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DOMESTIC HOT WATER CONSUMPTION IN FOUR LOW-INCOME APARTMENT BUILDINGS

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DOMESTIC HOT WATER CONSUMPTION IN FOUR LOW-INCOME APARTMENT BUILDINGS*

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ABSTRACT

Domestic hot water consumption is a major source of energy use in multifamily buildings. In contrast to space heating energy consumption, in which behavioral factors compete with the effect of climate, domestic hot water consumption is highly dependent on behavior. Consequently, knowledge of usage patterns is useful in understanding domestic hot water consumption, whether for calculating baseline usage or for estimating retrofit performance.

We investigated domestic hot water consumption in four apartment buildings (a total of 48 units) managed by the San Francisco Public Housing Authority. In each of the buildings, we monitored the performance of the domestic hot water system for six months, and interviewed the residents about their hot water usage patterns. We found the shape of the measured profiles of daily domestic hot water consumption to be different from profiles published in the literature. We constructed a model of household water consumption based on reported behavior, and found occupant-reported water consuming behavior to correspond well with measured data: building differences ranged from -19% (the model underpredicts) to 12% (the model overpredicts), and the average difference was approximately 12%. We found educational status to be the only significant sociodemographic predictor of estimated household hot water consumption.

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INTRODUCTION

In this paper, we examine domestic hot water consumption in four low-income apartment (multifamily) buildings. We have chosen this topic for several reasons. First, hot water consumption represents a significant use of energy in multifamily buildings: approximately 30% of national multifamily energy use is for domestic hot water consumption (in comparison to 15% in single-family houses).* This percentage is greater in cases where space heating needs are smaller—for example, in mild climates, and in new, thermally-efficient buildings (U.S. Department of Energy, 1985). Second, while behavioral factors compete with the effect of climate in driving space heating energy consumption, domestic hot water consumption is highly dependent on behavior. Hot water consumption is often influenced by cultural and social norms: American households use seven times the amount of hot water used by households in some industrial European countries (Schipper, 1982). In addition, in apartment buildings where hot water is typically master-metered, occupants have no economic incentive to conserve, and, therefore, hot water consumption can be relatively large as well as idiosyncratic. For example, in France, consumption of hot water in apartments with master metering may be as much as 50% larger than consumption in apartments with individual metering (Compagnie Generale des Eaux, 1970). Similar numbers have been observed in West Germany (Coe, 1978).

And third, knowledge of usage patterns is important in understanding domestic hot water consumption, whether for baseline usage or for estimating retrofit performance. There is currently very little information on how much energy is used for particular functions (e.g., heating, cooling, domestic hot water, cooking, and lighting), and there has been almost no research on the end uses of energy in multifamily buildings.** Consequently, it is difficult to optimize the selection of retrofits in multifamily buildings. End-use information is especially important because the potential for saving energy in multifamily buildings is large: retrofit activity in the multifamily sector could save 1.0 quad of energy per year by the year 2000 (Office of Technology Assessment, 1982).

* Approximately 22 percent of the energy consumed in residential buildings is used in multifamily buildings (1.89 quads) (U.S. Department of Energy, 1985).

** A recent review of domestic hot water energy use examined fifteen monitored buildings, only two of which were multifamily buildings (Usibelli, 1984).

In order to look more closely at patterns of hot water consumption in apartment buildings (and to evaluate the performance of an active solar retrofit), we investigated domestic hot water consumption in four buildings (a total of 48 units) managed by the San Francisco Public Housing Authority. In each of these buildings, we monitored the performance of the domestic hot water system from four to six months, and we interviewed the residents about their hot water usage patterns.

SITE DESCRIPTION AND TENANT PROFILE

The study site for our investigation of domestic hot water use was Holly Courts, California's first public housing project (1939), located in south-central San Francisco, and managed by the San Francisco Public Housing Authority. Holly Courts contains 118 apartments that are located in ten two-story, bungalow-style buildings. The project has 48 one-bedroom units, 60 two-bedroom, and 10 three-bedroom units, housing over 350 residents. The average apartment size is 794 ft^2. While the tenants are billed directly for their gas usage for space heating and cooking and for electricity, gas for heating the domestic hot water is master-metered and paid by the Housing Authority. Average monthly domestic hot water gas consumption per unit is about 32 therms, larger than the average monthly gas use of 21 therms for space heating and cooking.

