Multi-Family Building Energy Monitoring and Analysis, Domestic Hot Water Use and System Sizing Criteria Development: A Status Report

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Under a research project sponsored by New York State Energy Research and Development Authority, instrumented monitoring of heating plants and domestic hot water (DHW) has been done in 30 New York City multi-family buildings. Data points monitored (most hourly) on all buildings were: apartment, outdoor, boiler & DHW temperatures and burner on-off times. Additional points monitored in nine upgraded buildings were: stack temperature, DHW flow *in 15-minute increments*, oil & boiler make-up water flows, and DHW temperature before and after mixing valve and on the return line. The data set collected between July 1990 and September 1991 amounts to a database of more than 100 megabytes.

The project's objectives were to develop a comprehensive base of DHW and heating system operational data to fill gaps in knowledge, and to be used in future design and specification preparation and for improved operational procedures. Key problems addressed include:

- DHW requirements in multi-family buildings are currently calculated on the basis of questionable standards. Real time DHW flows provide the foundation for sizing (broken down by occupied apartment, per capita and other demographic data) than currently exists.

- Energy audit calculations used to determine savings on conservation measures, rely upon energy bills divided between space heating and the inaccurate (DHW) figures discussed above or some 'best guess' method. Project results define figures for DHW energy use, so that more reliable/accurate savings can be calculated.

Results of the project give DHW demand patterns; seasonal variations; weekday vs. weekend consumption; consumption vs. occupancy levels; coincidence of 15 and 60 minute demand periods; and average vs. peak demand levels.

The results of this research (in progress as of this paper) are being reviewed by ASHRAE for inclusion in their upcoming revision of DHW guidelines.

Introduction

The work described in this paper reflects the analysis to date on a research work-in-progress.

With the proliferation of personal computers and modems, multi-family building managers/owners have begun to install on-line monitoring systems. Characteristically, on-line systems monitor selected variables such as internal temperature (in one or as many as ten rooms), burner on/off, and heat timing device settings. Monitoring systems are installed in connection with a heat timer controlling device, and are usually managed by a supervisor in a central management office who on a daily or other basis "calls up" each building and observes current data and past data summaries. The supervisor or the building manager visits or telephones the building superintendent if there are conditions that indicate inefficient energy use, i.e., excessive on time, overheating in the apartments, over-ride of the heat timing device. On-line monitoring systems are used by a number of residential building management firms.

The existence of such systems in commercial operation provided a significant and economical opportunity to track more data points and to analyze and summarize operational data to form what is potentially the largest multi-family building operations/energy use database in existence.

This project used existing systems in operation by a building management firm, Ralph Langsam Associates, manager of over 6500 units. The systems where upgraded with additional monitoring points to collect more detailed information on hot water use in multi-family buildings.

The research has developed a comprehensive database of heating and domestic hot water (DHW) system operational data, based on 14 months of observation, in a set of multi-family buildings which will fill gaps in knowledge and can be used in future design and specification preparation and in operational procedures. Some of the key problems addressed by data analysis include:

- DHW requirements in NYC buildings are calculated on the basis of national ASHRAE and other standards of many years standing (which have been determined inaccurate).[1] This project has measured precisely the DHW flows in the observed buildings and has produced a better base of experience for sizing and operation of DHW in multi-family buildings than existed. This is a critical need for improved specifications and performance in newly renovated buildings. (The project has additional applicability in NYC as all multi-family buildings are to metered for water consumption by 1996; initial indications are of much higher than expected water use and costs in multi-family buildings.)

- Energy audit calculations used to determine savings on energy conservation measures, rely upon energy bills that are generally divided between space heating and DHW portion based on the inaccurate figures discussed above or some other 'best guess' method. (This is the case in all audits, with the exception of those very few cases where separate DHW systems and related fuel delivery data exist.) Investment decisions are then made on payback figures presented in the audit reports. This project should result in definitive figures for DHW energy use, so that more reliable/accurate savings can be calculated.

- In principle, a boiler and its burner should be sized so that on the coldest design day it will satisfy the steam requirements of the installed radiation (plus pickup factors) by running continuously. In practice, oversizing often causes cycling on the coldest days, indicating inefficient use. The data developed in this project will contribute to sizing determinations in the future - virtually all of which currently are done on an established practice, rule-of-thumb basis.

The research objectives can be summarized as follows: (a) to develop and analyze a comprehensive set of multi-family building operational energy performance data; and (b) to develop, based on the observed data, analyses of DHW consumption demand and energy requirements, boiler sizing versus installed radiation and versus heating requirements, all to be used in specification preparation and revision.

Research Approach

Building Selection

Critical to the success of the project was the reliability of the data and the cooperation of the building management firm. It was for this reason that Langsam Associates, which had a reputation as a well run building management firm, was selected. This decision has paid enormous dividends in equipment upkeep, availability of historical building records, and access to both the building facilities and operating personnel. The building selection was made from a set of about 70 Langsam sites that had heat computers[2] installed. An effort was made to include a diversity of building sizes, income levels, ethnic backgrounds and locales. Demonstration buildings are characteristic of the older and predominant stock of the over 120,000 New York City multi-family buildings.

The buildings selected ranged in size from 17 to 103 apartments, and have either 5 or 6 above ground stories. As noted in Table 1, these buildings were constructed pre-1902 (old law) or between 1902 and 1928 (new law). All the boilers are combination heat and hot water units, steel tube boilers and (primarily) air atomizing number 4 or 6 oil burners, with DHW generated by a tankless coil. A summary of general building characteristics are shown in Table 1.

Data Collection

Instrumented monitoring of heating plants and DHW was conducted for 14 months (from July 1990 through September 1991) in 30 multi-family buildings in New York City in association with an existing system operated by Ralph Langsam Associates - building managers.

