ENERGY USE AND DOMESTIC HOT WATER CONSUMPTION

Final Report
Phase 1

Prepared for

**THE NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY**

Project Manager
Norine H. Karins

Prepared by

ENERGY MANAGEMENT & RESEARCH ASSOCIATES

Fredric S. Goldner, C.E.M.
448 Neptune Avenue, Suite 15P
Brooklyn, NY 11224

1647-EEED-BES-91

Energy Authority
Report 94-19

November 1994

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DT

NOTICE

This report was prepared by the Energy Management & Research Associates in the course of performing work contracted for and sponsored by the Energy Management & Research Associates and the New York State Energy Research and Development Authority (hereafter the "Sponsors"). The opinions expressed in this report do not necessarily reflect those of the Sponsors or the State of New York, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it. Further, the Sponsors and the State of New York make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this report. The Sponsors, the State of New York, and the contractor make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

First printing: November 1994

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

New York State Energy Research & Development Authority has sponsored a project to develop comprehensive operating data on combined domestic hot water (DHW) and heating systems to be used in system design and specifications. DHW requirements in multi-family buildings are currently calculated on the basis of questionable standards. These new, more precise DHW flow data (broken down on a per capita basis) result in a better foundation for sizing decisions than existed heretofore.

Thirty New York City multifamily buildings with combined steam heating and DHW plants were instrumented to monitor (mostly hourly) apartment, outdoor, boiler and DHW temperatures, and burner on-off times. In nine buildings, which had been upgraded, additional data collected were: stack temperature, DHW flow in *15-minute increments*, oil and boiler make-up water flows, and DHW temperature before and after the mixing valve and on the return line. The data set collected for 14 months amounts to a data base of over 110 megabytes.

This report presents DHW demand patterns, seasonal variations, weekday vs. weekend consumption, consumption vs. occupancy levels, coincidence of 15-, 60-, 120-, and 180- minute demand periods, and average vs. peak demand levels, as well as figures for energy to generate DHW.

The format of guidelines presented in this report differs from those currently in use. The "Low - Medium - High" (LMH) users set of guidelines provide a range, rather than a specific, singular gallonage standard. By providing LMH tables and guidelines for their application the design engineer or contractor can then use these as a tool from which to select the appropriate level that matches the site being served. Values are presented for both New York sizing guidelines (developed from this study), as well as a set of 'National' figures (derived from a compilation of studies conducted in other cities). The LMH approach and 'National' guidelines were adopted for inclusion in the 1995 ASHRAE Handbook revision.

KEY WORDS

Hot water, monitoring, multi family building, system sizing, energy conservation, boiler.

ACKNOWLEDGEMENTS

I would like to thank the following for their cooperation and assistance Norine Karins of the Energy Authority; Mark Engel, Larry Conner, and the staff of Ralph Langsam Associates; David Suthergreen of Optimum Applied Systems Inc.; Perry Tripi of Energy Management & Research Associates; Peter Judd former Assistant Commissioner of the N.Y.C. Department of Housing Preservation and Development's - Energy Conservation Division (HPD-ECD); Roubina Israelian of HPD-ECD; Howard Silverman; and others who have helped review this work. The genesis of this work was derived from analysis and field work of the N.Y.C. - HPD Energy Conservation Division between 1984 and 1991.

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
EXECUTIVE SUMMARY	S-1
INTRODUCTION	1-1
RESEARCH APPROACH.....	2-1
Building Selection	2-1
Data Collection	2-3
Monitoring Equipment.....	2-3
Data Set.....	2-4
DATA ANALYSIS	3-1
Methodology	3-2
Statistical Confidence of the Data Set	3-3
FINDINGS	4-1
Population Density	4-1
Seasonal Variation.....	4-1
Leaks	4-1
Seasonal	4-5
Weekday vs. Weekend Consumption	4-5
Demand Flow Patterns.....	4-9
Demographics and Appliances.....	4-12
Time Of Day Of Peak Flows	4-12
Peak Demands and Average Consumption Values.....	4-17
Potential of Generating Storage	4-20
Comparison To Published ASHRAE Figures	4-22
PROPOSED SYSTEM SIZING CRITERIA	5-1
Low - Medium - High Guidelines.....	5-1
Development of National <i>LMH</i> Table	5-3
ENERGY USE ANALYSIS	6-1
DISCUSSION	7-1
System Oversizing.....	7-1
FUTURE WORK	8-1
REFERENCES	9-1
APPENDIX	Separate Cover

FIGURES

<u>Figure</u>	<u>Page</u>
1 Seasonal Comparison of DHW Consumption Average Gallons Per Capita Per Day	4-2
1-L Seasonal Comparison of DHW Consumption Average Gallons Per Capita Per Day - Leaks	4-2
2A Daily 60 Minute Average vs. Minimum Gallons Building 2	4-4
2B Daily 60 Minute Average vs. Minimum Gallons Building 10	4-4
3 Weekday vs. Weekend Consumption Gallons Per Capita: 7/90 - 2/91	4-6
4 Weekday vs. Weekend Consumption Gallons Per Capita, Composite	4-6
5 Weekday Consumption of DHW Gallons Per Capita, Composite	4-7
6 Weekend Consumption of DHW Gallons Per Capita, Composite	4-7
7 Weekday vs. Weekend Consumption Gallons Per Capita - Bldg #1 (Summer)	4-8
8 Weekday vs. Weekend Consumption Gallons Per Capita - Bldg #3 (Summer)	4-8
9 Seasonal Variations, Weekday Consumption Gallons Per Capita, Composite	4-10
9-L Seasonal Variations, Weekday Consumption Gallons Per Capita - Leaks, Composite	4-10
10 Seasonal Variations, Weekend Consumption Gallons Per Capita, Composite	4-11
10-L Seasonal Variations, Weekend Consumption Gallons Per Capita - Leaks, Composite	4-11

<u>Figure</u>	<u>Page #</u>
11 Maximum 15 Minute Times Frequency Weekday All Buildings (Winter)	4-13
12 Maximum 60 Minute Times Frequency Weekday All Buildings (Winter)	4-13
13 Maximum 120 Minute Times Frequency..... Weekday All Buildings (Winter)	4-14
14 Maximum 180 Minute Times Frequency..... Weekday All Buildings (Winter)	4-14
15 Maximum 15 Minute Times Frequency Weekend All Buildings (Winter)	4-15
16 Maximum 60 Minute Times Frequency Weekend All Buildings (Winter)	4-15
17 Maximum 120 Minute Times Frequency..... Weekend All Buildings (Winter)	4-16
18 Maximum 180 Minute Times Frequency..... Weekend All Buildings (Winter)	4-16
19 Comparison of DHW Peak Consumption Gallons Per Capita - Winter Period	4-19
19-L Comparison of DHW Peak Consumption Gallons Per Capita - Leaks, Winter	4-19
20 Parts of 3 Hour DHW Peak Consumption Gallons Per Capita - Winter Period	4-20
21 Storage Potential - Bldg #7 (Fall) Gallons Per Occup. Apt. - Weekday	4-21
22 Sample Consumption Patterns Building #1 - 3 Random Days	4-21
23 Energy Used To Produce DHW July - Sept. 1990 Data	6-1

TABLES

<u>Table</u>	<u>Page</u>
1 Building Characteristics.....	2-2
2 Tenant Demographics	2-2
3 Gallons of DHW Usage (Per Capita) - Winter	4-18
3-L Gallons of DHW Usage (Per Capita) - Winter (Minus Leaks).....	4-18
4 Average Gallons of DHW Per Day	4-23
5 Maximum Gallons of DHW Per Hour.....	4-23
4-L Average Gallons of DHW Per Day (- Leaks)	4-24
5-L Maximum Gallons of DHW Per Hour (- Leaks).....	4-24
6 Maximum Gallons of DHW Per Day.....	4-25
6-L Maximum Gallons of DHW Per Day (- Leaks)	4-25
7 New York Low - Medium - High Guidelines	5-1
Hot Water Demands And Use For Multi Family Buildings	
8 DHW Consumption Data From Other.....	5-4
Monitored Research Studies	
9 National Low - Medium - High Guidelines.....	5-5
Hot Water Demands and Use for Multi Family Buildings	

EXECUTIVE SUMMARY

The work described in this report represents an analysis of 14 months of real time monitored data aimed at developing domestic hot water (DHW) consumption and demand patterns for system sizing criteria. This work has been performed by Energy Management & Research Associates under contract to the New York State Energy Research and Development Authority.

