Measure Information Template – Central Hot Water Distribution Systems in Multifamily Buildings

2008 California Building Energy Efficiency Standards

[Heschong Mahone Group, June 23, 2006]

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Purpose

This document proposes changes to the requirements for central domestic hot water (CDHW) systems in multifamily residential buildings, and the procedures for calculating the estimated energy use of CDHW systems within the CEC approved alternative calculation method.

Overview

Description	Central DHW systems installed in new multifamily buildings will be required to include reverse flow prevention devices, risers and air release devices, and controls on the recirculation system and/or the gas burner. Additionally, the ACM programs will be revised to be able to model the effects of using various types of distribution system controls.
Type of Change	1. Mandatory measure: Reverse Flow Prevention The cold water make-up pipe shall have a spring-loaded check valve between the point where it joins with the hot water return pipe (or storage tank) and the next closest tee (serving cold water to other end uses). 2. Mandatory measure: Air Release Provision A vertical riser (tee and 12" to 18" pipe) with an automatic air release valve at the top must be installed on the hot water return pipe just before the recirculation pump (in terms of direction of water flow). 3. Mandatory measure: Crossover Prevention Single-lever faucets and shower mixing valves that allow crossover between the hot and cold water systems should not be installed. When such valves are used, backflow prevention valves are required on the hot and cold water lines between the fixture and the immediately preceding tee (in terms of intended direction of water flow). 4. Prescriptive requirement: Demand or Temperature Modulation Controls Recirculating hot water systems in multifamily buildings should have either temperature modulation controls or recirculation pump demand controls. 5. Modeling: Heat Loss from Recirculation Loop Improve the Heat Adjusted Recovery Load (HARL) equations in the Alternative Compliance Method (ACM) Manual to more closely model heat loss from the recirculation loop. 6. Modeling: Draw Schedule for Hot Water Define a draw schedule for hot water in multifamily buildings in the ACM Manual and ACM Programs.

Energy Benefits	Controls on hot water recirculation systems in MF buildings reduce gas consumption by either reducing the temperature of hot water being circulated (when the hottest water is not needed), or by turning off the recirculation pump when it is not needed.. The degree to which controls save energy varies by number of end users on the hot water circulation system, configuration of water heating and storage devices, type of control, and other factors. Demand controls can save between 0.5M and 9.2M Btus/dwelling unit per year. Temperature modulating controls can save between 0 and 7.3M Btus. There would be insignificant electrical savings and no peak demand reduction. Hot to cold water crossover through single-lever valves can increase water heating energy use by up to 40% for a significant portion of hours every day. That results in 3M to 8M therms/dwelling unit of wasted gas per year. There are no reliable sources of data for the percentage of systems that are currently installed without check valves on the CWS. If it were just 20% of new MF construction with CDHW systems, then reducing crossover with check valves (assuming 40% of the current 60,0000/yr new construction MF units have CDHW systems) would save between 19M therms and 38M therms of energy each year for every year's worth of new MF units built. There would be insignificant electrical energy savings and peak demand reduction.
Non-Energy Benefits	The riser and air release valve on the HWR line will reduce the instances of recirculation pumps malfunctioning (including overheating to failure), and the cost of maintenance personnel repairing them. Other elements of this proposed measure are not expected to have an appreciable effect on maintenance or any other non-energy benefit. In addition to energy savings, the control systems in the monitored buildings produced appreciable savings in the *amount* of hot water delivered, which saves on the pollution produced by water treatment, as well as the cost and required infrastructure. Because the recirculation pump is always ON when required, under the measures prescribed, occupant satisfaction with the hot water system is likely to be higher than with a timeclock control, which leads to lower maintenance costs.
Environmental Impact	There are no potential adverse environmental impacts related to the measures proposed. Correctly implemented, each element of the proposal would result in a decrease in both water and energy use by improving the efficiency of the overall CDHW system.

Technology Measures	The parts and controls recommended are readily and economically available from local suppliers. There are many manufacturers of Temperature Modulation Controls –ProTemp, ETE, EDC, Utilisave; and of Demand Control systems – Taco, ACT Metlin, UPONOR, WIRSBO. Once installed correctly, the parts do not require regular maintenance and are expected to last for many years. The pump controls need to be calibrated at the start, and then checked once every year to ensure proper functioning. The temperature modulation controls require calibration based on real time monitoring. This service is provided by EDC, but not yet by ProTemp.
Performance Verification	Check valves and the air release valves will require inspection for correct installation and operation. For the Pump controls, the inspector needs to ensure that the communication signals between the sensors, controller and actuators are functional. The proposed verification requirements are set out in the "Recommendations" section
Cost Effectiveness	The proposed changes for which we have data are inexpensive and show significant savings.
Analysis Tools	The proposed adjustments to the HARL equations, along with the proposed adjustment factors for control systems should be sufficient to quantify energy savings from the control systems described above. The adjustment factors will likely have to be adjusted according to the size of the hot water system.
Relationship to Other Measures	Changes suggested by others in the current LBNL DHW project may have to be taken into account in developing the HARL equations and usage budgets.

Background

The primary goals of the various research elements of this project were to find out:

- Current construction practices for domestic water heating systems in new multifamily buildings in California
- Reasonable assumptions for hot water draw schedules in multifamily buildings of various sizes
- Costs and Issues with various control strategies for central hot water recirculation
- Water and energy use patterns with various control strategies for central hot water recirculation
- Common failure modes with various recirculation controls

The research was very successful in garnering data on some of these issues, only marginally successful on others, and extremely enlightening on related additional issues that had not been originally conceptualized as part of the problem of understanding central hot water systems in MF buildings. Perhaps chief among the latter category is the importance of understanding "crossover" as an energy and water efficiency issue. See Appendices for complete reports.

PROPOSED MEASURES

1 Mandatory measure: Reverse flow prevention

The cold water make-up pipe shall have a check valve between the point where it joins with the hot water return pipe and the next closest tee (serving cold water to other end uses).

See measure 3 for an estimate of the energy and economics impacts of this measure.

2 Mandatory measure: Air release provision

A vertical riser (tee and 12" to 18" pipe) with an air release valve at the top must be installed on the hot water return pipe just before the recirculation pump (in terms of direction of water flow).

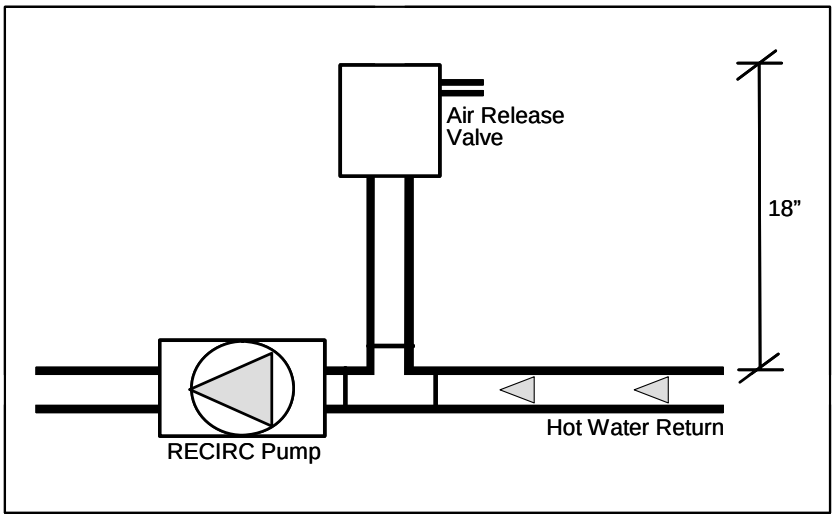

Figure 1. Air Release Valve on Hot Water Return Pipe

2.1 Energy Impact of Air Release Provision

In data received from EDC controls, 16 out of 36 failed systems had a failed pump. According to EDC, around 12% of their installed systems are in failure at any given time, so we estimate that at any time around 5% of all CDHW systems are in failure due to a failed pump, and that most of those pumps have failed due to air in the recirculation loop. This estimate is likely to be conservative because EDC sends out notices to its clients to inform them of pump failures, and encourage them to repair the pump.

EDC’s data shows that when a recirculation pump fails off or is intentionally shut off, then a common response by the maintenance personnel is to increase the HWS temperature by 15ºF on average. This response helps to reduce tenants complaining of excessive waiting time for hot water. To estimate the energy impact of increasing the HWS temperature in this case, we multiply the daily hot water consumption of 65 gal/day-unit by the temperature differential (15ºF) between the two conditions, times the embodied energy in that volume of water (8.3 BTU/gal-ºF). The resulting estimate is 30 therms per year per apartment are wasted. Scaling up to the approximately 40% of new MF construction that has central domestic hot water (CDHW) systems, this represents a loss of 709,000 therms per year statewide for one year’s worth (60,000 units) of MF new construction at the current construction rate.

2.2 Economic Impact of Air Release Provision

We obtained the retail price of a ¾” air bleed valve with a thumb screw during a telephone survey of three retail plumbing stores in the Sacramento area. The average retail cost among these three stores is $24. Assuming a retail price markup of 30% yields the wholesale price to a plumbing contractor of $16.80. The wholesale cost is the cost to the installing plumbing contractor, and thus the useful cost when considering new construction.

The labor required to install a single air bleed valve is less than 45 minutes. Using a labor charge of $100 per hour yields a maximum labor cost of $75 for this installation.

The energy saved by the air release provision (30 therms per year per apartment) has a net present value of $731, while the estimate of the cost of the measure is only $3.75 ($75 per loop, assuming 20 apartments on the loop).

3 Mandatory measure: Crossover prevention

Single-lever faucets and shower mixing valves that allow crossover between the hot and cold water systems should not be installed. When such valves are used, backflow prevention valves are required on the hot and cold water lines between the fixture and the immediately preceding tee (in terms of intended direction of water flow).

3.1 Presence of Crossover

As a measure to reduce the risk of scalding, it is common practice to install *single lever faucets and shower mixing controls* ("single-lever valves") in apartments. Through repeated use of a single-lever valve, the washer separating the cold water faucet supply (CWFS) and hot water faucet supply (HWFS) is eventually worn out. This creates an open pathway between the CWFS and the HWFS even in the highest quality lever. Certain single-lever valves are constructed in such a way that the hot and cold water are connected even when the valve is closed (i.e., no hot or warm water is being used).

This is acceptable in a building with no recirc loop because the hot water and cold water pressures are identical and stable, and so balance each other out and induce no crossover flow. When the recirc loop is switched on, these pressures vary around the loop, resulting in crossover flow.

Further, shower mixing valves allow the hot water supply and cold water supply to be openly connected when a shower-head shut-off is used (e.g., during "soap-up") in lieu of shutting the shower off at the valve.

When the cold and hot water supplies are connected in this manner, any pressure differential between the cold water line and hot water line will induce an exchange, called "crossover." Crossover goes both ways, so that tenants experience hot water where it shouldn't be, and have to run the cold water out of hot water pipes even when a recirculation loop should be assumed to have hot water readily available.

The hot water recirculation pump is typically installed near the end of the hot water return (HWR) line near the hot water storage tank. Most often, the cold water supply (CWS) and hot water return "tee" together between the recirculation pump and the hot water storage tank.

Any pressure differential between hot and cold water lines will cause crossover at single-lever valves. However, our research indicates crossover can be quite significant in systems without a check valve on the cold water supply ("makeup") line to the boiler or water heater. This is because the recirculation pump creates a low pressure on the return side of the loop *before* the pump, and a higher pressure *after* the pump. This induces a flow of cold water into the hot water return loop through any faulty single-lever valves and induces a backflow of hot water into the cold water makeup line (see Figure 2 below). This creates a secondary loop of hot water flowing from the primary loop through the cold water lines and back to the single-lever valves (see Figure 4 below). Note that installation of a check valve on the cold water supply will significantly reduce crossover, but not entirely prevent it (see Figure 3).