Each building has an independent, solar-assisted domestic hot water system located in a basement mechanical room. The original domestic hot water system consisted of a central gas-fired boiler connected to a 500 gallon storage tank and a pumped loop distribution system. The active domestic hot water solar system, which was installed three months before this study began, was designed to provide pre-heated water to the original gas-fired boiler equipment.

Three of the gas-fired boilers had input ratings of 280,000 Btu/hr, with control setpoints adjusted to provide continuous pumped loop operation. The fourth boiler had an input rating of 420,000 Btu/hr, with a control system that provided pumped loop operation only during boiler burner operation. The larger rating of the fourth boiler was due to equipment availability at the time of the previous boiler's failure and not because of a higher domestic hot water demand in that building. The boilers operated an average of 15-20% of the time. The boiler combustion efficiency was 60-70%. Over a six-month period, the average hot water delivery temperature was 137 ^{o}F (58 ^{o}C) with a range in the four buildings from 132 to 144 ^{o}F (56 to 62 ^{o}C).

Because Holly Courts is operated by the Housing Authority, the tenants are all low-income. The residents in these buildings are, in general, unmarried, female, about 45 years old, and have less than high school education (Tables I and II). Almost 40% of the sample is black, 32% are white, and 25% Hispanic. Over one-half the sample are unemployed or retired with only 12% working full-time, typically in a service occupation. In general, the population is stable with relatively little turnover in household composition from the previous year and with relatively long tenancy in the public housing complex.

METHODS

We first conducted an extensive review of the hot water usage literature to compile data on personal and household hot water consumption, appliance hot water consumption, sociodemographic correlates of hot water consumption, and the temporal pattern of hot water use.* The data obtained from this review provided the basis for the assumptions used in our hot water model (discussed below) and for the comparisons of our measurements with those reported by others.

Automatic data acquisition equipment was installed in four of the ten buildings at Holly Courts during March and April of 1985. Approximately thirteen sensors were installed in each building to monitor hot water consumption, delivery temperatures, supply temperatures, boiler operation, and solar system operation.

The domestic hot water system was monitored using a data acquisition system installed in each building's mechanical room. The system is a programmable stand-alone modular system that was designed to operate unattended in the mechanical rooms. All of the sensors were scanned every 15 seconds, with time integrated hourly values stored in memory. The stored data was transferred to LBL by telephone modem on a weekly schedule.

To minimize domestic hot water service interruptions, all water temperature measurements were conducted using pipe surface mounted and insulated thermocouples. A positive displacement water flow meter was installed to measure the total building hot water consumption. It was not possible to monitor individual apartment hot water consumption due to the physical layout.

*This compilation is available from the authors.

We also conducted a survey of the tenants of Holly Courts in order to understand daily domestic hot water use profiles, and compare tenant-reported hot water usage with actual (measured) hot water usage. The survey was conducted in May of 1985, five months after the solar retrofits were installed. Interviews were completed at 42 of the 48 units (88% response rate) in the four buildings being monitored. The interviews were conducted in English and Spanish and took approximately 20 minutes each. Residents were asked about their daily hot water use in the bathroom and kitchen, satisfaction with their hot water, awareness of the solar system, and their attitudes towards conservation.*

COMPARISON OF ESTIMATED AND ACTUAL HOT WATER USE

We constructed a simple, additive model of household (domestic) hot water use using our survey results and national averages to estimate daily consumption (Table III). The quantity of household hot water consumption was equal to the sum of the following activities: bathing (including showers), sink use, clothes washing, and dishwashing. Based on our survey results and the literature review mentioned previously, we assumed several conditions for a given household, as presented in Table III. For instance, the daily amount of hot water used for showering was equal to 2.5 gallons of hot water per minute used during a shower times the average length of a shower times the total number of showers taken per day. As another example, the daily amount of hot water used in sink use (e.g., washing hands) was equal to 3 gallons of hot water per person times the number of people in the household.