The data used to conduct this research was collected by heat computers that monitored the following data points on all buildings: internal apartment temperatures, outdoor temperature, burner on-off-times, boiler water (aquastat) temperature, and DHW temperature. The nine upgraded buildings (ID #s 1-3 & 5-10) had additional data monitoring equipment installed to record stack temperature, boiler make-up water flow, DHW flow in 15-minute increments, oil flow, DHW temperature before and after mixing valve and on the return line. These devices were polled periodically (every 15 minutes,

Table 1. Building Characteristics

Bldg. ID #	Total Apts.	Persons Per Apt.	Sq. ft./ Apt.	% Children	Public Laundry	In-Apartment % Dish-washers	In-Apartment % Clothes-washers	% Low Flow Showerheads	Fuel Type	# of Stories	Bldg. Type
1	23	1.455	900	3%	-	-	65%	-	4	5	new law
2	30	3.393	745	41%	-	-	67%	-	6	5	new law
3	34	2.688	757	31%	-	-	44%	50%	4	5	new law
5	90	2.571	558	36%	2	-	67%	-	6	5	new law
6	49	2.174	1265	10%	-	6%	31%	75%	6	6	new law
7	60	1.842	946	9%	3	40%	70%	50%	6	6	old law
9	80	1.683	768	7%	3	8%	25%	20%	6	6	old law
10	102	2.000	720	38%	-	-	26%	25%	4	6	new law
Average -		2.226	832	22%	1.0	7%	49%	28%			
Maximum -		3.393	1265	41%	3.0	40%	70%	75%			
Minimum -		1.455	558	3%	0.0	0%	25%	0%			

Table 2. Tenant Demographics

Bldg. ID #	At Home Patterns: All Work	1[a] & 1	Seniors	No Work	Family Types: Single	Couples	Family	1 Parent	Seniors	Income Levels: Public Assist.	Low Income	Middle Income	Other
1	48%	9%	43%	0%	48%	4%	4%	9%	35%	4%	0%	52%	43%
2	20%	30%	7%	43%	10%	7%	67%	17%	0%	43%	57%	0%	0%
3	0%	52%	12%	39%	6%	12%	85%	36%	12%	39%	79%	0%	0%
5	6%	17%	6%	76%	0%	27%	93%	72%	6%	23%	77%	0%	0%
6	31%	21%	21%	21%	10%	31%	31%	2%	21%	15%	42%	42%	4%
7	52%	3%	43%	5%	2%	66%	10%	0%	26%	0%	9%	95%	0%
9	41%	41%	14%	14%	14%	68%	14%	7%	7%	3%	20%	81%	4%
10	25%	0%	10%	65%	0%	50%	50%	0%	0%	50%	25%	25%	0%

(a) 1 works and 1 stays home.

hourly, or daily depending on the particular device) by the heat computer which then stored the data in memory. Via modem, Langsam staff called each building every third day to download the data onto disks that were delivered to, the investigator, Energy Management & Research Associates (EMRA). At EMRA, the data was then put through a FORTRAN data translation program which rearranges the data to an Rbase (database) readable format, as well as performing a number of preliminary calculations. The data was then loaded into a specially designed database where macros perform a second level of calculations. The Rbase environment was then used to perform specific analyses and output smaller data sets to Quattro Pro for graphical analyses and presentations.

Project monitoring examined operational conditions, which should be distinguished from monitoring building thermal characteristics, including heat loss.

Data Set

The data set covers all of the data collected by the building monitoring devices, building operational and tenant information requested from superintendents and property managers via questionnaires and interviews, and equipment and building condition data obtained through energy audits (performed by the author and colleagues).

As this is a work-in-progress, only data from July 1990 through February 1991 has been loaded into the database and analyzed as of this writing. This represents a database containing approximately 60 megabytes of an anticipated 100 megabytes of data (when all the data is fully loaded). Various tables in the database contain about 5 million data points. It is anticipated that the additional data will serve to further substantiate the findings presented here, and be used for further research into related areas.

This paper will focus on the a subset of eight of the nine buildings that had the additional monitoring installed. Building #8 (of the nine building subset) has been excluded due to anomalies in the (very unusual nocturnal) patterns of DHW use. In addition, the summer 1990 data for building #5, has been removed because of a change-over in operation from the boiler serving one 45 unit building, to serving two sister buildings (with a total of 90 apartments).

Data Analysis

Throughout the data several relationships have been examined: daily and seasonal variations in DHW demand patterns; consumption vs. occupancy levels; frequency and coincidence of 15 and 60 minute DHW demand periods; average consumption vs. peak demand levels; and boiler on-and-off cycle lengths.

A focal point for this research has been the examination of DHW consumption on a per capita basis. Historically, published data for DHW consumption was presented on a per apartment basis. While this may have been the most convenient way to review and present the data in the past, the current figures suggest that per capita analyses may be an important parameter. The per capita denominator has been chosen on the basis that it is people that consume water, not apartments or square footage, ... The per capita data can be converted back to per apartment figures by use of actual or estimated populations.

The first step to providing an accurate accounting of DHW use was to determine occupancy levels. Monthly vacancies compiled from Langsam's rent roll records were used to calculate the number of occupied apartments for all buildings. Data collection included fractions, which were used to represent occasions where leases ran into 1/2 or 1/3 of a month. Review of this data revealed that there was a variance in the occupancy of the different buildings over the time period investigated. Monthly occupancy rates in the buildings ranged from as low as 85 percent up to 100 percent. Overall, the average occupancy for all of the buildings was 95 percent. Vacancy figures have been used to eliminate DHW use variances due to differing occupancy levels, and to calculate the consumption of DHW per occupied apartment. The next step was to take a snapshot of how many occupants were in each apartment and determine the number of persons per apartment for each building. This was done with the assistance of the superintendents. These figures were then used as the denominator in all subsequent computations.

In order to more thoroughly analyze the data, monthly summaries were produced. These monthly figures were then used to create consumption levels and patterns for the summer (July and August), fall (October and November) and winter (December, January, and February) periods.

