DHW Modeling: System Sizing and Selection Criteria

A Study of Baseloads and Seasonal Efficiency

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DHW MODELING: SYSTEM SIZING AND SELECTION CRITERIA
A STUDY OF BASELOADS AND SEASONAL EFFICIENCY

Phase 2 – Final Report

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ABSTRACT

This report reviews highlights of the final results of Phase 1 of the research study on domestic hot water (DHW) consumption and demand levels for multi family buildings. The report focuses on the findings of the DHW Modeling portion of the second phase study which establishes system sizing and selection criteria, as well as heating system research of the building set on fuel consumption, and single pipe steam heating/DHW systems operations.

This second phase study used computer models to determine the most energy efficient and cost effective DHW systems for small to moderately sized multifamily buildings. The project used models of various types of DHW supply systems, such as: direct-fired storage tank, tankless coil, separate DHW boiler with storage, and direct-fired instantaneous. Optimization of both system sizing and minimum annual energy consumption was evaluated based on selection of instantaneous, storage, or combined instantaneous and storage requirements of systems. Where storage was deemed to be a requisite, optimum sizing of the storage system for minimum energy consumption was determined. The energy saving (or % efficiency) over the base case of the properly sized tankless coil system averaged 10% for direct-fired DHW heaters, 18% for separate DHW boiler w/(unfired storage) tank systems, and 15% for instantaneous DHW systems.

Life cycle costing analyses utilizing energy and equipment cost data reveal the economic benefits of applying the various equipment types and systems. The LCC savings over the tankless coil base case averaged 12.6% for the separate DHW boiler w/tank systems, and 12.8% for the instantaneous DHW systems. System sizing examples for a separate DHW boiler w/tank system designed using a new "30/3 guideline" developed from the research, as well as a peak load instantaneous system are presented.

Additionally, monitored research was conducted to better understand the energy usage patterns of heating and hot water systems. The report presents the results of the research on fuel consumption, and single pipe steam heating/DHW systems operations. The effects of seasonal efficiency were analyzed by examining daily fuel use vs. boiler run time at different outdoor temperatures, and during various seasons. Also, time of occurrence and duration of burner on-and-off cycles were studied to determine the trends and potential effects of system cycling. These data are presented in such a way as to illustrate real-time operations and show the negative effects of system oversizing, (an all-too-common practice in this stock of buildings). In addition to the heating data analyses, calculations (based on this project and prior DHW research) are presented that allow for a more accurate treatment of seasonally varied DHW consumption.

KEY WORDS

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

ACKNOWLEDGEMENTS

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SUMMARY

INTRODUCTION

This report is on Phase 2 of a multiyear project to develop comprehensive operating data on domestic hot water (DHW) systems for use in system design and specification. Phase 1 collected and analyzed extensive data on DHW consumption and demand patterns in multi family buildings, as described in Energy Use and Domestic Hot Water Consumption - Phase 1 (NYSERDA Report No. 94-19)[1]. Phase 2 collected further data and performed modeling to develop the most efficient and economic system designs. In addition, Phase 2 included data analysis to better understand boiler operation and fuel consumption as affected by weather.

Energy professionals have long been frustrated by the lack of reliable data upon which to size DHW generating equipment. Design engineers and contractors know that strict adherence to the traditional American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) data often results in undersized equipment. To be on the safe side, many of them oversize equipment resulting in systems with higher equipment and operating costs.

The Phase 2 study employed the Phase 1 data as well as more detailed 5-minute monitored data to evaluate both the energy and economic impacts of employing various combinations of instantaneous generation and/or storage systems to meet DHW loads. Additionally, in order to allow for the potential future development of a more-accurate and shorter-term energy use targeting/tracking methodology, the monitored research data was analyzed to better understand the energy usage patterns of heating and hot water systems. The report also presents the results of the research on fuel consumption, and single-pipe steam heating/DHW systems operations.

The data presented here reflects an enriched set of DHW demand and consumption figures (to include the more detailed periods of 5-minutes through 3-hour peaks), evaluation of the life cycle costs of potential generation and storage systems, analyses

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[1] Goldner, F.S. November 1994. Energy Use And Domestic Hot Water Consumption: Final Project Report-Phase 1. Report No. 94-19. New York State Energy Research and Development Authority, Albany, NY.

on single-pipe steam heating/DHW systems operations and effects on seasonal efficiency.

Phase 2 reviewed highlights of the Phase 1 research on DHW consumption and demand levels, as they relate to the recently published new ASHRAE guidelines and the recently released American Society of Plumbing Engineers (ASPE) *Domestic Water Heating Design Manual.*

Modeling was then performed to establish system sizing and selection criteria for small to moderately sized multifamily buildings. Model types included: direct fired storage tank, tankless coil, separate DHW boiler with storage, and direct fired instantaneous. *This study differs from previous work done in that it utilized over a year and a half of real-time/monitored data* (over 130 MB).

The culmination of the Phase 2 work was the development of a set of guidelines for specification and sizing of DHW equipment in multi family buildings.

DATA SETS

Instrumented monitoring of heating plants and DHW was conducted for 14 months in 30 multi-family buildings in Phase 1 and an additional 100 plus days in the Phase 2. Nine buildings received instrumentation upgrades to provide detailed DHW consumption data. Additionally, the data on several buildings was further upgraded to include recirculation flow information.

The data was collected using 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. For nine buildings, additional data collection included: stack temperature, boiler make-up water flow, DHW flow in 5- and 15-minute increments, oil flow, and DHW temperature before and after the mixing valve and on the return line.

The data includes that collected by Energy Management & Research Associates (EMRA) in New York City, as well as summary DHW data from studies in seven other locales (22 additional monitored sites) across the United States and Canada. Additionally, for the heating system weather analysis, a subset of data from the

Association of Energy Affordability's "Multi Family Research Project" was used to check the validity of some findings[2].

DHW SYSTEM MODELING AND FINDINGS

One of the key results of the Phase 1 research was the determination of accurate levels of DHW consumption and demand, and identification of factors affecting these levels. As part of this Phase 2 research, a series of computer models of DHW generation and storage systems were constructed to evaluate the energy efficiency and cost-effectiveness of various combinations of generation types and storage level schemes. The models were used to analyze the capabilities and effects (i.e., energy costs) of running different levels of instantaneous generation and storage capacity on each of the sites. The simulations ranged from a tankless coil in a combination heat/DHW boiler to a separately fired DHW system with the maximum of storage tank reserve. Application of the actual data was used in order to gain a clearer understanding of the dynamics of the interaction of load profiles on the DHW generation system.

The format for the guidelines presented differs from those currently used (predominantly *ASHRAE Handbook, Chapter 44, Table 7*)[3]. 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) and ASPE, who have indicated a preference for guidelines indicating "Low - Medium - High" (LMH) user values rather than singular volume values. 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 LMH tables (presented in the body of the report) include the more detailed level of "Peak 5-, Peak 15- and Peak-30 minute" gallon consumption, which should assist in the design process. In addition, the guidelines presented reflect per capita rather than per apartment based usage factors. This new approach has been adopted by ASHRAE T.C. 6.6 for inclusion in the *1995 Handbook* revision, and has also been included in the recently released ASPE *Domestic Water Heating Design Manual*.

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[2] We would like to thank David Hepinstall of the Association for Energy Affordability for access to this data for use this project.

[3] *1991 ASHRAE Handbook, HVAC Systems and Applications*. (Chapter 44 - Service Hot Water), ASHRAE, Atlanta.

Energy results

The building simulations revealed energy saving (or % efficiency) over the base case of the properly sized tankless coil system ranged from 3 to 18% for direct-fired DHW heaters, with an average of 10%. The advantage with separate DHW boiler w/tank systems ranged from 11 to 30%, and averaged 18%. Savings for instantaneous DHW systems ranged from 9 to 24%, averaging 15%. The variance in the range of savings is due to a combination of factors including the mix of generation vs. storage components (for the first two systems), shape of the consumption pattern, usage (LMH) level, recirculation system type, and load factors.

The base case - tankless coil systems were sized to meet both the hot water load and the heating load (based on a survey of the installed radiation at each site). Savings for the other system types would likely have been even greater had the tankless coil systems been grossly oversized, as is often the case when a contractor or engineer employs one of the many rule of thumb equipment selection methods that persist in the marketplace.

Life Cycle Costing

Costs of various system components were compiled for system economic analyses. These equipment costs and the energy costs computed by the various computer models were used in life cycle costing (LCC) models to evaluate the economic efficiencies of employing various systems to satisfy DHW needs. These analyses calculated the cost of owning and operating each potential system over a 20 year life span. To develop true life cycle costs, it was necessary to configure the models with certain basic economic and non-case-specific parameters in addition to the installed equipment costs and annual energy consumption. These parameters included equipment depreciation schedules, initial fuel cost, fuel cost escalation, tax rates, and discount rate. Constant values were used for all cases.

In addition to straight economics, one of the advantages of the separate DHW boiler w/tank systems is the flexibility the designer has to mix and match components (boilers and storage tanks) that are available in a vast array of sizes from various manufacturers. This provides the system designer the flexibility to more closely match the optimum (lowest cost) configuration that meets the building's load.

The LCC savings over the tankless coil ranged from 7 to 19% for the separate DHW boiler w/tank systems and from 10 to 19% for the instantaneous systems, and averaged 12.6% and 12.8%, respectively.

CONCLUSIONS / RECOMMENDATIONS FOR DHW SYSTEM DESIGN

Use of the LMH guidelines will allow for proper sizing of DHW systems. This will save buildings money in two ways: first, in lower initial equipment investments for smaller more correctly sized equipment; and second, in lower annual life cycle operating costs from higher operating (seasonal) efficiencies due to reduced cycling of equipment operating closer to full load.

Additionally, the results from the Phase 2 modeling/LCC research indicate that selection of either an instantaneous hot water heater, or a separate DHW boiler w/tank configuration will result in the optimum mix of low life cycle costs, high energy efficiencies, and in-the-field reliability. In small to mid-sized buildings (up to 80 apartments) it is recommended to install either a separate DHW boiler w/tank system sized to the "30/3" guideline, or an instantaneous system. In large buildings (100 plus apartments) and/or mid-sized to large buildings (more than 75 and less than 100 apartments) which fall into the upper end of the LMH classification scale (more toward the "High" category) it is recommended to install an Instantaneous system. (See the Sizing Example in Section 5 for instructions on how to determine the proper system size[s].)

HEATING SYSTEM WEATHER RELATED ANALYSIS

In analyzing a facility's energy usage against a controlling variable, such as weather or units of production, we attempt to remove consumption attributable to factors other than the main variable. This "other" portion of consumption, referred to as the facility's baseload usage, is then removed as an adjustment from the total consumption before analysis against the controlling factor. All too often professionals conducting such evaluations assume that if they can find a period during which only the baseload consumption is occurring, that level (of consumption) can be used to make adjustments across the entire year.

It is important to investigate what is actually occurring with the assumed baseload across the full year. (One should not assume that it is an even load throughout the year.) In multi family buildings the industry standard has been to consider the DHW load as the base. It is customary to take the summer fuel bills and project that level of consumption out evenly through 12 months. The argument is that during the summer period the heating plant is operating solely to provide DHW, and therefore all fuel use during this period can be attributed to that function. However, the present research showed that this is not the case. Also, until recently it had been assumed that DHW use, while variant between sites, was constant from month to month within a building. Results from the first phase have revealed the constant level assumption to be incorrect.

Summary Of Significant Issues

It is necessary to understand and adjust for what is actually occurring with the baseload across the full year. For DHW in a multifamily building the summer baseload level should be adjusted upward by a factor of 1.1 in fall, 1.25 in winter, and 1.23 in spring.

When combination heating/DHW systems are just generating DHW in the summer, the average heating plant system efficiency was found to be only 42%.

In evaluating energy use it is necessary to understand both the facility's operation and the underlying suppositions of the energy indices method to be employed.

The mean temperature of the day (computed as high - low / 2) is almost identical to average outdoor temperature, (computed by averaging the 24 hourly readings each day), and is therefore a good representation for weather conditions.

As load on a heating plant increases towards closer to full-load condition, the more efficiently the system operates. This phenomenon is a result of the boiler needing to operate for longer periods (increased daily burner runtime towards full-capacity condition) to supply larger heating loads at lower temperatures, and less cycling due to longer duration of each cycle runtime during colder periods.

All degree days are not equal. A degree day on a 50^{o} F day requires a different amount of fuel to satisfy it's related heating load than a degree day on a 25^{o} F day. It is not possible to compare energy consumption of a building in the fall to energy consumption (of that same building) during a winter period. A potential solution to the need to evaluate energy usage on a shorter-term (less than annual) basis would be development of a Seasonally Adjusted Degree Day Methodology (*SADDM*).

In multifamily buildings, the conventional 65-degree day base system may result in misleading conclusions when making year-to-year weather-adjusted energy usage and savings comparisons, particularly in buildings where the heating plant control algorithm differs from the assumptions of the conventional basis for calculating degree days.

Additionally, a full set of DD_55 (degree day 55) figures for every day from January 1991 through June 1997 have been included in Appendix A as a reference tool for energy and building professionals who choose to employ the use of this more appropriate (for N.Y.C. multifamily buildings) degree day computation methodology.

FUTURE WORK

The next potential phase of this project, would involve setting up a demonstration of efficient DHW systems. It would involve the installation and monitoring of a field demonstration of the most efficient DHW generation configurations revealed by the modeling and evaluations. This would be used to provide a field test of the analysis findings, and also act as case studies to promote change over to more energy and economically efficient DHW systems in the multi family building market.

Additional follow-up that should be investigated involves possible ways in which the DD_55 (degree day 55) reference tool data developed in this project can be shared electronically with end-users. One likely possibility would be to publish it on the Internet.

Additional work should go into research that uses the greater understanding of the effects of seasonal efficiency uncovered in this project to create an adaptable *SADDM*. Such a methodology would assist energy professionals and facility managers in evaluating shorter-term increases or decreases in consumption that are currently only apparent with annual analyses.

Section 1
INTRODUCTION

This report is on Phase 2 of a multiyear research project to develop comprehensive operating data on domestic hot water (DHW) systems for use in system design and specification. Phase 1 collected and analyzed extensive data on DHW consumption and demand patterns in multi family buildings. Phase 2 collected further data and performed modeling to develop the most efficient and economic system designs. In addition to the DHW system analyses conducted, this Phase 2 project also investigated some of the heating system data collected on the sites during the Phase 1 study to better understand boiler operation and fuel consumption as affected by weather. While many of the descriptors such as building selection criteria and tenant demographics can be found in greater detail in NYSERDA Report # 94-19 (Energy Use and Domestic Hot Water Consumption, Phase 1), we have included a brief overview of the Phase 1 work here in order to lay a base of knowledge for the reader.

GENERAL BACKGROUND

Energy professionals have long been frustrated by the lack of reliable data upon which to size DHW generating equipment. Design engineers and contractors know that strict adherence to the traditional American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) data often results in undersized equipment. To be on the safe side, many of them oversize equipment resulting in systems with higher equipment and operating costs.

This research reflects the particular concern for the energy efficiency and economic viability of multifamily buildings. Capital funds for housing as well as building self improvement funds are typically scarce; hence, it is imperative that none are wasted on oversized boilers and inefficient operation.

Phase 1

The Phase 1 project was an analysis of 14 months of real time monitored data aimed at developing DHW consumption and demand patterns for system sizing criteria. The research developed a comprehensive database of heating and domestic hot water system operational data, in a set of multi-family buildings which were planned to be used in future design and specification preparation.

The research objectives of Phase 1 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, to be used in specification preparation and revision.

To these ends data was collected in a total of 30 multi family buildings. At the beginning of Phase 1 a subset of these sites, 9 buildings (later identified as Buildings 1 through 3 and 5 through 10) had their monitoring systems upgraded with additional data monitoring equipment to collect the more detailed 15 minute DHW flow data that served as the basis for much of the analyses conducted. (For clarification it should be noted that Building 8 was discounted due to a flow meter equipment problem.)

Throughout the data several relationships were 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.

The key result of the Phase 1 research was the development of the "Low - Medium - High" (LMH) guidelines for DHW system sizing. The format of the guidelines presented in the Final Report (NYSERDA Report # 94-19) differs from those previously used (predominantly *ASHRAE Handbook Chapter 44, Table 7*). This new approach represented the results of discussions with system design professionals, including members of ASHRAE Technical Committee (T.C.) 6.6 (Service Hot Water), who indicated a preference for a "Low - Medium - High" set of guidelines, rather than a specific, singular volume value. By providing LMH tables and guidelines for their application, it was 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 original LMH tables included the more detailed level of "Peak 15 Minute" gallon consumption, to assist in the design process. One other significant difference is the use of per capita rather than per apartment based usage factors.

This effort coincided with work being conducted by American Gas Association (AGA) Labs into service hot water (SHW) consumption and loads for various types of commercial buildings. The LMH table was constructed using the monitored data from our Phase 1 study along with data collected by 9 other sets of researchers around North

America; (these are broken out in Section 8). The LMH approach and guidelines were adopted for inclusion in the 1995 ASHRAE Handbook revision.

Phase 2

The Phase 2 study employed the Phase 1 data as well as additional data collected in Buildings 7, 9 and 10 which had their monitoring systems upgraded to allow for more detailed - 5 minute - data. This was used to evaluate both the energy and economic impacts of employing various combinations of instantaneous generation and/or storage systems to meet DHW loads. In addition to the DHW work, in order to allow for the potential future development of a more-accurate and shorter-term energy use targeting/tracking methodology, the monitored research data was analyzed to better understand the energy usage patterns of heating and hot water systems. The report also presents the results of research on fuel consumption, and single pipe steam heating/DHW systems operations.

The two objectives of this research were: (a) analysis of a comprehensive set of multifamily building DHW consumption and demand data for the purposes of developing the most economic production system design(s) and (b) analysis of a the heating system data to better understand weather affected fuel consumption and boiler operations.

DHW System Modeling. The data presented here reflects an enriched set of DHW demand and consumption figures (to include the more detailed periods of 5 minutes through 3 hour peaks), evaluation of the life cycle costs of potential generation and storage systems, analyses on single pipe steam heating/DHW systems operations and effects on seasonal efficiency.

Phase 2 reviewed highlights of the Phase 1 of the research on DHW consumption and demand levels as they relate to the recently published new ASHRAE guidelines and the recently released American Society of Plumbing Engineers (ASPE) Domestic Water Heating Design Manual.

Modeling was then performed to establish system sizing and selection criteria for small to moderately sized multifamily buildings. The DHW supply systems (computer) model types used included: direct-fired storage tank, tankless coil, separate DHW boiler with storage, and direct-fired instantaneous. *This study differs from previous* *work done in that it utilized over a year and a half worth of real-time monitored data* (over 130 Mega Bytes). The data included DHW flows (at *5 and 15 minute intervals*, collected during Phase 2 and 1, respectively), recirculation flow, fuel flows, DHW temperatures before and after the mixing valve as well as on the return loop, boiler cycle times, and burner runtimes.

Optimization of both system sizing and minimum annual energy consumption was evaluated based on selection of instantaneous, storage, or combined instantaneous and storage system requirements. Where storage was deemed to be a requisite, optimum sizing of the storage system for minimum energy consumption was determined. Relative efficiency ratios for typical systems are presented. The energy saving (or percent efficiency) over the base case of the properly sized tankless coil system averaged 10% for direct-fired DHW heaters, 18% for separate DHW boilers with (unfired storage) tank systems, and 15% for instantaneous DHW systems.

Life cycle costing (LCC) analyses utilizing energy and equipment cost data revealed the economic benefits of applying the various equipment types and systems. The LCC savings over the tankless coil base case averaged 12.6% for the separate DHW boiler with tank systems and 12.8% for the instantaneous DHW systems. System sizing examples are presented for a separate DHW boiler with tank system designed using the new "30/3 guideline" developed from the research, as well as for a peak load Instantaneous system.

Heating System Data Analyses. The report reviews the effects of seasonal weather variations on heating system performance in multi-family buildings. By investigating the 14 months of actual operating data from 30 occupied sites (previously collected during Phase 1), the research has been able to document and clearly illustrate some previously held assumptions regarding seasonal efficiency of these systems.

The data set investigated included monitored apartment, outdoor and boiler water temperatures, burner on-off times, stack temperature, oil & boiler make-up water flows, and DHW temperatures at various points on the system. This data set represents what is potentially the largest multi-family building operations/energy use database in existence.

The effects of seasonal efficiency have been analyzed by examining daily fuel use vs. boiler runtime at different outdoor temperatures, and during the various seasons. Also, time of occurrence and duration of burner on-and-off cycles have been studied to determine the trends and potential effects of system cycling. These data are presented in such a way as to illustrate real-time operations and show the negative effects of system oversizing, (an all-too-common practice in this stock of buildings). In addition to the heating data analyses, calculations (based on this project and Phase 1) are presented that allow for a more accurate treatment of seasonally varied DHW consumption; (we suggest a series of seasonal DHW consumption level adjustment factors be used as opposed to the conventional practice of taking summer consumption and projecting that level evenly across the year.)

The research concludes by projecting how we may use this better understanding of the effects of seasonal efficiency to create a Seasonally Adjusted Degree Day Methodology (*SADDM*). Such a *SADDM* would assist energy professionals and facility managers in evaluating shorter-term increases or decreases in consumption, which are currently only apparent with annual analyses.

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 Langsam Property Services, which had a reputation as a well-run building management firm, was selected. This decision paid enormous dividends in terms of equipment upkeep, availability of historical building records, and access to both the building facilities and operating personnel. The 30 buildings that were used in both Phase 1 and Phase 2 were selected from approximately 70 Langsam sites in which OAS Heat Computers[4] were 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 more than 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 having 17 to 103 apartments, and have either five or six aboveground stories. Table 1 provides building characteristics, (for those sites in which we collected the most detailed level of data), including wether the buildings were constructed pre-1902 (old law) or between 1902 and 1928 (new law)[5]. 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.

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[4] 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.

[5] 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 were 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	In-apartment % Dish-washers	% Cloths washers	% Low flow shower-heads	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

DATA COLLECTION

Instrumented monitoring of heating plants and DHW was conducted for 14 months during Phase 1 in 30 multi-family buildings. (This included 15 minute DHW flow interval monitoring in the nine upgraded sites.) To enhance the database and provide additional information on DHW system operations, Phase 2 further upgraded Buildings 7, 9, and 10 to collect five minute interval recirculation and DHW flow data for an additional 100+ days. All of the sites were located in New York City and the monitoring systems were integrated into existing boiler control systems in buildings operated by Langsam Property Services.

The data was collected by Heat Computers that monitored the following data points on all 30 buildings: internal apartment temperatures, outdoor temperature, burner on-off-times, boiler water (aquastat) temperature, and DHW temperature. During Phase 1 nine buildings (ID #s 1-3 and 5-10) had additional data monitoring equipment and programming 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. During Phase 2 three buildings had their monitoring systems further upgraded with recirculation flow meters and had their capabilities expanded to collect both DHW consumption and recirculation flows in 5-minute increments. Measurements from the various devices were recorded periodically (every 5 minutes, 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 rearranged the data to an Rbase (data base) readable format, and performed a number of preliminary calculations. The data were then loaded into a specially designed data base where macros performed a second level of calculations. The Rbase environment was then used to perform specific analyses and output smaller data sets to Quattro Pro (a spreadsheet) for graphical analyses and presentations.

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

MONITORING EQUIPMENT

Data from the monitoring equipment was all collected by the Heat Computer. This was accomplished by having the Heat Computer 'talk to' or read the various sensors and meters on a cycle that repeats itself every 20 milliseconds (ms). The devices were essentially read continuously, and the data stored at set points in time (i.e., every hour on the hour for apartment and DHW temperature measurements, and every 5 or 15 minutes for DHW consumption and recirculation 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^{o} F within the rated 40 to 251^{o} F range. The stack temperature sensors were thermocouples rated from 4 to 1010 ^{o}F and are accurate to +/- 4 ^{o}F within that range. The DHW flow meter was installed on the cold water branch from city water before (i.e. upstream of) the boiler coil, mixing valve, and re-entry of the recirculation loop. 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, with the addition of some factor over or under the expected flow rates.

All buildings had 2 inch DHW flow meters installed, except for Building's 1 and 2 which employed a 1 inch and 1 1/2 inch meter, respectively. Installed models were rated for a maximum temperature of 250 ^{O}F and a maximum pressure of 250 PSI. The fluid flow range spanned 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 were experienced. The degree of error for each of the flow meters is +/- 1 1/2 percent. The boiler make-up water was recorded by 3/4 inch meters that are rated for a maximum temperature of 190 ^{O}F, a maximum pressure of 150 PSI, and 0.22 to 20 GPM. The fuel flow meters are rated for 1 to 50 gallons per hour (GPH).

DATA SETS

The information presented in this report reflects data collected in the process of two extensive DHW research project phases conducted by EMRA in New York City, as well as a compilation/analysis of summary DHW data from studies in seven other locales across the United States and Canada.

The Phase 1 research project (completed in 1993) consisted of fourteen months of real time monitoring in thirty NYC multifamily buildings. Nine of these sites had their monitoring equipment upgraded to collect DHW flow data in 15 minute intervals.

This second stage DHW project consisted of upgrading a subset of three of the sites to record DHW flow at 5-minute intervals and the addition of recirculation flow meters. This was done to: a) have a more precise picture of short term/instantaneous demand peaks; and b) to collect the missing parameters necessary to create an accurate simulation of real time operations. Data for the 5-minute interval building subset was collected for a period of 100 days.

The data also included building operational and tenant information requested from superintendents and property managers via questionnaires and interviews, building and apartment occupancy records, and equipment and building condition data obtained through energy audits (performed by the author and colleagues)[6].

