

MONITORED HOT WATER USE: A SEASONAL ANALYSIS

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ABSTRACT

Although hot water use is the second largest energy consumer in most American residences, it has not received the same degree of attention as has space conditioning. Most analyses of hot water energy consumption treat the hot water delivery system as an energy using appliance. Kempton's (1984) univariate analysis of hot water use in seven Michigan houses demonstrated that the residential hot water system is really "behaviorally driven" and that there is a great deal of variation in patterns of hot water end use behaviors.

This paper is a multivariate extension of Kempton's initial analysis, employing a more complete data set from the same houses. Hot water demand is disaggregated into discrete hot water use events and measured for time of occurrence, duration, volume and place of demand. Our analyses of the consumption of nine families reveal substantial variation in the relative frequency of different end uses from season to season that were of moderate size and statistically significant. Several families showed large, positive percentage differences in the relative frequency of bathing events (30 to 100%) from winter to summer, others showed negative differences of more modest proportions and some showed none at all. Several families also showed large proportionate increases in small, unallocated events in the summer time. While the overall effect of seasonal variation was to increase the incidence of high volume uses during the warmer months (bathing and laundry) this was partially compensated in some cases by lower average volumes.

Eight of nine families exhibited a statistically significant difference in the mean volume of at least one usage from season to season. Four families showed significant differences in the volumes of two uses and one family in three. Four families had their lowest mean bathing volumes in summer while two families had their highest volumes at this time.

For five families, regression models employing the mean external temperature as the independent variable explained five to 17 percent of the total variation in annual bathing volumes. The coefficients for temperature implied a decrease of .22 to .58 liters for every one degree increase in the ambient temperature. The size of the coefficient was sufficient to account for nearly all of the observed differences in seasonal mean volumes.

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INTRODUCTION

Families whose hot water usage was monitored over a one to three year period were found to exhibit substantial variation between families in the volume and duration of usage and in the energy required to heat the water. Using a subset of the data analyzed here, Kempton (1984) has described the hot water, hot water energy consumption, and system efficiency characteristics of these families for different end uses. In this paper we report evidence of seasonal variation in the amount and proportion of hot water that families devote to different uses. Using records of discrete water use events, we show that several families out of the nine families studied change the proportion of hot water devoted to different uses from season to season as well as the absolute amount of water per event. We also show that hot water usage is related to variations in the weather, as indexed by mean daily outside temperature.

DATA

The data are taken from records of electronically monitored hot water usage in nine homes in Michigan between 1983 and 1985. The water measurements are part of a comprehensive instrument package measuring many household energy variables (Weihl, Kempton and DuPage, 1983). Participants entered and left the project at different times and experienced different amounts of lost data due to equipment malfunction. The first family's data begins on 2 february 1983 and ends on 8 September 1984, while the last begins on 21 November 1984 and ends on 11 May 1985. The total number of days covered is from 150 to 590. The beginning and ending dates for each family and the number of days covered is presented in Table I. In most cases the data are not contiguous but contain one or more gaps of varying length.

TABLE I. RANGE OF DAYS COVERED BY EACH FAMILY'S DATA

	FAMILY NUMBER								
	0	1	2	3	4	5	6	7A	7B
Low	040	033	046	292	060	336	400	305	694
High	333	617	636	634	633	486	926	533	862
Range	293	584	590	342	573	150	526	228	168

Day 1 = 1 January 1983

The data are "water events", each event representing a single usage of hot water. We define a water event as a contiguous flow of hot water bounded by at least one minute without hot water use before and after. At least one minute is required between events due to technical constraints on our recording devices (Kempton, 1984). The beginning and end of each event was signaled by the monitored flow meter mounted at the hot water tank and the volume measured there allocated to whichever tap showed the greatest rise in temperature during the water flow. The algorithm used to perform this allocation has been reported previously (Weihl and Kempton, 1985). Manual analysis of minute by minute data for several days in four houses led Weihl and Kempton (1985) to estimate that 90% to 98% of these allocations are correct². For each event, we recorded the date, time, primary usage, duration, volume, tank heat and other measures of energy used. A separate data file for each family contains all of the events arranged by date and time of occurrence.

The number of events recorded on a single day might range from six to more than 40. The analysis was performed on a subsample of events from even numbered days in the case of large files and approximately 30 percent of the kitchen sink events for all families³. A distribution of the events analyzed by end use and season for each family is presented in Table II.

