DHW RECIRCULATION SYSTEM CONTROL STRATEGIES

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DHW Recirculation System Control Strategies

Final Report

Prepared for

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NOTICE

ABSTRACT

This study was the third step in a series of research projects that examined domestic hot water (DHW) issues in multi family buildings. The research analyzed the effects of varying control strategies of DHW recirculation systems in multi family buildings. The effects were measured through the use of real-time monitored DHW consumption and temperatures. DHW is the second largest component of a building's energy budget.

The purpose of a DHW recirculation system is to decrease the time, and subsequent water consumption, spent waiting for the water to achieve acceptable temperatures when called for. The question examined was whether it is necessary to continuously run recirculation pumps (as is general practice), or could DHW system energy consumption be reduced by operating the pumps with some type of control strategy? The project investigated this issue by analyzing a series of four different control strategies, employing detailed monitoring to closely observe the effects of each strategy. The four different operating strategies were: A) continuous operation (base case); B) shut down during the overnight period; C) shut down during the peak morning and evening periods; and D) cycled by a return line aquatint set at 110^{0} F. To accomplish this six sites had aquastats installed onto the DHW return lines, and a programmable timeclock wired into the pumps.

As compared to the base case (pump running 24 hours per day), Strategy B saved an average of 6%, Strategy C saved 6%, and Strategy D saved 11% of the DHW portion of a building's annual energy requirements. This is significant, as Strategy D translates into a savings of 4% of the building's total yearly fuel bill. As all of the rather simple control strategies evaluated employ low cost devices (under $250 installed), this should insure a large penetration rate for the control strategy recommendation.

Results from Tenant Water Quality Survey Questionnaires show that there was always an acceptable level of satisfaction, regardless of how the system was being controlled. On the average, the tenants rated the "hot water service" during test periods for Strategies A, B, and D as between "Good" and "Very Good". For Strategy C the rating was between "Fair" and "Very Good".

KEY WORDS

Hot water, monitoring, multi family building, control devices, energy conservation.

ACKNOWLEDGEMENTS

We would like to thank the cooperation and assistance of Norine Karins of NYSERDA; Mark Engel and the staff of Langsam Property Services; Peter Spinillo and Perry Tripi of EMRA; David Price of DSM Engineering Associates; David Suthergreen of Suthergreen Technologies; and others who have helped review this work.

TABLE OF CONTENTS

FIGURES

Figure		Page

TABLES

SUMMARY

This project was designed to analyze the effects of varying control strategies of domestic hot water (DHW) recirculation systems in multi family buildings. The effects were measured through the use of real-time monitored DHW consumption and temperatures. The purpose of the investigation of control strategies was to minimize energy use for DHW, which is the second largest component of a building's energy budget.

The purpose of a DHW recirculation system is to decrease the time spent waiting for the water to achieve acceptable usage temperatures thus decrease water consumption. However, the question examined was whether it is necessary to run recirculation pumps continuously (as is general practice) or could DHW system energy consumption be reduced by applying a low cost control strategy to the operation of the pumps?

The sites used in this research project met the following site selection criteria. Two sites in each of three size ranges: small (less than 45 apartments), medium (45 to 80 apartments), and large (greater than 80 apartments).

DHW systems in multi family buildings generally employ one of three types of return/recirculation systems. Prior to project commencement, all of the six buildings in this study had a forced recirculation system, with the pump running continuously.

CONTROL STRATEGIES

Currently most forced DHW recirculation systems in multi family buildings operate with the pump set-up to run continuously. This recirculation control project measured the energy savings achieved by cycling of pumps. The research has compared four operating strategies:

Strategy A)	Continuous operation (base case)
Strategy B)	Shutdown during overnight period
Strategy C)	Shutdown during peak morning and evening periods
Strategy D)	Cycling by a return line aquatint

Strategy A was used as a base case against which to determine the savings achievable by the other approaches. Strategy B's approach is to attempt to save energy by shutting down the pumps at night when few if any people use hot water. Strategy C's approach is to attempt to save energy by shutting down the pumps during peak (morning and evening) DHW usage periods, when the large volume of usage, in and of itself, causes circulation to occur. Strategy D, operated the pump only when the DHW temperature in the basement return line falls below 110^{O} F (controlled by a return line aquatint).

PROJECT METHODOLOGY

The following data was collected through instrumented monitoring: 5-minute DHW and recirculation flows, 5-minute running average after mixing valve and return line DHW temperatures, and daily circulation pump runtimes.

It was essential that this research compare the effects of operating the DHW recirculation systems with each strategy at each site. The project objective was to isolate effects attributable directly to the change in recirculation pump operations. For each building, data was collected for the four different strategies; (each building's data was compared with itself under the various strategies to account for variances of use that exist between buildings).

To alleviate seasonal (use variance) effects the sites were operated for two weeks under one scenario, then switched to the next scenario. This was done until each of the 4 strategies were run and data collected. At the end of a 'round' (completion of the fourth two-week scenario) a second round was begun with Strategy A again. Four testing rounds were conducted, one during each of the four seasons. Such a series of round robin 2-week sample frames was employed to remove the issue of seasonal variations that would be problematic if four 2-month long/single scenario operations periods were used. This round robin approach allowed for collection of a full two months of data for each strategy over the project period.

Another major factor that impacts greatly on DHW consumption is the number of persons living in the building. Vacancy figures were used to eliminate DHW consumption variances due to differing occupancy levels, and to adjust the consumption of DHW per occupied apartment. Adjustments were also made to account for occupant behavior due to variable inlet water temperatures encountered in each period. Lastly, tenant questionnaires were developed to assess the change in user response to DHW delivery service between the four different recirculation control strategies.

FINDINGS

Tenant Satisfaction

Responses to the water quality surveys show that the level of water delivery did not vary much between control strategies, except in the case of Strategy C. From the results of these Tenant Water Quality Survey Questionnaires, it appears that we can expect an acceptable level of satisfaction regardless of how the system is controlled, for all control strategies except for Strategy C.

Energy Use

Compared to the base case, (Strategy A - pump running 24 hours per day), Strategy B saved 5.5%, Strategy C saved 5.5%, and Strategy D saved 10.8%. These are significant savings, as the level of savings from Strategy D is equal to a savings of approximately 4% of a typical building's total annual fuel consumption. In addition to the fuel savings there is an electrical energy savings from the reduced run hours on the pumps. The average amount of energy expended to heat the recirculated DHW was 38% percent of the total energy used by to supply DHW during normal operations (base case Strategy A). The research results show that the energy spent on the recirculation loop was cut to an average of 31% of the DHW system total by Strategy B, to 34% with Strategy C, and down to 23% while employing Strategy D.

Water Consumption

One of the major concerns before beginning the research was that with the recirculation pump turned off people would let the water run for long periods of time in order to get hot water. Analysis revealed there was no appreciable difference in the volume of city water usage between any of the strategies. Additionally, this information along with the amount of DHW recirculated was also analyzed to further understand the systems' operations and our results.

The amount of DHW being recirculated under non-base case scenarios the volume was greatly reduced, which was the major contributor towards energy savings under the other strategies. Typically there was a moderate drop off in recirculated water from Strategy A to Strategies B and C, and a much more significant drop off with Strategy

D. Switching from Strategy A to Strategy D reduced the amount of water recirculated by an average of 74% annually.

Water Temperatures

Another variable that could effect the results was water temperature. Actual temperatures throughout the system were used in the calculation of the energy usage during each strategy. The reduction in DHW temperature at the basement return under Strategies B, C, and D also contributed to the energy savings, as the systems were not circulating higher-temperature DHW around the buildings as often under these three strategies.

Circulation Pump Runtimes

As the greatest savings were achieved while operating under Strategy D, the circulation pump runtimes were examined. The annual average pump run hours for Strategy D was approximately 6 hours per day.

CONCLUSIONS / RECOMMENDATION

Based on the results of this research, it appears that significant energy savings are available by installing a rather simple device that can provide paybacks of a few months. As compared to the base case of the pump running 24 hours per day (Strategy A), turning the pump off overnight (Strategy B) saves 6%, turning the pump off during morning and evening peaks (Strategy C) saves 6%, and controlling the pump with a return line aquatint set at 110^{o} F with a 5^{o} F deadband (Strategy D) saves 11%. The level of savings from Strategy D is equal to 4% of a typical building's total annual fuel consumption. This averaged to $784 per year per site. In addition to the fuel savings, the electrical energy savings would be from $5 to $13 per year in buildings with a 1/40-hp pump, and from $16 to $43 per year in buildings with a 1/12-hp pump due to the reduced run hours on the pumps. The aquastats used in this project cost $43, and were acquired from a general supply house. Conservative estimates from several heating and plumbing contractors of installed cost for this measure range between $150 and $250. The paybacks from such a straightforward operations change ranged between just over 1 month and 1 1/2 years, with the average payback being 7 months.

Scope Of This Issue

An evaluation of available data on multi family buildings reveals that the average New York City apartment consumes 865 gallons of #2 oil (or equivalent) per year. On average, for the buildings studied, 37% of all fuel consumption was used to supply DHW. There are two million apartments in New York City multi family buildings, and we estimate approximately one third of these sites have recirculation systems. Results of the research indicate that recirculation systems are responsible for an average of 38% of DHW energy consumption in the sites studied. Using these figures, DHW recirculation systems consume over 80 million gallons of oil per year (in the New York City stock alone). Assuming a penetration rate of only 10% to 20%, implementation of Strategy D, (the reverse acting return line aquatint set at 110^{o} F with a 5^{o} F deadband, which provides an 11% savings) will yield between 866,000 and 1.73 million of gallons of energy conserved annually.

It is clear that this measure should be implemented immediately in all buildings that are currently employing continuously running forced recirculation systems.

Section 1
INTRODUCTION

This project was designed to analyze the effects of varying control strategies of domestic hot water (DHW) recirculation systems in multi family buildings. The effects were measured through the use of real-time monitored DHW consumption and temperatures. This project was the next logical step in a sequence of NYSERDA-sponsored research efforts that investigated DHW consumption and demand levels[1], (resulting in a revision of the industry standard - ASHRAE and ASPE guidelines for system sizing), and evaluated generation system design issues[2]. The purpose of the investigation of control strategies was to minimize energy use for DHW, which is the second largest component of a building's energy budget.

The purpose of a DHW recirculation system is to decrease the time spent waiting for the water to achieve acceptable usage temperatures thus decrease water consumption. However, the question examined was wether it is necessary to run recirculation pumps continuously (as is general practice) or could DHW system energy consumption be reduced by applying some sort of control strategy to the operation of the pumps? This project addressed this issue by analyzing the effects of a series of four different control strategies, by employing detailed monitoring to closely observe the effects of each scenario. The effective design of this research was possible due to the vast amount of knowledge obtained over the course of the prior DHW projects conducted by the principal investigators. Additionally, the proposed project was able to take advantage of a large amount of monitoring equipment already in place in the subject buildings. All of the control strategies evaluated were selected in part based on the fact that they employ low-cost devices (under $200 installed), which should help insure a large penetration rate for the resulting control strategy recommendation.

The sites used in this research project were chosen from the stock of Langsam Property Services (as in the prior two DHW projects) and Weiss Realty. This allowed use of

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1 Goldner, F.S. 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.

2 Goldner, F.S. and D.C. Price, Nov. 1996, *DHW Modeling: System Sizing and Selection Criteria, Phase 2 - Draft Final Project Report*, Prepared for New York State Energy Research and Development Authority by Energy Management & Research Associates.

much monitoring and data collection equipment already in place. In addition, in the previous projects these realty companies had been most cooperative and provided ready access to their exceptional records and data which were required in the analysis. The buildings chosen also meet the following site selection criteria. Two sites in each of three size ranges: small (less than 45 apartments), medium (45 to 80 apartments), and large (greater than 80 apartments).

Table 1 is a list of the sites and the number of apartments in each:

PROJECT BUILDINGS

ID#	Address	Apartments
12	1526 Beach	25
31	533-37 Tinton	42
7	2105 Burr	60
9	3120 Buhre	80
10	620 Trinity	102
30	2900-16 St Theresa	103

Table 1

The project research buildings are characteristic of the older (and predominant) stock of the more than 120,000 New York City multi family buildings. The buildings ranged in size from 25 to 103 apartments and have either five or six above-ground stories. All but one have combination steam and DHW generating, steel tube boilers, (one site has a combination system with a cast iron boiler.) The DHW is generated in a "tankless" coil just under the surface of the boiler water.

DHW systems in multi family buildings generally employ one of two types of return/recirculation systems. The first type is a gravity return system. Monitored data indicates that such systems have a very low flow, ranging from 0 to 0.5 gallons per minute (gpm). The second type is a forced recirculation system. 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 (particularly on upper floors) to receive sufficiently hot water. The pumps are either run continuously or may be cycled on and off by an aquatint. Prior to project commencement, all of the six buildings in this study had a forced recirculation system, with the pump running continuously. Another 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.

Figures 1 & 2 (p. 1-4) depict representative DHW consumption and recirculation flow patterns found in the buildings. While pumps *should be* sized to meet an individual building's requirements, common practice is "one size fits all," "this pump worked in the last building," or "that's what we had on the shelf" methodology. In fact, among the six project sites (which featured a considerable range of layout types and system lengths), we found only either a 1/12 horsepower (hp) or 1/40 hp (in the two smallest buildings) pump. In the overnight period when there is little or no consumption pumps reach their maximum capacity rate of approximately 11 gpm for the 1/12 hp pumps or 4.5 gpm for the 1/40 hp pumps. As the consumption level increases there is an inverse relationship within the recirculation flow.

CONTROL STRATEGIES

Currently most forced DHW recirculation systems in multi family buildings operate with the pump set-up to run continuously. Data uncovered in a previous DHW project[3] led us to believe that this may not be necessary. This recirculation control project measured the energy savings achieved by cycling of pumps. The research has compared four operating strategies:

- Strategy A) Continuous operation (base case)
- Strategy B) Shutdown during overnight period
- Strategy C) Shutdown during peak morning and evening periods
- Strategy D) Cycling by a return line aquatint

The research required an aquatint be installed onto the DHW return line, and a programmable timeclock wired into the pump.

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[3] Goldner and Price, Nov. 1996.

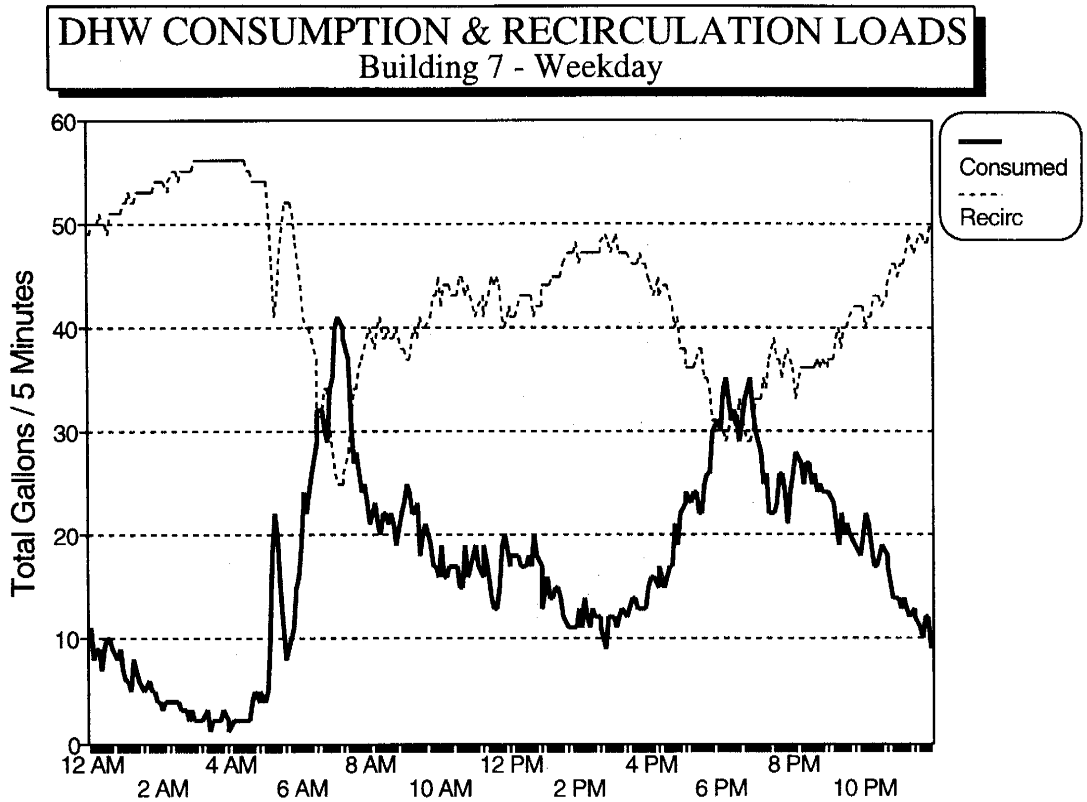

Figure 1

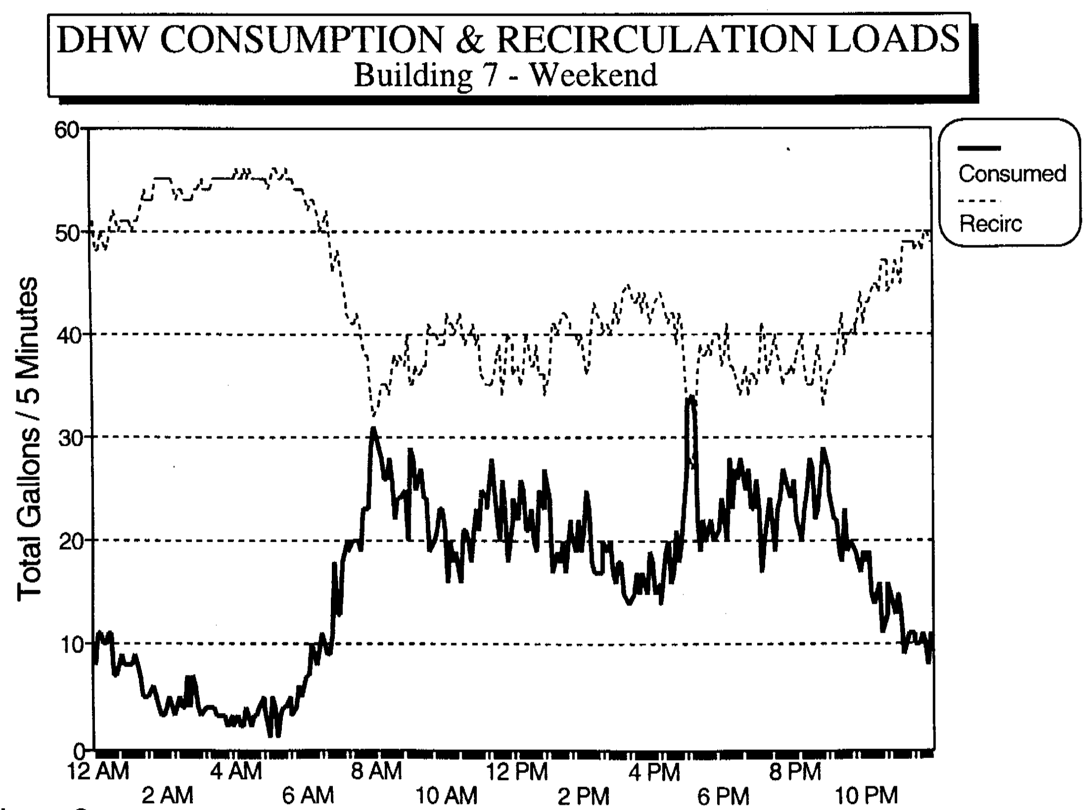

Figure 2

Strategy A was used as a base case against which to determine the savings achievable by the other approaches. Strategy B's approach is to attempt to save energy by shutting down the pumps at night when few if any people use hot water. After careful review of the data it was determined that the pumps should be shut off from 11:50 pm to 5:20 am each night. Strategy C's approach is to attempt to save energy by shutting down the pumps during peak DHW usage periods, when the large volume of usage, in and of itself, causes circulation to occur. Review of the data determined that the pumps should be shut off from 5:45 am to 8:15 am each morning and 5:45 pm to 9:15 pm each evening. Strategy D, operated the pump only when the DHW temperature in the basement return line falls below $110^{o}F$ (controlled by a return line aquatint).

Section 2
PROJECT METHODOLOGY

As we are aware from previous research, different buildings use varying volumes of DHW. It was therefore essential that this research compare the effects of operating the DHW recirculation systems with each strategy at each site. Six sites were selected and equipped with the necessary pump control devices (both a return line aquatint and a programmable timeclock wired into the recirculation pump) and monitoring equipment. The project objective was to isolate effects attributable directly to the change in recirculation pump operations. This was accomplished by controlling as many of the other factors that might effect DHW or energy consumption, and holding them constant.

For each building, data was collected for the four different strategies; (each building's data was compared with itself under the various strategies to account for variances of use that exist between buildings). In order to alleviate seasonal (use variance) effects the sites were operated for two weeks under one scenario (i.e., scenario 1a), then switched (by EMRA field personnel) to the next scenario (i.e., scenario 1b). This continued until each of the 4 strategies were run and data collected. At the end of a 'round' (completion of the fourth two-week scenario) a second round was begun with Strategy A again. Four testing rounds were conducted, one during each of the four seasons. (There were breaks between the end of one round and the beginning of the next; i.e., from the end of round 2 near the end of August and the beginning of the Fall - official heating season in October.) Such a series of round robin 2-week sample frames was employed to remove the issue of seasonal variations that would be problematic if four 2-month long/single scenario operations periods were used. This round robin approach allowed for collection of a full two months of data for each strategy over the project period.

__Terminology__

The terminology used throughout the paper shall follow the following format:

> **Strategy** ***X*** (capital letter) - refers to one of the four pump operating modes.

Round *X* (number) - one complete sequence of 2-week round robin periods, during which each building was operated under all four strategies.

Scenario *Xx* (number, lowercase letter) - denotes the specific 2-week period during Round *X* when the pump was operated by the mode defined under a given strategy (*x*); (denoted with an under case letter, to differentiate it from discussion/results dealing with all periods under Strategy *X*.)

The following data was collected through instrumented monitoring: DHW flows, recirculation flows, DHW temperatures before and after the mixing valve and on the return line, recirculation pump daily runtimes, along with aquatint temperatures, boiler make-up water volumes, fuel flows, boiler run times, and stack temperatures. Cold water inlet temperatures were measured manually by the site superintendents, every week, and double-checked every second week by EMRA field staff. These were not electronically monitored since cold water inlet temperatures exhibit only seasonal variations[4]; (it was, therefore, not necessary to monitor this variable with a sensor that reads on a 5 minute interval.)

Data collection was conducted by tieing into specially adapted units of the buildings' existing Heat Computers[5]. OAS (the Heat Computer manufacturer) developed routines to collect (and output) 5-minute DHW and recirculation flows, as well as 5-minute running average after mixing valve and return line DHW temperatures, and daily circulation pump runtimes.