The third data component consists of information from various studies investigating a myriad of DHW issues, ranging from energy conservation improvements to boiler control. These studies were conducted in various cities within the United States and Canada. The seven locations spanned from New Jersey to Minneapolis, San Francisco, and Toronto, a total of 22 additional monitored sites. Each of these studies consisted of collection of DHW consumption data. This data was compiled in summary format (e.g. Average Day, Maximum Hour, Maximum Day), by Bill Thrasher of AGA Labs[7]. Since the original studies had not set out to determine DHW demand for system sizing purposes, it was necessary to further break down the data by employing extrapolations based upon our New York studies. These figures were then used, along with the New York data to compose a set of "National" system sizing guidelines.

Descriptions of the other sites are in the referenced studies of: Pearlman and Milligan, Ciz and Milligan, DeCioco, Vine et al, Taylor and Force, Nelson, Center for Energy and the Urban Environment, and TES Ltd. (See Section 8.)

All of the following graphs and tables were developed as part of the research conducted on the two EMRA/NYSERDA (New York) data sets, with the exception of the "National LMH" table (# 3) - which encompassed available data from all the studies.

BUILDING SET FOR HEATING ANALYSIS

The data set employed for the heating system analysis part of the research includes all of the data collected in all 30 sites by the building monitoring devices during both Phase 1 and Phase 2, as well as the manually compiled information described earlier. The information amounts to a data base containing over 130 megabytes of data. Various tables in the data base contain about 12 million data points.

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[6] See Goldner, F.S.. Nov. 1994. for a more detailed description of the buildings' physical and resident composition and the selection process.

[7] Thrasher, W.H. and D.W. DeWerth. 1993. 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. Cleveland.

Additionally, a second subset of data from the Association of Energy Affordability's "Multi Family Research Project" (MFRP) was used to check the validity of some of the analysis methodology and the findings by comparing them to a different building set in a different weather year, (the 1995-96 heating season)[8].

[8] We would like to thank David Hepinstall of the Association for Energy Affordability for access to this data for use this project.

Section 3
DATA ANALYSIS

A focal point of both the Phase 1 and Phase 2 research was the examination of DHW consumption on a per capita basis. Historically, published data for DHW consumption has been 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 figures from this research suggest that per capita analysis 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, ... If necessary, the per capita data can be converted back to per apartment figures based on actual or estimated populations.

Monthly consumption summaries were produced as part of Phase 1. 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.

In Phase 2, a series of computer models of DHW generation and storage systems were constructed to evaluate the energy efficiency and cost-effectiveness of various combinations of generation types and storage level schemes. The existence of 14 months of real-time 15 minute flow data for eight buildings (Phase 1 data collection) and 5 minute flows for the three building subset (Phase 2 data collection) has enabled us to go past the theoretical models that had been used in the past. The models were used to analyze the capabilities and effects (i.e. energy costs) of running different levels of instantaneous generation and storage capacity on each of the sites. The DHW model simulations ranged from a tankless coil in a combination heat/DHW boiler to a separately fired DHW system with the maximum of storage tank reserve. Application of the actual data was used in order to gain a clearer understanding of the dynamics of the interaction of load profiles on the DHW generation system.

METHODOLOGY

As discussed previously, the DHW and building operations data was collected by the sensors and meters that were wired into each building's Heat Computer. After the collected data arrived at EMRA, it was translated via a proprietary FORTRAN program which read three files of two or three 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 FORTRAN program also performed a number of preliminary calculations. These included reading all of the DHW flow data and computing the daily average, and maximum and minimum consumptions, as well as denoting the times that these flows occurred.

Only days in which all ninety-six 15-minute readings or 288 5-minute readings existed (i.e., a complete day's data record) were selected. The program reviewed all the flows to select the maximum 5-minute through 15-minute consumption. This information was then written to a special file, as were any equal flows and their times[9]. Gallons of DHW consumed in all 4 consecutive 15-minute periods were then calculated. This information was used to derive the daily maximum 60-minute peak volume and time of occurrence, as well as multiple occurrences of equal flows. Successive calculations were used to determine minimum 60-minute flows, average 60-minute ('Hour') consumption, and 30-minute 2- and 3-hour peak consumption parameters.

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 consumption refers to the mean volume of DHW consumed for all days where a complete day of data exists. Reformatted raw data and computed values were then loaded into various tables in the specially designed project data base, where macros were used to compute monthly average values of various parameters (i.e. gallons per average hour, maximum 5-, 30-, 15-, 60-, 120- and 180-minute demand levels, ...), 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 Rbase runs. QPro was also employed to conduct graphical analyses of the data and to create many of the table and graph presentations in this report.

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9 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'.

The DHW system models were created by combining basic thermodynamic principals with the empirical data obtained from recent research projects. More specifically, the DHW system models were constructed in a spreadsheet environment, and are based on a discrete time analysis method. Each spreadsheet row represented a time period corresponding to the period of the data set to be analyzed, i.e. 5 or 15 minutes. At the beginning of each time cycle, the data (in the form of DHW consumption, recirculation flow and temperatures) was used to determine the load on the system. To this load was added the standing losses for the period. Then, depending on the system type and prior conditions, the load was satisfied from either the available thermal mass or by a fuel burn. This cycle was repeated for each 5- or 15-minute interval over the data collection interval.

As a validity check during the model development, the calculated fuel consumption for the tankless coil model was compared to the actual fuel consumption data for the corresponding period. Calculated consumption and actual data varied less than 5% over a 4-month period. Because all of the installed systems in the data set were of the tankless coil type, no further validity checks could be run for the other models.

Cost of various system components were compiled in order to conduct system economic analyses. Life cycle costing (LCC) models were developed by adapting ENVEST (energy investment financial analysis software) to evaluate the economic effectiveness of the various system designs. These used equipment costs and the energy costs computed by the various energy models (above) to evaluate the economic efficiencies of employing different systems to satisfy the building's DHW needs. In order to develop true life cycle costs it was necessary to configure the ENVEST program with certain basic economic and non-case-specific parameters in addition to the installed equipment costs and annual energy consumption. These parameters included equipment depreciation schedules, initial fuel cost, fuel cost escalation, tax rates, and discount rate. These analyses calculated a net present value (NPV) cost of owning and operating each potential system over the course of a 20-year life. These results were then compared to determine the approach that would provide the greatest economic benefit for the site.

The flow curve graphs presented later in this report represent 15-minute (Figures 1-3) or 5-minute (Figures 4-9) 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.

Section 4
DHW SYSTEM MODELING AND FINDINGS

DEMAND FLOW PATTERNS

To properly design a DHW system for multifamily buildings it is necessary to understand their unique consumption *and* demand patterns.

Consumption Levels

Multifamily buildings manifest distinct seasonal variations of DHW consumption levels. The daily average consumption in the summer rose 10% in the fall and then by 13% during the winter period. Consumption then fell 1% in the spring and falls again 19% during the summer period.

Consumption is generally slightly higher on weekends (Saturday and Sunday) than on weekdays (Monday through Friday). This pattern held true in all seasons, (except for a few buildings during the summer). The average weekend day consumption is 7.5% greater than the average weekday day level.

Consumption Flows

The 15-minute DHW flow data was analyzed to produce demand-flow curves (see Figure 1). 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 in the late morning and continues on until around 1 or 2 PM. Usage then tapers off fairly evenly through the rest of the day. Examination of the composite weekday and weekend graph (Figure 1) illustrates that the weekend peak was greater, at 1.09 gal/capita, than any of the weekday peaks, at 0.87 gal/capita.

Two morning peaks can be observed in the composite weekday curve, the first between 6 and 8 AM, and the second between 9:30 AM and noon. Particular sites fall into one of these two peaks. Some general knowledge of the tenant populations may explain this difference. Buildings with large numbers of either working tenants and middle income populations experience the early morning peak; buildings with a large

WEEKDAY vs. WEEKEND CONSUMPTION
GALLONS PER CAPITA, COMPOSITE

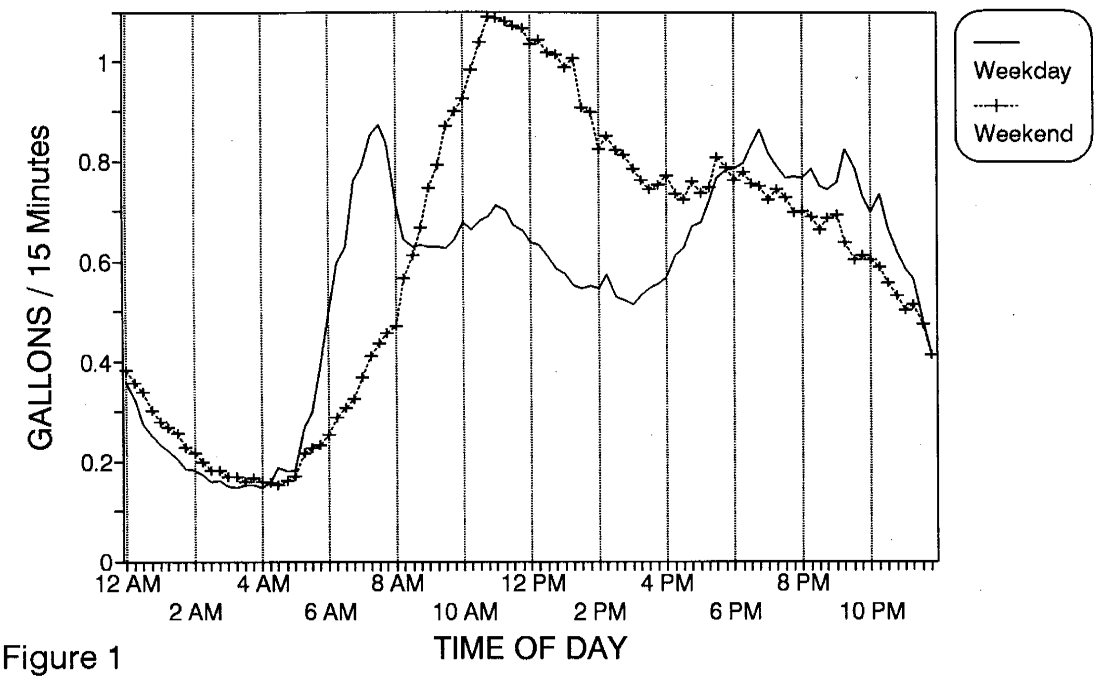

Figure 1

percentage of children exhibit the later morning peak (especially during the summer period).

Figures 2 and 3 clearly illustrate the seasonal variations in both the usage patterns and consumption levels between summer, fall, winter and spring. Note that, the highest peaking level occurs during winter weekends.

Recirculation Flows

DHW systems in multi family buildings generally employ one of three types of return/recirculation systems. The first option is to have no recirculation piping at all. This is most often found in the smallest end of the multifamily sector, where there are short runs between the supply source (boiler/heater) and the furthest tap (as in building #1.) The second type of system, (as in study building #9), was a gravity return. The monitored data (Figures 4 and 5) indicates that these systems have a very small flow, ranging from 0 to 0.5 gpm. The third type of system is forced recirculation. Such a system employs a small (fractional horsepower) pump to keep water flowing, thus avoiding stagnation and the need to run the tap for a long period to receive

SEASONAL VARIATIONS,WEEKDAY CONSUMPTION
GAL per CAPITA, COMPOSITE

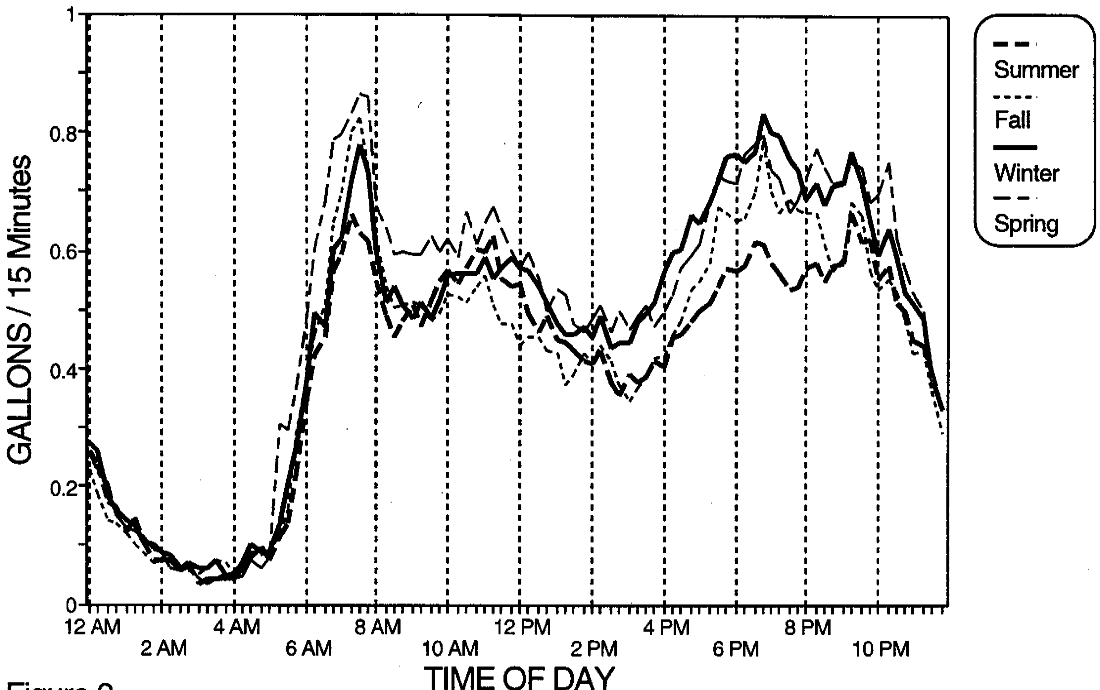

Figure 2

SEASONAL VARIATIONS,WEEKEND CONSUMPTION
GAL per CAPITA, COMPOSITE

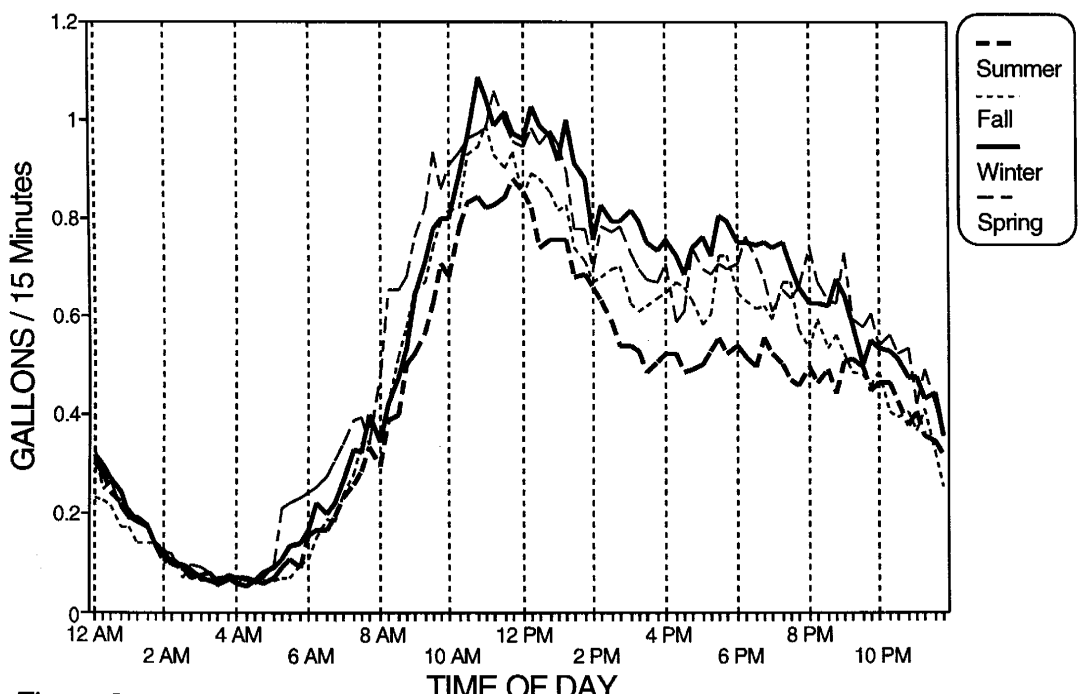

Figure 3

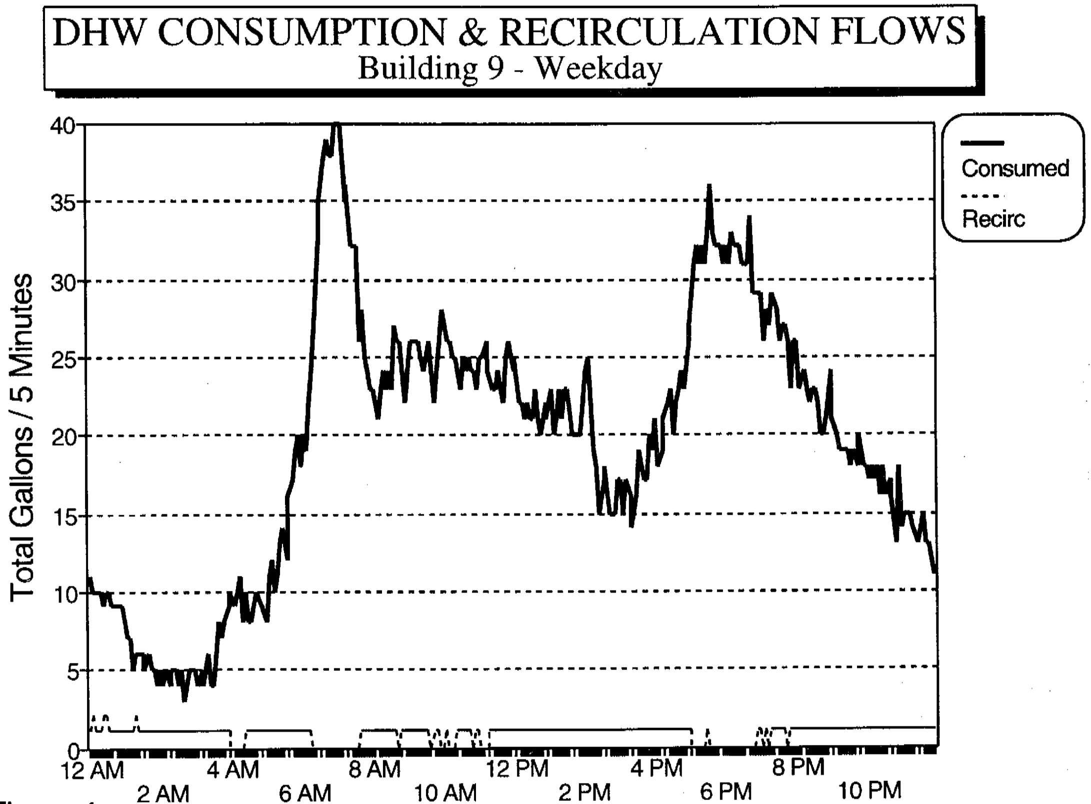

Figure 4

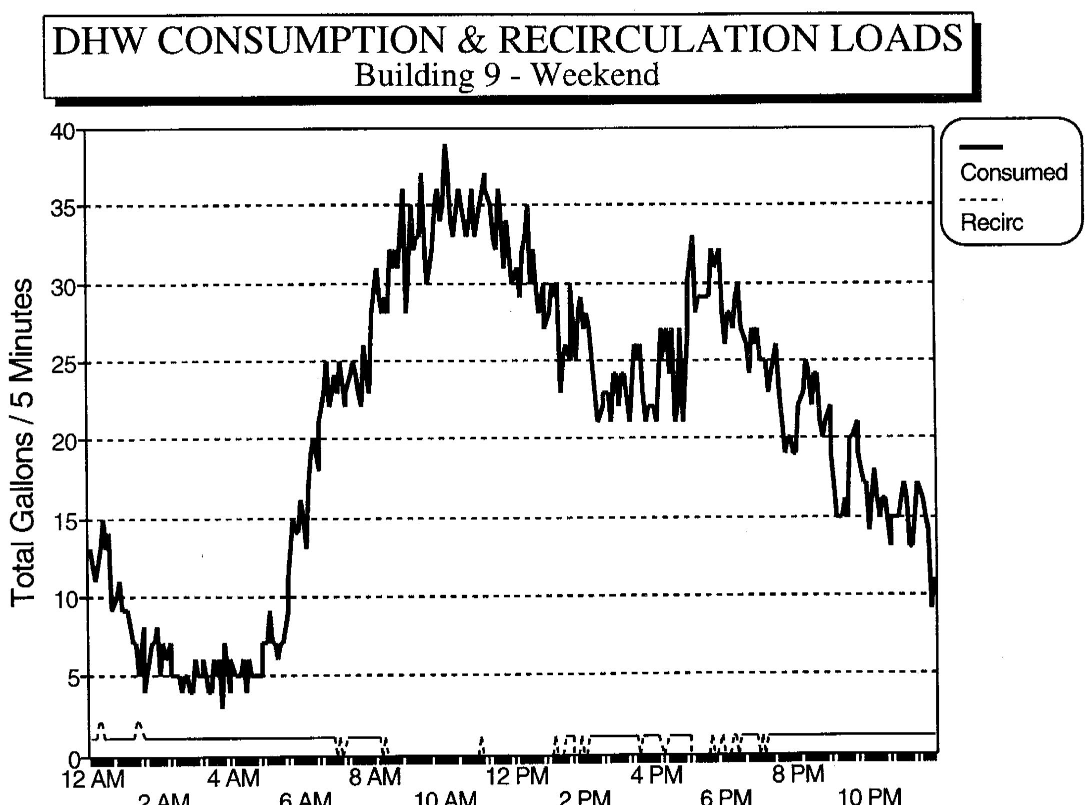

Figure 5

sufficiently hot water (particularly on upper floors). The pumps are either run continuously, (as in Buildings 7 and 10), or may be cycled on and off by an aquastat.

Figures 6 through 9 depict the DHW consumption and recirculation flow patterns in Buildings 7 and 10. (While recirculation pumps *should be* sized to meet each individual building's requirements, common practice is one size fits all. Thus the same pump size was observed in all of the Phase 2 study sites.[10]) In the overnight period when there is little or no consumption, the pump reaches its maximum capacity rate of approximately 11 GPM. As the consumption level grows there is an inverse relationship within the recirculation flow[11].

CALCULATING DEMAND

One of the key objectives of the Phase 1 research project was to determine accurate levels of DHW consumption and demand, and identify factors affecting these levels. A comparison of the Phase 1 findings to the recent *1991 ASHRAE Handbook (Chapter 44, Table 7)*[12] figures indicate use of unadjusted ASHRAE estimates will result in undersizing of systems, as the monitored data reveal consumption and peaks well above the *Handbook* recommendations[13]. As a result of the uncertainty regarding actual DHW levels many engineers and contractors have employed enormous safety factors, which results in oversized, inefficient systems.

The guidelines presented, in both this report and the Phase 1 report, differs in substance and format 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) and ASPE, who have indicated a preference for a "Low-Medium-High" (LMH) users set of guidelines, rather than a specific, singular volume value. By providing

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10 A methodology for proper pump size selection can be found in the *1995 ASHRAE Applications Handbook*, p. 45.5.

11 This occurs because when no one in a building is using hot water the DHW distribution loop piping is full to capacity and therefore the pump can pump at its maximum rate. When occupants begin to open taps throughout the building, the pressure in the piping drops, and the volume of water being moved by the pump drops proportionally (inversely to the consumption flows increase).

12 *1991 ASHRAE Handbook, HVAC Systems and Applications*. (Chapter 44 - Service Hot Water), ASHRAE, Atlanta.

