Domestic Hot Water Loads, System Sizing and Selection for Multifamily Buildings

Fredric S. Goldner and David C. Price, Energy Management & Research Associates

The paper presents highlights of the final results of the initial phase of a NYSERDA funded research study on domestic hot water (DHW) consumption and demand levels, as they relate to the soon-to-be-released new ASHRAE guidelines. The paper also reviews the initial findings of the second phase study which focuses on system sizing & selection criteria. This second phase study used models to properly select and size DHW equipment and 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, tankless coil with storage tank(s), 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 data included DHW flows (at *5 and 15 minute intervals),* recirculation flow, fuel flows, DHW temperatures before and after the mixing valve as well as on the return loop, and boiler cycle times and burner runtimes. The models utilized the measured data to determine optimized requirements.

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. Relative efficiency ratios for typical systems are presented.

Life cycle costing analyses utilizing energy and equipment cost data reveal the economic benefits of applying the various equipment types and systems.

Introduction

Energy professionals have long been frustrated by the lack of reliable data upon which to size domestic hot water (DHW) generating equipment. Design engineers and contractors know that strict adherence to 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 ongoing research reported here 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.

What are presented here are analyses of real-time monitored data that were used to develop reliable data on DHW consumption and demand patterns and subsequent system sizing guidelines. Additionally, the data has been used to evaluate both the energy and economic impacts of employing various combinations of instantaneous generation and/or storage systems to meet these loads. The research has been performed by Energy Management & Research Associates (EMRA) under a contract with New York State Energy Research and Development Authority (Energy Authority).

Historically, DHW requirements in multifamily buildings have been calculated on the basis of national ASHRAE and other standards of many years standing, which have proved to be inaccurate. The projects reviewed here measured DHW flows precisely in the observed buildings, producing a more comprehensive base of information necessary for determining both required sizing and operating costs. This is a critical need in the process of renovating buildings or in the design of new systems.

The two areas covered by this research are: (a) development and analysis of a comprehensive set of multifamily building DHW system operational data and (b) developing, based on the observed data, analyses of DHW consumption demand and energy requirements, and life cycle costs for various types of DHW production systems.

The data presented here reflects the full set of DHW demand and consumption analyses, and a preliminary assessment of the life cycle costs of potential generation and storage systems.

Data Sets

The information presented in this paper reflects data collected in the process of two extensive DHW research projects 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 initial research project (completed in 1993) consisted of fourteen months of real time monitoring in thirty NYC multifamily buildings. Eight of these sites had their monitoring equipment upgraded to collect DHW flow data in 15 minute intervals. These data were collected by computerized heating controllers, which monitor these data points in all thirty buildings: Temperatures - in apartments, of outdoor air, boiler water (aquastat) and DHW; and burner on-off times. Eight upgraded buildings had additional data monitoring equipment installed to record stack temperature, boiler make-up water flow, DHW flow in 15-minute increments, oil flow, DHW temperature before and after the mixing valve and on the return line. Depending on the particular device these sensors were polled every 15 minutes, hourly or daily, by the computer which stored the data in memory. Via modem, the management company staff called each building every third day to download the data onto disks that were delivered to Energy Management & Research Associates.

The second stage project consisted of upgrading a subset of three of the sites to record DHW flow in 5 minute increments 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 this building subset, was then collected for a period of 100 days.

The data sets cover all of the data collected by the building monitoring devices, building operational and tenant information requested from superintendents and property managers via questionnaires and interviews, building and apartment occupancy records, and equipment and building condition data obtained through energy audits.

The third 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 U.S. and Canada. The 7 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 (i.e. Average Day, Maximum Hour, Maximum Day), by Bill Thrasher of AGA Labs (Thrasher and DeWerth 1993). 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 the two New York studies [1]. These figures were then used, along with the New York data to compose a set of "National" system sizing guidelines.

Building Set

Within the New York research (Goldner 1993) 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 and predominant stock of the over 120,000 New York City multifamily buildings. The buildings selected range in size from 17 to 103 apartments in either five or six above-ground stories. These buildings were built before 1902 or between 1902 and 1928. All have combination steam and DHW generating, steel tube boilers with (primarily) Nos. 4 or 6 oil, air-atomizing burners. DHW is generated in a "tankless" coil just under the surface of the boiler water.[2]

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, CEUE, and TES Ltd.