The research has developed a comprehensive database of heating and domestic hot water system operational data, in a set of multi-family buildings which can be used in future design and specification preparation and in operational procedures.

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.

Building selection 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. These buildings were constructed pre-1902 (old law) or between 1902 and 1928 (new law). All the boilers were 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.

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. Nine upgraded buildings 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.

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, 60, 120 and 180 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.

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, fall, winter and spring periods.

FINDINGS

The number of persons per apartment 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 3.9 fold, the average being 124.14 gallons per day. When population density is considered the usage differed by 2.4 fold, with an average of 54.10 gal/capita per day.

One of the most distinct findings is the seasonal variation of DHW consumption. Consumption levels rise from summer to fall to winter.

A weekday vs. weekend comparison of gallons of DHW consumed by each building reveals that there is generally a slightly higher level of consumption on weekends than on weekdays, with weekend day consumption being 7.5% greater.

Much work has gone into the 15 minute DHW flow meter data analysis to produce demand-flow curves. 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 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. 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. The concurrence of the 15, 60, 120 and 180 minute peaks strengthens the use of 2 and 3 hour maximum consumption levels for storage models. The most frequent minimum 60 minute consumption periods occurred at 4:00 AM on both weekdays and weekends. This demand period data will be used when evaluating DHW system sizing and storage options.

Fifteen, 60, 120 and 180 minute maximum demand and hourly average consumption figures were compiled to examine peak needs in contrast to total volume. An examination of the data reveals that in comparison to the use in a maximum 60 minute period the average hour consumption is only 42% 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 (33%) of the DHW consumed in the peak hour. Lastly, there is slightly (27%) 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 strategy.

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 Olivares¹ of Ontario Hydro, that we choose this level of consumption with which to base any potential sizing parameters.

¹ Olivares, T.C.. 1987. *HOT WATER SYSTEM DESIGN FOR MULTI-RESIDENTIAL BUILDINGS*. Report No. 87-239-K, Ontario Hydro Research Division, Ontario.

Comparison to Published ASHRAE Figures

As previously discussed, the available data for DHW consumption levels has not been considered suitable enough to use for system sizing decisions. ASHRAE (industry standard) data is 68% below the monitored consumption, for the daily average gallons of DHW per apartment. The ASHRAE per apartment figure is in fact 27% lower than the per capita consumption, of 54.10 gallons/capita/day. Examining maximum hourly consumption, ASHRAE data is 30% below the monitored consumption, of 13.46 gallons, on a per apartment basis. Maximum day consumption comparison, reveals that the ASHRAE data is 65% below the monitored consumption for the maximum day gallons of DHW per apartment. Again, the ASHRAE per apartment figure is lower (21%) than the per capita consumption, of 88.0 gallons/capita/day². The results to date indicate use of unadjusted ASHRAE estimates will result in undersizing.

PROPOSED SYSTEM SIZING CRITERIA

The format for the guidelines presented differs from those currently used (predominantly *ASHRAE Handbook Chapter 44, Table 7*). This new approach represents the results of discussions with system design professionals, including members of ASHRAE Technical Committee (T.C.) 6.6 (Service Hot Water), who have indicated a preference for a "Low - Medium - High" (LMH) guidelines, rather than a specific, singular volume value. By providing LMH tables and guidelines for their application, it is felt that the design engineer or contractor can use these as a tool to better match the situation at the site they are serving. Additionally, the figures presented in the LMH tables include the more detailed level of "Peak 15 Minute" gallon consumption, which should assist in the design process. One other significant difference is the use of per capita rather than per apartment based usage factors.

While it was not the original intention of the Energy Authority or Energy Management & Research Associates, in the process of completing this project, the author was approached by ASHRAE's T.C. 6.6 to develop a set of values that went past just the New York City market. This effort coincided with work being conducted by American

² 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.

Gas Association (AGA) Labs into service hot water (SHW) consumption and loads for various types of commercial buildings. The data presented in Table 9 along with similar guidelines on other building types (from the AGA research) is intended to update the existing ASHRAE hot water demand values and represents changes in numbers of water consuming devices, personal habits, life styles, and sanitation needs since the late 1960's. The LMH approach and 'National' guidelines were adopted for inclusion in the 1995 ASHRAE Handbook revision.

ENERGY USE ANALYSIS

An evaluation of the energy used to produce DHW was conducted for the summer period. This analysis revealed that an average of 150.6 gallons of DHW (used at the tap) was produced for each 1 gallon of # 6 oil (or equivalent) consumed by the burner. This can be used as a check against results of energy savings predictions from audit calculations, for DHW conservation related measures.

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%.

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. Generally, the individual responsible will use a 'what was there before', 'looks like ...', or some rough rule-of-thumb method. 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. The 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

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. Phase II of this project which will investigate these issues with the assistance of further collection of *5 minute* total DHW flows and (newly installed) recirculation flows in a subset of three of the sites began in March 1993.

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

Section 1

INTRODUCTION

The work described in this report covers the analysis of 14 months of real-time monitored data aimed at developing domestic hot water (DHW) consumption and demand patterns for system sizing criteria. This work has been performed by Energy Management & Research Associates under a research project sponsored by the New York State Energy Research and Development Authority.

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 10 rooms), burner on/off, and heat-timing device settings. Monitoring systems are installed in connection with a heat-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 via modem 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; e.g., excessive on time, overheating in the apartments, or an over-ride of the control system. (The on-line devices are not usually used to determine lack of heat conditions; phone calls from the tenants bring such to the attention of management.) On-line monitoring systems are used by a number of residential building management firms.

The existence of on line monitoring 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 data base in existence.

This project used existing systems operated by the building management firm of Ralph Langsam Associates, which manages over 6500 multi family building units. The systems were upgraded with additional monitoring points to collect more detailed information on hot water use.

The research has developed a comprehensive data base of heating and DHW system operational data based on 14 months of observation, in a set of multi-family buildings.

This information 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 New York City buildings are calculated on the basis of national ASHRAE and other standards of many years standing (which have been determined to be inaccurate¹). 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 previously existed. This accuracy is a critical need for improving specifications and performance in newly renovated buildings. (The project has additional applicability in New York City as all multi family buildings are to be 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 the 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 provides more 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 are currently done on an established practice, rule-of-thumb basis.

¹ Derived by the work of the New York City Department 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).

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.

Section 2

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 these reasons that Ralph 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 30 buildings were selected from a set of approximately 70 Langsam sites that had OAS Heat Computers² installed. An effort was made to include a diversity of building sizes, income levels, ethnic backgrounds, and locales. The demonstration buildings are characteristic of the older, predominant stock of the over 120,000 New York City multi-family buildings. The nine buildings were located in a variety of diverse neighborhoods throughout the Bronx.

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)³. All the boilers are combination heat and hot water units, steel tube boilers, and (primarily) air atomizing No. 4 or 6 oil burners, with DHW generated by a tankless coil. A summary of general building characteristics is shown in Table 1.

² Heat computers are devices that control the boiler-burner plant and collect data for building managers. (The heating plant operation in the individual buildings is controlled by a device equipped with leads to internal sensors in a number of apartments. When the internal sensors "vote" for heat or are "satisfied", the burner/boiler operation is automatically determined. The on-line monitoring system simply reports operational data.) These systems were specifically adapted for this research.

³ Old Law and New Law refers to the time of building construction. More specifically, these terms denote the construction regulations effecting multi family buildings built previous to 1902 (Old Law) and between 1902 and 1928 (New Law). The most predominant difference being the general building shape and number of window openings (which affect the definition of "rental rooms").

BUILDING CHARACTERISTICS

BLDG ID #	TOTAL APTS	Persons per apt.	Sq ft/ apt	% Children	Public laundry	% Dish- washers	% Cloths washers	In-apartment shower- heads	% Low flow 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 1

TENANT DEMOGRAPHICS

BLDG ID #	<i>"At Home Patterns"</i>				<i>"Family Types"</i>					<i>"Income Levels"</i>			
	All work	1 * & 1	Seniors	No work	Single	Couples	Family	1 parent	Seniors	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%	36%	6%	12%	33%	36%	12%	33%	67%	0%	0%
5	6%	17%	6%	71%	0%	24%	24%	47%	6%	23%	77%	0%	0%
6	31%	23%	23%	23%	10%	31%	35%	2%	21%	13%	42%	42%	4%
7	50%	3%	41%	5%	2%	62%	10%	0%	26%	0%	7%	93%	0%
9	38%	38%	12%	12%	14%	61%	14%	7%	7%	3%	18%	76%	4%
10	25%	0%	10%	65%	0%	50%	50%	0%	0%	50%	25%	25%	0%

* 1 works & 1 stays home

Table 2

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 monitoring system operated by Ralph Langsam Associates. Nine buildings were instrumented to provide detailed DHW consumption data.

