang
Richard A. Grot

Building Equipment Division
Center for Building Technology
National Engineering Laboratory
U.S. Department of Commerce
National Bureau of Standards
Washington, DC 20234

October 1980



QC

100

.U56

80-2136

1980

DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

APR 1 1981

100-200-721
Q100
1158
12 10 3/36
1480

NBSIR 80-2136

**ENERGY CONSUMPTION AND USAGE
CHARACTERISTICS FROM FIELD
MEASUREMENTS OF RESIDENTIAL
DISHWASHERS, CLOTHES WASHERS AND
CLOTHES DRYERS**

Yui-May L. Chang
Richard A. Grot

Building Equipment Division
Center for Building Technology
National Engineering Laboratory
U.S. Department of Commerce
National Bureau of Standards
Washington, DC 20234

October 1980

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

The measured energy consumption and usage characteristics for household dishwashers, clothes washers, and clothes dryers for ten townhouses at Twin Rivers, N.J. are presented. Whenever the dishwashers and/or clothes washers were in use, the energy consumption, water consumption, frequency of usage, and water temperature were measured by a data acquisition system. The energy requirement for heating hot water could be established from the water heater's characteristic in a previous related report (NBSIR 78-1496). The electrical energy of electric clothes dryers and the gas consumption of gas clothes dryers were measured, as well as their frequency and duration of use, and exhaust temperature. Typical household usage patterns of these major appliances are also included.

It was found that, in general, the electrical energy required to operate dishwashers and clothes washers is about one tenth of the energy consumption for heating hot water. Cold water usage is about three times the hot water usage for each load of laundry. The energy loss from a pilot light burner of a gas dryer is about 50 percent of the total gas consumption of that dryer. As far as habits are concerned, the average family utilizes the dishwasher every other day and the laundry about five loads a week.

Key Words: Clothes dryer usage characteristics; clothes washer usage characteristic; data profiles; dishwasher usage characteristic; energy consumption; field measurements; usage patterns; water consumption.

UNITS OF MEASURE AND S.I. CONVERSION FACTORS

In NBS Document LC 1056, revised August 1975, guidelines were established to reaffirm and strengthen the commitment of NBS to the greatest practicable use of the International System of Units (S.I.) in all of its publications and also in all of its dealings with the science and engineering communities and with the public. In this report the measurements are those of the U.S. customary units as they appear in the referenced standards, in order that the readers may give full attention to the organization and compilation of the criteria.

The following conversion factors are appropriate for the units of measure that appear in this report:

Energy

1 British thermal unit (Btu) = 1055.056 joule (J)
1 kilowatt-hour (kWh) = 3600000.0 joule (J)

Temperature

1 degree Fahrenheit ($^{\circ}\text{F}$) = $(1.8)^{-1}$ kelvin (K) or ($^{\circ}\text{K}$)
Temperature Fahrenheit ($^{\circ}\text{F}$) = $(459.67 + \text{temp. } ^{\circ}\text{F})/1.8$ ($^{\circ}\text{K}$)

Time

1 hour (h) = 60 minutes (min) = 3600 seconds (s)

Volume

1 U.S. liquid gallon (gal) = 0.003785412 meter³ (m³)
= 3.785412 liters (L)

TABLE OF CONTENTS

	<u>Page</u>
LIST OF TABLES	vi
LIST OF FIGURES	vii
1. INTRODUCTION	1
2. INSTRUMENTATION USED FOR MONITORING USAGE OF DISHWASHERS, CLOTHES WASHERS, AND CLOTHES DRYERS	3
3. ENERGY CONSUMPTION AND USAGE CHARACTERISTICS OF DISHWASHERS	4
4. ENERGY CONSUMPTION AND USAGE CHARACTERISTICS OF CLOTHES WASHERS	11
5. ENERGY CONSUMPTION AND USAGE CHARACTERISTICS OF CLOTHES DRYERS	17
6. DISCUSSION OF RESULTS	23
7. CONCLUSIONS	26
REFERENCES	27

LIST OF TABLES

	<u>Page</u>
Table 1. Occupant and townhouse characteristics.	2
Table 2. Dishwasher characteristics.	5
Table 3. Average daily usage characteristics of dishwashers.	6
Table 4. Average per use characteristics of dishwashers.	10
Table 5. Clothes washer characteristics.	12
Table 6. Average daily usage characteristics of clothes washers.	13
Table 7. Average per use characteristics of clothes washers.	16
Table 8. Clothes dryer characteristics.	18
Table 9. Average daily usage and per cycle use characteristics of clothes dryers.	19
Table 10. Average daily energy consumption of dishwashers, clothes washers and clothes dryers.	24
Table 11. Comparison of results from the Twin Rivers test site with other sources [8].	25

LIST OF FIGURES

	<u>Page</u>
Figure 1. Dishwasher daily energy consumption, townhouse #8.	7
Figure 2. Dishwasher daily water consumption, townhouse #8.	8
Figure 3. Dishwasher daily maximum water temperature, townhouse #8.	8
Figure 4. Clothes washer daily energy consumption, townhouse #8.	14
Figure 5. Clothes washer daily hot water consumption, townhouse #8.	14
Figure 6. Clothes washer daily cold water consumption, townhouse #8.	14
Figure 7. Clothes washer daily maximum water temperature, townhouse #8.	15
Figure 8. Clothes washer daily usage, townhouse #8.	15
Figure 9. Clothes washer daily usage duration, townhouse #8.	15
Figure 10. Gas clothes dryer daily energy consumption, townhouse #8.	20
Figure 11. Electric clothes dryer daily energy consumption, townhouse #9.	21
Figure 12. Clothes dryer daily usage, townhouse #8.	22
Figure 13. Clothes dryer daily usage duration, townhouse #8.	22
Figure 14. Clothes dryer daily maximum exhaust temperature, townhouse #8.	22

1. INTRODUCTION

The usage patterns of dishwashers, clothes washers, and clothes dryers from a field experiment for single-family dwellings are presented. This was part of the Appliance Labeling Program* to investigate the usage and energy consumption of these household appliances. The test site was ten selected townhouses located in Twin Rivers, New Jersey, occupied by typical families of two adults and one to three children aged from 1 to 15 years. A summary of occupants in each townhouse is given in table 1. The chosen community in Twin Rivers, New Jersey had been studied extensively by researchers in Princeton University [1, 2]. The ten townhouses were selected by their previous energy usage data as a reasonable but small sample to reflect the total energy usage of a townhouse community. The appliances were those installed in the townhouses either supplied by the builder or replaced by the occupants. No attempt was made to select any particular manufacturer's model of any of the three appliances. The measurement period was from spring of 1976 to summer of 1977.

Since none of these appliances would be operated continuously by occupants, data were collected only during the occurrences of operations. The data acquisition system recorded a scan of all channels whenever the status of an event changed for any of these appliances in the townhouse. In this way, both the frequency and the duration of usage could be recorded.

Studies of these appliances were aimed at obtaining data on their energy consumption, water consumption, and frequency of usage. Measurements also included temperatures of water supply to dishwashers and clothes washers, and the exhaust temperature of clothes dryers. The energy needed for heating hot water for dishwashers and clothes washers was calculated using the water heater's characteristics presented in [3] and the measured hot water consumption of the appliance. It was found that the energy requirement for heating hot water is approximately 10 times that for operating the appliances. Since the water heater is an independent appliance, energy usage for heating hot water depends on the efficiency of the water heater. Usage patterns of the dishwasher and clothes washer have the most effect on energy conservation because these appliances account for the majority of residential hot water consumption. As for clothes dryers, the gas dryers with pilot light burners showed that the energy loss due to continuous burning of the pilot was approximately 6 to 7 cubic feet of gas per day. The pilot lights constituted about 50 percent of the average daily energy consumption of the gas dryers. Dryers with electric ignition burners had a lower average energy consumption as well as operating energy consumption rate. The average consumption rate was calculated as the energy consumed per hour when the dryer was being operated. Each of these major appliances--dishwashers, clothes washers, and clothes dryers--will be discussed separately in the following sections.

* This project was initially sponsored by the Energy Appliance Labeling Program of the Center for Consumer Products Technology, National Bureau of Standards, through an interagency agreement with the Federal Energy Administration (now the Department of Energy).

Table 1. Occupant and Townhouse Characteristics

Townhouse Number	Electric or Gas	Number of Adults	Number of Children	Children's Ages	Number of Bedrooms
1	E	2	2	6,8	3
2	E	2	1	6	3
3	G	2	1	3	2
4	G	2	3	6,7,9	3
5	E	2	2	10,13	3
6	E	2	2	10,13	4
7	G	2	2	2,4	3
8	G	2	2	1,3	3
9	E	2	1	15	3
10	E	2	2	2,6	2 converted to 3

2. INSTRUMENTATION USED FOR MONITORING USAGE OF DISHWASHERS, CLOTHES WASHERS, AND CLOTHES DRYERS

Instrumentation was installed in each townhouse so that the energy and water usage of the clothes washers, clothes dryers and dishwasher were measured using electric or gas meters, and water meters, depending on the type of appliances. Standard utility meters were modified to produce a pulse train proportional to the quantity of energy or water used. For electric meters, two holes were drilled in the Faraday disk and an optical isolator was installed such that a photo detector was actuated for each half revolution of the disk (corresponding to 0.018 Wh). For gas meters, a square was attached to the $1/2 \text{ ft}^3$ dial such that the corners of the square contacted a microswitch for each $1/4$ revolution of the dial (corresponding to $1/8 \text{ ft}^3$ of gas consumed). For water meters, a miniature magnetic reed switch was installed between the magnetic coupling of the metering mechanism and the meter indicator. The arrangement produced a pulse for each $1/350$ gallon of water used. Then pulses were divided electrically by 32 to produce a pulse for each 0.09 gallon of water. The pulse trains of each of these meters were summed by counters and the counters were read every five minutes by the data acquisition system. Water meters were installed on hot and cold water supplies of the clothes washer on the hot water supply to the dishwasher, and on the cold water inlet to the water heater. Electric meters were installed on the electrical lines to the dishwashers, clothes washers, and electric clothes dryers. A gas meter was installed on the gas supply line to the gas dryers. Thermocouples were also installed on the hot water supply lines to the clothes washers and dishwashers, and on the inlet and outlet water lines of the water heaters. These thermocouples were attached to the surface of the pipes and wrapped with insulation. Relays were installed on the clothes washers and the clothes dryers. These relay contacts would be opened and closed as these appliances were used. The closures were sensed by the electronic control package of the data acquisition system which would scan all channels when the appliance was turned on or off. This recorded the number of times and duration the appliances were in use. The data gathered by the data acquisition system were recorded on magnetic tapes which were processed on minicomputers at the Center for Building Technology to produce the quantities reported herein.