13 Goldner, Nov. 1994

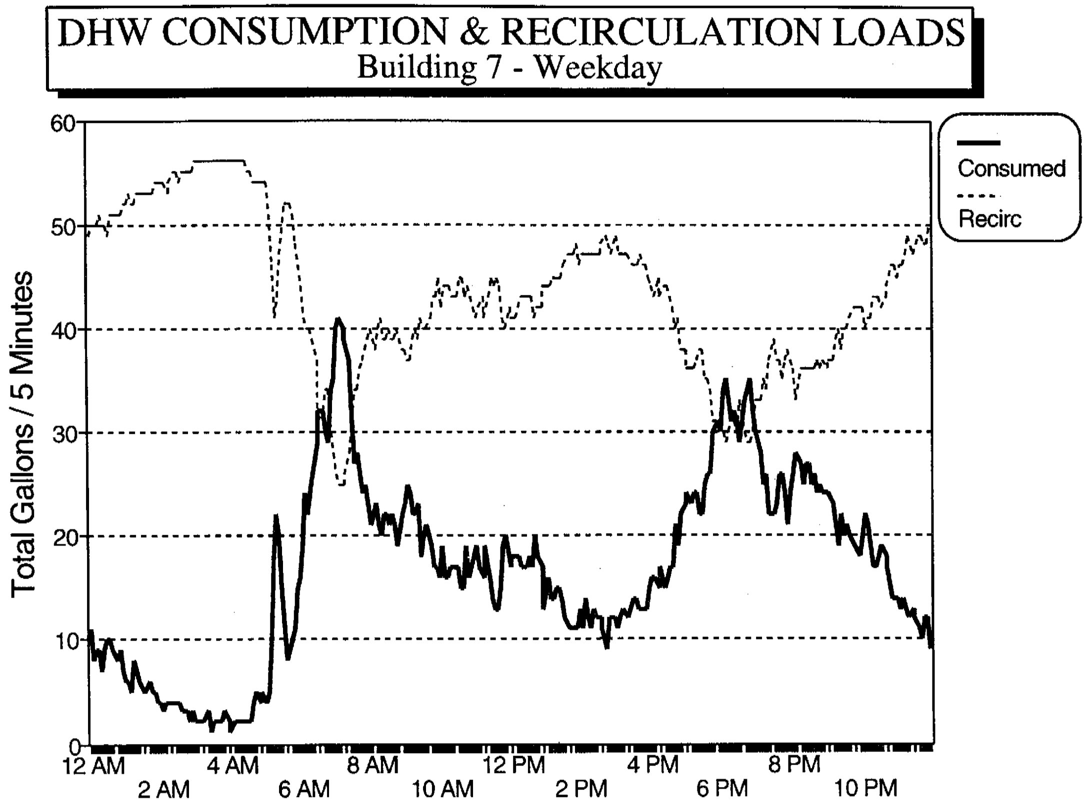

Figure 6

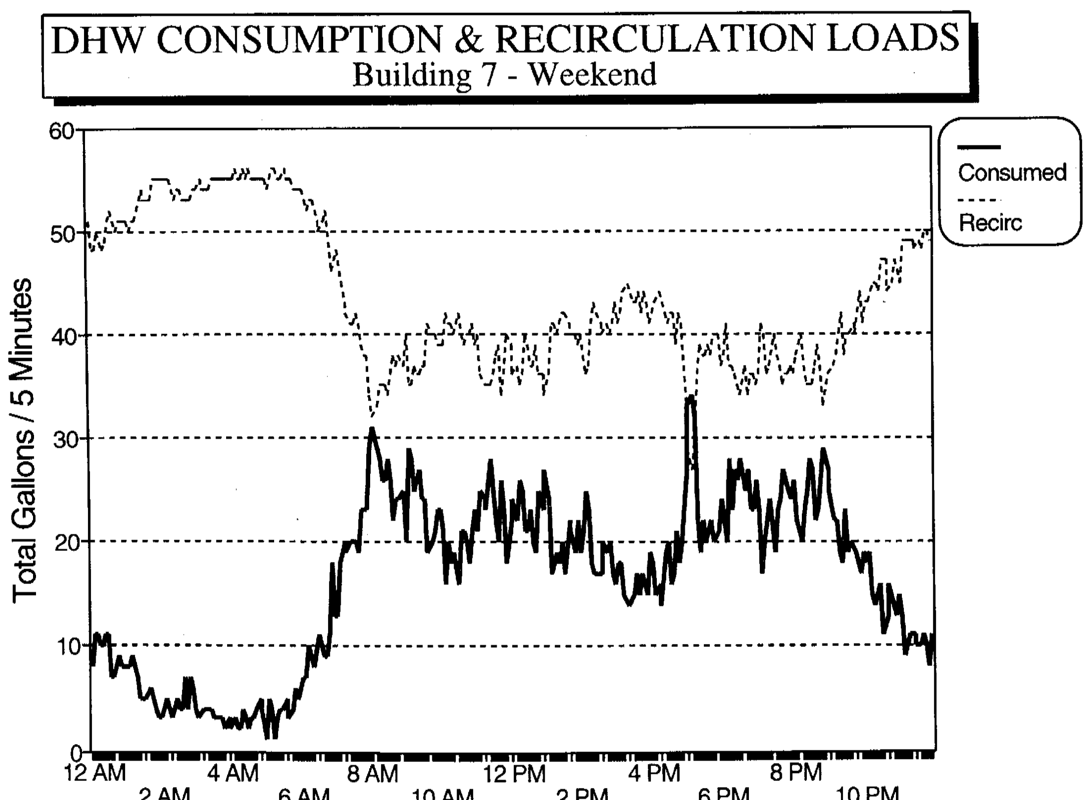

Figure 7

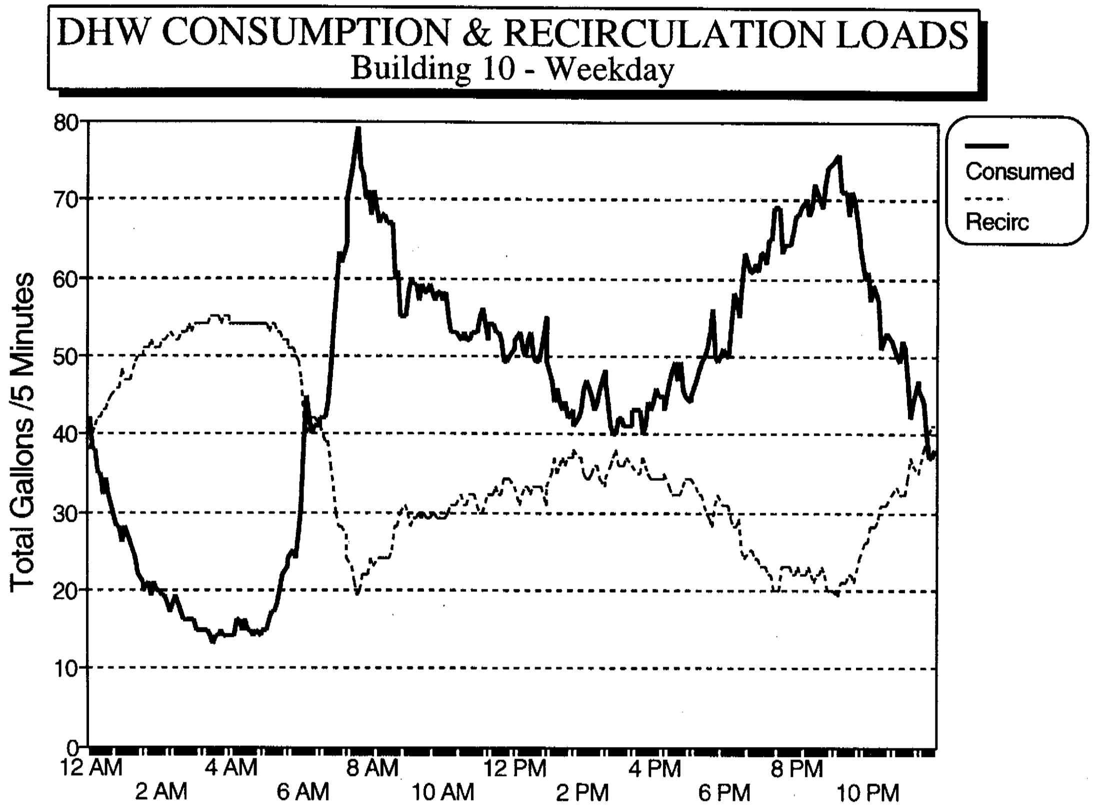

Figure 8

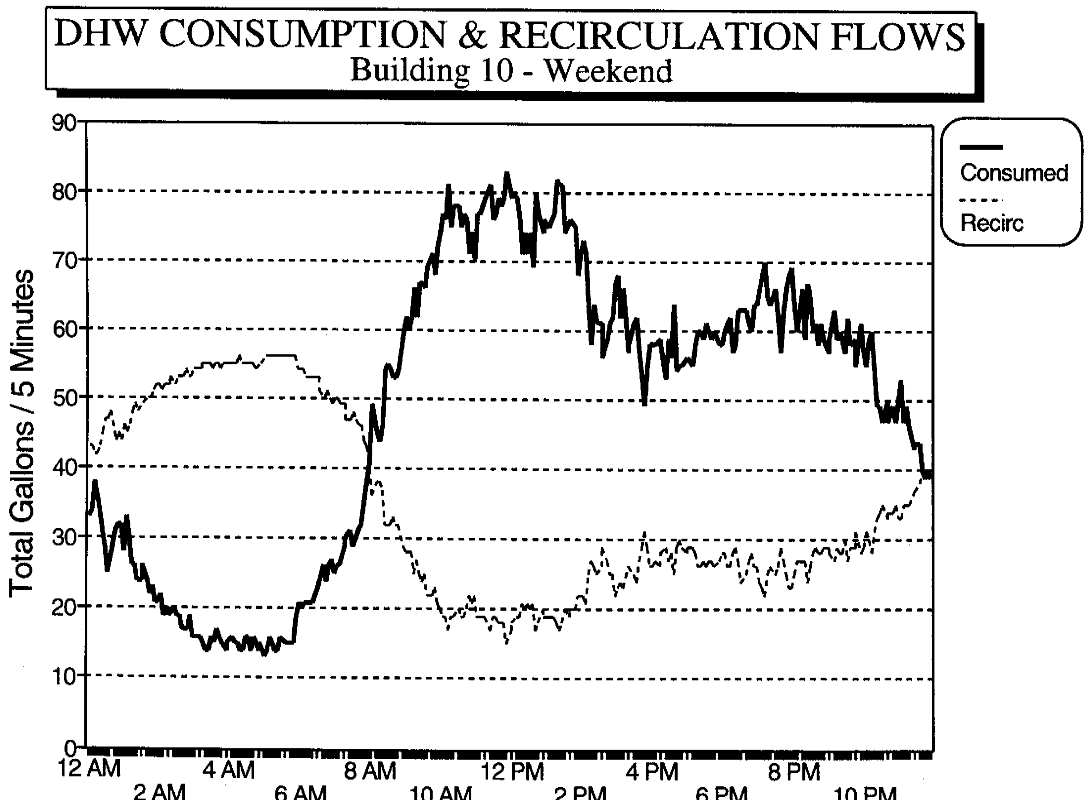

Figure 9

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 here in the LMH tables include the more detailed level of Peak 5-minute, Peak 15-minute and Peak 30-minute consumptions, which should assist in the design process. Another significant difference, is the use of per capita rather than per apartment based usage factors. This new approach was, in fact adopted by ASHRAE T.C. 6.6 for inclusion in the *1995 Handbook* revision, and has been included in the ASPE *Domestic Hot Water Design Manual*[14].

The first step in calculating demand is determining the demographic profile of the project and building occupants. Building occupants have been found to consume hot water with fairly predictable patterns based on demographic categories. Users can be lumped into categories of "low," "medium," and "high" volume water consumers as a function of the building and occupant demographics. Table 2 indicates a variety of occupant classifications, one or a combination of which should describe any particular multifamily building. For example, a luxury condominium in an area inhabited predominantly by young couples will tend to fall into the "all occupants work" category of low anticipated water consumption. By contrast, a low-income housing project will generally fall somewhere between the "low income" and "no occupants work" categories of high volume water consumption. Keep in mind that the presence of an abundance of hot water consuming appliances such as clothes- or dishwashers will tend to increase hot water consumption. Thus, if the luxury condominium building example above intended or allowed the future installation of a clotheswasher in each unit, the LMH Factor should be augmented from "low" to "medium." It is up to the designer and his/her knowledge of the project to determine this category.

Once this LMH factor has been determined, values for hot water consumption can be selected from Table 3. Values are indicated per capita in maximum flows of 5 minutes, 15 minutes, 30 minutes, one hour, two hours, three hours, one day, and an average day. Thus, anticipated consumption values can be determined using the anticipated maximum building population for these time frames. These values will be used later in selecting and sizing the domestic hot water equipment.

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14 *Domestic Water Heating Design Manual*. American Society of Plumbing Engineers, Westlake Village, CA, 1998.

Demographic Characteristics Correlation to DHW Consumption

Demographic Characteristics	LMH Factor
No occupants work Public assistance & low income (mix) Family & 1 parent households (mix) High % of Children Low income	**HIGH**
Families Public assistance Singles 1 parent households	**MEDIUM**
Couples Higher population density Middle income Seniors One person works, 1 stays home All occupants work	**LOW**

Table 2

National

LOW - MEDIUM - HIGH GUIDELINES

Hot Water Demands and Use for Multi Family Buildings

	Maximum Hour	**Peak 15 Minutes**	**Maximum Day**	**Average Day**
Low	2.8 gal (10.5 L)/person	1.0 gal (4.0 L)/person	20.0 gal (76.0 L)/person	14.0 gal (53.0 L)/person
Med	4.8 gal (18.0 L)/person	1.7 gal (6.4 L)/person	49.0 gal (185.0 L)/person	30.0 gal (114.0 L)/person
High	8.5 gal (32.5 L)/person	3.0 gal (11.5 L)/person	90.0 gal (340.0 L)/person	54.0 gal (205.0 L)/person

	Peak 5 Minutes	**Peak 30 Minutes**	**Maximum 2 Hours**	**Maximum 3 Hours**
Low	0.4 gal (1.5 L)/person	1.7 gal (6.5 L)/person	4.5 gal (17.0 L)/person	6.1 gal (23.0 L)/person
Med	0.7 gal (2.6 L)/person	2.9 gal (11.0 L)/person	8.0 gal (31.0 L)/person	11.0 gal (41.0 L)/person
High	1.2 gal (4.5 L)/person	5.1 gal (19.5 L)/person	14.5 gal (55.0 L)/person	19.0 gal (72.0 L)/person

Note: These gallonages are for DHW delivered to the tap at 120^{o}F

Table 3

Research and practical experience in different areas of North America indicate that there are variances in DHW use between geographical locations. However, no distinctive pattern can be identified based on the available data. More research should be done in this area.

Note that the values in Table 3 are for centrally fired systems. Individual-apartment water heater systems are likely to have lower levels of consumption. This is due to the fact that the majority of individual systems are set up so that the resident is paying for fuel directly, thus encouraging conservation.

In buildings where corrective maintenance cannot be maintained, a factor of safety of 20 - 30% may be employed to compensate for poorly maintained fixtures[15].

Once a portion of the range has been selected, the figures should be converted into per apartment or per building gallonage by multiplying by 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.)

RELATIONSHIPS OF LOADS

Peak Demands & Average Consumption

Five-, 15-, 30-, 60-, 120- and 180-minute maximum demand and hourly average consumption figures may be used to examine peak needs in contrast to total volume of DHW consumed. This type of analysis is useful in setting out new system design and sizing parameters and evaluating a mix of instantaneous generation and storage options. Analysis of the monitored data has revealed that in comparison to the use in a maximum 60-minute period, the average hour consumption is only 42% of that peak. This suggests 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 5- and 15-minute peak periods demonstrates that the highest (5-minute) peak requires 40% of the DHW consumed within the 15-minute peak. Review of the 15- and 60-minute peak periods reveals that the highest (15-minute) peak is equal

[15] Based on the findings of Phase 1 of this study and Vine et al. 1987.

to 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 makes a case for investigating some type of off-peak generation and storage strategy.

An examination of 1-, 2- and 3-hour demands shows 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. Figures 10 and 11 illustrate how all of the peak volumes contribute to the 1-hour and 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. Thus, 46% of the DHW consumed during the peak 3-hour demand each day is needed within the maximum 60-minutes. Another 29% of the gallons are 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. These relationships can be used to model various configurations of hot water supply systems.

Concurrence Of Peaks

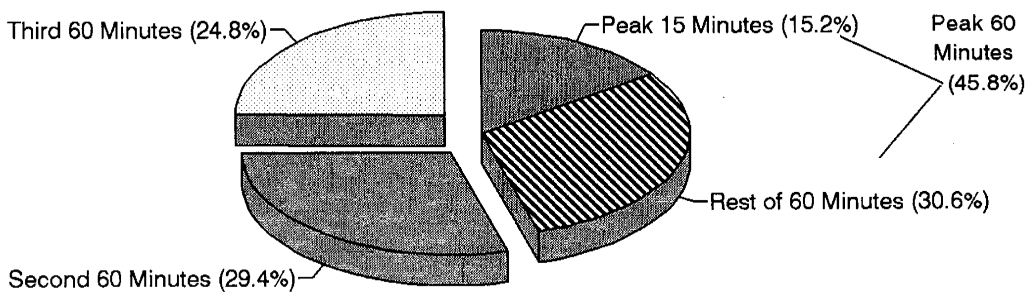
While flow curves show the general usage patterns of a building, peaking times and flows are used to more closely identify demands on/requirements of the boiler. The 5-, 15-, 60-, 120- and 180-minute maximum demand times coincide with each other. These volumes should therefore be addressed as different (time length) measurements within the same peak DHW draw, so the system can be designed to satisfy this load. An instantaneous system designed to meet the 5-minute draw will have no problem meeting the rest of the load. Generation and storage systems should be designed to provide hot water for the average load and to meet the short, sharp peaks.

SYSTEM SELECTION CONSIDERATIONS

Computer Modeling

A series of computer models of DHW generation and storage systems were constructed to evaluate the energy efficiency and cost effectiveness of various combinations of generation types and storage level schemes. The existence of 14 months of real-time 15-minute flow data for eight buildings and 5-minute flows for the three building subset enabled us to improve on previous theoretical models. The models have been used to

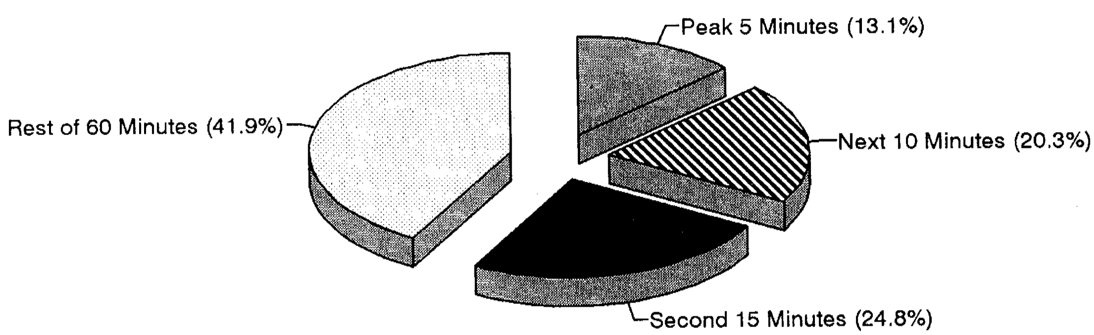
PARTS OF 3 HOUR DHW PEAK CONSUMPTION
GALLONS PER CAPITA - WINTER PERIOD



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

Figure 10

PARTS OF PEAK 60 MINUTES
DHW CONSUMPTION



** note: All percentages represent the portion of the 60 minute peak.*

Figure 11

analyze the capabilities and effects (i.e., energy costs) of running different levels of instantaneous generation and storage capacity on each of the sites. The simulations ranged from a tankless coil in a combination heat/DHW boiler to a separately fired DHW system with the maximum of storage tank reserve. Application of the actual data was used in order to gain a clearer understanding of the dynamics of the interaction of load profiles on the DHW generation system.

The models were created by combining basic thermodynamic principals with the empirical data obtained from recent research projects. More specifically, the DHW system models were constructed in a spreadsheet environment, and are based on a discrete time analysis method. Each (spreadsheet) row represented a time period corresponding to the period of the data set to be analyzed, i.e. 5 or 15 minutes. At the beginning of each time cycle, the data, in the form of DHW consumption, recirculation flow and temperatures, was used to determine the load on the system. To this load was added the standing losses for the period. Then, depending on the system type and prior conditions, the load was satisfied from either the available thermal mass or by a fuel burn. This cycle was repeated for each 5- or 15-minute interval over the data collection interval.

Due to the complexity and variation in heating equipment installations, estimating standing losses has always been a problem. Previous research on space heating systems has indicated that these losses are primarily a function of system type, burner capacity and burner cycling. In an attempt to provide a level playing field in which to evaluate the various systems a value of 1.25% of burner capacity was used for each model. In order to account for the losses associated with burner cycling, a separate component was added each time the burner cycled on or off. As combustion efficiency of equipment can also vary greatly, investigation into typical efficiencies for the various classes of equipment was undertaken[16]. From this it was determined that it is possible to find a range of efficiencies for any one of the system types, dependent on items such as fuel source, manufacturer, price ... . There does though seem to be a differing set of ranges for equipment in each of the system types, as well as a generally agreed upon baseline efficiency level that may be expected of each class. Based on this information the tankless coil model was set (in the model computations) at 80% (combustion

[16] Phone conversations of 2/5 thru 2/7/96 with John Woodworth, former Technical Director of The Hydronics Institute, and Frank Stanonik of Gas Appliance Manufacturers Association (GAMA). They are also both members of ASHRAE Technical Committee 6.6 (Service Hot Water).

efficiency), the separate DHW boiler with storage tank at 85%, direct-fired DHW heater at 80%, and the instantaneous system at 85%. While any particular piece of equipment might perform better or worse than these levels, all parties consulted agreed that these were fair, representative values. (In fact, there tends to be a potentially greater upside to the more expensive separate DHW boiler w/ storage tank and the instantaneous systems.)

As a validity check (on the computer model), the calculated fuel consumption for the tankless coil model was compared to the actual fuel consumption data for the corresponding period. Calculated consumption and actual data varied less than 5% over a four-month period. Because all of the installed systems in the data set were of the tankless coil type, no further validity checks could be run for the other models.

In order to simulate generic systems and facilitate simulation of multiple system sizes, several system parameters (i.e. boiler mass, storage tank surface areas) were typically sized as a function of burner capacity or storage capacity, based on information gleaned from manufacturer's literature.

Due to the volume of available data, and the size of the resultant spreadsheets, the systems were simulated a week at a time. A computer spreadsheet was used to create the models.

SYSTEM TYPES

As anybody who has been around multifamily buildings for a while can testify, there seem to be as many different types of DHW heating systems as there are designers who design them. What they all attempt to accomplish is to provide the correct mix of generation capacity and storage to satisfy both the peaks and the average load. In instantaneous type systems the system has the capacity to meet peak loads without any required storage. Other systems are designed to supply only the average daily load, while peaks are supplied from a storage system. The focus of this research was to determine the relative differences between the various combinations from both an operating cost (i.e. energy efficiency) and from capital cost standpoints. It is to this end that the following systems were chosen to be modeled.

Tankless Coil

This type of DHW system is composed of a water-to-water heat exchanger (tankless coil) inserted into a boiler (either steam or hot water). Balance of components usually includes a mixing valve to temper the DHW supply to the building. The boiler is sized to supply both heating and DHW needs, which results in a grossly oversized DHW heater during the non-heating months. Advantages of this type of system include low cost and relatively high operating efficiencies during the heating season. The disadvantage is the low operating efficiency during the non-heating season.

Due to the prevalence of this system type, this system has been used as a benchmark against which each of the other systems was compared.

Direct-Fired DHW Heater

This type of DHW system is composed of a storage tank with an integral burner. The balance of components may or may not include a separate DHW mixing valve to temper the DHW supply to the building. The larger examples of this type of system are characterized by large, single- or two-stage, burners and relatively small storage capacity. The primary function of the storage is to minimize short cycling of the burner and the associated temperature swings inherent with this type of burner control. For this reason the selection of burner size and storage capacity is usually limited. The advantages of this type of system are the low cost and increased operating efficiencies associated with a system sized closer to the intended load, and decreased standing losses due the smaller size of the equipment. The disadvantages of this type of system include limited size selection and tendency to premature failure due to burn-through caused by sediment build-up on heat exchanger surfaces.

Separate DHW Boiler with Storage Tank

This system comprises a boiler sized to make only DHW and a separate storage tank. Balance of components may or may not include a separate DHW mixing valve to temper the DHW supply to the building. The boilers are available with multi-stage or instantaneous type burners, which minimizes burner cycling. Since each component can be sized and selected separately, a greater choice exists in designing the system. By designing a system with a larger storage capacity the storage tank can be utilized to satisfy peak loads with a smaller boiler. The advantages of this type of system are greater design flexibility, a lower pre-mature failure rate due to separating the burner and the area of sedimentation, and higher operating efficiencies.

In modeling this system, for each building, to determine optimal energy use and economic mix of equipment sizing, a range of generation and storage mixtures were computed. These varied from relatively large generators (boilers) with a very small volume of storage (tanks), to very small generators with large volumes of storage. .

Instantaneous DHW System

The instantaneous style DHW system is characterized by a separate DHW heater with minimal integral or external storage capacity. Some systems of this type that have minimal volume of water (less than 50 gallons) in the boiler are sometimes referred to as semi-instantaneous by their manufacturers. (These systems share the same operating characteristics as laid out in this model.) DHW temperature is controlled by the continuous modulation of the burner. This type of system control mitigates the need for a separate mixing valve. The advantage of a system of this type is high operating efficiency due to small standing losses. The primary disadvantage is higher cost due to the larger burner capacities required to meet peak load and the sophisticated control system required to maintain close temperature tolerances. While not specifically evaluated here, steam- and hot-water fired instantaneous DHW heaters (essentially external tankless coils), due to the relatively large mass and burner capacity of the primary boiler plant, share operating characteristics with the tankless coil type of system.

ENERGY RESULTS

Each building was determined to fall within a level (category) of the LMH guidelines. Then, based on occupancy the LMH table was used to determine DHW consumption. Five-minute peak values were then used to size the instantaneous type systems.

For the separate DHW boiler with tank system, 90% of this peak value was used as the starting point. The storage tank sizes were then varied so as to create a system that was capable of supplying a minimum of 99% of the load. To establish several points to define a curve, the boiler capacity was then dropped in stages by *X* BTUH (*X* varied by building), and the process was repeated.

Due to the limited selection available for direct-fired storage tanks, it did not seem practical to repeat the process described in the preceding paragraph. Instead, burner and storage capacities of several existing models chosen from manufacturers' catalogs were utilized in the simulations.

The results of the individual building simulations are presented in Tables 4 through 11. The energy saving (or percent efficiency) over the base case of the properly sized tankless coil system ranged from 3 to 18% for direct-fired DHW heaters, with an average of 10%. The advantage of separate DHW boiler w/tank systems ranged from 11 to 30%, with an average of 18%. The range of energy/efficiency savings for instantaneous DHW systems was 9 to 24%, averaging 15%. The variance in the range of savings is due to a combination of factors, including the mix of generation vs. storage components (for the first two systems), shape of the consumption pattern, usage (LMH) level, recirculation system type, and load factors.

These base case - tankless coil systems were sized to meet both the hot water load and the heating load (based on a survey of the installed radiation at each site). Savings for the other system types would likely have been even greater had the tankless coil systems been grossly oversized, as is often the case when a contractor or engineer employs one of the many rule of thumb equipment selection methods that persist in the marketplace.