All of the following graphs and tables were developed as part of the research conducted on the two New York data sets, with the exception of the "National LMH" table (#2) - which encompassed available data from all the studies.

Demand Flow Patterns

In order to properly design a DHW system for multifamily buildings it is useful 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 falls by 1% in the spring and falls again 19% during the summer period. It is not clear why the spring consumption is not lower, similar to the fall level.

Weekday vs. weekend comparison of gallons of DHW consumed by buildings reveals that there is generally a slightly higher level of consumption on weekends (Saturday and Sunday) than on weekdays (Monday through Friday). This phenomenon is true in all seasons, (with only certain buildings not exhibiting this tendency during the summer). The average weekend day consumption is 7.5% greater than the average weekday day level.

Consumption Flows

Much work has gone into the 15 minute DHW flow data analysis 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 later AM and continues on until around 1:00 to 2:00 PM, the usage then tapers off fairly evenly through the rest of the day. Examination of the composite weekday and weekend graph illustrates that the weekend peak is greater, at 1.09 gal/capita, than any of the weekday peaks, at 0.87 gal/capita.

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

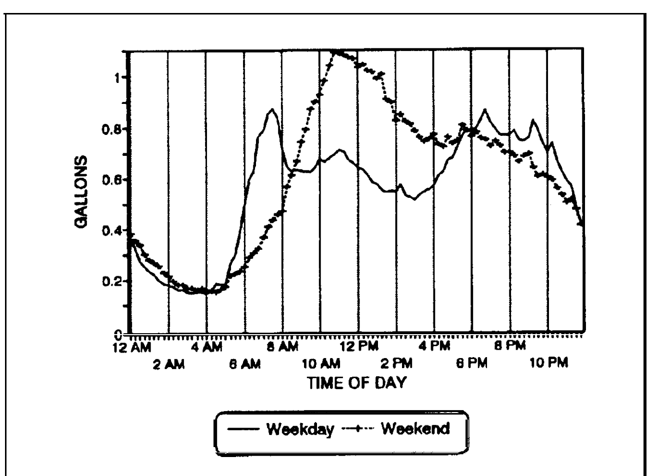

Figure 1. Weekday vs. Weekend Consumption (Gallons Per Capita, Composite)

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

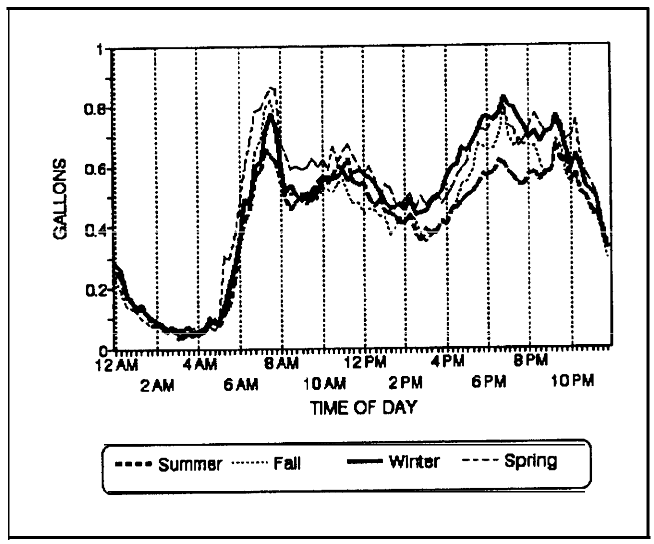

Figure 2. Seasonal Variations, Weekday Consumption (Gallons Per Capita, Composite)