3. ENERGY CONSUMPTION AND USAGE CHARACTERISTICS OF DISHWASHERS

The physical characteristics of dishwashers in each townhouse are given in table 2. Measurements of operating characteristics on each dishwasher included electrical energy consumption, water consumption, and maximum inlet water temperature. Energy required by dishwashers is the sum of the electrical energy used to operate the unit and the energy used to heat the hot water consumed in dishwashing. The energy for heating the hot water could be calculated from the hot water consumption and the efficiency of performance of the water heater in each townhouse [3].

The total energy consumption is

$$E_T = E + \gamma_1 W \quad (1)$$

where E_T is the total energy consumption,
 E is the electrical energy to operate the dishwashers in kWh,
 W is the hot water consumption in gallons,

and γ_1 is the average amount of energy per gallon of supplied hot water from water heaters in kWh/gal for electric homes and in ft³/gal for gas homes [3]. Table 3 gives the values of γ_1 obtained from the hot water heater characteristics of each home.

The energy unit of E_T would be kWh for electric homes. However, for those homes with gas water heaters, E and γ_1 of equation (1) are not in the same energy units since they came from two different energy sources. For the purpose of comparison, gas consumption was converted to Btu, so E_T is also in Btu.

Average daily usage of dishwashers in each townhouse, together with the corresponding water heater's characteristics is given in table 3. The hot water usage per day of these dishwashers was between four to 10 gallons, with an average of 6.5 gal/day. The percentage of hot water used for the dishwashing was between 5 percent and 25 percent with an average of 11 percent of total hot water consumption. The electrical energy required to operate the dishwashers, E , was measured to be 0.1 to 0.5 kWh/day, with an average of 0.27 kWh/day, which is equivalent to about 17 percent of the total energy required to wash the dishes per day. This result confirmed the estimated figures of the dishwashers' energy usage [4].

The daily profiles of electrical energy usage, hot water consumption, and maximum water temperature of the dishwasher in townhouse #8 are shown in figures 1 to 3. These profiles illustrate the usage pattern of this particular dishwasher. Since the dishwashers were not utilized every day it would be more appropriate to investigate the per usage characteristics among them. Townhouse #8 is a typical unit to represent the general usage of these appliances.

2. INSTRUMENTATION USED FOR MONITORING USAGE OF DISHWASHERS, CLOTHES WASHERS, AND CLOTHES DRYERS

Instrumentation was installed in each townhouse so that the energy and water usage of the clothes washers, clothes dryers and dishwasher were measured using electric or gas meters, and water meters, depending on the type of appliances. Standard utility meters were modified to produce a pulse train proportional to the quantity of energy or water used. For electric meters, two holes were drilled in the Faraday disk and an optical isolator was installed such that a photo detector was actuated for each half revolution of the disk (corresponding to 0.018 Wh). For gas meters, a square was attached to the $1/2 \text{ ft}^3$ dial such that the corners of the square contacted a microswitch for each $1/4$ revolution of the dial (corresponding to $1/8 \text{ ft}^3$ of gas consumed). For water meters, a miniature magnetic reed switch was installed between the magnetic coupling of the metering mechanism and the meter indicator. The arrangement produced a pulse for each $1/350$ gallon of water used. Then pulses were divided electrically by 32 to produce a pulse for each 0.09 gallon of water. The pulse trains of each of these meters were summed by counters and the counters were read every five minutes by the data acquisition system. Water meters were installed on hot and cold water supplies of the clothes washer on the hot water supply to the dishwasher, and on the cold water inlet to the water heater. Electric meters were installed on the electrical lines to the dishwashers, clothes washers, and electric clothes dryers. A gas meter was installed on the gas supply line to the gas dryers. Thermocouples were also installed on the hot water supply lines to the clothes washers and dishwashers, and on the inlet and outlet water lines of the water heaters. These thermocouples were attached to the surface of the pipes and wrapped with insulation. Relays were installed on the clothes washers and the clothes dryers. These relay contacts would be opened and closed as these appliances were used. The closures were sensed by the electronic control package of the data acquisition system which would scan all channels when the appliance was turned on or off. This recorded the number of times and duration the appliances were in use. The data gathered by the data acquisition system were recorded on magnetic tapes which were processed on minicomputers at the Center for Building Technology to produce the quantities reported herein.

3. ENERGY CONSUMPTION AND USAGE CHARACTERISTICS OF DISHWASHERS

The physical characteristics of dishwashers in each townhouse are given in table 2. Measurements of operating characteristics on each dishwasher included electrical energy consumption, water consumption, and maximum inlet water temperature. Energy required by dishwashers is the sum of the electrical energy used to operate the unit and the energy used to heat the hot water consumed in dishwashing. The energy for heating the hot water could be calculated from the hot water consumption and the efficiency of performance of the water heater in each townhouse [3].

The total energy consumption is

$$E_T = E + \gamma_1 W \quad (1)$$

where E_T is the total energy consumption,
 E is the electrical energy to operate the dishwashers in kWh,
 W is the hot water consumption in gallons,

and γ_1 is the average amount of energy per gallon of supplied hot water from water heaters in kWh/gal for electric homes and in ft³/gal for gas homes [3]. Table 3 gives the values of γ_1 obtained from the hot water heater characteristics of each home.

The energy unit of E_T would be kWh for electric homes. However, for those homes with gas water heaters, E and γ_1 of equation (1) are not in the same energy units since they came from two different energy sources. For the purpose of comparison, gas consumption was converted to Btu, so E_T is also in Btu.

Average daily usage of dishwashers in each townhouse, together with the corresponding water heater's characteristics is given in table 3. The hot water usage per day of these dishwashers was between four to 10 gallons, with an average of 6.5 gal/day. The percentage of hot water used for the dishwashing was between 5 percent and 25 percent with an average of 11 percent of total hot water consumption. The electrical energy required to operate the dishwashers, E , was measured to be 0.1 to 0.5 kWh/day, with an average of 0.27 kWh/day, which is equivalent to about 17 percent of the total energy required to wash the dishes per day. This result confirmed the estimated figures of the dishwashers' energy usage [4].

The daily profiles of electrical energy usage, hot water consumption, and maximum water temperature of the dishwasher in townhouse #8 are shown in figures 1 to 3. These profiles illustrate the usage pattern of this particular dishwasher. Since the dishwashers were not utilized every day it would be more appropriate to investigate the per usage characteristics among them. Townhouse #8 is a typical unit to represent the general usage of these appliances.

Table 2. Dishwasher Characteristics

Townhouse Number	Model*	Short Cycle
1	A	no
2	A	no
3	B	no
4	B	no
5	A	no
6	A	no
7	C	no
8	C	no
9	D	no
10	E	no

* All dishwasher models were from the same manufacturer, supplied by the developer or purchased by the occupants. Code letters A, B, C etc. indicate different models

Table 3. Average Daily Usage Characteristics of Dishwashers

Townhouse #	E _D		W _D		Y ₁		H _D		H _{WH}		E		(E _D /E)*100%		W _{WH}		(W _D /W _{WH})*100%		E _{WH}		Days of Measurement
	Electrical Energy Consumption per day	Hot Water Consumption per day	Heat Content of Supplied Hot Water per day	Heat Content of Water Consumed per day	Heat Content of Drawn Hot Water from Water Heater per day	Total Energy Consumption per day	Percentage of Electrical Energy Consumption per day	Water Consumption of Hot Water Heater per day	Percentage of Hot Water Usage of Dishwashers	Energy Consumption of Hot Water Heater per day	Percentage of Electrical Energy Consumption per day	Water Consumption of Hot Water Heater per day	Percentage of Hot Water Usage of Dishwashers	Energy Consumption of Hot Water Heater per day							
Electric Homes	kWh	gal	kWh/gal	kWh (Btu)	kWh (Btu)	kWh (Btu)	%	gal	%	kWh (Btu)	%	gal	%	kWh (Btu)	%	gal	%	ft ³ (Btu)	%	ft ³ (Btu)	
1	0.14	5.73	0.186	1.06 (3618)	8.1 (27645)	1.20 (4096)	12%	45.0	13%	10.9 (37201)	73-140										
2	0.15	4.27	0.201	0.85 (2901)	12.6 (43004)	1.00 (3413)	15%	63.3	7%	16.4 (55973)	166-199										
5	0.30	10.16	0.203	2.06 (7031)	15.8 (53925)	2.36 (8055)	13%	80.4	13%	20.0 (68260)	230-280										
6	0.25	6.60	0.292	1.92 (6553)	17.2 (58704)	2.17 (7406)	11%	71.9	9%	22.4 (76451)	270-280										
9	0.39	8.51	0.232	1.97 (6724)	13.3 (45393)	2.36 (8055)	16%	57.9	15%	18.3 (62458)	11-60										
10	0.29	4.39	0.235	1.03 (3515)	15.8 (53925)	1.32 (4505)	22%	67.6	6%	21.5 (73380)	94-152										
Gas Homes	kWh (Rtu)	gal	ft ³ /gal	ft ³ (Btu)	ft ³ (Btu)	Btu	%	gal	%	ft ³ (Btu)	%	gal	%	ft ³ (Btu)	%	gal	%	ft ³ (Btu)	%	ft ³ (Btu)	
3	0.32 (1092)	7.87	0.75	5.90 (5900)	40.3 (40300)	6992	16%	60.3	13%	97.0 (97000)	230-280										
4	0.41 (1741)	9.66	0.67	6.47 (6470)	25.1 (25100)	8210	21%	39.3	25%	59.9 (59990)	230-280										
7	0.17 (580)	3.85	0.60	2.31 (2310)	41.4 (41400)	2890	20%	74.6	5%	81.9 (81900)	95-180										
8	0.16 (546)	4.22	0.53	2.23 (2230)	28.3 (28300)	2776	20%	57.1	7%	72.6 (72600)	95-180										
Average Values of All Homes	0.27	6.53					17%	61.7	11%												