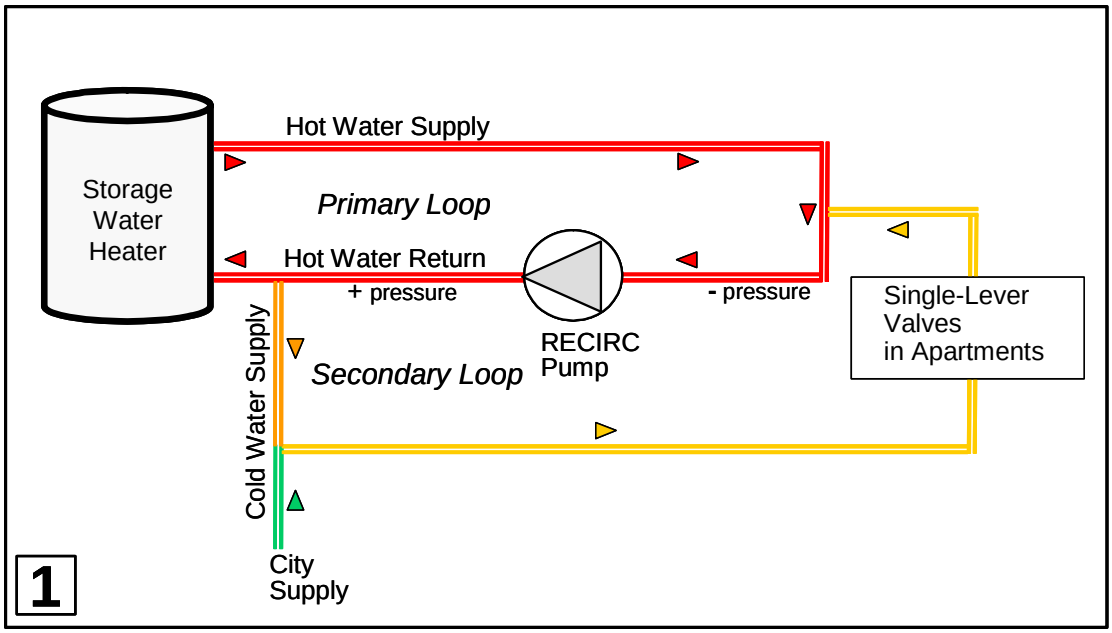

Figure 2: Crossover Flow Induction Without Check Valve

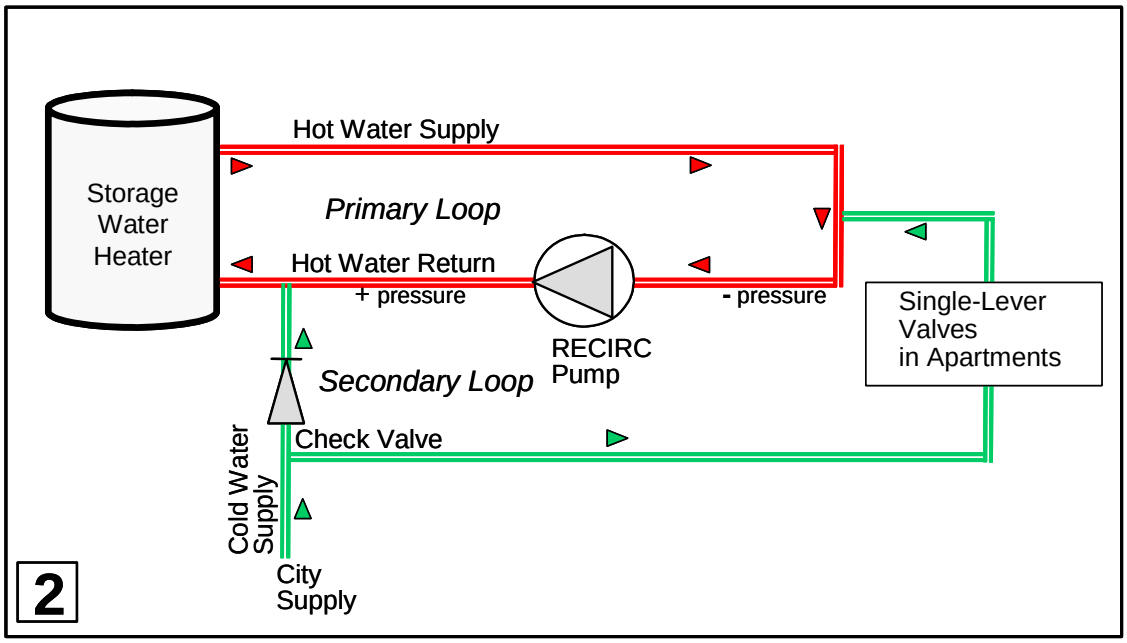

Figure 3. Crossover Flow Induction Eliminated with Check Valve

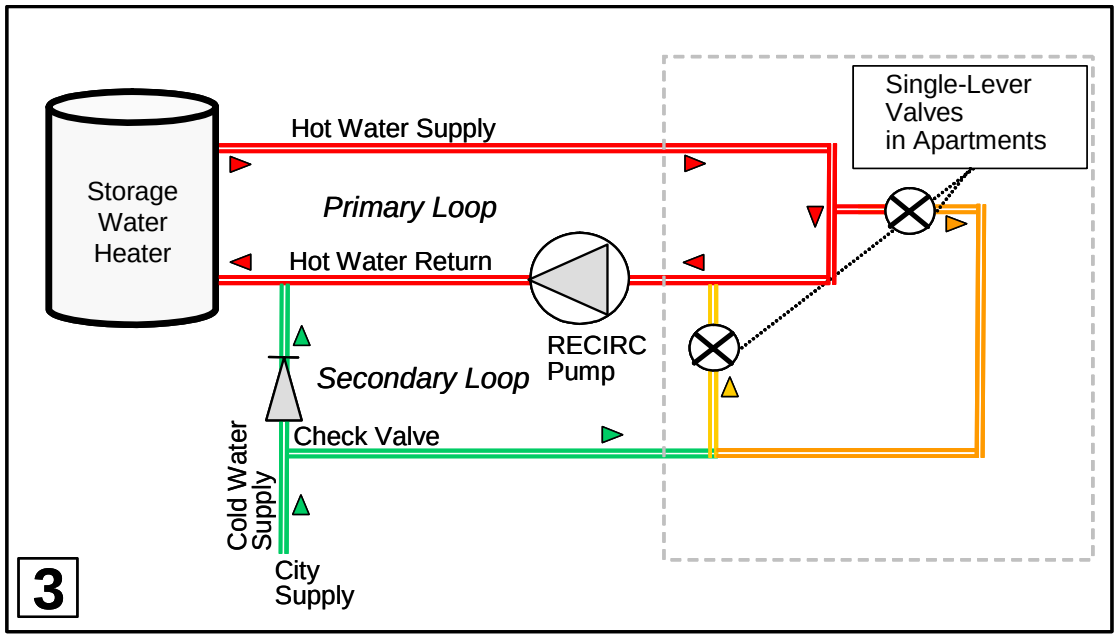

Figure 4. Crossover Flow Induction Across Single Lever Valves in Apartments

Evidence of the crossover problem emerges from the fact that, during periods of zero demand while the pump is on, the HWR flowrate is *greater* than the hot water supply (HWS) flowrate. Additionally, at those times, the CWS flowrate is negative. The logged data from St Helena (Figure 5) shows these exact symptoms[1].

Figure 6 shows time-series data from one overnight logging period at the St Helena site. It is typical of other overnight periods that we recorded. The data show the CWS temperature tracking the hot water tank temperature (e.g., increasing when the tank temperature increases), which is a symptom of crossover. This symptom would also occur due to heat conduction along the copper pipe from the tank to the cold water temperature sensor mounted on the outside wall of the cold water pipe; however, a closer analysis of the data also showed that there was no time lag between the tank temperature changes and the CWS temperature. There would have been a time lag if the rise in CWS temperature (tracking the tank temperature) were due to conduction through the copper pipes, instead of due to water flow. The closer analysis also showed no transient effects that would have been present if the heating of the CWS was due to conduction through the copper.

[1] Note that Figure 5 shows flowrates plotted against "discrepancy in flowrate check" – this value is equal to HWS – (HWR + CWS), i.e. it quantifies the error in the flowmeter readings, since HWS should always be exactly equal to (HWR+CWS) in a closed system.