Another major factor that impacts greatly on DHW consumption is the number of persons living in the building. As the data collection period took place over a year-long period, there was some changes in occupancy, as leases run out, and vacant

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[4] Records from George Birman (engineer and building owner) of measurements taken over a 5-year period; and logs from Phase 1 Project.

[5] 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.

apartments are filled. To compensate for this factor, building occupancies were tracked (using the managing agent's excellent record system), and adjustments calculated. Monthly vacancies compiled from Langsam's rent roll records were used to calculate the number of occupied apartments for all buildings during each scenario. Vacancy figures were used to eliminate DHW consumption variances due to differing occupancy levels, and to adjust the consumption of DHW per occupied apartment.

The total energy consumed by a DHW system with a recirculation return system is composed of two parts. Part 1 is the energy required to heat the cold make-up water to the chosen supply temperature. Part 2 is the energy required to maintain the recirculation system at an acceptable temperature. Varying Part 2 loads by altering the recirculation system control methodologies can effect Part 1 loads as well; thus, it was necessary to establish a complete energy balance to account for all energy consumed.

The following formula was used to calculate the energy balance:

$$BTU_{total} = [F_{dhw} \times (T_{sup} - T_{in}) \times 8.33] + [F_{recirc} \times (T_{sup} - T_{recirc}) \times 8.33]$$

Where:

BTU_{total} = total amount of energy consumed by the DHW system.
F_{dhw} = total flow of cold water added to the DHW system (gallons)
F_{recirc} = volume of water being recirculated (gallons)
T_{in} = temperature of the water entering the system.
T_{recirc} = temperature of the water in the recirculation return line.
$T_{sup.}$ = temperature of the water leaving the mixing valve.
8.33 = lbs/gal (of water)

The amount of energy used for each 5-minute monitoring interval was calculated. The intervals for each scenario (2-week period) were then totaled and averaged for a base 5-minute period to determine the energy required to produce the building's DHW for that scenario of the round. The difference between the calculated values (in BTUs, for each scenario) on the left side of the equation was used to compare the four different scenarios each round. This process was carried out for all of four (seasonal) rounds worth of data.

The results of these computations were then analyzed, including an adjustment for the varying occupancy levels. This was accomplished by compiling of the monthly records collated from the building management, and then adjusting the BTU consumption levels accordingly.

Following initial reviews of the computations, and system conditions (i.e. water temperatures) were completed, it became apparent that other factors were effecting the level of water use, and hence the test results. The most prominent of these was from variations in inlet (city) water temperatures. While the inlet water temperature changed only three to five degrees F from the beginning to end of rounds 1, 2, and 4, it dropped 10 degrees during the Round 3 (Fall) test period. (Figure 3 shows the weekly change in cold water temperatures. Data points represent an average/composite of the temperatures measured by the supers in all the sites.) It was necessary to eliminate the deviation and control for the external effect of what occupants were doing at the tap due to the difference in cold water temperatures. I.e., individuals prefer a particular temperature when washing their hands or taking a shower; and to achieve a desired

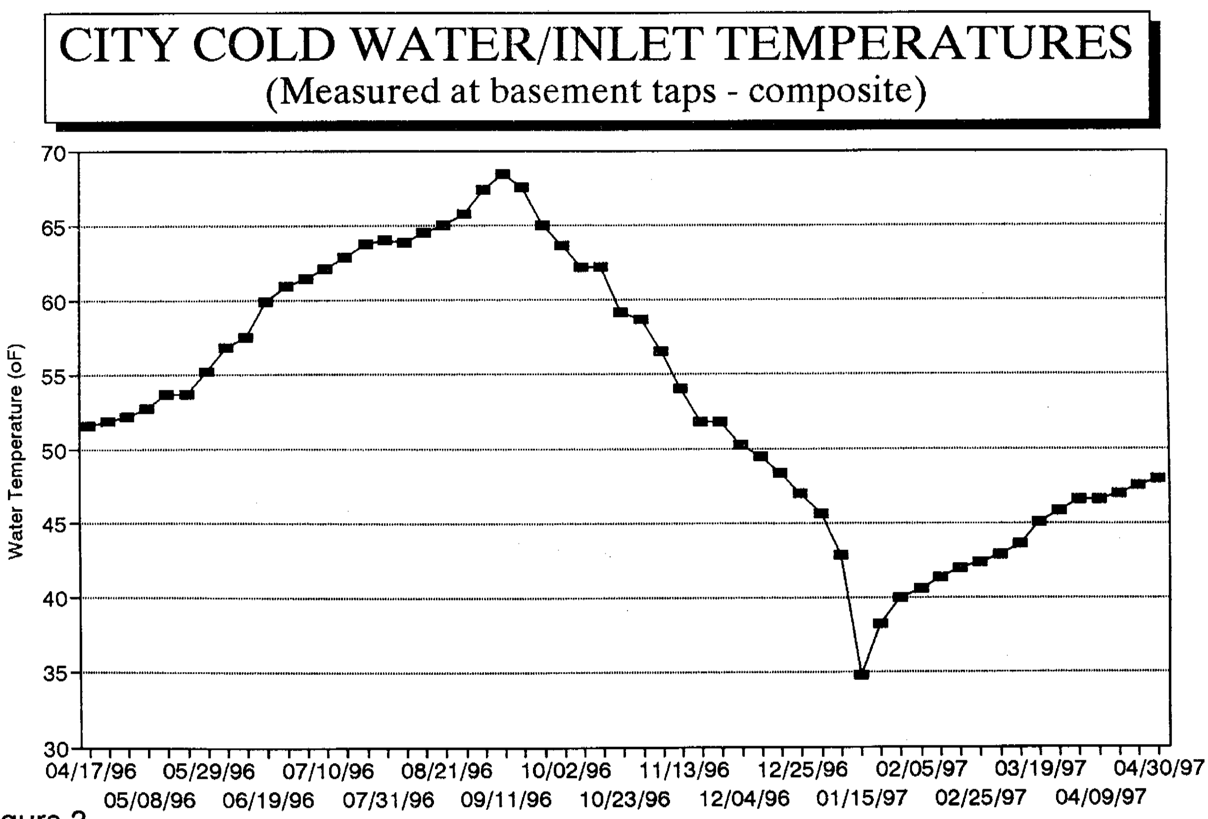

Figure 3

temperature at the tap, they use different hot and cold water mix percentages. (E.g., if you want 20 gallons of 90-degree water and the supply/hot water temperature is 120 degrees and cold water 60 degrees, you would use 10 gallons of each; if, at a different time, the cold water was now 50 degrees, you would use 11 1/2 gallons of the heated water and only 8 1/2 gallons of cold water to get the same mixed water result.) To account for occupant behavior due to variable inlet water temperatures, we employed the following adjustment to the volume of DHW flow in each period:

$$ADJ_{Factor} = 1 + ((AVG\ T_{in} - MEDIAN\ T_{in}) / (AVG\ T_{sup} - AVG\ T_{in}))$$

Where:

ADJ_{Factor} = inlet water temperature adjustment
AVG T_{in} = average inlet water temperature for a scenario (i.e. 2c)
MEDIAN T_{in} = median inlet water temperature for the entire round
AVG T_{sup} = average temperature of the water leaving the mixing valve
(AVG T_{sup} - AVG T_{in}) = temperature rise

This ADJ Factor was then calculated for each scenario for each building. It was then applied as follows, in each of the 5-minute BTU calculations:

$$BTU_{total} = [F_{dhw} \times ADJ_{Factor} \times (T_{sup} - T_{in}) \times 8.33] + [F_{recirc} \times (T_{sup} - T_{recirc}) \times 8.33]$$

The other significant factor which has an effect on the volume of DHW use is human behavior. Specifically, the use of different volumes of DHW in reaction to varying outdoor temperatures. Numerous studies have documented the increased use of DHW as outdoor temperature drops[6]. In our study the effects of this relationship became particularly apparent during the Fall test period. Unfortunately, we were not able to derive a simple mathematical adjustment factor to describe this complex relationship. A complicating factor, we believe, is that people are more cognizant of, and react

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[6] Goldner, F.S. Nov. 1994, and

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.

(Note: the Thrasher and DeWerth study, in the original data analysis, summarizes the findings of six other researchers.

differently to a 5-degree drop from, say, 55 to 50 degrees in the Fall than to the same 5-degree drop from 35 to 30 degree temperature change during the middle of Winter. To correct for this behavioral variance we employed the use of an additional 2-week base case (Scenario a) test period at the end of each round. This second/additional Scenario a was then averaged together with the original Scenario a data for each round. This procedure normalized for time periods at both extremes of conditions during a given seasonal round. It was possible to use this procedure for all but Round 2 (Summer), as in the month between the end of Round 2 and beginning of Round 3 (Fall) a different set of tests was run to evaluate the energy use effects of varying aquatint control settings.

After completing the inlet water temperature adjustment procedure, all the energy consumption analyses were then rerun for each round and set of data points. The resultant figures for each scenario in each round were then compared against the base case to compute the changes (savings) attributable to the control strategy. Next, these numbers were annualized by taking the average BTU and DHW consumption per 5-minute period and multiplying it by the number of 5-minute periods in a year. The results from each scenario across all four rounds were converted into a calendar year savings by computing a value of 2 1/2 months each relative usage for the Spring and Fall periods (Rounds 1 and 3), and 3 1/2 months each relative usage for the Summer and Winter periods (Rounds 2 and 4).

Building 10 Issues

In the course of analyzing the data it became apparent that a number of problems were occurring in the Building 10 that were unrelated to the project but were nonetheless affecting parts of the building system the project was attempting to study. This, unfortunately, negated the ability to properly evaluate the effect of the control changes at this site. First, sometime towards the end of Round 1, the building super went on disability, while still keeping his apartment; thus hampering the manager's ability to refill this position. This affected maintenance and systems upkeep (in a problematic, but generally well run site). As the data indicated, sometime between the building selection process and Round 1, leaks which had been repaired in prior years began to reappear. A detailed review of the 5-minute and daily data (at the time of analysis) revealed that Building 10 had developed severe leaks that became increasingly greater over the course of the project. At times the leaks, measured by the daily minimum hourly consumption (which in most buildings is zero at some overnight time period), was as high as 150 to 200 gph. More thorough review showed that in three of the four rounds the leakage was greater in the scenario d period than in the scenario a period.

Due to the leaks, the DHW flow portion of the energy use at this site represents a greater percentage of the DHW energy load (as compared to the recirculation flow) than in the other buildings, or what should have been in this building in the absence of the severe leaks. We can also see the impact of the leakage in the extremely high pump runtimes during the various scenario d runs. Due to the effect of these problems on the building's operation and DHW consumption, a decision was made to discount the affected data in many of the following analyses. We did, however, leave the original data in this report to illustrate that, regardless of all else it is still necessary to do building housekeeping (maintenance), and issues such as extremely large leaks can undermine all other efforts.

MONITORING EQUIPMENT

Data from the monitoring equipment was collected by means of the Heat Computer. This is accomplished by having the Heat Computer "talk to" or read the various sensors and meters on a cycle that repeats every 20 milliseconds (ms). The devices were essentially read continuously (for building operations purposes), and the data stored at set points in time (i.e., every hour on the hour for apartment and DHW temperature measurements, and every five minutes for DHW flows and temperatures). 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 is installed on the cold water branch from city water before (upstream of) the boiler coil, mixing valve, and re-entry of the recirculation loop. Meter selection was based on pipe diameter and flow rates. The meter capacities were chosen based on expected flow ranges derived from ASHRAE and other sources and then adding a safety factor to handle water flows over or under the projected rates.

All buildings have 2-inch DHW flow meters installed, except for Building #31 which employs a 1 1/2-inch meter. Installed models were rated for a maximum temperature of 250 ^{o}F and a maximum pressure of 250 PSI. The fluid flow range spans from 0.7 to 87.2 GPM for the 1 1/2-inch meter, and 0.88 to 131.6 GPM for the 2-inch meters. These ranges more than adequately covered the flows that have been experienced. The degree of error for each of the flow meters is +/- 1 1/2 percent.

DATA COLLECTION

The building's Heat Computer collected data in the specified intervals from the sensors and meters. Via modem, EMRA called each building every third day and downloaded the data. The data was then put through a custom-designed FORTRAN data translation program which rearranged it to an Rbase (database) readable format and performed a number of preliminary calculations. The data was then loaded into a specially designed database where macros performed a second level of calculations. The Rbase environment was then used to perform specific analyses and output smaller data sets to a Quattro Pro spreadsheet for graphical analyses and presentations.

To assure data reliability, the downloaded data was reviewed at least once a week to check that all systems were operating within expected parameters.

TENANT WATER QUALITY SURVEYS

Tenant Questionnaires were developed to assess the change in user response to DHW delivery service between the four different recirculation control strategies. The level of user satisfaction was evaluated by use of the tenant questionnaires and interviews with building supers. A sample questionnaire is provided in Table 2 (p. 2-9). The form was designed to gauge the perceived level of DHW delivery quality during the "past two weeks," or particular scenario. The questionnaire was also provided in Spanish for use in the two buildings with a significant number of Spanish only speaking tenants (over 10-15%). For these buildings the questionnaires were produced as a back to back (1 side English & 1 side Spanish) form. The tenant surveys were conducted four times. The first was administered after Scenario 1a, Round 1. This survey served both as an evaluation of Strategy A and also as a "control" for the general level of complaints. To avoid potential Hawthorne effects the questionnaires were spaced out, so that the

Sample Tenant Water Quality Questionnaire

ENERGY MANAGEMENT & RESEARCH ASSOCIATES

49 Murdock Court, Suite 6J, Brooklyn, New York 11223 (718) 332-2926

TENANT QUESTIONNAIRE

For: 2900 St Theresa Avenue

July 24, 1996

Dear Tenant:

We have continued to do work to improve the hot water system in a number of sites including your building. In order so that we (Energy Management & Research Associates in conjunction with **Langsam Property Services**) may improve similar systems in this and other buildings, we are asking that you please take a moment to fill out this brief questionnaire, and return it in the postage-paid envelope enclosed. All responses shall be kept confidential.

Please limit your responses to all numbered questions to the conditions during the past 2 week period only. Issues on hot water quality prior to that point may be marked in the comment section at the bottom of the page.

Thank you for your assistance in this matter.

Date: ______________

1) How has the hot water service been **during the past 2 weeks**?

___ Excellent
___ Very Good
___ Good
___ Fair
___ Poor
___ Unacceptable

2) When you turn on the hot water tap **during the past 2 weeks** the water is?

___ Always hot
___ Sometimes hot, sometimes I must wait a minute to get hot water
___ Sometimes hot, sometimes I must wait a *few* minutes to get hot water
___ I always must wait a few minutes to get hot water
___ Never hot

3) Have your usage habits changed during the past 2 weeks?

___ No ___ Yes (how? ________________________________)

4) Other Comments: (optional)

____

____

Table 2

second survey conducted at the end of Scenario 2a - Round 2. Subsequent surveys were similarly spaced[7]. To help ensure cooperation of the supers in the distribution of the questionnaires, a small stipend (of $25) was given to them each round. Each super was then supplied with one questionnaire and one stamped return envelope for each apartment. These were distributed under each apartment door on the last day of the scenario period.

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[7] Briefly, the Hawthorne Effect describes the phenomenon in which participants in an experiment will change their behavior in accordance to what they think the researcher is looking for as an expected response. For the purposes of this research our mere presence, in the form of the questionnaires, could have caused the occupants to think about the hot water system and potentially change their behavior; the occupants were not aware of what specifically we were doing or looking for. By spacing the surveys out for a period of at least 10 weeks between each, the occupants tend to forget about our presence and go about their normal routines.

Section 3
DATA ANALYSES

Data analyses for this report include all monitoring data for rounds 1 through 4. The data totals approximately 5 million data points in the various tables. In addition, all the water quality survey responses (for all four control strategies) have been compiled and evaluated.

TENANT SATISFACTION

The overall questionnaire response rate of 45% for Round 1 was greater then expected, with 187 forms being returned out of 412 distributed. The response rate from tenant questionnaires stayed relatively high, with 37%, 40% and 40% being returned for Round's 2, 3 and 4, respectively.

A small percentage of the responses came back much later than distributed. It was felt that these should be discounted as they may have reflected conditions during one of the other operating strategies. It was decided that any forms postmarked more than two weeks after distribution would be excluded from the analysis. The number of responses eliminated from the analysis based on this criteria was 9, 16, 7, and 14 for questionnaires 1, 2, 3, and 4, respectively.

Results from the Tenant Water Quality Survey Questionnaires showed that there was always an acceptable level of satisfaction, regardless of how the system was being controlled. As can be seen in Figure 4 (p. 3-2), on average for all sites the tenants rated the "hot water service" during test periods for Strategies A, B, and D as between "Good" and "Very Good." For Strategy C (off during peaks) the rating was between "Fair" and "Good." Figure 5 (p. 3-2) illustrates summary responses for all buildings to question #2 (Q2) for each of the control strategies. As shown in the figure, the level of water delivery did not vary much between control strategies, except in the case of Strategy C. Examining the responses for Strategy C, the percentage of respondents who must wait for hot water to come from the taps increases as we go progressively across the graph categories from left to right. Those who must "always wait" is greater for this control strategy than any other. These results seem to validate the questionnaire methodology, in that it is Strategy C in which the tenants would most

TENANT WATER QUALITY SURVEY
Comparison of Control Strategies

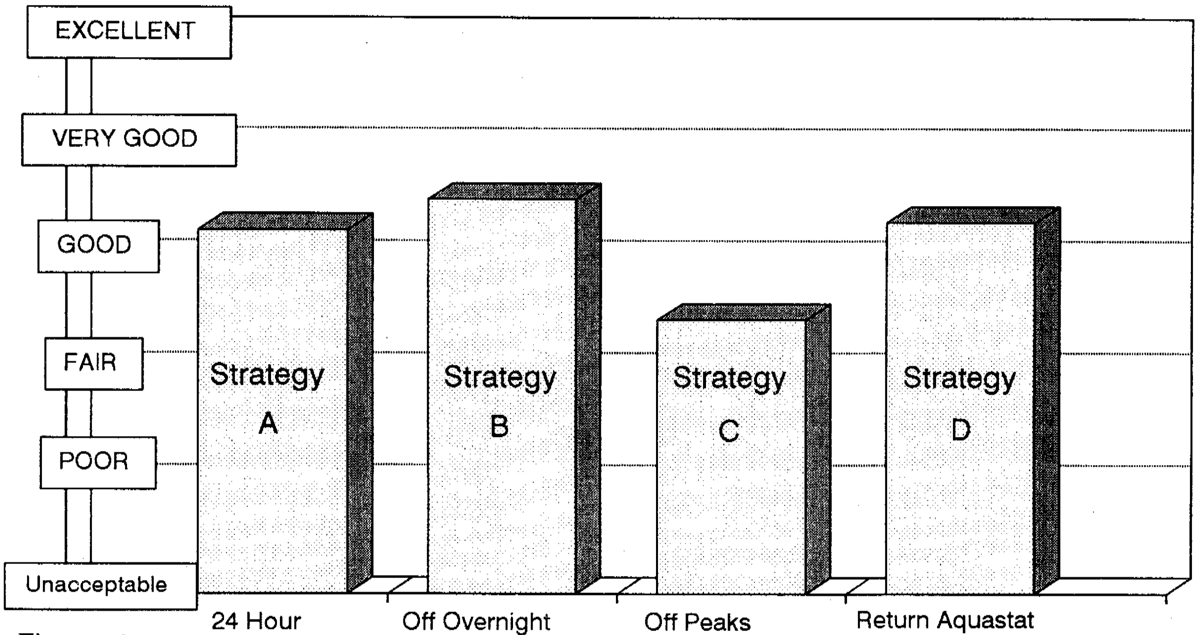

Figure 4

TENANT WATER QUALITY SURVEY
Comparison of Control Strategies (Q2)

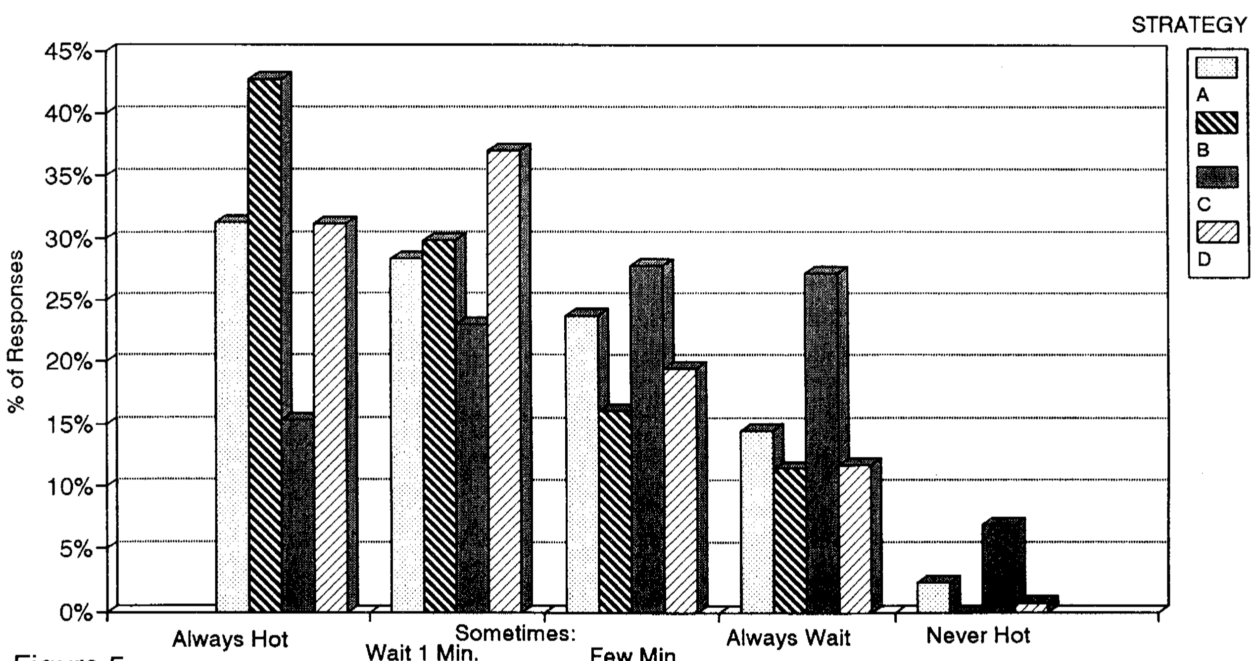

Figure 5

likely see a difference (as the pumps were shut down during the morning and evening peaks when most people were using water), and the responses reflect this.

Figures 6 through 10 (p. 3-3 to 3-5) break out the responses to question #1 on a building-by-building basis. It is important to recognize that each individual water user probably has his or her own reference value for good or excellent. (Note that, in Figures 6 through 10, building # 33 is the second wing of building # 30, and building # 32 is the second wing of building # 31.) The individual building results do not vary notably from the preceding summary results. To further check the results, additional breakdowns were done. Figures 11 and 12 (p. 3-6) break down the response by answer to question #1 for Strategies A and D (pump on 24 hours and return line aquatint), respectively. The majority of tenants considered both of these control operations about equal, as most of the respondents classified the quality as either very good or good.