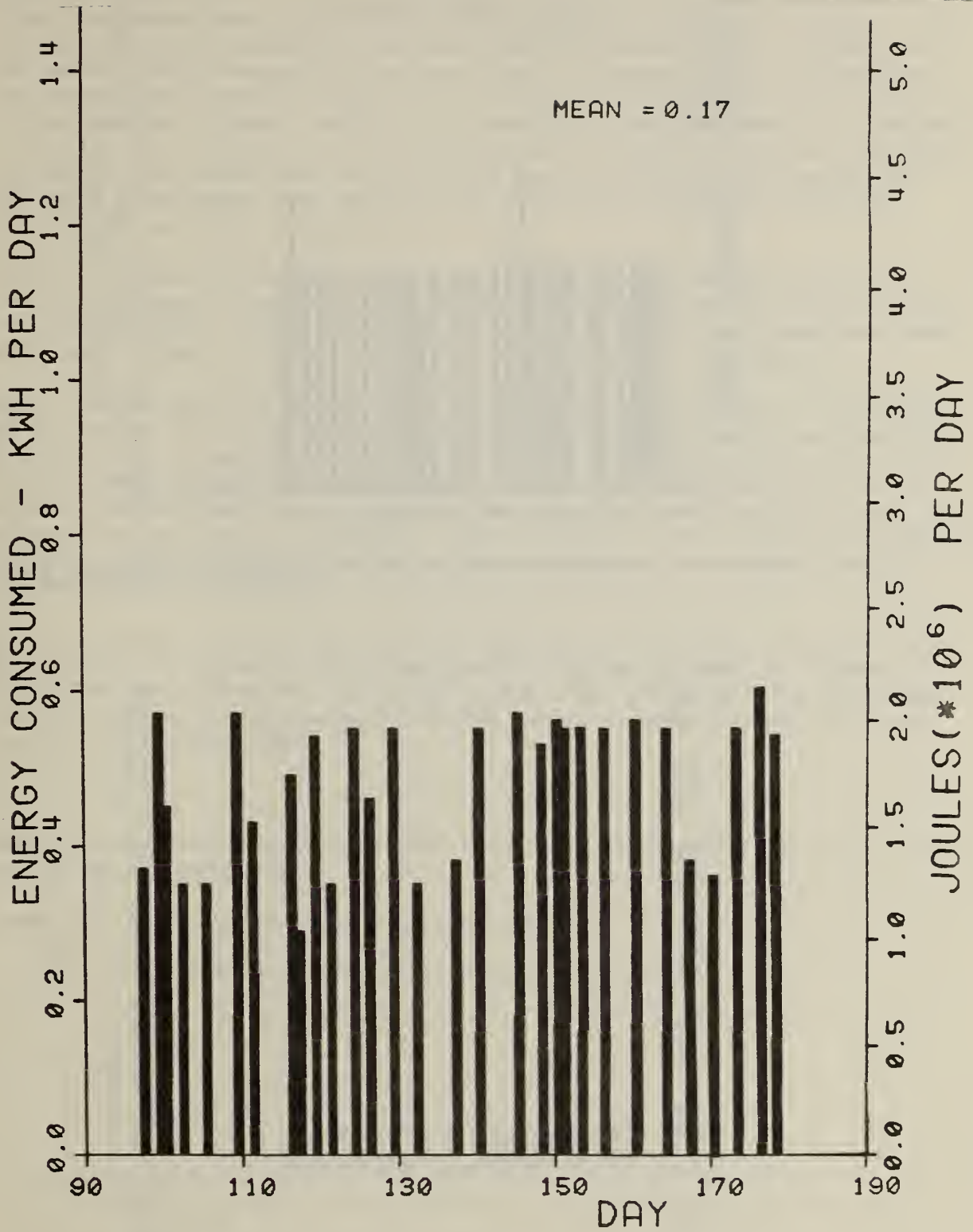


Figure 1. Dishwasher daily energy consumption, townhouse #8.

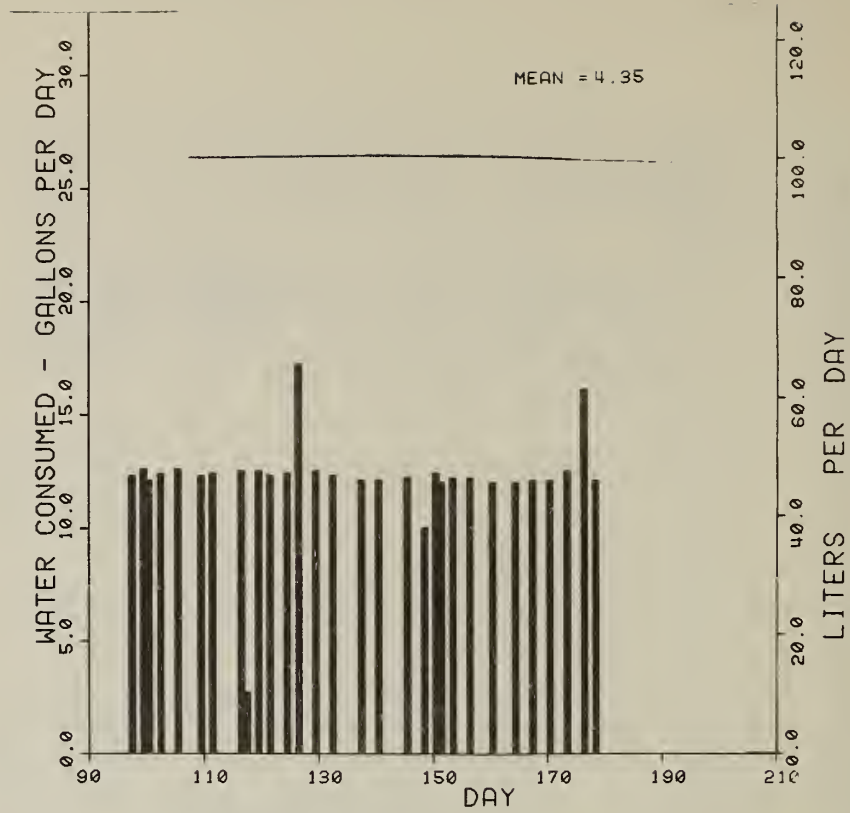


Figure 2. Dishwasher daily water consumption, townhouse #8.

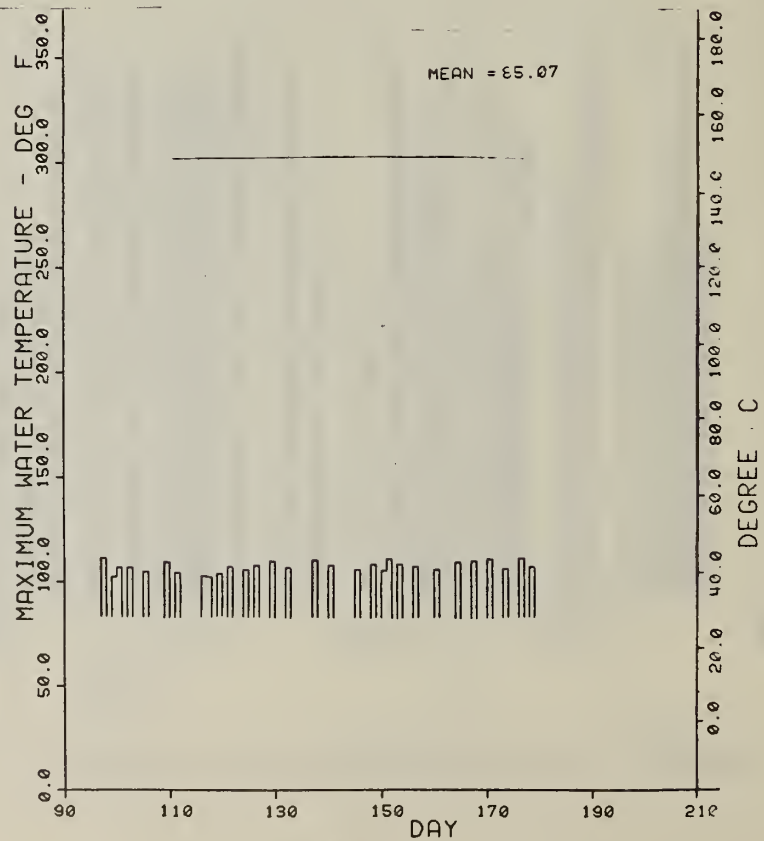


Figure 3. Dishwasher daily maximum water temperature, townhouse #8.