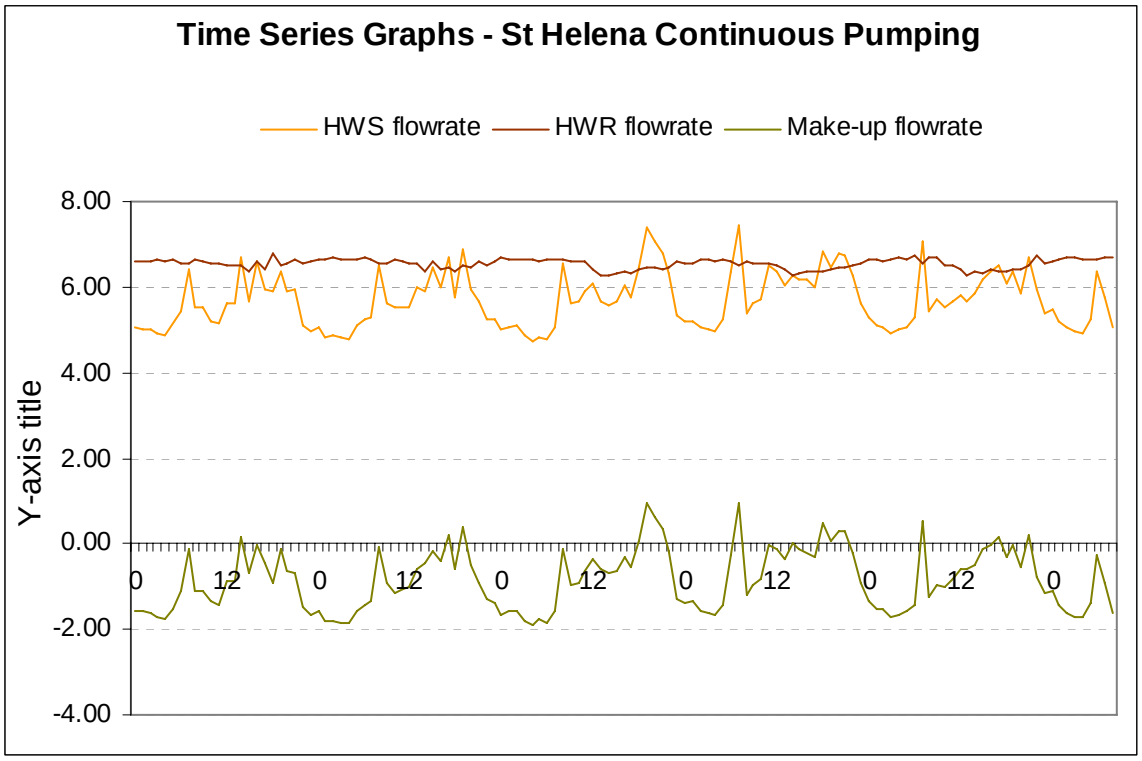

Figure 5 - Logged Flowrate Data - St Helena

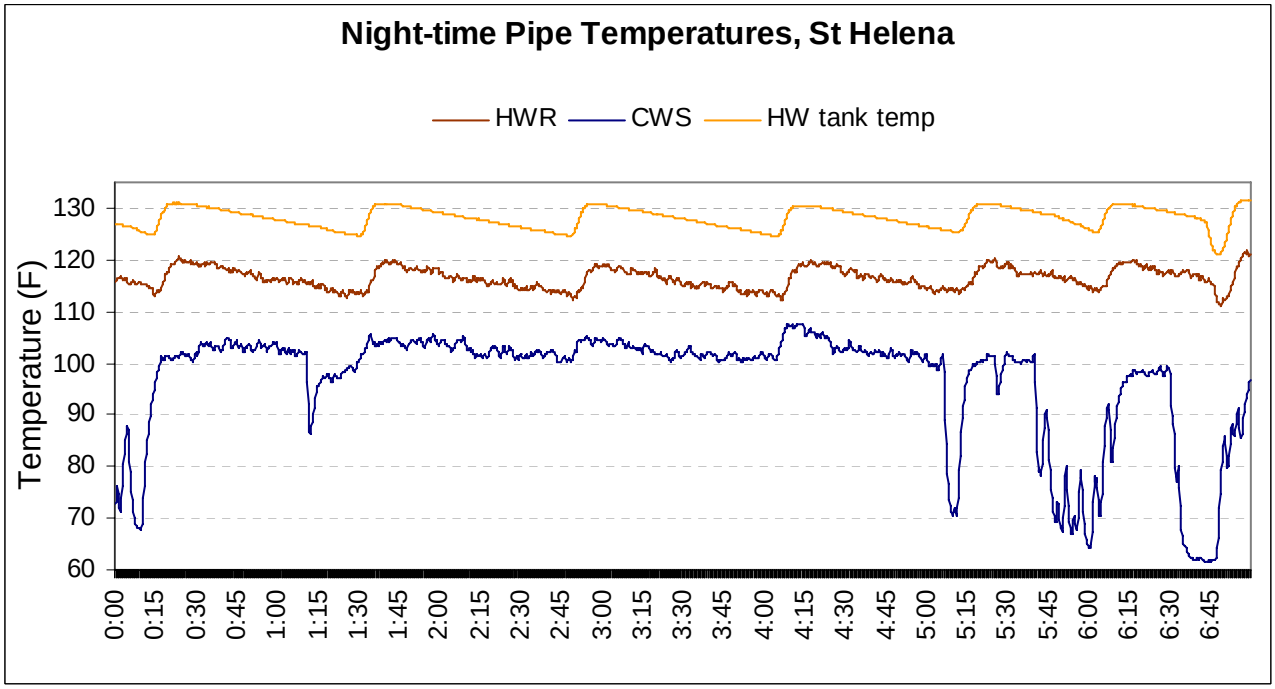

Figure 6 - Night-time Pipe Temperatures, St Helena

3.2 Estimate of Annual Savings from Reducing Crossover

Crossover can be reduced both by installing a spring-loaded check valve on the cold water supply (CWS) line before it tees into the hot water return (HWR) line, and by reducing the connection of hot and cold water lines at single-lever valves (shower mixing valves and single-lever faucets). These two measures together will cause a significant reduction in crossover, but are not expected to completely eliminate it. Also, there are two options for reducing hot and cold water connections at single-lever valves:

- Valves that only allow mixing in a chamber "downstream" from the hot and cold line washers in the valve, and
- Check valves installed in the hot and cold water supply lines leading to the single-lever valves

For the sake of our analysis, we assume that these two options are equal.

In the smaller of the two monitored buildings, estimated crossflow averaged 1.27 gallons per minute, while in the larger building it averaged 2.72 gallons per minute. Both these figures are conservative because several of the control algorithms switched the pumps off for certain periods and therefore reduced crossflow. The figures are also conservative because they do not account for crossflow that does not pass through the cold-water make-up pipe.

To produce a conservative estimate of heat loss due to crossover we multiplied the crossover flow rates by the difference in temperature between the hot water tank and the hot water return pipe. This yielded 2500 Btu/hr at Oakland and 9400 Btu/hr at the (smaller) St Helena site.

These estimates of loss are highly conservative and vary widely between the two sites, so to estimate the energy impact of crossover, we multiply the estimated crossflow (approximately 2 gpm) [2] by a temperature differential of 5ºF between the tank and HWR pipe, and multiply by the embodied energy in that volume of water with that temperature differential. The resulting estimate is that 52 therms per year per apartment are wasted by crossover.

Scaling up to the approximately 40% of new MF construction that has central domestic hot water (CDHW) systems, this represents a loss of 1.2 million therms per year statewide for one year's worth of MF new construction at the current construction rate. We recommend a requirement that all new CDHW systems have (a) a check valve at the cold water supply, and either (b1) check valves on hot and cold water supply lines feeding every single-lever valve in the building, or (b2) no single-lever valves that allow for crossover. We estimate that this combination of measures will reduce crossover by over 90%,[3] saving approximately 1.1 Million therms/year for each year's stock of new MF buildings.

3.3 Economic Impact of Check Valve

We obtained the retail prices shown in the table during a telephone survey of three retail plumbing stores in the Sacramento area. We assumed a retail price markup of 30% to yield the wholesale price to a plumbing contractor. The wholesale cost is the cost to the installing plumbing contractor, and thus the useful cost when considering new construction.

The labor required to install a single check valve is less than 20 minutes. Using a labor charge of $100 per hour yields a maximum labor cost of $35 for this installation.

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[2] It might seem that a conservative estimate of the energy impact of crossover should not start with the **peak** CFR, but the CFR at the time when crossover will be the lowest. However, the peak CFR estimate we have is the lower bound for the peak condition, and we did not have the ability to get a good estimate of either the upper bound for the peak period or the average (or upper or lower bound) for the least crossover periods. It is therefore likely that using the minimum CFR for the peak condition is a fair or conservative estimate of average crossover.

[3] It will not reduce it to zero because of tenant supplied appliances, such as portable dishwashers and clothes washers, or modifications to fixtures beyond the control of the builder or even building management.

The energy saved from this measure (52 therms per year per apartment) has a net present value of $1270. The materials plus labor cost of the measure, per apartment assuming 7 valves per apartment, would be approximately $290. Note that there will also be a cost associated with the main reverse flow prevention valve on the HWR pipe, but this cost is negligible per apartment.

Diam.	Resistance Type	Installation	Retail Price	Wholesale Price
½”	Swing	Sweat	$5.22	$3.65
½”	Swing	Thread	$6.81	$4.77
½”	Spring	Sweat	$8.50	$5.95
¾”	Spring	Sweat	$12	$8.40
1”	Spring	Sweat	$15	$10.50
2”	Spring	Thread	$58	$40.60

Table 1. Typical Costs of Check Valves in the Sacramento Region

4 Prescriptive requirement: Demand or Temperature Modulating Controls

Establish new prescriptive requirement that recirculating hot water systems in multifamily buildings have either temperature modulation controls or recirculation pump demand controls.

4.1 Effect on Gas Consumption

To date, we have detailed data on the operation of two buildings with a variety of controls on the recirculation pump and the water heater. One of the buildings has eight apartment units and the other has 121, see appendix for details of the characteristics of each building. We monitored each building in its base case (continuous pumping), and then with three other control regimes

Building location	**Oakland**	**St Helena**
# apartments	121	8
Total water heater capacity (Btu per hour)	900,000 (3x300,000)	135,000
Base case	**Continuous**: Recirculation pump running 24hrs, burner maintains storage water between set upper and lower temperature bounds	**Continuous**: Recirculation pump running 24hrs, burner maintains storage water between set upper and lower temperature bounds
Regime #1	**Timeclock**: The recirc pump switches off from 1-4 a.m.	**Timeclock**: The recirc pump switches off from 11 p.m.-5 a.m.
Regime #2	**Demand control**: recirc pump switches on if there is demand AND HWR temp is below 104F. Switches off again at 110F	**Demand control**: recirc pump switches on if there is demand AND HWR temp is below 100F. Switches off again at 101F-
Regime #3	**Aquastat**: The recirc pump switches off when the HWR temp reaches 100F, switches off again at 106F	**Temperature modulation**: The recirc pump runs continuously and the setpoint of the storage water varies hourly according to demand data from previous weeks*.

* The burner also switches on if the HWR temperature falls below 100F (to accommodate periods of exceptionally high demand) and switches off if the HWS temperature exceeds 135F (to prevent scalds).

4.2 Annual Savings Estimates

The monitored data for the (larger) Oakland site shows that there are small differences between the four control regimes. The aquastat shows a small increase in gas consumption which we attribute to the normal variation in usage from one week to the next. The 5% saving from the demand controller equates to 816,000 Btu/yr compared with the base case.

	Weekdays	**Weekends**	**Average week**	**Savings compared to continuous pumping**	**Annual savings/unit vs. Continuous (MBtu)**
Continuous pumping	0.14	0.14	0.14	0%	
Aquastat	0.15	0.13	0.14	-5%	-0.47
Timeclock	0.14	no data	0.14	-1%	-0.01
Demand	0.13	0.12	0.13	5%	0.49
Average	0.14	0.13	0.14	N/A	

Figure 7 – Burner on-time – Oakland summary table

The monitored data for the (smaller) St Helena site shows quite large variations in gas consumption between the four regimes. The highest savings are achieved by demand controls, which would save

an average of 9.15 MBtus per apartment per year. Demand controls in the larger building only save an average of 0.8 MBtus per apartment per year.

Since smaller buildings have more down time (i.e. time during which there is zero demand), we expected that the savings from demand controls would be more in the smaller building than in the larger. The data from our monitoring study provides evidence for this effect. Consequently, the savings possible from a demand control system are less (on a per unit basis) for a system serving a large number of apartments than one serving a small number. HMG is monitoring a third building with 20 apartments no the loop, and data from this building will provide a third data point that will allow us to estimate the relationship between system size and savings.

High savings are also achieved by temperature modulation controls in the smaller building. These savings cannot be compared between the two buildings because this system could not be installed in the larger building, but we see no reason to believe that similar savings could not be achieved in the larger building. Logged data from EDC Controls suggests that temperature modulation controls can achieve significant savings in a wide variety of building types. EDC's data shows an average of 27% savings.

	Weekdays	**Weekends**	**Average week**	**Savings compared to continuous pumping**	**Annual savings/unit vs. Continuous (MBtu)**
Comtinuous pumping	0.14	0.14	0.14	0%	0
Demand	0.08	0.06	0.08	44%	9.15
Timeclock	0.14	0.13	0.14	1%	0.30
Temperature modulation	0.09	0.10	0.09	35%	7.26

Figure 8 - Burner on-time – St Helena summary table

The table below provides estimates of the therm savings statewide from a Prescriptive Requirement for CDHW systems in new multifamily construction to have either a demand control or a temperature modulation control. The calculation assumes that half of the new projects choose demand control and the other half choose temperature modulation.

There are currently about 60,000 new multifamily units built per year in California and our research indicates that about 40% of those will have a CDHW system.

Statewide Savings Estimate for Demand Controls and Temperature Modulation Controls			
# of MF new const/yr		60,000	
Percent that have CDHW		40%	
Assumed % to use Demand Control		50%	
Demand controls		**Temperature modulation controls**	
Lower bound of savings (Btu/unit)	490,000	Lower bound of savings (Btu/unit)	0
Upper bound of savings (Btu/unit)	9,150,000	Upper bound of savings (Btu/unit)	7,260,000
Lower bound of stwd. savings (Btu)	5,880,000,000	Lower bound of stwd. savings (Btu)	0
Upper bound of stwd. savings (Btu)	109,800,000,000	Upper bound of stwd. savings (Btu)	87,111,000,000
M therms (lower bound)	58,800	M therms (lower bound)	0
M therms (upper bound)	1,098,000	M therms (upper bound)	871,000

Figure 9: Statewide Energy Savings Estimate for Demand Controls and Temperature Modulation Controls on CDHW Systems

4.3 Economic Impact

4.3.1 Economic Impact of Temperature Modulation Controls

The cost for a Temperature Modulating controller depends on the size and complexity of the hot water system and the desired controller features. The retail cost for the ProTemp model PT-64, a typical controller suitable for a small building (up to approximately 30 units), is approximately $750. The retail cost for the ProTemp model PT-76, a typical controller suitable for larger buildings, costs $1900. Installation, start-up, and programming time for each of these models is less than two hours by an experienced installer, assuming they have the necessary components and common tools readily available. The total installed cost is therefore around $2100 per system.

The savings from temperature modulation controls (up to 7.3 MBtu per apartment per year) have a net present value of $1779. Assuming that 20 apartments are controlled by the system this yields a net present value of $17,790.