Seasons Defined

The idea of analyzing seasonality of water usage originated in the analysts' informed supposition that some people vary the temperature and perhaps the duration of their showering or bathing according to the ambient temperature, and that frequency of bathing and of laundry usage might differ from summer to winter. Additionally, we have evidence from data collected on thermostat setting behavior from the same families that some people exhibit thermostat management strategies in the transition seasons of spring and fall that are different from the strategy they employ in the winter. This effect has been reported earlier in a paper by Kempton and Krabacher (1984). Accordingly we attached a variable to each event reflecting the mean daily external temperature for the study area and defined the seasons so as to capture the transition periods between winter and summer. Spring was defined as March 16 through June 15, Summer as June 16 through September 15, Fall as September 16 through November 15 and Winter as November 16 through March 15.

We do not believe that the sampling and definition process introduced any systematic biases in the data, although our evidence is indirect. Sampling by Julian date meant that all days of the week are included and examination of the data reveals no noticeable variation in the proportion of kitchen sink events from season to season across all the families. Our analysis was performed upon two microcomputers using the SL-MICRO statistical package.

RESULTS

We first looked for seasonal effects by tabulating the type of event by the season of the year for each family. These results are presented in Table II. Events were categorized as kitchen sink, bathroom sink, bathing, laundry and unallocated uses. The Chi squared statistic for five families ranged from 30 to 70 with 12 degrees of freedom (d.f.) and from 17 to 186 with 12 d.f. for three families. The critical value for Chi squared at the .01 percent level of confidence is 26.217 for 12 degrees of freedom.

Table II. Relative frequency of water use events by season.

Event	Family 0					Family 1					Family 4				
	Winter	Spring	Summer (Percent)	Fall	Mean	Winter	Spring	Summer (Percent)	Fall	Mean	Winter	Spring	Summer (Percent)	Fall	Mean
Unallocated	7.3	5.9	15.3	18.5	13.0	4.7	4.8	5.4	4.6	5.0	12.7	3.3	4.0	-	5.9
Kitchen sink	28.7	27.1	26.1	26.0	26.9	20.0	19.9	19.1	19.1	19.6	40.8	28.5	29.0	-	31.8
Bathroom sink	46.7	56.5	43.3	41.0	45.3	55.3	49.9	47.9	55.8	50.8	23.6	36.7	40.5	-	34.4
Bathing	6.7	9.4	12.1	7.5	8.8	9.5	9.6	12.1	9.7	10.5	6.4	13.2	12.9	-	11.4
Laundry	10.7	1.2	3.2	7.0	6.1	10.5	15.8	15.6	10.8	14.1	16.5	18.3	13.6	-	16.5
Total ^a	100.1	100.1	100.0	100.0	100.1	100.0	100.0	100.1	100.0	100.0	100.0	100.0	100.0	-	100.0
Events	150	85	157	200	597	1885	2239	2796	371	7291	818	1511	882	-	3211
	$\chi^2 = 30.07^*$ D.F. = 12					$\chi^2 = 56.68^*$ D.F. = 12					$\chi^2 = 186.85^*$ D.F. = 8				
	Family 3					Family 5					Family 2				
Unallocated	6.4	9.2	15.1	7.0	9.7	1.8	2.2	2.7	2.6	2.2	5.3	4.4	7.6	8.4	6.0
Kitchen sink	23.9	20.6	18.3	24.8	21.5	31.2	34.2	30.1	29.7	31.9	24.5	21.0	31.7	30.1	25.6
Bathroom sink	37.5	40.9	37.6	37.7	38.4	43.8	37.1	38.7	41.3	40.6	42.2	45.0	30.3	33.4	39.4
Bathing	22.2	19.6	19.0	18.4	20.2	6.8	6.8	9.2	9.5	7.4	21.8	23.0	21.4	23.4	22.4
Laundry	9.9	9.8	10.0	12.0	10.1	16.4	19.7	19.3	16.8	18.0	6.2	6.6	9.0	4.7	6.5
Total ^a	99.9	100.1	100.0	99.9	99.9	100.0	100.0	100.0	99.9	100.1	100.0	100.0	100.0	100.0	99.9
Events	1295	1005	1113	440	3853	2385	1687	957	380	5409	486	544	290	299	1619
	$\chi^2 = 70.91^*$ D.F. = 12					$\chi^2 = 35.97^*$ D.F. = 12					$\chi^2 = 36.83^*$ D.F. = 12				
	Family 6					Family 7A					Family 7B				
Unallocated	8.0	7.9	8.7	-	8.0	4.0	-	2.2	4.5	4.1	5.0	5.1	-	-	5.0
Kitchen sink	20.5	24.9	19.5	-	22.0	27.4	-	46.7	21.9	26.0	34.1	25.8	-	-	28.5
Bathroom sink	24.0	23.6	19.5	-	23.5	20.2	-	20.0	24.2	22.6	34.9	40.9	-	-	39.0
Bathing	16.9	14.6	28.2	-	16.7	32.3	-	28.9	30.1	30.6	17.2	19.7	-	-	18.9
Laundry	30.7	29.0	24.1	-	29.7	16.1	-	2.2	19.3	16.7	8.8	8.5	-	-	8.6
Total ^a	100.1	100.0	100.0	-	99.9	100.0	-	100.0	100.0	100.0	100.0	100.0	-	-	100.0
Events	1819	1134	195	0	3148	124	0	45 ^b	269	438	501	1066	0	0	1567
	$\chi^2 = 29.82^*$ D.F. = 8					$\chi^2 = 17.39^*$ D.F. = 8					$\chi^2 = 12.62^{**}$ D.F. = 4				