The data for this research were 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 and 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, and DHW temperature before and after mixing valve and on the return line. Measurements from these devices were recorded periodically (every 15 minutes, 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 were then put through a custom-designed (proprietary) FORTRAN data translation program which rearranges the data to an Rbase (data base) readable format, as well as performing a number of preliminary calculations. The data were then loaded into a specially designed data base 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 (spreadsheet) for graphical analyses and presentations.

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

MONITORING EQUIPMENT

Data from the monitoring equipment was all collected by the Heat Computer. This is accomplished by having the Heat Computer 'talk to' or read the various sensors and

meters on a cycle that repeats itself every 20 ms (milliseconds). The devices were essentially read continuously (for building operations purposes), and the data stored at set points in time (i.e., every hour on the hour for apartment and DHW temperature measurements, and every 15 minutes for DHW flow). The computer also continuously noted and stored certain daily high and low values (i.e., stack and outdoor temperatures).

All water temperature sensors were thermistors accurate to ± 1 °F within the rated 40 to 251 °F range. The stack temperature sensors were thermocouples rated from 4 to 1010 °F and are accurate to ± 4 °F within that range. The DHW flow meter is installed on the cold water branch from city water before/upstream of the boiler coil, mixing valve and re-entry of the recirculation loop, (see illustrative pipe diagram, in the Appendix). These meters range in size from 1 to 2 inches in diameter. Meter selection was based on pipe diameter and flow rates. The meter capacities were chosen based on expected flow ranges derived from ASHRAE and other sources and then adding some factor over or under the expected flow rates.

All buildings have 2 inch DHW flow meters installed, except for Building #'s 1 and 2 which employ a 1 inch and 1 1/2 inch meter, respectively. Installed models were rated for a maximum temperature of 250 °F and a maximum pressure of 250 PSI. The fluid flow range spans from 0.4 to 52.8 gallons per minute (GPM) for the 1 inch meter, 0.7 to 87.2 GPM for the 1 1/2 inch meter, and 0.88 to 131.6 GPM for the 2 inch meters. These ranges more than adequately covered the flows that have been experienced. The degree of error for each of the flow meters is $\pm 1\frac{1}{2}$ percent. The boiler make-up water was recorded by 3/4 inch meters that are rated for a maximum temperature of 190 °F, a maximum pressure of 150 PSI, and 0.22 to 20 GPM. The fuel flow meters are rated for 1 to 50 GPH.

DATA SET

The data set includes 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).

Data from July 1990 through September 1991 have been loaded into the data base and analyzed. This represents a data base containing over 110 megabytes of data. Various tables in the data base contain about 10 million data points:

- 345,000 rows of 15 minute data on the 9 building set
- 86,000 rows of hourly data on the 9 building set
- 150,000 rows of hourly data on the 21 building set
- 279,000 rows of boiler cycle data - all buildings
- 19,000 rows of low outdoor temperature data - all buildings
- 8,500 rows of daily minimum, maximum, and average hourly DHW consumption
- 3,700 rows of maximum 15 minute DHW demand data from the 9 building set.

Data monitoring was conducted at all thirty sites by the existing Heat Computers. The process of going from the full set of thirty buildings down to the 9 that were upgraded with the additional meters and sensors was in part pre-defined by budget parameters. While it would have been ideal to upgrade all thirty sites with the more detailed equipment, the project budget allowed for this to be done in only 9 buildings. These 9 sub-set sites were selected as a representative sample of the whole (thirty) building set. Care was taken to include the same level of population and local diversity previously described in general "Building Selection" criteria.

This report focuses on 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 use⁴. In addition, the summer 1990 data for Building 5 have been removed because of a changeover in operation from the boiler serving one 45-unit building, to serving two sister buildings (with a total of 90 apartments). Lastly, the DHW flow meter in Building 6 developed a problem that resulted in improper readings as of the May 1991 period; therefore all data from that point forward have been eliminated (resulting in no second summer analysis for Building 6.)

⁴ See "Individual Building Flow Curves" in the appendix.

Section 3

DATA ANALYSIS

Data analysis included the investigation of several relationships: daily and seasonal variations in DHW demand patterns; consumption vs. occupancy levels; frequency and coincidence of 15-, 60-, 120- and 180-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 were 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 one half (1/2) or one third (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 percent⁵. Vacancy figures have been used to eliminate (both inter- and intra-building) 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.

⁵ See month by month "Number of Occupied Apartments" and "Percent of Occupied Apartments" tables in the appendix.

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 (June, July, August and September), fall (October and November), winter (December, January, February, and March) and spring (April and May) periods.

METHODOLOGY

As discussed previously, the DHW and building operations data were collected by the sensors and meters that were wired into each building's Heat Computer. After the collected data arrived at EMRA, it was put through a proprietary FORTRAN data translation program which read three files of two (2) or three (3) days data from an ASCII file which presented data in screen-wide formats, (designed for building management use). The program stripped the source files of heading and label text; combined all data in building, date, and time order; and rearranged the data to a format that was compatible with the Rbase (data base) application designed for analysis. The other function of the FORTRAN program was to perform a number of preliminary calculations. These included reading all of the DHW flow data and computing the daily average, and the maximum and minimum consumptions, as well as denoting the times that these flows occurred.

To accomplish this, all the data were read and only the days in which all ninety six 15-minute readings existed were selected (i.e., a complete day's data was recorded.) The program then reviewed all the flows to select the maximum 15-minute consumption. This information was then written to a special file, as were any equal flows and their times⁶. Another pass at the data calculated the gallons of DHW consumed in all 4 consecutive 15-minute periods. This was used to derive the daily maximum 60-minute peak volume and time of occurrence, (as well as multiple occurrences of equal flows.) Successive passes determined minimum 60-minute flows and average 60-minute ('Hour') consumption.

For the purpose of the discussion below, average hourly consumption refers to the mean volume of DHW consumed during the specified time frame, and average daily

⁶ For example, if in Building 1 on February 4th a peak 15-minute flow of 26 gallons was identified at 7:30 AM, and if that same (maximum) flow (of 26 gallons) was noted for the period ending at 6:15 PM, then both readings were written to the 'peak record file'.

consumption refers to the mean volume of DHW consumed for all days where a complete day of data exists. Both the reformatted raw data and the computed values were then loaded into various tables in the specially designed project data base, where macros performed a second level of calculations. The macros were used to compute monthly average values of the parameters presented in this report (i.e. gallons per average hour, maximum 15-and 60-minute flows, ..., see printouts in appendix), compile frequency tables of times-of-event occurrence (i.e., maximum and minimum 60-minute flows), and calculate the length of boiler on-and-off cycles. The Rbase environment was also used to perform additional analyses and output smaller data sets to Quattro Pro (QPro). The QPro spreadsheet environment was used to manipulate the flow values derived from the monthly Rbase runs, adjust by division of occupied apartments and persons per apartment. These figures were used to prepare seasonal consumption values (e.g., "average hour gallons of DHW per capita - Winter period"). QPro was also employed to conduct graphical analyses of the data and to create many of the table and graph presentations in this report.

The flow curve graphs presented later in this report represent 15-minute profiles of consumption (data which has never been available at this level of detail previously). These graphs are created by plotting the average of all the 12:00 - 12:15 readings and then the average consumption for the 12:15 - 12:30 period ...) on weekdays and weekends, respectively.