Another, possibly more significant, less objective, measurement of the quality of hot water delivery service is broached through question #2. This question asked the tenant to report on how often and/or how long it takes for hot water to come out of the tap. Figures 13 and 14 (p. 3-7) illustrate the responses to this question on a building-by-

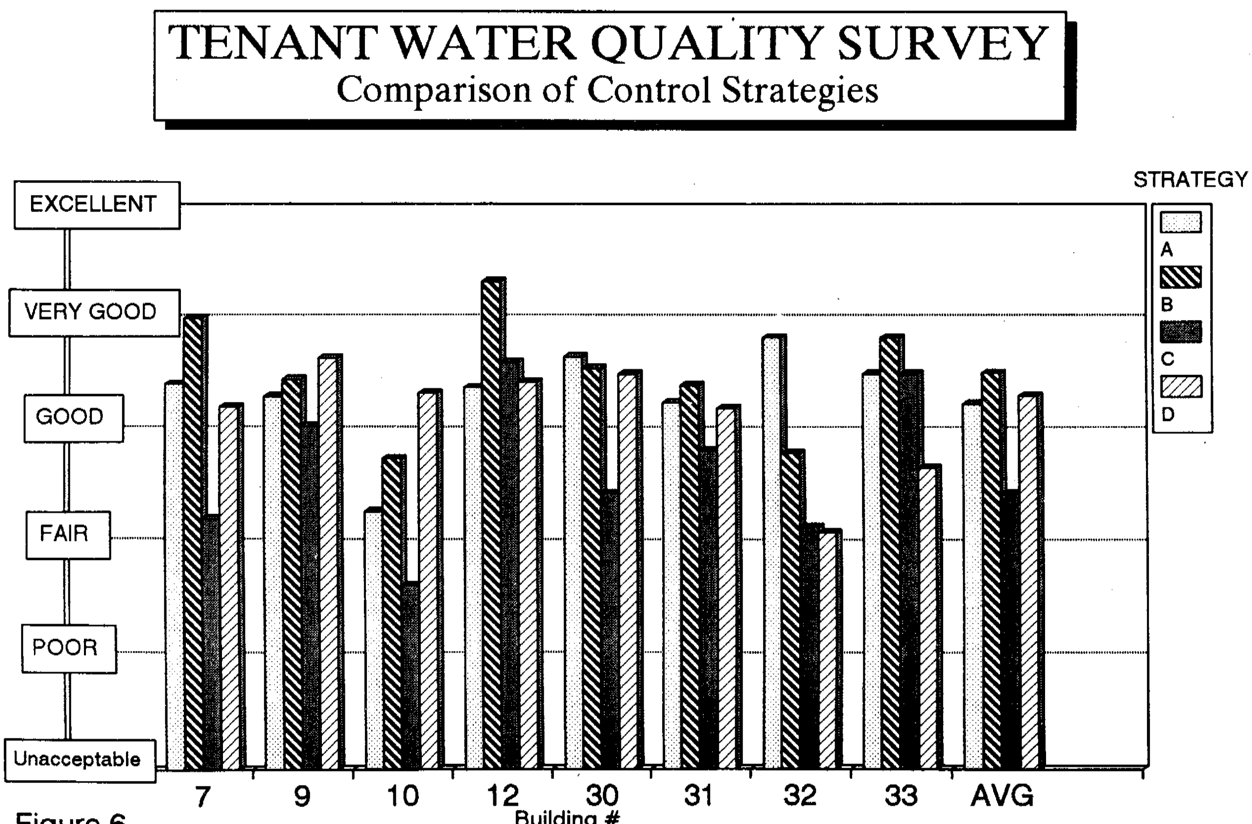

Figure 6

TENANT WATER QUALITY SURVEY
STRATEGY A - PUMP ON 24 HOURS

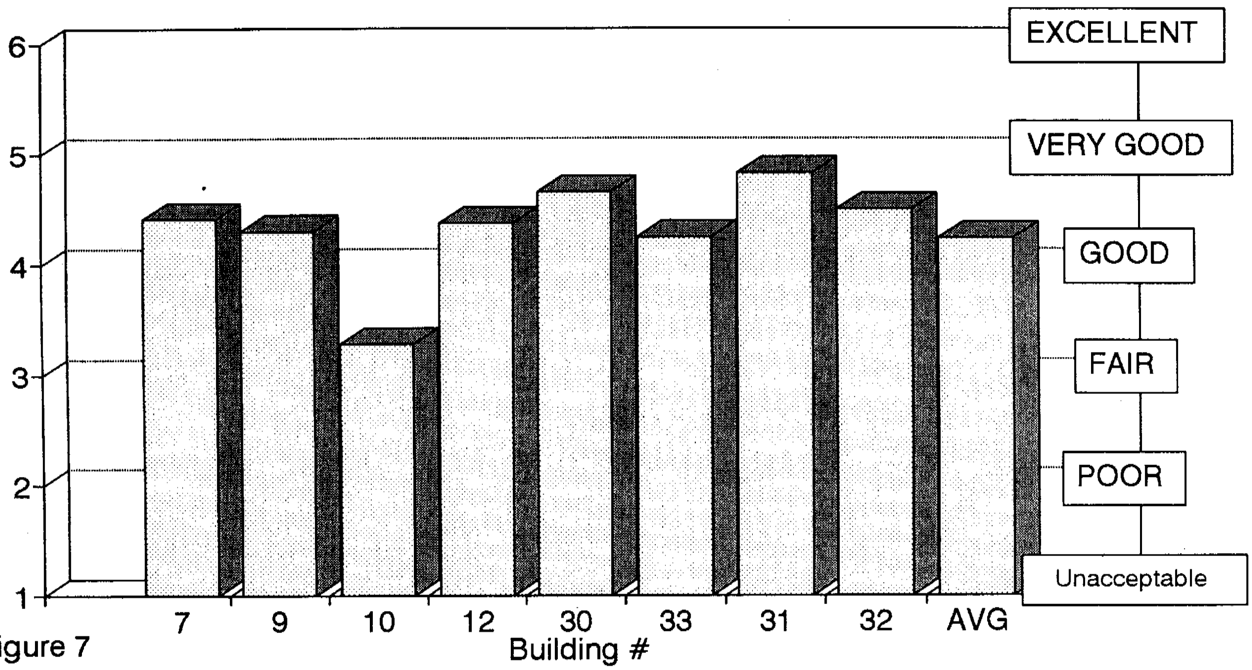

Figure 7

TENANT WATER QUALITY SURVEY
STRATEGY B - PUMP OFF OVERNIGHT

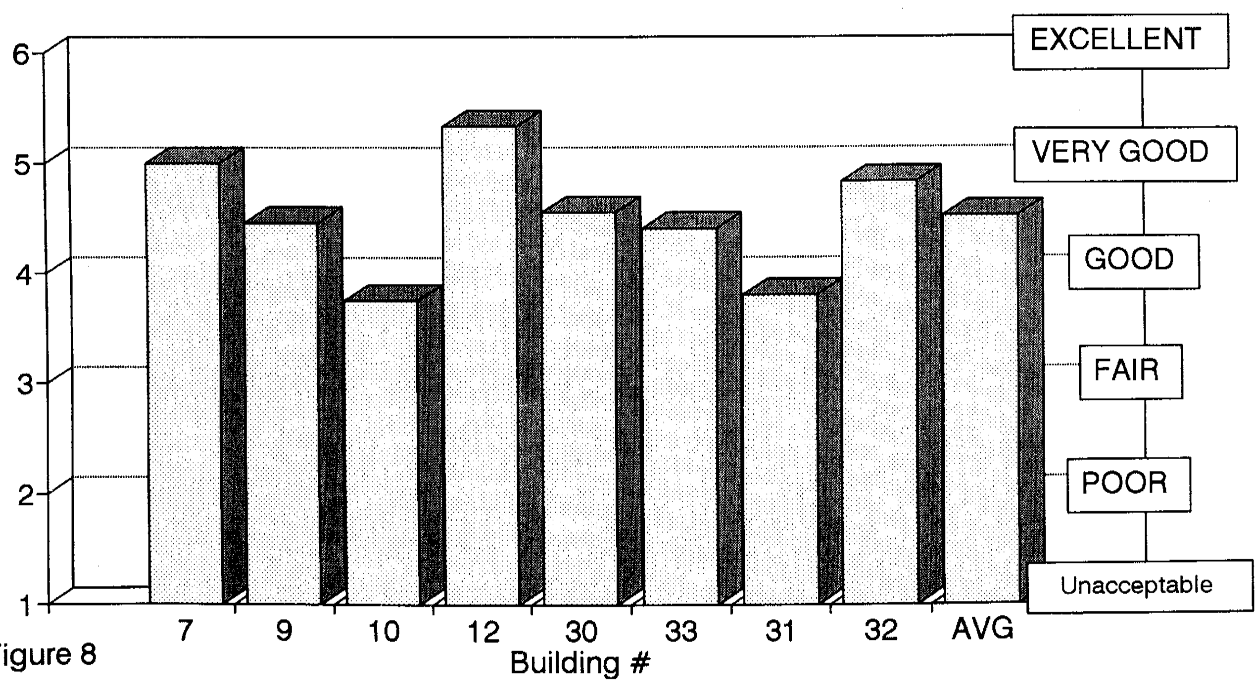

Figure 8

TENANT WATER QUALITY SURVEY
STRATEGY C - PUMP OFF PEAK TIMES

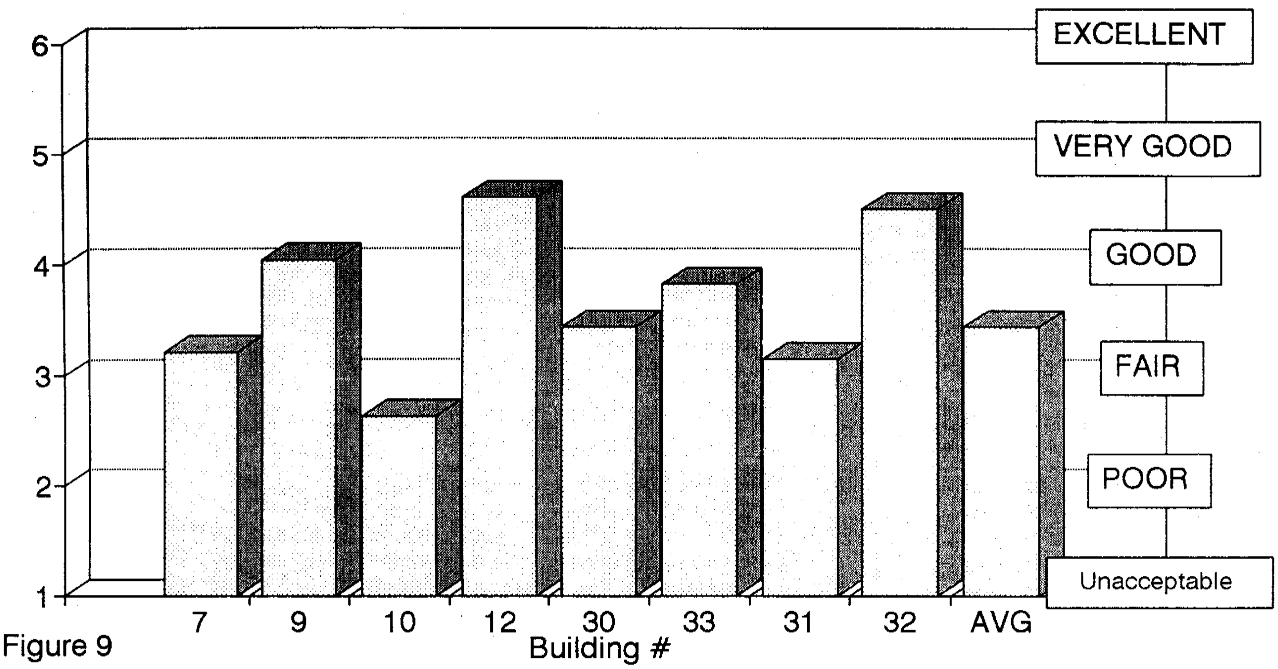

Figure 9

TENANT WATER QUALITY SURVEY
STRATEGY D - RETURN LINE AQUASTAT

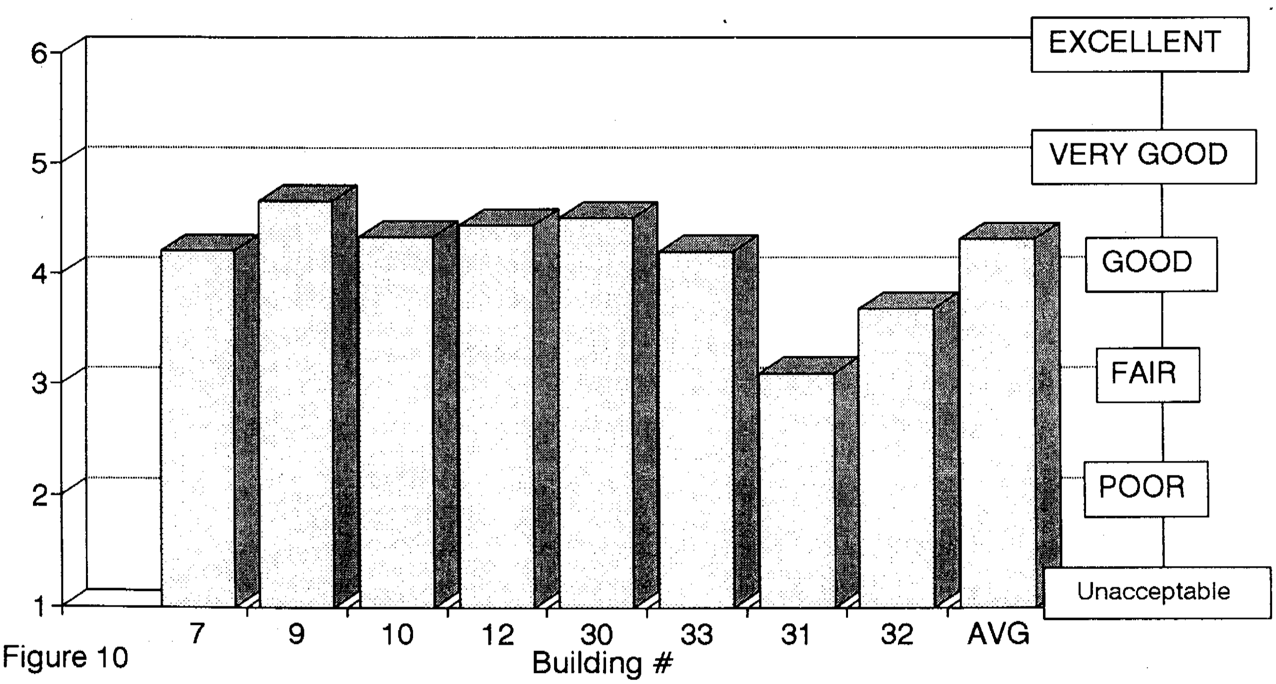

Figure 10

TENANT WATER QUALITY SURVEY
Pump on 24 Hours (All Sites - Q1)

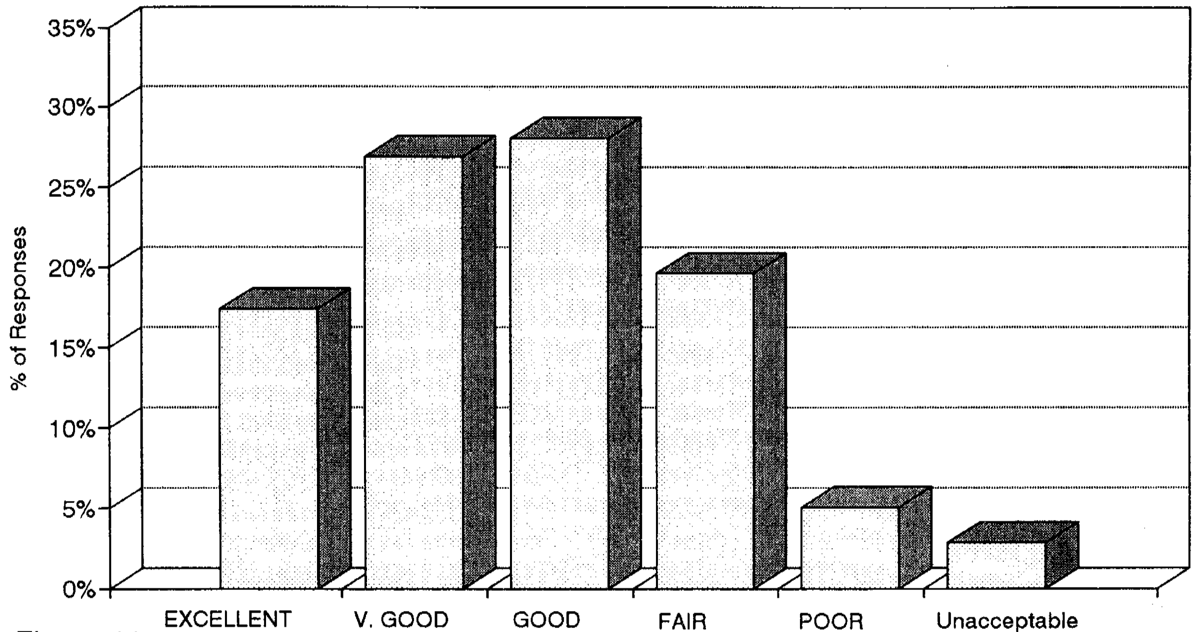

Figure 11

TENANT WATER QUALITY SURVEY
Return Line Aquastat (All Sites - Q1)

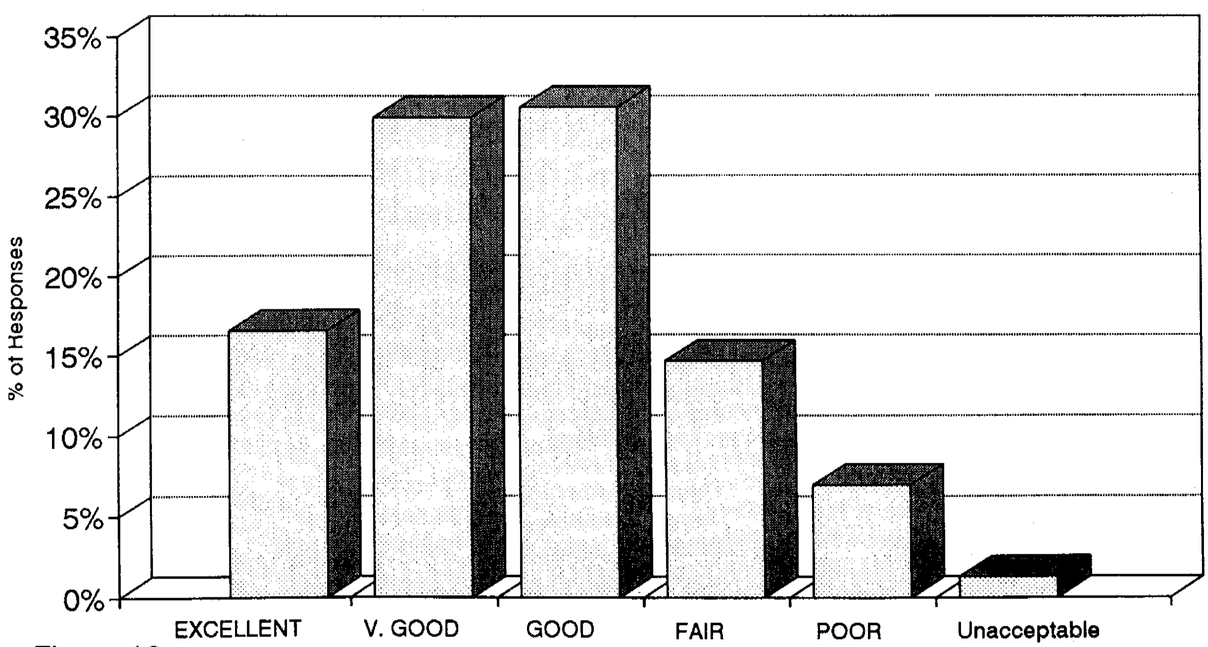

Figure 12

TENANT WATER QUALITY SURVEY

STRATEGY A - PUMP ON 24 HOURS (Q2)

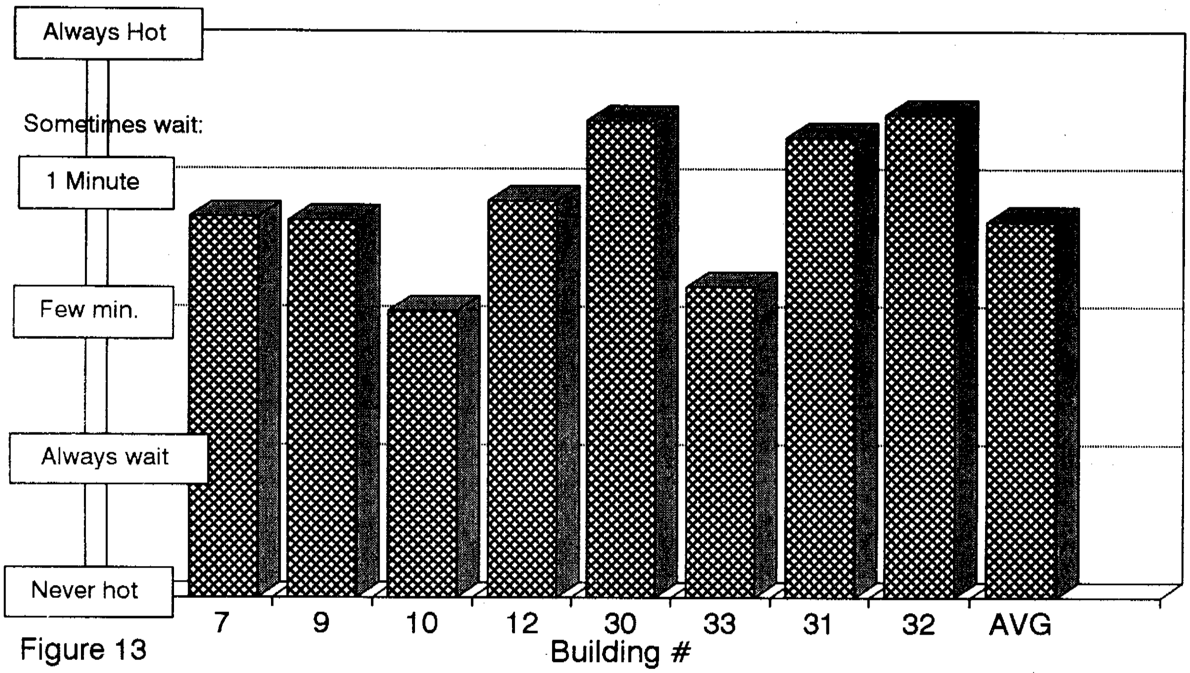

Figure 13

TENANT WATER QUALITY SURVEY

STRATEGY D - RETURN LINE AQUASTAT (Q2)

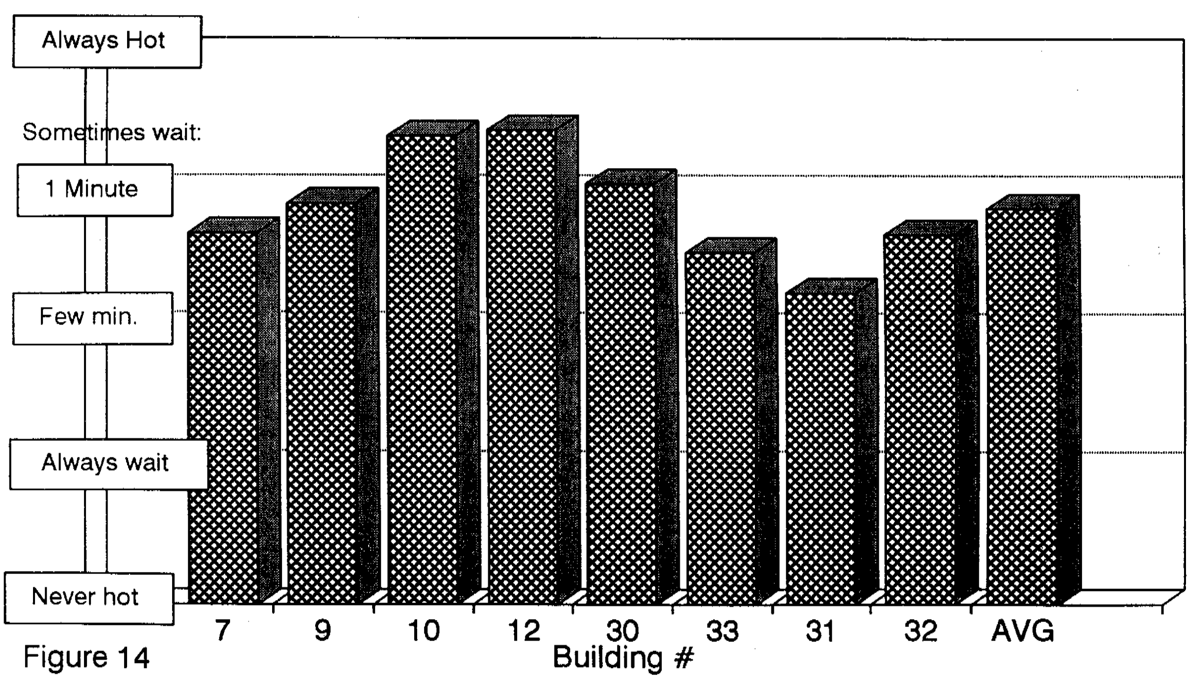

Figure 14

building basis. Even in those cases where tenants in a building called the water quality less than "good," they stated that they only sometimes have to wait between one and a few minutes for hot water to reach the tap. These responses are broken down in more detail, by answer type, in Figures 15 and 16 (p. 3-9).