a Totals may not add to 100 due to rounding.

b Includes 10 events from spring.

* Significant at the .01 level of confidence.

** Significant at the .02 level of confidence.

Counter Balancing Effects

While all families varied from season to season in the proportion of events in each usage category, each was unique in the pattern of this variation. Family 0 showed a much higher proportion of very short, unallocated events in the summer and fall, about 17.5 percent, compared to 6.5 percent in the winter and spring. Usage of the bathroom sink averaged 45.3 percent but was as high as 56.5 percent in spring and as low as 41 percent in fall. Bathing events averaged 8.8 percent, 12.1 percent in summer and 6.7 percent in winter. The mean volume of their bathing event was 82 liters while their summer mean was only 63 liters, so that frequency and volume have a compensating effect. Similarly, mean volume for bathroom sink usage was 3.9 liters when their frequency rose to 56 percent compared to the overall mean of 4.8 liters. Seasonal mean volumes for each family are presented in Table III.

Family 1 showed a constant proportion of unallocated and kitchen sink uses. Their spring bathroom sink usage dropped 5 percentage points from fall and winter and their summer usage dropped another 2 points, from 55.8 percent in fall to 47.9 in summer. Summer shower usage was 25 percent higher than the rest of the year, 12.1 percent compared to 9.6 percent. Spring and summer laundry averaged 15.7 percent compared to 10.6 percent for fall and winter.

For Family 1, their bathroom sink uses and laundry uses did not differ appreciably in mean volume from season to season, 2.2 liters and 14.4 liters respectively. Their bathing/shower volumes changed by 25 percent from winter and spring to summer, from approximately 39 liters to 29 liters per event. Thus total hot water devoted to bathing did not change in summer. The difference in the seasonal mean volumes is significant statistically and will be discussed in the next section.

Family 4 had only 10 events out of 3,221 occurring in fall as a consequence of equipment failures, so their analysis is based on three seasons. Unallocated events were three to four times higher in winter over spring and summer, 12.7 compared to 3.7 percent. Most likely these correspond to a much lower proportion of bathroom sink events. We assume that a large number of short hand washings did not cause a sufficient temperature rise to be detected and allocated. The spring and summer bathing events for this family were twice the winter proportion, 13 percent compared to 6.4. Summer volumes were 25 percent less than those of winter, 30.7 liters compared to 42.2, and those of spring were midway between these. The mean duration of winter baths were only .2 minutes longer however, 7.8 compared to 8.0 minutes. Laundry usage was 16.5 percent in winter, 18.3 in spring and 13.6 in summer. The higher rate of laundry in spring was accompanied by a much greater volume per use, 29.8 liters compared to 18.2 in winter and summer. Spring was clearly the high hot water usage season for this family. On a standardized basis of 882 total events per season, this family consumed about 2200 liters bathing in winter, 3500 liters in summer and 4200 liters in spring.

Compounding Effects

Family 3 doubled the proportion of unallocated events during summer from 7 to 15 percent. Kitchen sink events were highest during fall at 24.8 percent, declining steadily to 18.3 percent in summer. Bathing events were highest in winter, 22.2

percent, declining to 18.4 percent in fall. The mean summer volume for baths was 61.7 liters compared to an average of more than 70 liters the rest of the year and 71.9 liters in winter. For this family the frequency and volume differences in bathing between winter and summer compound to increase hot water usage in winter and lower it in summer.

Family 5 exhibited only modest variations in the proportions of uses from season to season. Bathing was 37.5 percent more frequent in summer and fall than in winter and spring, 9.5 percent compared to 6.8. The volume of bath events was 49.3 liters in summer, 39.9 in fall, 37.5 in winter and 35.6 in spring. The summer increase in frequency is compounded by greater volumes, rather than being offset, as in the case of Family 1. Laundry usage averaged 16.6 percent in fall and winter, 19.5 in spring and summer, with little deviation from the annual mean of 21.3 liters per event. Winter was the lowest season for hot water usage and summer the highest, followed by fall and then spring.