STATISTICAL CONFIDENCE IN THE DATA SET

As part of the evaluation process, exploratory data analysis (EDA) was performed⁷. The statistics are intended to offer an indication of dispersion and suggest a measure of the strength of certain factors influencing the consumption of DHW. The data for the selected variables tested were drawn from the building characteristics (Table 1), daily average gallons of DHW (Table 4), and maximum gallons of DHW per hour (Table 5). Following is a description of the nomenclature used:

⁷ Exploratory Data Analysis (EDA) is used to organize and give form to unstructured data. It's application is commonly directed at arriving at a result when no theory is used to guide the analysis. EDA can be used to confirm a suspicion without necessarily inferring direct causality. One may use plots, graphs, and other data manipulation techniques such as regression to make informed judgements about the nature of the data, and thereby suggest certain relationships based upon the results of the EDA.

1 BLDG ID	Building identification
2 WHRFLOW	Winter average DHW
3 #WDAYS	No. of winter days
4 #APTS	No. of apartments per building
5 PPAPT	No. of people per apartment
6 PWASH	Public washers (laundry)
7 DWASH	Dish washers
8 CWASH	Cloth washers in apartment
9 WASH1	Public and dish washers combination
10 ALLWASH	Public, dish and cloth washers combo.
11 HWPCAP	Avg. gallons per day/per capita
12 HWPOA	Avg. gallons per day/ per occupied apt.
13 MHPCAP	Max. gallons per hour/per capita
14 MHPOA	Max. gallons per hour/per occupied apt.

The descriptive statistics associated with each of the relevant variables are identified in the appendix. The variance provides a measure of dispersion or spread around the mean. Each variable was subjected to a goodness-of-fit test based on the concept of normal distribution. The factors were found to be satisfactory at the 95% confidence interval, except for DWASH and ALLWASH which were skewed by a lack of complete data. The mean, standard deviations, and minimum and maximum values are summarized in the appendix.

Beyond descriptive statistics, a simplified DHW model was developed based largely on the classical multiple regression model employing ordinary least squares. The selection of dependent variables (estimators) was essentially based upon "a priori" - before hand or prior knowledge. The suspicion that certain factors are more relevant in DHW sizing is a central assumption and will be confirmed by correlation using the regression model. It should be noted that a high correlation does not always provide an inference of causality. Therefore, the analyses assumes but does not attempt to prove causality.

Basic to the multivariate analysis is the notion that the dependent variable, in this case WHRFLOW, is a linear function of a series of independent factors of the following generalized form:

WHRFLOW : is a function of (#WDAYS, #APTS, APTSIZE, ..., Ki)
where a priori #WDAYS, #APTS, APTSIZE, ..., Ki > 0

The generalized statistical concept implied in the above example is a simplification of reality.

The full regression model was used to evaluate the winter hourly data for domestic hot water consumption. The variables WASH1 and ALLWASH were formed by combination. The estimators were found to provide strong indications of positive impact on WHRFLOW of DHW as demonstrated by the high degree of correlation. However, the inclusion of ALLWASH appears to weaken the efficiency of the equation, but it is not a fatal flaw. The effect of ambient temperatures as indicated by heating degree days and the presence of water flow limiting devices was not separately tested. The flow data recorded was assumed to accommodate such cold weather effects, especially when one considers that the maximum demand for DHW water occurred during the winter season. In all, eight different regression models were developed. The summary of the accompanying model/equations are as follows:

$$\text{Eq. 1 } \text{WHRFLOW} = \text{CONSTANT} + \text{\#WDAYS} + \text{APTSIZE} + \text{PPAPT} - \text{PWASH} - \text{DWASH} - \text{CWASH} + \text{ERROR TERM.}$$

$$\text{Eq. 2 } \text{WHRFLOW} = \text{CONSTANT} + \text{\#WDAYS} + \text{\#APTS} + \text{APTSIZE} - \text{ALLWASH} + \text{ERROR TERM.}$$

$$\text{Eq. 3 } \text{WHRFLOW} = \text{CONSTANT} + \text{\#WDAYS} + \text{\#APTS} + \text{DWASH} - \text{CWASH} + \text{ERROR TERM.}$$

$$\text{Eq. 4 } \text{WHRFLOW} = \text{CONSTANT} + \text{\#WDAYS} + \text{\#APTS} + \text{DWASH} + \text{ERROR TERM.}$$

$$\text{Eq. 5 } \text{WHRFLOW} = \text{CONSTANT} + \text{\#WDAYS} + \text{APTSIZE} + \text{PPAPT} + \text{DWASH} - \text{CWASH} + \text{ERROR TERM.}$$

$$\text{Eq. 6 } \text{WHRFLOW} = \text{CONSTANT} + \text{\#APTS} + \text{\#WDAYS} + \text{APTSIZE} - \text{PPAPT} + \text{DWASH} + \text{ERROR TERM.}$$

$$\text{Eq. 7 } \text{WHRFLOW} = \text{CONSTANT} + \text{\#WDAYS} + \text{\#APTS} - \text{PPAPTS} - \text{DWASH} - \text{MHPCAP} + \text{ERROR TERM.}$$

$$\text{Eq. 8 } \text{MHPCAP} = \text{CONSTANT} + \text{HWPCAP} - \text{HWPOA} + \text{MHPOA} + \text{ERROR TERM.}$$

Some selected common measures are found in the table on page 3-7.

The R^2 and Adjusted (corrected) R^2 denotes the goodness of fit used to validate previous assumptions. The results show favorable and strong relationship. While no

attempt was made to maximize R^2 by increasing the number of dependent variables, the adjusted R^2 provides a more conservative reading. The partial regression coefficients associated with each equation signify the strength of the estimator (variable) while all other values are held constant. Those values should be thought of as partial derivatives.

The Durbin-Watson (DW) statistic provided indicates a measure of the likelihood of the absence of (in this instance) first-order serial correlation. The assumption underlying this statistic is that the errors associated with different observed values are uncorrelated. A correlation in the error term can be induced by the carry-over cumulative effects of omitting variable(s) in the regression model. The presence of serial correlation does not affect the unbiasedness or consistency of the ordinary least-square regression estimators. It may, however, affect its efficiency. The DW statistic should normally lie between 0 and 4. A DW near 2 indicates no first order serial correlation, and a negative serial correlation is associated with DW greater than 2, which is more desirable. The factor set utilized is said to be largely absent of first order serial correlation.

The descriptive statistical measurement provided and the results of regression estimates offer a substantiated basis for the reliance on the observed data and characteristics of the buildings to make reasonable judgements regarding the consumption of domestic hot water and the sizing of hot water units thereof.

STATISTICAL REGRESSION TEST RESULTS

Dependent Variable = WHRFLOW

Independent Var. Equation	<u>#WKDAY</u>	<u>#APTS</u>	<u>APTSIZE</u>	<u>PPAPT</u>	<u>PWASH</u>	<u>DWASH</u>	<u>CWASH</u>	<u>WASH1</u>	<u>ALLWASH</u>	<u>SEE</u>	<u>ARS</u>	<u>RS</u>	<u>DW</u>
1	X		X	X	X	X	X			3663.14	0.9100	0.9871	2.6574
2	X	X	X						X	7663.90	0.6100	0.8300	2.4810
3	X	X				X	X			2136.69	0.9694	0.9869	3.1134
4	X	X				X				11204.46	0.1578	0.5187	2.9331
5	X		X	X		X	X			3782.86	0.9040	0.9726	1.5743
6	X	X	X	X		X				9763.67	0.3605	0.8173	2.5212
7	X	X		X		X			X	9813.55	0.3539	0.8154	2.8292
EQUATION 8 MEASURES MHPCAP										0.2328	0.9695	0.9826	1.9259

Where SEE = Standard error of the estimate

ARS = Adjusted (corrected R Squared)

RS = R Sq.

DW = Durbin-Watson statistic

Section 4

FINDINGS

POPULATION DENSITY

The number of people 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 DHW consumption levels differed by 3.9 fold from a low of 52.97 to a high of 207.77 gallons/occupied apartment, the average being 124.14. When population density is considered, the usage ranges from 31.47 to 74.99 gallons per capita (gal/capita), with an average of 54.10 gal/capita, a difference of 2.4 fold. More detailed demographic data will be discussed later.

SEASONAL VARIATION

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. The average consumption of 45.95 gallons of DHW per capita per day (gal/capita) in the summer rose by 14% to 52.49 gal/capita in the fall and then by 15% to 60.41 gal/capita during the winter period. The consumption then rose by 2% to 61.69 gal/capita in the spring and fell 21% to 48.50 gal/capita during the second summer period.