The results indicate that systems that have smaller burner capacity and larger storage volume tend to operate most efficiently. All else being equal, the differences between the models were a function of standing losses. With standing losses set at 1.25% of burner capacity plus tank losses, where applicable, the increase in standing losses associated with larger storage volumes was more than offset by the reduction in standing losses achieved by utilizing a smaller heating unit.

An additional consideration that needs to be taken into account when interpreting this data is the combustion efficiency obtainable on commercially available equipment. While either 80% or 85% (for the tankless coil and direct-fired DHW heaters, or separate DHW boiler w/tank and instantaneous systems respectively) was used for all systems to create a level playing field (i.e. non-manufacturer or model specific), several equipment types, particularly the instantaneous and the separate DHW boiler w/tank systems, are available with higher combustion efficiencies. Another more practical consideration would be the size of the storage tank that can be installed at the site. For retrofit situations, this can become the governing condition.

Energy Use & LCC Comparison of Systems - Bldg #1

		Burner Capacity (BTUH)	Storage Capacity (gal.)	Fuel Consumed MMBtu's/Yr	% Effic. over Base (TC) Case	Year 1 Savings vs. Base	20 Year Energy Cost	System NPV Cost
Tankless Coil		1,330,000		715	--	$0	$82,557	$27,696
Direct Fired	a)*	369,000	69	587	18%	$575	$67,799	$23,693
Storage Tank	b)	300,000	221	589	18%	$566	$68,023	$30,813
Separate DHW	a)	325,000	100	539	25%	$790	$62,268	$27,141
Boiler w/ Tank	b)	205,000	200	510	29%	$921	$58,915	$24,107
	c)	205,000	300	512	28%	$911	$59,176	$24,726
	d)	163,000	370	499	30%	$969	$57,687	$22,777
	e)	150,000	500	497	30%	$980	$57,403	$22,857
Instantaneous		340,000		544	24%	$770	$62,796	$23,481

* *letters represent different configurations*

Table 4

Energy Use & LCC Comparison of Systems - Bldg #2

		Burner Capacity (BTUH)	Storage Capacity (gal.)	Fuel Consumed MMBtu's/Yr	% Effic. over Base (TC) Case	Year 1 Savings vs. Base	20 Year Energy Cost	System NPV Cost
Tankless Coil		2,535,000		2,964	--	$0	$342,398	$108,765
Direct Fired	a)*	1,000,000	201	2,831	5%	$602	$326,943	$102,795
Storage Tank	b)	800,000	411	2,809	5%	$700	$324,430	$102,975
	c)	720,000	594	2,784	6%	$813	$321,542	$105,651
Separate DHW	a)	1,120,000	495	2,639	11%	$1,462	$304,861	$102,071
Boiler w/ Tank	b)	1,000,000	855	2,627	11%	$1,518	$303,438	$101,405
	c)	875,000	1230	2,612	12%	$1,587	$301,657	$99,673
	d)	750,000	1605	2,595	12%	$1,664	$299,699	$100,606
	e)	625,000	1980	2,570	13%	$1,776	$296,818	$99,705
Instantaneous		1,285,000		2,676	10%	$1,298	$309,079	$94,728

** letters represent different configurations*

Table 5

Energy Use & LCC Comparison of Systems - Bldg #3

		Burner Capacity (BTUH)	Storage Capacity (gal.)	Fuel Consumed MMBtu's/Yr	% Effic. over Base (TC) Case	Year 1 Savings vs. Base	20 Year Energy Cost	System NPV Cost
Tankless Coil		1,700,000		3,320	--	$0	$383,444	$111,836
Direct Fired	a)*	720,000	125	3,219	3%	$453	$371,813	$109,309
Storage Tank	b)	600,000	221	3,201	4%	$534	$369,726	$110,302
	c)	600,000	411	3,208	3%	$501	$370,582	$114,316
Separate DHW	a)	725,000	105	2,926	12%	$1,774	$337,908	$103,897
Boiler w/ Tank	b)	650,000	420	2,969	11%	$1,578	$342,949	$105,213
	c)	575,000	735	2,960	11%	$1,620	$341,850	$104,093
	d)	500,000	1040	2,946	11%	$1,683	$340,251	$104,753
	e)	425,000	1355	2,910	12%	$1,845	$336,099	$104,697
Instantaneous		760,000		3,010	9%	$1,395	$347,650	$100,395

** letters represent different configurations*

Table 6

Energy Use & LCC Comparison of Systems - Bldg #5

		Burner Capacity (BTUH)	Storage Capacity (gal.)	Fuel Consumed MMBtu's/Yr	% Effic. over Base (TC) Case	Year 1 Savings vs. Base	20 Year Energy Cost	System NPV Cost
Tankless Coil		3,500,000		5,227	--	$0	$603,733	$170,357
Direct Fired	a)*	1,000,000	201	4,588	12%	$2,873	$529,981	$156,040
Storage Tank	b)	800,000	411	4,714	10%	$2,309	$544,464	$160,648
	c)	720,000	594	4,602	12%	$2,812	$531,554	$160,713
Separate DHW	a)	900,000	330	4,516	14%	$3,200	$521,594	$156,648
Boiler w/ Tank	b)	800,000	630	4,483	14%	$3,350	$517,755	$154,331
	c)	700,000	930	4,392	16%	$3,759	$507,246	$150,786
	d)	600,000	1230	4,212	19%	$4,569	$486,449	$144,143
	e)	500,000	2400	4,279	18%	$4,268	$494,193	$151,137
Instantaneous		1,010,000		4,569	13%	$2,962	$527,712	$152,053

** letters represent different configurations*

Table 7

Energy Use & LCC Comparison of Systems - Bldg #6

		Burner Capacity (BTUH)	Storage Capacity (gal.)	Fuel Consumed MMBtu's/Yr	% Effic. over Base (TC) Case	Year 1 Savings vs. Base	20 Year Energy Cost	System NPV Cost
Tankless Coil		2,800,000		4,485	--	$0	$518,020	$147,426
Direct Fired	a)*	720,000	125	4,069	9%	$1,870	$470,027	$134,765
Storage Tank	b)	600,000	221	4,124	8%	$1,623	$476,353	$138,422
	c)	600,000	411	4,153	7%	$1,495	$479,645	$141,173
Separate DHW	a)	765,000	105	3,657	18%	$3,726	$422,385	$122,210
Boiler w/ Tank	b)	650,000	420	3,961	12%	$2,360	$457,456	$132,992
	c)	575,000	735	3,924	13%	$2,526	$453,190	$131,652
	d)	500,000	1040	3,819	15%	$2,995	$441,133	$129,305
	e)	500,000	1355	3,548	21%	$4,217	$409,786	$122,198
Instantaneous		805,000		4,000	11%	$2,180	$462,054	$132,187

* *letters represent different configurations*

Table 8

Energy Use & LCC Comparison of Systems - Bldg #7

		Burner Capacity (BTUH)	Storage Capacity (gal.)	Fuel Consumed MMBtu's/Yr	% Effic. over Base (TC) Case	Year 1 Savings vs. Base	20 Year Energy Cost	System NPV Cost
Tankless Coil		5,000,000		3,212	--	$0	$370,947	$103,590
Direct Fired	a)*	800,000	411	2,944	8%	$1,202	$340,095	$94,702
Storage Tank	b)	600,000	221	2,860	11%	$1,583	$330,328	$99,361
	c)	540,000	125	2,801	13%	$1,847	$323,534	$104,767
Separate DHW	a)	850,000	100	2,671	17%	$2,435	$308,457	$94,012
Boiler w/ Tank	b)	700,000	700	2,659	17%	$2,488	$307,081	$95,293
	c)	550,000	900	2,637	18%	$2,588	$304,528	$94,015
	d)	400,000	2400	2,572	20%	$2,879	$297,056	$98,390
Instantaneous		900,000		2,677	17%	$2,406	$309,180	$91,733

** letters represent different configurations*

Table 9

Energy Use & LCC Comparison of Systems - Bldg #9

		Burner Capacity (BTUH)	Storage Capacity (gal.)	Fuel Consumed MMBtu's/Yr	% Effic. over Base (TC) Case	Year 1 Savings vs. Base	20 Year Energy Cost	System NPV Cost
Tankless Coil		3,500,000		2,331	--	$0	$269,267	$79,886
Direct Fired	a)*	369,000	411	1,958	16%	$1,681	$226,108	$73,652
Storage Tank	b)	369,000	221	1,937	17%	$1,772	$223,773	$71,428
	c)	540,000	125	1,995	14%	$1,511	$230,472	$68,323
Separate DHW	a)	480,000	100	1,840	21%	$2,209	$212,580	$65,427
Boiler w/ Tank	b)	430,000	200	1,829	22%	$2,262	$211,204	$65,298
	c)	380,000	612	1,825	22%	$2,278	$210,808	$66,306
	d)	330,000	830	1,798	23%	$2,402	$207,621	$65,520
	e)	280,000	1000	1,739	25%	$2,663	$200,916	$64,382
Instantaneous		580,000		1,868	20%	$2,083	$215,809	$64,950

** letters represent different configurations*

Table 10

Energy Use & LCC Comparison of Systems - Bldg #10

		Burner Capacity (BTUH)	Storage Capacity (gal.)	Fuel Consumed MMBtu's/Yr	% Effic. over Base (TC) Case	Year 1 Savings vs. Base	20 Year Energy Cost	System NPV Cost
Tankless Coil		6,500,000		5,237	--	$0	$604,895	$169,536
Direct Fired	a)*	1,500,000	200	4,960	5%	$1,245	$572,929	$166,726
Storage Tank	b)	1,250,000	400	4,874	7%	$1,634	$562,962	$168,440
	c)	1,000,000	600	4,753	9%	$2,179	$548,961	$170,730
Separate DHW	a)	1,450,000	100	4,371	17%	$3,897	$504,864	$153,771
Boiler w/ Tank	b)	1,250,000	675	4,390	16%	$3,813	$507,017	$155,297
	c)	1,150,000	1100	4,377	16%	$3,871	$505,545	$156,340
	d)	1,050,000	1600	4,363	17%	$3,935	$503,903	$156,378
	e)	950,000	2400	4,347	17%	$4,005	$502,095	$157,564
Instantaneous		1,500,000		4,418	16%	$3,687	$510,254	$147,781

** letters represent different configurations*

Table 11

LIFE CYCLE COSTING

Cost of various system components were compiled in order to conduct system economic analyses. LCC models used these equipment costs and the energy costs computed by the various models (above) to evaluate the economic efficiencies of employing different systems to satisfy a building's DHW needs. These analyses calculated a NPV cost of owning and operating each system over a 20 year life span. The results were then compared to determine the approach that will provide the greatest economic benefit for the site.

The LCC analyses were undertaken by adapting ENVEST software. To develop true life cycle costs it was necessary to configure the program with certain basic economic and non-case-specific parameters in addition to the installed equipment costs and annual energy consumption. These parameters included equipment depreciation schedules, initial fuel cost, fuel cost escalation, tax rates, and discount rate. Constant values were used for all cases.

Boilers and DHW system equipment in multifamily buildings fall into the Internal Revenue Service's modified accelerated cost recovery system (MACRS) depreciation classification of residential rental property. This schedule allows for the equipment to be depreciated over 27.5 years using the straight line method. Discussion with building owners/managers, their accountants, and other financial professionals resulted in the selection of a 50% tax rate (as typical for most sole owners, partnerships, and subchapter S corporations), and a discount rate of 6.5%, chosen as the 20-year midpoint between 10- and 30-year treasury notes, which were at approximately 6.2% and 6.8%, respectively. As it is potentially possible for the equipment evaluated to run on more than one particular type of fuel, a *generic* fuel type with a value of 1 MMBTU per unit was used. A base price of $4.50 per MMBTU was selected, based on an average cost of the most typical fuels used in these systems. Fuel cost escalations projections were taken from the U.S. Department of Energy's 1994 forecasts for price changes in this end use sector over the next 20 years.[17] The resultant annual growth

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[17] Reference Case (Appendix A), Table 3 - Energy Prices by End Use and Source. Annual Energy Outlook 1994, DOE/EIA 0383(94), January 1994.

Following the approach used for the selection of the Generic fuel price, the escalation rates represent an average of the price changes for the DOE categories of Natural Gas, Distillate Fuel (#2 oil), and Residual Fuel (#6 oil).

rates applied in the models were: 2.71% beginning in 1995, 2.73% from 2000, and 2.05% from 2005 thru the end of the model period.

The results of the individual building LCC models are presented in Tables 4 through 11[18]. While the "20 Year Energy Costs" exhibit the same relationships as "% Efficiency vs. Base" (i.e., in Table 9 for Building 7), as expected, the fiscal advantage of the various systems' life cycle NPVs do not exhibit the same relationships. Examination of the system NPV costs reveal that configuration (c) of the direct-fired storage tank has the lowest LCC, 9% less than that of the tankless coil (base case). Configuration (c) of the separate DHW boiler w/tank and the instantaneous system are similarly 9% and 11%, respectively, more efficient than the Tankless Coil design.

Reviewing the NPVs of various configurations of separate DHW boiler w/tank (Table 9), even though the energy cost of configuration (d) is lower, the incremental cost of the large volume of storage (2400 gallons) overcomes the reduced cost of the smaller generator. Also, the distinction between configurations (a) and (b), as well as between (b) and (c) is in large part due the lack of real-world price differences between the hot water generator models.

Other real-world issues that must be considered in conjunction with the lower NPV of the direct-fired storage tank system are available sizes. These units come as packaged systems, with the generator/burner and storage tank all part of one integral unit. The combination of generator capacities and storage volumes is quite limited. Additionally, in retrofit situations the larger, lower-operating-cost systems often are too large to fit through the boiler room door, or too heavy to be installed without excessively large equipment. In addition, many building managers and heating plant professionals have reported poor track records of direct-fired storage units. Their in-the-field lifetimes often are as low as 3 to 5 years.

One of the advantages of the separate DHW boiler w/tank systems is the flexibility they offer the system designer to mix and match components (boilers and storage tanks) that are available in a vast array of sizes, from various manufacturers. This enables the

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[18] The tankless coil system cost was determined by calculating the marginal difference between the cost of the combination heating/DHW plant vs. the cost of installing a heat only boiler.

designer to more closely match the optimum (lowest cost) configuration meeting the building's load.

In order to develop a functional set of system selection and design guidelines, we took the systems that were determined to have the best LCC value and computed how they would have been arrived at by employing the LMH tables. To do this, the burner capacity was divided by 8.33 lbs/gallon of water, then by the delta T (in degrees F), next by the heater/boiler efficiency, and finally by the building occupancy (number of persons). This figure of Gallons/Capita per Maximum Hour, was then converted into Peak-30 and Peak-15 minute equivalents. These numbers were then compared to the values in the LMH tables. Table 12 displays the results of the evaluation for the two most efficient (in terms of LCC) separate DHW boiler w/tank systems for each building. From this analysis it was determined that the separate DHW boiler w/tank system design that will provide lowest life cycle costs and meet building hot water requirements is a system designed with a generator size based on the peak 30-minute demand, and storage tank(s) volume based on the maximum 3-hour demand ("30/3" generator/storage sizing guideline).

LCC savings over the tankless coil ranged from 7 to 19% for the separate DHW boiler w/tank systems, and from 10 to 19% for the instantaneous systems, and averaged 12.6% and 12.8%, respectively.

The "30/3" guideline holds true for all but Buildings 5 and 10. Further explanation as to why these sites differed from the rest led to an investigation of usage patterns and shapes via load factors (LFs). The LF is a number used to represent a facility's energy usage (in this case DHW consumption) average vs. peak demand load. The LF was computed by dividing the average hour consumption by the (hour normalized) 15 minute peak demand. LF measurement is used by electric utilities and other sectors of the energy and engineering industry to characterize consumption loads. As revealed in Table 12, Buildings 5 and 10 have considerably larger load factors (0.39 and 0.40, respectively) than any of the other sites. This *may* be due to the fact that these are the two largest buildings in terms of number of apartments.

Lastly, the authors wonder if the vast majority of building management personnel responsible for making equipment investment decisions, who now generally rely on first cost as the key parameter, would be swayed by the NPV analysis. For example,

Data for Developing System Size Optimization

			------- Separate DHW Boiler w/Tank -------				Instantaneous	
BLDG	# OF Apts	Burner BTUH	EQUIV. SYSTEM SIZE*	Storage Gal.	EQUIV. SYSTEM SIZE*	L.C.C. Savings over T.C.	L.C.C. Savings	LOAD FACTOR
1	23	163,000	p 30	370	m 3h	17.8%	15.2%	0.18
		150,000	p 45	500	m 4+h	17.5%		
2	30	875,000	p 35	1230	m 2h	8.4%	12.9%	0.26
		625,000	m 2h	1980	m 3h	8.3%		
3	34	725,000	p 15	105	p 15m	7.1%	10.2%	0.22
		575,000	p 25	735	m 2h	6.9%		
6	49	765,000	p 15	105	p 10m	17.1%	10.3%	0.27
		500,000	p 40	1040	m 2.5h	12.3%		
7	60	850,000	p 10	100	p 10m	9.2%	11.4%	0.25
		550,000	p 25	900	m 2.5h	9.2%		
9	80	280,000	m 2h	1000	m 4+h	19.4%	18.7%	0.25
		330,000	m 1h	830	m 3h	18.0%		
5	90	600,000	m 3+h	1230	>97% load	15.4%	10.7%	0.39
		700,000	m 3h	930	m 1h	11.5%		
10	102	1,450,000	p 30	100	p 2m	9.3%	12.8%	0.40
		1,250,000	m 1h	675	p 20m	8.4%		
Average						*12.6%*	*12.8%*	*0.28*

*Key: p 30 = peak 30 minutes
m 3h = maximum 3 hours

Table 12

we question whether for Building 7 (Table 9), the $66,419 or $61,767 saving in energy cost, for separate DHW boiler w/tank configuration (c) and the instantaneous system, respectively, vs. a tankless coil, over the 20-year system life might not be a more effective tool than LCC NPV saving for the target audience.

Section 5
CONCLUSIONS AND RECOMMENDATIONS ON SYSTEM DESIGN

As previously mentioned, DHW requirements in multifamily buildings have been calculated on the basis of national ASHRAE and other standards of many years standing (which have been determined inaccurate[19]). The research described in this report measured precise DHW flows to create a better basis for sizing DHW systems in multifamily buildings than previously existed. The analysis of this data was used in the development of the LMH system approach and sizing tables. These values can be employed by energy professionals, engineers, or contractors to design appropriately sized DHW systems.

Use of the LMH guidelines will allow for proper sizing, which will save buildings money in two ways: first, in lower initial equipment investments, for smaller more correctly sized equipment; and second, in lower annual life cycle operating costs, due to higher operating (seasonal) efficiencies as a result of equipment operating closer to full load and therefore reduced cycling.

Additionally, the results from the Phase 2 modeling/LCC research indicate that selection of either an instantaneous hot water heater, or a separate DHW boiler w/tank configuration will result in the optimum mix of low life cycle cost, high energy efficiency, and in-the-field reliability.

In small- to mid-sized buildings (up to 80 apartments), either a separate DHW boiler w/tank system sized to the 30/3 guideline, or an instantaneous system should be installed. In large buildings (100 plus apartments) and/or mid-sized to large buildings (more than 75 and less than 100 apartments), which fall into the upper end of the LMH classification scale (more toward the High category), install an instantaneous system. (See the following Sizing Example for instructions on how to determine the proper system size[s].)

As illustrated in Table 12, whichever system is selected, the building can expect an average savings of about 12 1/2% over a properly sized Tankless Coil system.

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[19] Goldner, Nov. 1994.

Sizing Example

The following four pages are intended as a guide to assist DHW system designers in applying the LMH sizing tables and approach, and the 30/3 guideline or 5-minute peak - instantaneous system described above.

DHW SYSTEM SIZING EXAMPLE

Consider a 58-unit apartment building whose occupants are a mix of families, some singles, and middle income couples in which most adults work. There is a public laundry in the basement with a few washers. The leases prohibited both clothes and dishwashers in the apartments (although conversations with the superintendent confirmed that a moderate number of people had such appliances.)

Step 1) **Compute** the **maximum potential occupancy**, based on local standards/expectations, and conversations with building owner or manager.

For example: multiply the number of 3 bedroom apartments (4) by the maximum number of persons in such an apartment (5), which results in a total number of persons (20). This is then added to the resultant sum from all other apartment sizes, as below.

Apartment size	# of apts.	x	Maximum # persons/apt		
3 bedroom apts.	4	x	5	=	20
2 bedroom apts.	14	x	4	=	56
1 bedroom apts.	25	x	3.5	=	87.5
Studios	15	x	2.25	=	33.75
Building total			round up to:		198 persons

Step 2) **Determine** the Low, Medium, or High **(LMH)** Usage **Factor** (demographic profile) of the project and building occupants from Table 2, based on knowledge of the building, conversations with building owner or manager, and observations. Consider the effect of either currently installed or potential future additions of appliances (e.g., washers), that might raise a building to a higher usage category.

Based on the information above, the MEDIUM Usage Factor was selected.

a. Instantaneous Systems

For either an instantaneous DHW only system or a tankless coil in a combination heating/DHW boiler, first find the system load in gallons per hour (GPH) based on the Peak 5-minute demand. Next convert this to a BTU/hr rating. This can then be used to select equipment.

Step 3a) **Compute** the **system load** using the LMH Usage Factor and the 5-minute peak demand values in Table 3 (LMH Guidelines).

LMH Factor	# People	x	Demand Category	x	# periods/hr	=	Peak System Load
MED	198	x	Peak 5 minutes .7 gal/capita	x	12	=	1663 GPH

Step 4a) **Convert** the system **load to a BTU/Hr rating**.

DHW load in GPH	x	conversion	x	Temp. rise	x	1 / Boiler Combustion Effic.	=	DHW load in BTU/Hr
1663 GPH	x	8.33 lbs/gal	x	90^{0} F	x	1/.8 (80% C.E.)	=	1,558,439 BTU/Hr

Instantaneous DHW-Only Heater:

If sizing an instantaneous DHW-only heater, the 1,558,439 BTU/Hr should be the size of the DHW heater*. (*Note that a higher combustion efficiency should actually be used for sizing an instantaneous heater; use 85% or efficiency specified in equipment documentation.)

Combination Heating/DHW Boiler:

When sizing a tankless coil in a combination heating/DHW boiler, the 1663 GPH is the coil size to be ordered. The 1,558,439 BTU/Hr is the additional load capacity for DHW to be added to the combination heat/hot water boiler. The DHW coil capacity (1,558,439 BTU/Hr) must be added to the space heating load. (In an existing steam heating distribution system the heating load should be computed by the equivalent direct radiation (EDR) methodology.)

b. Estimating DHW Consumption in Existing Buildings

Step 5) To estimate how much hot water is used in a building for energy consumption or savings calculations, use the LMH Usage Factor and the **Average Day** hot water value in Table 3 (LMH Guidelines). In this calculation in place of the "maximum potential occupancy" from Step 1, use **actual current** (or best guess recent) **occupancy** level.

LMH Factor	Current # of People	x	Demand Category	=	System Load
MED	153	x	Average Day 30.0 gal/capita	=	4590 Gals/Day

c. Generation & Storage Systems

For a system with a mix of generation and storage: calculate the generator size based on the Peak 30-minute demand to obtain a BTU/hr rating; calculate the storage tank volume based on the Maximum 3-hour demand.

Step 3c) **Compute** the **system load** using the Peak 30-minute and Maximum 3-hour hot water values in Table 3.

LMH Factor	# People	x	Demand Category	x	# periods/hr	=	System Load
MED	198	x	Peak 30 minutes 2.9 gal/capita	x	2	=	1148 GPH

LMH Factor	# People	x	Demand Category	=	Storage Volume
MED	198	x	Maximum 3 hours 11.0 gal/capita	=	2178 gallons

Step 4c) Next, **convert** the **load into equipment ratings**.

DHW load in GPH	x	conversion	x	Temp. rise	x	1 / Boiler Combustion Effic.	=	DHW load in BTU/Hr
1148 GPH	x	8.33 lbs/gal	x	90^{o}F	x	1/.85 (85% C.E.)	=	1,012,536 BTU/Hr

The 1,012,536 BTU/hr is the size of the hot water heater (generator). This heater should then be used to supply 2100 gallons of unfired storage tanks.

Demographic Characteristics Correlation to DHW Consumption

Demographic Characteristics	LMH Factor
No occupants work Public assistance & low income (mix) Family & 1 parent households (mix) High % of Children Low income	**HIGH**
Families Public assistance Singles 1 parent households	**MEDIUM**
Couples Higher population density Middle income Seniors One person works, 1 stays home All occupants work	**LOW**

Table 2

National

LOW - MEDIUM - HIGH GUIDELINES

Hot Water Demands and Use for Multi Family Buildings

	Peak 5 Minutes	**Peak 15 Minutes**	**Peak 30 Minutes**	**Maximum Hour**
Low	0.4 gal (1.5 L)/person	1.0 gal (4.0 L)/person	1.7 gal (6.5 L)/person	2.8 gal (10.5 L)/person
Med	0.7 gal (2.6 L)/person	1.7 gal (6.4 L)/person	2.9 gal (11.0 L)/person	4.8 gal (18.0 L)/person
High	1.2 gal (4.5 L)/person	3.0 gal (11.5 L)/person	5.1 gal (19.5 L)/person	8.5 gal (32.5 L)/person

	Maximum 2 Hours	**Maximum 3 Hours**	**Maximum Day**	**Average Day**
Low	4.5 gal (17.0 L)/person	6.1 gal (23.0 L)/person	20.0 gal (76.0 L)/person	14.0 gal (53.0 L)/person
Med	8.0 gal (31.0 L)/person	11.0 gal (41.0 L)/person	49.0 gal (185.0 L)/person	30.0 gal (114.0 L)/person
High	14.5 gal (55.0 L)/person	19.0 gal (72.0 L)/person	90.0 gal (340.0 L)/person	54.0 gal (205.0 L)/person

Note: These gallonages are for DHW delivered to the tap at 120°F

Table 3

Section 6
HEATING SYSTEM WEATHER-RELATED ANALYSIS

ANALYZING USAGE: "KNOW YOUR BASELINE"

In analyzing a facility's energy usage against a controlling variable such as weather or units of production, we attempt to remove consumption attributable to factors other than the main variable. This "other" portion of consumption, referred to as the facility's baseload usage, is then removed as an adjustment from the total consumption before analysis against the controlling factor. All too often professionals conducting such evaluations assume that if they can find a period during which only the baseload consumption is occurring, that level (of consumption) can be used to make adjustments across the entire year. Examples of this might be lighting during the winter (in a building with electrically driven air-conditioning and a non-electric heating system), or the summer DHW load in a fossil fuel-driven heating/DHW system.