Other Patterns

Family 2 had nearly twice as many unexplained uses in summer and fall as in winter and spring about 8 percent compared to 5 percent. This family had a marked shift in usage from the bathroom sink in winter and spring to the kitchen sink in summer and fall. Bathroom sink events declined from 43 to 33 percent while kitchen sink events rose from 22 to 31 percent. The winter and spring bath sink volumes are much higher than the summer and fall kitchen sink volumes, implying lower hot water use from this effect. Probably this is the result of more quick hand washing done in the kitchen during warmer weather. Family 2 had a constant proportion of bathing events across all seasons, higher laundry use in the summer and lower in the fall.

Family 6 had almost 94 percent of its 3161 analyzed events concentrated in winter and spring. For these seasons only very modest differences are observable in proportions of usage. Family 7a also had too little data available for spring and summer to permit much interpretation of their relative frequencies of use. Family 7b was a separate family that lived in the house of Family 7a after that family moved out. They had usable data for only winter and spring. Bathing and bathroom sink use increased between these periods while use of the kitchen sink declined. Bathing events decreased in mean volume from 8.6 to 5.1 liters and the bathroom sink volume declined from 3.5 to 2.3 liters. The biggest difference was in the volumes of laundry usage, 39.8 liters in winter and 14.3 liters in spring.

Two overall patterns emerge from this review. For two families, the season of peak volume or large volume uses corresponded with the season of higher frequency, producing a substantial difference in total hot water used. For three families, the high frequency seasons corresponded with lower volume periods so as to moderate the variation in total use. In two cases volume declines in bathing should have outweighed increases in frequency, while in one case the frequency increase dominates, implying greater usage of hot water. In general, there was an increase in the incidence of high volume uses during the warmer months, partially compensated in some cases by lower average volumes.

Differences in Usage Volumes from Season to Season

In this section we discuss the differences in mean volumes and mean durations of events between seasons. The mean volumes by usage type and season for each family are presented in Table III. The mean durations are presented in Table IV. Since different seasons of an individual family's behavior are clearly not independent samples, it is not appropriate to employ a difference in means test that requires the assumption of independent samples. What we have are repeated measurements on the same populations, but lack of equal sample sizes and the magnitude of the data set made the calculation of difference scores between each pair of seasons impractical.

Accordingly we constructed confidence intervals around each seasonal mean and inspected them to see if their boundaries overlapped. Following Blalock (1972), 95% confidence intervals corresponding to a one-tailed test of significance were constructed by multiplying the estimated standard error of each mean by plus or minus 1.645. When the upper boundary of a smaller mean within a set was smaller than the lower boundary of a larger mean, we concluded that the means in question were statistically different at the .05 significance level. For example, Family 4's mean kitchen sink volume in winter was 5.327 liters, and the mean for summer 3.731 liters (Table III). The 95% confidence interval for summer was $\pm .556$ and the upper boundary for the confidence interval was 4.287. The confidence interval for winter was $\pm .888$ and the lower boundary 4.539. Based on our criterion, we concluded that these means are statistically distinct.

Within each usage group for a family, those means that are different by this test are underlined, and an asterisk appears above the group. We see that only Family 4 exhibits a seasonal difference in kitchen sink volume by this test, that three families, 2, 7a and 7b, exhibit differences in mean bathroom sink volumes while six of the nine families differed in their bathing volumes from season to season and five of the nine differed in the volumes of their laundry usage. In a number of cases the amounts by which the higher mean exceeds the lower are in the range of 20 to 50 percent, for bathing, the largest volume usage, these differences are 30 to 50 percent. Family 1 showed a significant difference only in bathing volumes, Family 6 only in laundry and Family 7a only in bathroom sink volume. Families 0, 2, 3, and 7b varied significantly in two usages and Family 4 varied significantly in three usages, all except for the bathroom sink.

Employing the same procedures and criterion, we found eight instances where the mean duration of each usage in minutes varied significantly from season to season. Family 4 ran their kitchen sink for an average of 2.557 minutes in winter, but only 2.032 and 2.023 minutes in spring and summer respectively. Their bath events required 7.045 minutes in spring, but 7.842 minutes in summer. As pointed out earlier, this difference in bath duration is in the opposite direction from the difference in bath volume. Family 1 took baths that averaged 7.5 minutes in winter, but only 6.2 minutes in summer.