LEAKS

An unexpected finding was the occurrence of higher consumption levels in the spring period than during the winter. As Figure 1 shows, that this is not the case at all sites. This unanticipated condition prompted investigation into possible reasons. The issue of leaks had been previously raised by an astute building owner (one of the project reviewers). The existence of, in some cases, more than zero to minimal consumption in the overnight time periods indicated the possibility of leaks in the DHW systems. While it is sometimes reasonable to expect limited usage between 2:00 and 5:00 AM, it

SEASONAL COMPARISON of DHW CONSUMPTION AVERAGE GALLONS PER CAPITA PER DAY

Figure 1

SEASONAL COMPARISON of DHW CONSUMPTION AVG. GALLONS PER CAPITA PER DAY - LEAKS

Figure 1-L

is also reasonable to assume that at some point there should be no usage at all. Tracking DHW in 15-minute increments allows us to isolate the minimal flows that are constantly being drawn from the system.

Graphical analysis of daily 60-minute average vs. minimum 60-minute gallon consumptions for each building over the 14-month data period reveals that, in fact, some of the consumption is leak driven. Examination of Figure 2A (Building 2) illustrates how the pattern formed by a large leak (lower line in dashed circle) is mirrored in the average consumption pattern above it. This large minimum hour (60-minute) consumption is likely the representation of a leak in the distribution piping or, possibly, a number of faulty faucets. One can project that if these minimum-hour gallonages, which are occurring at 4:00 AM, are in fact representations of leaks, then it is clear that this additional level of water is being drawn through the DHW system for the entire day. While some buildings in fact have long periods of zero gallons of minimum 60-minute consumption (as would be expected in a site with no leaks), consumption in other buildings appears to be driven by these leaks at times.

The worst case is Building 10 (Figure 2B.) Here we see that the minimum-hour consumption or 'leak level' is a major driving factor in the building's consumption pattern. As the volume of leaks became greater (from 3/91 through 5/91), the total consumption follows the same exact slope. Then, as the leaks were partially addressed, the building's consumption fell correspondingly. Further investigation of this issue was conducted by the building management and research team during the period between 12/92 and 3/93. Calls to the Heat Computer in Building 10 showed that a large leakage problem still existed, as the DHW meter was recording flows of not less than 60 or 70 gallons per 15-minute interval in the overnight time period.

After being alerted to the issue, the building manager and super have begun to visit the apartments. Many improperly working faucets have been identified and repaired or replaced. In one case, the manager found a bathtub hot water faucet that had been constantly running for so long that it had frozen in position, could not be shut, and the entire fixture had to be replaced. The 15-minute readings were perceptively lower in the following data download. In fact, minimum/overnight readings have now dropped to a level of 20 gallons per 15-minute interval (from 60), and all apartments have yet to be inspected. It is clear that in this site the DHW consumption readings were driven considerably higher by "fixable leaks."

Daily 60 Minute Average vs. Minimum Gal Bldg 2

Figure 2A * Note how 'leak' displayed in minimum pattern is mirrored in average, above.

Daily 60 Minute Average vs. Minimum Gal Bldg 10

Figure 2B

While it can be argued that DHW supply systems should not be designed to be leak detection systems, we should also not be designing to offset total mismanagement. It is reasonable to expect that engineering and other energy professionals will use some level of safety factors when sizing a system, but we should also assume that these systems will be operated with some level of normal maintenance. In order to account for the consumption recorded that is attributable to leaks and remove such from the overall consumption, the minimum 60-minute flows were subtracted from the gross consumption for each building on a month-by-month basis. The majority of the tables and graphs in the following analyses are presented both with and without leaks removed. *(Tables and figures with an "L" designation after the #, i.e. Figure 1 L, refer to data with the leaks removed.)*

Seasonal

Analysis of the seasonal DHW consumption levels after the volume attributable for leaks has been removed reveals a slightly more expected pattern, with the spring consumption (just slightly) below winter levels. As Figure 1-L illustrates, the average consumption of 39.67 gallons of DHW per capita per day (gal/capita) in the summer rose by 10% to 43.77 gal/capita in the fall and then by 13% to 49.25 gal/capita during the winter period. The consumption then fell by 1% to 48.61 gal/capita in the spring and fell 19% to 39.32 gal/capita during the second summer period. It is not clear why the spring consumption is not still lower, similar to the fall level, but the favorable comparison of first to second summer levels (in both the 'leak' and 'non-leak' analyses) acts as a positive check on the data collected.

WEEKDAY vs. WEEKEND CONSUMPTION

A weekday vs. weekend comparison of gallons of DHW consumed by each building (Figure 3) 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 consumption level of 50.89 gal/capita.

WEEKDAY vs. WEEKEND CONSUMPTION

GALLONS PER CAPITA : 7/90 - 2/91

Figure 3

WEEKDAY vs. WEEKEND CONSUMPTION

GALLONS PER CAPITA, COMPOSITE

Figure 4

WEEKDAY CONSUMPTION OF DHW GALLONS PER CAPITA, COMPOSITE

Figure 5

WEEKEND CONSUMPTION OF DHW GALLONS PER CAPITA, COMPOSITE

Figure 6

WEEKDAY vs. WEEKEND CONSUMPTION

GALLONS PER CAPITA - BLDG #1 (Summer)

Figure 7

WEEKDAY vs. WEEKEND CONSUMPTION

GALLONS PER CAPITA - BLDG #3 (Summer)

Figure 8

Demand Flow Patterns

Much work has gone into the 15-minute DHW flow meter data analysis to produce demand-flow curves (see Figures 4, 5 & 6). 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 begins later in the morning 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 1.09 gal/capita, than any of the weekday peaks, at 0.87 gal/capita.

In examining the composite weekday curve (Figure 4), two morning peaks can be observed, the first between 6:00 and 8:00 AM, and the second between 9:30 AM and 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 exhibit 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 7) is an example of a working class building with a large 6:00 to 8:00 AM spike, low mid-day use, and an 'after dinner - wash the dishes' peak at about 7:00 PM. Building 3 (Figure 8) is an example of the later morning 10:00 to 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 9, 9-L, 10 and 10-L clearly illustrate the seasonal variation in both the usage patterns and consumption levels between summer, fall, winter, and spring. Note that, after removing consumption caused by leaks in some buildings, the highest peaking level occurs during winter weekends. (Another check on the reliability of data collection over time is the positive match of both weekday and weekend consumption patterns and levels that appears when plotting the first summer readings against the second summer data; see figure in the appendix.)

SEASONAL VARIATIONS, WEEKDAY CONSUMPTION GAL per CAPITA, COMPOSITE

Figure 9

SEASONAL VARIATIONS, WEEKDAY CONSUMPTION GAL per CAPITA - LEAKS, COMPOSITE

Figure 9-L

SEASONAL VARIATIONS, WEEKEND CONSUMPTION GAL per CAPITA, COMPOSITE

Figure 10

SEASONAL VARIATIONS, WEEKEND CONSUMPTION GAL per CAPITA - LEAKS, COMPOSITE

Figure 10-L

DEMOGRAPHICS AND APPLIANCES

Statistical analyses and regression models were run on the data set to determine any correlations that might exist between occupant demographics or installed appliances and levels of DHW consumption. Based on tests of the factors delineated in Tables 1 & 2, a number of conclusions can be drawn.

It was found that those buildings where a large percentage of occupants stayed at home and did not work (identified as "No Work" in the "At Home Pattern" category), this factor had the strongest influence on consumption. Where "All Work(ed)" the influence was almost nil. In fact, the results seem to fit common/intuitive expectations.

The top five factors (table categories) deemed to have the greatest impact on higher DHW use were: No Work, Public Assistance and Low Income (combined), Family and One Parent (combined), Children, and Low Income (when viewed separately). The lowest five factors with a casual relationship were deemed to be: Population Density, Middle Income, Seniors, One & One (1 person works, 1 stays home), and the All Work groupings.

Multivaritive regression analyses performed on the installed appliances and DHW data concluded that the presence of large numbers of apartment clothes and dishwashers as well as public washers correlated well to higher levels of DHW consumption.