Findings

The number of persons per apartment (Table 1) in the building set ranged from 1.5 to 3.4 people/apt, with an average of 2.2 people/apt. Using a per occupied apartment analysis the consumption levels differed by 3.8 fold from a low of 52.57 to a high of 198.87 gallons/occupied apartment, the average being 115.46. When population density is considered the usage ranges from 31.23 to 76.44 gallons per capita, with an average of 51.04 gal/capita, a difference of 2.4 fold. More detailed demographic data will be discussed later.

One of the most distinct findings is the seasonal variation of DHW consumption. Figure 1 clearly illustrates that consumption levels rise from summer to fall to winter. This was true in all but one building. The average consumption of 44.14 gallons of DHW per capita (gal/capita) in the summer rose by 14% to 50.38 gal/capita in the fall and then by 13% to 57.01 gal/capita during the winter period.

A weekday vs. weekend comparison of gallons of DHW consumed by each building (Figure 2) reveals that there is generally a slightly higher level of consumption on weekends (Saturday and Sunday) than on weekdays (Monday through Friday). A more detailed analysis, not shown here, reveals that this is true in all but a few individual building cases during the summer period. For the 8 month period of data, the average weekend day consumption of 54.71 gal/capita is 7.5% greater than the average weekday day level of 50.89 gal/capita.

Much work has gone into the 15 minute DHW flow meter data analysis to produce demand-flow curves (see Figures 3 & 4). There is a distinct difference between weekday and weekend DHW consumption patterns. Weekdays have a minimal overnight usage, then a morning peak, followed by lower afternoon demand and then an evening or night-time peak. Weekends have just one major peak which

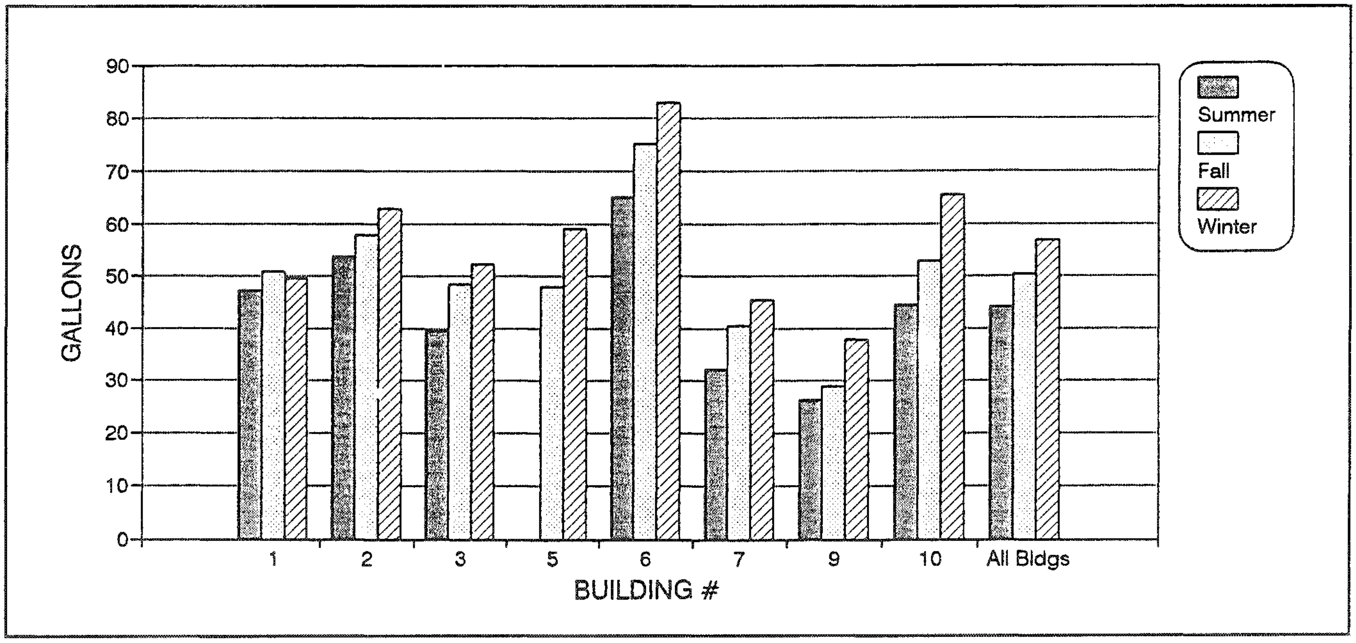

Figure 1. Seasonal Comparison of DHW Consumption (Average Gallons Per Capita Per Day)

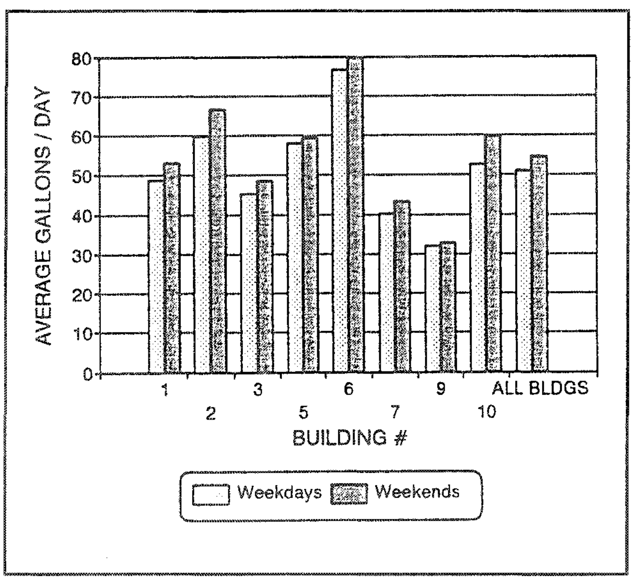

Figure 2. Weekday vs. Weekend Consumption (Gallons Per Capita: 7/90 - 2/91)

begins later AM and continues on until around 1:00 to 2:00 PM, the usage then tapers off fairly evenly through the rest of the day. Examination of the composite weekday and weekend graphs illustrates that the weekend peak is greater, at 1.05 gallons per capita, than any of the weekday peaks, at 0.84 gal/capita.