We were surprised to find this much variation across nearly all of the families. We had anticipated that one or more would show some seasonality, but not the vast majority. Of course, the amount of statistically significant variation identified is dependent upon the width of the interval chosen. An interval of .975 or .99 in width

TABLE III. MEAN WATER EVENT VOLUMES IN LITERS BY USAGE TYPE AND SEASON

EVENT/SEASON	FAMILY NUMBER								
	0	1	2	3	4	5	6	7A	7B
<u>Kitchen Sink</u>					*				
Winter	4.512	3.479	2.596	5.747	<u>5.427</u>	4.289	7.967	6.513	1.805
Spring	7.131	3.274	3.483	5.757	4.716	3.966	7.546	8.417	1.572
Summer	5.316	3.237	2.079	6.740	<u>3.731</u>	4.906	4.681	7.031	---
Fall	4.360	3.453	1.894	6.619	1.623	4.030	3.225	6.669	---
Mean	5.048	3.323	2.573	6.108	4.690	4.267	7.590	6.762	1.662
<u>Bathroom Sink</u>			*					*	*
Winter	5.915	2.129	<u>2.882</u>	2.596	3.690	3.304	6.379	<u>3.082</u>	<u>3.502</u>
Spring	3.911	2.176	<u>5.322</u>	2.818	4.248	3.316	7.059	2.300	<u>2.332</u>
Summer	3.510	2.378	2.295	2.466	3.864	4.983	5.994	8.77	---
Fall	5.509	2.006	1.614	2.474	2.738	4.648	4.170	<u>10.302</u>	---
Mean	4.822	2.226	3.539	2.607	4.020	3.686	6.602	8.160	2.667
<u>Bathing</u>	*	*	*	*	*	*			
Winter	<u>99.758</u>	<u>38.78</u>	36.261	<u>71.945</u>	<u>42.174</u>	37.468	54.432	43.599	8.617
Spring	73.544	<u>41.339</u>	<u>33.917</u>	<u>70.681</u>	36.902	<u>35.633</u>	52.730	22.560	5.102
Summer	<u>63.162</u>	<u>29.476</u>	<u>42.645</u>	<u>61.734</u>	<u>30.674</u>	<u>49.329</u>	14.201	33.736	---
Fall	<u>98.168</u>	35.107	39.447	<u>70.149</u>	15.760	41.316	60.570	35.732	---
Mean	81.895	35.232	37.159	68.656	35.653	39.907	49.741	37.732	6.123
<u>Laundry</u>	*			*	*		*		*
Winter	<u>6.826</u>	14.906	18.877	26.302	<u>18.114</u>	20.089	<u>10.664</u>	47.847	<u>39.808</u>
Spring	0.260	14.956	10.184	<u>30.263</u>	<u>29.766</u>	21.893	<u>14.553</u>	3.22	<u>24.311</u>
Summer	1.472	13.767	7.618	23.219	<u>18.191</u>	22.592	11.293	---	---
Fall	<u>1.724</u>	15.582	15.781	<u>21.998</u>	---	22.403	7.304	43.247	---
Mean	3.916	14.446	12.754	25.835	24.199	21.336	12.040	43.959	29.326

*underlined means different at .05 significance level based on comparison of 95% confidence intervals

TABLE IV. MEAN WATER EVENT DURATIONS IN MINUTES BY USAGE TYPE AND SEASON

EVENT/SEASON	FAMILY NUMBER								
	0	1	2	3	4	5	6	7A	7B
<u>Kitchen Sink</u>									
					*				
Winter	2.000	1.737	2.218	2.332	<u>2.557</u>	1.977	2.387	2.941	2.129
Spring	2.217	1.683	2.351	2.536	<u>2.032</u>	1.953	2.599	5.00	2.015
Summer	2.146	1.734	2.043	2.593	<u>2.023</u>	2.073	2.421	3.867	---
Fall	1.846	1.775	1.933	2.422	1.500	1.956	2.000	2.678	---
Mean	2.019	1.721	2.154	2.459	2.199	1.984	2.473	3.035	2.058
<u>Bathroom Sink</u>									
			*					*	
Winter	1.900	1.742	<u>1.434</u>	1.537	2.021	1.846	2.489	<u>1.840</u>	2.160
Spring	1.792	1.735	<u>2.000</u>	1.620	2.245	1.813	2.481	1.500	2.154
Summer	1.706	1.759	1.682	1.629	2.118	1.968	4.526	4.143	---
Fall	1.841	1.778	1.560	1.590	2.00	1.860	2.000	<u>4.231</u>	---
Mean	1.831	1.748	1.705	1.592	2.164	1.858	2.590	3.566	2.155
<u>Bathing</u>									
		*			*				
Winter	13.000	<u>7.531</u>	6.500	8.531	<u>8.058</u>	4.242	6.717	13.125	3.826
Spring	10.125	<u>7.247</u>	6.208	9.010	<u>7.045</u>	3.982	6.430	9.000	3.524
Summer	11.842	<u>6.210</u>	8.613	8.458	<u>7.842</u>	5.170	5.091	7.333	---
Fall	14.667	7.111	7.986	9.247	6.000	3.861	9.000	11.580	---
Mean	12.615	6.847	7.047	8.707	7.434	4.338	6.467	11.642	3.611
<u>Laundry</u>									
			*				*		
Winter	2.000	2.548	<u>3.567</u>	3.289	3.311	2.356	<u>2.401</u>	9.050	5.364
Spring	1.000	2.466	<u>2.134</u>	3.653	3.394	2.471	<u>3.188</u>	4.0	5.681
Summer	1.800	2.381	2.385	3.216	2.992	2.568	3.574	---	---
Fall	1.429	2.400	3.921	2.981	---	2.547	3.400	9.481	---
Mean	1.722	2.443	2.840	3.318	3.282	2.449	2.741	9.288	5.578