4.3.2 Economic Impact of Demand Controls

The small market for demand controls at present makes it difficult to quantify the cost of systems. The demand control system used in the monitored sites costs approximately $1100, with a $100 per month lease charge thereafter. The initial $1100 cost includes a specialized pump with flanges and isolation valves, the controller, and 4-6 hours of installation and setup time.

The savings from temperature modulation controls (up to 9.1 MBtu per apartment per year) have a net present value of $2230. Assuming that 20 apartments are controlled by the system this yields a net present value of $22,300.

4.4 Current Availability and Use of Recirculation Controls

4.4.1 Control Types

Data gathered from the Architects, Plumbing Engineers, Energy Consultants, and Developers shows that temperature controls ('aquastats') that switch the burner on or off based on temperature, are the most commonly specified of all the control systems. Data gathered from Contractors shows the same trend – that Temperature controls are more commonly installed compared to other types of controls. Data gathered from Distributors however indicates that Timer Controls are the most commonly sold. This could either mean that a large number of Timer Controls are purchased after construction and installed without professional help, or that this data set is not large enough to draw a firm conclusion.

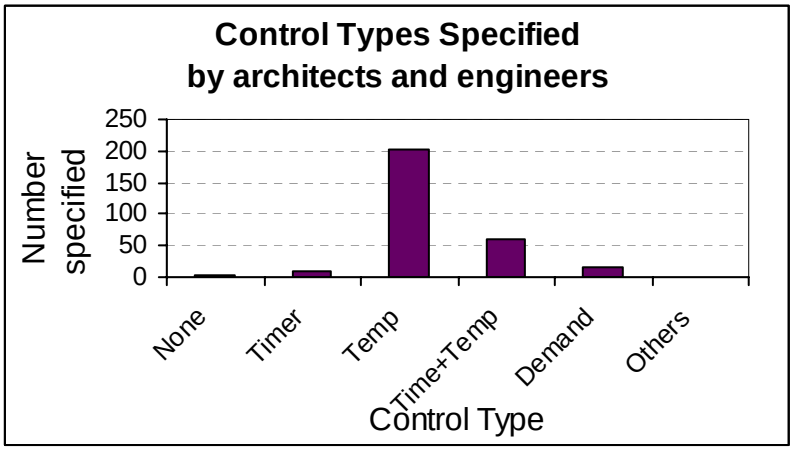


Figure 10. Control Types Specified

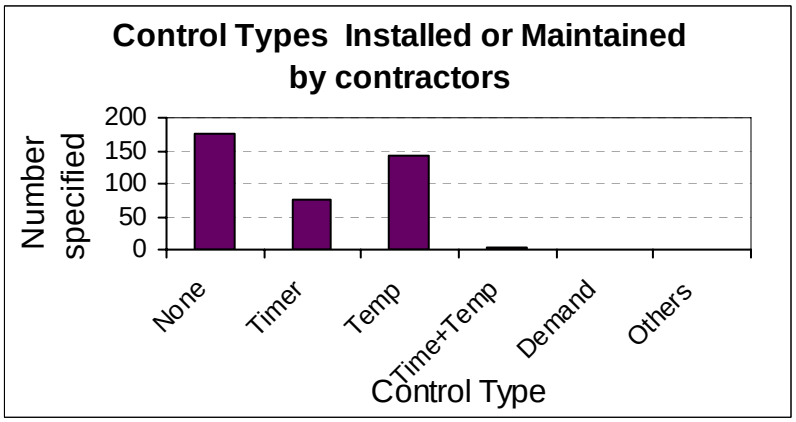


Figure 11. Control Types Installed or Maintained

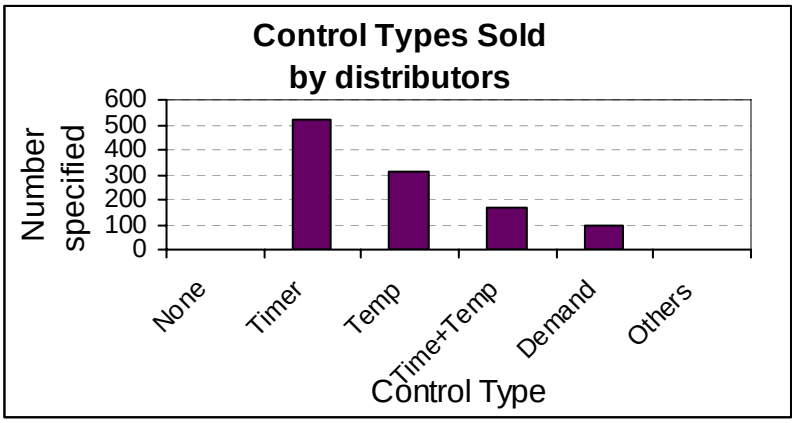


Figure 12. Control Types Sold

4.4.2 Availability of Controls

The respondents indicated that most recirculation controls were readily available, with a lead time of 1 day to a maximum of 3 days in case of an unusually busy time. According to the Contractors, this was true for the Timer, Temperature and the Timer + Temperature controls. They were unable to comment on the Demand or other controls (such as ProTemp). The Distributors however indicated that Demand controls were just as readily available. This applies to markets that have a demand for central water heating systems and controls and distributors that deal in these.

The following manufacturers and plumbing suppliers were mentioned as sources for the controls for the recirculation loops in the central water heating systems by the plumbing contractors and design team professionals we surveyed:

Johnston
Howard Industries
Raypak
Rheem
Pace Supply
HK Ferguson
Todd
Slakey Brothers
Hajoca

4.4.3 Cost of Controls – Parts

There is no fixed cost for the controls as it depends on the size and location of the job. It became obvious that asking for the cost of a temperature modulating control, for example, was a bit like asking "how long is a piece of string?" The cost quoted for a timer control ranged from $35 to $100. Temperature controls ranged from $23 to $100 each. Time + Temperature controls ranged between $58 and $200. One source quoted a Demand Control at $100 while other sources could not provide a value for it. One plumber told us that demand controls are essentially free because recirculation pumps with a demand control are the same price as those without it. Temperature Modulating controls for the ProTemp model PT-64 suitable for a small building (up to approximately 30 units) cost $750 and the ProTemp model PT-76 suitable for larger buildings costs $1902.

Other additional costs are very small compared to the project budget. The relatively low-cost additional items could include additional valves, regulators, pipe fittings, or a different size/type of pump, among others.

4.4.4 Cost of Labor to install controls

We obtained data for installing Timer, Temperature and Timer + Temperature controls. The average time quoted for the job was 1 hr to 2 hrs, and the cost was $95 to $190. One plumber told us that there is no additional labor cost for installing demand controls. It appears that installing controls as a retrofit may incur a cost as indicated above, whereas installing the control as part of a new system installation may not incur the additional cost.

4.4.5 Additional Savings from Controls

Data from manufacturers shows savings but some plumbing contractors dispute whether any savings actually materialize. Often the controls are not set up correctly, or are (intentionally or

unintentionally) modified. When this causes tenant complaints, the controls are decommissioned. More hard data is required on additional savings from the controls and the persistence of these savings.

4.4.6 Calibration Required for Controls

Once the time or temperature, or time/temperature schedule has been set on the controls, no further calibration is usually required for the Timer, Temperature or the Timer + Temperature controls, according to the respondents. Similar data could not be obtained for the Demand control, but sources at one control manufacturer that makes and installs temperature modulation controls, and also installs remote monitoring of system performance, indicated that they will reset schedules and/or temperatures when usage patterns so indicate.

4.4.7 Maintenance Required for Controls

According to most respondents, the controls do not require maintenance. One source stated that controls should be checked once every 6 to 12 months. Another source stated that temperature controls typically do not require maintenance, but timer controls need to be checked, and reset every spring and fall according to the changing time table of the residents. Time required for a typical maintenance call is 1 to 2 hours according to the Contractors. The cost to the owner was quoted variously as $85 or $180.

As mentioned above, operation of one type of temperature modulation control is monitored remotely by the manufacturer. This data allows the manufacturer to pinpoint when there is a system failure – even if the failure is in a portion of the system (e.g., the boiler or pump) that they do not manufacture. The manufacturer then dispatches recommendations for system maintenance to the property owner or his/her designee so that the failing equipment can be fixed or replaced.

5 Modeling: Heat loss from recirculation loop

At present the Heat Adjusted Recovery Load (HARL) equations in the Alternative Compliance Methods (ACM) Manual provide a very rough approximation to pipe heat loss because they assume a constant temperature along the entire pipe. We propose a revision to the HARL equations to more closely model heat loss from the recirculation loop. The HARL equations also include adjustment factors for the control system, which should be revised to include the new prescribed control system types. We propose that the revision of the HARL equations should include the following steps:

- Validation of Title 24 2005 Heat Adjusted Recovery Load (HARL) Equation. HARL was based on 1992 HWSIM model developed by Davis Energy Group.
- Development of Improved Heat Loss Algorithms
- Inclusion of Environmental Conditions in Heat Loss Algorithms. Temperature of incoming water and gas, as well as outside air temperature.

6 Modeling: Draw schedule for hot water

6.1 Magnitude of draw

Monitored data shows that the overall magnitude of hot water usage at the two sites is in line with the 65 gallon per day figure assumed in the 2005 standards. The smaller building has a higher draw than predicted, and this is likely to be due to the large number of children observed at the site, and perhaps

to the agricultural work carried out by many of the residents. The larger building has a slightly lower draw than predicted, and there was no particular demographic characteristic observed at the site.

6.2 Shape of Draw Schedule

At both sites the shape of the daily draw schedule showed a less pronounced morning peak than the 2005 Title 24 schedule (see Figure 13, note that all schedules have been normalized so the area under each curve is the same). This is likely to be because residents of multifamily housing are less likely to have "traditional" 9-5 working hours than residents of single-family houses.

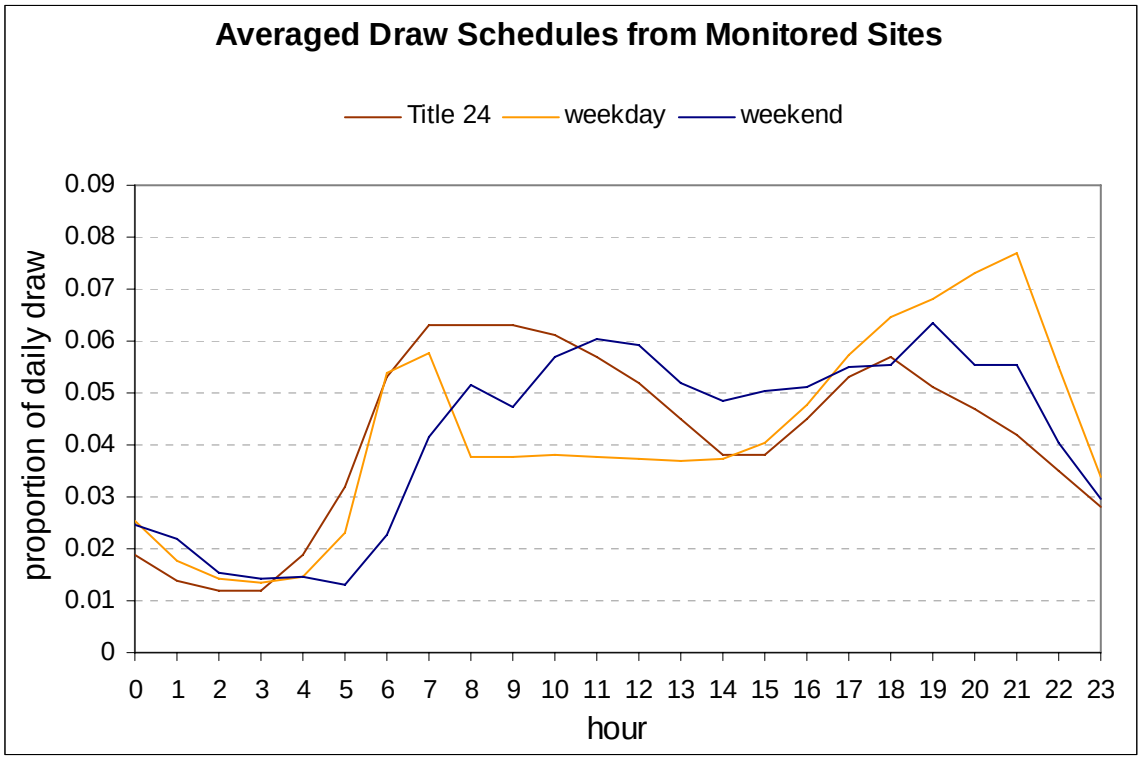


Figure 13 – Weekday and weekend draw schedules for the two monitored buildings, compared with Title 24 2005 residential draw schedule

6.3 Effect of Controls on Draw Schedule

In both buildings the *amount* of hot water used was reduced by adding the control systems. The greatest reduction was produced by the demand system (61% at St Helena, 35% at Oakland), then the timeclock system (49% and 25%) and the temperature modulation controls (40% and 19%). We expected that amount of hot water would be reduced by the timeclock and the demand systems because they are shutting off the recirculation pump and therefore eliminating crossflow, but we did not expect the temperature modulation control to reduce the amount of hot water used.