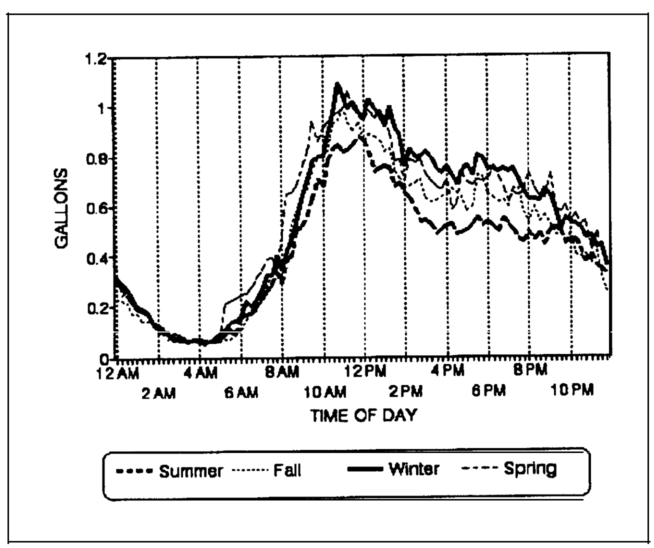

Figure 3. Seasonal Variations, Weekend Consumption (Gallons Per Capita, Composite)

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 further tap. The second type of system, as exists in study building #9, is a gravity return. The monitored data indicates that these systems see a very small flow ranging from O to 0.5 gpm. The third type of system is forced recirculation. Such a system employs a small pump to keep water flowing, thus avoiding stagnation and the need to run the tap for a long period (particularly on upper floors) to receive sufficiently hot water. The pumps are either run continuously, as seen in the study buildings #7 & #10, or may be cycled on and off by an aquastat.

Figures 4 & 5 depict the DHW consumption and recirculation flow patterns in building #7. (While these 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 sites.) 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.

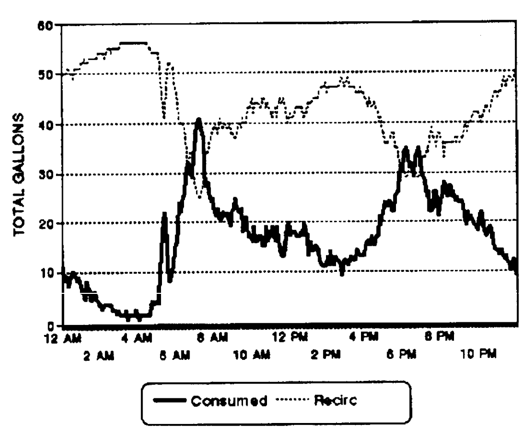

Figure 4. DHW Consumption & Recirculation Flows, (Building 7- Weekday)

Calculating Demand

One of the key objectives of the initial research project was to determine accurate levels of DHW consumption & demand, and to identify factors affecting these levels. A comparison to current *ASHRAE Handbook (Chapter 44, Table 7)*[3] 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 (Goldner 1993). 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.

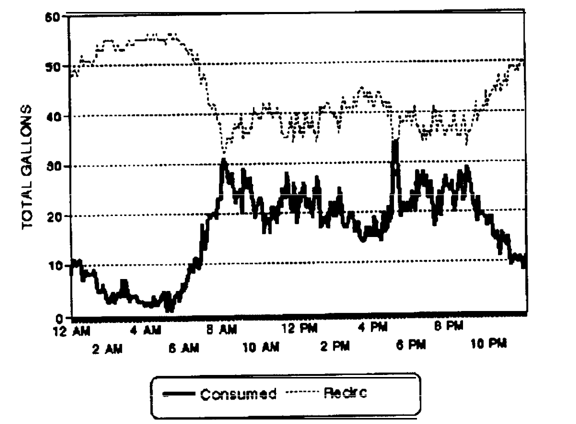

Figure 5. DHW Consumption & Recirculation Flows, (Building 7- Weekend)

The format for the guidelines presented differs from those currently used (predominantly *ASHRAE Handbook Chapter 44, Table 7).* This new approach represents the results of discussions with system design professionals, including members of ASHRAE T.C. 6.6 (Service Hot Water), who have indicated a preference for a "Low - Medium - High" (LMH) users set of guidelines, rather than a specific, singular volume value. By providing LMH tables and guidelines for their application it is felt that the design engineer or contractor can use these as a tool to better match the situation at the site they are serving. Additionally, the figures presented in the LMH tables include the more detailed level of "Peak 5 and Peak 15 Minute" gallon consumption, which should assist in the design process. One other significant difference, in this study, 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.