Table 4 reports the average per usage measurements of dishwashers, obtained from the daily data. It is interesting to find out that the occupants in these townhouses used dishwashers on an average of once every two days. The average electrical energy to wash one load of dishes, E_U , is 0.55 kWh, and the average water consumption per each load of dishes, \bar{W} , is 13.8 gallons. The variations in water usage per load, from 10 to 18 gallons, were due to the adjustments of water valves. For example, dishwasher models of townhouses #1 and #2 were identical, but their per-load hot water consumption was quite different; the values were 18.51 gal/use and 11.24 gal/use, respectively. The valve adjustments were manually set at different settings when the dishwashers was first installed.

The data acquisition system was designed to monitor major appliances such that two adjacent townhouses (e.g. #1 and #2) would be considered as a pair for data recording. Most of the appliances in each pair of townhouses were also selected with the same models for the purpose of comparison.

Table 4 shows that the values of E_U seem to follow the pattern of dishwasher models in the townhouses given in table 2, meaning that energy used per cycle is a function of appliance design. Except for townhouses #9 and #10, which had unmatched dishwasher models, table 4 shows that the difference in the average electrical energy consumption per usage is less than 10 percent. The value of E_U for the dishwasher in townhouse #9 was close to that in townhouses #5 and #6. This might be due to the fact that these three townhouses had the same dishwasher models.

As pointed out earlier, the electrical energy used to operate the dishwasher, E , is about 17 percent of the total energy required to wash the dishes. Therefore, the estimated total energy needed, \hat{E}_T , to operate the dishwasher for one cycle could be obtained from the overall average electrical energy per load, \bar{E}_U , as follows:

$$\hat{E}_T = \bar{E}_U / .17 \quad (2)$$

Because hot water consumption ranged from 10 to 18 gal/use (see table 4) this is a rough approximation.

From table 4, \bar{E}_U was given as 0.55 kWh; then

$$\hat{E}_T = 3.3 \text{ kWh or } 11263 \text{ Btu or } 11.3 \text{ ft}^3 \text{ of gas.}$$

Table 4. Average Per Use Characteristics of Dishwashers

Townhouse #	U _D Number of Usage per day	E _{IJ} Electric Energy Consumption		W _H Hot Water Consumption		H _H Heat Content of Water Consumption		E Total Energy Consumption		β _I Energy Consumed to heat one Gal. of Water		E _{WH} Energy Consumption for Hot Water per use	
		per use kWh	gal	kWh	Btu	kWh	Btu	kWh	Btu	kWh/gal	kWh	Btu	
1	0.31	0.45	18.15	3.37	11502	3.82	13038	0.194	3.52	12014			
2	0.37	0.41	11.24	2.24	7645	2.63	8976	0.210	2.37	8089			
5	0.58	0.52	17.51	3.55	12116	4.07	13891	0.223	3.90	13311			
6	0.50	0.50	13.20	3.85	13140	4.35	14847	0.244	3.22	10990			
9	0.70	0.56	12.15	2.82	9625	3.38	11536	0.239	2.90	9898			
10	0.42	0.69	10.45	2.45	8362	3.14	10717	0.250	2.59	8840			
Gas Homes		kWh (Btu)	gal	ft ³	Btu	Btu	Btu	BTU/gal	ft ³	Btu			
3	0.46	0.69 (2355)	16.99	12.83	12830	15185	15185	1260	21.4	21400			
4	0.72	0.71 (2423)	13.41	8.98	8980	11403	11403	1050	14.08	14080			
7	0.31	0.54 (1843)	12.45	7.47	7470	9370	9370	1860	14.02	14020			
8	0.34	0.49 (1672)	12.52	6.63	6630	8302	8302	520	6.51	6510			
Average Values of All Homes	0.54	0.55	13.81										

4. ENERGY CONSUMPTION AND USAGE CHARACTERISTICS OF CLOTHES WASHERS

Table 5 gives the physical characteristics of clothes washers in each townhouse. In addition to measurements similar to those taken on dishwashers (electrical energy consumption, water consumption, maximum water temperature, and number of usages), the total time of use was also measured. The water consumption included hot water as well as cold water measurements.

By applying the same method as for the dishwasher to calculate the energy for heating water, the total energy requirement for operating the clothes washers could be obtained from equation (1). The energy unit of E_T is in kWh for electric houses and in Btu for gas homes.

The average daily usage of clothes washers in each townhouse, together with their water heater characteristic, is given in table 6. Since all clothes washers had water level selections of low, medium, or high (L/M/H), and cycle selections of normal or permanent press (N/P), their daily electrical energy usages and water consumption, both hot and cold, would have a wider variation range than the dishwashers. This was mainly due to the different washing habits and soil conditions of clothes of the occupants.

The average electrical energy consumption of these clothes washers was found to be approximately 0.13 kWh/day, which is about 10 percent of the total energy usage for operating these appliances per day. This is also close to the estimated figures in [4]. As for the hot water consumption, the average usage was 7.5 gal/day, which is equivalent to 12 percent of the daily water consumption of the water heaters. The cold water usage, except for the clothes washers in townhouse #10, was about three times that of the hot water usage, and the total water consumption was about 27 gal/day. As shown in table 5, the clothes washer in townhouse #10 was a completely different model from the rest, with more cycle selections. Data for this machine indicates a higher hot water consumption and a lower cold water consumption than other clothes washers. The hot water usage was even higher than the cold water usage in general. That might be due to user selection of water temperature. The average data (excluding townhouse #10) was also included in table 6 as a comparison. Figures 4 to 9 display the daily profiles of electrical energy consumption, hot and cold water consumption, maximum water temperature, number of loads, and total time of usage of clothes washer in townhouse #8 to demonstrate the variation of these parameters. Table 7 presented the average results of clothes washers for all townhouses. It was found that the occupants washed a load of clothes twice every three days, for an average of 0.70 usage/day. The average duration of usage was about 20 minutes per day and slightly under 30 minutes per wash. These findings were very close to the measurements reported by Purdue University [5]. As far as the individual per usage data were concerned, electrical energy per usage for all clothes washers was fairly close, especially for the same models. The water consumption, both hot and cold, mostly depended on selected water level. The duration per use was mainly a manual cycle selection from occupants' individual habits and soil condition. Generally speaking,

to run the clothes washer once, the average electrical energy consumption was about 0.19 kWh and the water consumption was about 40 gallons, in which 25 percent was hot water. The estimated total energy needed to wash each load of clothes including heating hot water could be obtained as:

$$\hat{E}_T = 1.9 \text{ kWh or } 6484 \text{ Btu or } 6.5 \text{ ft}^3 \text{ of gas.}$$

Table 5. Clothes Washer Characteristics

Townhouse Number	Model*	Level Selection	Cycle Selection
1	A	L/M/H	N/P
2	A	L/M/H	N/P
3	B	L/M/H	N/P
4	B	L/M/H	N/P
5	A	L/M/H	N/P
6	A	L/M/H	N/P
7	C	L/M/H	N/P
8	C	L/M/H	N/P
9	C	L/M/H	N/P
10	D	Cont. L-H	8-cycle auto.

Legend: L = Low
M = Medium
H = High
N = Normal
P = Permanent press

* All clothes washers except that in townhouse #10 were from the same manufacturer, supplied by the developer or purchased by the occupants. They are all top-load models with water volume of approximately 40 gallons/load.

Code letters A, B, C etc. indicate different models.

Table 6. Average Daily Usage Characteristics of Clothes Washers

Townhouse #	Electric Energy Consumption		Hot Water Consumption		Cold Water Consumption		Total Water Consumption		Heat of Water Consumption		Heat of Water Consumption		Total Energy Consumption		(E _p /E) X 100% Electrical Energy per day		W _{WH} Total Water Consumption per day		(W _H /W _{WH}) X 100% Percentage of Hot Water usage for Clothes Washers		Days of Measurement	
	kWh	gal	gal	gal	gal	gal	gal	gal	kWh/gal	kWh (Btu)	kWh (Btu)	kWh (Btu)	%	gal	gal	%	%	gal				
1	0.12	6.12	20.99	27.11	0.186	1.14 (3891)	1.26 (4300)	10%	45.0	14%	73-140											
2	0.16	7.03	22.90	29.93	0.201	1.41 (4812)	1.57 (5358)	10%	63.3	11%	166-199											
5	0.07	4.20	12.76	16.96	0.203	0.85 (2901)	0.92 (3140)	8%	80.4	6%	230-280											
6	0.13	10.40	24.20	34.60	0.292	3.04 (10376)	3.17 (10819)	4%	71.9	15%	230-280											
9	0.13	8.08	19.47	27.55	0.232	1.87 (10785)	2.00 (6826)	7%	57.9	14%	96-174											
10	0.16	13.43	11.67	25.10	0.235	3.16 (10785)	3.32 (11331)	5%	67.6	20%	96-174											
Gas Homes	kWh	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal	gal
3	0.13 (444)	5.72	19.58	25.30	0.75	4.29 (4290)	4.734	9%	60.3	10%	230-280											
4	0.12 (410)	1.80	16.14	17.94	0.67	1.21 (1210)	1.620	25%	39.3	5%	230-280											
7	0.18 (614)	12.87	25.44	38.31	0.60	7.72 (7720)	8.334	7%	74.6	17%	95-180											
8	0.16 (546)	5.81	21.47	27.29	0.53	3.08 (3080)	3.626	15%	57.1	10%	95-180											
Average Values of All Homes	0.13	7.54	19.46	27.00				10%		12%												
Average Values W/O # 10	0.13	6.88	20.32	27.20				11%		11%												