Using this model, we estimated daily household water consumption for each unit and averaged consumption for all the units in each building we monitored (Table IV). We also calculated total building hot water usage by multiplying household averages by the number of units in each building. We compared estimated usage with measured usage, and found the differences to be relatively small: the range was from -19% (the model underpredicts) to 12% (the model overpredicts), and the average difference was approximately 12% for the four buildings. It is important to note that measured usage was adjusted to take into account the amount of leakage occurring in these buildings (as reflected in late night-early morning hot water consumption). "Leakiness" is reported at

*Copies of the questionnaire are available from the authors.

the bottom of Table IV, and it is interesting to note that the model is less accurate where the most leaking occurs. Accordingly, we suspect that the model's estimates would be more accurate when these leaks are fixed as well as when other water uses are included in the model (e.g., many people in the survey noted they use hot water to mop the floors).

The average measured household consumption, 74 gallons/day, in this project is slightly higher than any of the average values reported in the literature (which average around 65-70 gallons/day). The differences might be because those values are reported for single-family dwellings, or because leakage has not been completely accounted for. In addition, in this case, the Housing Authority pays for the hot water gas consumption, so we would expect higher usage for a "free" commodity.

PROFILE OF CONSUMPTION PATTERNS

Hot water consumption varies with the time of day, the day of the week, and the month of the year. A typical daily profile at Holly Courts shows peaks in the morning and evening indicating household bathing practices, peaks around meal times for cooking and dishwashing, and scattered peaks throughout the day for clothes washing. Figure 1 shows the hourly variation in domestic hot water consumption for a one week period in Building D, a nine-unit building. While the average daily consumption in the building varies between 30 and 40 gallons per hour, peak events exceed 150 gallons per hour.

Standard consumption profiles are presented in Figure 2 and are widely used for sizing domestic hot water systems as well as for estimating retrofit performance. Recently, additional profiles have been published that reflect different household types (Ontario Hydro, 1984). However, there is almost no information on hot water usage patterns in multifamily buildings.

We observed different usage patterns on weekdays and weekends; hence, we constructed separate profiles for these periods. Figure 3 shows average weekday and weekend profiles (based on 40 and 20 days respectively) for Building F, a fifteen-unit building. The weekend profile shows a very large peak during the middle of the day while the weekday profile is more evenly spread out with two distinctive, smaller peaks in the morning and early evening. The weekday profile does not resemble the profiles reported in the literature and may be more representative of homes that are occupied during the entire day (i.e., there is constant use).

What is curious about both profiles is the constant hot water consumption between midnight and 5:00 a.m., roughly 20 gallons per hour. It is speculated that this consumption represents leaks from faucets and taps in the apartments. This continuous loss of hot water down the bathroom and kitchen drains represents 20 - 30% of the total hot water consumption, amounting to thousands of dollars a year for the 118-unit complex.

The survey data were used to construct an end-use breakdown for the daily profiles by combining their reported frequency of use with standard usage factors. The largest daily hot water use (43% of total) is for bathing and showering, which is split evenly between the morning and evening periods. Clothes washing is the next largest user (30%), and occurs during the morning, afternoon, and evening periods, with the greatest usage in the morning. The third main hot water use is dishwashing (26%), and follows the same pattern as clothes washing.

The reported data on time and frequency of hot water use were combined to form an average daily profile, which is compared to the measured average daily profile in Fig. 4. (The average measured nightime flow was added to the reported data to account for the leaking faucets.) The profiles are remarkably close, giving support to the reliability of the occupant-reported data.