The first step in calculating demand is determining the demographic profile of the project and building occupants. Different types of building occupants have been found to consume hot water with fairly predictable patterns. Users can be lumped into three typical categories of "low," "medium," and "high" volume water consumers as a function of the building and occupant demographics. Table 1 indicates a variety of occupant classifications, one or a combination of which should describe any particular multifamily building. For example, a luxury condominium

Table 1. 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**

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. To wit, if the condominium building example above intended or allowed the future installation of a clotheswasher in each unit, the demographic category 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 2. Values are indicated per capita in maximum flows of 5 minutes, 15 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.

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

Note that the figures presented (in Table 2) 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 these 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[4].

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

Relationships of Loads

Peak Demands and Average Consumption

Five, 15, 60, 120 and 180 minute maximum demand and hourly average consumption figures may be used to examine peak needs in contrast to total volume. 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 peak 15 minutes. Review of the 15 and 60 minute peak periods reveals that the highest (15 minute) peak is equal 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 volume of DHW used to satisfy the 120 minute maximum is 75% of what is needed during the peak 180 minute span. In Figures 6 and 7 we can see how all of the peak volumes contribute to the 1 hour and 3 hour peak demand on the

Table 2. National: Low - Medium - High Guidelines: Hot Water Demands and Use for Multifamily Buildings

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

	Peak 5 Minutes	Maximum 2 Hours	Maximum 3 Hours
Low	0.4 gal (1.5 L)/person	5.0 gal (18.0 L)/person	6.1 gal (23.0 L)/person
Med	0.7 gal (2.5 L)/person	8.0 gal (31.0 L)/person	11.0 gal (41.0 L)/person
High	1.15 gal (4.4 L)/person	14.5 gal (55.0 L)/person	19.0 gal (72.0 L)/person

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. That reveals that 46% of the DHW consumed during the peak 3 hour demand each day is needed within the maximum 60 minutes. Another 29% of the 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.

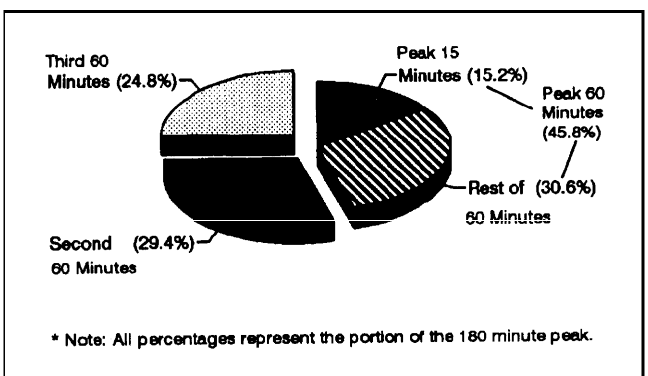

Figure 6. Parts of 3 Hour DHW Peak Consumption - Winter Period

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. There is an exact coincidence of 60 and 15 minute maximum demand times on the weekends. During weekdays the mornings have a close match of 60 and 15 minute demands, and there is an exact match during the evening periods. Review of the 120 and 180 minute peaking periods reveals that there is again an exact coincidence with both these periods and the 15 and 60 minute peaks. While a detailed time analysis on the 5 minute peaks has yet to be conducted, visual surveys of flow graphs strongly suggest that there is a match between all 5 and 15 minute peaking times.

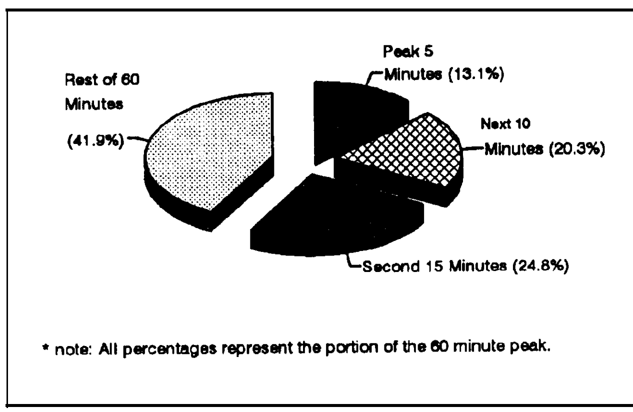

Figure 7. Parts of Peak 60 Minutes DHW Consumption

Instantaneous Generation vs. Storage Selection Considerations

As part of the ongoing (second stage) research project, a series of 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 3 building subset is enabling us to go past the theoretical models that have been used in the past. The models are being 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 will range from an oversized 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.