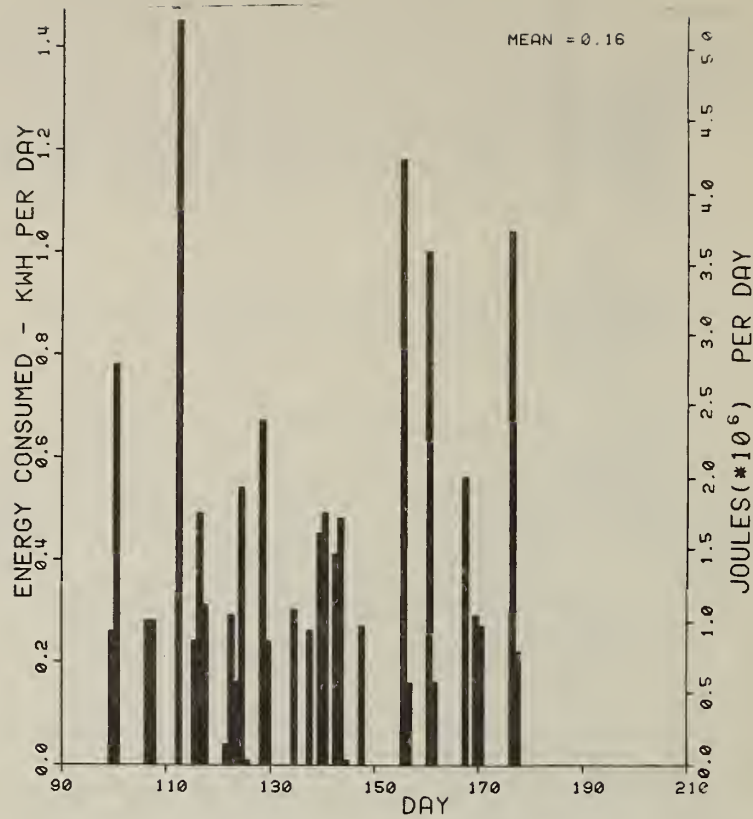


Figure 4. Clothes washer daily energy consumption, townhouse #8.

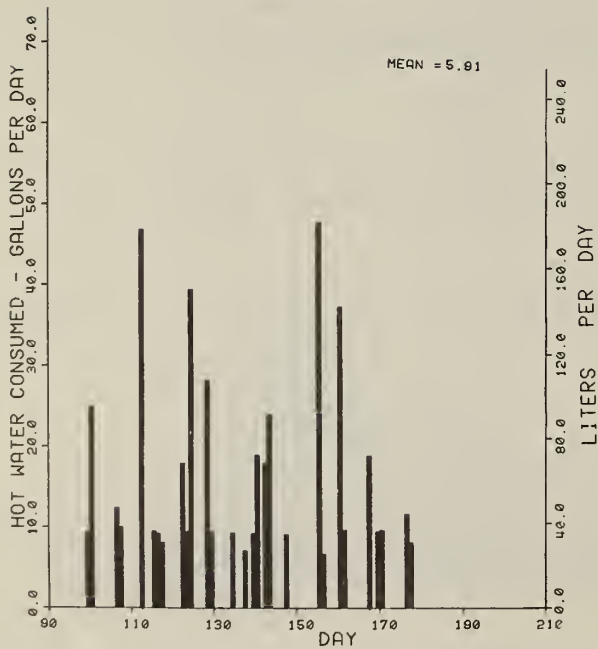


Figure 5. Clothes washer daily hot water consumption, townhouse #8.

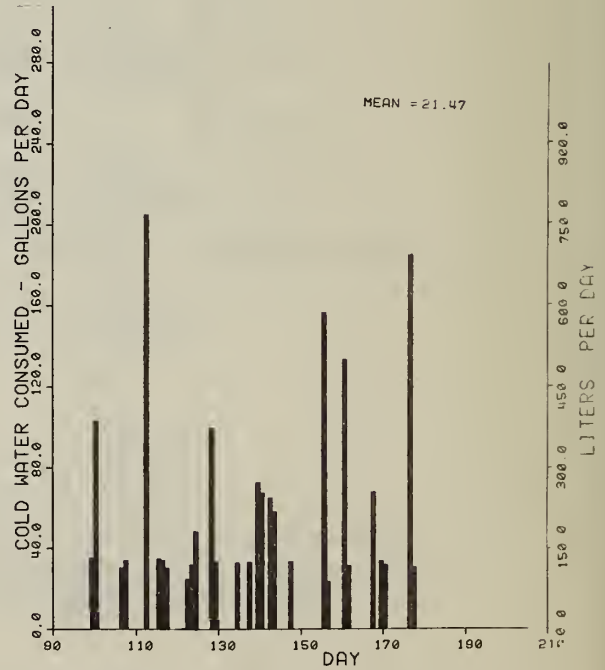


Figure 6. Clothes washer daily cold water consumption, townhouse #8.

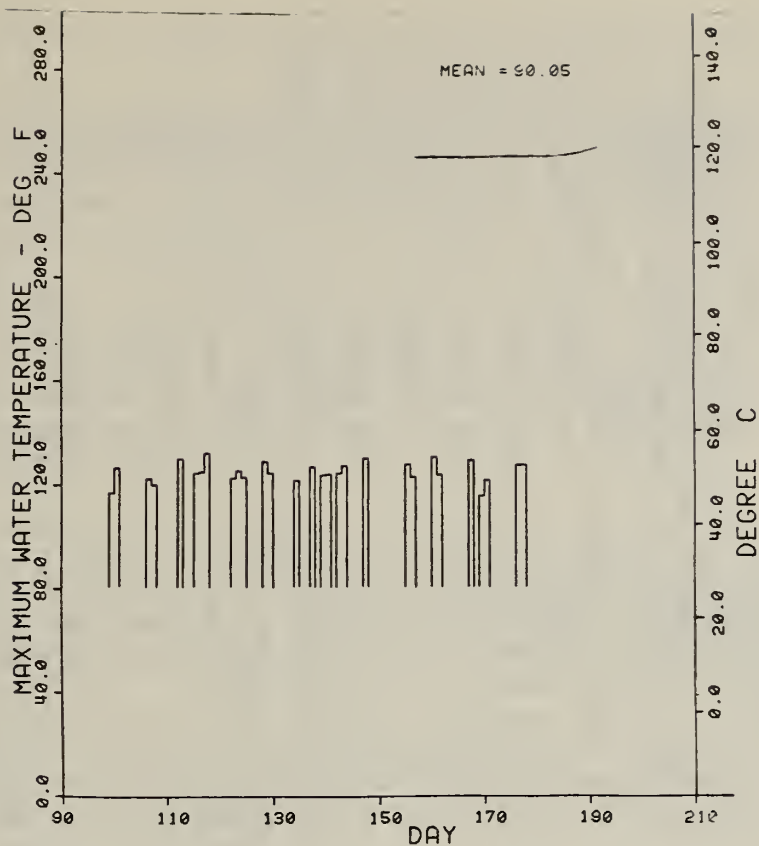


Figure 7. Clothes washer daily maximum water temperature, townhouse #8.

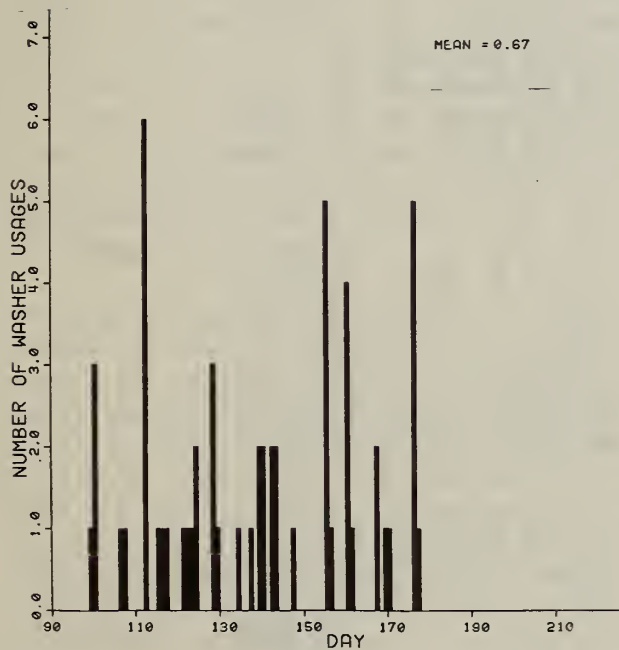


Figure 8. Clothes washer daily usage, townhouse #8.

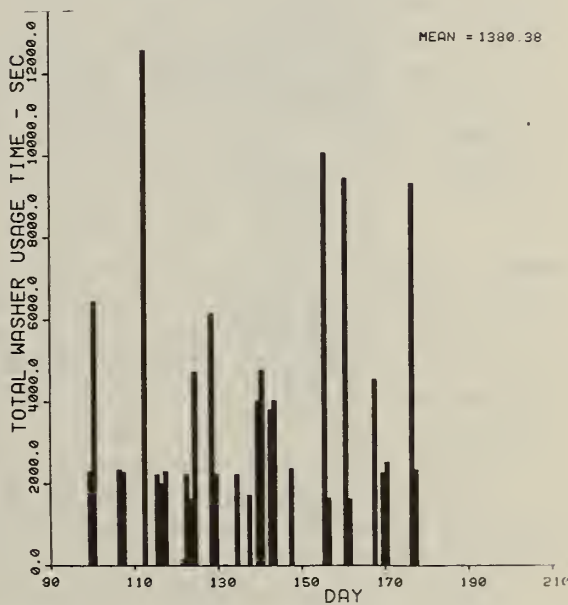


Figure 9. Clothes washer daily usage duration, townhouse #8.