In examining the composite weekday curve (Figure 3), two morning peaks can be observed, the first between 6:00 & 8:00 AM and the second between 9:30 AM & noon. By examining individual buildings, it is possible to observe that particular sites fall into one of these two peaks. Some general knowledge of the tenant populations (Tables 1 and 2) may serve to explain this difference. The buildings with occurrence of large numbers of either working tenants and middle income populations appearing as the early morning peak; and buildings with a large percentage of children possibly falling into the later morning peak (especially so during the summer period).

Building # 1 (Figure 5) is an example of a working class building with a large 6:00 - 8:00 AM spike, low mid-day use, and an 'after dinner - wash the dishes' peak at about 7:00 PM. Building # 3 (Figure 6) is an example of the later morning peak 10:00 - noon peak. There are, of course, buildings with a mix of these two patterns. This area requires more research before any concrete conclusions can be drawn.

Figures 7 and 8 clearly illustrate the seasonal variation in both the usage patterns and consumption levels between summer, fall and winter. Note that the highest peaking level occurs during winter weekends.

While flow curves show us the general usage patterns of a building, peaking times and flows can be used to more closely identify demands on/requirements of the boiler. Maximum 15 minute demand times (Figures 9 and 10) occur most often at 7:45 AM and 7:00, 7:15, 8:45 & 9:15 PM on weekdays and 10:45 & 11:15 AM & 6:15 PM on

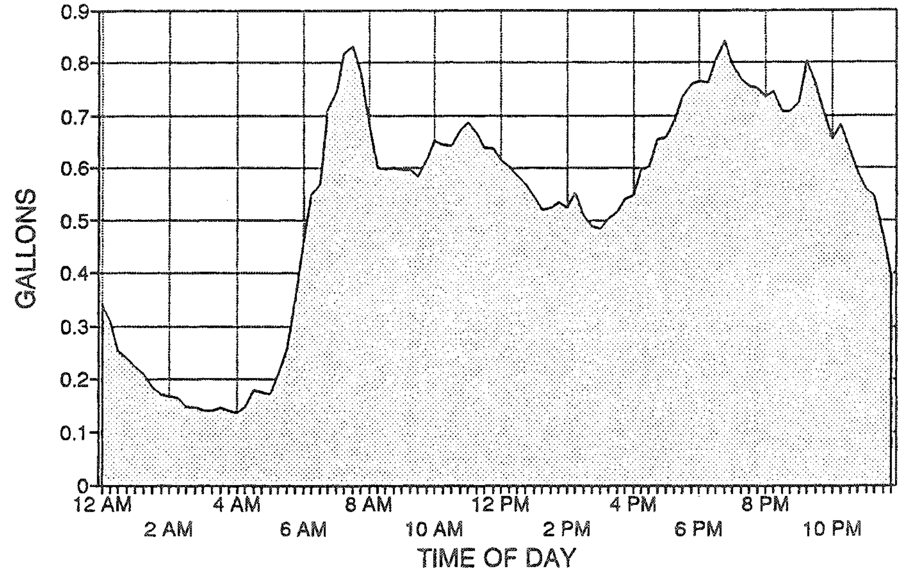

Figure 3. Weekday Consumption of DHW (Gallons Per Capita, Composite 7/90 - 2/91)

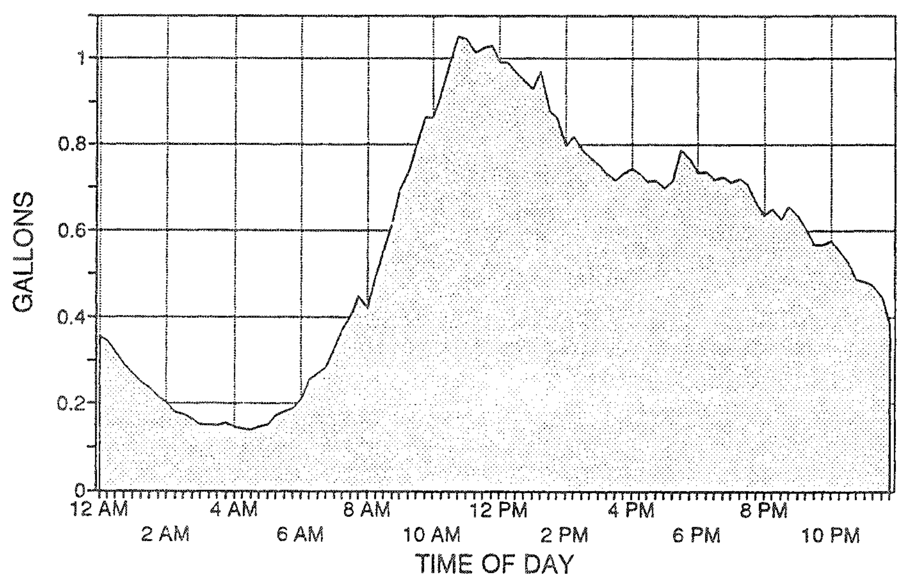

Figure 4. Weekend Consumption of DHW (Gallons Per Capita, Composite 7/90 - 2/91)

weekends. This can then be compared to the maximum 60 minute demand periods (Figures 11 and 12). *(Note: the times listed on the frequency graphs represent the 15 or 60 minute periods ending at XX:XX.)* There is an exact coincidence of 60 and 15 minute maximum demand times on the weekends. During weekdays the mornings have a close match of 60 and 15 minute demands, and there is an exact match during the evening periods. The most frequent minimum 60 minute consumption periods occurred at 4:00 AM on both weekdays and weekends. This