In addition to the tenant surveys, supers were also questioned by EMRA field staff during the bi-weekly control change site visits as to any complaints regarding the DHW service. No change was noted by any of the supers throughout the testing period. From the results of these Tenant Water Quality Survey Questionnaires, it appears that we can expect an acceptable level of satisfaction regardless of how the system is controlled, for all control strategies except for Strategy C.

ENERGY USE

Table 3 (p. 3-10) shows the raw (BTU) and relative energy use for each of the strategies during Rounds 1 (Spring) and 2 (Summer) and Table 4 (p. 3-11) shows this data for Rounds 3 (Fall) and 4 (Winter). Figure 17 (p. 3-12) illustrates combined results from Rounds 1 through 4 seasonally annualized. Compared to the base case, (Strategy A - pump running 24 hours per day), Strategy B saved 5.5%, Strategy C saved 5.5%, and Strategy D saved 10.8%. These are significant savings, as the level of savings from Strategy D is equal to a savings of approximately 4% of a typical building's total annual fuel consumption. Breaking the numbers down (Table 5, p. 3-13), we see that one building saved 21%, three buildings saved between 8 and 11%, one saved 3%, and one site (Building 10, which had extenuating circumstances due to the previously explained unrelated problems) had an increase of 2%.

Converting the BTUs saved into an equivalent amount of gallons of #6 fuel oil (used by a majority of these sites), and assuming a cost of $0.60 per gallon, the resultant annual average savings ranged from $371 to $763 for the various strategies. This is as compared to an installed cost of about $200 or less for any of the strategy's controls.

In addition to the fuel savings there is an electrical energy savings from the reduced run hours on the pumps. This shall be discussed later in the report.

A larger percentage of the fuel savings was achieved in the Summer and Spring periods. This likely has to do with a combination of different factors, including

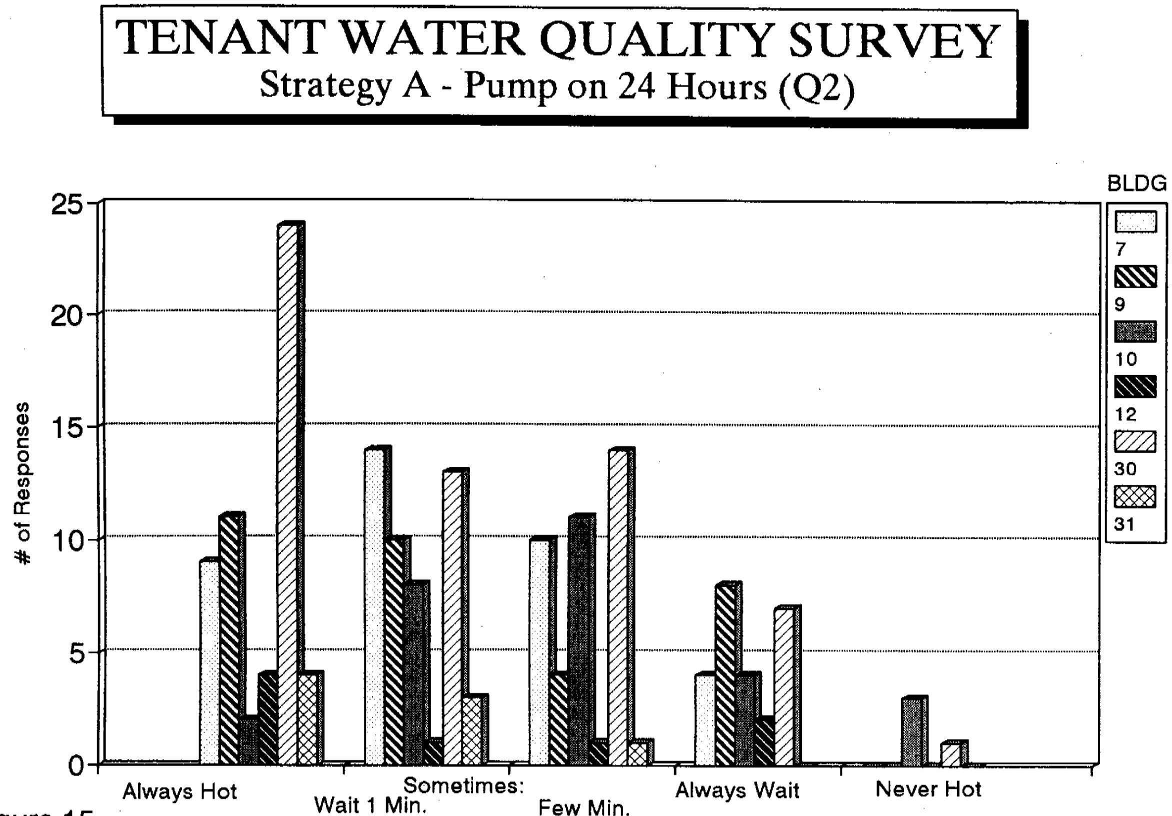

Figure 15

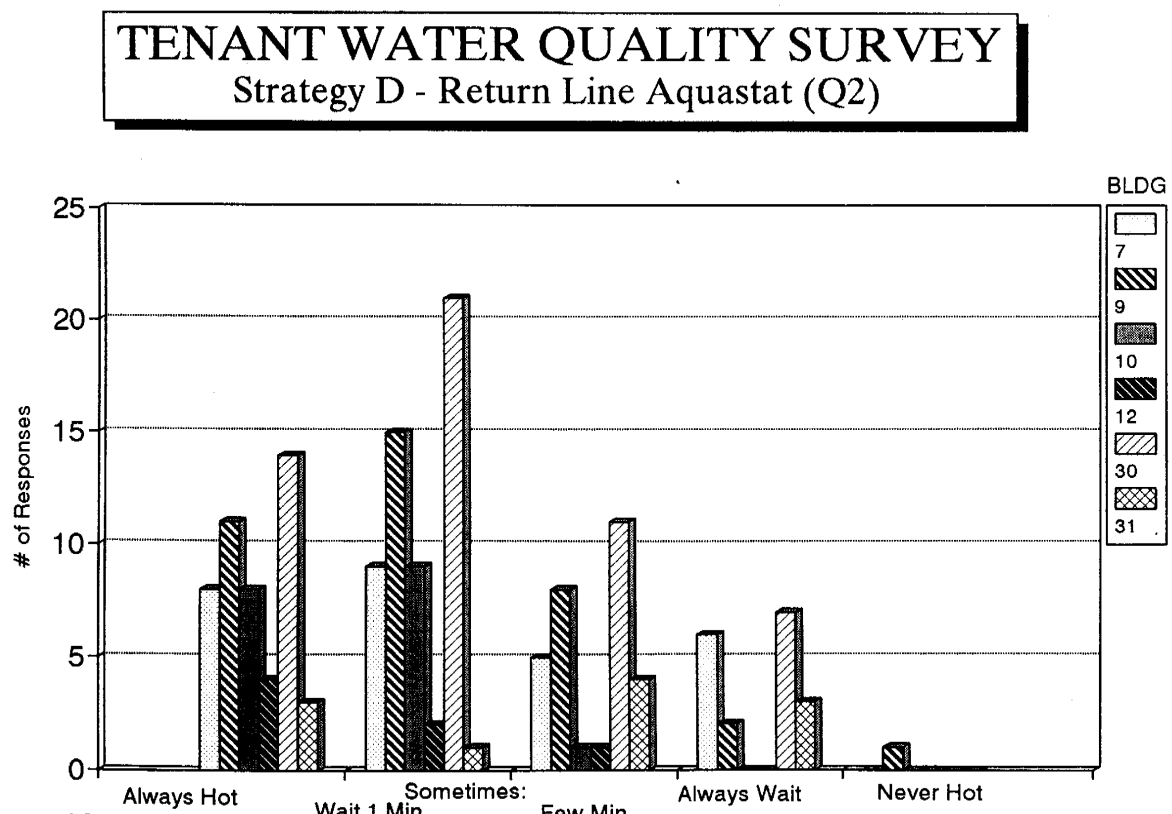

Figure 16

Table 3: ANALYSIS OF ROUND 1 AND 2 BTU DATA

Raw Data -- Avg BTU/5 minutes

Bldg\Roun	1a	1b	1c	1d	2a	2b	2c	2d
7	16,208	16,809	16,645	14,967	13,181	12,151	12,210	10,924
9	19,532	16,010	16,157	16,084	18,582	14,923	14,128	12,320
10	24,078	24,535	24,538	24,767	21,022	20,268	22,257	21,837
12	7,784	8,096	7,459	6,680	6,568	5,935	6,095	5,240
30	20,381	19,722	20,066	17,052	18,471	16,797	14,838	14,454
31	16,143	16,904	15,978	14,446	14,181	13,124	12,716	13,047
Avg	17,354	17,013	16,807	15,666	15,334	13,866	13,707	12,970

% of Energy Used vs Base Case

Bldg	1a	1b	1c	1d	2a	2b	2c	2d
7	100.0%	103.7%	102.7%	92.3%	100.0%	92.2%	92.6%	82.9%
9	100.0%	82.0%	82.7%	82.3%	100.0%	80.3%	76.0%	66.3%
10	100.0%	101.9%	101.9%	102.9%	100.0%	96.4%	105.9%	103.9%
12	100.0%	104.0%	95.8%	85.8%	100.0%	90.4%	92.8%	79.8%
30	100.0%	96.8%	98.5%	83.7%	100.0%	90.9%	80.3%	78.3%
31	100.0%	104.7%	99.0%	89.5%	100.0%	92.6%	89.7%	92.0%
Avg	100%	99%	97%	89%	100%	90%	90%	84%

Equiv. Gals # 6 Oil / Year

Bldg	1a	1b	1c	1d	2a	2b	2c	2d
7	11,382	11,804	11,689	10,510	9,256	8,533	8,575	7,672
9	13,716	11,243	11,346	11,295	13,049	10,479	9,922	8,652
10	16,909	17,230	17,232	17,392	14,762	14,233	15,630	15,335
12	5,466	5,686	5,238	4,691	4,612	4,168	4,280	3,680
30	14,312	13,850	14,091	11,975	12,971	11,795	10,420	10,151
31	11,337	11,871	11,221	10,145	9,958	9,217	8,930	9,162
Avg	12,187	11,947	11,803	11,001	10,768	9,738	9,626	9,108

Cost Savings per Year - (figuring # 6 Oil @ $.60/gal)

Bldg								
7	$0	($253)	($184)	$523	$0	$434	$409	$951
9	$0	$1,484	$1,422	$1,453	$0	$1,542	$1,877	$2,638
10	$0	($193)	($194)	($290)	$0	$318	($521)	($343)
12	$0	($132)	$137	$465	$0	$267	$199	$560
30	$0	$277	$133	$1,402	$0	$705	$1,531	$1,692
31	$0	($320)	$70	$715	$0	$445	$617	$477
Avg		$223	$313	$749		$655	$741	$1,005

Table 4: ANALYSIS OF ROUND 3 AND 4 BTU DATA

Raw Data -- Avg BTU/5 minutes

Bldg\Roun	3a	3b	3c	3d	4a	4b	4c	4d
7	15,878	13,696	14,695	14,919	19,595	18,758	20,409	19,354
9	20,212	17,080	17,878	17,579	22,999	23,684	23,114	19,088
10	27,402	25,629	28,027	28,173	36,834	35,568	34,960	36,820
12	7,192	6,776	7,148	6,626	8,143	7,741	7,843	8,113
30	23,256	22,079	23,133	22,916	27,073	27,651	26,448	25,851
31	16,908	14,951	15,908	16,119	21,934	23,462	23,865	23,894
Avg	18,475	16,702	17,798	17,722	22,763	22,811	22,773	22,187

% of Energy Used vs Base Case

	3a	3b	3c	3d	4a	4b	4c	4d
7	100.0%	86.3%	92.5%	94.0%	100.0%	95.7%	104.2%	98.8%
9	100.0%	84.5%	88.5%	87.0%	100.0%	103.0%	100.5%	83.0%
10	100.0%	93.5%	102.3%	102.8%	100.0%	96.6%	94.9%	100.0%
12	100.0%	94.2%	99.4%	92.1%	100.0%	95.1%	96.3%	99.6%
30	100.0%	94.9%	99.5%	98.5%	100.0%	102.1%	97.7%	95.5%
31	100.0%	88.4%	94.1%	95.3%	100.0%	107.0%	108.8%	108.9%
Avg	100%	90%	96%	95%	100%	100%	100%	98%

Equiv. Gals # 6 Oil / Year

Bldg	3a	3b	3c	3d	4a	4b	4c	4d
7	11,151	9,618	10,319	10,477	13,760	13,173	14,332	13,592
9	14,194	11,995	12,555	12,345	16,151	16,632	16,232	13,404
10	19,243	17,998	19,682	19,785	25,867	24,978	24,551	25,857
12	5,050	4,758	5,019	4,653	5,719	5,436	5,508	5,698
30	16,332	15,505	16,245	16,093	19,012	19,418	18,573	18,154
31	11,874	10,499	11,171	11,319	15,403	16,476	16,759	16,779
Avg	12,974	11,729	12,499	12,445	15,985	16,019	15,993	15,581

Cost Savings per Year - (figuring # 6 Oil @ $.60/gal)

Bldg								
7	$0	$919	$499	$404	$0	$353	($343)	$101
9	$0	$1,319	$983	$1,109	$0	($289)	($49)	$1,648
10	$0	$747	($263)	($325)	$0	$533	$789	$6
12	$0	$175	$19	$238	$0	$170	$126	$13
30	$0	$496	$52	$143	$0	($244)	$263	$515
31	$0	$825	$421	$333	$0	($644)	($814)	($826)
Avg		$712	$242	$300		($95)	$63	$271

DHW Recirculation Control Strategies

% of Energy Used vs Base Case (Full Yr)

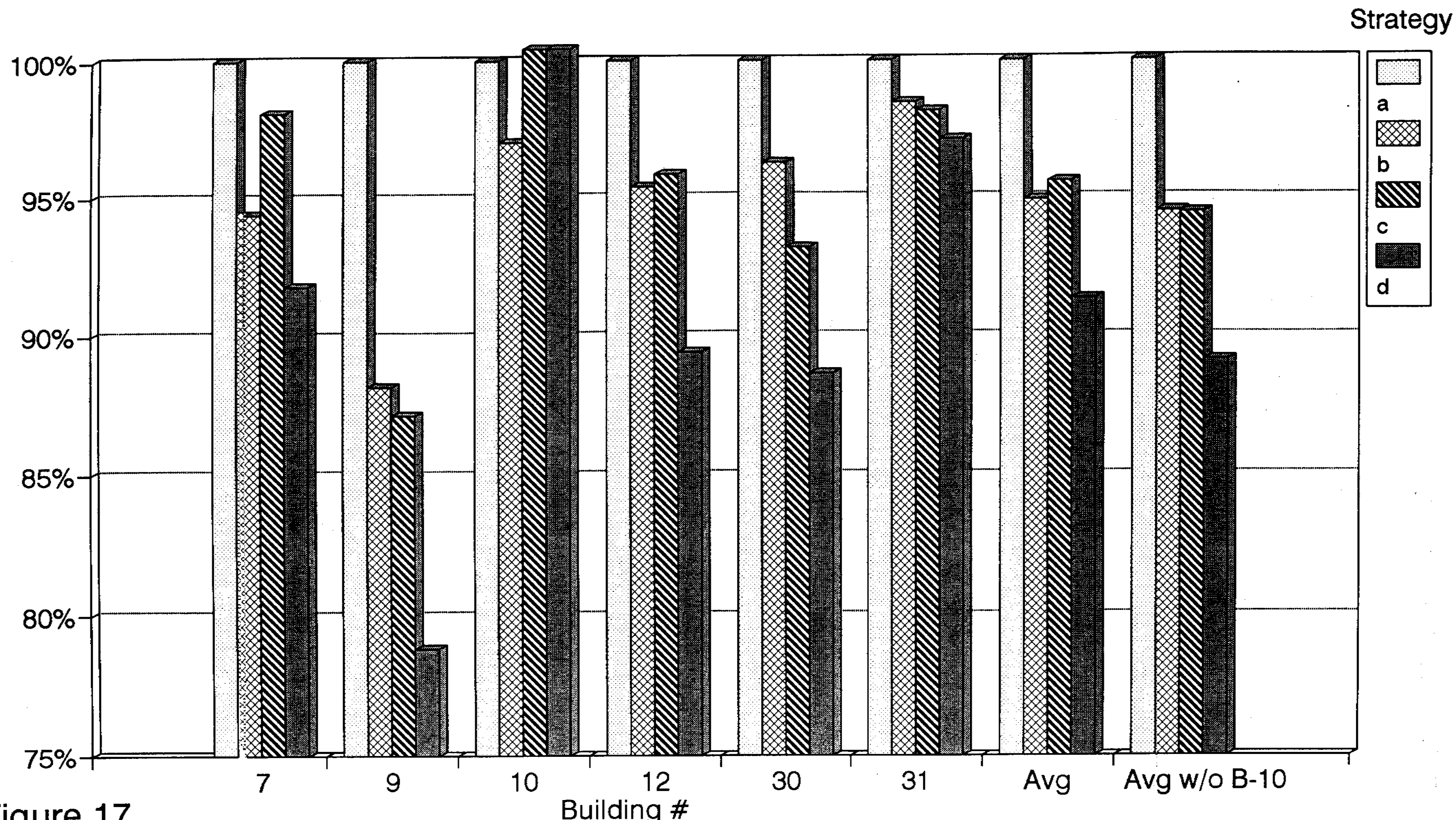

Figure 17

Table 5

% OF ENERGY USE & SAVINGS vs BASE CASE - YEAR ROUND

% of Energy Used vs Base Case - Year Round				
\Scenario	a	b	c	d
7	100.0%	94.4%	98.1%	91.8%
9	100.0%	88.1%	87.2%	78.8%
10	100.0%	97.0%	101.1%	102.3%
12	100.0%	95.4%	95.8%	89.4%
30	100.0%	96.3%	93.2%	88.6%
31	100.0%	98.4%	98.1%	97.1%
Avg	100.0%	94.9%	95.6%	91.3%
Avg w/o Bldg 10		94.5%	94.5%	89.2%

Cost Savings per Year - (figuring # 6 Oil @ $.60/gal)					
\Scenario	a	b	c	d	
7	$0	$368	$85	$500	
9	$0	$950	$1,034	$1,784	
10	$0	$438	($20)	($273)	(#4 Oil @ $.70)
12	$0	$196	$183	$451	(#2 Oil @ $.80)
30	$0	$296	$562	$966	
31	$0	$47	$45	$117	
Avg	$0	$382	$315	$591	
Avg w/o Bldg 10		$371	$382	$763	

consumption levels and losses in the piping system due to outdoor temperatures. In certain cases other factors also contributed to reduced savings at certain times. For example in Building 30 the savings during rounds 3 and 4 appear to have been reduced due to very high supply water temperatures, which was likely a result of an improperly operating mixing valve. Similarly, in Building 9 during Scenario 1d, the aquatint setting was not adjusted properly (it was set close to 120° F) resulting in the pump circulating considerably more water than necessary.

Figures 18 and 19 (p. 3-15) illustrate that the amount of energy expended to heat the recirculated DHW was 38% percent of the total energy used by to supply DHW during normal operations (base case Strategy A). The objective of this project was to find an effective and practical method of reducing this consumption level. The research results show that the energy spent on the recirculation loop was cut to an average of 31% of the DHW system total by Strategy B, to 34% with Strategy C, and down to 23% while employing Strategy D.