Table 7. Average Per Usage Characteristics of Clothes Washers

Townhouse #	U _D No. of Usage per day	t _D Duration of Usage per day	t _U Duration of Usage per use	E _U Elec. Energy Consumption per use	W _{HU} Hot Water Consumption per use	W _{CU} Cold Water Consumption per use	W _{TU} Total Water Consumption per use	H		E
								Heat Content of Hot Water Consumption per use	Total Energy Consumption per use	
	sec	sec	sec	kWh	gal	gal	gal	kWh (Btu)	gal	kWh (Btu)
Elect. Homes										
1	0.67	519	775	0.18	9.13	31.33	40.46	1.70 (5802)	40.46	1.88 (6416)
2	0.75	629	839	0.21	9.37	30.53	39.90	1.88 (6416)	39.90	2.09 (7133)
5	0.47	765	1627	0.14	8.89	27.02	35.91	1.80 (6143)	35.91	1.94 (6621)
6	0.82	1562	1905	0.16	12.67	29.50	42.17	3.70 (12628)	42.17	3.86 (13174)
9	0.66	1238	1876	0.20	12.24	29.50	41.64	2.83 (9659)	41.64	3.03 (10341)
10	0.71	1119	1576	0.23	18.91	16.44	35.35	4.44 (15154)	35.35	4.67 (15939)
Gas Homes										
3	0.75	1460	1947	0.17 (580)	7.63	26.11	33.74	5.72 (5720)	33.74	6.300
4	0.53	1180	2226	0.23 (785)	3.40	30.45	33.85	2.28 (2280)	33.85	3065
7	1.02	1831	1795	0.18 (614)	12.62	24.94	37.56	7.57 (7570)	37.56	8184
8	0.67	1380	2060	0.24 (819)	8.67	32.04	40.71	4.60 (4600)	40.71	5419
Average Values of All Homes	0.70	1168	1663	0.19	10.35	27.78	38.13			
Average Values Without TH#10	0.70	1174	1672	0.19	9.40	29.04	38.44			

5. ENERGY CONSUMPTION AND USAGE CHARACTERISTICS OF CLOTHES DRYERS

The function of clothes dryers is to evaporate the moisture in damp clothes. Energy is required to supply heat to the drum and to rotate the drum with a load of clothes. Energy consumption for operating this appliance is the main concern for studies on energy conservation of both electric and gas dryers. The physical characteristics of clothes dryers in each townhouse are given in table 8. With regard to the manufacturer's design of the clothes dryer, besides the heat input, there are other factors which affect energy usage of dryers, such as rotating speed, blowing capacity, and air flow patterns inside the dryer. For our purpose, it is sufficient to record energy consumption, number of uses, time of use, and exhausted air temperature. From these measurements the energy consumption per usage and per hour of operation are determined.

Table 9 presents clothes dryer data on a daily basis as well as on a per-use basis. The electric energy consumption of electric dryers, in kilowatt hours, includes energy for heat input, rotation of drum, and blowing of air. For gas dryers, the gas consumption in cubic feet considers only energy needed to heat the air, without measurement of the required electric energy for drum rotation and air blowing. For the purpose of comparison, conversions from both kilowatt hour and cubic feet of gas to Btu were also included in table 9. In addition, table 9 indicates that the occupants in these townhouses utilized dryers on an average of twice every three days (0.77 usage/day) and a little over 30 minutes per day. Furthermore, the average time of running a load was calculated to be about 42 minutes.

For electric clothes dryers, the average energy consumption was measured as 1.37 kWh/day and 2.07 kWh/load. Since the majority of clothes dryers had timers to control the running time, the length of time for each load would have a large variation, as would the per-usage consumption. As a standard method for comparison, the energy consumption for operating individual clothes dryers for one hour was obtained. The average value was found to be 2.83 kWh/hr, which is equivalent to 9659 Btu/hr. With gas dryers, the average energy consumption in operation was 97.3 cubic feet of gas per hour (i.e., 9730 Btu/hr). Since the gas consumption was not including electrical energy, gas dryers would require additional operating energy. From other articles [6] it was estimated that approximately 10 percent should be added for operating energy.

Figures 10 and 11 illustrate the energy consumption of clothes dryers in townhouses #8 and #9, respectively, to show the pattern of occupant usage. The amount of constant usage in townhouse #8 was due to the pilot light of the dryer burning continuously. The per-hour usage analysis for those dryers with pilot lights (townhouses #7 and #8) was a little different, since the energy burned by pilots was independent of appliance usage. Table 9 also indicated that the pilot lights in townhouses #7 and #8 consumed more than 50 percent of the total daily energy usage for gas dryers; the values were 7.04 and 5.80 cubic feet per day of gas, respectively. Even though the energy consumption of domestic clothes dryers is only a small portion of the total amount of national energy usage, it is still worth considering other alternatives

to eliminate this waste. For the purpose of energy conservation, most manufacturers have switched to electric ignition burners for gas dryers to replace pilot lights. The changeover has taken place during the last 10 to 15 years [7]. Figures 12 to 14 represent the frequency of usage, duration of usage, and maximum air temperature of clothes dryer in townhouse #8.

Table 8. Clothes Dryer Characteristics

Electric Dryers

Townhouse Number	Model*	Auto-Dry
1	A	yes
2	B	no
5	B	no
6	B	no
9	B	no
10	B	no

Gas Clothes Dryers

Townhouse Number	Model*	Auto-Dry	Ignition
3	C	no	Electronic
4	D	no	Electronic
7	E	no	Pilot
8	E	no	Pilot

* All clothes dryer models except that in townhouse #1 were from the same manufacturer supplied by the developer or purchased by the occupants. They are all front load models.

Code letters A, B, C etc. indicate different models.

Table 9. Average Daily Usage and Per Cycle Use Characteristics of Clothes Dryers

Townhouse #	E _D Energy Consumption per day		U _D Number of Usage per day	t _D Time of Usage per day	t _U Time of Usage per Use	E _U Energy Consumption per Use		E _{HR} Energy Consumption for Operation per hour	E _p Energy Consumption of pilot per day	Days of Measurement
	kWh	Btu				kWh	Btu			
Electric Homes										
1	1.07	3652	0.68	*	*	1.58	5393	*	*	73-140
5	0.81	2764	0.46	1111	2415	1.76	6007	2.62	8942	238-280
6	1.62	5529	0.72	1847	2565	2.24	7645	3.16	10782	219-280
9	1.22	4164	0.58	1629	2808	2.10	7167	2.70	9215	96-174
10	2.12	7236	0.80	2615	3269	2.65	9044	2.92	9966	96-174
Average Values of Electric Homes										
	1.37	4676	0.65	1800	2764	2.07	7064	2.83	9659	
Gas Homes										
3	3.59	3590	0.91	2030	2230	3.95	3950	6.36	6360	230-280
4	4.95	4950	0.97	1835	1892	5.10	5100	9.71	9710	230-280
7	15.26	15260	1.18	2533	2146	12.93	12930	10.19	10190	95-180
8	12.61	12610	0.68	1973	2901	18.54	18540	12.66	12660	95-180
Average Values of Gas Homes										
			0.94	2093	2292			9.73	9730	
Average Values of All Homes										
			0.77	1946	2529				9729	

* Missing Data

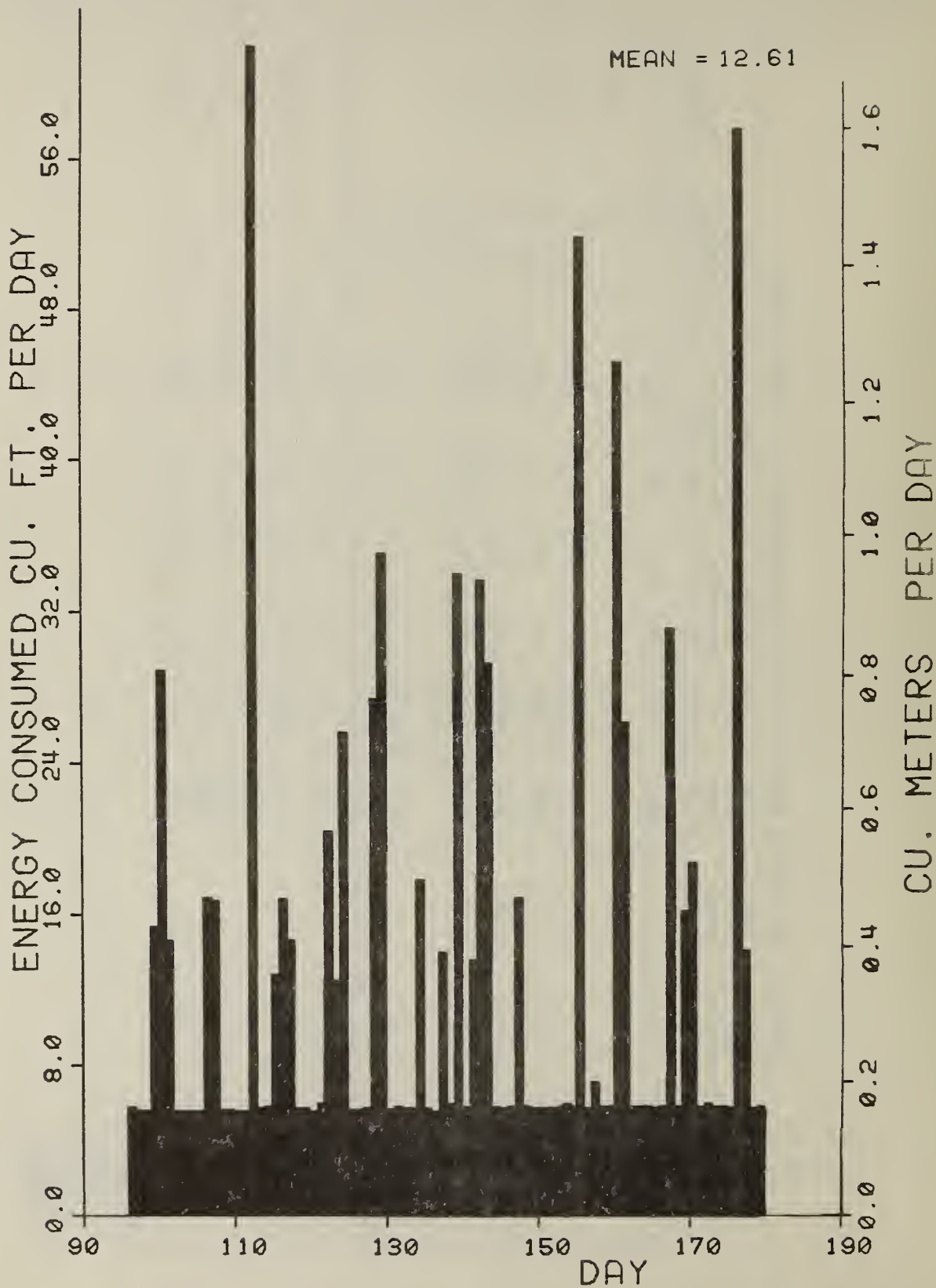


Figure 10. Gas clothes dryer daily energy consumption, townhouse #8.