*underlined means different at .05 significance level based on comparison of 95% confidence intervals

would have found fewer differences. Since this was an exploratory study, we chose to minimize the risk of concluding that there was no difference when in fact a difference existed by employing a moderate criterion for significance. As five families are represented by only half of their data, our procedure is in fact conservative.

There are two apparent large patterns in bathing volume variation. Families 0, 1, 3 and 4 had their lowest mean bathing volumes in summer while families 2 and 5 had their highest volumes at this time. For these two families, their lowest volumes were in spring. Most families with their lowest volume in summer had their highest volume in winter. Family 3 had virtually identical volumes for fall, winter and spring with only summer low while Family 0 had identical columns for fall and winter. Family 4 also had its highest volume season in winter (Fall was excluded from this analysis due to too few observations.) For Family 1, the highest mean volume, 41.339 liters, came in spring, although it is not statistically different from the winter mean of 38.789. Both are statistically different from the summer mean, 29.476.

Families 0 and 4 present the clearest evidence of adjusting to warmer temperatures with lower volumes while families 1 and 3 make an adjustment only in summer. Families 2 and 5, with their highest volumes in summer, tending downward from fall through spring, are not as easily explained. From Table IV we can see that they had longer average durations during summer even though these did not meet our criterion for statistical difference.

Regression Analysis of the Effects of Weather

The net effect of external temperature upon bathing volumes was examined directly through the use of multiple regression models, using mean daily temperature to explain the variance in volume. The time of occurrence of each event was also included in the models to control for the fact that in several families whose members have regular bathing schedules, different family members systematically take longer or shorter showers than others. We also examined models that allowed the slope of the weather variable or the intercept to change with the seasons. The models estimated are presented in Table V.

Families 0, 1, 4 and 6 exhibit a significant negative coefficient for external temperature ranging in magnitude from $-.22$ to $-.58$. Family 3 exhibits no relationship between volume and temperature for the year as a whole, but a significant, negative coefficient during the spring and summer months, $-.4831$. In general, the results suggest these families reduce the volume of hot water used in their baths or showers by about $1/4$ to $1/2$ a liter for every increase on one degree fahrenheit in the mean daily temperature. The variables "spring and summer temperature" and "fall temperature" are slope-shifting dummy variables that take the value of external temperature during the indicated season and zero otherwise.

For three of these families, the effect of the temperature coefficient is off-set during certain seasons by a positive intercept term whose consequence is to increase the constant term of that family's equation during the appropriate season. One example of this is Family 0. In their case, the equation captures the effect of a change in household composition and a resultant change in bathing habits. These models explain only a modest proportion of the total variance in bathing volumes, five to 17 percent.

We doubt that these results are solely the consequence of longer times required for water to reach bathing temperatures in winter. The difference in mean bathing durations are in many cases longer than one minute, too long for this factor to be the