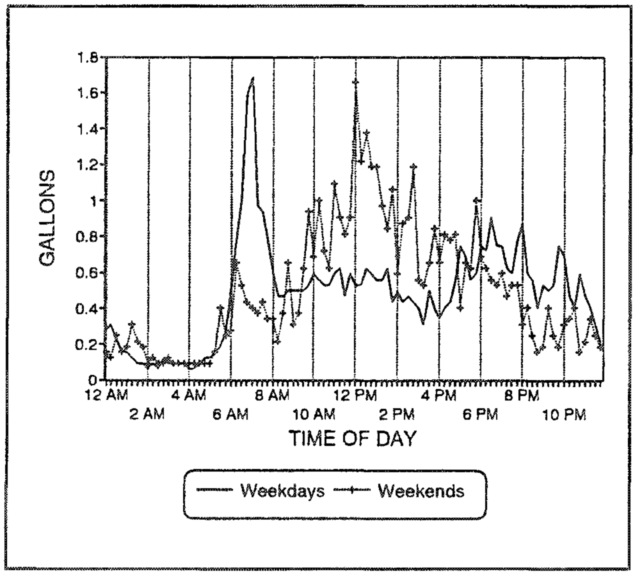

Figure 5. Weekday vs. Weekend Consumption - Gallons Per Capita - BLDG #1 (Summer)

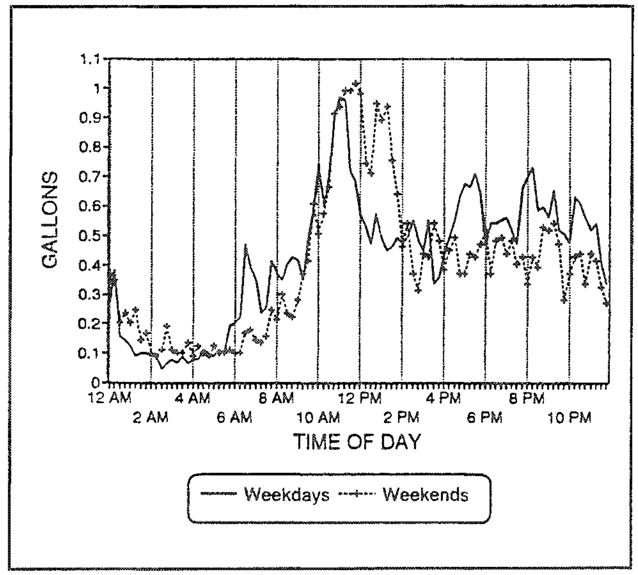

Figure 6. Weekday vs. Weekend Consumption - Gallons Per Capita - BLDG #3 (Summer)

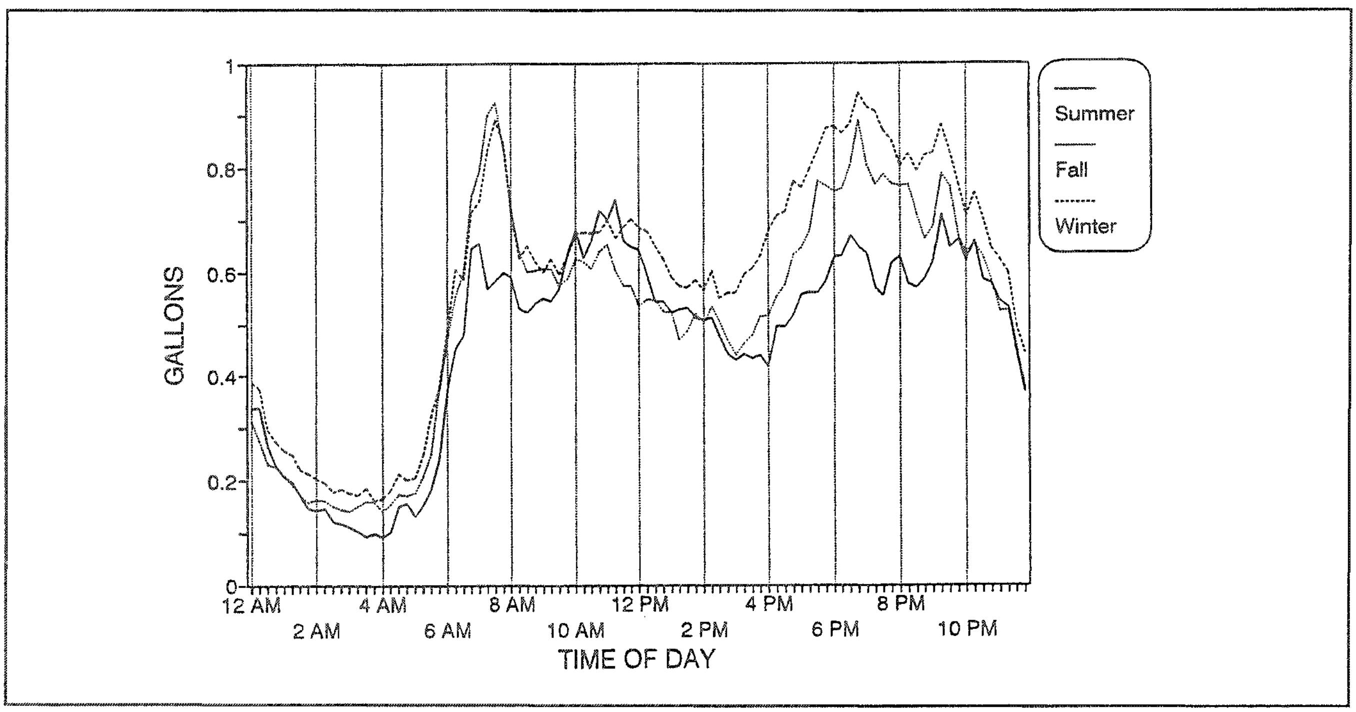

Figure 7. Seasonal Variations, Weekday Consumption (Gal Per Capita, Composite)

demand period data will be used when evaluating DHW system sizing and storage options. It will also be used when comparing the coincidence of DHW and heating demands on the boiler.