MEAN = 1.22

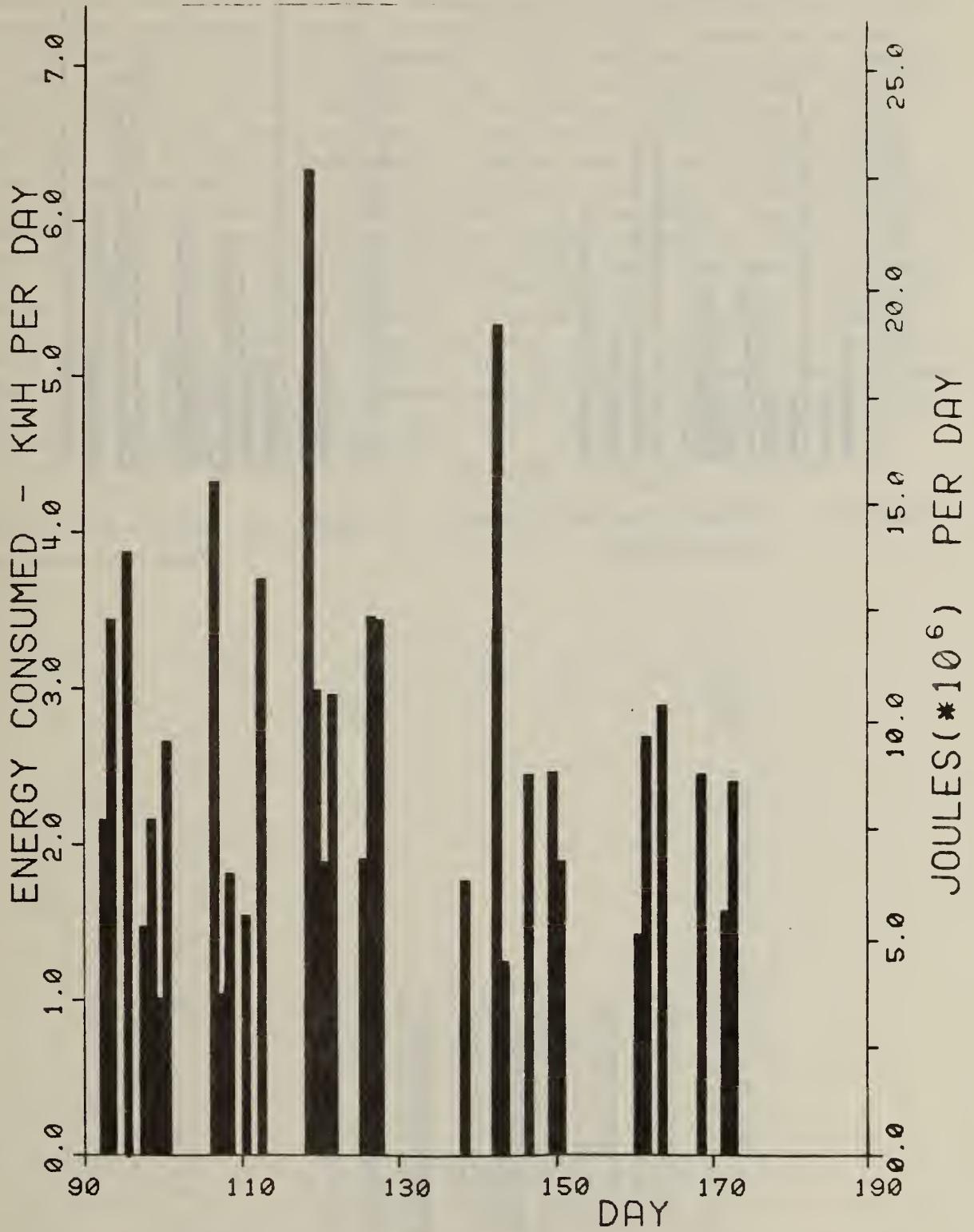


Figure 11. Electric clothes dryer daily energy consumption, townhouse #9.

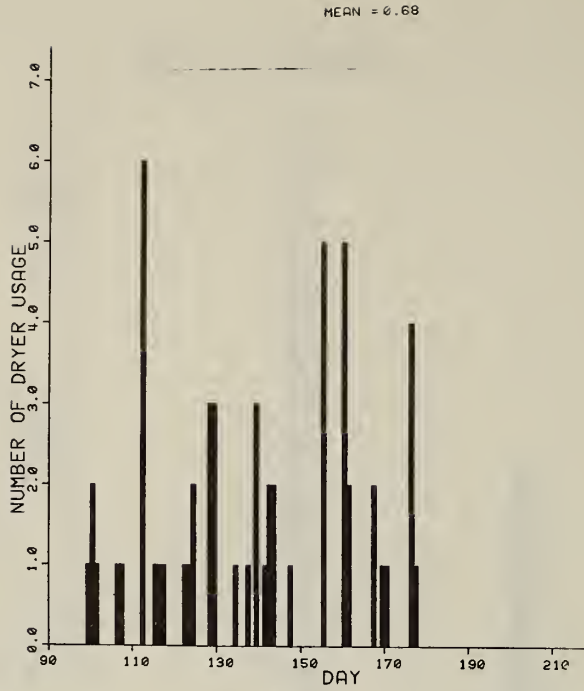


Figure 12. Clothes dryer daily usage, townhouse #8.

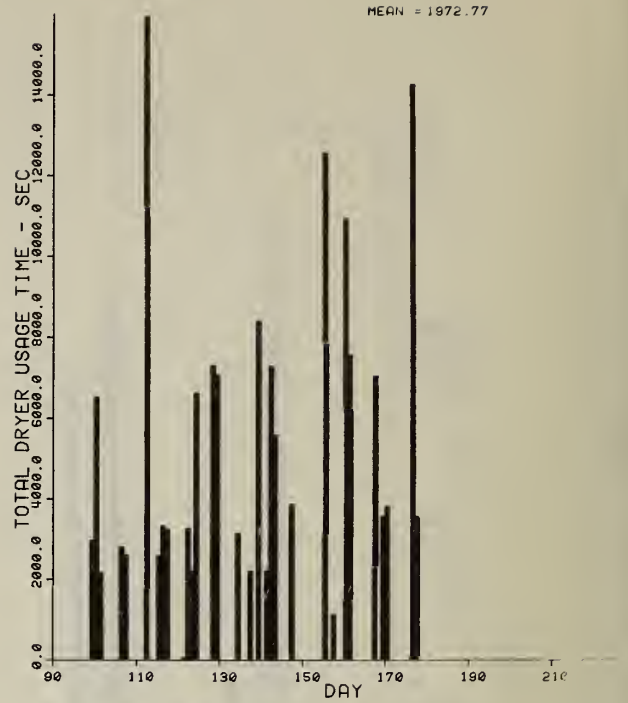


Figure 13. Clothes dryer daily usage duration, townhouse #8.

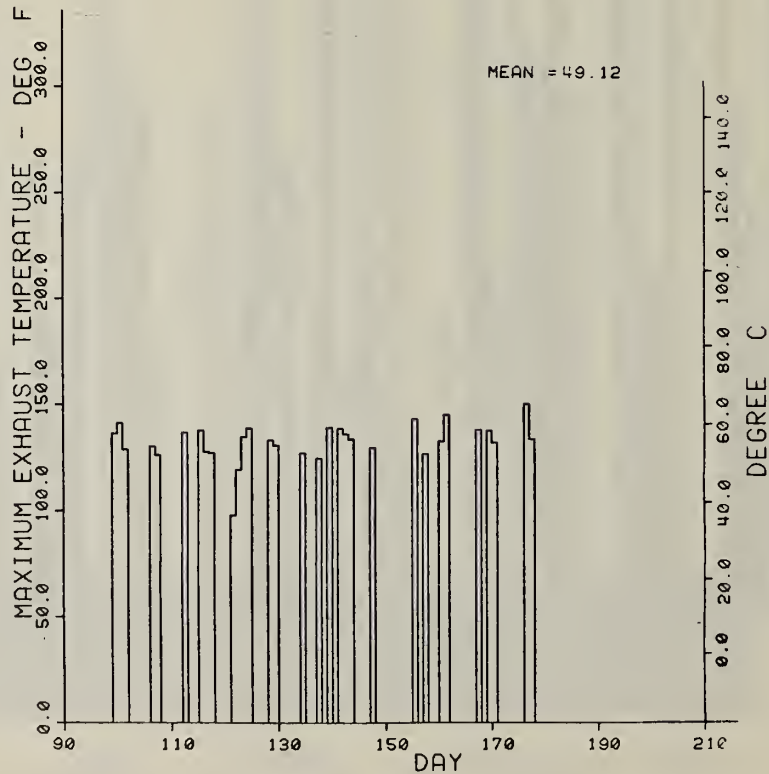


Figure 14. Clothes dryer daily maximum exhaust temperature, townhouse #8.