CORRELATES OF ESTIMATED HOT WATER CONSUMPTION

In contrast to the previous analysis of hot water consumption at the building level, we also examined whether there were any significant correlates of estimated individual unit hot water consumption which might account for variation in usage. We first estimated household hot water consumption based on the regression model described previously. We then regressed estimated household hot water use on the following household characteristics:

1. Number of years lived at Holly Court
2. Number of years lived in apartment
3. Age of respondent
4. Education of respondent
5. Households with/without children (5 yrs. old or less)
6. Special uses of hot water
7. Other uses of hot water

8. Reported presence of leaky faucet
9. Satisfaction with hot water temperature
10. Hot water conservation index

We found education to be the only significant variable (at the .01 significance level) of household hot water use. Thus, the more education the respondent had, the more hot water used in the household. Because education is often highly correlated with income, it is likely that those people with higher education had more water using appliances. This was partially true in our sample: education was significantly related (.05 level) to clothes washers (but not to dishwashers). There was no significant correlation of hot water consumption to hot water delivery temperature, but that is not unexpected. Only 43% of the total hot water use is sensitive to water temperature (bathing and showering), with the remaining usage a function of appliance set-points (clothes and dishwashers).

CONCLUSIONS

Very little data exist on end-use energy consumption in multifamily buildings, especially, low-income households. This investigation has shown that average household hot water consumption in public housing, after accounting for leaks, is slightly greater than average consumption in single-family dwellings. We attribute most of this difference to the economic circumstances: the Housing Authority pays for the gas for heating the water.

We were able to model hot water consumption for low-income apartment buildings with moderate success (12% average error). Deviations from our estimates are due largely to leaks in buildings rather than to the behavior of the tenants. Estimated profiles of hot water consumption in these buildings compared very well with profiles from actual data. However, the hot water profiles in these buildings were somewhat different from those reported in the literature. The use of this very simplified model may alleviate the need for detailed monitoring in the long run, although, in the short run, the need for this kind of data collection is needed to verify the results of our modelling in other kinds of buildings.

ACKNOWLEDGEMENTS

We would like to acknowledge the help of the following people: Charles Goldman for analyzing the consumption data and organizing it in such a way that we could make sense of it, and for reviewing the paper; Ron Atkielski and JoAnn Cortez at the Housing Authority of San Francisco for their assistance and cooperation; Jeff Reed of the Pacific Gas and Electric Company for providing utility data; Steve Gold and Kathy Greely for their assistance with the survey; Mike Rothkopf for his review comments; Les Lewicki for installation of the monitoring equipment; and the residents of Holly Courts for their time and cooperation.

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Table I. Holly Courts demographics.

	Mean	Standard Deviation	Range	Sample Size
Number of years lived in Holly Courts	9.5	6.7	1-28	42
Number of years lived in same apt.	8.2	6.6	1-23	42
Age of respondent (years)	45.5	16.7	21-82	40
Education of tenant (years)	10.6	4.0	0-17	40
Avg. household size (people)	2.6	1.6	1-9	42

Table II. Holly Courts occupant profile.

Sex of respondent (N=42)	7.1% 92.9%	Male Female
Ethnicity of respondent (N=41)	4.9% 39.0% 31.7% 24.4%	Asian American Black Caucasian Hispanic
Marital status of respondent (N=42)	40.5% 7.1% 28.6% 23.8%	Single Married Separated Other
Employment status of respondent (N=41)	12.2% 22.2% 14.6% 48.8%	Working full time Working part time Retired Unemployed
Occupational status of respondent (N=11)	18.2% 9.1% 72.7%	Professional Craft Service

Table III. Hot water use model.

Shower	2.5 gallons/minute X Minutes/shower* X Total showers/day*
Bath	12.5 gallons/bath X Total baths/day*
Sink	3 gallons/person/day X Persons/household*
Clothes washing	25 gallons/load X Loads/day* Adjusted for hand washing - 3 gallons X Hand washing events/day* for people with washers* - 2 gallons X Hand washing events/day* X Persons/household* for people without washers
Dishwashing	15 gallons/day for people with dishwashers* 3 gallons/person/day X Persons/household* for people without dishwashers
HOT WATER USE = Shower + Bath + Sink + Clothes washing + Dishwashing	

*From survey.

Table IV. Comparison of estimated and measured hot water consumption.*

	Total	Bldg. D	Bldg. E	Bldg. F	Bldg. G
Estimated daily household use (gallons/household/day)	76	59	76	90	69
Estimated daily personal use (gallons/capita/day)	31	34	34	29	27
Number of units	48	9	15	15	9
Estimated total daily building use (gallons/building/day)	3642	531	1140	1350	621
Measured total daily building use (gallons/building/day)	3560	658	1018	1209	675
Difference between measured and estimated (gallons)		-127	122	93	-54
Difference between measured and estimated (percent)		-19	12	8	-8
Leakiness (percent of total gallons that leak)		11	27	24	3

*Actual consumption was measured over the period May-August 1985.