TIME OF DAY OF PEAK FLOWS

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 11 and 15) occur most often at 7:45 AM and 7:00, 7:15, 8:45, and 9:15 PM on weekdays and 10:45 and 11:15 AM and 6:15 PM on weekends. This can then be compared to the maximum 60-, 120-, and 180-minute demand periods (Figures 12 thru 14 and 16 thru 18). *(Note: the times listed on the frequency graphs represent the 15-, 60-, 120- or 180-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

Maximum 15 Minute Times Frequency Weekday All Buildings (Winter)

Figure 11

Maximum 60 Minute Times Frequency Weekday All Buildings (Winter)

Figure 12

Maximum 120 Minute Times Frequency Weekday All Buildings (Winter)

Figure 13

Maximum 180 Minute Times Frequency Weekday All Buildings (Winter)

Figure 14

Maximum 15 Minute Times Frequency Weekend All Buildings (Winter)

Figure 15

Maximum 60 Minute Times Frequency Weekend All Buildings (Winter)

Figure 16

Maximum 120 Minute Times Frequency Weekend All Buildings (Winter)

Figure 17

Maximum 180 Minute Times Frequency Weekend All Buildings (Winter)

Figure 18

demands, and there is an exact match during the evening periods. When reviewing the 120- and 180-minute peaking periods we can observe that there is again an exact coincidence with both these periods and the 15- and 60-minute peaks. The concurrence of these peaks strengthens the use of 2- and 3-hour maximum consumption levels for storage models. The most frequent minimum 60-minute consumption periods occurred at 4:00 AM on both weekdays and weekends. This 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.

PEAK DEMANDS AND AVERAGE CONSUMPTION VALUES

Fifteen-, 60-, 120- and 180-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, and in 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 42% 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 (33%) of the DHW consumed in the peak hour. Lastly, there is slightly (27%) 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 strategy.

Figure 19 (and Figure 19-L) illustrate the that the peak 60-minute demand is 61% of what is consumed during the maximum 120-minute period; and that the volume of DHW used to satisfy the 120-minute maximum is 75% of what is needed during the peak 180-minute span. From Figure 20 we can see how all of the peak volumes contribute to the 3-hour peak demand on the DHW generation and/or storage system. Fifteen percent of the DHW will be used during the peak 15-minutes, with the rest of the peak hour requiring an additional 31% of the total volume. These figures reveal that 46% of the DHW consumed during the peak 3-hour demand each day is needed within the maximum 60-minutes. Another 29% of the volume is used within the second 60-minute period, then there is a drop off to only 25% of the total volume being drawn off during the third 60-minute period of the peak three hours.

GALLONS OF DHW USAGE (PER CAPITA) - WINTER

TOTAL APTS	BLDG ID #	AVERAGE HOUR	Avg. hr consumption % of 15 min. max	15 MIN. MAX.	15 min. max consumption % of 60 min. max	60 MINUTE MAXIMUM	Avg. hr consumption % of 60 min. max
23	1	2.178	78%	2.776	37%	7.516	29%
30	2	2.650	120%	2.203	32%	6.898	38%
34	3	3.059	110%	2.782	35%	8.021	38%
90	5	2.475	160%	1.548	30%	5.176	48%
49	6	3.396	145%	2.335	32%	7.252	47%
60	7	1.880	114%	1.654	35%	4.723	40%
80	9	1.594	118%	1.349	34%	4.001	40%
102	10	2.907	176%	1.654	30%	5.564	52%
Average -		2.517	128%	2.038	33%	6.144	42%
Maximum -		3.396	176%	2.782	37%	8.021	52%
Minimum -		1.594	78%	1.349	30%	4.001	29%
Fold difference -		2.13		2.06		2.00	

Table 3

GALLONS OF DHW USAGE (PER CAPITA) - WINTER (minus LEAKS)

TOTAL APTS	BLDG ID #	AVERAGE HOUR	Avg. hr consumption % of 15 min. max	15 MIN. MAX.	15 min. max consumption % of 60 min. max	60 MINUTE MAXIMUM	Avg. hr consumption % of 60 min. max
23	1	2.078	76%	2.751	37%	7.416	28%
30	2	2.394	112%	2.139	32%	6.642	36%
34	3	2.589	97%	2.665	35%	7.551	34%
90	5	1.881	134%	1.399	31%	4.583	41%
49	6	2.470	117%	2.104	33%	6.327	39%
60	7	1.662	104%	1.599	36%	4.505	37%
80	9	1.365	106%	1.292	34%	3.771	36%
102	10	1.978	139%	1.422	31%	4.635	43%
Average -		2.052	111%	1.921	34%	5.679	37%
Maximum -		2.589	139%	2.751	37%	7.551	43%
Minimum -		1.365	76%	1.292	31%	3.771	28%
Fold difference -		1.90		2.13		2.00	

Table 3-L

COMPARISON OF DHW PEAK CONSUMPTION GALLONS PER CAPITA - WINTER PERIOD

Figure 19

* Maximums

COMPARISON OF DHW PEAK CONSUMPTION GALLONS PER CAPITA - LEAKS, WINTER

Figure 19-L

* Maximums

These relationships can be used to model various configurations of hot water supply systems. As noted earlier, these peaking and one-, two- and three-hour consumption peaks are occurring concurrently, so they must be considered in the context of the overall consumption patterns in order to further evaluate generation and storage options.

Potential of Generating Storage

Figure 21 illustrates the actual consumption curve in a sample building (No. 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), which is equivalent to leveling the 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 capacity, respectively. Figure 22 depicts daily fluctuations as well as the multiple peaks and valleys that occur during the course of individual days, revealing even more opportunity for generation and draws from storage.

PARTS OF 3 HOUR DHW PEAK CONSUMPTION GALLONS PER CAPITA - WINTER PERIOD

** Note: All percentages represent the portion of the 180 minute peak.*

Figure 20

STORAGE POTENTIAL - BLDG 7 (FALL) **GALLONS PER OCCUP. APT. - WEEKDAY**

Figure 21

SAMPLE CONSUMPTION PATTERNS **BLDG 1 - 3 RANDOM DAYS**

Figure 22

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 Olivares⁸ of Ontario Hydro, that we choose this level of consumption with which to base any potential sizing parameters.

COMPARISON TO PUBLISHED ASHRAE FIGURES

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 68% below the monitored consumption of 124.14 gallons for the daily average gallons of DHW per apartment. The ASHRAE per apartment figure is, in fact, 27% lower than the per capita consumption of 54.10 gal/capita/day. Examining maximum hourly consumption (Table 5) we see that the ASHRAE data of 9.38 gallons is 30% below the monitored consumption of 13.46 gallons on a per apartment basis. Table 6, maximum day consumption, reveals that the ASHRAE data, at 69.75 gallons, is 65% below the monitored consumption of 200.6 gallons for the maximum day gallons of DHW per apartment. Again, the ASHRAE per-apartment figure is lower (21%) than the monitored per capita consumption of 88.0 gal/capita/day⁹. (Tables 4-L, 5-L and 6-L delineate the daily average, maximum hourly, and maximum daily gallons of DHW consumption after waste due to leaks have been removed. While the levels are slightly below those mentioned above, they are correspondingly greater than ASHRAE.) The results to date indicate use of unadjusted ASHRAE estimates will result in undersizing.

⁸ Olivares, T.C.. *HOT WATER SYSTEM DESIGN FOR MULTI-RESIDENTIAL BUILDINGS*. Report No. 87-239-K, Ontario Hydro Research Division, Ontario. 1987.

⁹ 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" (bottom line of each table) gallon figures.

AVERAGE GALLONS OF DHW PER DAY

Monitored data			ASHRAE ¹⁰	
TOTAL APTS	Per Capita	Per Occup. Apt.	# of Apts	Per Apt.
23	48.31	70.27	20 or less	42.0
30	61.24	207.77		
34	62.65	168.38		
49	75.00	163.04	50	40.0
60	39.16	72.14		
80	31.47	52.97	75	38.0
90	55.99	143.98		
102	65.99	131.99	100	37.0
Average	54.10	124.14		39.25

Table 4

MAXIMUM GALLONS OF DHW PER HOUR

Monitored data			ASHRAE ¹⁰	
TOTAL APTS	Per Capita	Per Occup. Apt.	# of Apts	Per Apt.
23	7.17	10.42	20 or less	12.0
30	7.07	24.00		
34	7.37	19.82		
49	6.93	15.07	50	10.0
60	4.34	7.99		
80	3.43	5.78	75	8.5
90	5.49	14.11		
102	5.32	10.49	100	7.0
Average	5.89	13.46		9.38

Table 5

¹⁰ 1987 ASHRAE Handbook, HVAC Systems and Applications. (Chapter 54 - Service Hot Water), ASHRAE, Atlanta.