Fifteen and 60 minute maximum demand and hourly average consumption figures were compiled to examine peak needs in contrast to total volume. This type of analysis will be useful in setting out new system design

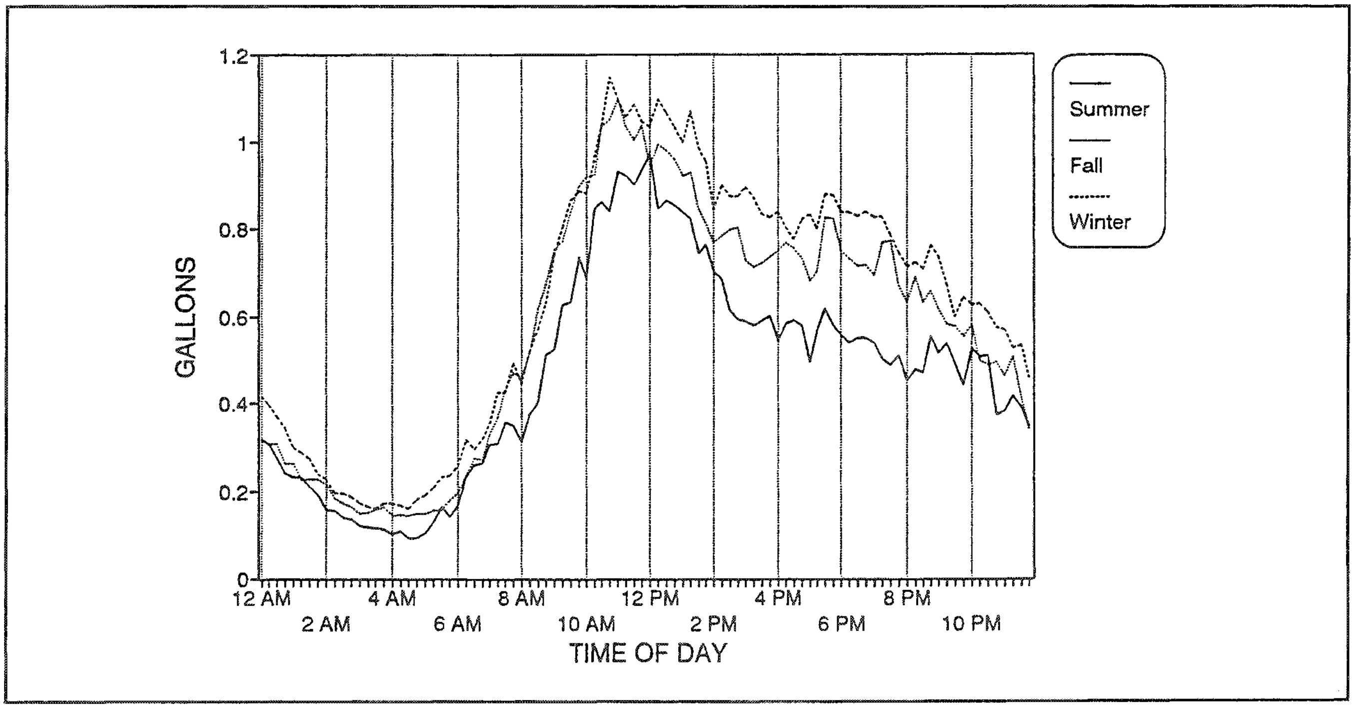

Figure 8. Seasonal Variations, Weekend Consumption (Gal Per Capita, Composite)

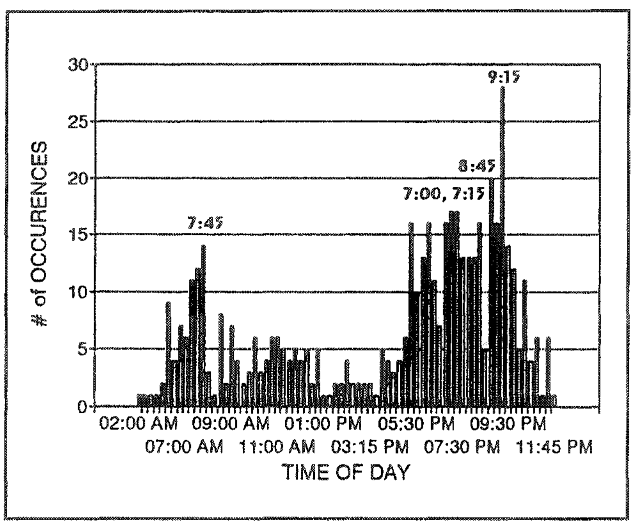

Figure 9. Maximum 15 Minute Times Frequency - Weekday - All Bldgs. (Winter)

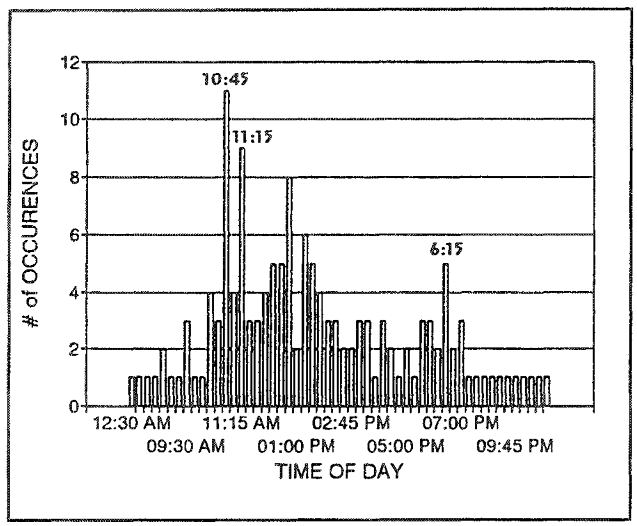

Figure 10. Maximum 15 Minute Times Frequency - Weekend - All Bldgs. (Winter)

and sizing parameters and evaluating a mix of instantaneous generation and storage options. An examination of Table 3 reveals that in comparison to the use in a maximum 60 minute period the average hour consumption is only 41% of that peak; thus suggesting that there may be the possibility of generating storage capacity to meet that peak during many other (average or below average demand) hours of the day. Comparisons of the 15 and 60 minute peak periods shows that the highest (15 minute) peak is equal to about one third (34%) of the DHW consumed in the peak hour. Lastly, there is slightly (25%) more DHW consumed in the average hour than in the highest 15 minute period of the day; this again makes a case for some type of off-peak generation and storage