It is important to investigate what is actually occurring with the assumed baseload across the full year. One should not assume that it is an even load. In multi family buildings such as those in the monitored study, the industry standard has been to consider the DHW load as the base. In evaluating a building's fuel use, it is customary to take the summer fuel bills and project that level of consumption out evenly through 12 months. The argument is that during the summer period the heating plant is operating solely to provide DHW, so all fuel use during this period can be attributed to that function. Also, until recently, it had been assumed that DHW use, though varying from site to site, was constant (from month to month) within a building. Results from the Phase 1 research revealed this assumption to be incorrect[20].

Analysis of the seasonal DHW consumption levels reveals a pattern. As Figure 12 illustrates, the average summer consumption rose by 10% in the fall and then by 13% during the winter period. The consumption then fell by 1% in the spring and fell 19% during the second summer period.

To compensate for the higher levels of DHW being used during the non-summer months, it is necessary to adjust the baseline fuel consumption. This is done by

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[20] Goldner, F.S. Nov. 1994.

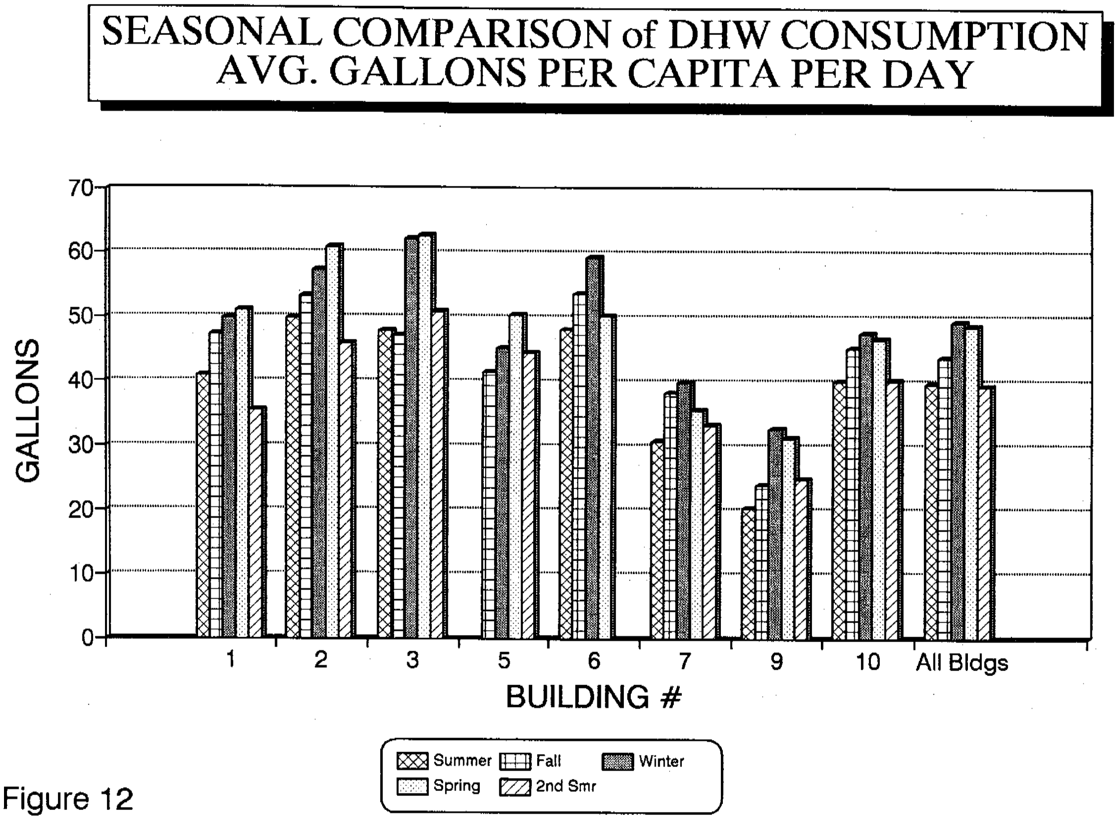

Figure 12

multiplying the average daily units of fuel (gallons of oil in the study buildings) by the number of days in each season and also by the multiplier for increased DHW consumption.

For example, Figure 13 illustrates the fuel use for study Building 7. We can clearly see that there is a constant base level of fuel consumption during the summer months, for providing DHW. Once this baseload has been determined, the fuel use for the other seasons is reduced by an amount equal to this level adjusted upward by the appropriate factor (of 1.1 in fall, 1.25 in winter, and 1.23 in spring).

Two other potential issues arise when investigating factors that effect the DHW load. First, supply water coming into the DHW system is colder during the non-summer months. Manual spot measurements show a delta T of -20^{0} F during the winter, compared to the average temperature of summer city (supply) water. Calculating this against a typical 60^{0} F temperature rise (for DHW heating) results in approximately 30% more energy needed to heat the water during the colder months. Second, as described in the following section, the boiler/burner unit operates considerably more efficiently as the outdoor temperature drops. An analysis of the system's operations during the summer reveals that they deliver DHW at an average efficiency of 42%[21]. The second issue tends to have the inverse effect of the first, so for the purposes of this analysis these have been considered mutually negating.

SYSTEMS OPERATIONS & GENERIC METHODOLOGY

Once the baseload has been broken out from the overall consumption, the remainder of the energy use can then be evaluated against the controlling variable. Before using even some of the most accepted methods, it is advisable to re-evaluate both the facility operation and underlying suppositions of the method to be employed.

For a space heating application, the most commonly used methodology is to calculate the fuel used per heating degree day (HDD). The initial daily fuel consumption evaluation of gallons of oil per HDD (Gal/DD) resulted in a relatively flat level across the heating season (see Figure 14). This appeared to contradict the widely held assumption that equipment is more efficient the closer it operates to full load. Upon further review of the buildings' operation and control strategy, it became apparent that some of the basic principles behind standard HDDs were not correct for this stock of buildings. An HDD (as published by the National Climatic Data Center) is equal to 65^{o} F minus the average of the high and low recorded temperatures for a day. HDDs are calculated for any day on which the average (mean) temperature falls below 65^{o} F. The assumption is that during the heating season, whenever the outdoor temperature falls below 65^{o} F the heating system will act to keep the interior space at 65^{o} F. For this stock of buildings, the algorithm employed by the heating plant controls does not conform with that hypothesis. New York City's Housing Maintenance Law requires that when the outside temperature falls below 55^{o} F the building must provide an interior temperature of not less than 68^{o} F[22]. The various controls used throughout

[21] The analysis compared total BTU OUT to BTU IN. With BTU OUT = Gallons of DHW consumed x 8.33 lb/gal x ((Average of temperature leaving the mixing valve and temp. of return water) - temp. of inlet supply water) x 1 BTU/lb/^{o}F, and BTU IN = gallons of oil burned x BTU/gallon.

[22] In fact, the law states that between Oct. 1 and May 31 during the hours from 6 am to 10 pm when the outside temperature falls below 55^{o} F the building must provide an interior temperature of not less than 68^{o} F, and from 10 pm to 6 am when the outside temperature falls below 40^{o} F the building must provide an interior temperature of not less than 55^{o} F. As most generally available data is for average daily temperature, the case above and DD_55 data presented later have been simplified and calculated using only the daytime control temperature settings as a parameter. It should be noted that a more exacting representation would be obtained by calculating the degree hours against the two different, 'daytime' and nighttime', regulation levels.

BOILER RUNTIME vs. FUEL USED

Building 7

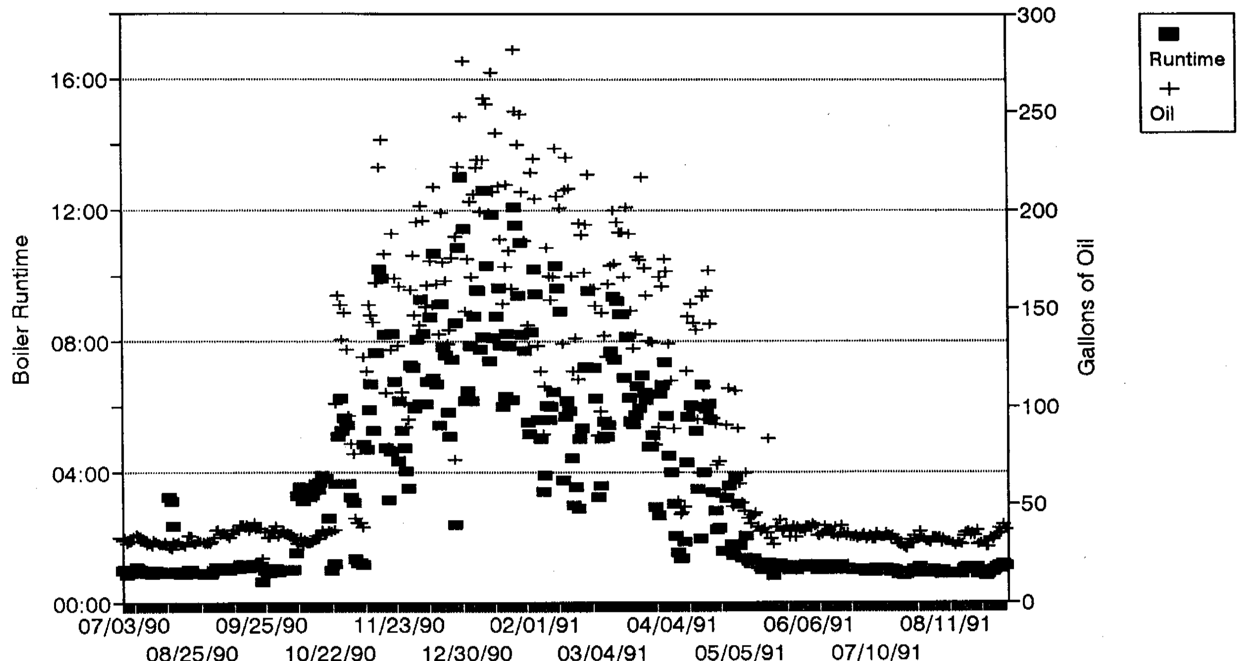

Figure 13

TEMPERATURE vs. GAL/DD - Adj. for 55

Building 7

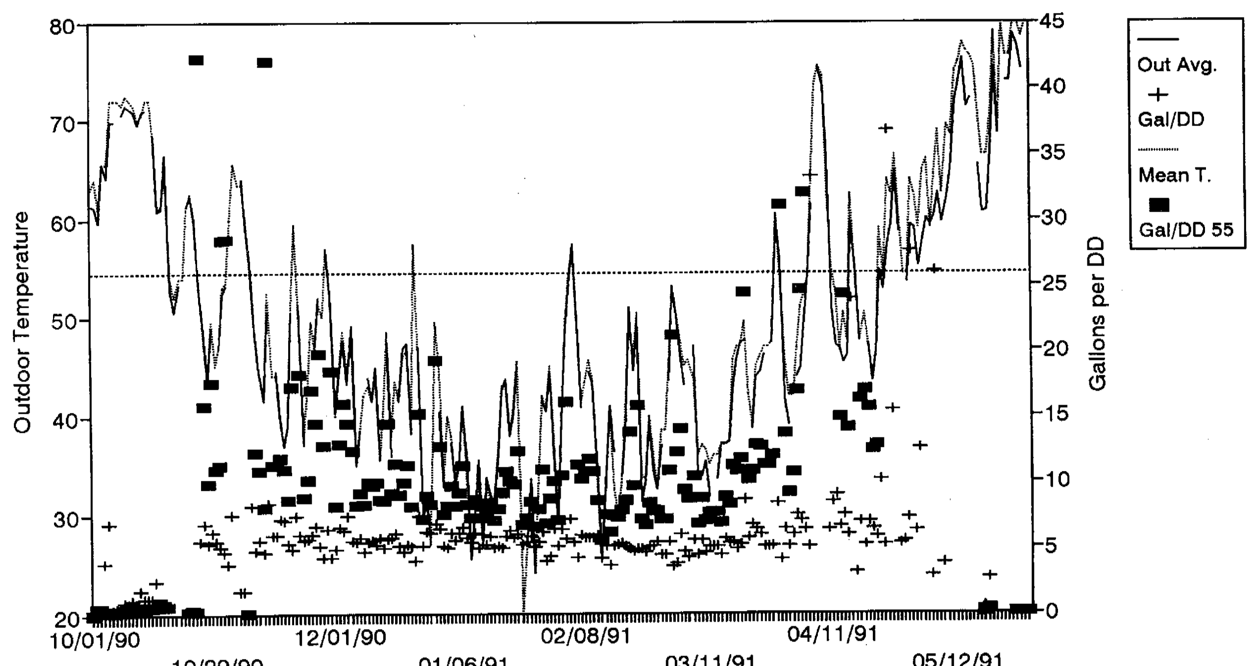

Figure 14

this stock of over 120,000 buildings are set up to comply with this code. Thus, the underlying theory of a 65^{O} F based HDD does not hold true, and should not be employed in calculating the energy use indices for these facilities.

Using the data collected in this project, it was possible to calculate a new HDD set based on the control strategy. The new 55^{O} F base HDD (DD_55) tables were compiled by employing the condition that HDDs are computed only for days in which the mean temperature fell below 55^{O} F. On those days, the mean temperature for the day was subtracted from 68. This gave a more accurate model on which to evaluate building performance.

Included in Appendix A is a breakdown of the yearly totals of DD_55 and DD_65 (the commonly available 65-degree-based figure) for 1991 through 1996. Note that the difference between the annual pairs of degree day figures vary significantly from year to year. This further proves that use of the traditional 65-degree-based degree days as a method of calculating energy use and savings can result in misleading conclusions, (when making year-to-year weather-adjusted usage comparisons). Further examination of the individual date DD_55 and DD_65 degree day figures reveals that, while on cold days, e.g., 1/2/91, the DD_55 base system accumulates three more degree days, whereas on warmer days, e.g., 4/6/91, the normal 65-degree-based system (DD_65) can accumulate an even greater number of "false" degree days. That is, degree days are calculated, when in fact no heating is being called for. This then exaggerates to an even greater extent the misleading results that can occur from use of the 65-degree-based system as compared to the DD_55 ("Degree Day 55") methodology.

Figure 15: EXAMPLE OF HOW TRADITIONAL DD_65 METHODOLOGY INTRODUCES ERROR

Examination of a 30-unit apartment building reveals a consumption of 27,090 gallons of number 2 fuel oil in 1993. As a result of an energy audit, the building management installed energy conservation measures and implemented new operating procedures during 1994. In 1995 the consumption was 23,615 gallons. In the following example the consumption has been weather-adjusted with both the 55 Degree Day base (DD_55) and the 65 Degree Day base (DD_65). The results illustrate the error (or overestimation in this case), that exists when employing the traditional DD_65 methodology.

1993 - 27,090 gallons total consumption
8,127 gal for DHW
18,963 gal for heating

Weather adjustment with 55 degree day base:

$$18{,}963_{\text{ gal}} / 5188_{\text{ DD\_55}} = 3.655_{\text{ gal/DD\_55}} \times 5072_{\text{ 6 yr avg DD\_55}} =$$
$$18{,}539 + 8{,}127 = 26{,}666 \text{ gallons}$$

Weather adjustment with 65 degree day base:

$$18{,}963_{\text{ gal}} / 4749_{\text{ DD\_65}} = 3.993_{\text{ gal/DD\_65}} \times 4769_{\text{ 6 yr avg DD\_65}} =$$
$$19{,}043 + 8{,}127 = 27{,}170 \text{ gallons}$$

The building then installed ECMs during 1994

1995 - 23,615 gallons total consumption
7,085 gal for DHW
16,531 gal for heating

Weather adjustment with 55 degree day base:

$$16{,}531_{\text{ gal}} / 5003_{\text{ DD\_55}} = 3.304_{\text{ gal/DD\_55}} \times 5072_{\text{ 6 yr avg DD\_55}} =$$
$$16{,}758 + 7{,}085 = 23{,}843 \text{ gallons}$$

Weather adjustment with 65 degree day base:

$$16{,}531_{\text{ gal}} / 4724_{\text{ DD\_65}} = 3.499_{\text{ gal/DD\_65}} \times 4769_{\text{ 6 yr avg DD\_65}} =$$
$$16{,}688 + 7{,}085 = 23{,}772 \text{ gallons}$$

Summary:

	DD_65	DD_55	Difference
1993	27,170	26,666	
1995	23,772	23,843	

Savings:

gallons	3,397	2,823	574
Dollars	$3,228	$2,682	$546
% cost			20%

We see in this example how use of the traditional DD_65 methodology introduces a 20% error factor in the computed cost savings. A run of other site evaluations, comparing the DD_55 and DD_65 methodologies, reveals that while the level of error may vary both in magnitude as well as in direction (in some cases overestimation and others underestimation), the traditional 65-degree-based method always results in an incorrect appraisal in the change of (weather adjusted) energy consumption. This takes on even greater importance in the soon-to-be-deregulated environment, as even more energy projects will be instituted under some type of performance contracting (such as shared savings).

The analyses were then rerun against the DD_55 values. In Figure 14 we see that in fact the efficiency of the heating system increases (lower Gal/DD 55, solid squares) as the outdoor temperature drops, and the boiler is operating at closer to full load. As we approach the shoulder months of spring the efficiency drops, resulting in a higher Gal/DD 55. It is also interesting to note on this graph that the mean temperature (mean T) of the day, computed as high - low / 2, is almost identical to the average outdoor temperature (Out Avg.), computed by averaging the 24 hourly readings collected each day (the only notable differences appear toward the upper right hand corner of the graph). It was initially thought that the mean temperature (average of high and low temperatures), did not properly represent the true condition of a day.

Figure 16 more clearly illustrates how, as the load on the heating plant increases, the more efficiently the system operates to fulfill this demand. Each point on the graph represents the amount of fuel used on a given day to provide heat to the building. The load is represented by be number of degree days (DD_55) for a given day. We can see that at higher load levels, e.g., colder days with more degree days (when more heating is needed), system efficiency increases.

As all of the monitored (heating system) data for this study was collected in the 1990-91 heating season, we felt that it was important to see if this observation of increased efficiency with increased load held true under different weather conditions. To this end, data from the MFRP research project, collected during the 1995-96 heating season was examined. Figure 17 illustrates that the phenomenon of increased efficiency at closer to full loads holds true as projected.

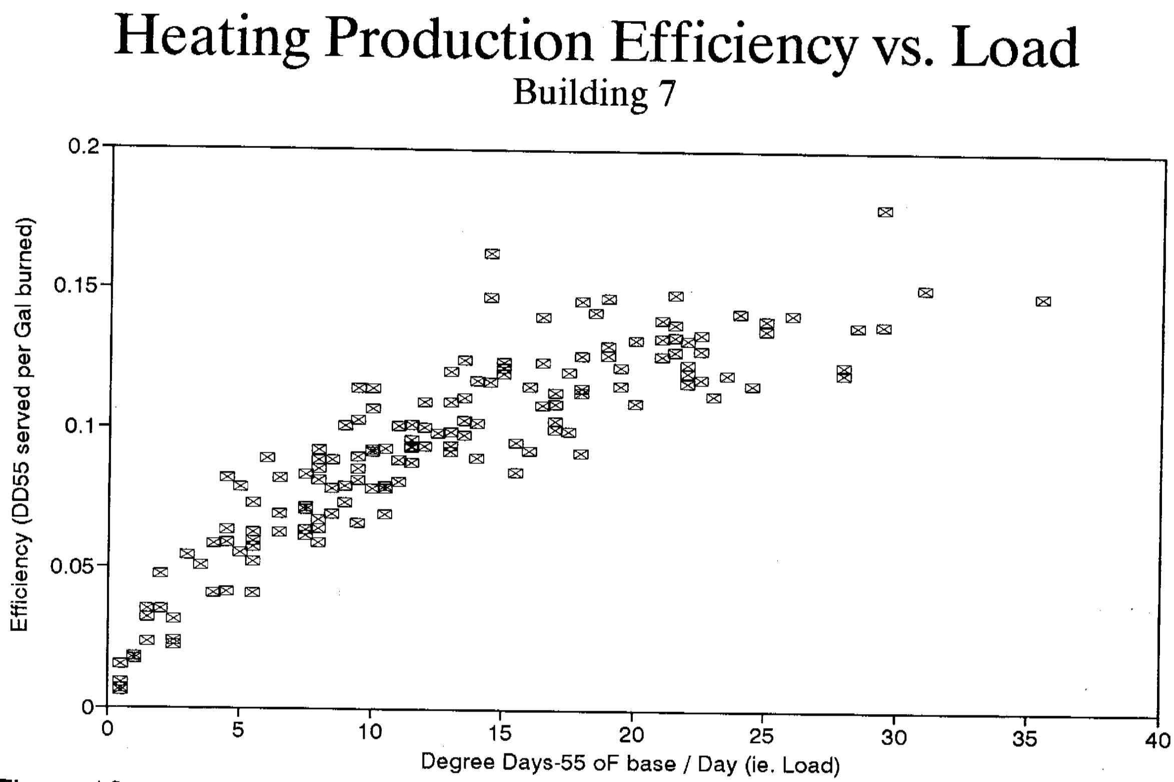

Figure 16

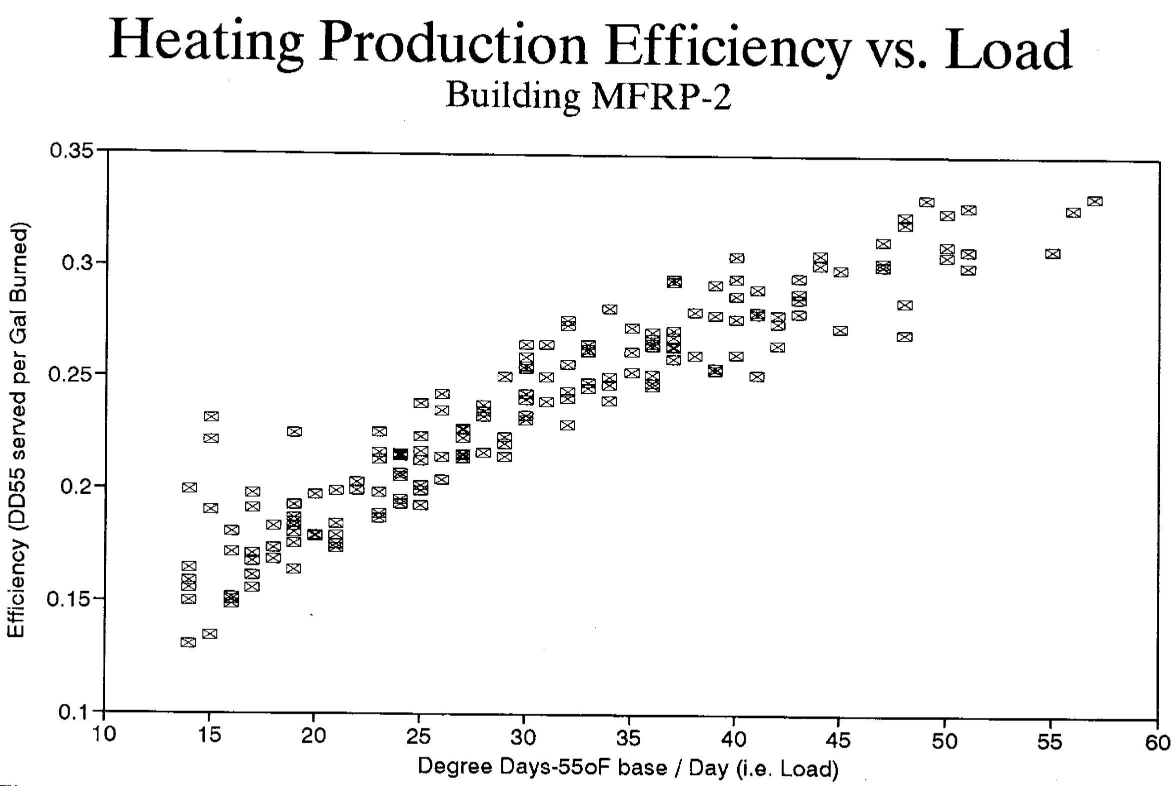

Figure 17

Following similar analyses (to those presented for Building 7, illustrated in Figures 13, 14 and 16) for all eight sites for which detailed data was available, individual site data was compiled to produce Figures 18, 19, and 20. Figure 18 illustrates fuel use for heating vs. outdoor temperature. Clearly, as the outdoor temperature decreases there is a resultant increase in fuel use efficiency, delineated as a lower Gal/HDD (using the 55 DD base). The explanation of why this greater seasonal efficiency occurs is illustrated in Figure 19, which shows a direct correlation between the decrease in Gal/HDDs as daily burner runtime increases. Finally, Figure 20 documents that the increased runtime is a function of the boiler needing to operate for longer periods, at closer to full capacity, to supply larger heating loads at lower temperatures. Some smaller portion of the increase in the runtime is also attributable to higher DHW loads during these seasons. Examination of the consumption data on a seasonal basis suggests that the buildings are operating approximately 30% more efficiently during the winter as compared to the fall and spring.