AVERAGE GALLONS OF DHW PER DAY (- LEAKS)

Monitored data			ASHRAE ¹⁰	
TOTAL APTS	Per Capita	Per Occup. Apt.	# of Apts	Per Apt.
23	45.45	66.10	20 or less	42.0
30	53.76	182.40		
34	53.49	143.76		
49	53.23	115.73	50	40.0
60	36.11	66.51		
80	26.82	45.14	75	38.0
90	45.36	116.65		
102	44.19	88.38	100	37.0
Average	44.34	101.87		39.25

Table 4-L

MAXIMUM GALLONS OF DHW PER HOUR (- LEAKS)

Monitored data			ASHRAE ¹⁰	
TOTAL APTS	Per Capita	Per Occup. Apt.	# of Apts	Per Apt.
23	7.02	10.21	20 or less	12.0
30	6.80	23.05		
34	7.01	18.84		
49	6.03	13.10	50	10.0
60	4.21	7.75		
80	3.21	5.40	75	8.5
90	5.05	12.98		
102	4.54	9.71	100	7.0
Average	5.48	12.63		9.38

Table 5-L

MAXIMUM GALLONS OF DHW PER DAY

Monitored data			ASHRAE ¹⁰	
TOTAL APTS	Per Capita	Per Occup. Apt.	# of Apts	Per Apt.
23	93.6	136.2	20 or less	80.0
30	93.6	317.6		
34	104.6	281.1		
49	103.8	225.7	50	73.0
60	57.9	106.6		
80	45.4	76.5	75	66.0
90	89.8	230.8		
102	115.1	230.1	100	60.0
Average	88.0	200.6		69.75

Table 6

MAXIMUM GALLONS OF DHW PER DAY (- LEAKS)

Monitored data			ASHRAE ¹⁰	
TOTAL APTS	Per Capita	Per Occup. Apt.	# of Apts	Per Apt.
23	86.7	126.1	20 or less	80.0
30	80.9	274.6		
34	89.7	241.1		
49	83.6	181.8	50	73.0
60	52.4	96.5		
80	39.6	66.7	75	66.0
90	72.8	187.2		
102	74.0	148.0	100	60.0
Average	72.5	165.3		69.75

Table 6-L

Section 5

PROPOSED SYSTEM SIZING CRITERIA

LOW - MEDIUM - HIGH GUIDELINES

The format for the guidelines presented here differs from those currently used (predominantly *ASHRAE Handbook Chapter 44, Table 7*). This new approach represents the results of discussions with system design professionals, including members of ASHRAE T.C. 6.6 (Service Hot Water), who have indicated a preference for a "Low - Medium - High" (LMH) users set of guidelines, rather than a specific, singular volume value. By providing LMH tables and guidelines for their application it is felt that the design engineer or contractor can use these as a tool to better match the situation at the site they are serving. Additionally, the figures presented in the LMH tables include the more detailed level of "Peak 15-Minute" gallon consumption, which should assist in the design process. One other significant difference from the ASHRAE approach is the use of per capita-based rather than per apartment-based usage factors.

New York

LOW - MEDIUM - HIGH GUIDELINES

Hot Water Demands and Use for Multi Family Buildings

	Maximum Hour	Peak 15 Minutes	Maximum Day	Average Day
Low	4.0 gal/person	1.5 gal/person	40.0 gal/person	27.0 gal/person
Med	6.0 gal/person	2.0 gal/person	73.0 gal/person	44.0 gal/person
High	8.0 gal/person	3.0 gal/person	90.0 gal/person	54.0 gal/person

Table 7

While there is recognition that diversification factors based on the size of the building likely play a role in allowing systems to be smaller on a gallons-per-capita (or per apartment) basis as the facility gets increasingly larger, (this size effect has not been seen in either our research sites or other recent research done by Carpenter & Kokko¹¹), it is clear that other factors such as occupant income levels, population densities, and appliances have a greater effect on consumption.

The following are guidelines for selecting/applying of the low, medium, or high values:

Higher concentrations of certain demographic characteristics correlate to increased DHW consumption. The following categories, in descending order of magnitude, can be used to select from the gallnage range presented in the LMH tables.

No occupants work	
Public assistance and low income (mix)	
Family and 1-parent households (mix)	HIGH
High percent of Children	
Low income	
Families	
Public assistance	
Singles	MEDIUM
One parent households	
Couples	
Higher population density	
Middle income	
Seniors	LOW
One person works, one stays home	
All occupants work	

Additionally, either the existence or anticipated installation of appliances such as apartment clothes and dishwashers, and public clothes washers, should be considered as a factor in increasing the design capacity of the DHW system towards a higher volume. Building management practices, such as the explicit prohibition of apartment washers (in the lease), or the existence of bath/kitchen hook-ups should be factored into the

¹¹ Carpenter, S.C. and J.P. Kokko. *Estimating Hot Water Use In Existing Commercial Buildings*. ASHRAE Transactions 94(2):3-12. 1988.

design process. A diversification factor that lowers the probability of coincident consumption may also be employed in larger buildings.

In buildings where corrective maintenance cannot be maintained, leaks are found to contribute an additional 20 to 30% to the DHW consumption.¹²

The design engineer or contractor should use his or her knowledge of the facility, locale, planned or foreseen demographics, and other applicable information to apply the LMH guidelines above in selecting the most appropriate portion of the range from the LMH domestic hot water tables.

Once a portion of the range has been selected, the figures should be converted into per apartment or per building gallonage by multiplication with existing building occupancies (for energy calculations), or maximum occupancy levels based on persons per apartment size/type (for new system design). For example, studios = 2 persons, 1-bedroom apartments = 3 persons, 2-bedrooms = 3-5 persons, ... (depending on local standards or regulations.)

If customization is desired to select the most appropriate system sizing levels for a particular building, it is recommended that the current consumption be monitored for a short period. The best time to conduct this monitoring would be a series of winter weekend days, during which the design engineer should focus on/identify the 2- to 3-hour peak periods that generally occur between 10:00 AM and 2:00 PM. A system designed to meet these DHW demands should satisfy all other year-round requirements.

Development of National LMH Table

While it was not the original intention of the Energy Authority or Energy Management & Research Associates, the author was approached by ASHRAE's Technical Committee (T.C.) 6.6 while completing this project and asked to develop a set of values that went past just the New York City market. This effort coincided with work being conducted by Bill Thrasher of AGA Labs into service hot water (SHW) consumption and loads for various types of commercial buildings (under ASHRAE Research Project 600). The data presented in Table 9 along with similar guidelines on

¹² Based on the findings of this study and Vine et al. 1987. (see Section 9)

**DHW CONSUMPTION DATA FROM OTHER
MULTI-FAMILY MONITORED RESEARCH STUDIES**

<u>Study*</u>	<u>Bldg ID</u>	<u>Average Day</u>	<u>Maximum Hour</u>	<u>Maximum Day</u>	<u>Peak 15 Minutes</u>	<u>Location</u>
1	a	15.18	2.79	20.13	0.95	Toronto
1	b	18.96	2.92	28.77	0.99	
1	c	25.96	4.58	37.62	1.56	
1	d	20.56	3.3	28.55	1.12	
1	e	23.27	3.04	29.42	1.03	
2		23	3.7	37.0	1.27	New Jersey
3	a	47.2	7.7	75.9	2.60	San Francisco
3	b	41.5	6.7	66.8	2.29	
3	c	34.2	5.5	55.0	1.89	
3	d	30.2	4.9	48.6	1.67	
4		27.2	4.1	43.8	1.39	New Jersey
5		24	3.9	38.6	1.32	
6	a	23.2	4.85	34.2	1.65	Minneapolis
6	b	20.9	3.4	34.4	1.15	
6	c	31.6	4.28	75.6	1.46	
6	d	16.1	4.1	27.2	1.39	
6	e	13.6	3.5	21.4	1.19	
6	f	17	4.4	22.1	1.50	
6	g	21.6	7.4	34.7	2.52	
6	h	29.9	8.8	52.4	2.99	
7		12.1	n/a	19.5	n/a	Canada
8	a	45.45	7.416	86.7	2.751	New York
8	b	53.76	6.642	80.9	2.139	
8	c	53.49	7.551	89.7	2.665	
8	d	45.36	4.583	72.8	1.399	
8	e	53.23	6.327	83.6	2.104	
8	f	36.11	4.505	52.4	1.599	
8	g	26.82	3.771	39.6	1.292	
8	h	44.19	4.635	74.0	1.422	
AVERAGE:		30.19	4.98	48.67	1.69	
MAXIMUM:		53.76	8.80	89.70	2.99	
MINIMUM:		12.10	2.79	19.47	0.95	

* Study: 1 - Perlman & Milligan; Ciz and Milligan; 2 - DeCioco; 3 - Vine et al; 4 - Taylor & Force; 5 - Nelson; 6 - CEUE; 7 - TES Ltd; 8 - Goldner/EMRA. See Section 9 for full references.