Model Descriptions

These 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 row represent 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 bum. For the analysis to date, this cycle was repeated for each 5 minute interval over a four month interval. Future efforts of the research shall continue the same process on the 14 months of 15 minute interval data.

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 the combustion efficiency of the equipment can also vary greatly, a value of 80% was used for all of the models.

As a validity check, 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 type systems and to allow multiple system sizes to be simulated quickly, several of the 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 spreadsheet was used to create the models.

Potential Systems

As anybody who has been around multifamily buildings for a while can tell you, 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. This can result in an instantaneous type system, where the system has the capacity to meet peaks load without any required storage to a system designed to supply only the average daily load with the peaks supplied from a storage system. The focus of this research is to determine the relative difference between the various combinations from both an operating cost standpoint (i.e. most energy efficient) and from a least cost standpoint. 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 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 of this type of system is the low operating efficiency during the non-heating season.

Due to the prevalence of this system type, this system will be used as a benchmark to which each of the other systems will be measured.

Tankless Coil with Storage Tank. The basics of this system type are similar to the tankless coil described above with the exception of the addition of a DHW storage tank. The addition of the DHW tank allows for greater DHW supply capacity in situations where the size of the tankless coil is limited or a there is a desire to downsize the boiler. The balance of components will usually include a mixing valve to temper the DHW supply to the building. The advantage of this type of system is the low cost of adding additional supply capacity to an existing system. The disadvantages of this type of system are the increased standing losses associated with the increased surface area of the storage tank.

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 samples 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 bum-through caused by sediment build-up on heat exchanger surfaces.

Separate DHW Boiler with Storage Tank. This system comprises a boiler sized to just make DHW with 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 the greater design flexibility, a lower pre-mature failure rate due to separating the burner and the area of sedimentation and increased operating efficiencies.

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 (less than 50 gallons) of water 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. Type of system control mitigates need for a separate mixing valve. The advantage of a system of this type is high operating efficiencies 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

To date we have completed the analysis for building #7. This site is a 60 unit apartment building that was determined to fall within the “medium” level category of the LMH guidelines. A theoretical occupancy of 120 people (2 persons per apt.) was used to enter the LMH Table to determine DHW consumption. The 5 minute peak values were then used to size the Instantaneous Type systems.

For the Separate DHW Boiler w/ 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. In order to establish several points with which to establish a curve, the boiler capacity was then dropped by 150,000 BTUH 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, the burner and storage capacities from several existing models were chosen from manufacturers’ catalogs and were utilized in the simulations.

The results of the simulations are presented in Table 3.

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

Some additional considerations that need to be taken into account when interpreting this data is the combustion efficiency obtainable on commercially available equipment. While 80% was used for all of the systems in order to create a level playing field, several of the 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.

Life Cycle Costing

Cost of various system components were compiled in order to conduct system economic analyses. Life cycle costing (LCC) models used these equipment costs and the energy costs computed by the various models (above) to evaluate the economic efficiencies of employing different

Table 3. Energy Use Comparisons of Systems

	Burner Capacity (BTUH)	Storage Capacity (gal.)	Fuel Consumed MMBtu's/Yr	% Efficiency Increase vs. Base
Tankless Coil	5,000,000	0	3,255	0%
Direct Fired	a) 800,000	411	2,982	8%
Storage Tank	b) 600,000	221	2,841	13%
	c) 540,000	125	2,784	14%
Separate DHW	a) 850,000	100	2,802	14%
Boiler w/ Tank	b) 700,000	700	2,754	15%
	c) 550,000	900	2,707	17%
	d) 400,000	2,400	2,631	19%
Instantaneous	900,000	0	2,786	14%

systems to satisfy the building's DHW needs. 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 can then be compared to determine the approach that will provide the greatest economic benefit for the site. Once a complete set of energy and cost analyses has been completed on the full set of monitored buildings it is expected that recommendations will be made as to the best LCC choices for various building types. (i.e., it may be found that certain economies of scale are needed to install the most energy efficient equipment, thus eliminating a particular DHW system configuration for small buildings. This will be the focus of the next step in the project.)