TABLE V. REGRESSION COEFFICIENTS OF BATHING VOLUMES
ON EXTERNAL TEMPERATURE AND SEASON

INDEPENDENT VARIABLES	FAMILY NUMBER							
	0	1	2	3	4	5	6	7B
Time of Day	<i>-.0110</i> <i>.7904</i>	<i>-.0031</i> <i>.8811</i>	<i>-.0195</i> <i>10.98</i>	<i>.0109</i> <i>19.47</i>	<i>.0031</i> <i>2.94</i>	---	<i>-.444</i> <i>69.66</i>	---
External Temperature	<i>-.5827</i> <i>4.912</i>	<i>-.2190</i> <i>23.83</i>	<i>.0360</i> <i>.1866</i>	<i>-.0578</i> <i>.5210</i>	<i>-.2552</i> <i>25.94</i>	<i>.1743</i> <i>3.716</i>	<i>-.4074</i> <i>18.80</i>	<i>.0661</i> <i>1.738</i>
Spring and Summer Temperature	---	---	---	<i>-.4831</i> <i>16.67</i>	---	---	---	---
Fall Tempera- ture	---	---	---	---	---	<i>-1.161</i> <i>3.203</i>	---	---
Spring Intercept	---	<i>7.285</i> <i>12.17</i>	---	---	---	---	---	<i>-5.553</i> <i>7.337</i>
Spring and Summer Intercept	---	---	---	<i>25.865</i> <i>17.23</i>	---	---	---	---
Fall Intercept	<i>19.074</i> <i>3.317</i>	---	---	---	---	<i>56.283</i> <i>3.218</i>	---	---
Constant	<i>97.84</i>	<i>47.76</i>	<i>46.85</i>	<i>64.90</i>	<i>45.98</i>	<i>31.69</i>	<i>96.67</i>	<i>7.31</i>
R ²	<i>.1767</i>	<i>.0513</i>	<i>.0303</i>	<i>.0823</i>	<i>.0642</i>	<i>.0153</i>	<i>.1357</i>	<i>.0284</i>
Overall F	<i>3.434</i>	<i>13.779</i>	<i>5.631</i>	<i>17.340</i>	<i>13.524</i>	<i>2.043</i>	<i>41.297</i>	<i>4.279</i>
Mean Volume	<i>81.895</i>	<i>35.232</i>	<i>37.159</i>	<i>68.656</i>	<i>35.653</i>	<i>39.907</i>	<i>49.741</i>	<i>6.123</i>
n	<i>52</i>	<i>768</i>	<i>363</i>	<i>778</i>	<i>366</i>	<i>399</i>	<i>529</i>	<i>296</i>

F values printed in italics

Critical Values of F

1,40 D.F.	p = .05	4.08
1, ∞ D.F.	p = .05	3.84
	p = .01	6.64
	p = .001	10.83

only cause. Additionally, separate regressions of both duration and flow rate against temperature and time of day showed the duration models less efficient and the flow rate model equal to or greater than the efficiency of the volume models discussed here. This leads us to feel that part of the explanation must be a modification in bathing criteria not simply an adjustment to heat lost in the plumbing system during winter.

The model estimated for Family 7b is contradictory to the others with a small, positive coefficient for temperature and a negative intercept for spring. The model for Family 5 is also contradictory, with a positive coefficient for temperature throughout the year compensated by a large negative coefficient in fall and a positive fall intercept. With less than two percent of the variance explained by this model, there is little room for interpretation, except to reaffirm that Family 5 is different from the others. Interviews with Family 2 bought out the fact that Bill, who showered earlier in the day than Renee, regularly took a shorter shower. The time coefficient confirms this.

The models estimated account surprisingly well for the differences in mean volumes displayed in Table III. For example, at the mean seasonal temperatures experienced by Family 3, 51.95 degrees in spring and 69.92 degrees in summer, the equation implies a difference in volumes of 8.73 liters, compared to the recorded means of 70.68 and 61.73 liters. The temperature coefficient for Family 1 implies a difference of 9.424 liters at winter and summer means of 28 and 71 degrees. The difference in these means in Table III is 9.3123.

The equations for five families were used to predict the volume of a bath taken at noon across a range of temperatures and plotted in Figure 1. Because of the nature of their equation, only Family 3 shows a curvilinear response to temperature. Families 0 and 1 are represented by step functions. Mean daily temperatures range in the upper 30s to low 40s at the onset of spring in the study region and at the end of fall. Fall mean temperatures would not exceed 70 degrees.