CALCULATED PHYSICS vs. BUILDING REALITY

As a reality check on the calculations, the computed gallons of fuel for DHW production were compared to fuel delivery records for the year in which the research took place. The energy audit community has established that DHW is responsible for between 25% and 50% of a multi family building's fuel consumption. The actual percentage is largely dependent on the demographic characteristics of occupants in a particular building. When lacking specific knowledge about the site, the industry standard has been to assume that one third of the fuel consumption is attributable to DHW production. Table 6 (p. 3-16) shows the results of the comparison. Under normal, base case, operation the study sites used between 28% and 48% of their annual fuel consumption to provide DHW, with an average of 37%. Comparing this range to the known demographics of the sites on a building by building

Energy For Recirculated DHW as a % of the Total DHW Energy Load

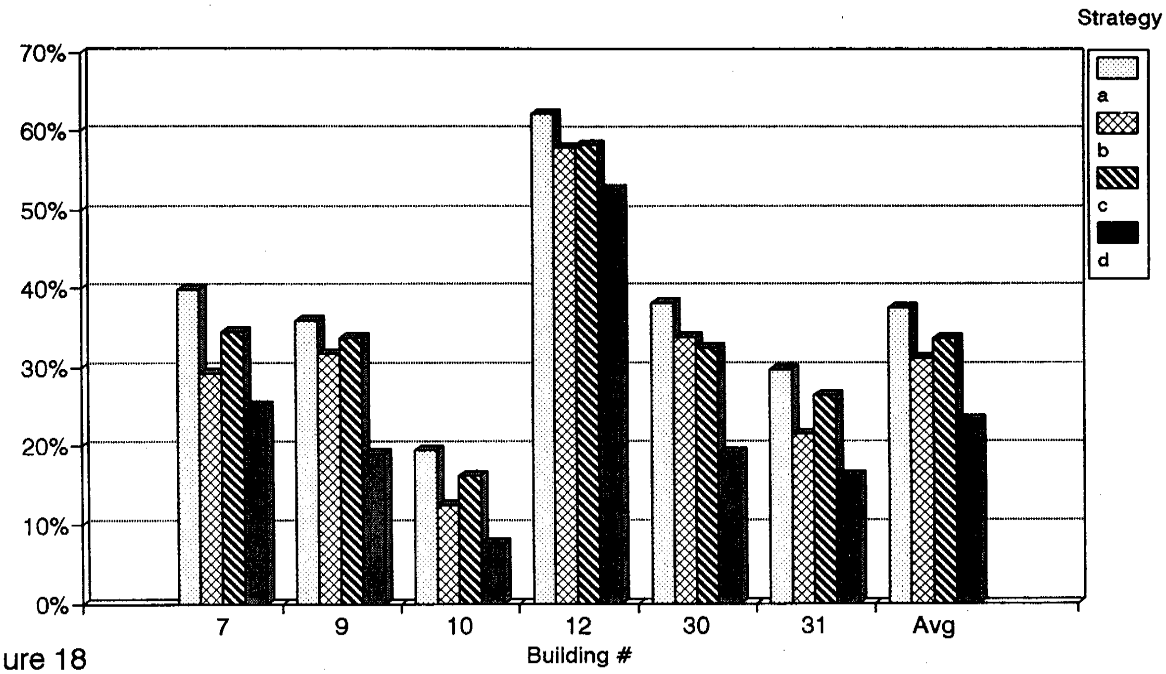

Figure 18

Energy For Recirculated DHW as a % of the Total DHW Energy Load (All Sites)

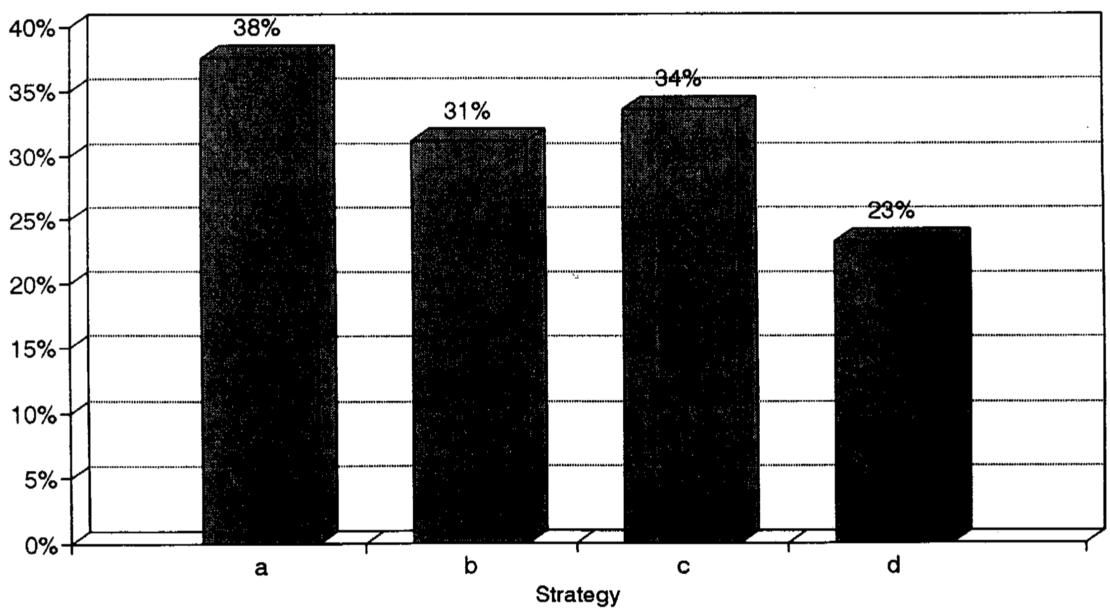

Figure 19

basis, we find that both those on the high and low end fit the appropriate characteristics defined in the LMH tables delineated in the first DHW research project[8].

DHW PERCENTAGE OF BUILDING'S TOTAL ENERGY CONSUMPTION

Bldg ID#	Fuel Type	% DHW
7	6	28%
9	6	38%
10	4	39%
12	2	37%
30	6	32%
31	6	48%
Avg		37%

Table 6

Another reality check on the results was to compare the burner runtimes under each of the strategies (Figure 20, p. 3-17). This comparison could only be done for the Summer (Round 2) data, as the systems were consuming fuel for space heating in all other rounds. During Summer, when the system is only running to produce DHW, there was an average 15% less burner runtime under Strategy D. This correlated quite closely to the energy savings of 16% reported for this mode of control during the same period. Figure 21 (p. 3-17) depicts how this close correlation is also apparent on a

[8] The "Low - Medium - High" (LMH) guidelines represent a relatively new approach for DHW system sizing. They were developed as part of the earlier project (Goldner, F.S. Nov. 1994) as the result of discussions with system design professionals, including members of ASHRAE T.C. 6.6 (Service Hot Water). They indicated a preference for a LMH users 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. In brief, the part of the LMH range that a building falls into is dependent on it's occupant makeup, and concentration of DHW using appliances. These factors are then used, along with the building's population density to determine the necessary system size from a detailed set of tables. The LMH tables were adopted for inclusion in the 1995 revision of the ASHRAE Handbook, and the 1998 American Society of Plumbing Engineers (ASPE) Domestic Water Heating Design Manual.

BURNER RUNTIMES DURING SUMMER

Average Daily Runtime

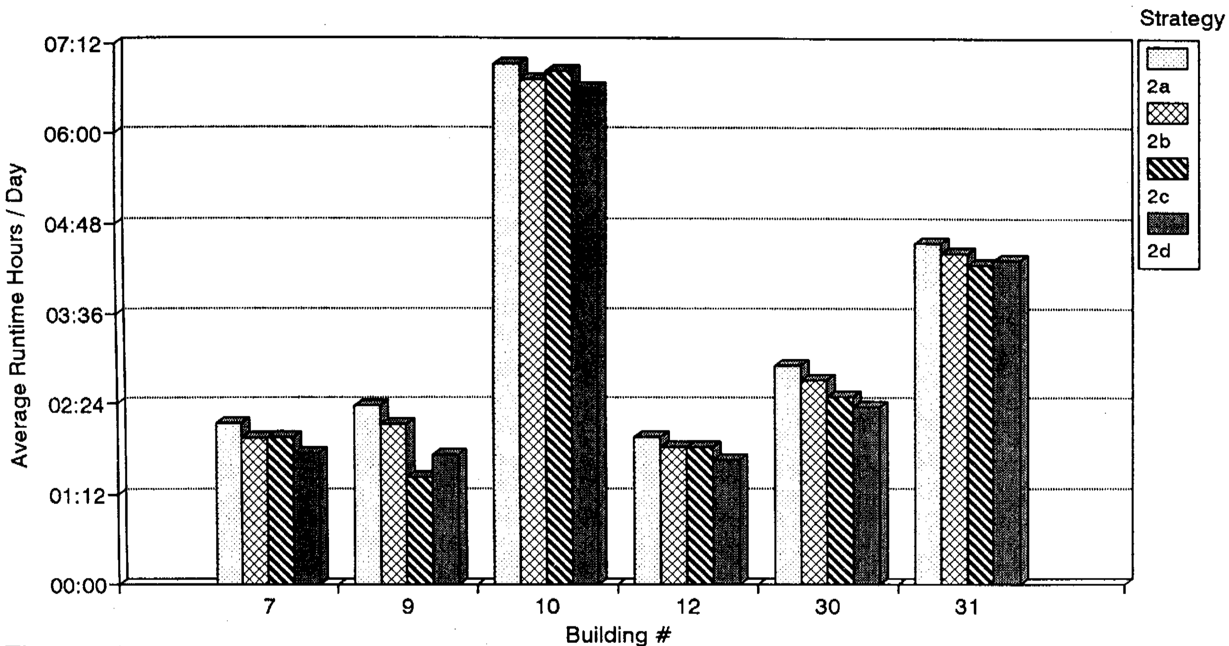

Figure 20

REDUCTION IN RUNTIME & ENERGY USE

For Strategy D vs. A in Summer

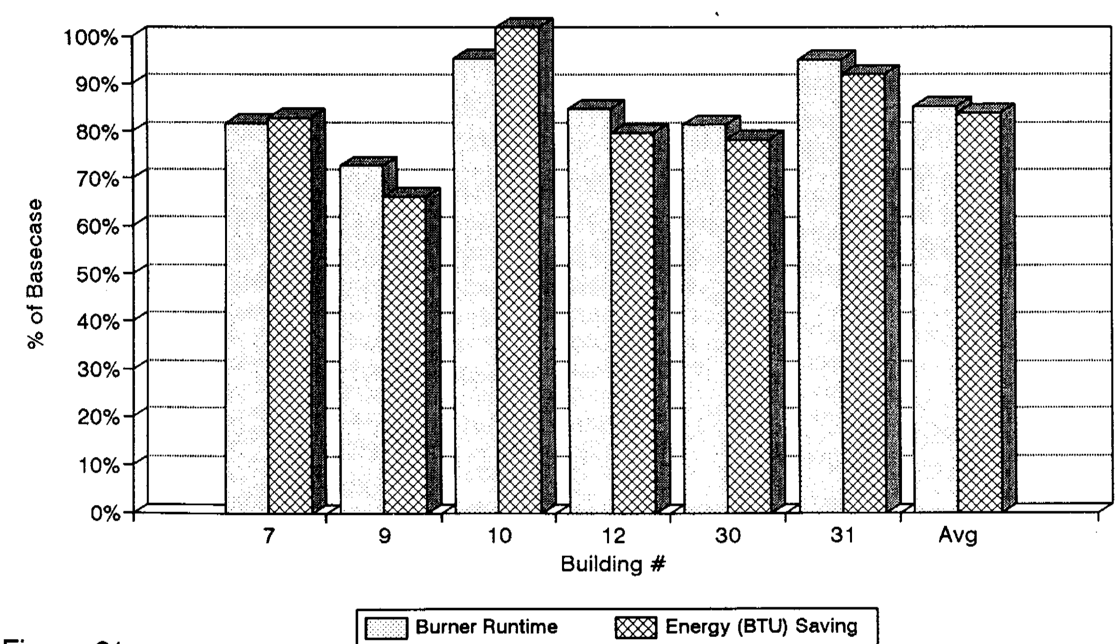

Figure 21

building-by-building basis. Of course, this burner runtime statistic does not directly mimic fuel use. It fails to account for items such as number of start-ups, cycling, and seasonal efficiency.

Overall, these reality checks seem to verify the research methodology's validity and results.

WATER CONSUMPTION

One of the major concerns before beginning the research was that with the recirculation pump turned off people would let the water run for long periods of time in order to get hot water. The concern was that the potential savings in energy would be eaten up by additional water usage costs. To evaluate this issue, an investigation was made of the volume of water consumed during each control scenario (round and strategy) at each building. As can be seen in Figures 22 through 25 (p. 3-19 and 3-20), and Figure 30 (p. 3-23), there was no appreciable difference in the volume of city water usage between any of the strategies. Additionally, this information along with the amount of DHW recirculated was also analyzed to further understand the systems' operations and our results.

As to the amount of DHW being recirculated, we see (in Figures 26 to 30, p. 3-21 to 3-23) that under non-base case scenarios the volume was greatly reduced, which was the major contributor towards energy savings under the other strategies. Typically there was a moderate drop off in recirculated water from Strategy A to Strategies B and C, and a much more significant drop off with Strategy D. Switching from Strategy A to Strategy D reduced the amount of water recirculated by an average of 74% annually (the reduction ranged from 83 to 56%). On average for these sites operating under Strategy A, a building recirculated approximately 3 gallons of DHW for each 2 gallons that were consumed. By changing the pump control over to Strategy D, on average just over 1 gallon was recirculated for every 3 gallons consumed.

OTHER FACTORS

Water Temperatures

Another variable that could effect the results was water temperature. Actual temperatures throughout the system were used in the calculation of the energy usage