The LCC analyses were undertaken by adapting ENVEST (energy investment financial analysis software). In order 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 MACRS (modified accelerated cost recovery system) 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 are currently 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 has been 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 US DOE's 1994 forecasts[5] for price changes in this end use sector over the next 20 years. The resultant annual growth rates applied in the models are: 2.71% beginning in 1995, 2.73% from 2000, and 2.05% from 2005 thru the end of the model.

The results of the LCC models are presented in Table 4. It is interesting to note that while the "20 Year Energy Costs" exhibit the same relationships as the "% Efficiency vs. Base" (in Table 3), as expected, the fiscal efficacies of the various systems' life cycle NPV 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 at 10% less expensive than the Tankless Coil (base case). Configuration (c) of the Separate DHW Boiler w/Tank and the Instantaneous system are similarly 8% and 9%, respectively, more efficient than the Tankless Coil design.

In reviewing the NPVs of various configurations of Separate DHW Boiler w/Tank we see that even though the

Table 4. Life Cycle Cost Comparisons of Systems

	Equipment Costs (Installed)	20 Year Energy Costs	System NPV Cost
Tankless Coil	$8,300*	$375,981	$104,910
Direct Fired	a) $20,470	$344,458	$105,909
Storage Tank	b) $16,735	$328,134	$98,785
	c) $13,000	$321,601	$94,193
Separate DHW	a) $15,800	$323,579	$96,883
Boiler w/Tank	b) $19,400	$318,098	$98,193
	c) $18,600	$312,647	$96,448
	d) $26,920	$303,935	$100,195
Instantaneous	$14,000	$321,783	$95,037

* 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.

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 difference in the hot water generator models.

Another set of real world issues that must be considered in conjunction with the lower NPV of the Direct Fired Storage Tank system is that of available sizes. These units come as packaged systems, with the generator/burner and storage tank all part of one integral unit. The combination of ranges of generator capacity to storage volume is quite limited. Additionally, in retrofit situations the larger, lower operating cost systems often are just to large to fit through the boiler room door, or are to heavy to be installed without similarly too large equipment. Lastly, 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 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 meets the building's load.

The authors wonder if the vast majority of those building management personnel who are responsible for making equipment investment decisions, who now generally rely on first cost as the key parameter, would be swayed by the NPV analysis. We question whether the $63,334 or $54,198 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 for the target audience.

Conclusions. 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[1]. The research described in this paper measured precise DHW flows to create a better base of experience for sizing of 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 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. Firstly, in lower initial equipment investments, for smaller more correctly sized equipment; and secondly, in lower annual - life cycle operating costs from higher operating (seasonal) efficiencies due to reduced cycling of equipment operating closer to full load.

Additionally the initial results from the 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.

Future Work

Work to be conducted in the near term will involve similar analysis of the remaining two sites with 5 minute data, and full analysis of all 14 months of 15 minute flow data from the full building set. Upon completion of these runs all the results will be compiled and an evaluation conducted to determine if the economics of the various system options remain equal, or if economies of scale (due to available equipment costs) vary the least cost choices for different building sizes.

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Endnotes

1. Goldner, F. S. 1993. Energy Use and DHW Consumption Research Project, Draft final project report. Prepared for New York State Energy Research and Development Authority. Prepared by Energy Management & Research Associates.

2. See Goldner, "Multi-Family Building Energy Monitoring and Analysis, Domestic Hot Water Use and System Sizing Criteria Development: A Status Report", *Proceedings from the ACEEE 1992 Summer Study on Energy Efficiency in Buildings*, for a more detailed description of the buildings' physical and resident composition and the selection process.

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

4. Based on the findings of this study and Vine et al. 1987.

5. 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).

6. Goldner 1993.

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