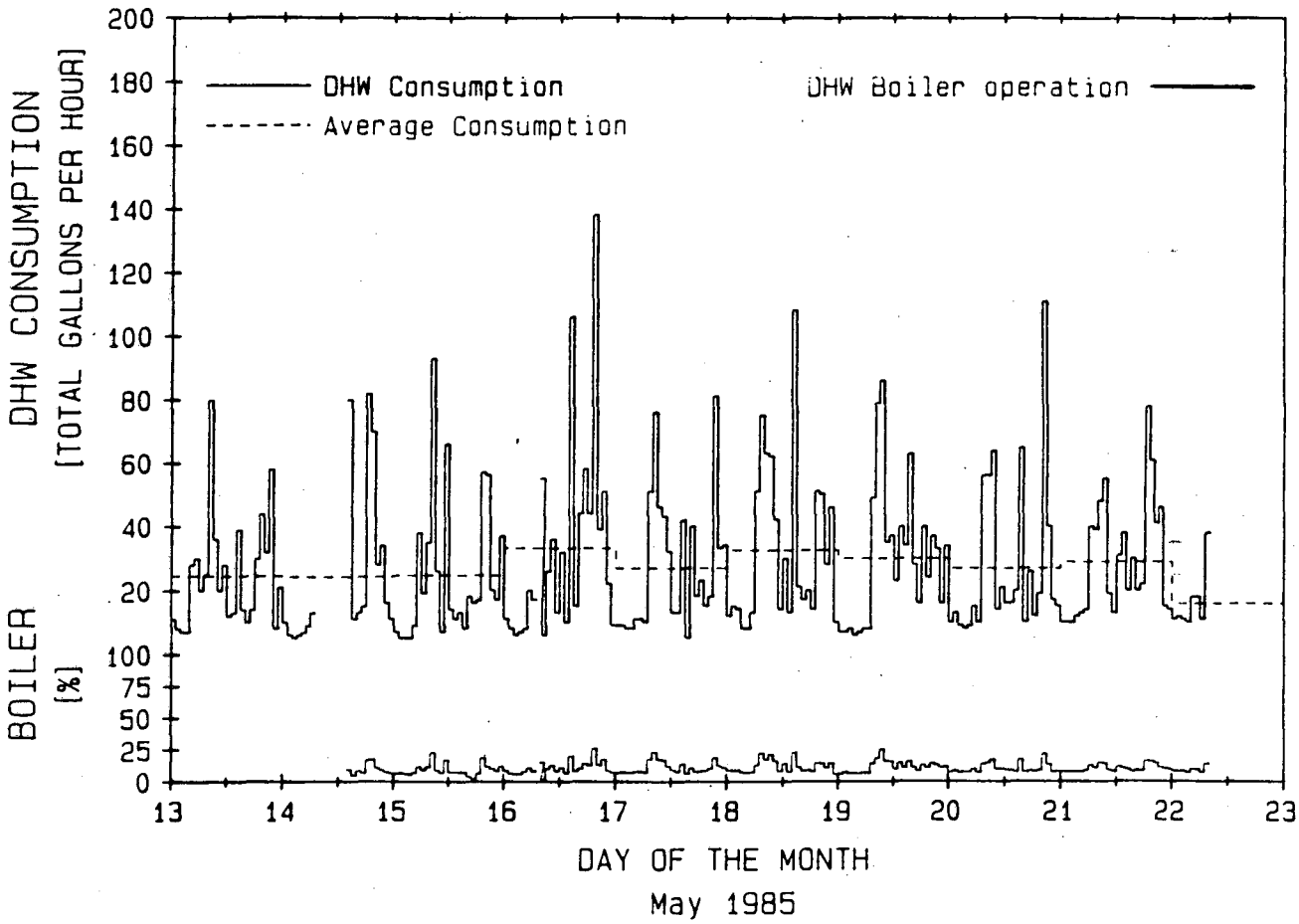

Figure 1. Domestic hot water consumption and boiler on-time for nine-unit Building D, Holly Courts, San Francisco, California, June 4-11, 1985.