DHW CONSUMPTION FOR ROUND 1
Average Gallons per Day

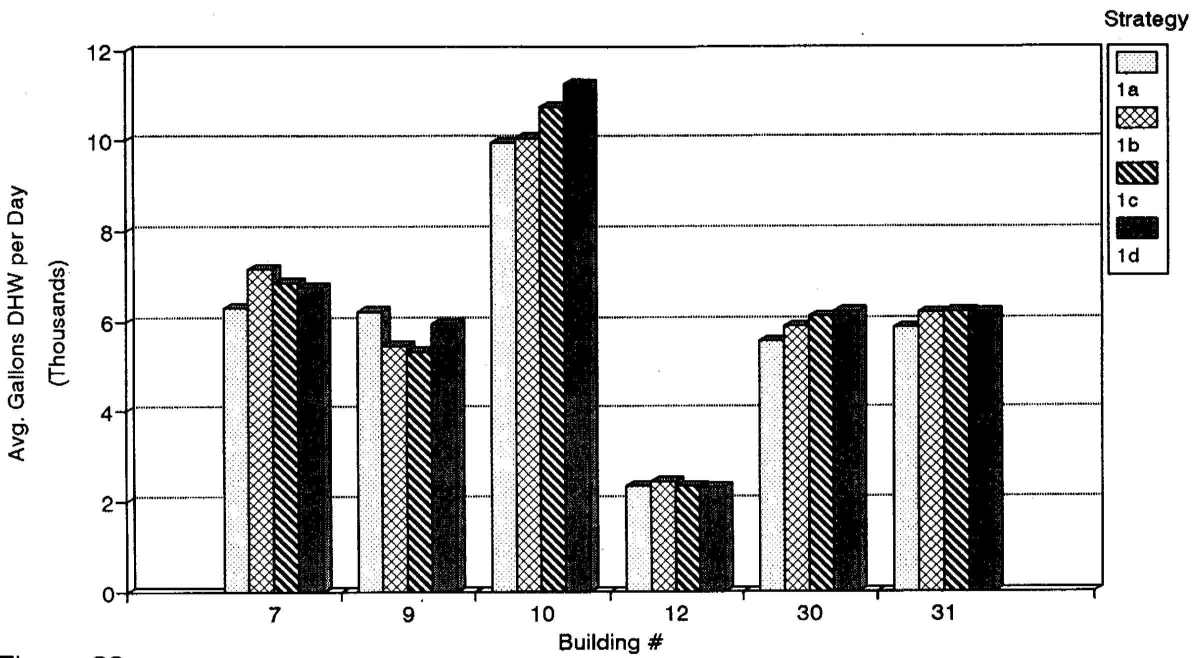

Figure 22

DHW CONSUMPTION FOR ROUND 2
Average Gallons per Day

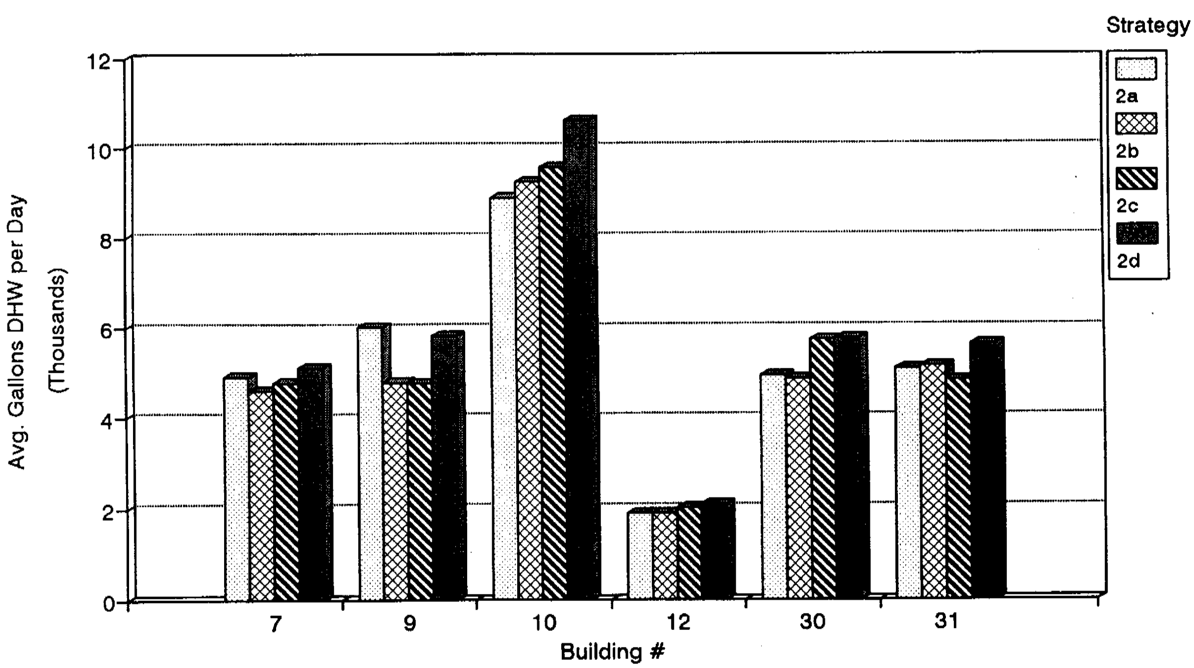

Figure 23

DHW CONSUMPTION FOR ROUND 3
Average Gallons per Day

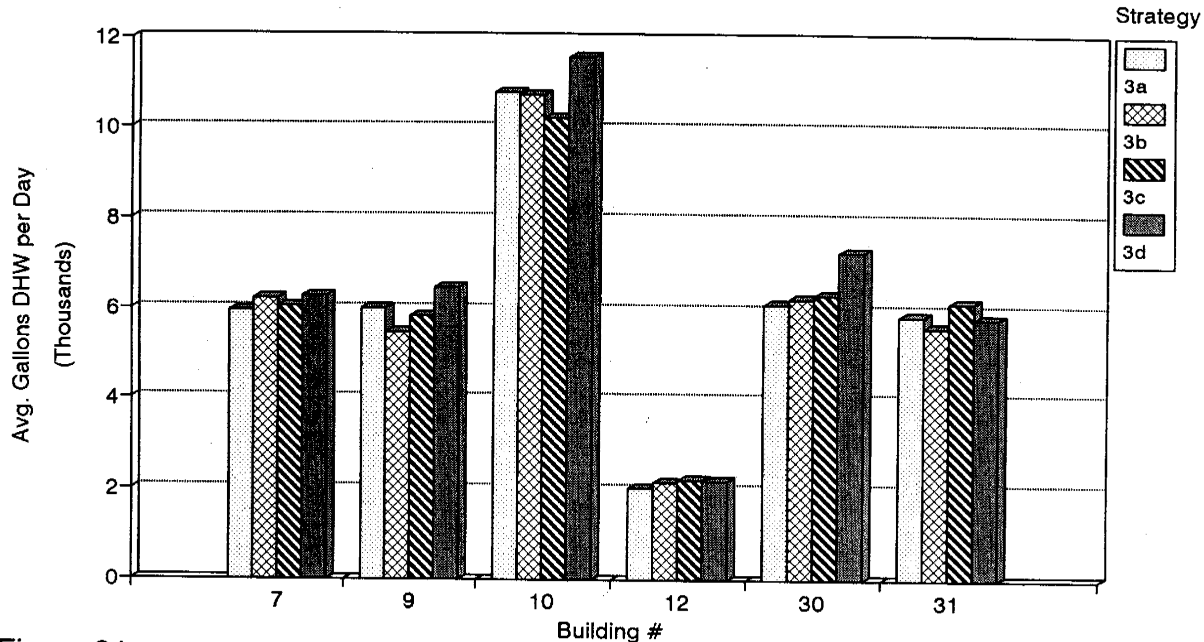

Figure 24

DHW CONSUMPTION FOR ROUND 4
Average Gallons per Day

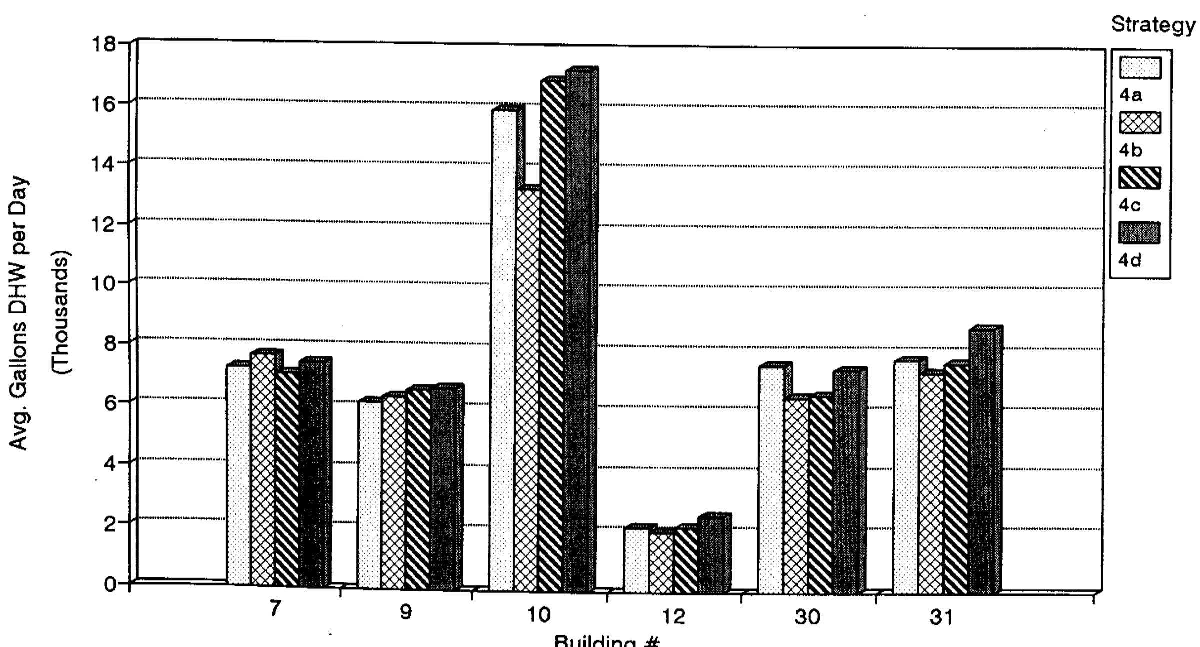

Figure 25

RECIRCULATION FLOW FOR ROUND 1
Average Gallons per Day

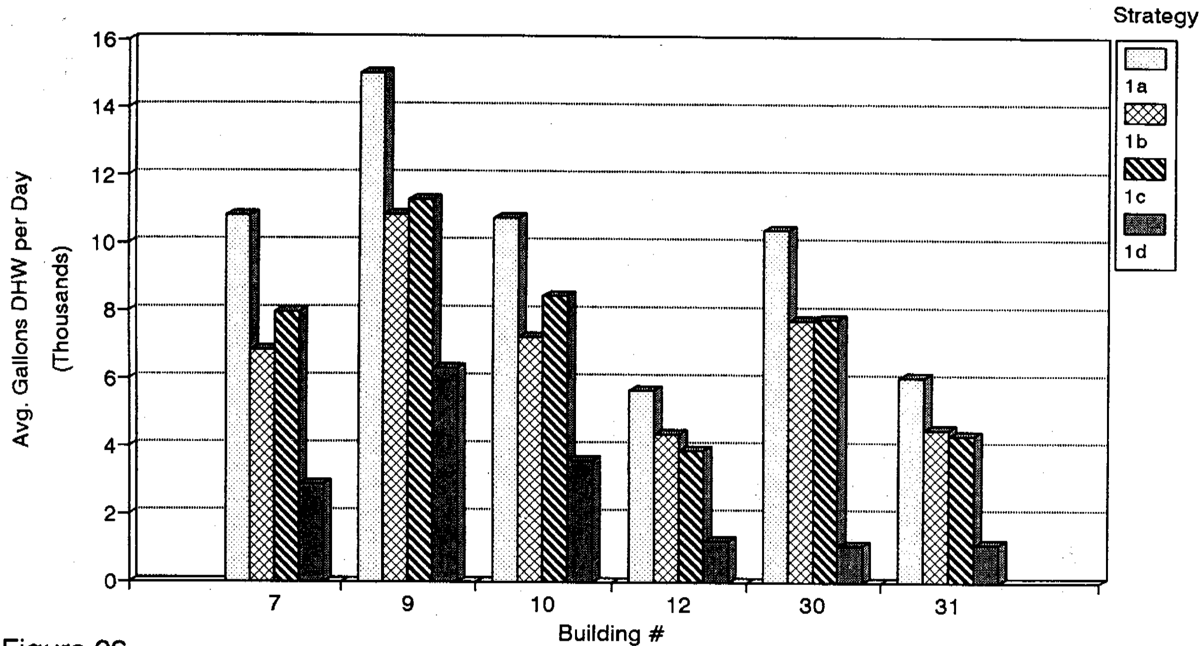

Figure 26

RECIRCULATION FLOW FOR ROUND 2
Average Gallons per Day

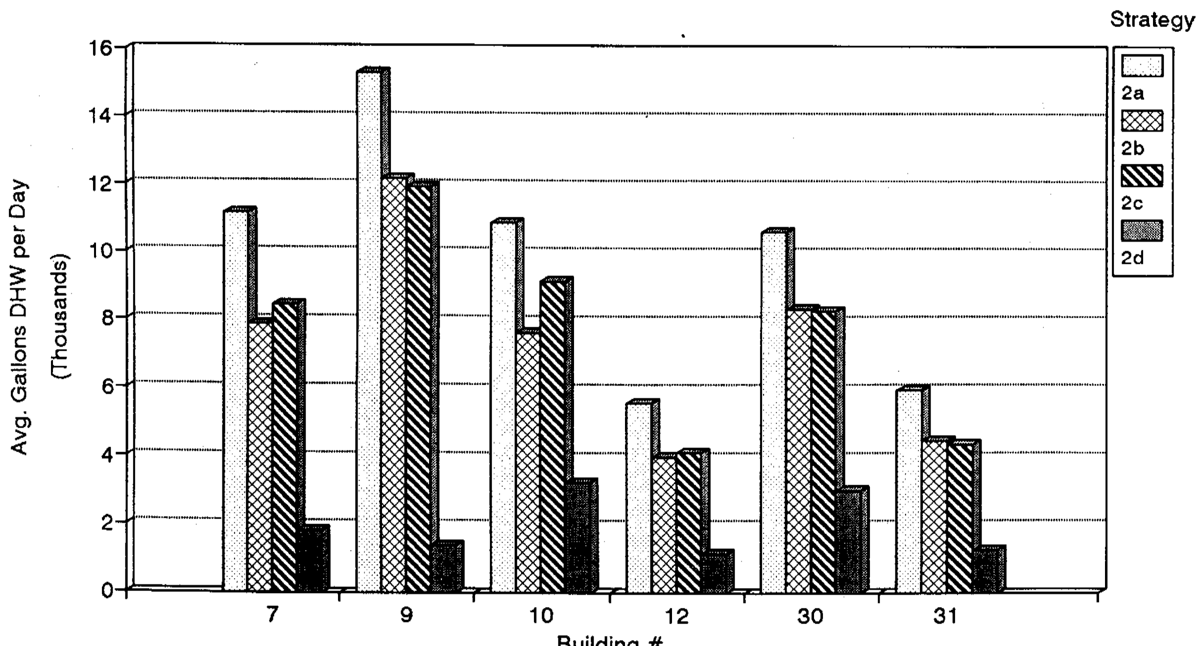

Figure 27

RECIRCULATION FLOW FOR ROUND 3
Average Gallons per Day

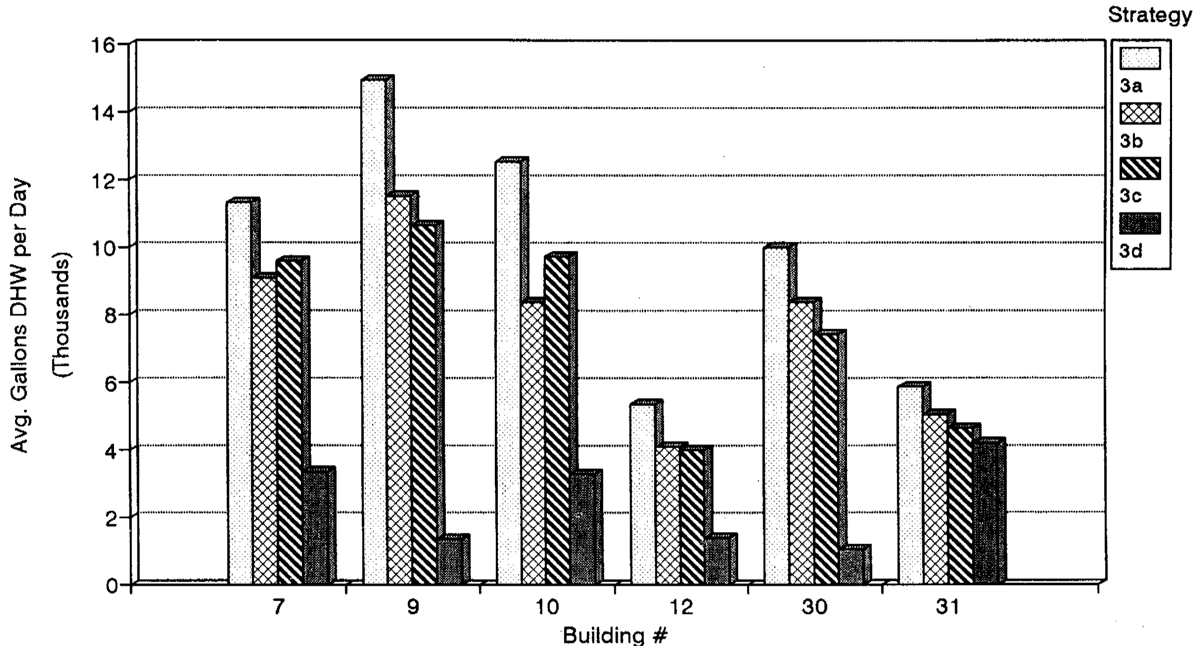

Figure 28

RECIRCULATION FLOW FOR ROUND 4
Average Gallons per Day

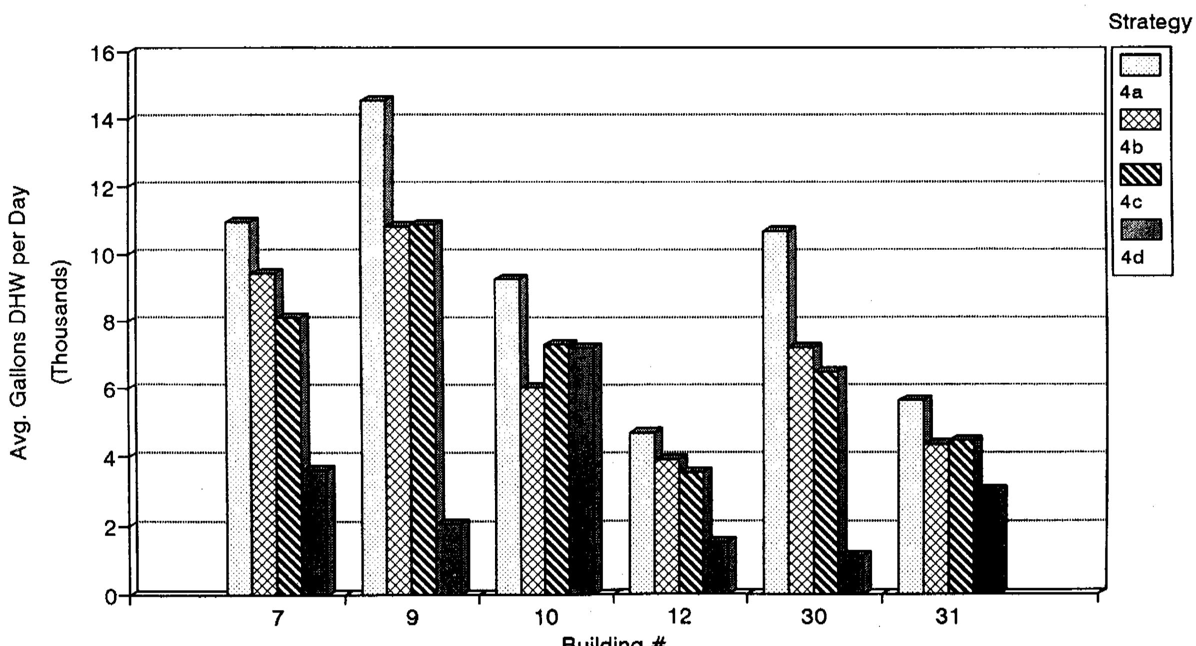

Figure 29

DHW CONSUMPTION vs. RECIRCULATION FLOW
All Bldgs - Avg Gal/Day For Each Round

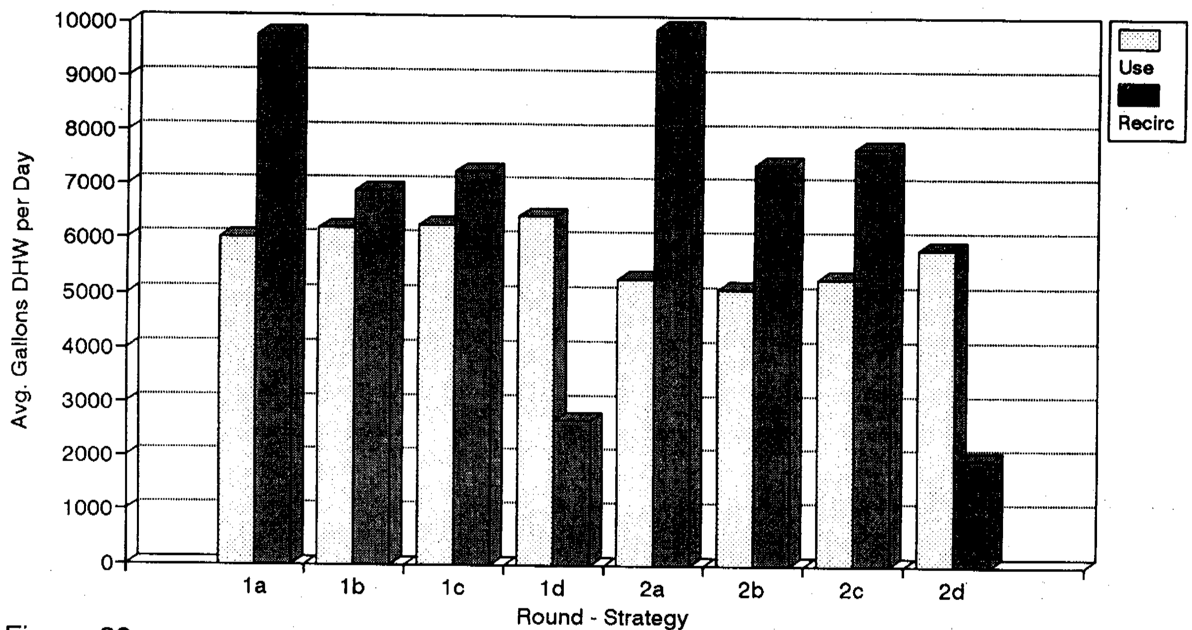

Figure 30a

DHW CONSUMPTION vs. RECIRCULATION FLOW
All Bldgs - Avg Gal/Day For Each Round

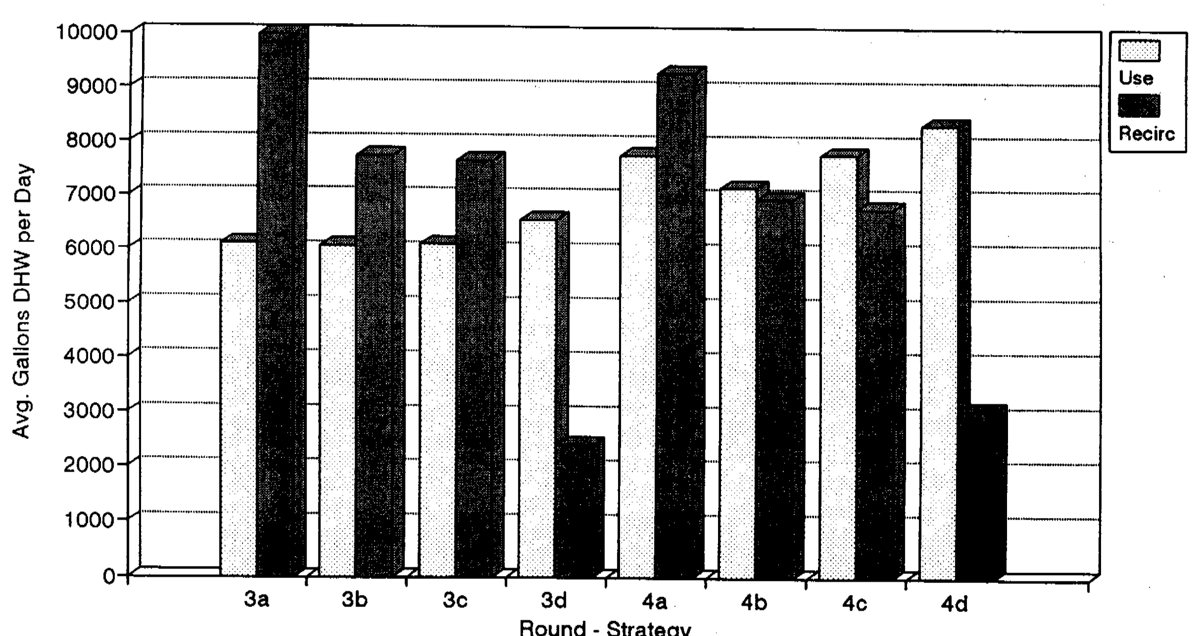

Figure 30b

during each strategy. Figures 31 to 34 (p. 3-25 and 3-26) illustrate the average temperature of DHW after the mixing valve, (i.e., going up to the apartments), at each site during rounds 1 through 4. Other than in Building 30, there were no significant differences of DHW temperatures for the different strategies, which probably accounts for the similar levels of tenant satisfaction with regard to water delivery reported in the responses to the questionnaires. As noted earlier, during rounds 3 and 4 Building 30 delivered very high supply water temperatures, apparently as a result of an improperly operating mixing valve. This situation likely contributed to the lower energy savings achieved at these times. Review of Figures 35 through 38 (p. 3-27 and 3-28) illustrate the reduction in DHW temperature at the basement return under Strategies B, C, and D. This also contributed to the energy savings, as the systems were not circulating higher-temperature DHW around the buildings as often under these three strategies.

The Whole Picture

A comparison of Figures 39 and 40 (Building 7 during Round 2 Scenario a and Scenario d, weekdays, on p. 3-29) provides an excellent overall illustration of what is happening in the buildings' DHW systems. Here we see the DHW consumption and recirculation flows plotted against both the supply and return water temperatures. Examining Figure 39 it should occur to the reader to ask wether it is really necessary to circulate 130- to 145-degree DHW around the building's piping system? Comparing this to Figure 40 we see that the answer to this question is "no". We can note that the supply temperature of the hot water available at any given five-minute time period during the day is almost identical in the two graphs[9]. Further review of these two figures reveals the changes in both the recirculation consumption curve and volume, as well as the temperature of the water in the return piping. The energy savings comes from the enormous reduction during overnight and late-night periods, along with the some smaller but significant savings during all but the highest early morning and evening peaking consumption periods.

Circulation Pump Runtimes

As the greatest savings were achieved while operating under Strategy D, the circulation pump runtimes for each site were examined. The controls (consisting of a reverse-

[9] While these two graphs are for the same building during a relatively similar time we should recognize that the consumption flow curves, though similar, are not exactly the same. This would be the case with any set of random days.