Recommendations

1 Proposed HARL Equations

The HARL equations should be adjusted in the light of further data analysis from this project and from others involved in the current LBNL hot water research, in time for the 2008 Title 24 revisions.

2 Proposed Adjustment Factors and Controls Credits

The adjustment factors and controls credits should be adjusted in the light of further data analysis from this project and from others involved in the current LBNL hot water research, in time for the 2008 Title 24 revisions.

3 Proposed Daily Draw Schedules

A multifamily-specific draw schedule should be developed from the monitored data from this project ,and from other research sources, in time for the 2008 Title 24 revisions.

4 Proposed Water Heating Budget

Using monitored data from this project we will develop a proposal that quantifies the effect of the number of bedrooms (in addition to the number of dwellings) on heating budget.

5 Proposed Verification

For the proposed measures, a combination of construction inspection and Performance Testing would be required to ensure that the system is operating adequately.

5.1 Verification Requirements

Check valves:

- Construction Inspection: Insure check valves are present as necessary, according to the plans, are of the specified type and size, and are installed in the correct flow direction.

Water measurements:

- Construction Inspection: When multiple hot water recirculation loops are driven by a single pump, it is recommended that the system should be balanced per the procedures defined by the Testing Adjusting and Balancing Bureau (TABB) National Standards.

Air release valve:

- Construction Inspection: Insure air release valves are present as necessary, according to the plans, are of the specified type and size, and are installed in the correct orientation.
- Testing: Test the equipment and verify the correct operation.

Recirculation pump:

- Construction Inspection: Insure recirculation pumps are present as necessary, according to the plans, are of the specified type and size, and are installed in the correct flow direction.

Control Systems:

- Testing: Test that all the sensors are communicating with the controller correctly. For temperature modulation controls this includes the pump operation signal (pump on and off) and the temperature sensor(s). For demand controls this includes the flow sensor and temperature sensor(s).
- Testing: Test that the system is functioning within the bounds established by the design documents.

Hot water pipe insulation:

- Construction Inspection: Insure pipe insulation is present as necessary, according to the plans, and is of the specified type and size. Insure insulation is continuous and no gaps are present between sections.

Material for Compliance Manuals

This list will be updated further as the project progresses.

1. Add the following choices to Table R3-9 of the Res ACM.

Table R3-9 – Multiple Dwelling Unit Recirculating System Control Choices

Distribution System Measure	**Code**	**Description**
Temperature Control	RTmp	Recirculation system, with an aquastat control to switch recirc pump on and off
Timer/Temperature Control	RTmTmp	Recirculation system, with a timeclock and temperature control
Temperature Modulation Control	RTmpMod	Recirculation system, with the water heater temperature setpoint controlled to vary the intensity depending on the load
Demand Control	RDmd	Recirculation system, with demand control on the recirc pump

2. We will revise the equations for the calculation of Hourly Adjusted Recovery Load (HARL) in Appendix RG (Water Heating Calculation Method) of the Res ACM. The equations will change to reflect a more accurate calculation of the Hourly Recirculation Distribution Loss (HRDL), which is a component of the HARL.

3. Based on our hot water draw schedule research, we will propose a new table with hourly fractions specifically suited to multifamily buildings. This table would be in addition to Table RG-1 (Hourly Water Heating Schedule) in Appendix RG of the Res ACM that can be used for single family homes.

Future Work

1.1 Additional Research

There is a significant amount of additional research that is needed on this topic. For example, although the data set leading to the recommendations in this report are extensive in terms of evaluating the impact of several control strategies in a number of settings, clearly the sample size is not sufficient to be definitive. We recommend a replication of this research on a much larger set of buildings, with a larger variety of hot water system types. At a minimum, twenty more buildings should be monitored including:

- High-rise MF (both for-sale and for-rent)
- Single room occupancy buildings (this is an expanding segment)
- Senior MF housing
- Buildings with multiple, staged boilers
- Buildings with boilers with OEM modulating controls
- Buildings with water heaters
- Boilers or water heaters located outside the building
- Systems with underground piping

Future work should also determine the extent of seasonal variations in:

- Hot water demand
- Heat loss and system performance based on outside air temp
- Cold water temp and its impact
- Gas consumption based on the above factors and gas delivery temp

A more extensive economic analysis also needs to include seasonal variations in gas prices and pricing structures. This analysis, for example, should include the forecast cost of propane in the areas of the state not served by natural gas.

1.2 Acceptance Testing Protocols

Protocols need to be established, and added to the Residential Compliance Manual, for Acceptance Testing for central water heating features that are mandatory or prescribed. Currently, absence of an Acceptance Testing protocol results in violations of the code going unnoticed.

1.3 Commissioning and Monitoring

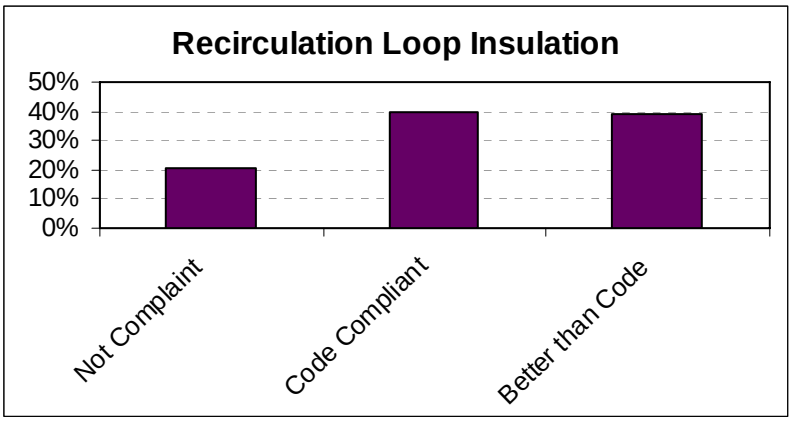
For the 2011 standards it may be desirable to move toward a goal of requiring permanent monitoring and "continuous commissioning" of controls, given the expected continuing reductions in the cost of collecting, transmitting and storing monitored data on installed systems. This data will be a great asset for future research and Code change proposals.

Before monitoring of installed systems can be required by Code, the benefits of monitoring must be established in field trials, perhaps in conjunction with existing logged data from controls system vendors.

1.4 Recirculation Loop Insulation

Data collected from Architects, Plumbing Engineers, Energy Consultants, and Developers shows that recirculation loop pipes are usually insulated either to code or better than code, depending on the location of the pipes.

In some cases however, the pipes are not insulated, which is a violation of the code. However, prior to the 2005 revisions to the Building Energy Efficiency Standards, this code requirement was arguably ambiguous. None of the Building Departments surveyed have kept a copy of the plumbing drawings for MF buildings after a project has passed its final inspection. Some Building Departments check the plumbing drawings set at the time of processing the permit, but even this is not always the case. As a result, if there is a code violation, such as lack of the mandatory minimum insulation in the recirculation pipes, it is practically impossible to check it once the project has been built and the pipes are buried. It was evident during the surveys that knowledge of this fact resulted in a degree of complacency among the developers and plumbers regarding pipe insulation.



Developing an Acceptance Testing protocol for recirculation loop insulation will result in savings. The cost to insulate pipes was quoted as 25 cents to 47 cents per linear foot by one source.

1.5 Vent dampers

Vent dampers are currently not required by code, and may present a significant opportunity for energy savings at low cost.

1.6 Other Features Recommended for Future Acceptance Testing

- Verify Hot Water Supply and Hot Water Return temperatures are in acceptable range
- If multiple recirculation loops exist on a single system, then verify that each pump size is properly balanced for each loop.
- Verify flow sensor operates properly in a Demand Control system

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Abrams, Donald W and Alan C. Shedd. 1996. "Effect of Seasonal Changes in Use Patterns and Cold Inlet Water Temperature on Water-Heating Loads." ASHRAE Winter Meeting Vol. 102, Pt. 1. Atlanta.

This paper presents long-term test data obtained from 20 commercial buildings and 16 residential sites. This data illustrates the substantial effects of variations in hot water load determinants on energy use, annual system performance, and utility costs. The

data is meant to compliment load profiles of the ASHRAE Handbooks and other design references. Authors, Donald W. Abrams and Alan C. Shedd of D.W. Abrams of P.E. & Associates of Atlanta, conclude that daily hot water use varies greatly from annual average figures, that the design and performance analysis of water heating systems should include consideration of variations in cold inlet water supply temperature on a monthly basis (not just annual), and that the potential performance of alternative high-efficiency water heating systems may be more affected by variations in load and cold inlet water temperature than their conventional counterparts.

Baskin, Evelyn and Robert Wendt. 2004. "Numerical Evaluation of Alternative Residential Hot Water Distribution Systems." ASHRAE Annual Meeting, Vol. 110 Pt. 2: 1-11.

This report, based on the numeric simulation of four different hot water distribution systems in a conventional home in three different locations, found that system configuration and location as well as pipe material and insulation will noticeably impact the performance of distribution systems. The authors conclude: demand recirculation systems and parallel pipe systems made of PEX reduce waiting time for hot water as well as energy use and water waste, adding pipe insulation is only effective if hot water uses are clustered around a short time frame, attic distributions systems should not be insulated (in addition to the existing attic insulation), and copper pipes are less effective in retaining heat when located below the floor slab than clustered.

Becker, B.R., W.H Thrasher, D.W. DeWerth. 1991. "Comparison of Collected and Compiled Existing Data on Service Hot Water Use Patterns in Residential and Commercial Establishments." ASHRAE Annual Meeting Vol. 97 Pt. 2: 231-39.

This paper summarizes the results of the phase 1 ASHRAE research project RP-600 on hot water use, extensively reviewing the existing published data, creating a database on hot water consumption in commercial and residential buildings, and in turn, using this data to determine where current data is inadequate. For commercial buildings, the following buildings types were analyzed: dormitories, hospitals, hotels, laundries, nursing homes, office buildings, recreational facilities, restaurants and schools. For residential buildings, single- and multifamily houses were analyzed.

Becker, B.R., and K.E. Stogsdill. 1990. "Development of a Hot Water Use Database." ASHRAE Vol. 95 N. 2: 422-27.

Understanding that the values used for sizing and performance of water heaters are conservative and produce 'inaccurate results,' authors Bryan Becker and Kevin Stogsdill of the University of Missouri, Kansas City, study the factors that influence domestic water heating, so as to provide a basis for updating data on domestic hot water system use patterns. As a result of this research, a database was developed for hot water use which included: system characteristics, hot water use patterns (hourly, daily, and seasonally), and demographic and climatic factors. Results of this study are consistent with others of its kind, however, this study covers a broader range of use patterns. The study found overall hourly peak use and average daily use higher than reported by ASHRAE.

Buderus Hydronic Systems. n.d. "Logamatic Control HS2105." Product Specifications. Salem, NH. http://www.buderus.net/. (accessed June 16, 2006).