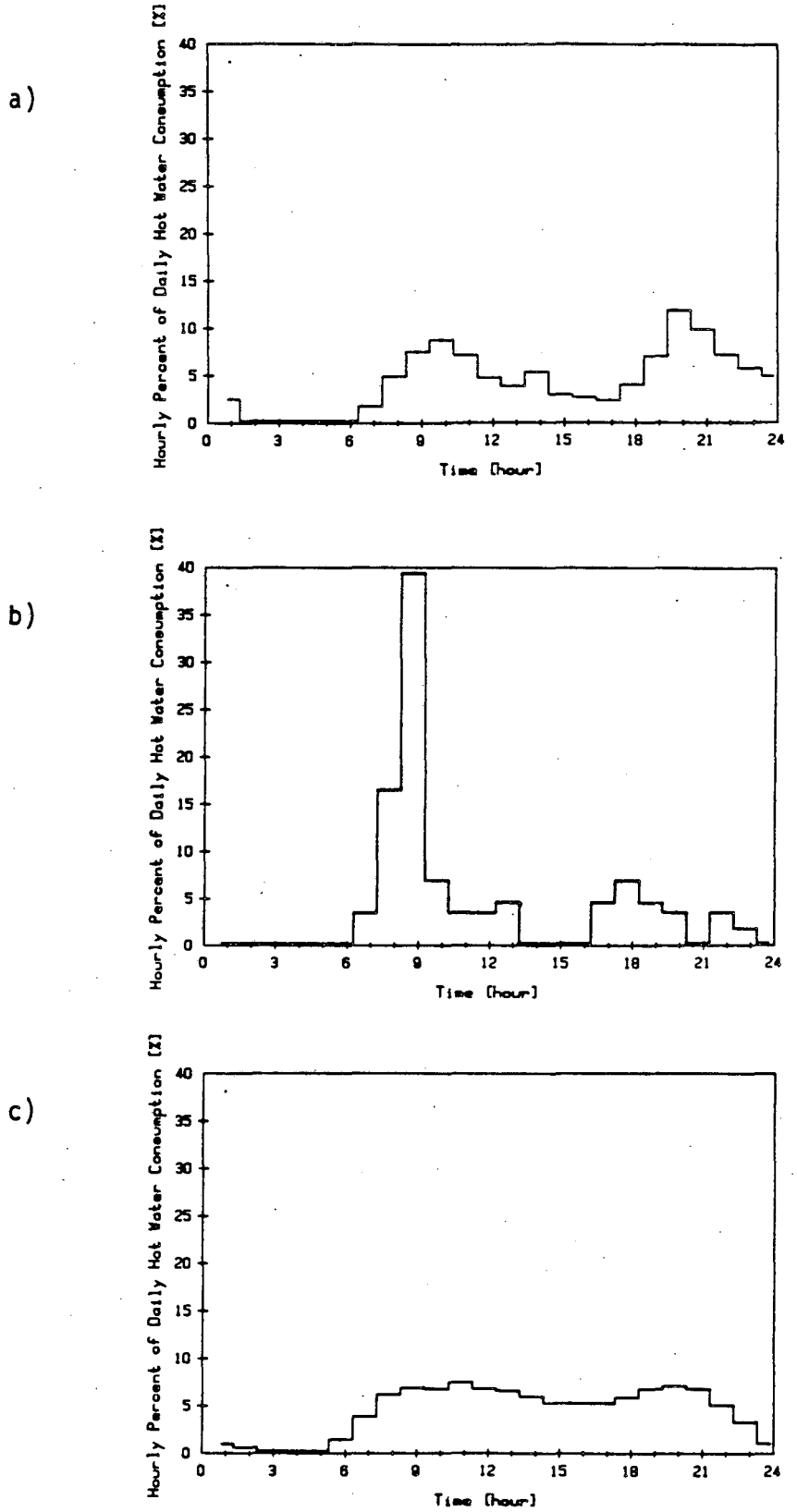

Figure 2. Comparison of domestic hot water profiles: a) RAND 1974, based on 21 New Jersey apartments, b) NSDN 1981, based on 15 single-family houses and 202 apartments (in three apartment buildings) over six-month period, and c) Holly Court 1985, based on 48 apartments (in four apartment buildings) over a six-month period. [Source for RAND and NSDN profiles: Barvir et al., 1981].