DHW TEMPERATURES FOR ROUND 1

Average Temp. After Mixing Valve

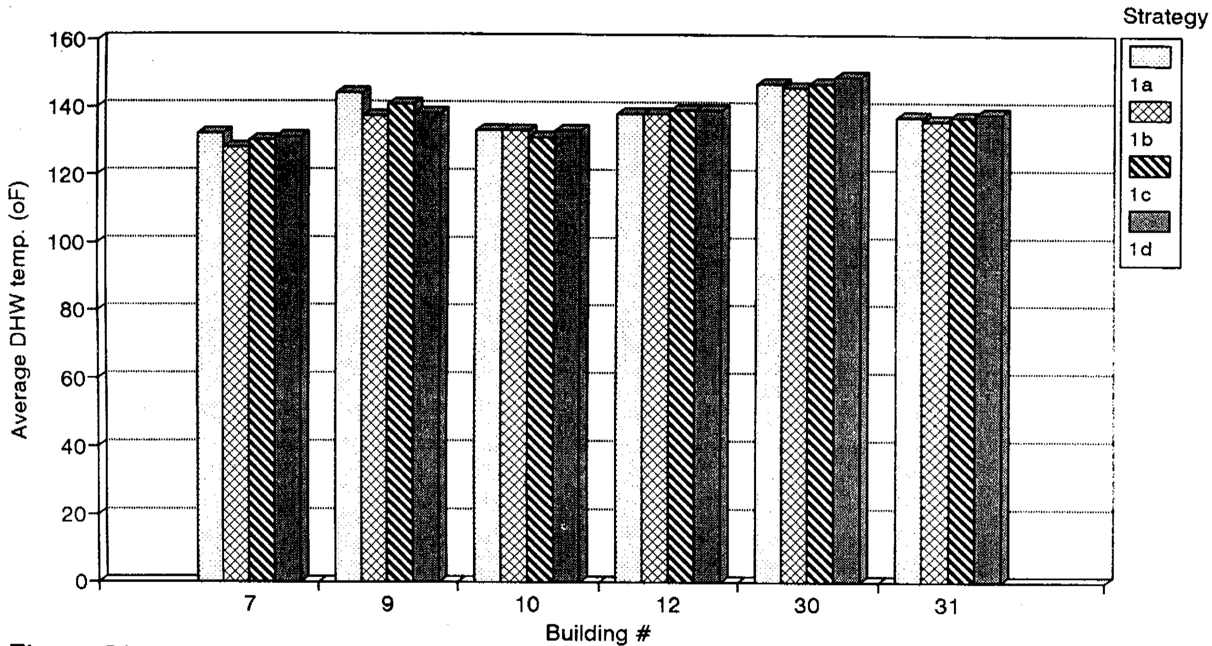

Figure 31

DHW TEMPERATURES FOR ROUND 2

Average Temp. After Mixing Valve

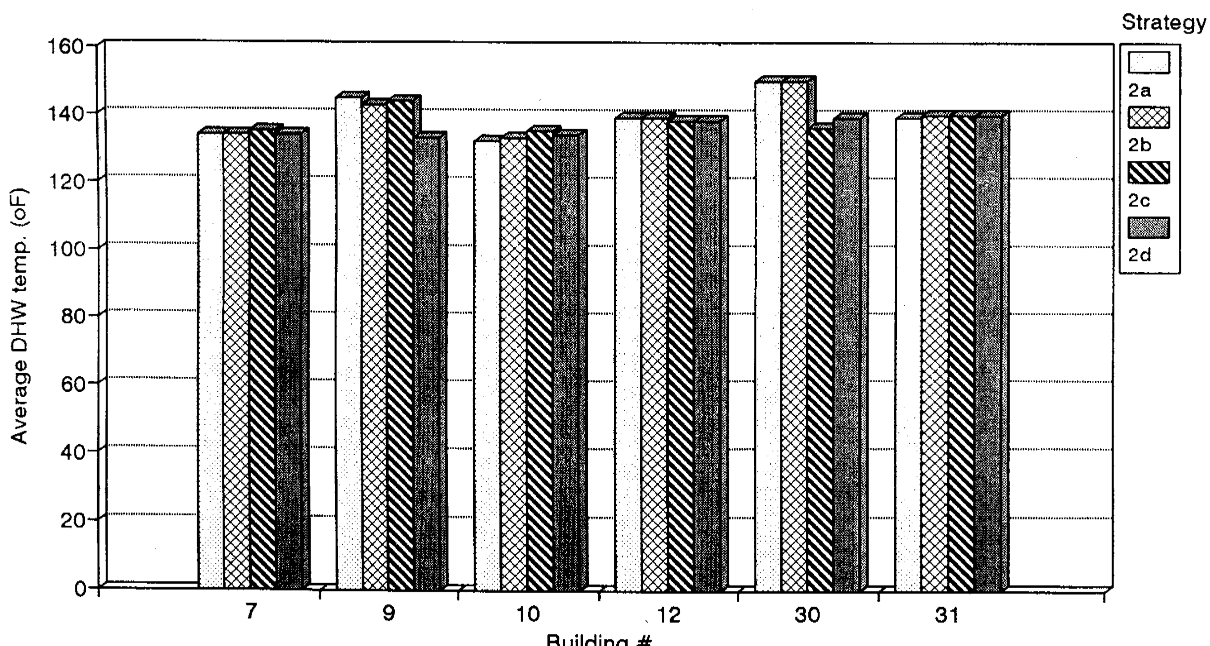

Figure 32

DHW TEMPERATURES FOR ROUND 3

Average Temp. After Mixing Valve

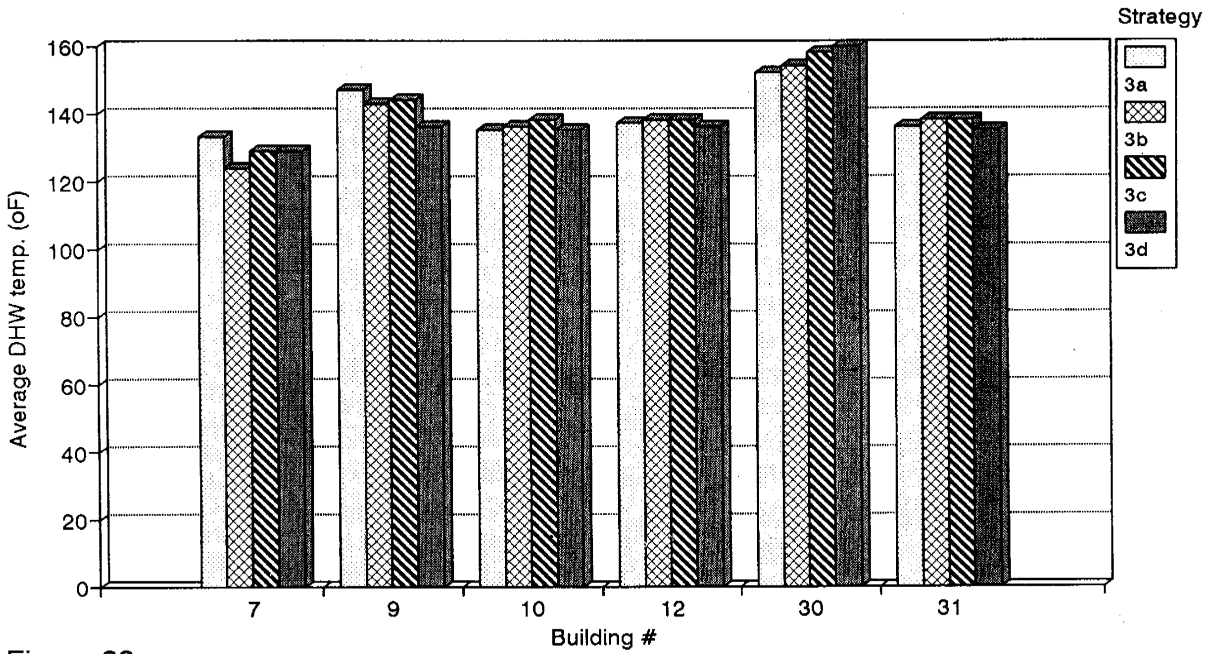

Figure 33

DHW TEMPERATURES FOR ROUND 4

Average Temp. After Mixing Valve

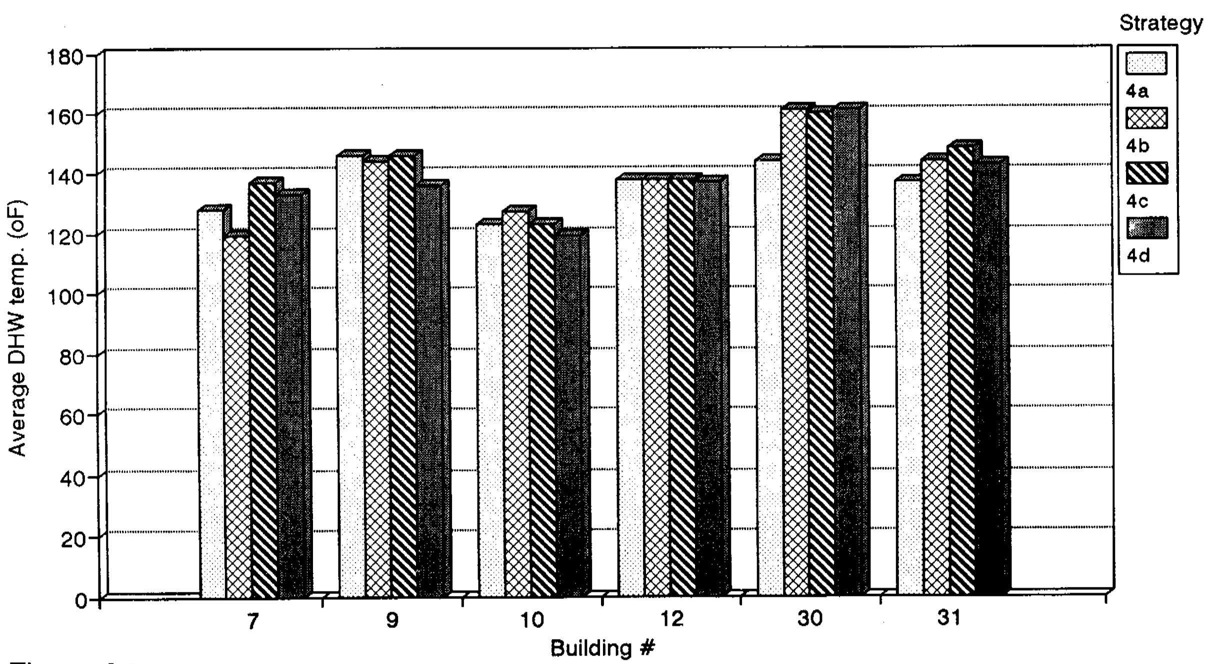

Figure 34

RETURN LINE TEMPERATURES FOR ROUND 1

Average Temp. at Basement Return

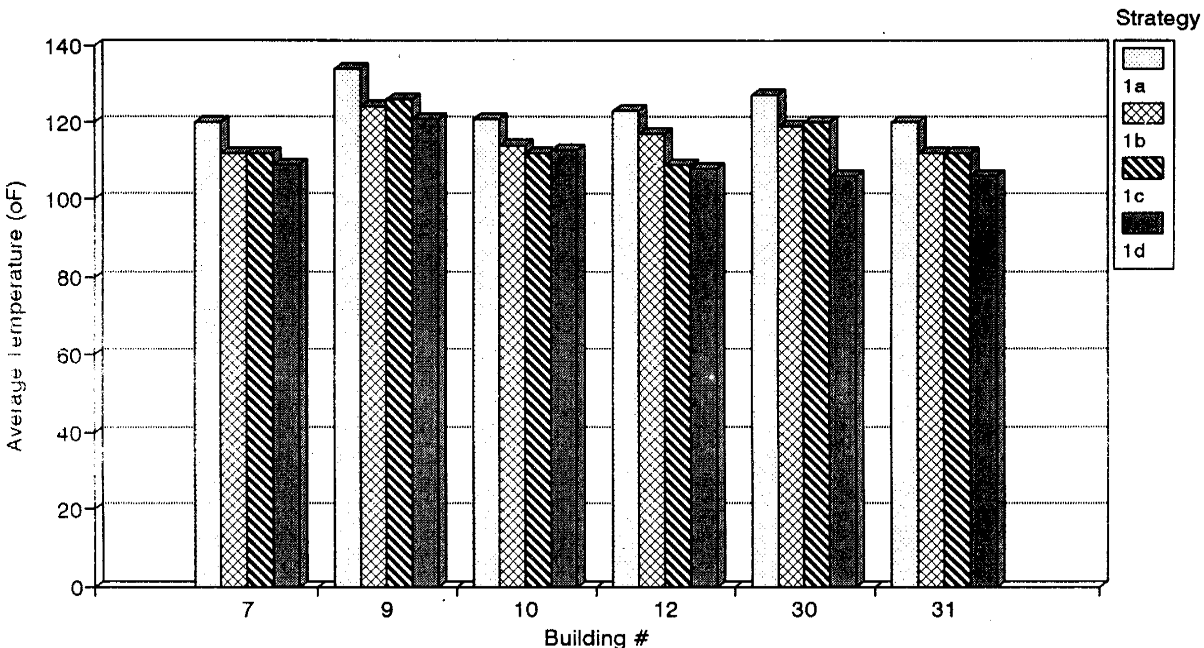

Figure 35

RETURN LINE TEMPERATURES FOR ROUND 2

Average Temp. at Basement Return

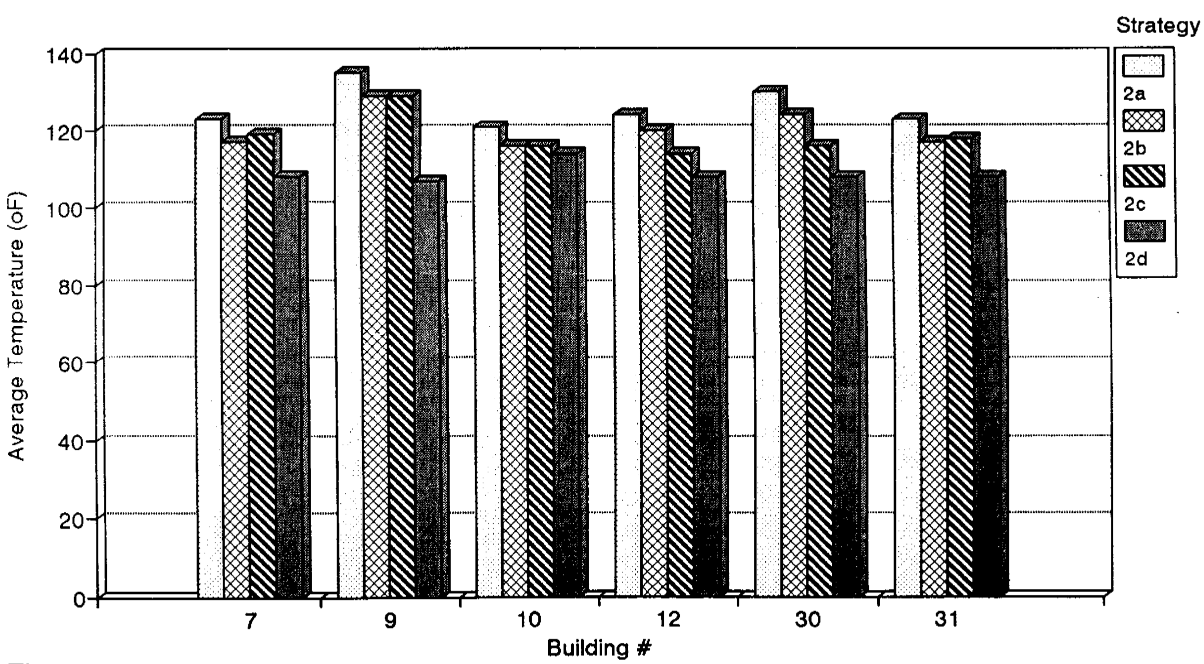

Figure 36

RETURN LINE TEMPERATURES FOR ROUND 3

Average Temp. at Basement Return

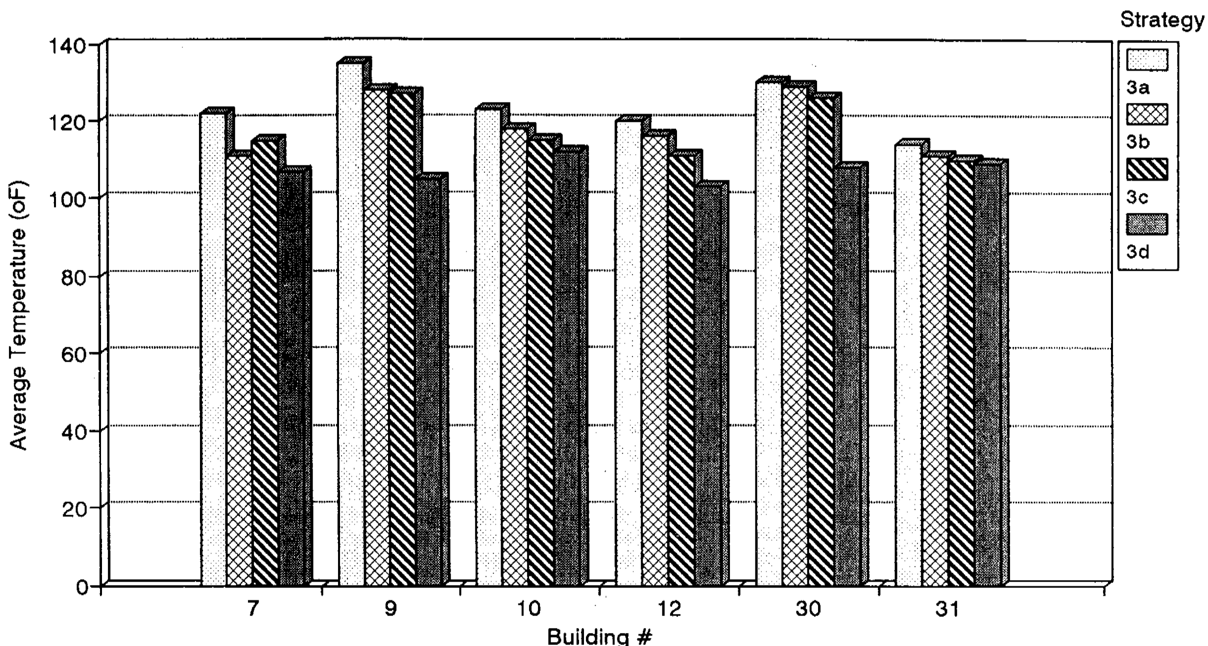

Figure 37

RETURN LINE TEMPERATURES FOR ROUND 4

Average Temp. at Basement Return

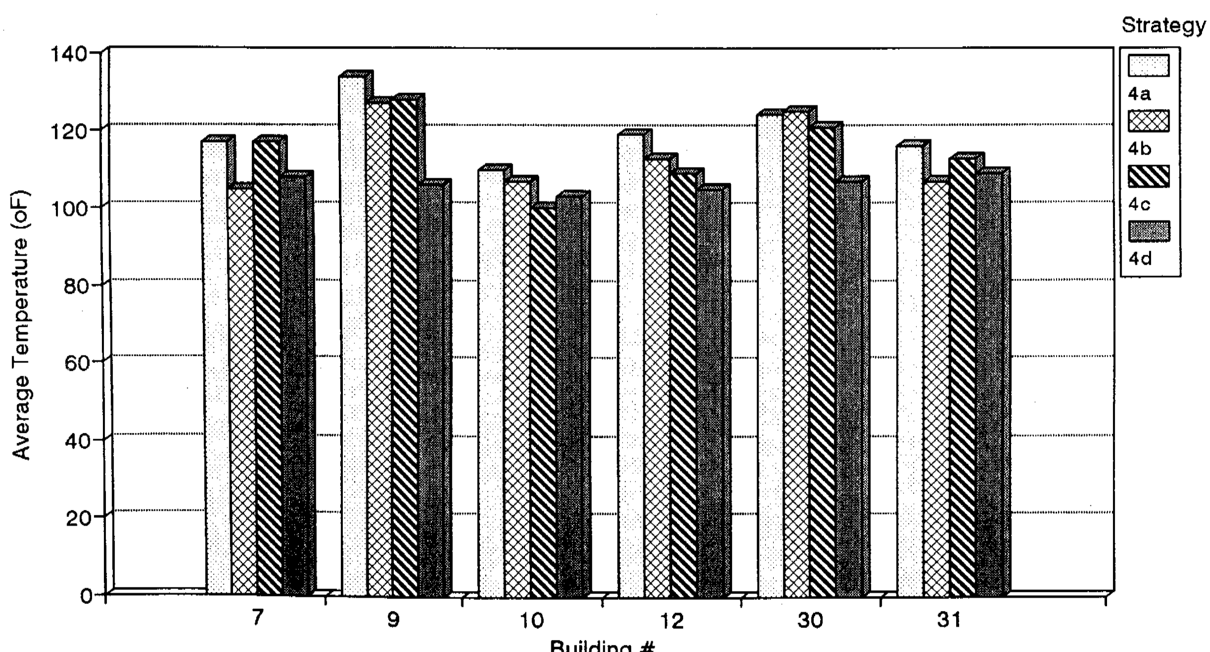

Figure 38

DHW Consumption & Recirc Flows, Supply & Return Temperatures (Bldg 7-Round 2a)

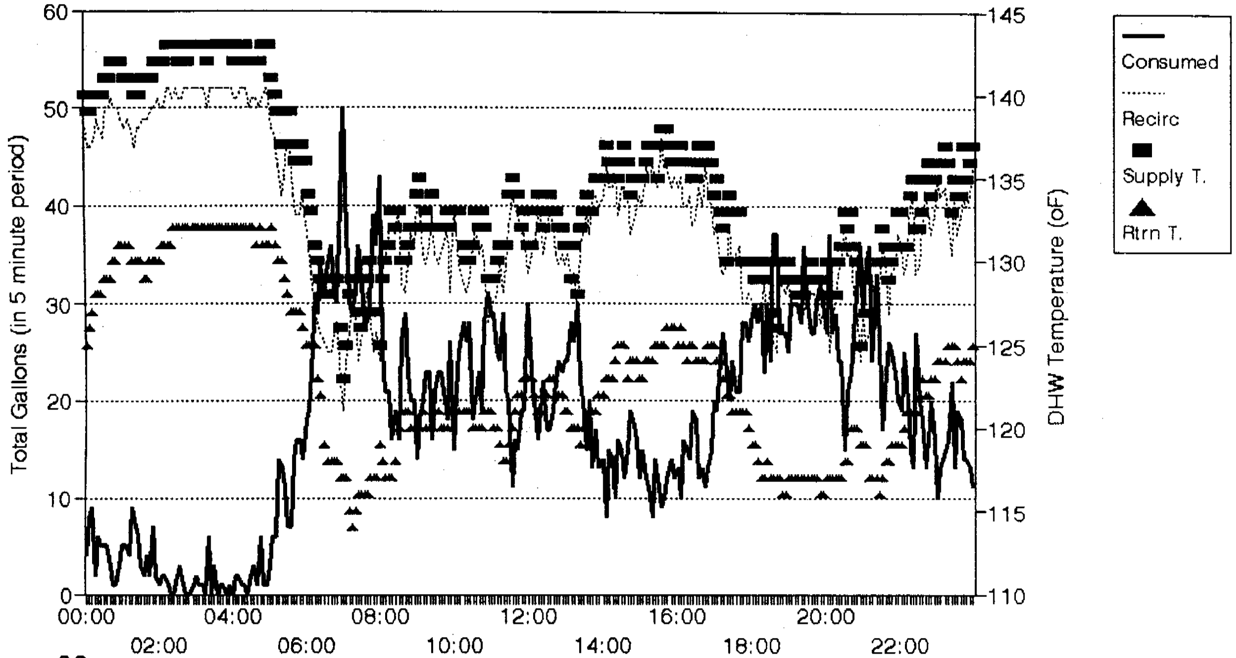

Figure 39

DHW Consumption & Recirc Flows, Supply & Return Temperatures (Bldg 7-Round 2d)

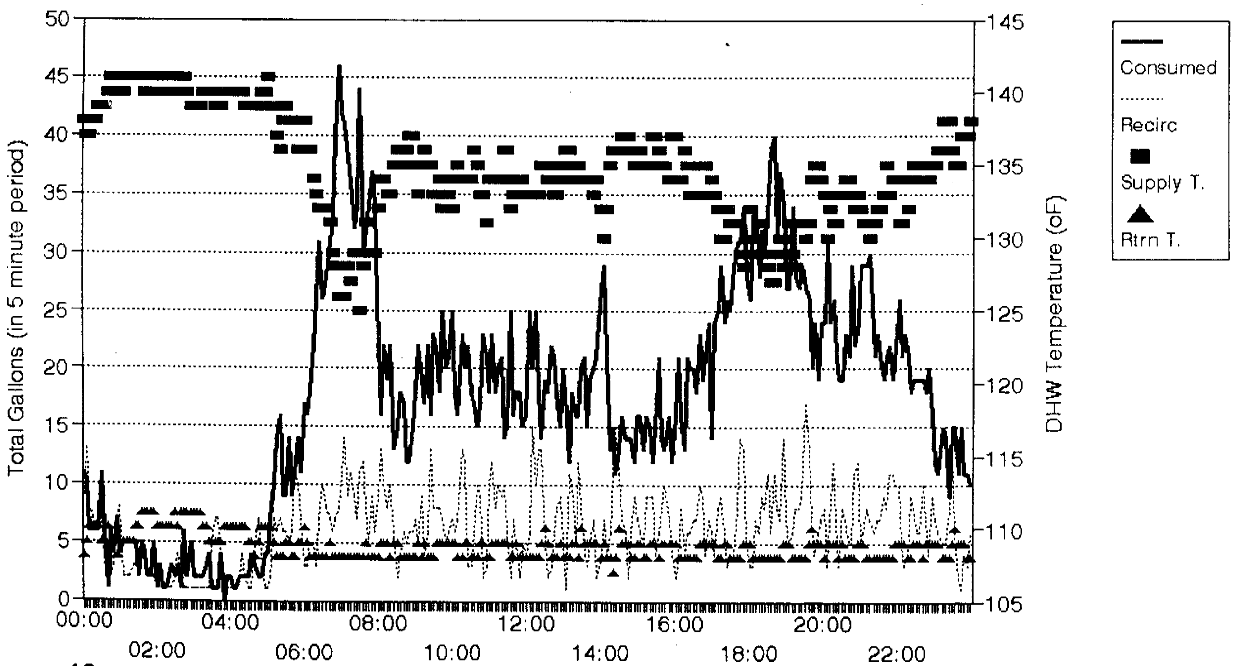

Figure 40

acting aquatint) were set so that the pumps ran whenever the return water temperature fell below 110° F, and continued to run until the temperature rose to 115° F, and then shut off. As illustrated in Figure 41 (p. 3-31), the annual average pump run hours per day for Strategy D was 6 hours 58 minutes for all the study sites, and 5 hours 57 minutes when we discount Building 10. Figure 42 (p. 3-31) reveals how the reduction in run hours varied across the different seasons. The range of daily pump runtimes at each site is illustrated by the high-low graphs in Figures 43 through 46 (p. 3-32 and 3-33). (Note that the higher than the rest of the year runtimes for Building 9 in Round 1 were due to the improper aquatint setting, as discussed earlier.) The variance for any individual day has to do with the amount of DHW consumed, the temperature of incoming water, the cycling of the boiler, and the coincidence of DHW use throughout a building.

Varied Aquatint Settings

At the end of Round 2 we used the month of September, prior to the start of the Round 3 (Fall) test period, to experiment with varied aquatint temperature settings. First, the aquatint control of the pump was reset to 105° F, with the same 5° F deadband (Scenario 2e), and collected data for two weeks. This produced a 5% savings in energy consumption compared to the Scenario 2d (similar 110° F) period. Next, the aquatint control of the pump was reset to 115° F, with the same 5° F deadband (Scenario 2f). This resulted in an 8% increase in energy use as compared to Scenario 2d.