The State of California, Department of Water Resources, Division of Planning and Local Assistance. 1998. "Technology in Water Management," in *The California Water Plan Update: Bulletin 160-98*. (PDF Version of document downloaded from http://rubicon.water.ca.gov/pdfs/b160cont.html June 15, 2006).

This chapter of the "California Water Plan Update" from the State of California, discusses the present status and anticipated future development of water management technologies. The State concludes that desalting technologies can only meet a small market due to high cost. As a result, it highlights: 1) demand reduction technologies (landscape irrigation, residential indoor water use, interior CII water use, agricultural water use technologies); 2) water treatment technologies (recycling, desalting, treatment of contaminated groundwater); 3) water supply/flood control technologies (inflatable dams, weather modification, long term weather forecasting); 4) and environmental water use technologies (wetlands management, real-time water quality measurement, fish screen technologies, temperature control technology); as viable other technologies.

California Energy Commission. Mar. 2002. "Life Cycle Cost Methodology." *2005 California Building Energy Efficiency Standards.* (PDF Version of document downloaded from http://cacx.org/title24/2005standards/archive/rulemaking/documents/document_list.html June 16, 2006).

This report summarizes the results of initiatives to improve the 2001 California energy efficiency standards for residential and commercial buildings. This document is the first part of a two part report, containing four measures analyzed by the CEC: nonresidential lighting, HVAC (Demand Control Ventilation, DCV), residential construction quality of walls, and water heating distribution systems. Of special interest to HMG's report, the CEC recommends that the modeling methodology of water heating distribution systems be revised (as to better be able to determine domestic hot water energy load and in turn better reflect actual conditions), that distribution system multipliers be updated (given the new costs of distribution systems and new range of representative buildings), and that adding a mandatory requirement for parallel piping to prescriptive requirements be considered.

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California Public Utilities Commission. "DEER Database." (accessed November 2005).

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Diamond, Rick. 1995. "Energy Savings Rise High in Multifamily Buildings." *Home Energy Magazine Online*. Sept/Oct. http://www.homeenergy.org/ (accessed June 12, 2002).

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EDC Technologies, Inc. Company and Technology Description. Sebastopol, CA. http://www.savgas.com/. (accessed June 16, 2006).

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U.S. EPA. 2006. "Estimating Potential Savings from Demand Controlled Pumping Systems."

Eley, Charles. May 2004. "Residential Water Heating Hourly Calculations." Presentation at the CEC Workshop May, 30 2002.

Energy Management and Control. "Pro-Temp Controllers." Product Features. http://savehotwater.com/.

Goldner, Frederic S. 1996. "Try These On for Size: New Guidelines for Multifamily Water Heating." *Home Energy Magazine Online*. Jul/Aug. http://www.homeenergy.org/. (accessed June 12, 2002).

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Author, Frederic S. Goldner, founding principal at Energy Management and Research Associates, argued in this article that the significant energy cost of providing a continuous stream of hot water to top-floor tenants can be significantly reduced with the use of a simple return line aquastat.

Hendron, Bob and Paul Reeves. Apr. 2004. "Domestic Hot Water Benchmark for Building America." Presentation at the IBACOS Residential DHW Expert Meeting. Pittsburgh, PA.

In this presentation, authors Hendron and Reeves discuss DHW benchmarking based on end-use consumption, hourly DHW profiles and the mains temperature equation. The second part of the presentation demonstrates how to get from the Building America specifications of DHW systems or from manufacturers specifications to the inputs needed for annual simulation of DHW data. This presentation is part of a report published by Building America, "Expert Meeting Summary Report: Efficient DHW Systems."

Heschong Mahone Group, Inc. Feb. 2004. "Multifamily DHW Case Project." Meeting Notes. Sacramento, CA.

---. Dec. 2005. "PIER Water Heating Research Opportunities: Lessons from the Statewide Hot Water PAGette." Submitted to the California Energy Commission.

In this report, the Heschong Mahone Group Inc. focuses on the subject of water heating research. This report does not directly assess the so-called "Water Heating PAGette –" a Southern California Gas Company (SCG) and National Resources Defense Council (NRDC) convened panel of experts on water heating issues for IOUs – but instead focuses on the necessity of research in this field. Research recommendations are made for 1) water heating technologies (solar water heating, tankless water heaters, demand response electric water heaters); 2) hot water distribution (single family residential, multifamily residential); and 3) market assessment.

Honeywell Inc. 2001. "L4081A, B and L6081A,C Multiple Aquastat Controllers." Product Data. (PDF version of document downloaded from customer.honeywell.com/request.cfm?form=60-2105 June, 16 2006).

IBACOS Inc. Jun. 2004. ""Expert Meeting Summary Report: Efficient DHW Systems." Building America KAAX-3-33410-04. (PDF version of document downloaded from www.ibacos.com/.../Whole%20House/KAAX-3-33410-04. B.2%20-%20Expert%20Meeting%20Summary%20Report.pdf).

In Collaboration with the DOE and NREL, IBACOS Inc. (Integrated Building and Construction Solutions), consultants of the basic science of home performance and best construction practices and processes in Pittsburgh, PA, wrote this paper in preparation for a major meeting in new technologies in domestic hot water systems. This paper contains a short background section on domestic hot water systems, the meeting logistics and objectives, and a list of presenters with a summary of each presentation given on April 8, 2004.

Jordan, Ulrike and Klaus Vajen. May 2001. "Realistic Domestic Hot-Water Profiles in Different Time Scales." Marburg, Germany: Universität Marburg.

This paper presents and compares realistic domestic hot water load profiles in three time scales: 1 minute, 6 minutes and 1 hour. Researchers, Ulrike Jordan and Klaus Vajen of the University of Marburg, Germany carried out this study within the Solar Heating and Cooling Program of the International Energy Agency (IEA SHC). The 1 min. time scale was chosen to account for realistic conditions, the 6 min. to carry out simulations with time steps higher than 1 min., and the 1 hour to enable the simulation of large solar heating systems with simulation times higher than 6 min.

Koeller and Co. Aug. 2004. "A Report on Potential Best Management Practices." Prepared for the California Urban Water Conservation Council. Yorba Linda, CA.

This is the first annual report of a three year report on urban water use best practices. Four potential best management practices were studied: pre-rinse spray valves for the food service industry, x-ray film processor recycling units, steam sterilizer retrofits, and residential and small commercial weather-based irrigation controllers.

Lobenstein, Mary Sue. 1993. "Controlling Recirculation Loop Heat Losses." *Home Energy Magazine Online*. Jan/Feb. http://www.homeenergy.org/ (accessed June 12, 2002).

This article recommends the use of attached recirculation loops as an alternative to regularly turning the hot water pump off to save energy and cost. The author, Mary Sue Lobenstein, concludes, that the demand based control system is probably a better strategy (in comparison with a time-based control system, in terms of savings) and that a monitoring service be present after installation to ensure best performance of the system.

--- and Martha J. Hewett. 1995. "The Best Boiler and Water Heating Retrofits." *Home Energy Magazine Online*. Sept/Oct. http://www.homeenergy.org/ (accessed June 12, 2002).

This article presents the best retrofitting practices for boilers and water heaters in multifamily buildings. The focus of this study was the region of Minneapolis-St. Paul. Three types of retrofits were researched: steam building retrofits, hot water heating building retrofits, and domestic hot water retrofits. Authors, Mary Sue Lobenstein and Martha Hewett, determined that the key to program success is not only the confirmed energy savings and retrofit performance, but a comprehensive implementation program. In addition, they encouraged the development of convenient services to identify retrofit options for building owners and small financial incentives to ensure a high rate of installation in a market largely driven by first costs.

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Pacific Gas and Electric Company. May 2002. "Code Change Proposal for: Hourly Water Heating Calculations." *Codes and Standards Enhancement Initiative.* (PDF Version of Document downloaded from http://cacx.org/title24/2005standards/archive/rulemaking/documents/document_list.html June 16, 2006)

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---, Heschong Mahone Group, and Nehemiah Stone. 2002. "Multifamily Domestic Hot Water." Presentation at the CEC Workshop May 2002.

Padian, F.L Andrew. 1999. "Fuel Use in Multifamily Buildings." Nov/Dec. *Home Energy Magazine Online*. http://www.homeenergy.org/. (accessed June 12, 2002).

In this article, Andrew Padian, a housing specialist with Steven Winter Associations, a building systems consulting firm, discusses fuel use in multifamily buildings. Padian explains the 14,000 unit survey of New York City's low income multifamily buildings in detail, revealing that these buildings were consuming large amounts of energy for

heating and domestic hot water. He concludes that fuel use analyses of a building should be mandatory at the beginning of any building investigation, that high fuel use for heating is generally caused by overheating and the lack of night set-back controls, and that unnecessary fuel use does not depend on age, orientation, number of floors, number of apartments, or type of fuel used in the building, but instead relies heavily on the management and maintenance of the building.

R.F. MacDonald Co. 2002. "A Robust, Highly Efficient Multi-Stage Pump." *Boiler and Pump Talk.* Winter Ed.

Rittlemann, William. Jul. 2004. "Field Investigation of 18 Solar-Assisted Domestic Hot Water Systems with Integral Collector Storage." *Building America: Journal or Conference Papers: Domestic Hot Water (DHW).*

This field investigation was executed to validate the energy performance of the solar assisted residential hot water systems (DHW) of the community of Civano in Tuscon, AZ. 18 homes were monitored over a 15-to 24-month period, including 9 systems with electric water heaters and 9 systems with gas-fired water heaters. The energy impacts of pipe-lengths and hot water recirculation systems are also examined. The results of the investigation found that systems with extensive piping consume as much as 200% more energy than the 'best systems' and that recirculation systems with ICS consume as much as 600% more than a non-solar DHW systems. For the HMG study, we are particularly interested in the main water temperature data found in this report.

Sahagian, Tom and Norine Karins. 1997. "Multifamily Research Gets in Hot Water." *Home Energy Magazine Online*. Jul/Aug. http://www.homeenergy.org/ (accessed June 11, 2002).

Salzberg, Edward. Sept. 2001. "The Effect of the Hot Water Distribution System on Water Heating Operations." *Plumbing Engineer.* 43-50.

In this article, Author Edward Salzberg argues that the quality of hot water distribution systems has a significant impact on the operation of the water heater assembly and that without an appropriate hot water maintenance system, the normal water heating criteria are 'invalid.' Sallzberg also argues that the 100 foot length limitation criteria for hot water circulation systems is no longer valid due to the extreme escalation in water and energy costs and the implementation of sewer surcharge fees for water.

Schultz, W.W. and V.W. Goldschmidt. 1983. "Distribution Efficiency and Characteristics of Start-up and Shutdown of Flow in Hot Water Distribution Lines." ASRAE Trends Vol. 89: 42-60.

This study is motivated by the losses in the distribution line of a residential hot water system. Two cases were studied using theoretical analysis and experimental data: the unsteady, 'no-flow' condition, in which the heat in the distribution line is gradually lost to the surroundings, and the unsteady, 'start-up' condition. It was found that the parameters with the largest effects are: tubing diameter, length, insulation, and the draw schedule.

Stewart, William E, Charles K. Saunders, Carol L.G. Dona. "Part I: Field/Laboratory Experiments and Simulation Model." *Evaluation of Service Hot Water Distribution Systems Losses in Residential and Commercial Installations.* Atlanta: ASHRAE, 1999.

This paper is the first part of a two part series on hot water system heat loss. This paper summarizes field and laboratory experiments of heat loss in various piping systems. The experiments included insulated and non-insulated tubing over a range of flow rates and inlet water and ambient temperatures. In addition, a numerical model was developed to simulate the heat losses as to be applicable to other systems of piping

---. "Part II: Simulations and Design Practices." *Evaluation of Service Hot Water Distribution Systems Losses in Residential and Commercial Installations.* Atlanta: ASHRAE, 1999.