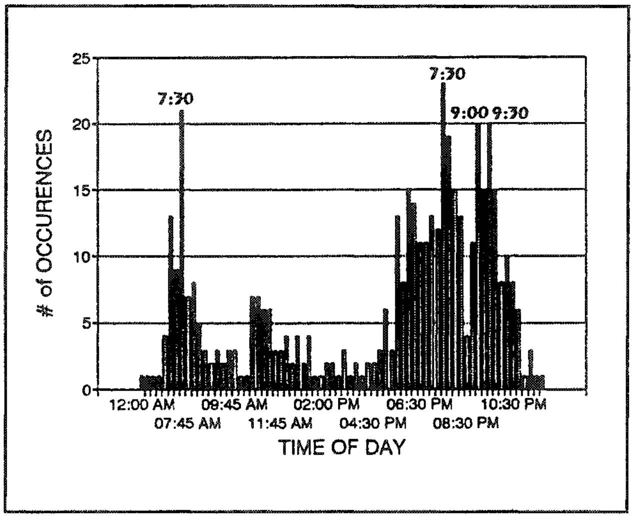

Figure 11. Maximum 60 Minute Times Frequency - Weekday - All Buildings (Winter)

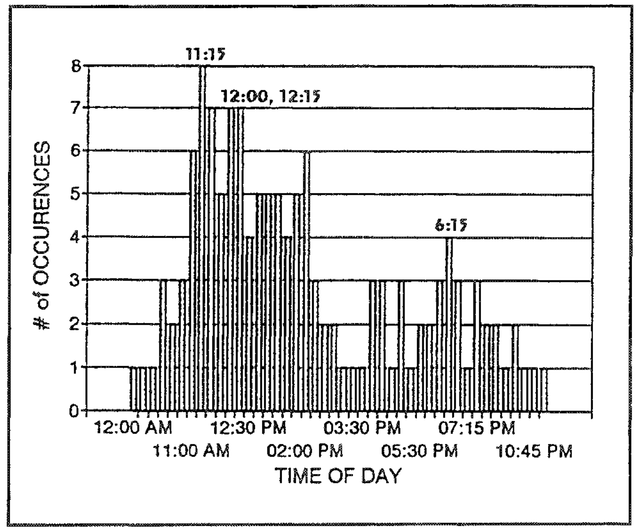

Figure 12. Maximum 60 Minute Times Frequency - Weekend - All Bldgs. (Winter)

Table 3. Gallons of DHW Usage (Per Capita) - Winter

Total Apts.	Bldg. ID #	Average Hour	Difference Avg./15 Max.	15 Min. Max.	Difference 60/15 Max.	60 Minute Maximum	Difference Avg./60 Max.
23	1	2.072	77%	2.681	37%	7.210	29%
30	2	2.626	123%	2.130	32%	6.732	39%
34	3	2.183	90%	2.436	38%	6.405	34%
90	5	2.469	161%	1.532	30%	5.140	48%
49	6	3.452	148%	2.337	32%	7.319	47%
60	7	1.895	114%	1.668	36%	4.698	40%
80	9	1.579	118%	1.343	34%	3.950	40%
102	10	2.728	171%	1.597	30%	5.338	51%
Average -		2.265	125%	1.835	34%	5.500	41%
Maximum -		3.452	171%	2.681	38%	7.319	51%
Minimum -		1.380	77%	0.791	30%	2.704	29%
Fold Difference -		2.50		3.39		2.71	

strategy. These peaking and hourly consumption figures must be considered in conjunction with coincidence of peaks and overall consumption patterns to further evaluate this issue.

Figure 13 illustrates the actual consumption curve in a sample building (# 7 - fall 1990 data). The bottom line (0.75) represents average consumption (for a 15 minute period, the period for which all data is taken), this is equivalent to levelizing the building's DHW consumption equally across the entire day. Under one possible scenario, the building's DHW needs would be met by generating storage during low consumption periods, represented by the white areas under the line, to be used during peak times. The other two lines illustrate levels of 10 and 25% excess storage capacity respectively.

It is apparent from the data that both the highest consumption levels and peak volumes occur on winter weekend days. It is therefore logical, as suggested by Olivares[3]

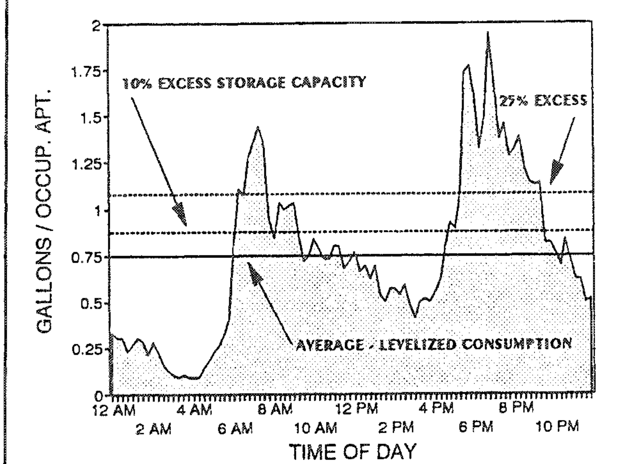

Figure 13. Storage Potential - Bldg. #7 - Weekday (Fall)

of Ontario Hydro, that we choose this level of consumption with which to base any potential sizing parameters.