Figure 21 documents that the trend of increasing burner runtimes occurs over the whole housing stock and is not limited to the sites with more detailed data collection. The highest average daily burner runtime of eight hours and 32 minutes (8:32) occurs in January, and is 3.2 times longer than the lowest average daily runtime of two hours and 39 minutes (2:39) which occurs in August.

While total daily runtime begins to explain the increase in operating efficiency during the colder months, as the boiler is running at closer to full loads, it does not shed light on all pertinent issues. To gain greater insight, time of occurrence and duration of burner on-and-off cycles were studied to determine the trends and potential effects of system cycling. As shown in Table 13 the day was broken down into three periods. Period 1, midnight (00:00) to 5:30 AM, represents the overnight time during which little to no DHW is used[23] and the system comes on only to maintain minimum boiler water temperature (during the summer period) and/or to satisfy heat calls. Period 2, 5:30 to 9 AM, represents a peak DHW demand period as well as the early morning heating boost period. Period 3, 9 AM to midnight (23:59), covers the rest of the day, including a mix of high and low demand times.

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[23] Goldner, F.S. Nov. 1994.

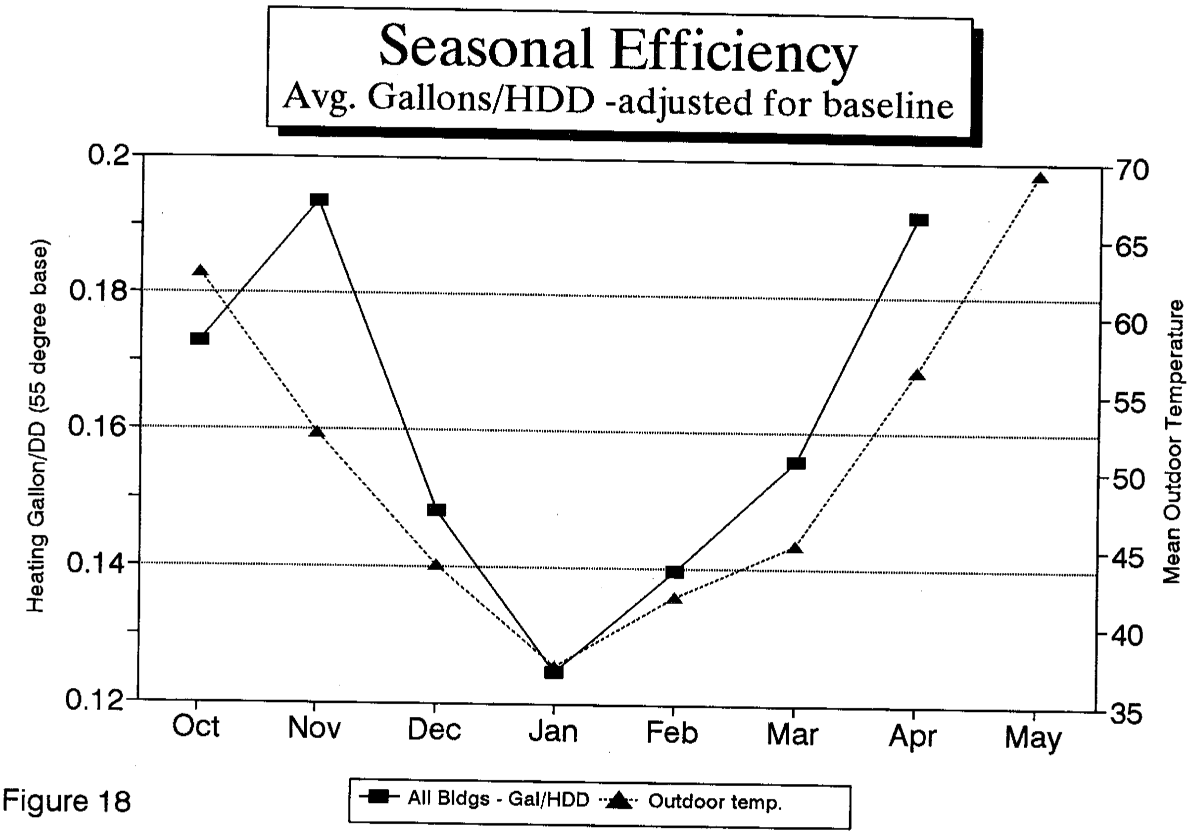

Figure 18

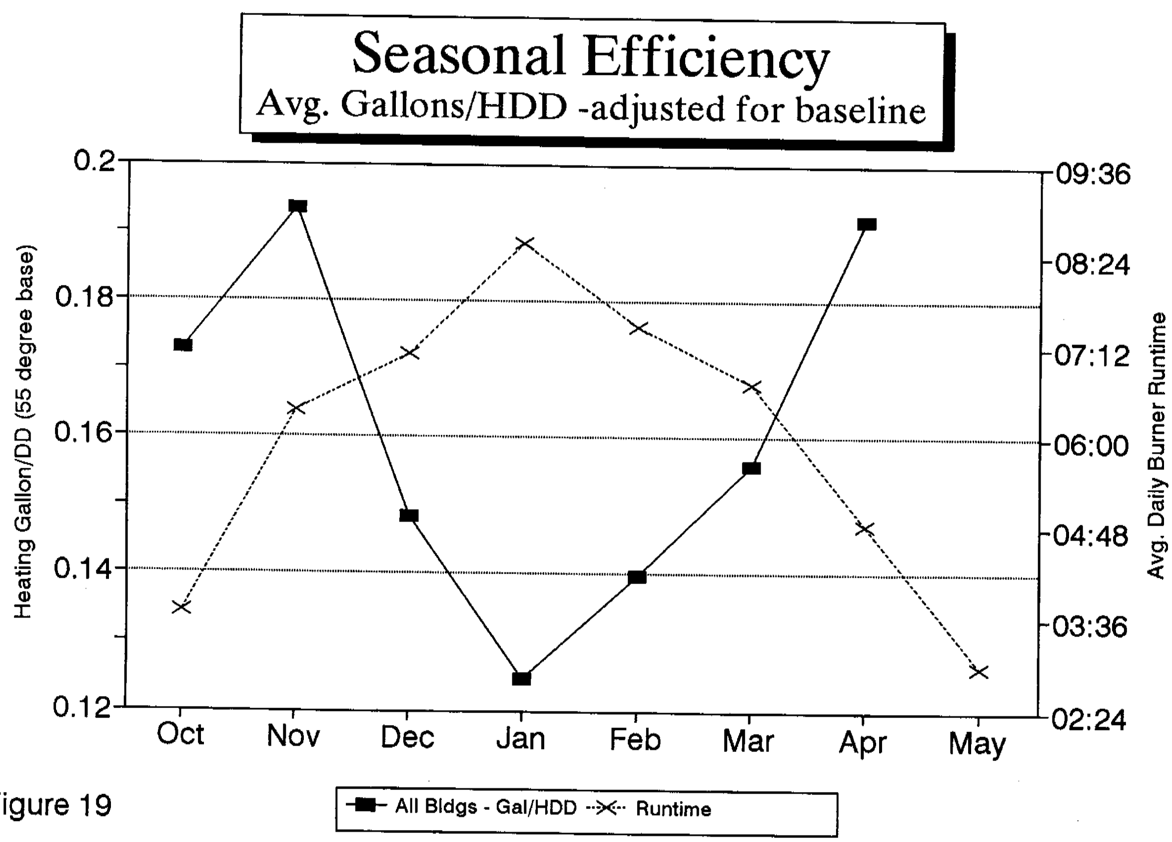

Figure 19

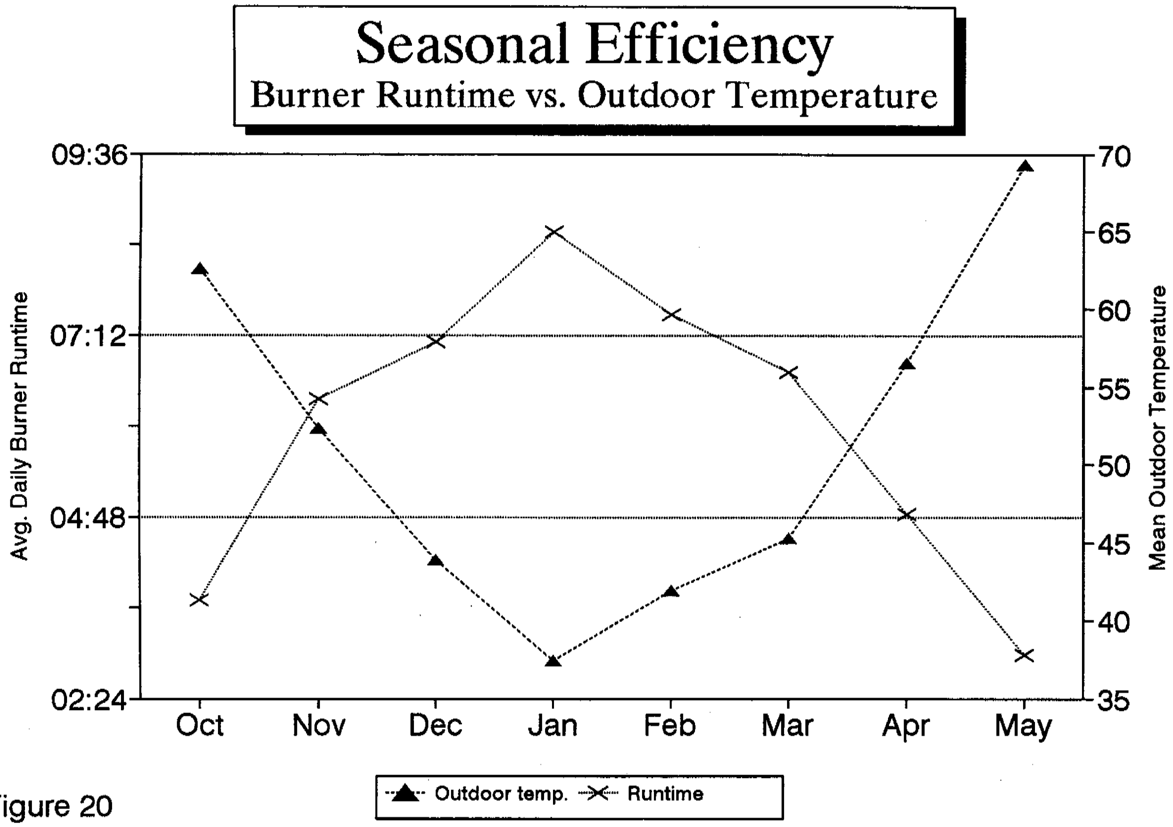

Figure 20

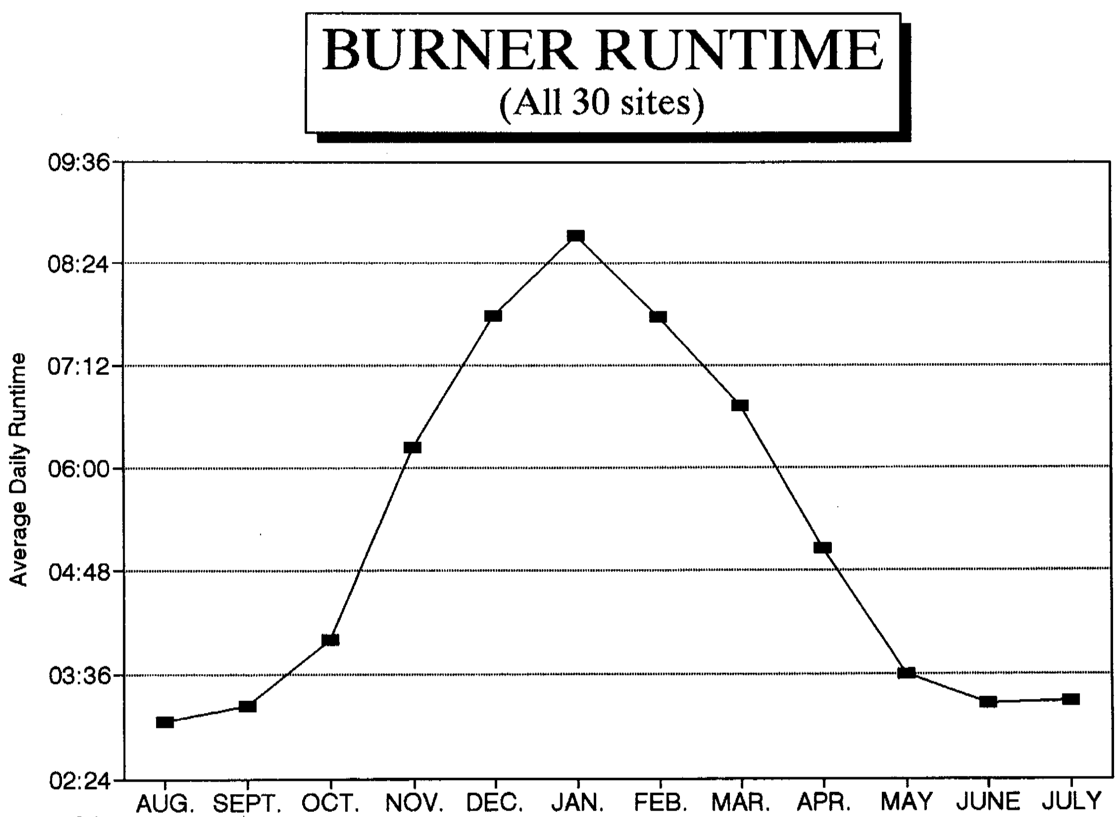

Figure 21

BOILER CYCLE TIME LENGTHS

SEASON	00:00 to 5:30 ON TIME AVERAGE	00:00 to 5:30 OFF TIME AVERAGE	5:30 to 9:00 ON TIME AVERAGE	5:30 to 9:00 OFF TIME AVERAGE	09:00 to 23:59 ON TIME AVERAGE	09:00 to 23:59 OFF TIME AVERAGE	SEASON
Summer	00:05:00	01:03:14	00:05:07	00:36:19	00:05:21	00:36:13	Summer
Fall	00:06:35	00:54:08	00:13:03	00:24:15	00:09:57	00:33:07	Fall
Winter	00:09:22	00:38:57	00:22:21	00:15:29	00:14:31	00:26:19	Winter
Spring	00:05:12	00:58:34	00:08:50	00:25:48	00:06:08	00:30:31	Spring
AVERAGE	00:06:32	00:53:43	00:12:20	00:25:28	00:08:59	00:31:32	AVERAGE

** NOTE: Times are in HOURS : MINUTES : SECONDS (HH:MM:SS).*

Table 13

A significant amount of energy is lost from the heating plant each time it cycles, due to shut down and start up losses. Examination of Table 13 illustrates the occurrence of longer-duration runtimes, which reduce the system inefficiencies attributable to cycling, during colder periods.

TOWARD AN ALTERNATIVE METHODOLOGY

The data analysis has documented some of the previously held beliefs regarding improved seasonal efficiency at higher loads. One of the more interesting relationships revealed by this project is between seasonal efficiency (measured in Gal/DD 55) and the number of HDDs for the period. A month-by-month analysis of consumption suggests that there may be a direct correlation between degree days in a period and the efficiency level for that period. A potential next step would be further testing of this hypothesis on a larger group of buildings during other (weather pattern) years to refine the mathematical relationship. This could provide a valuable new energy use targeting/ tracking methodology. Such a methodology would assist energy professionals and facility managers in evaluating shorter-term increases or decreases in consumption, that are currently only apparent with annual analyses.

SUMMARY OF SIGNIFICANT ISSUES

- It is necessary to understand and adjust properly for what is actually occurring with the assumed baseload across the full year.
  - For DHW in a multifamily building, the summer baseload level should be adjusted upward by a factor of 1.1 in fall, 1.25 in winter, and 1.23 in spring.
- When combination heating/DHW systems are just generating DHW in the summer, the average heating plant system efficiency was found to be only 42%.
- In evaluating energy use, it is necessary to understand both facility operation and the underlying suppositions of the energy indices method to be employed.
- The mean temperature of a day (computed as high - low / 2) is almost identical to the average outdoor temperature (computed by averaging the 24 hourly readings each day), and is therefore a good representation for weather conditions.
- As the load on a heating plant increases toward (closer to) full-load conditions, the more efficiently the system operates. This phenomenon is a result of the boiler needing to operate for longer periods (increased daily burner runtime at closer to full capacity conditions) to supply larger heating loads at lower temperatures, as well as less cycling, due to longer duration of each cycle runtime.

- All degree days are not equal. A degree day on a 50^{o} F day requires a different amount of fuel to satisfy related heating load than does a degree day on a 25^{o} F day. Therefore it is not possible to compare energy consumption of a building in the fall to, a winter period. A potential solution to the need to evaluate energy usage on a shorter-term (less than annual) basis is the development of a Seasonally Adjusted Degree Day Methodology (SADDM).

- In multifamily buildings the conventional 65-degree-day base system may result in misleading conclusions when making year-to-year weather-adjusted energy usage and savings comparisons, (in buildings where the heating plant control algorithm differs from the assumptions of the conventional basis for calculating degree days).

A full set of DD_55 (degree day 55) figures for every day from January 1991 through June 1997 have been included in Appendix A as a reference tool for energy and building professionals who choose to employ the use of this more appropriate (for N.Y.C. multifamily buildings) degree day computation methodology.

Section 7
FUTURE WORK

The next potential phase of this project, would involve setting up a demonstration of efficient DHW systems. Brooklyn Union's RD&D had expressed interest in participating in this activity. This would involve the installation and monitoring of a field demonstration of the most efficient DHW generation configurations revealed by the modeling and evaluations. It would be used to provide a field test of the analysis findings. It would also provide a set of case studies to be used to promote the changeover to more energy and economically efficient DHW systems in the multi family building market.

Additional follow-up that should be investigated involves possible ways in which the DD_55 (degree day 55) data developed in this project can be shared electronically with end-users. The possibility should be considered of publishing a full set of DD_55 figures for every day from January 1991 through current (similar to the format that have been included in Appendix A) as a reference tool for those energy and building professionals who choose to employ the use of this more appropriate, (for N.Y.C. multifamily buildings), degree-day-computation methodology. One likely possibility would be to publish it on the Internet.

Additional work should go into research that uses the greater understanding of the effects of seasonal efficiency uncovered in this project to create an adaptable *SADDM*. Such a methodology would assist energy professionals and facility managers in evaluating shorter-term increases or decreases in consumption that are currently only apparent with annual analyses.

Section 8
REFERENCES

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

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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).

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9. Vine, E., R. Diamond, and R. Szydlowski. *Domestic Hot Water Consumption In Four Low Income Apartment Buildings*. Energy, Volume 12, No. 6. 1987.

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APPENDIX A:

DD_55 Reference Tables

DD_55 - 55 DEGREE BASED HEATING DEGREE DAYS - CENTRAL PARK

Monthly Summary

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1991	1016	815	815	426	45	0	0	0	15	191	558	959
1992	995	944	933	600	190	14	0	0	14	177	419	912
1993	971	1024	899	492	28	0	0	0	0	277	553	944
1994	1307	1042	822	288	71	0	0	0	0	157	416	761
1995	904	1015	697	413	63	0	0	0	0	111	706	1094
1996	1158	981	894	417	121	0	0	0	0	222	725	819
1997	1103	757	785	406	46	13						
1998												
1999												

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Table 14

Table 15: DD_55 vs. DD_65 HEATING DEGREE DAYS - CENTRAL PARK

Yearly Summary

Year	DD_55	DD_65	Difference
1991	4840	4589	5.5%
1992	5198	4862	6.9%
1993	5188	4749	9.2%
1994	4864	4663	4.3%
1995	5003	4724	5.9%
1996	5337	5029	6.1%

Table 16: DD_55 vs. DD_65 HEATING DEGREE DAYS - CENTRAL PARK

Daily Summary

Date	DD_55	DD_65
01/01/91	36	33
01/02/91	26	23
01/03/91	32	29
01/04/91	36	33
01/05/91	34	31
01/06/91	28	25
01/07/91	32	29
01/08/91	38	35
01/09/91	36	33
01/10/91	30	27
01/11/91	41	38
01/12/91	33	30
01/13/91	35	32
01/14/91	38	35
01/15/91	31	28
01/16/91	24	21
01/17/91	23	20
01/18/91	30	27
01/19/91	31	28
01/20/91	19	16
01/21/91	38	35
01/22/91	55	52
01/23/91	40	37
01/24/91	32	29
01/25/91	47	44
01/26/91	41	38
01/27/91	36	33
01/28/91	18	15
01/29/91	20	17
01/30/91	20	17
01/31/91	36	33
02/01/91	39	36
02/02/91	28	25
02/03/91	21	18
02/04/91	17	14
02/05/91	18	15
02/06/91	19	16
02/07/91	25	22
02/08/91	26	23
02/09/91	23	20
02/10/91	25	22
02/11/91	34	31
02/12/91	43	40
02/13/91	33	30
02/14/91	24	21
02/15/91	33	30
02/16/91	46	43
02/17/91	37	34
02/18/91	34	31
02/19/91	24	21
02/20/91	18	15
02/21/91	25	22
02/22/91	19	16
02/23/91	38	35
02/24/91	34	31
02/25/91	29	26
02/26/91	35	32
02/27/91	36	33
02/28/91	32	29
03/01/91	24	21
03/02/91	18	15
03/03/91	17	14
03/04/91	18	15
03/05/91	23	20

03/06/91	22	19	04/17/91	14	11	05/29/91	0	0
03/07/91	21	18	04/18/91	21	18	05/30/91	0	0
03/08/91	33	30	04/19/91	23	20	05/31/91	0	0
03/09/91	32	29	04/20/91	22	19	06/01/91	0	0
03/10/91	31	28	04/21/91	24	21	06/02/91	0	0
03/11/91	35	32	04/22/91	21	18	06/03/91	0	0
03/12/91	31	28	04/23/91	16	13	06/04/91	0	0
03/13/91	31	28	04/24/91	18	15	06/05/91	0	2
03/14/91	30	27	04/25/91	0	7	06/06/91	0	0
03/15/91	31	28	04/26/91	0	8	06/07/91	0	0
03/16/91	23	20	04/27/91	0	7	06/08/91	0	0
03/17/91	23	20	04/28/91	0	7	06/09/91	0	0
03/18/91	22	19	04/29/91	16	13	06/10/91	0	0
03/19/91	20	17	04/30/91	14	11	06/11/91	0	0
03/20/91	19	16	05/01/91	14	11	06/12/91	0	0
03/21/91	27	24	05/02/91	0	5	06/13/91	0	0
03/22/91	26	23	05/03/91	0	9	06/14/91	0	0
03/23/91	29	26	05/04/91	17	14	06/15/91	0	0
03/24/91	25	22	05/05/91	0	9	06/16/91	0	0
03/25/91	32	29	05/06/91	0	8	06/17/91	0	0
03/26/91	28	25	05/07/91	0	4	06/18/91	0	1
03/27/91	22	19	05/08/91	0	3	06/19/91	0	2
03/28/91	14	11	05/09/91	0	9	06/20/91	0	0
03/29/91	30	27	05/10/91	0	6	06/21/91	0	0
03/30/91	41	38	05/11/91	0	3	06/22/91	0	0
03/31/91	37	34	05/12/91	0	0	06/23/91	0	0
04/01/91	31	28	05/13/91	0	0	06/24/91	0	0
04/02/91	34	31	05/14/91	0	0	06/25/91	0	0
04/03/91	30	27	05/15/91	0	0	06/26/91	0	0
04/04/91	15	12	05/16/91	0	0	06/27/91	0	0
04/05/91	17	14	05/17/91	0	0	06/28/91	0	0
04/06/91	0	7	05/18/91	0	6	06/29/91	0	0
04/07/91	0	0	05/19/91	14	11	06/30/91	0	0
04/08/91	0	1	05/20/91	0	8	07/01/91	0	0
04/09/91	0	6	05/21/91	0	3	07/02/91	0	0
04/10/91	0	3	05/22/91	0	0	07/03/91	0	0
04/11/91	18	15	05/23/91	0	0	07/04/91	0	0
04/12/91	21	18	05/24/91	0	5	07/05/91	0	0
04/13/91	24	21	05/25/91	0	5	07/06/91	0	0
04/14/91	24	21	05/26/91	0	0	07/07/91	0	0
04/15/91	23	20	05/27/91	0	0	07/08/91	0	0
04/16/91	0	5	05/28/91	0	0	07/09/91	0	0