Table 8

other building types (from the AGA research) are intended to update the existing ASHRAE hot water demand values and represent changes in numbers of water consuming devices, personal habits, life styles, and sanitation needs since the late 1960s. The results of these efforts were reviewed, (and the Table 9 data adopted), for inclusion in the 1995 ASHRAE Handbook revision. Table 8 contains the data from which the National LMH table (Table 9) was developed. Much of the data was summarized by Bill Thrasher in the AGA report to T.C. 6.6; the remaining data came from EMRA's New York project. Note that all of the studies did not record values for every parameter (i.e., Maximum Day). In cases where only daily average gallons or hourly maximums exist, it was possible to use these figures and the relationships of average to peak consumption found in the more detailed studies to calculate the missing values. For example, in Study No. 3, the maximum hour gallons was computed by multiplying the average day gallon figure by a factor derived by examining the relationship between all the other average day values and their respective maximum day consumptions. While these are, by their nature, approximations, they seem to fall in the range suggested by the actual values and should therefore be considered of use.

Note on actual reported vs. calculated figures in Table 8: figures that were actually reported in the various monitored data studies appear as the darker (normal) print, calculated figures appear as the lighter (thinner) typeface.

Review of the other studies, discussions with L. Spielvogel (author of the present ASHRAE Table 7), and analysis of the data has resulted in the following 'National' LMH Guidelines:

National **LOW - MEDIUM - HIGH GUIDELINES**

Hot Water Demands and Use for Multi Family Buildings

	Maximum Hour	Peak 15 Minutes	Maximum Day	Average Day
Low	3.0 gal (11.0 L)/person	1.0 gal (4.0 L)/person	20.0 gal (76.0 L)/person	14.0 gal (53.0 L)/person
Med	5.0 gal (19.0 L)/person	2.0 gal (6.5 L)/person	49.0 gal (185.0 L)/person	30.0 gal (114.0 L)/person
High	9.0 gal (34.0 L)/person	3.0 gal (11.5 L)/person	90.0 gal (340.0 L)/person	54.0 gal (205.0 L)/person

Table 9

Both research and practical experience in different areas of North America indicate that there are variations in DHW use between geographical locations. There is no distinctive pattern that can be identified with the available data. More research should be done in this area.

Note that the figures presented (in both tables 7 and 9) are for centrally fired systems; individual apartment water heater systems are likely to have lower levels of consumption. The numbers in the LMH tables also may vary from the *ASHRAE Table 7* due to the fact that the ASHRAE work¹³ was conducted in 1967-68, and a greater abundance of water-consuming devices are in use today, along with the change in personal habits over time.

¹³ Werden, R.G and L.G. Spielvogel. *SIZING OF SERVICE WATER HEATING EQUIPMENT in Commercial and Institutional Buildings*. Report No. 2, Project RP61, Edison Electric Institute, New York. 1969.

Section 6

ENERGY USE ANALYSIS

An evaluation of the energy used to produce DHW was conducted for the summer period, when the systems are used strictly for DHW purposes. As depicted in Figure 23 this analysis revealed that an average of 150.6 gallons of DHW (used at the tap) was produced for each 1 gallon of No. 6 oil (or equivalent¹⁴) consumed by the burner. The volume of DHW produced by 1 gallon of No. 6 oil equivalent ranged, by a factor of 2, from 102 to 206 gallons. Included in these figures are various levels of combustion efficiency, standby losses, pipe insulation, and other real-time factors that affect the operation of systems in occupied buildings. These numbers can be used as a check against results of energy savings predictions from audit calculations related to DHW conservation related measures (such as low flow showerheads).

Figure 23

¹⁴ One gallon of No. 6 oil = 149,690 BTU

Section 7

DISCUSSION

SYSTEM OVERSIZING

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 New York City) are often found to be oversized by between 30 and 200%¹⁵.

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 loads¹⁶. Generally, the individual responsible will use a 'what was there before', 'looks like ...', or some rough rule-of-thumb method. In new construction, the correct method is to 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 (equivalent direct radiation) method. To this (heating load) 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. The guidelines developed as a result of this research will allow for proper sizing, which will save buildings money in two ways. First, lower initial equipment investments will result from smaller, more correctly sized equipment; and second, in lower annual - lifecycle 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.

¹⁵ Experience of ECD. Oversizing percentages were computed against the building's radiation load plus an estimated DHW load.

¹⁶ It would be most efficient to install separate space heating and DHW systems, but it is unlikely that a significant percentage of the New York City market will take this route any time soon, in the light of the resistance to having an additional mechanical system to care for.

Section 8

FUTURE WORK

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. A second phase of the research project will investigate these issues with collection of *5-minute* total DHW flows and (newly installed) recirculation flows in a subset of three of the sites this work began in March 1993.

This second phase project will use the real-time/monitored data to evaluate models of various types of DHW supply systems, such as: direct fired storage tank, tankless coil, tankless coil with storage tank, separate DHW boiler with storage, and direct fired instantaneous. The models will utilize the measured data to determine optimized requirements. Optimization shall be evaluated for both peak-load sizing and for minimum annual energy consumption based on the selection of instantaneous, storage, or the combined instantaneous and storage requirements of the system. Where storage is deemed to be a requisite optimum, sizing of the storage system for minimum energy consumption, will be determined. Relative efficiency ratios for typical systems shall be presented.

A survey of equipment manufacturers and installers and other industry sources will be used to determine the costs of generic system components. Results of life cycle costing analyses utilizing the energy and equipment cost data determined during the study will be presented. The economic benefits of applying various equipment types and systems to a range of building sizes shall be demonstrated.

In the process of creating the data base for this project a substantial amount of boiler operation and apartment temperature data were collected. Analysis of this data will reveal insights pertaining to heating production and distribution.

Section 9

REFERENCES

**The following referenced studies were
used to create the National LMH Guidelines:**

1. Carpenter, S.C. and J.P. Kokko. *Estimating Hot Water Use In Existing Commercial Buildings*. ASHRAE Transactions 94(2):3-12. 1988.
2. Ciz, J.B.. *Performance of Domestic Hot Water Systems in Five Apartment Buildings (Part I - Installation and Commissioning)*. OHRD Rpt. 86-77-K. 1986.
3. Milligan, N.H. *Performance of Domestic Hot Water Systems in Five Apartment Buildings (Part II - Analysis and Results)*. OHRD Rpt. 87-53-K. 1987.
4. Minneapolis data collected from various system controls studies conducted by the Center for Energy and the Urban Environment (CEUE). Consumption and load data from those studies was analyzed by Thrasher et. al. (reference below).
5. Pearlman, M. and N.H. Milligan. *Hot Water And Energy Use In Apartment Buildings*. ASHRAE Transactions, Vol. 94, Pt. 1. 1988.
6. T E S Limited. *Monitoring of the Commercial/Industrial Solar Demonstration Program Year 4 Final Report*. Renewable Energy Branch, Energy Mines and Resources, Canada. 1989.
7. Taylor, H. and F. Force. *Patterns of Domestic Hot Water Consumption for a Multifamily Building*. Proceedings of the 1986 ACEEE Summer Study on Energy Efficiency in Buildings. 1986.
8. Thrasher, W.H. and D.W. DeWerth. *Comparison Of Collected And Compiled Existing Data On Service Hot Water Use Patterns In Residential And Commercial Establishments - Phase II Final Report*. American Gas Association Laboratories, ASHRAE research project 600-RP. 1993.
9. Vine, E., R. Diamond, and R. Szydlowski. *Domestic Hot Water Consumption In Four Low Income Apartment Buildings*. Energy, Volume 12, No. 6. 1987.