As previously discussed, the available data for DHW consumption levels has not been considered suitable enough to use for system sizing decisions. Table 4 illustrates that the ASHRAE (industry standard) data, at 39.25 gallons, is 66% below the monitored consumption, of 115.46 gallons, for the daily average gallons of DHW per apartment. The ASHRAE per apartment figure is in fact 23% lower than the per capita consumption, of 51.04 gallons/capita/day. Examining maximum hourly consumption (Table 5) we see that the ASHRAE data, 9.38 gallons, is 25% below the monitored consumption, of 12.38 gallons, on a per apartment basis[4]. The results to date indicate use of unadjusted ASHRAE estimates will result in undersizing. When this research is concluded, specific sizing criteria will be put forth. Such guidelines will be based on per capita consumption and estimated maximum occupancy levels based on apartment size.

An evaluation of the energy used to produce DHW was conducted for the summer period (when the systems are used strictly for DHW purposes.) This analysis revealed that an average of 997.6 gallons of DHW (used at the tap) was produced for each 1 MMBtu consumed by the burner. The volume of DHW produced by 1 MMBtu ranged, by a factor of 2, from 684 to 1379 gallons. Included in these figures are various levels of combustion efficiency, standby loses, pipe insulation and other real time factors that effect the operation of systems in occupied buildings.

Table 4. Average Gallons of DHW Per Day

Monitored Data			ASHRAE[5]	
Total Apts.	Per Capita	Per Occup. Apt.	# of Apts.	Per Apt.
23	49.70	72.29	20 or less	42.0
30	58.61	198.87		
34	45.98	123.57		
49	76.44	166.18	50	40.0
60	40.42	74.45		
80	31.23	52.57	75	38.0
90	53.61	137.85		
102	54.92	109.85	100	37.0
Average	51.04	115.46		39.25

Table 5. Maximum Gallons of DHW Per Hour

Monitored Data			ASHRAE[5]	
Total Apts.	Per Capita	Per Occup. Apt.	# of Apts.	Per Apt.
23	6.86	9.98	20 or less	12.0
30	6.76	22.92		
34	5.87	15.78		
49	6.80	14.79	50	10.0
60	4.32	7.95		
80	3.28	5.53	75	8.5
90	4.68	12.03		
102	5.03	10.06	100	7.0
Average	5.45	12.38		9.38

These numbers can be used as a check against results of energy savings predictions from audit calculations, for DHW conservation related measures (such as low flow showerheads).

Discussion

A principal impetus behind this research was the lack of reliable data on DHW use in multi-family buildings. As a result of this information void, it was found that DHW generating systems and combined heating/DHW boilers (which represent 90 to 95% of the systems in N.Y.C.) are often found to be oversized by between 30 and 200%[6].

When installing a boiler either as a replacement during rehabilitation or for new construction, it is necessary to provide for the heating and hot water loads.[7] Generally, the individual responsible will use a 'what was there before', 'looks like ...', or some rough rule-of-thumb method. The correct method would be to (in new construction) design the radiation to meet the heat loss of the envelope and then to (starting point for rehab in an inhabited building) size the boiler output to supply the radiation; this is known as the EDR method. To this the DHW load must be added. Given that the DHW demands are unknown, enormous safety factors are employed. The author has seen factors equal to doubling of the heat load boiler size. These factors contribute to considerable oversizing, even when the heating portion is done properly. Guidelines developed as a result of this research will allow for proper sizing which will save buildings money in two ways. Firstly, in lower initial equipment investments, for the smaller more correctly sized equipment; and secondly, in lower annual - life cycle operating costs from higher operating (seasonal) efficiencies due to reduced cycling of equipment operating closer to full load. Additional savings may be achieved by using the DHW consumption patterns to evaluate different scenarios for optimizing storage vs. instantaneous generation configurations.

Future Work

In near term goals are to complete the analysis of the 14 month data set by evaluating 1991 spring and summer data against the parameters discussed in this paper. This will be used to create a year-round summary. Figures for maximum 2 and 3 hour demands, and maximum daily consumption loads will be developed to better analyze supply and storage models. The seasonal efficiency of the boiler/burner units employed to make DHW (during the non-heating periods) will be calculated. Through additional work on both DHW consumption data and energy requirements, boiler sizing needed to produce DHW may be determined.

Recommendations

Further analysis of the 14 month data set that should be pursued in the future includes complete modeling of a DHW system (boiler operations, storage tank temperature fluctuations and water flows); calculation of the percentage of energy used for DHW vs. heating; coincidence of DHW demand vs. heating calls; and calculations of oversizing of existing boilers (in study buildings) based on actual DHW and EDR loads.

In the process of creating the database for this project much boiler operation and apartment temperature data was collected. Analysis of this data will reveal insights pertaining to heating production and distribution.

Acknowledgements

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Endnotes

1. Derived by the work of the N.Y.C. Dept. of Housing Preservation and Development's - Energy Conservation Division (ECD) in the analysis of buildings for energy audits, boiler replacement and other programs. Substantiated in phone conversations by various members of ASHRAE Technical Committee 6.6 (Service Hot Water).

2. Heat computers are devices that control the boiler-burner plant and are used to collect data for building managers. These were adapted for the purposes of this research.

3. Olivares, T. C. 1987. *Hot Water System Design for Multi-Residential Buildings*. Report No. 87-239-K, Ontario Hydro Research Division, Ontario.

4. The figures for monitored data are per occupied apartment. The difference between the research and ASHRAE gallonages would be greater if full occupancy had existed at all times. Percent differences were calculated using the "average" gallon figures.

5. *1987 ASHRAE Handbook, HVAC Systems and Applications*. (Chapter 54 - Service Hot Water), ASHRAE, Atlanta.

6. Experience of ECD. Oversizing percentages were computed against the building's radiation load plus an estimated DHW load.

7. It would be most efficient to install separate space heating and DHW systems, but it is unlikely that a large percentage of the New York market will take this route any time soon, in the light of the resistance to having an additional mechanical system to care for.