6. DISCUSSION OF RESULTS

The measurement method used for determining energy consumption, water consumption, and usage frequency of these major appliances was that of continuous data recording in order to seek their average consumption as well as usage patterns. Table 10 is summary of the total energy consumption and hot water usage for all these appliances. The comparison between homes was somewhat difficult due to the fact that individual families had their own habits in operating these appliances. Furthermore, differences in usage frequencies of household dishwashers, clothes washers, and clothes dryers exist between values recorded from the test site and data obtained by other sources for the Department of Energy (DoE)^[8]. Considering the fact that the measurement method used by other sources assigned by DoE was mainly field data surveying rather than continuous field data recording, and their sample sizes were much larger than those of the Twin Rivers site, discrepancies in results of usage frequencies by these two methods were expected. However, the per-load energy consumption and hot water consumption of these appliances seemed to be in agreement, in spite of the difference in measurement methods. Table 11 gives a comparison of average energy consumption, hot water consumption, and usage data of dishwashers, clothes washers, and clothes dryers obtained from these two measurements.

Table 10. Average Daily Energy Consumption of Dishwashers (1), Clothes Washers (2), and Clothes Dryers (3)

Townhouse #	W ₁₂ Hot Water Consumption of (1) and (2)	(W ₁₂ /W) X 100% Percentage of Hot Water of (1) and (2)	E ₁₂		E _{T12}		E _{T23}		E _{T123}	
			gal	%	kWh	Btu	kWh	Btu	kWh	Btu
1	11.85	27%	0.26	8396	2.46	8396	2.33	7952	3.53	12048
2	11.30	18%	0.31	8771	2.57	8771	*	*	*	*
5	14.36	18%	0.37	11195	3.28	11195	1.73	5905	4.09	13959
6	17.0	24%	0.38	18225	5.34	18225	4.79	16348	6.96	23754
9	16.59	29%	0.52	14881	4.36	14881	3.22	10990	5.58	19044
10	17.82	26%	0.45	15836	4.64	15836	5.44	18567	6.76	23072
Average Values										
Average of Electric Homes	14.82	23.67	0.38	12884	3.77	12884	3.50	11952	5.38	18375
Gas Homes										
3	13.59	23%	0.45	11726	8324	15316				
4	11.46	30%	0.63	9830	6570	14780				
7	16.72	22%	0.35	11224	23594	26484				
8	10.03	17%	0.32	6402	16236	19012				
Average Values of Gas Homes	12.95	23%	0.44	9796	13681	18899				
Average Values of All Homes	14.07	23.4%	0.40	11649	12720	18608				

* Missing Data

Table 11. Comparison of Results From the Twin Rivers Test Site With Other Sources [8]

	Dishwashers		Clothes Washers		Clothes Dryers	
	Twin Rivers	Other Sources	Twin Rivers	Other Sources	Twin Rivers	Other Sources
Average energy consumption - kwh/use	0.55	0.674*	0.19	0.22	2.07***	2.0
Average hot water consumption - gal/use	13.81	15	9.40	12.49**		
Average annual load	197	416	255	416	281	416

* normal cycle only.

** WARM/COLD cycle assumption.

*** electric clothes dryers only.

7. CONCLUSION

As given by table 10, the electrical energy consumption for the hot water consuming appliances, (dishwashers and clothes washers), E_{12} , was found to be about 0.40 kWh/day; and the hot water consumption, W_{12} , was approximately 14 gal/day or 23 percent of the total hot water heater's daily consumption. The total energy consumed by these two appliances turned out to be 11649 Btu/day, which is equivalent to 3.4 kWh/day or 11.65 ft³ of gas per day, depending on the source of energy.

Gas clothes dryers with pilot lights have enormous standby losses, more than 50 percent of the total daily energy usage for the appliance. Furthermore, the electric energy for drum rotation and air blowing were omitted from the measurements of all gas dryers, so the actual total energy consumption of gas dryers could not be determined. Therefore, only electric dryers were taken into account in investigating the actual combined energy usage of these appliances.

Clothes washers and clothes dryers are normally considered to be a pair of major appliances. Referring to tables 7 and 9, their frequencies of usage for each townhouse were very close and the overall average usage per day was only 10 percent apart. As illustrated in figures 4, 8, 10 and 12, the usage patterns of the washer and dryer in townhouse #8 shows that their energy consumption is in agreement for days when they were in use. The average energy consumption for the set of washer and dryer (electric), E_{23} , was found to be 3.5 kWh/day and they were being used approximately twice every three days or five loads each week.

For all three appliances, the average total energy consumption was calculated to be 5.38 kWh/day. Again, only electric dryers were considered, as shown in table 10. In addition, table 10 gives the energy units in Btu as well as kilowatt hours for both electric and gas homes, to reveal the actual energy usage in each townhouse and to consolidate these appliances for conditions of energy conservation. For example, gas dryers with pilot lights indicated a tremendous waste as compared to those with electric ignition burners. Finally, the estimated combined energy consumption, from tables 3 and 7 and the electric dryers' average energy usage, was summed to be 7.27 kWh per usage for all three appliances.

REFERENCES

1. Grot, R. A. and Socolow, R. H., "Energy Utilization in a Residential Community," Energy Demand, Conservation and Institution Problems. ed. Michael Macrakis (Cambridge, Mass., MIT Press 1974).
2. Socolow, R. H., "The Twin Rivers Program on Energy Conservation in Housing: Highlights and Conclusions," Energy and Buildings, Vol. 1, No. 3, April, 1978.
3. Grot, R. A. and Galowin, L. S., "Preliminary Data on the Field Performance of Storage-Type Residential Water Heaters," NBSIR 78-1496, April, 1979. Available from NTIS, PB-295.431.
4. Fuchs, A. J., "Water Temperature Effects in Laundering and Automatic Dishwashing," Proceedings of the Conference on Major Home Appliance Technology for Energy Conservation, Purdue University, West Lafayette, Indiana, pp. 180-185, February 27-March 1, 1978.
5. Tree, D. R., Hamilton, J. F. and Herrick, R. W., "Energy Measurements of Major Home Appliances in Four Residential Homes," Proceedings of the Conference on Major Home Appliance Technology for Energy Conservation, Purdue University, West Lafayette, Indiana, pp. 214-228, February 27-March 1, 1978.
6. Hollowell, G. T., "Clothes Dryer Energy Consumption," ERDA Conference on Technical Opportunities for Energy Conservation in Appliances, May 11, 1976.
7. Cox, J. D., and Kornguth, H., "Appliance Energy Conservation through the Application of Electric Ignition Systems," Proceedings of the Conference on Major Home Appliance Technology for Energy Conservation, Purdue University, West Lafayette, Indiana, pp. 225-264, February 27-March 1, 1978.
8. Davies, A.D., Kelly, R., Lewis, A.C., Lovett, C.D. and Wang, T.J., "Household Appliance Usage Data," NBSIR 80-1994, February 1980.

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET <i>(See instructions)</i>	1. PUBLICATION OR REPORT NO. NBSIR 80-2136	2. Performing Organ. Report No.	3. Publication Date October 1980
4. TITLE AND SUBTITLE ENERGY CONSUMPTION AND USAGE CHARACTERISTICS FROM FIELD MEASUREMENTS OF RESIDENTIAL DISHWASHERS, CLOTHES WASHERS, AND CLOTHES DRYERS			
5. AUTHOR(S) Yui-May L. Chang and Richard A. Grot			
6. PERFORMING ORGANIZATION <i>(If joint or other than NBS, see instructions)</i> NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			7. Contract/Grant No. 8. Type of Report & Period Covered
9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS <i>(Street, City, State, ZIP)</i>			
10. SUPPLEMENTARY NOTES <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.			
11. ABSTRACT <i>(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)</i> The measured energy consumption and usage characteristics for household dishwashers, clothes washers, and clothes dryers for ten townhouses at Twin Rivers, N.J., are presented. Whenever the dishwashers and/or clothes washers were in use, the energy consumption, water consumption, frequency of usage, and water temperature were measured by a data acquisition system. The energy requirement for heating hot water could be established from the water heater's characteristic in a previous related report (NBSIR 78-1496). The electrical energy of electric clothes dryers and the gas consumption of gas clothes dryers were measured, as well as their frequency and duration of use, and exhaust temperature. Typical household usage patterns of these major appliances are also included. It was found that, in general, the electrical energy required to operate dishwashers and clothes washers is about one tenth of the energy consumption for heating hot water. Cold water usage is about three times the hot water usage for each load of laundry. The energy loss from a pilot light burner of a gas dryer is about 50 percent of the total gas consumption of that dryer. As far as habits are concerned, the average family utilizes the dishwasher every other day and the laundry about five loads a week.			
12. KEY WORDS <i>(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)</i> Clothes dryer usage characteristics; clothes washer usage characteristic; data profiles; dishwasher usage characteristic; energy consumption; field measurements; usage patterns; water consumption.			
13. AVAILABILITY <input checked="" type="checkbox"/> Unlimited <input type="checkbox"/> For Official Distribution. Do Not Release to NTIS <input type="checkbox"/> Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. <input checked="" type="checkbox"/> Order From National Technical Information Service (NTIS), Springfield, VA. 22161			14. NO. OF PRINTED PAGES 34 15. Price \$6.00