This paper is the second part of a two part series on hot water system heat loss. The data compiled from a field and laboratory study described in the companion paper are compared to the simulation results of the model. The model simulations are also compared to previous design guidelines leading to new suggestions for design practices and the use of the numerical model.

Taco, Inc. "New Add-On Power Controls Provide Energy Savings System Protection and Increase Comfort Control" http://www.taco-hvac.com/. (accessed June 16, 2006).

Water Management Inc. n.d. "Estimate Your Water Savings." http://www.watermgt.com/ (accessed May 2006).

Wendt, Robert and Evejp Basidn. 2003. "Are you GeHJng into Hot Water?" *Home Energy Magazine Online*. Sept/Oct. http://www.homeenergy.org/ (accessed June 16, 2006).

---, Evelyn Baskin, David Durfee. Mar. 2004. "Evaluation of Residential Hot Water Distribution Systems." Oak Ridge, TN: Oak Ridge National Lab.

The goal of this project is to simulate and compare the energy and water performance, economics and barriers to use of various domestic hot water distribution systems in new and existing California residences and to evaluate the potential statewide impact of the use of more efficient hot water distribution systems. Authors Robert Wendt, Evelyn Baskin and David Durfee of Oak Ridge National Lab in Tennessee, studied cold start and clustered use draw cycles, retrofit and new construction, and estimated utility cost savings of various distribution systems. They found that continuous recirculation systems add substantial construction costs as well as operating costs and energy waste (although they minimize wait times). In addition, adding a demand recirculation pump and controls though increasing system costs, reduces operating cost, waste and wait times. Lastly, new construction markets sensitive to first cost should consider centrally locating their water heater, which in turn cuts wait times and waste.

Appendices

1 APPENDIX: Nomenclature

QUANTITY	SYMBOL
Hot Water Tank Temperature	T_{tank}
Water Temperature at Tank Top	T_{ttop}
Hot Water Supply Temperature	T_{HWS}
Hot Water Return Temperature	T_{HWR}
Cold Water Make-up Water Temperature	T_{CW}
Blended Make-up Temperature	T_{blend}
Gas Temperature	T_{gas}
Outside Air Temperature	T_{OA}
Boiler Room Temperature	T_{BRM}
Semi-Conditioned Space Temperature	T_{SCS}
Boiler Supply Temperature	T_{BS}
Boiler Return Temperature	T_{BR}
Boiler Pump Signal	S_{BP}
Burner Signal	S_{burn}
Recirculation Pump Signal	S_{RP}
Hot Water Supply Flowrate	F_{HWS}
Hot Water Return Flowrate	F_{HWR}
Make-up Flowrate	F_{CW}

2 APPENDIX: Methodology

2.1 Survey Methodology

The survey was conducted primarily over the telephone, augmented by visits to building sites and Building Departments. The respondents were selected based on their experience with central water heating systems in multifamily buildings. Only respondents with direct experience with the systems were chosen for the surveys. The survey responses were consolidated to present a statewide picture of the current market for central domestic water heating systems with controls on the recirculation loops. The response sample is not as large as we would have hoped because many of the sources to be interviewed could not spare the time for a survey. It typically required multiple attempts to obtain the responses that we did get. Even though the results represent a fairly wide spectrum, a deeper set of data would help refine these results further.

1. The results are based on a response by Architects, Plumbing Engineers, Energy Consultants, Developers and Building Departments, representing 118,000 units(rounded to the nearest 1000); and Contractors representing installation in 23,000 units and maintenance in 2000 units (rounded to the nearest 1000). This sample size however cannot be used directly to represent a certain percentage of the total multifamily housing stock of 167,000 units built in the state of California in the last three years as the number of units represented by the categories mentioned above are not mutually exclusive (e.g., an architect and an energy consultant may have worked on a common building).

2. The response represents 292 central domestic water heating systems with recirculation loops and controls specified or modeled in the last 3 years by the Architects, Plumbing Engineers, Energy Consultants and Developers; 134 systems installed and 94 systems maintained in the last 12 months by the Plumbing contractors; and 1525 recirculation pumps and 1055 recirculation controls sold by the Distributors in the last 3 years (with 177 central water heating systems sold in the last 12 months).
3. In the case of Building Departments where they had not had any central water heating systems in their multifamily projects in the last 3 years, the response was simply recorded as the fact that there was no such installation activity in those areas. In the case of Building Departments that did permit projects with central water heating systems in the last 3 years, staff were unable to provide quantified data on the number of buildings and units with central water heating systems, or details about the systems. This was primarily because it is not part of the information the Building Departments collect or maintain in their databases. The Building Department databases typically provide information such as Number of permits issued for multifamily units, (typically without distinguishing between new construction and renovation) and the Valuation of the jobs permitted. In the absence of quantifiable data from the Building Departments, it was not possible to estimate the number of total central water heating systems installed during the last three years across any jurisdictions

However, conducting the survey provided useful information regarding the general distribution of central water heating systems across the state of California.

2.2 Monitoring Methodology

Data collected by HMG at the two monitored sites included air and water temperatures at several locations (e.g., top of tank, supply line ~5' from tank, return line next to pump, boiler room air temp, etc.). It included flow rates of the hot water supply line, hot water return line, cold water makeup line, and gas line into the boiler or water heater. It also included boiler/water heater burn times (via the gas valve solenoid), and recirculation pump run time. Data collected from the participating controller company included temperatures for the hot water supply, hot water return, and cold water makeup lines, but no flow data. It also included boiler/water heater burn times.

HMG attempted to log data from the sensors described above for seven consecutive days in each of the four control conditions. Due to unavoidable issues with the data, we repeated some sequences to ensure we had seven days of usable data. We also bench-calibrated all the sensors and calibrated the flowmeters when we installed them on the hot water supply systems.

Location	St. Helena	Emeryville	Oakland
Floors	2	3	3
Units/Hot water system	8	20	121
Type of system	Single water heater	Boiler and storage tank	Three water heaters
Existing control	Broken timeclock	None (continuous pumping)	None (recirc pump unplugged)
Pipe insulation	Minimal	Average	Extensive
HWS pipe diam leaving boiler room	1.5”	2.5”	4”
Cold water makeup pipe diam	1.5”	2.5”	4”
HWR pipe diam entering boiler room	0.75”	0.75”	2”

Table 2 Characteristics of Monitored Buildings

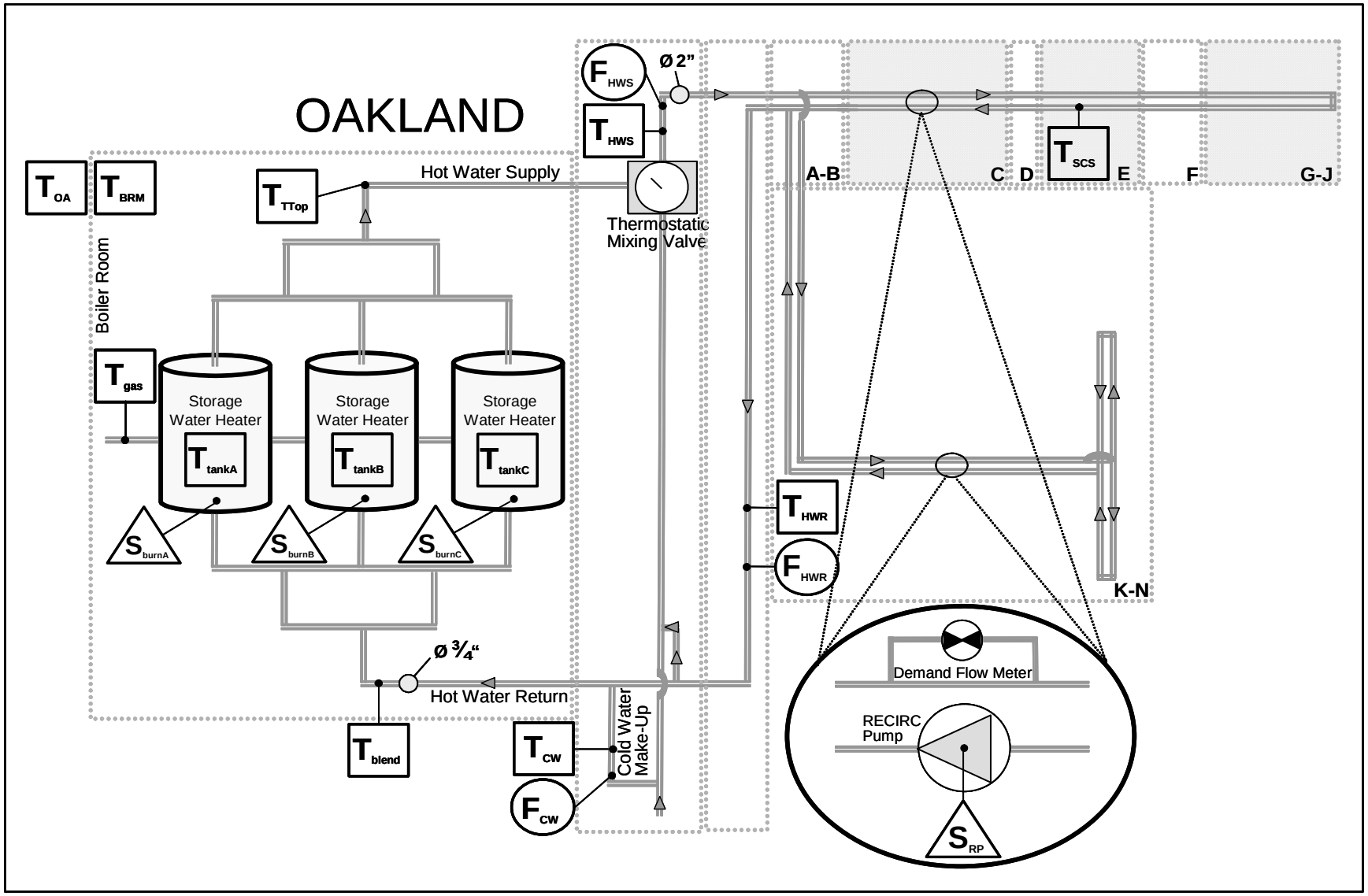


Figure 14. Schematic Layout of the Domestic Water Heating System and Individual Monitoring Points – Oakland