07/10/91	0	0	08/21/91	0	0	10/02/91	0	0
07/11/91	0	0	08/22/91	0	0	10/03/91	0	0
07/12/91	0	0	08/23/91	0	0	10/04/91	0	0
07/13/91	0	0	08/24/91	0	0	10/05/91	0	0
07/14/91	0	0	08/25/91	0	0	10/06/91	0	2
07/15/91	0	0	08/26/91	0	0	10/07/91	15	12
07/16/91	0	0	08/27/91	0	0	10/08/91	13	10
07/17/91	0	0	08/28/91	0	0	10/09/91	0	5
07/18/91	0	0	08/29/91	0	0	10/10/91	0	3
07/19/91	0	0	08/30/91	0	0	10/11/91	0	7
07/20/91	0	0	08/31/91	0	0	10/12/91	13	10
07/21/91	0	0	09/01/91	0	1	10/13/91	13	10
07/22/91	0	0	09/02/91	0	2	10/14/91	17	14
07/23/91	0	0	09/03/91	0	0	10/15/91	0	3
07/24/91	0	0	09/04/91	0	0	10/16/91	0	6
07/25/91	0	0	09/05/91	0	0	10/17/91	16	13
07/26/91	0	0	09/06/91	0	0	10/18/91	0	1
07/27/91	0	0	09/07/91	0	0	10/19/91	0	5
07/28/91	0	0	09/08/91	0	0	10/20/91	20	17
07/29/91	0	0	09/09/91	0	0	10/21/91	19	16
07/30/91	0	0	09/10/91	0	0	10/22/91	0	9
07/31/91	0	0	09/11/91	0	0	10/23/91	0	6
08/01/91	0	0	09/12/91	0	0	10/24/91	0	3
08/02/91	0	0	09/13/91	0	0	10/25/91	0	4
08/03/91	0	0	09/14/91	0	0	10/26/91	0	3
08/04/91	0	0	09/15/91	0	0	10/27/91	0	5
08/05/91	0	0	09/16/91	0	0	10/28/91	13	10
08/06/91	0	0	09/17/91	0	0	10/29/91	22	19
08/07/91	0	0	09/18/91	0	0	10/30/91	16	13
08/08/91	0	0	09/19/91	0	0	10/31/91	14	11
08/09/91	0	1	09/20/91	0	7	11/01/91	0	9
08/10/91	0	0	09/21/91	0	7	11/02/91	0	7
08/11/91	0	0	09/22/91	0	7	11/03/91	16	13
08/12/91	0	0	09/23/91	0	3	11/04/91	23	20
08/13/91	0	0	09/24/91	0	0	11/05/91	28	25
08/14/91	0	0	09/25/91	0	0	11/06/91	25	22
08/15/91	0	0	09/26/91	0	2	11/07/91	23	20
08/16/91	0	0	09/27/91	0	7	11/08/91	26	23
08/17/91	0	0	09/28/91	0	8	11/09/91	27	24
08/18/91	0	0	09/29/91	0	5	11/10/91	27	24
08/19/91	0	0	09/30/91	15	12	11/11/91	25	22
08/20/91	0	0	10/01/91	0	0	11/12/91	25	22

11/13/91	24	21
11/14/91	19	16
11/15/91	17	14
11/16/91	17	14
11/17/91	27	24
11/18/91	25	22
11/19/91	17	14
11/20/91	0	9
11/21/91	0	4
11/22/91	0	5
11/23/91	0	7
11/24/91	16	13
11/25/91	31	28
11/26/91	32	29
11/27/91	32	29
11/28/91	24	21
11/29/91	16	13
11/30/91	16	13
12/01/91	13	10
12/02/91	19	16
12/03/91	22	19
12/04/91	29	26
12/05/91	39	36
12/06/91	31	28
12/07/91	27	24
12/08/91	19	16
12/09/91	33	30
12/10/91	33	30
12/11/91	33	30
12/12/91	33	30
12/13/91	33	30
12/14/91	33	30
12/15/91	38	35
12/16/91	40	37
12/17/91	36	33
12/18/91	35	32
12/19/91	52	49
12/20/91	33	30
12/21/91	28	25
12/22/91	27	24
12/23/91	28	25
12/24/91	31	28
12/25/91	33	30
12/26/91	36	33
12/27/91	27	24
12/28/91	28	25
12/29/91	22	19
12/30/91	30	27
12/31/91	38	35
01/01/92	33	30
01/02/92	25	22
01/03/92	22	19
01/04/92	23	20
01/05/92	22	19
01/06/92	27	24
01/07/92	26	23
01/08/92	30	27
01/09/92	29	26
01/10/92	25	22
01/11/92	27	24
01/12/92	32	29
01/13/92	22	19
01/14/92	17	14
01/15/92	40	37
01/16/92	45	42
01/17/92	44	41
01/18/92	42	39
01/19/92	50	47
01/20/92	45	42
01/21/92	37	34
01/22/92	34	31
01/23/92	23	20
01/24/92	28	25
01/25/92	43	40
01/26/92	42	39
01/27/92	38	35
01/28/92	35	32
01/29/92	32	29
01/30/92	31	28
01/31/92	26	23
02/01/92	35	32
02/02/92	38	35
02/03/92	34	31
02/04/92	34	31
02/05/92	35	32
02/06/92	40	37
02/07/92	36	33
02/08/92	33	30
02/09/92	41	38
02/10/92	46	43
02/11/92	31	28
02/12/92	46	43
02/13/92	41	38
02/14/92	30	27
02/15/92	30	27
02/16/92	22	19
02/17/92	27	24
02/18/92	26	23
02/19/92	23	20
02/20/92	23	20
02/21/92	25	22
02/22/92	32	29
02/23/92	31	28
02/24/92	27	24
02/25/92	31	28
02/26/92	30	27
02/27/92	29	26
02/28/92	27	24
02/29/92	41	38
03/01/92	31	28
03/02/92	27	24
03/03/92	32	29
03/04/92	33	30
03/05/92	29	26
03/06/92	27	24
03/07/92	25	22
03/08/92	26	23
03/09/92	20	17
03/10/92	23	20
03/11/92	27	24
03/12/92	36	33
03/13/92	37	34
03/14/92	37	34
03/15/92	39	36
03/16/92	48	45
03/17/92	28	25

03/18/92	35	32	04/29/92	23	20	06/10/92	0	0
03/19/92	34	31	04/30/92	19	16	06/11/92	0	0
03/20/92	33	30	05/01/92	13	10	06/12/92	0	0
03/21/92	35	32	05/02/92	0	3	06/13/92	0	0
03/22/92	39	36	05/03/92	0	0	06/14/92	0	0
03/23/92	36	33	05/04/92	0	9	06/15/92	0	0
03/24/92	33	30	05/05/92	19	16	06/16/92	0	0
03/25/92	29	26	05/06/92	22	19	06/17/92	0	0
03/26/92	21	18	05/07/92	18	15	06/18/92	0	0
03/27/92	20	17	05/08/92	15	12	06/19/92	0	0
03/28/92	28	25	05/09/92	0	9	06/20/92	0	0
03/29/92	22	19	05/10/92	0	8	06/21/92	0	0
03/30/92	23	20	05/11/92	0	7	06/22/92	0	5
03/31/92	20	17	05/12/92	13	10	06/23/92	14	11
04/01/92	24	21	05/13/92	0	6	06/24/92	0	0
04/02/92	27	24	05/14/92	0	3	06/25/92	0	0
04/03/92	28	25	05/15/92	0	8	06/26/92	0	0
04/04/92	26	23	05/16/92	13	10	06/27/92	0	0
04/05/92	21	18	05/17/92	16	13	06/28/92	0	0
04/06/92	15	12	05/18/92	0	3	06/29/92	0	0
04/07/92	20	17	05/19/92	0	6	06/30/92	0	0
04/08/92	15	12	05/20/92	13	10	07/01/92	0	0
04/09/92	19	16	05/21/92	0	0	07/02/92	0	0
04/10/92	17	14	05/22/92	0	0	07/03/92	0	1
04/11/92	22	19	05/23/92	0	0	07/04/92	0	0
04/12/92	23	20	05/24/92	0	0	07/05/92	0	0
04/13/92	28	25	05/25/92	18	15	07/06/92	0	0
04/14/92	24	21	05/26/92	17	14	07/07/92	0	0
04/15/92	25	22	05/27/92	13	10	07/08/92	0	0
04/16/92	25	22	05/28/92	0	7	07/09/92	0	0
04/17/92	23	20	05/29/92	0	5	07/10/92	0	0
04/18/92	26	23	05/30/92	0	6	07/11/92	0	0
04/19/92	24	21	05/31/92	0	6	07/12/92	0	0
04/20/92	20	17	06/01/92	0	4	07/13/92	0	0
04/21/92	14	11	06/02/92	0	2	07/14/92	0	0
04/22/92	14	11	06/03/92	0	0	07/15/92	0	0
04/23/92	0	0	06/04/92	0	0	07/16/92	0	0
04/24/92	0	5	06/05/92	0	1	07/17/92	0	0
04/25/92	20	17	06/06/92	0	0	07/18/92	0	0
04/26/92	22	19	06/07/92	0	0	07/19/92	0	0
04/27/92	17	14	06/08/92	0	0	07/20/92	0	0
04/28/92	19	16	06/09/92	0	0	07/21/92	0	0

07/22/92	0	0	09/02/92	0	0	10/14/92	0	6
07/23/92	0	1	09/03/92	0	0	10/15/92	13	10
07/24/92	0	1	09/04/92	0	0	10/16/92	0	5
07/25/92	0	0	09/05/92	0	0	10/17/92	0	1
07/26/92	0	0	09/06/92	0	0	10/18/92	13	10
07/27/92	0	0	09/07/92	0	0	10/19/92	19	16
07/28/92	0	0	09/08/92	0	0	10/20/92	0	3
07/29/92	0	0	09/09/92	0	0	10/21/92	0	0
07/30/92	0	0	09/10/92	0	0	10/22/92	0	0
07/31/92	0	0	09/11/92	0	0	10/23/92	0	4
08/01/92	0	0	09/12/92	0	0	10/24/92	17	14
08/02/92	0	0	09/13/92	0	1	10/25/92	15	12
08/03/92	0	0	09/14/92	0	2	10/26/92	0	5
08/04/92	0	0	09/15/92	0	1	10/27/92	0	0
08/05/92	0	0	09/16/92	0	0	10/28/92	0	4
08/06/92	0	0	09/17/92	0	0	10/29/92	16	13
08/07/92	0	0	09/18/92	0	0	10/30/92	18	15
08/08/92	0	0	09/19/92	0	0	10/31/92	0	7
08/09/92	0	0	09/20/92	0	0	11/01/92	0	6
08/10/92	0	0	09/21/92	0	0	11/02/92	0	1
08/11/92	0	0	09/22/92	0	0	11/03/92	0	0
08/12/92	0	0	09/23/92	0	0	11/04/92	0	7
08/13/92	0	0	09/24/92	0	2	11/05/92	0	8
08/14/92	0	0	09/25/92	14	11	11/06/92	0	6
08/15/92	0	1	09/26/92	0	8	11/07/92	13	10
08/16/92	0	0	09/27/92	0	3	11/08/92	0	5
08/17/92	0	0	09/28/92	0	0	11/09/92	0	1
08/18/92	0	0	09/29/92	0	0	11/10/92	13	10
08/19/92	0	0	09/30/92	0	4	11/11/92	16	13
08/20/92	0	0	10/01/92	17	14	11/12/92	0	9
08/21/92	0	0	10/02/92	15	12	11/13/92	14	11
08/22/92	0	0	10/03/92	0	5	11/14/92	26	23
08/23/92	0	0	10/04/92	0	0	11/15/92	30	27
08/24/92	0	0	10/05/92	0	4	11/16/92	31	28
08/25/92	0	0	10/06/92	16	13	11/17/92	23	20
08/26/92	0	0	10/07/92	18	15	11/18/92	26	23
08/27/92	0	0	10/08/92	0	7	11/19/92	29	26
08/28/92	0	0	10/09/92	0	6	11/20/92	29	26
08/29/92	0	0	10/10/92	0	1	11/21/92	17	14
08/30/92	0	0	10/11/92	0	0	11/22/92	13	10
08/31/92	0	0	10/12/92	0	7	11/23/92	0	5
09/01/92	0	0	10/13/92	0	8	11/24/92	18	15

11/25/92	17	14	01/06/93	28	25	02/17/93	30	27
11/26/92	13	10	01/07/93	28	25	02/18/93	40	37
11/27/92	18	15	01/08/93	27	24	02/19/93	48	45
11/28/92	23	20	01/09/93	36	33	02/20/93	48	45
11/29/92	24	21	01/10/93	43	40	02/21/93	42	39
11/30/92	26	23	01/11/93	38	35	02/22/93	32	29
12/01/92	24	21	01/12/93	31	28	02/23/93	36	33
12/02/92	25	22	01/13/93	29	26	02/24/93	43	40
12/03/92	26	23	01/14/93	35	32	02/25/93	45	42
12/04/92	30	27	01/15/93	33	30	02/26/93	44	41
12/05/92	31	28	01/16/93	33	30	02/27/93	41	38
12/06/92	35	32	01/17/93	33	30	02/28/93	40	37
12/07/92	30	27	01/18/93	37	34	03/01/93	42	39
12/08/92	33	30	01/19/93	37	34	03/02/93	42	39
12/09/92	41	38	01/20/93	34	31	03/03/93	28	25
12/10/92	36	33	01/21/93	32	29	03/04/93	30	27
12/11/92	24	21	01/22/93	22	19	03/05/93	34	31
12/12/92	32	29	01/23/93	26	23	03/06/93	35	32
12/13/92	30	27	01/24/93	23	20	03/07/93	27	24
12/14/92	31	28	01/25/93	30	27	03/08/93	27	24
12/15/92	26	23	01/26/93	37	34	03/09/93	26	23
12/16/92	23	20	01/27/93	30	27	03/10/93	33	30
12/17/92	21	18	01/28/93	33	30	03/11/93	31	28
12/18/92	25	22	01/29/93	33	30	03/12/93	33	30
12/19/92	27	24	01/30/93	37	34	03/13/93	33	30
12/20/92	23	20	01/31/93	27	24	03/14/93	33	30
12/21/92	35	32	02/01/93	43	40	03/15/93	38	35
12/22/92	28	25	02/02/93	53	50	03/16/93	33	30
12/23/92	28	25	02/03/93	31	28	03/17/93	27	24
12/24/92	40	37	02/04/93	30	27	03/18/93	47	44
12/25/92	38	35	02/05/93	28	25	03/19/93	35	32
12/26/92	37	34	02/06/93	28	25	03/20/93	31	28
12/27/92	43	40	02/07/93	28	25	03/21/93	24	21
12/28/92	28	25	02/08/93	27	24	03/22/93	31	28
12/29/92	24	21	02/09/93	39	36	03/23/93	29	26
12/30/92	21	18	02/10/93	30	27	03/24/93	24	21
12/31/92	17	14	02/11/93	30	27	03/25/93	15	12
01/01/93	29	26	02/12/93	36	33	03/26/93	20	17
01/02/93	39	36	02/13/93	33	30	03/27/93	14	11
01/03/93	33	30	02/14/93	34	31	03/28/93	17	14
01/04/93	21	18	02/15/93	35	32	03/29/93	19	16
01/05/93	17	14	02/16/93	30	27	03/30/93	18	15

03/31/93	23	20	05/12/93	0	0	06/23/93	0	0
04/01/93	29	26	05/13/93	0	2	06/24/93	0	0
04/02/93	26	23	05/14/93	0	4	06/25/93	0	0
04/03/93	26	23	05/15/93	0	1	06/26/93	0	0
04/04/93	25	22	05/16/93	0	0	06/27/93	0	0
04/05/93	25	22	05/17/93	0	1	06/28/93	0	0
04/06/93	21	18	05/18/93	0	3	06/29/93	0	0
04/07/93	20	17	05/19/93	14	11	06/30/93	0	0
04/08/93	18	15	05/20/93	14	11	07/01/93	0	0
04/09/93	16	13	05/21/93	0	7	07/02/93	0	0
04/10/93	14	11	05/22/93	0	3	07/03/93	0	0
04/11/93	18	15	05/23/93	0	0	07/04/93	0	0
04/12/93	17	14	05/24/93	0	0	07/05/93	0	0
04/13/93	16	13	05/25/93	0	0	07/06/93	0	0
04/14/93	19	16	05/26/93	0	0	07/07/93	0	0
04/15/93	15	12	05/27/93	0	0	07/08/93	0	0
04/16/93	0	9	05/28/93	0	0	07/09/93	0	0
04/17/93	18	15	05/29/93	0	0	07/10/93	0	0
04/18/93	13	10	05/30/93	0	0	07/11/93	0	0
04/19/93	15	12	05/31/93	0	1	07/12/93	0	0
04/20/93	16	13	06/01/93	0	1	07/13/93	0	0
04/21/93	17	14	06/02/93	0	4	07/14/93	0	0
04/22/93	20	17	06/03/93	0	0	07/15/93	0	0
04/23/93	0	8	06/04/93	0	0	07/16/93	0	0
04/24/93	16	13	06/05/93	0	5	07/17/93	0	0
04/25/93	16	13	06/06/93	0	4	07/18/93	0	0
04/26/93	23	20	06/07/93	0	0	07/19/93	0	0
04/27/93	20	17	06/08/93	0	0	07/20/93	0	0
04/28/93	13	10	06/09/93	0	0	07/21/93	0	0
04/29/93	0	8	06/10/93	0	0	07/22/93	0	0
04/30/93	0	6	06/11/93	0	0	07/23/93	0	0
05/01/93	0	0	06/12/93	0	0	07/24/93	0	0
05/02/93	0	0	06/13/93	0	0	07/25/93	0	0
05/03/93	0	4	06/14/93	0	0	07/26/93	0	0
05/04/93	0	5	06/15/93	0	0	07/27/93	0	0
05/05/93	0	2	06/16/93	0	0	07/28/93	0	0
05/06/93	0	0	06/17/93	0	0	07/29/93	0	0
05/07/93	0	0	06/18/93	0	0	07/30/93	0	0
05/08/93	0	2	06/19/93	0	0	07/31/93	0	0
05/09/93	0	0	06/20/93	0	0	08/01/93	0	0
05/10/93	0	0	06/21/93	0	0	08/02/93	0	0
05/11/93	0	0	06/22/93	0	0	08/03/93	0	0

08/04/93	0	0	09/15/93	0	0	10/27/93	0	9
08/05/93	0	0	09/16/93	0	0	10/28/93	15	12
08/06/93	0	0	09/17/93	0	0	10/29/93	13	10
08/07/93	0	0	09/18/93	0	0	10/30/93	17	14
08/08/93	0	0	09/19/93	0	0	10/31/93	22	19
08/09/93	0	0	09/20/93	0	0	11/01/93	23	20
08/10/93	0	0	09/21/93	0	0	11/02/93	23	20
08/11/93	0	0	09/22/93	0	0	11/03/93	22	19
08/12/93	0	0	09/23/93	0	0	11/04/93	19	16
08/13/93	0	0	09/24/93	0	0	11/05/93	13	10
08/14/93	0	0	09/25/93	0	0	11/06/93	16	13
08/15/93	0	0	09/26/93	0	0	11/07/93	26	23
08/16/93	0	0	09/27/93	0	0	11/08/93	26	23
08/17/93	0	0	09/28/93	0	0	11/09/93	22	19
08/18/93	0	0	09/29/93	0	0	11/10/93	19	16
08/19/93	0	0	09/30/93	0	0	11/11/93	18	15
08/20/93	0	0	10/01/93	15	12	11/12/93	13	10
08/21/93	0	0	10/02/93	0	1	11/13/93	17	14
08/22/93	0	0	10/03/93	0	5	11/14/93	0	2
08/23/93	0	0	10/04/93	0	3	11/15/93	0	0
08/24/93	0	0	10/05/93	13	10	11/16/93	13	10
08/25/93	0	0	10/06/93	13	10	11/17/93	0	9
08/26/93	0	0	10/07/93	0	1	11/18/93	13	10
08/27/93	0	0	10/08/93	0	0	11/19/93	15	12
08/28/93	0	0	10/09/93	0	0	11/20/93	23	20
08/29/93	0	0	10/10/93	19	16	11/21/93	28	25
08/30/93	0	0	10/11/93	21	18	11/22/93	19	16
08/31/93	0	0	10/12/93	17	14	11/23/93	16	13
09/01/93	0	0	10/13/93	18	15	11/24/93	19	16
09/02/93	0	0	10/14/93	22	19	11/25/93	35	32
09/03/93	0	0	10/15/93	0	6	11/26/93	34	31
09/04/93	0	0	10/16/93	0	6	11/27/93	18	15
09/05/93	0	0	10/17/93	0	1	11/28/93	13	10
09/06/93	0	0	10/18/93	0	2	11/29/93	24	21
09/07/93	0	0	10/19/93	14	11	11/30/93	26	23
09/08/93	0	0	10/20/93	15	12	12/01/93	28	25
09/09/93	0	0	10/21/93	0	4	12/02/93	20	17
09/10/93	0	0	10/22/93	13	10	12/03/93	14	11
09/11/93	0	0	10/23/93	16	13	12/04/93	19	16
09/12/93	0	0	10/24/93	0	9	12/05/93	18	15
09/13/93	0	0	10/25/93	0	2	12/06/93	25	22
09/14/93	0	0	10/26/93	14	11	12/07/93	23	20

12/08/93	22	19	01/19/94	64	61	03/02/94	40	37
12/09/93	24	21	01/20/94	59	56	03/03/94	37	34
12/10/93	19	16	01/21/94	54	51	03/04/94	29	26
12/11/93	32	29	01/22/94	44	41	03/05/94	28	25
12/12/93	36	33	01/23/94	43	40	03/06/94	32	29
12/13/93	29	26	01/24/94	28	25	03/07/94	26	23
12/14/93	23	20	01/25/94	31	28	03/08/94	26	23
12/15/93	24	21	01/26/94	49	46	03/09/94	35	32
12/16/93	29	26	01/27/94	52	49	03/10/94	29	26
12/17/93	33	30	01/28/94	25	22	03/11/94	29	26
12/18/93	30	27	01/29/94	29	26	03/12/94	32	29
12/19/93	27	24	01/30/94	38	35	03/13/94	25	22
12/20/93	27	24	01/31/94	44	41	03/14/94	20	17
12/21/93	22	19	02/01/94	46	43	03/15/94	20	17
12/22/93	31	28	02/02/94	45	42	03/16/94	33	30
12/23/93	36	33	02/03/94	41	38	03/17/94	39	36
12/24/93	39	36	02/04/94	38	35	03/18/94	39	36
12/25/93	38	35	02/05/94	29	26	03/19/94	33	30
12/26/93	44	41	02/06/94	31	28	03/20/94	26	23
12/27/93	53	50	02/07/94	35	32	03/21/94	27	24
12/28/93	45	42	02/08/94	50	47	03/22/94	19	16
12/29/93	47	44	02/09/94	51	48	03/23/94	0	6
12/30/93	44	41	02/10/94	55	52	03/24/94	0	8
12/31/93	43	40	02/11/94	48	45	03/25/94	22	19
01/01/94	32	29	02/12/94	41	38	03/26/94	24	21
01/02/94	26	23	02/13/94	34	31	03/27/94	22	19
01/03/94	37	34	02/14/94	43	40	03/28/94	21	18
01/04/94	37	34	02/15/94	41	38	03/29/94	28	25
01/05/94	40	37	02/16/94	36	33	03/30/94	24	21
01/06/94	47	44	02/17/94	33	30	03/31/94	20	17
01/07/94	43	40	02/18/94	21	18	04/01/94	15	12
01/08/94	45	42	02/19/94	21	18	04/02/94	20	17
01/09/94	49	46	02/20/94	15	12	04/03/94	16	13
01/10/94	47	44	02/21/94	20	17	04/04/94	19	16
01/11/94	39	36	02/22/94	26	23	04/05/94	19	16
01/12/94	35	32	02/23/94	37	34	04/06/94	16	13
01/13/94	32	29	02/24/94	32	29	04/07/94	20	17
01/14/94	39	36	02/25/94	37	34	04/08/94	22	19
01/15/94	54	51	02/26/94	44	41	04/09/94	19	16
01/16/94	59	56	02/27/94	48	45	04/10/94	0	8
01/17/94	38	35	02/28/94	44	41	04/11/94	13	10
01/18/94	48	45	03/01/94	37	34	04/12/94	19	16

04/13/94	17	14	05/25/94	0	0	07/06/94	0	0
04/14/94	0	3	05/26/94	0	0	07/07/94	0	0
04/15/94	0	1	05/27/94	0	7	07/08/94	0	0
04/16/94	0	5	05/28/94	0	5	07/09/94	0	0
04/17/94	0	9	05/29/94	0	0	07/10/94	0	0
04/18/94	0	7	05/30/94	0	0	07/11/94	0	0
04/19/94	0	0	05/31/94	0	0	07/12/94	0	0
04/20/94	0	8	06/01/94	0	0	07/13/94	0	0
04/21/94	13	10	06/02/94	0	0	07/14/94	0	0
04/22/94	16	13	06/03/94	0	0	07/15/94	0	0
04/23/94	15	12	06/04/94	0	0	07/16/94	0	0
04/24/94	0	0	06/05/94	0	0	07/17/94	0	0
04/25/94	0	3	06/06/94	0	0	07/18/94	0	0
04/26/94	14	11	06/07/94	0	0	07/19/94	0	0
04/27/94	0	0	06/08/94	0	0	07/20/94	0	0
04/28/94	0	1	06/09/94	0	0	07/21/94	0	0
04/29/94	15	12	06/10/94	0	0	07/22/94	0	0
04/30/94	0	0	06/11/94	0	0	07/23/94	0	0
05/01/94	0	2	06/12/94	0	0	07/24/94	0	0
05/02/94	13	10	06/13/94	0	0	07/25/94	0	0
05/03/94	0	8	06/14/94	0	0	07/26/94	0	0
05/04/94	0	7	06/15/94	0	0	07/27/94	0	0
05/05/94	0	4	06/16/94	0	0	07/28/94	0	0
05/06/94	0	9	06/17/94	0	0	07/29/94	0	0
05/07/94	0	7	06/18/94	0	0	07/30/94	0	0
05/08/94	0	9	06/19/94	0	0	07/31/94	0	0
05/09/94	0	2	06/20/94	0	0	08/01/94	0	0
05/10/94	0	2	06/21/94	0	0	08/02/94	0	0
05/11/94	0	5	06/22/94	0	0	08/03/94	0	0
05/12/94	0	4	06/23/94	0	0	08/04/94	0	0
05/13/94	13	10	06/24/94	0	0	08/05/94	0	0
05/14/94	0	4	06/25/94	0	0	08/06/94	0	0
05/15/94	0	0	06/26/94	0	0	08/07/94	0	0
05/16/94	0	0	06/27/94	0	0	08/08/94	0	0
05/17/94	13	10	06/28/94	0	0	08/09/94	0	0
05/18/94	0	7	06/29/94	0	0	08/10/94	0	0
05/19/94	17	14	06/30/94	0	0	08/11/94	0	0
05/20/94	15	12	07/01/94	0	0	08/12/94	0	0
05/21/94	0	4	07/02/94	0	0	08/13/94	0	0
05/22/94	0	0	07/03/94	0	0	08/14/94	0	0
05/23/94	0	0	07/04/94	0	0	08/15/94	0	0
05/24/94	0	0	07/05/94	0	0	08/16/94	0	0