DEBUNKING OLD TRADE BELIEFS

Many trade practitioners are of the belief that the pumps used on these recirculation systems are designed only to be run continuously, and will fail prematurely if they are cycled. Background research was done before this project began to determine if an aquatint control would not be viable due to this issue. The author spoke with several of the major fractional horsepower pump manufacturers' design and application engineers via phone and in person at the annual ASHRAE meeting/exposition. All manufacturers assured us that while the pumps of many years past did have a problem with cycling, all recent and current models experience no operational problems due to being run in a cycling mode, and such operation would not in any way affect their useful service life. In fact, they pointed out that many of the same models that we find on DHW

RECIRCULATION PUMP RUNTIME
Annual Average Hours/Day For Strategy D

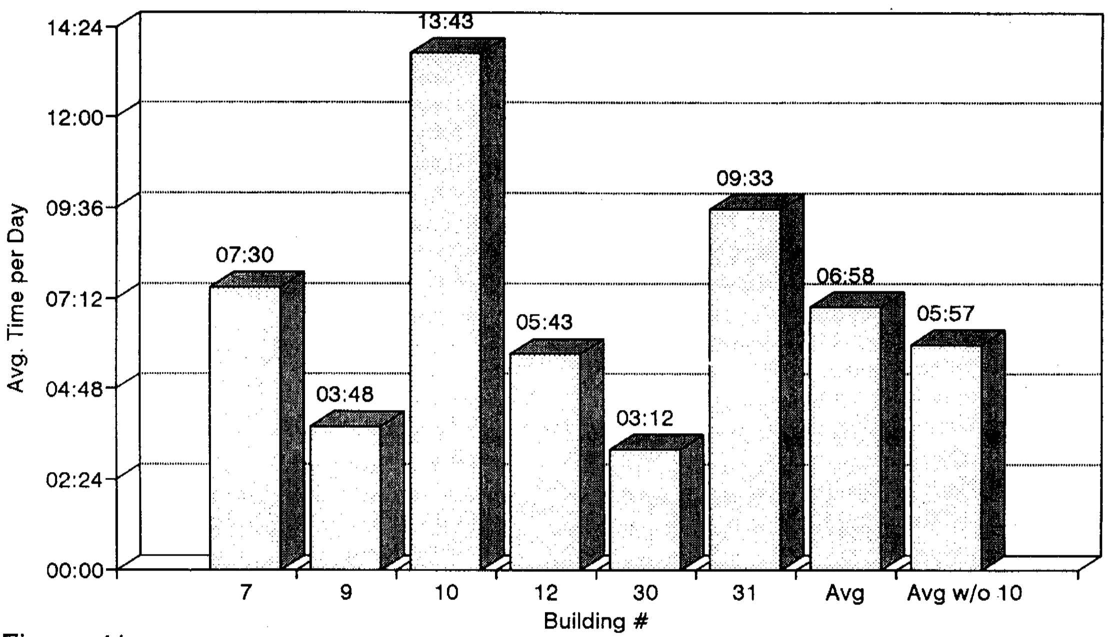

Figure 41

RECIRCULATION PUMP RUNTIME
Average Hours / Day For Strategy D

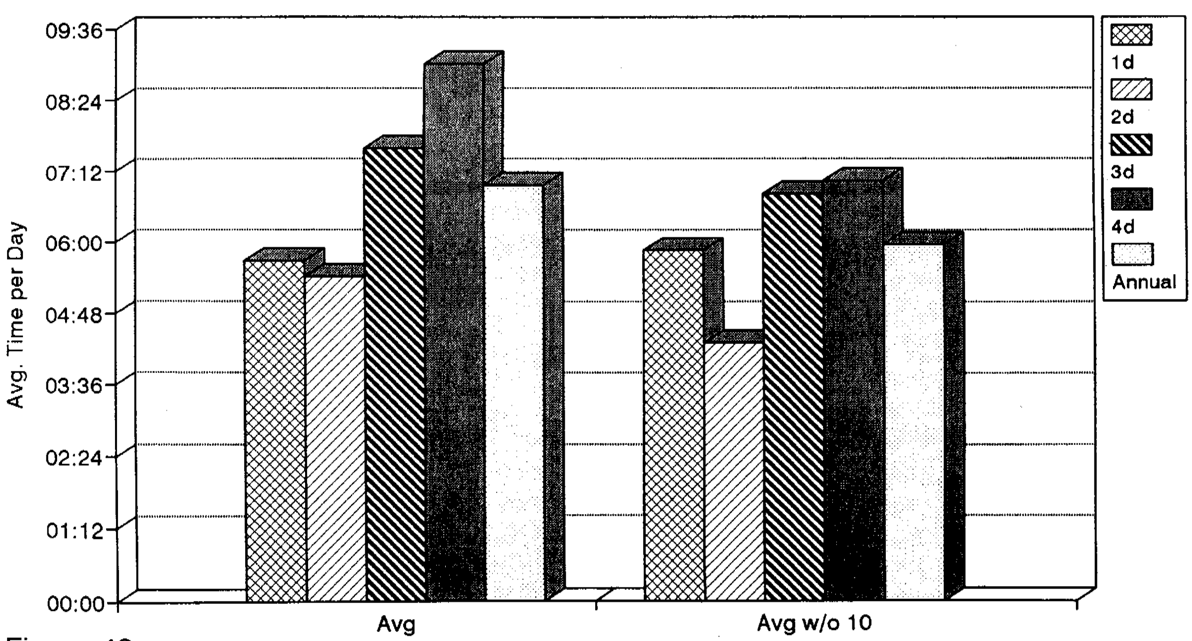

Figure 42

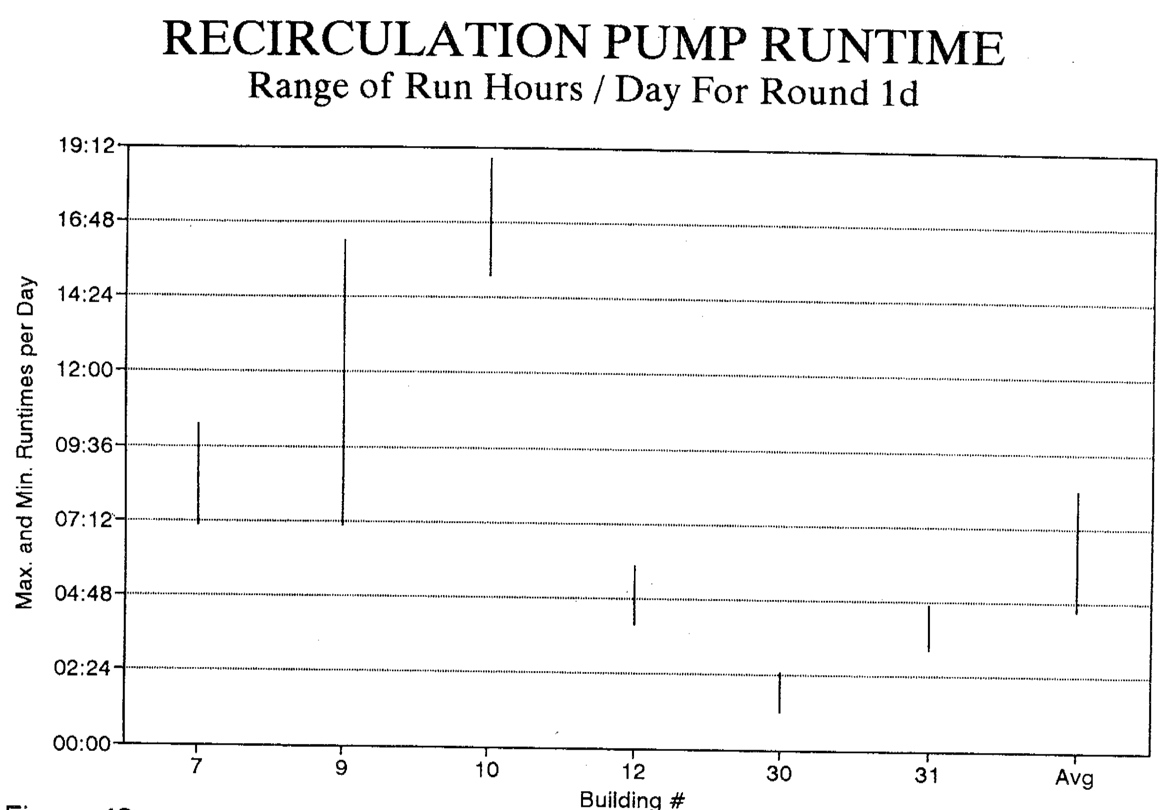

Figure 43

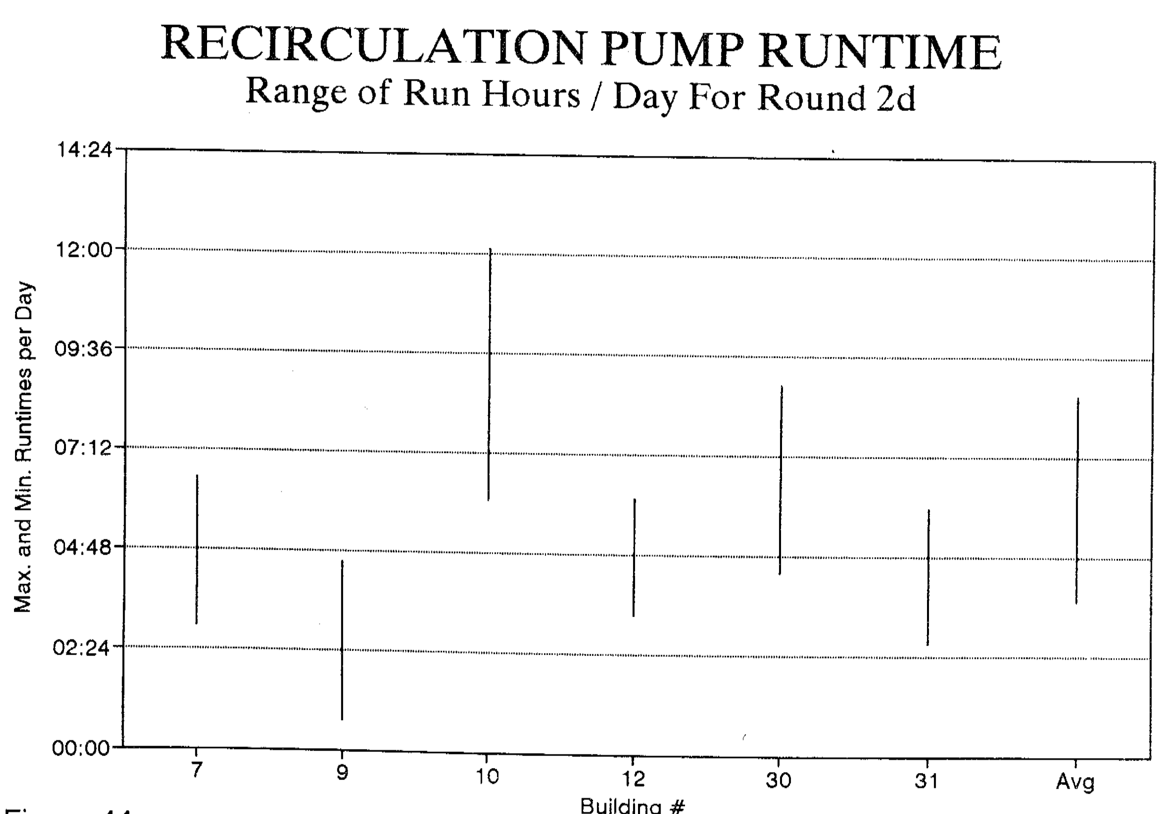

Figure 44

RECIRCULATION PUMP RUNTIME
Range of Run Hours / Day For Round 3d

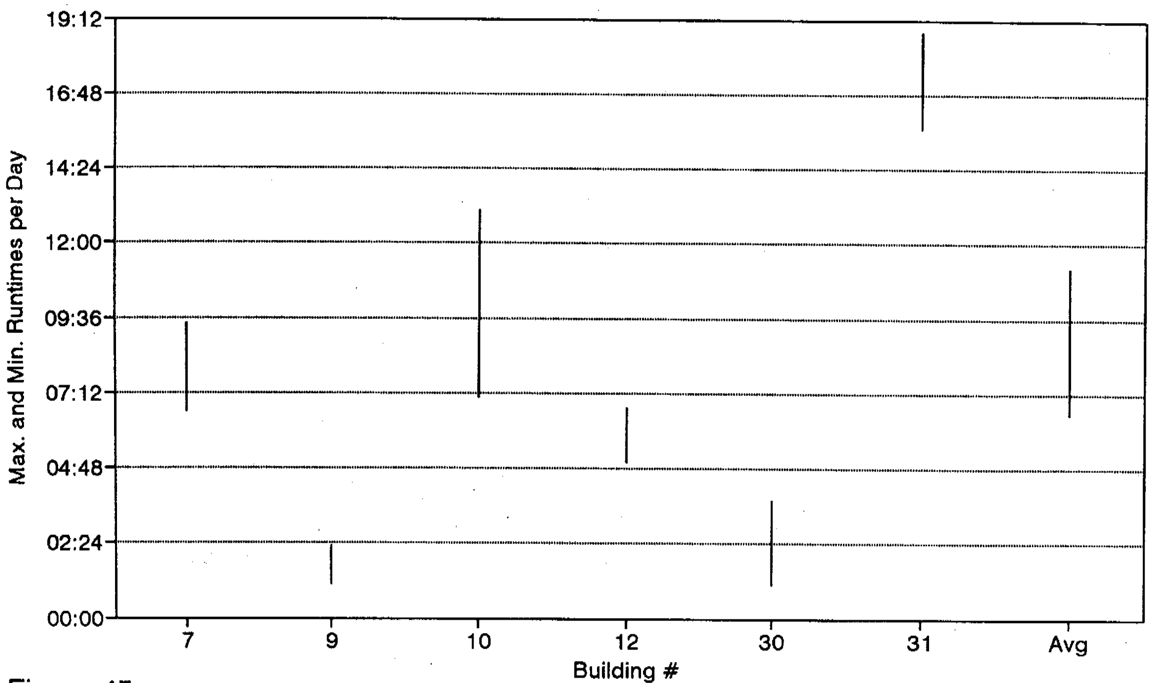

Figure 45

RECIRCULATION PUMP RUNTIME
Range of Run Hours / Day For Round 4d

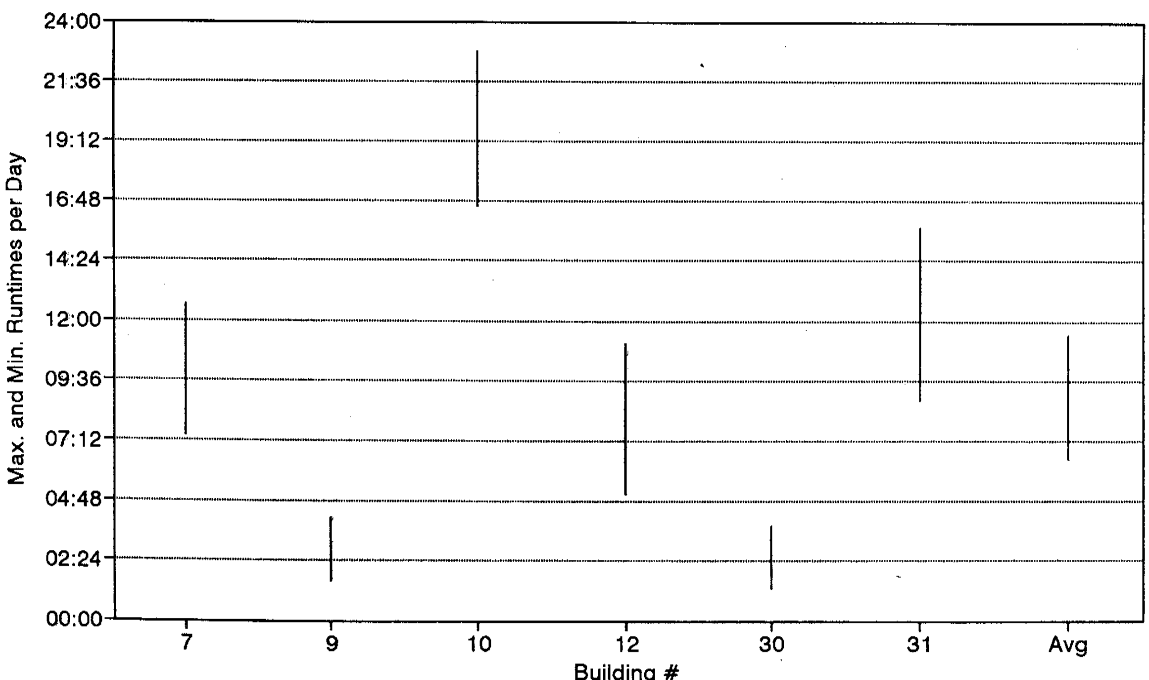

Figure 46

recirculation systems are employed in more sophisticated HVAC systems in which they are installed to run in various types of cycling modes.

PUMP ELECTRICAL ENERGY SAVINGS

In addition to the fuel savings, an additional electric savings is derived from the reduced hours that the recirculation pump is running. While this project did not directly monitor pump electrical usage, it is possible, using the specifications as listed on the pump nameplates the recorded circulation pump run hours, and a number of assumptions calculate approximate dollar savings, using the formula:

$$\left(\begin{array}{c}\text{Pump}\\ \text{hp}\end{array}\right) \times \left(\begin{array}{c}.746\\ \text{KW/hp}\end{array}\right) / \left(\begin{array}{c}\text{motor}\\ \text{efficiency}\end{array}\right) \times \left(\begin{array}{c}\text{factor for}\\ \text{pump}\\ \text{loading issues}\end{array}\right) \times \left(\begin{array}{c}\text{reduced pump}\\ \text{runtime}\end{array}\right) \times \left(\begin{array}{c}\text{cost}\\ \text{of}\\ \text{electricity}\end{array}\right) = \begin{array}{c}\text{annual}\\ \text{savings}\end{array}$$

Problems with arriving at a precise estimate of savings relate to a number of factors. First, the majority, if not all of pumps found on DHW systems in multifamily buildings were selected not as a result of a careful design process, but rather have been selected and installed using the "one size fits all," "this pump worked in the last building," or "that's what we had on the shelf" methodology. In fact, in all six of the project sites (which between them had a considerable range of types of layouts and system lengths) we found only either 1/40-hp or 1/12-hp pumps. Secondly, even if these pumps had been more precisely selected based on the actual fully loaded conditions, the systems consistently operate at a full range of part-load situations. (I.E., whenever someone in the building opens a tap it reduces pressure in the DHW piping loop. Over the course of a day these pumps are forced to operate across the entire range from full to no-load conditions.) This acts to lower the pump/motor efficiency. Moreover, friction, rotational, and other losses occur at low-load conditions (i.e., during peak DHW consumption times). Lastly, there is the issue of electrical rates. What service classification rate is the building on? Is the building on a kwh only, or a kwh and KW (demand) based rate? If the building is on a demand based rate, is the pump cycled off or on during any given month's peak electrical period.

For our calculations we used a motor efficiency of 75%, a 2/3 factor for pump loading, a marginal kwh cost of $0.056/kwh (from Con Edison's SC-9 rate) for demand based rate energy cost savings, and a marginal kwh cost of $0.105/kwh for savings in a building on a non-demand based rate (i.e., Con Edison's SC-2).

Using the figures and assumptions above we conservatively estimate that electrical savings due to reduced pump run hours will range from $5 to $13 per year in buildings with a 1/40-hp pump, and from $16 to $43 per year in buildings with a 1/12-hp pump.

Section 4
CONCLUSIONS / RECOMMENDATION

Based on the results of this research, it appears that significant energy savings are available by installing a rather simple device that can provide paybacks of a few months. As compared to the base case of the pump running 24 hours per day (Strategy A), turning the pump off overnight (Strategy B) would save 6%, turning the pump off during morning and evening peaks (Strategy C) would save 6%, and controlling the pump with a return line aquatint set at 110^{o} F with a 5^{o} F deadband (Strategy D) would save 11%. These are a significant savings. The level of savings from Strategy D is equal to 4% of a typical building's total annual fuel consumption. In addition to the fuel savings, the electrical energy savings would be from $5 to $13 per year in buildings with a 1/40-hp pump, and from $16 to $43 per year in buildings with a 1/12-hp pump due to the reduced run hours on the pumps. The aquastats used in this project cost $43, and were acquired from a general supply house. Conservative estimates from several heating and plumbing contractors of installed cost for this measure range between $150 and $250.

SCOPE OF THE ISSUE

What is the scope of this issue? An evaluation of available data on multi family buildings reveals that the average New York City apartment consumes 865 gallons of #2 oil (or equivalent) per year (adjusted for normal degree day conditions).[10] On average, for the buildings studied, 37% of all fuel consumption was used to supply DHW: (this, along with range of 28% to 48% for the study sites, accords with general industry estimates of 25% to 50%.) There are two million apartments in New York City multi family buildings[11], and we estimate approximately one third of these sites have recirculation systems. Results of the research indicate that recirculation systems are responsible for between 30% and 62% of DHW energy consumption in the sites studied. Using an average of 38%, DHW recirculation systems consume of over 80 million gallons of oil per year (in the New York City stock alone).

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[10] Goldner, F.S. and P.H. Judd. 1989. *BEUTS (Building Energy Use Tracking System) - Final Project Report,* New York State Energy Research and Development Authority.

[11] Stegman, M.. 1993. *Housing and Vacancy Report - 1991*, New York City Department of Housing Preservation and Development.

Significant savings can be achieved by employing simple, low-cost devices to reduce the recirculation load while maintaining the water delivery quality. By documenting the savings from such a straightforward operations change and providing effective technology transfer to decision-makers in the target audience[12] it is quite reasonable to expect a very high penetration rate for the recommended strategy. Assuming a penetration rate of only 10% to 20%, implementation of Strategy D, (the reverse acting return line aquatint set at 110^{o} F with a 5^{o} F deadband, which provides an 11% savings) will yield between 866,000 and 1.73 million of gallons of energy conserved annually.

BUILDING ECONOMIC ANALYSIS

The specific savings level and length of time it will take to payback the cost of installing the pump control aquatint will vary according to a number of factors. These include what the building's total energy consumption is (i.e., is it a very high energy user or a miser), the percentage of that load that is attributable to DHW, fuel costs (i.e., price per gallon or therm), electric rate, and to some extent the layout of the building DHW distribution system. The buildings in this study saved an average of $784 per year with the implementation of Strategy D. The paybacks ranged between just over 1 month and 1 1/2 years, with the average payback being 7 months. In fact, four of the sites had paybacks of less than 6 months.

It is clear that this measure should be implemented immediately in all buildings that are currently employing continuously running forced recirculation systems.

---

[12] A special summary ("fact sheet") on this project will be prepared by EMRA for general distribution. This "fact sheet" will highlight, with the use of graphics, the energy savings, DHW consumption reduction, and related effects of the project. Copies of this fact sheet will be sent to all the major building owner/management organizations, for redistribution to their members. EMRA will also prepare a direct mailing of the project report and fact sheet to key industry leaders in the New York City area.

Additionally, two workshops will be held for the New York housing, energy and contractor communities. EMRA will also work to get the recommendations and findings integrated into the curriculum of seminars and workshops focusing on this stock of buildings. Lastly, the findings of this project will be presented to energy and engineering professionals at national conferences; an ASHRAE Seminar on this topic has already been scheduled at the time of this writing.

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DHW Recirculation System Control Strategies
Report 99-1

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George E. Pataki, Governor

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