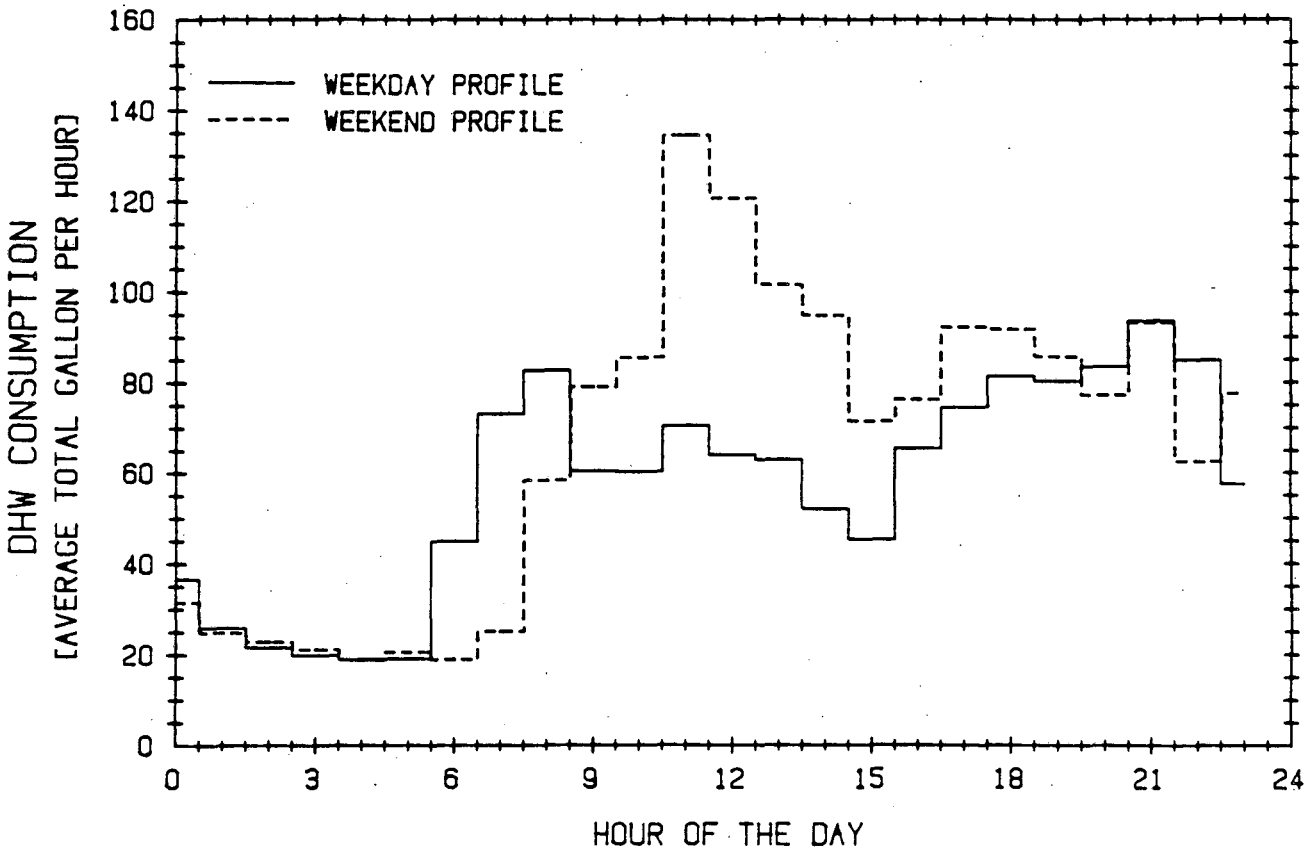

Figure 3. Average weekend and weekday domestic hot water profiles for fifteen-unit Building F, Holly Courts, San Francisco, California.