08/17/94	0	0	09/28/94	0	0	11/09/94	0	3
08/18/94	0	0	09/29/94	0	6	11/10/94	19	16
08/19/94	0	0	09/30/94	0	5	11/11/94	22	19
08/20/94	0	0	10/01/94	0	9	11/12/94	22	19
08/21/94	0	0	10/02/94	0	6	11/13/94	13	10
08/22/94	0	0	10/03/94	14	11	11/14/94	0	9
08/23/94	0	0	10/04/94	13	10	11/15/94	0	4
08/24/94	0	0	10/05/94	15	12	11/16/94	18	15
08/25/94	0	0	10/06/94	14	11	11/17/94	18	15
08/26/94	0	0	10/07/94	0	5	11/18/94	13	10
08/27/94	0	0	10/08/94	0	1	11/19/94	13	10
08/28/94	0	0	10/09/94	0	0	11/20/94	19	16
08/29/94	0	0	10/10/94	13	10	11/21/94	13	10
08/30/94	0	0	10/11/94	15	12	11/22/94	18	15
08/31/94	0	0	10/12/94	15	12	11/23/94	30	27
09/01/94	0	0	10/13/94	0	8	11/24/94	35	32
09/02/94	0	0	10/14/94	0	6	11/25/94	22	19
09/03/94	0	0	10/15/94	0	8	11/26/94	27	24
09/04/94	0	1	10/16/94	13	10	11/27/94	33	30
09/05/94	0	0	10/17/94	0	7	11/28/94	13	10
09/06/94	0	0	10/18/94	0	2	11/29/94	16	13
09/07/94	0	0	10/19/94	0	0	11/30/94	22	19
09/08/94	0	0	10/20/94	0	2	12/01/94	26	23
09/09/94	0	0	10/21/94	0	1	12/02/94	22	19
09/10/94	0	0	10/22/94	0	3	12/03/94	14	11
09/11/94	0	2	10/23/94	0	7	12/04/94	0	8
09/12/94	0	0	10/24/94	0	5	12/05/94	0	9
09/13/94	0	0	10/25/94	0	7	12/06/94	0	6
09/14/94	0	0	10/26/94	16	13	12/07/94	21	18
09/15/94	0	0	10/27/94	15	12	12/08/94	34	31
09/16/94	0	0	10/28/94	14	11	12/09/94	31	28
09/17/94	0	0	10/29/94	0	8	12/10/94	25	22
09/18/94	0	0	10/30/94	0	2	12/11/94	29	26
09/19/94	0	0	10/31/94	0	1	12/12/94	40	37
09/20/94	0	0	11/01/94	0	6	12/13/94	36	33
09/21/94	0	0	11/02/94	16	13	12/14/94	30	27
09/22/94	0	2	11/03/94	0	7	12/15/94	29	26
09/23/94	0	2	11/04/94	0	0	12/16/94	32	29
09/24/94	0	0	11/05/94	0	0	12/17/94	25	22
09/25/94	0	0	11/06/94	0	0	12/18/94	24	21
09/26/94	0	0	11/07/94	14	11	12/19/94	28	25
09/27/94	0	0	11/08/94	0	6	12/20/94	29	26

12/21/94	23	20	02/01/95	27	24	03/15/95	0	7
12/22/94	20	17	02/02/95	35	32	03/16/95	17	14
12/23/94	21	18	02/03/95	42	39	03/17/95	15	12
12/24/94	21	18	02/04/95	36	33	03/18/95	19	16
12/25/94	18	15	02/05/95	50	47	03/19/95	21	18
12/26/94	26	23	02/06/95	55	52	03/20/95	21	18
12/27/94	25	22	02/07/95	48	45	03/21/95	13	10
12/28/94	21	18	02/08/95	45	42	03/22/95	21	18
12/29/94	34	31	02/09/95	45	42	03/23/95	22	19
12/30/94	42	39	02/10/95	34	31	03/24/95	26	23
12/31/94	35	32	02/11/95	30	27	03/25/95	23	20
01/01/95	22	19	02/12/95	48	45	03/26/95	18	15
01/02/95	32	29	02/13/95	48	45	03/27/95	20	17
01/03/95	40	37	02/14/95	41	38	03/28/95	21	18
01/04/95	41	38	02/15/95	38	35	03/29/95	20	17
01/05/95	47	44	02/16/95	27	24	03/30/95	21	18
01/06/95	38	35	02/17/95	28	25	03/31/95	21	18
01/07/95	24	21	02/18/95	25	22	04/01/95	22	19
01/08/95	34	31	02/19/95	24	21	04/02/95	26	23
01/09/95	34	31	02/20/95	24	21	04/03/95	23	20
01/10/95	38	35	02/21/95	30	27	04/04/95	20	17
01/11/95	38	35	02/22/95	33	30	04/05/95	37	34
01/12/95	31	28	02/23/95	27	24	04/06/95	29	26
01/13/95	17	14	02/24/95	31	28	04/07/95	16	13
01/14/95	0	9	02/25/95	36	33	04/08/95	26	23
01/15/95	0	8	02/26/95	40	37	04/09/95	13	10
01/16/95	0	9	02/27/95	38	35	04/10/95	23	20
01/17/95	20	17	02/28/95	30	27	04/11/95	18	15
01/18/95	27	24	03/01/95	29	26	04/12/95	18	15
01/19/95	29	26	03/02/95	33	30	04/13/95	17	14
01/20/95	24	21	03/03/95	35	32	04/14/95	18	15
01/21/95	27	24	03/04/95	32	29	04/15/95	19	16
01/22/95	34	31	03/05/95	28	25	04/16/95	15	12
01/23/95	34	31	03/06/95	22	19	04/17/95	16	13
01/24/95	33	30	03/07/95	22	19	04/18/95	0	7
01/25/95	30	27	03/08/95	17	14	04/19/95	0	1
01/26/95	31	28	03/09/95	38	35	04/20/95	0	3
01/27/95	33	30	03/10/95	38	35	04/21/95	13	10
01/28/95	41	38	03/11/95	31	28	04/22/95	0	2
01/29/95	40	37	03/12/95	25	22	04/23/95	13	10
01/30/95	33	30	03/13/95	13	10	04/24/95	15	12
01/31/95	32	29	03/14/95	15	12	04/25/95	0	7

04/26/95	0	6	06/07/95	0	0	07/19/95	0	0
04/27/95	0	2	06/08/95	0	0	07/20/95	0	0
04/28/95	0	1	06/09/95	0	0	07/21/95	0	0
04/29/95	0	7	06/10/95	0	0	07/22/95	0	0
04/30/95	16	13	06/11/95	0	0	07/23/95	0	0
05/01/95	15	12	06/12/95	0	0	07/24/95	0	0
05/02/95	19	16	06/13/95	0	1	07/25/95	0	0
05/03/95	0	5	06/14/95	0	0	07/26/95	0	0
05/04/95	0	1	06/15/95	0	0	07/27/95	0	0
05/05/95	0	7	06/16/95	0	0	07/28/95	0	0
05/06/95	0	5	06/17/95	0	0	07/29/95	0	0
05/07/95	0	7	06/18/95	0	0	07/30/95	0	0
05/08/95	0	9	06/19/95	0	0	07/31/95	0	0
05/09/95	0	3	06/20/95	0	0	08/01/95	0	0
05/10/95	14	11	06/21/95	0	0	08/02/95	0	0
05/11/95	15	12	06/22/95	0	0	08/03/95	0	0
05/12/95	0	7	06/23/95	0	0	08/04/95	0	0
05/13/95	0	1	06/24/95	0	0	08/05/95	0	0
05/14/95	0	6	06/25/95	0	0	08/06/95	0	0
05/15/95	0	4	06/26/95	0	0	08/07/95	0	0
05/16/95	0	0	06/27/95	0	0	08/08/95	0	0
05/17/95	0	5	06/28/95	0	1	08/09/95	0	0
05/18/95	0	0	06/29/95	0	0	08/10/95	0	0
05/19/95	0	9	06/30/95	0	0	08/11/95	0	0
05/20/95	0	0	07/01/95	0	0	08/12/95	0	0
05/21/95	0	0	07/02/95	0	0	08/13/95	0	0
05/22/95	0	0	07/03/95	0	0	08/14/95	0	0
05/23/95	0	0	07/04/95	0	0	08/15/95	0	0
05/24/95	0	0	07/05/95	0	0	08/16/95	0	0
05/25/95	0	0	07/06/95	0	0	08/17/95	0	0
05/26/95	0	7	07/07/95	0	0	08/18/95	0	0
05/27/95	0	0	07/08/95	0	0	08/19/95	0	0
05/28/95	0	3	07/09/95	0	0	08/20/95	0	0
05/29/95	0	0	07/10/95	0	0	08/21/95	0	0
05/30/95	0	0	07/11/95	0	0	08/22/95	0	0
05/31/95	0	0	07/12/95	0	0	08/23/95	0	0
06/01/95	0	0	07/13/95	0	0	08/24/95	0	0
06/02/95	0	0	07/14/95	0	0	08/25/95	0	0
06/03/95	0	0	07/15/95	0	0	08/26/95	0	0
06/04/95	0	0	07/16/95	0	0	08/27/95	0	0
06/05/95	0	0	07/17/95	0	0	08/28/95	0	0
06/06/95	0	0	07/18/95	0	0	08/29/95	0	0

08/30/95	0	0	10/11/95	0	0	11/22/95	29	26
08/31/95	0	0	10/12/95	0	0	11/23/95	30	27
09/01/95	0	0	10/13/95	0	0	11/24/95	31	28
09/02/95	0	0	10/14/95	0	0	11/25/95	33	30
09/03/95	0	0	10/15/95	0	8	11/26/95	28	25
09/04/95	0	0	10/16/95	15	12	11/27/95	19	16
09/05/95	0	0	10/17/95	15	12	11/28/95	17	14
09/06/95	0	0	10/18/95	0	7	11/29/95	34	31
09/07/95	0	0	10/19/95	0	2	11/30/95	37	34
09/08/95	0	0	10/20/95	0	0	12/01/95	25	22
09/09/95	0	0	10/21/95	0	4	12/02/95	27	24
09/10/95	0	0	10/22/95	15	12	12/03/95	25	22
09/11/95	0	1	10/23/95	0	1	12/04/95	23	20
09/12/95	0	0	10/24/95	0	1	12/05/95	27	24
09/13/95	0	0	10/25/95	0	7	12/06/95	25	22
09/14/95	0	0	10/26/95	15	12	12/07/95	32	29
09/15/95	0	0	10/27/95	0	7	12/08/95	37	34
09/16/95	0	0	10/28/95	0	4	12/09/95	35	32
09/17/95	0	0	10/29/95	17	14	12/10/95	44	41
09/18/95	0	0	10/30/95	18	15	12/11/95	48	45
09/19/95	0	2	10/31/95	16	13	12/12/95	47	44
09/20/95	0	0	11/01/95	14	11	12/13/95	44	41
09/21/95	0	0	11/02/95	0	3	12/14/95	37	34
09/22/95	0	0	11/03/95	0	1	12/15/95	30	27
09/23/95	0	7	11/04/95	22	19	12/16/95	31	28
09/24/95	0	6	11/05/95	28	25	12/17/95	32	29
09/25/95	0	4	11/06/95	25	22	12/18/95	33	30
09/26/95	0	2	11/07/95	22	19	12/19/95	40	37
09/27/95	0	0	11/08/95	25	22	12/20/95	47	44
09/28/95	0	0	11/09/95	31	28	12/21/95	43	40
09/29/95	0	4	11/10/95	25	22	12/22/95	37	34
09/30/95	0	5	11/11/95	0	8	12/23/95	34	31
10/01/95	0	2	11/12/95	20	17	12/24/95	38	35
10/02/95	0	0	11/13/95	32	29	12/25/95	37	34
10/03/95	0	0	11/14/95	23	20	12/26/95	40	37
10/04/95	0	0	11/15/95	24	21	12/27/95	41	38
10/05/95	0	0	11/16/95	30	27	12/28/95	37	34
10/06/95	0	0	11/17/95	30	27	12/29/95	36	33
10/07/95	0	5	11/18/95	26	23	12/30/95	33	30
10/08/95	0	1	11/19/95	24	21	12/31/95	29	26
10/09/95	0	5	11/20/95	25	22	01/01/96	28	25
10/10/95	0	2	11/21/95	22	19	01/02/96	35	32

01/03/96	43	40	02/14/96	36	33	03/27/96	33	30
01/04/96	50	47	02/15/96	36	33	03/28/96	32	29
01/05/96	51	48	02/16/96	42	39	03/29/96	32	29
01/06/96	56	53	02/17/96	41	38	03/30/96	21	18
01/07/96	51	48	02/18/96	41	38	03/31/96	18	15
01/08/96	48	45	02/19/96	36	33	04/01/96	19	16
01/09/96	45	42	02/20/96	23	20	04/02/96	21	18
01/10/96	42	39	02/21/96	19	16	04/03/96	19	16
01/11/96	47	44	02/22/96	15	12	04/04/96	19	16
01/12/96	38	35	02/23/96	19	16	04/05/96	26	23
01/13/96	36	33	02/24/96	18	15	04/06/96	24	21
01/14/96	32	29	02/25/96	13	10	04/07/96	30	27
01/15/96	37	34	02/26/96	17	14	04/08/96	28	25
01/16/96	43	40	02/27/96	20	17	04/09/96	31	28
01/17/96	29	26	02/28/96	22	19	04/10/96	28	25
01/18/96	25	22	02/29/96	39	36	04/11/96	16	13
01/19/96	27	24	03/01/96	40	37	04/12/96	0	0
01/20/96	42	39	03/02/96	36	33	04/13/96	19	16
01/21/96	39	36	03/03/96	40	37	04/14/96	20	17
01/22/96	33	30	03/04/96	41	38	04/15/96	23	20
01/23/96	30	27	03/05/96	21	18	04/16/96	17	14
01/24/96	21	18	03/06/96	26	23	04/17/96	23	20
01/25/96	34	31	03/07/96	39	36	04/18/96	13	10
01/26/96	33	30	03/08/96	49	46	04/19/96	0	8
01/27/96	24	21	03/09/96	50	47	04/20/96	0	4
01/28/96	36	33	03/10/96	43	40	04/21/96	0	0
01/29/96	35	32	03/11/96	34	31	04/22/96	0	0
01/30/96	29	26	03/12/96	27	24	04/23/96	0	0
01/31/96	39	36	03/13/96	21	18	04/24/96	14	11
02/01/96	48	45	03/14/96	14	11	04/25/96	0	3
02/02/96	45	42	03/15/96	16	13	04/26/96	0	2
02/03/96	51	48	03/16/96	27	24	04/27/96	14	11
02/04/96	55	52	03/17/96	27	24	04/28/96	0	6
02/05/96	57	54	03/18/96	17	14	04/29/96	0	9
02/06/96	48	45	03/19/96	24	21	04/30/96	13	10
02/07/96	40	37	03/20/96	24	21	05/01/96	0	9
02/08/96	32	29	03/21/96	24	21	05/02/96	0	4
02/09/96	25	22	03/22/96	30	27	05/03/96	13	10
02/10/96	26	23	03/23/96	30	27	05/04/96	0	9
02/11/96	25	22	03/24/96	23	20	05/05/96	0	4
02/12/96	42	39	03/25/96	16	13	05/06/96	19	16
02/13/96	50	47	03/26/96	19	16	05/07/96	15	12

05/08/96	0	9	06/19/96	0	0	07/31/96	0	0
05/09/96	13	10	06/20/96	0	0	08/01/96	0	0
05/10/96	0	2	06/21/96	0	0	08/02/96	0	0
05/11/96	0	0	06/22/96	0	0	08/03/96	0	0
05/12/96	14	11	06/23/96	0	0	08/04/96	0	0
05/13/96	17	14	06/24/96	0	0	08/05/96	0	0
05/14/96	14	11	06/25/96	0	0	08/06/96	0	0
05/15/96	0	7	06/26/96	0	0	08/07/96	0	0
05/16/96	16	13	06/27/96	0	0	08/08/96	0	0
05/17/96	0	2	06/28/96	0	0	08/09/96	0	0
05/18/96	0	5	06/29/96	0	0	08/10/96	0	0
05/19/96	0	0	06/30/96	0	1	08/11/96	0	0
05/20/96	0	0	07/01/96	0	0	08/12/96	0	0
05/21/96	0	0	07/02/96	0	0	08/13/96	0	0
05/22/96	0	0	07/03/96	0	0	08/14/96	0	0
05/23/96	0	0	07/04/96	0	0	08/15/96	0	0
05/24/96	0	0	07/05/96	0	0	08/16/96	0	0
05/25/96	0	1	07/06/96	0	0	08/17/96	0	0
05/26/96	0	5	07/07/96	0	0	08/18/96	0	0
05/27/96	0	8	07/08/96	0	0	08/19/96	0	0
05/28/96	0	8	07/09/96	0	0	08/20/96	0	0
05/29/96	0	6	07/10/96	0	0	08/21/96	0	0
05/30/96	0	7	07/11/96	0	0	08/22/96	0	0
05/31/96	0	0	07/12/96	0	0	08/23/96	0	0
06/01/96	0	0	07/13/96	0	0	08/24/96	0	0
06/02/96	0	0	07/14/96	0	0	08/25/96	0	0
06/03/96	0	7	07/15/96	0	0	08/26/96	0	0
06/04/96	0	0	07/16/96	0	0	08/27/96	0	0
06/05/96	0	0	07/17/96	0	0	08/28/96	0	0
06/06/96	0	0	07/18/96	0	0	08/29/96	0	0
06/07/96	0	0	07/19/96	0	0	08/30/96	0	0
06/08/96	0	0	07/20/96	0	0	08/31/96	0	0
06/09/96	0	0	07/21/96	0	0	09/01/96	0	0
06/10/96	0	0	07/22/96	0	0	09/02/96	0	0
06/11/96	0	0	07/23/96	0	0	09/03/96	0	0
06/12/96	0	0	07/24/96	0	0	09/04/96	0	0
06/13/96	0	0	07/25/96	0	0	09/05/96	0	0
06/14/96	0	0	07/26/96	0	0	09/06/96	0	0
06/15/96	0	0	07/27/96	0	0	09/07/96	0	0
06/16/96	0	0	07/28/96	0	0	09/08/96	0	0
06/17/96	0	0	07/29/96	0	0	09/09/96	0	0
06/18/96	0	0	07/30/96	0	0	09/10/96	0	0

09/11/96	0	0	10/23/96	0	4	12/04/96	24	21
09/12/96	0	0	10/24/96	0	5	12/05/96	26	23
09/13/96	0	1	10/25/96	0	5	12/06/96	27	24
09/14/96	0	0	10/26/96	0	8	12/07/96	28	25
09/15/96	0	0	10/27/96	0	3	12/08/96	27	24
09/16/96	0	0	10/28/96	0	8	12/09/96	30	27
09/17/96	0	5	10/29/96	13	10	12/10/96	30	27
09/18/96	0	5	10/30/96	0	7	12/11/96	25	22
09/19/96	0	0	10/31/96	13	10	12/12/96	24	21
09/20/96	0	0	11/01/96	22	19	12/13/96	26	23
09/21/96	0	0	11/02/96	24	21	12/14/96	28	25
09/22/96	0	2	11/03/96	26	23	12/15/96	26	23
09/23/96	0	6	11/04/96	23	20	12/16/96	25	22
09/24/96	0	9	11/05/96	16	13	12/17/96	17	14
09/25/96	0	5	11/06/96	0	9	12/18/96	17	14
09/26/96	0	6	11/07/96	0	3	12/19/96	29	26
09/27/96	0	3	11/08/96	0	0	12/20/96	41	38
09/28/96	0	0	11/09/96	13	10	12/21/96	42	39
09/29/96	0	2	11/10/96	24	21	12/22/96	35	32
09/30/96	0	2	11/11/96	29	26	12/23/96	27	24
10/01/96	0	1	11/12/96	30	27	12/24/96	14	11
10/02/96	0	0	11/13/96	32	29	12/25/96	30	27
10/03/96	14	11	11/14/96	33	30	12/26/96	32	29
10/04/96	21	18	11/15/96	35	32	12/27/96	25	22
10/05/96	20	17	11/16/96	33	30	12/28/96	23	20
10/06/96	17	14	11/17/96	24	21	12/29/96	16	13
10/07/96	0	8	11/18/96	19	16	12/30/96	23	20
10/08/96	0	8	11/19/96	23	20	12/31/96	42	39
10/09/96	0	4	11/20/96	28	25	01/01/97	46	43
10/10/96	14	11	11/21/96	30	27	01/02/97	30	27
10/11/96	19	16	11/22/96	27	24	01/03/97	15	12
10/12/96	18	15	11/23/96	27	24	01/04/97	20	17
10/13/96	0	8	11/24/96	25	22	01/05/97	18	15
10/14/96	0	2	11/25/96	19	16	01/06/97	24	21
10/15/96	17	14	11/26/96	23	20	01/07/97	36	33
10/16/96	0	3	11/27/96	38	35	01/08/97	36	33
10/17/96	0	0	11/28/96	41	38	01/09/97	37	34
10/18/96	0	7	11/29/96	34	31	01/10/97	31	28
10/19/96	14	11	11/30/96	27	24	01/11/97	41	38
10/20/96	15	12	12/01/96	15	12	01/12/97	45	42
10/21/96	14	11	12/02/96	20	17	01/13/97	42	39
10/22/96	13	10	12/03/96	25	22	01/14/97	40	37

01/15/97	38	35	02/26/97	24	21	04/09/97	32	29
01/16/97	33	30	02/27/97	0	5	04/10/97	29	26
01/17/97	50	47	02/28/97	15	12	04/11/97	23	20
01/18/97	56	53	03/01/97	25	22	04/12/97	19	16
01/19/97	56	53	03/02/97	16	13	04/13/97	0	8
01/20/97	42	39	03/03/97	30	27	04/14/97	19	16
01/21/97	35	32	03/04/97	33	30	04/15/97	19	16
01/22/97	26	23	03/05/97	27	24	04/16/97	13	10
01/23/97	28	25	03/06/97	26	23	04/17/97	17	14
01/24/97	33	30	03/07/97	32	29	04/18/97	27	24
01/25/97	24	21	03/08/97	24	21	04/19/97	22	19
01/26/97	39	36	03/09/97	37	34	04/20/97	18	15
01/27/97	37	34	03/10/97	25	22	04/21/97	16	13
01/28/97	28	25	03/11/97	25	22	04/22/97	13	10
01/29/97	41	38	03/12/97	31	28	04/23/97	0	9
01/30/97	42	39	03/13/97	35	32	04/24/97	17	14
01/31/97	34	31	03/14/97	27	24	04/25/97	14	11
02/01/97	24	21	03/15/97	29	26	04/26/97	0	7
02/02/97	27	24	03/16/97	38	35	04/27/97	0	6
02/03/97	26	23	03/17/97	31	28	04/28/97	13	10
02/04/97	32	29	03/18/97	24	21	04/29/97	0	4
02/05/97	23	20	03/19/97	31	28	04/30/97	0	2
02/06/97	30	27	03/20/97	27	24	05/01/97	0	2
02/07/97	31	28	03/21/97	25	22	05/02/97	0	7
02/08/97	36	33	03/22/97	24	21	05/03/97	0	7
02/09/97	36	33	03/23/97	35	32	05/04/97	0	8
02/10/97	36	33	03/24/97	32	29	05/05/97	0	7
02/11/97	35	32	03/25/97	23	20	05/06/97	0	5
02/12/97	33	30	03/26/97	17	14	05/07/97	18	15
02/13/97	39	36	03/27/97	15	12	05/08/97	14	11
02/14/97	31	28	03/28/97	0	9	05/09/97	14	11
02/15/97	28	25	03/29/97	17	14	05/10/97	0	9
02/16/97	36	33	03/30/97	0	5	05/11/97	0	2
02/17/97	39	36	03/31/97	24	21	05/12/97	0	0
02/18/97	23	20	04/01/97	26	23	05/13/97	0	7
02/19/97	0	7	04/02/97	19	16	05/14/97	0	5
02/20/97	21	18	04/03/97	15	12	05/15/97	0	1
02/21/97	17	14	04/04/97	0	3	05/16/97	0	9
02/22/97	14	11	04/05/97	16	13	05/17/97	0	7
02/23/97	28	25	04/06/97	0	9	05/18/97	0	8
02/24/97	31	28	04/07/97	0	2	05/19/97	0	0
02/25/97	42	39	04/08/97	19	16	05/20/97	0	3

05/21/97	0	9
05/22/97	0	9
05/23/97	0	4
05/24/97	0	1
05/25/97	0	3
05/26/97	0	2
05/27/97	0	8
05/28/97	0	3
05/29/97	0	3
05/30/97	0	3
05/31/97	0	0
06/01/97	0	0
06/02/97	0	8
06/03/97	13	10
06/04/97	0	5
06/05/97	0	3
06/06/97	0	5
06/07/97	0	6
06/08/97	0	3
06/09/97	0	0
06/10/97	0	0
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