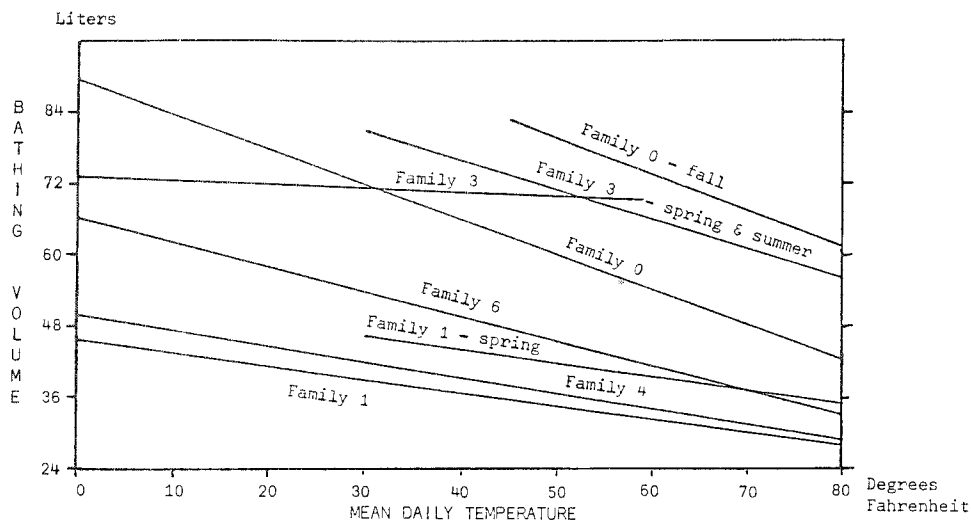


Figure 1. Bathing volume by daily temperature.

SUMMARY

The nine families studied exhibited shifts in the relative frequency of different types of hot water uses from season to season that were of moderate size and statistically significant. Several families showed large, positive percentage differences in the relative frequency of bathing events (30 to 100%) from winter to summer, others showed negative differences of more modest proportions and some showed none at all. Several families also showed large proportionate increases in small, unallocated events in the summer time. While the overall effect of seasonal variation was to increase the incidence of high volume uses during the warmer months (bathing and laundry) this was partially compensated in some cases by lower average volumes.

Eight of nine families exhibited a statistically significant difference in the mean volume of at least one usage from season to season. Four families showed significant differences in the volumes of two uses and one family in three. Four families had their lowest mean bathing volumes in summer while two families had their highest volumes at this time.

For five families, regression models employing the mean external temperature as the independent variable explained five to 17 percent of the total variation in annual bathing volumes. The coefficients for temperature implied a decrease of .22 to .58 liters for every one degree increase in the ambient temperature. The size of the coefficient was sufficient to account for nearly all of the observed differences in seasonal mean volumes.

Some of the sources of variation in a single family's usage from season to season are surely the same as those responsible for variation in usage between families: family values and behavior patterns, family occupations, changes in family size and composition. Families whose members use community facilities such as pools or spas could show marked variation in frequency of bathing and hair washing as the schedules of different members change. This is also true for families whose children participate in school athletics and utilize school showers during the season of their sport. Farm families such as Family 6 in this study may be engaged in much "dirty work" in some seasons, requiring more hot water for laundry or bathing. More outdoor activities in warmer weather means increased need to wash bodies and clothes. The differences in laundry volumes found in this study are most probably the result of changes in the washing machine setting of the wash and rinse cycles. The impulse to do this may have come from factors already mentioned or from changes in family size and composition. The birth of a baby, children going away to camp or returning from college, change in a spouse, all of these can be the source of seasonal variations in the way we use hot water in our homes.

The high degree of seasonal variability in hot water usage and the strong relationship of bathing volumes to weather suggest that further detailed study of seasonal patterns among larger samples would be rewarding. Energy requirements for water heating are a major concern of utility planners. While these requirements vary primarily due to differences in ground water temperature from season to season, our findings suggest that substantial variation of volumes results from habits or preferences of water consumers. Whether any of this can be influenced by educational

or policy measures is another question, but greater understanding of the behavioral determinants of variability is certainly desirable.

FOOTNOTES

1. Our research is part of the MSU Family Energy Project in the Institute for Family and Child Study, College of Human Ecology. This work is supported by the Michigan Agricultural Experiment Station (Project 3152, Gladhart and Morrison, Principal Investigators). The data were collected as part of work supported by grants from the National Science Foundation (BNS 82-10088, Kempton and Keith, Principal Investigators) and the Kellogg Biological Station Small Farms Project. This is Michigan Agricultural Experiment Station Journal Article No. 12040.

2. Restricted access to some bathrooms necessitated a single probe for bathroom sink and tub in three houses so bathing and sink use are distinguished using a 15 liter cutoff. Based on an analysis of the water use in four houses with separately monitored bathroom uses, bathing is considered to be 15 liters and above, bathroom sink use less than 15 liter. At a fifteen liter cutoff, showers are incorrectly attributed to the sink only for a few of the quickest showers (seen only in house 2), and sink use is misattributed to the shower only for rare long uses such as prolonged hair washing (Kempton, 1984).

3. We sampled the data from the larger family files to reduce it to manageable proportions by selecting events with even numbered Julian days. After this procedure the files of five families ranged from 3000 to 6000 events, one family had 11,000 and another family 21,000 events; two families had 2000 or fewer. We next discarded approximately two thirds of the kitchen sink events of each family by retaining only those events that began on a minute that ended in three of the ten digits, 0 through 9.

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