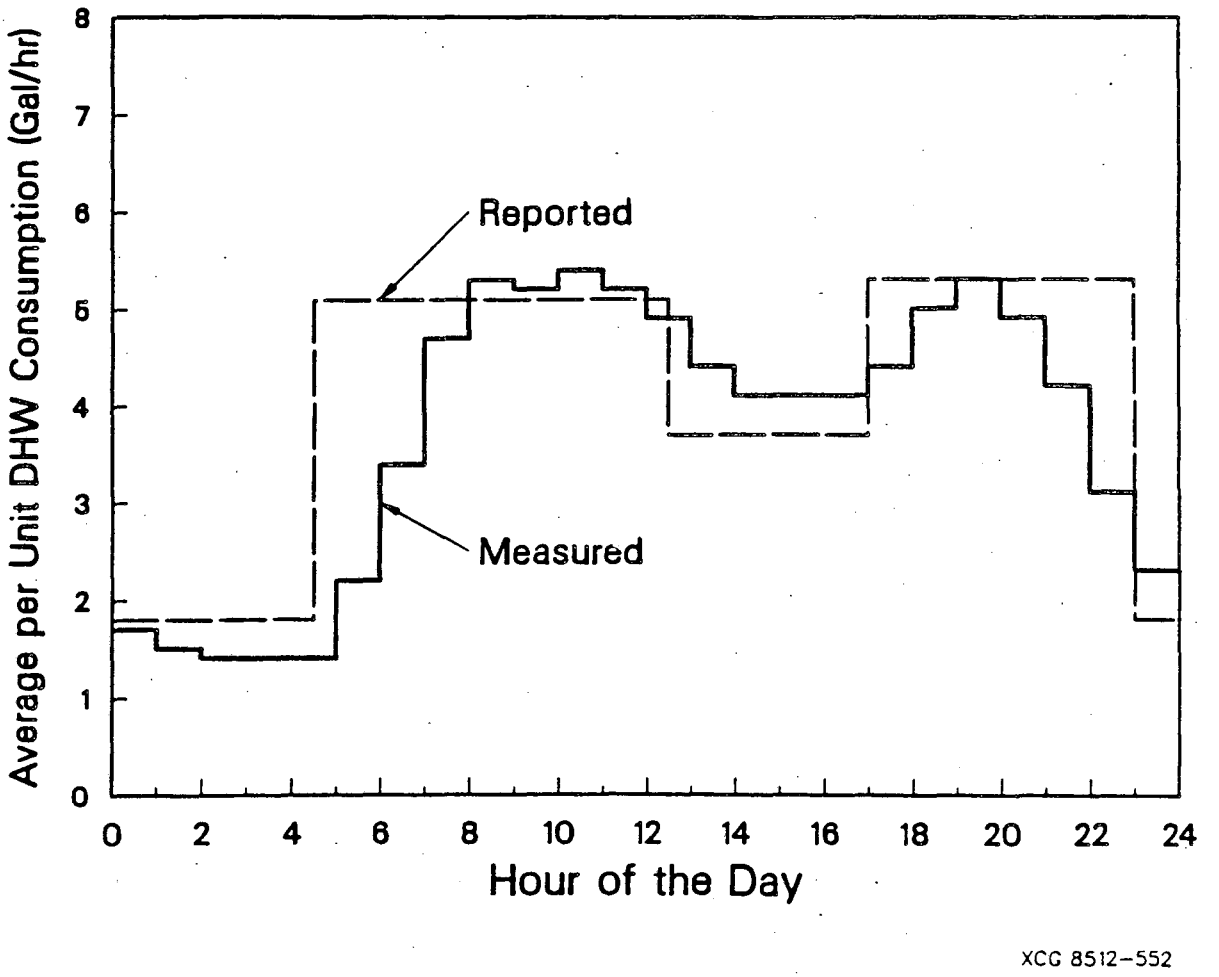

Figure 4. Reported versus measured domestic hot water use for 48 units, Holly Courts, San Francisco, California, March 21, 1985 - August 22, 1985.

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