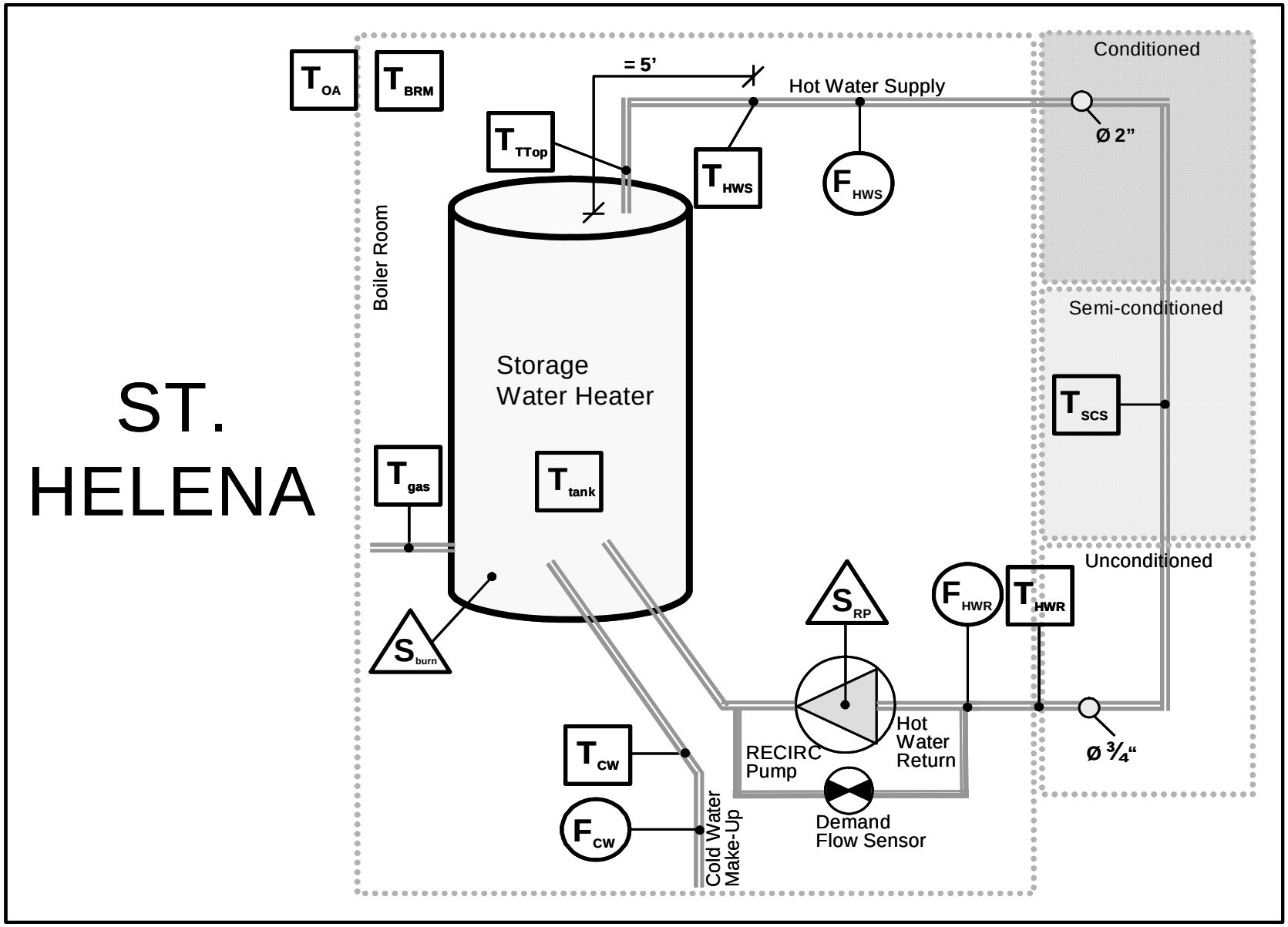


Figure 15. Schematic Layout of the Domestic Water Heating System and Individual Monitoring Points – St. Helena

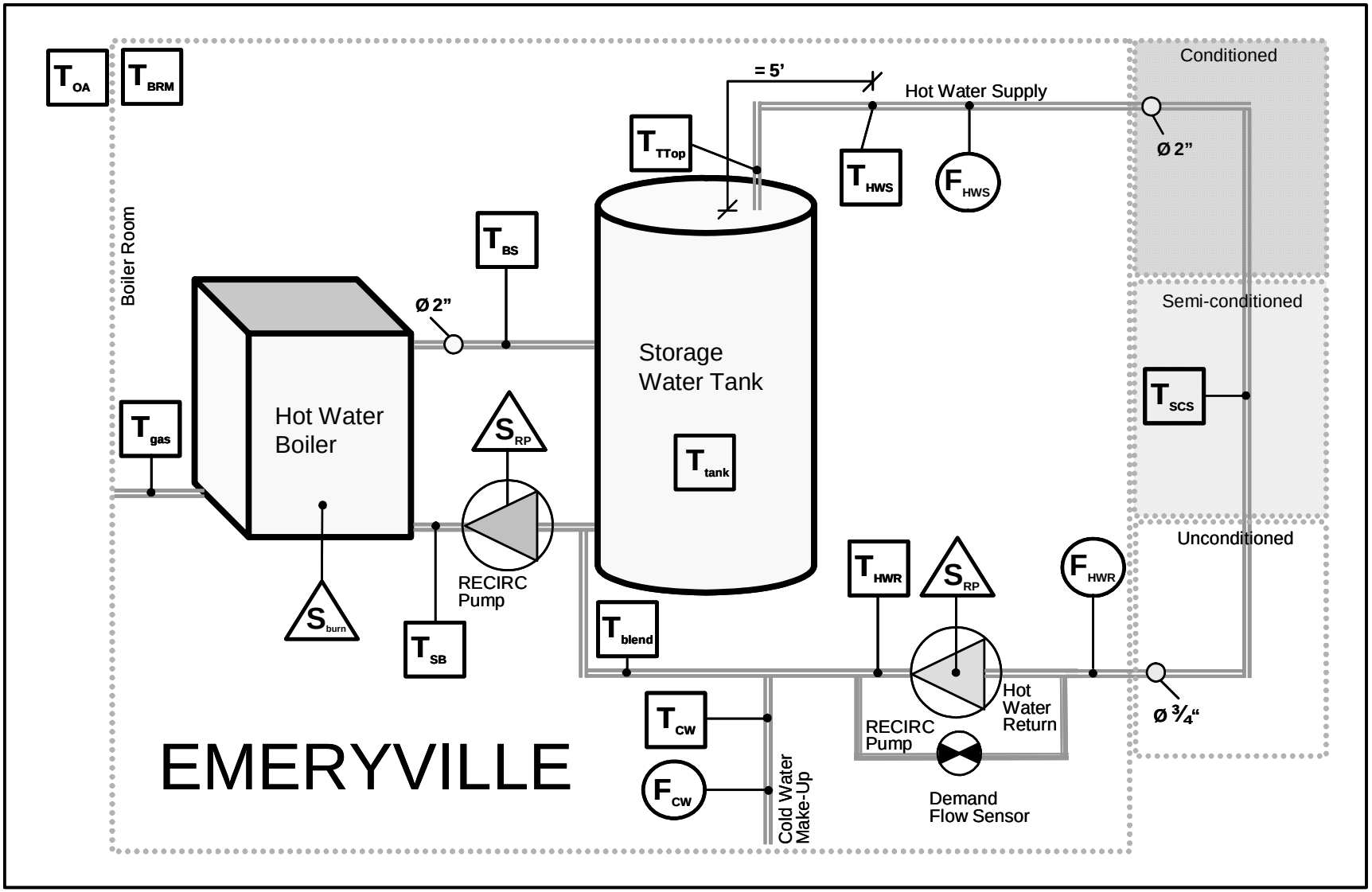


Figure 16. Schematic Layout of the Domestic Water Heating System and Individual Monitoring Points – Emeryville

3 APPENDIX: Magnitude of Experimental Errors

3.1 Water Flowmeters

Surveyor verified that when the flow was shut off along each section of pipe (using the valves) the flowmeters all read zero. This was verified in both Oakland and St Helena

The non-intrusive (ultrasonic) flowmeters used in this monitoring read the velocity of flow within the pipe and calculate the expected volumetric flow rate using information about the pipe cross-section. Therefore, if pipes have a significant amount of material (e.g., calcium) deposited on the inside walls, the flowmeters might overestimate actual flow. Therefore, adjustments to flowmeter readings when necessary to correct for any apparent errors always reduced estimated flow rates (instead of increasing them). The flowmeter manufacturer also advised us that dissolved gases in the water could result in an overestimate of the volumetric flow rate, which again would support adjusting the flow values downward rather than upward if required.

After taking initial readings from the flowmeters, we found an apparent error. After consulting the flowmeter manufacturer, we shielded all cabling from the flow meters to the data-loggers (to prevent EMI based fluctuations caused by the pump motor), and shortened some of the cabling so that paired sets (from the two ends of the flowmeters) were exactly the same length. This resulted in very minor improvement in the readings.

After further consultation with the flowmeter manufacturer, we recalibrated the flowmeters with an additional method beyond what we had originally employed. This too resulted in very minor improvements to the data quality.

We made the final correction after noticing that the magnitude of the apparent error in hot water flow tracked exactly with the air temperature of the boiler room. Consulting with the manufacturer, we were able to verified that the air temperature did affect the readings from the flowmeters, and that this was a source of error that the manufacturer had not previously been aware of. Correcting for this error gave us very good data on flow that matched the physical calibration results.

3.2 Gas Flowmeters

We used a residential size gas meter to determine the boiler input capacity. The gas meter is capable of measuring a flowrate up to 415 SCFH. It has a special sweep hand that completes one revolution for every 0.5 ft^3 of gas that passes through. We installed the gas meter such that the boiler was the only gas appliance on the meter. With the boiler firing, we measured the time required for the sweep hand to complete a certain number of revolutions, to yield the gas flowrate and thus the boiler consumption per unit time. We compared this data with the information stamped on the boiler nameplate and discovered that the nameplate rating is 14% higher than the capacity measured with the gas meter (St. Helena).

4 Appendix – monitoring and datalogging Equipment used during this project

4.1 Dynasonics Transit-Time Flowmeter

Image 1. Image of the Dynasonics Transit-Time Flow Meter Installed on a Pipe (Dynasonics 2006)

The Dynasonics Ultrasonic Clamp-On Flow Meter is a non-invasive flow meter that allows solids to pass through the pipe without affecting the meter and thus eliminates the need for Y-strainers or other filtering devices. The meter provides an instantaneous rate and accumulated flows (totalizer) as well as a 4-20mA output signal and pulse output signal. The flow meter provides a direct interface to data collection systems. These systems are designed to "replace mechanical flow meters in applications where liquid conditions tend to damage or impede mechanical flow meter operation" (Dynasonics 2006).

4.1.1 Operating Principles

Dynasonics product specifications state the following about the transit-time flow meter operating principles:

> *"Transit time flow meters utilize two transducers which function as both ultrasonic transmitters and receivers. The flow meters operate by alternately transmitting and receiving a frequency modulated burst of sound energy between the two transducers. The burst is first transmitted in the direction of fluid flow and then against fluid flow. Since sound energy in a moving liquid is carried faster when it travels in the direction of fluid flow (downstream) than it does when it travels against fluid flow (upstream), a differential in the times of flight will occur. The sound's time of flight is accurately measured in both directions and the difference in time of flight calculated. The liquid velocity (V) inside the pipe can be related to the difference in time of flight (dt) through the following equation: V = K*D*dt, where K is a constant and D is the distance between the transducers."*

Diagram depicting the sound energy transmission between the transducers (Dynasonics 2006)

4.1.2 Specifications

SPECIFICATION **Series TFXL**

DESCRIPTION	SPECIFICATION
Liquid Types	Most clean liquids or liquids containing moderate amounts of suspended solids or aeration.
Power Requirements	11-30 VDC @ 0.25A
Velocity	0.1 to 40 FPS [0.03 to 12.4 MPS]
Inputs/Outputs	**4-20mA Output (standard output)** Resolution: 12-bit for all outputs Power: Source Insertion loss: 5V maximum Loop impedance: 900 Ohms maximum Isolation: Can share ground common with power supply — isolated from piping system **Turbine Frequency Output/TTL -Pulse Output** Switch selectable Type: Non-ground referenced AC / Ground referenced square wave Amplitude: 100mVpp minimum / 5VDC Frequency range: 0-1,000Hz Duty cycle: 50% ±10%
Display	Type 2 line x 8 character LCD; Top row: 0.7" [18mm] tall, 7-segment; Bottom row: 0.35" [9mm] tall, 14-segment Rate 8 maximum rate digits, lead zero blanking Total 8 maximum totalizer digits, exponential multipliers from –1 to +6
Units	Engineering Units: Feet, gallons, ft^3, million-gal, barrels (liquor & oil), acre-feet, lbs, meters, m^3, liters, million-liters, kg Rate Units: sec, min, hr, day
Ambient Temperature	General Purpose: 0 to +185 °F [-20 to +85 °C]; Hazardous Locations: 0 to +105 °F [-20 to +40 °C]
Liquid Temperature	0 to +185 °F [-20 to +85 °C]
Enclosure	NEMA 3 [Type 3] ABS or polycarbonate, CPVC, Ultem®, brass or SS hardware, 3W x 6L x 2.5H inches [75W x 150L x 63L mm], pipe mount
Transducer Type	Clamp-on, uses time of flight ultrasonic
Pipe Sizes	1/2" and higher
Pipe Materials	Carbon steel, stainless steel, copper, and plastic
Accuracy	±1% of reading at rates above 1 FPS [0.3 MPS]; ±0.01 FPS [.003 MPS] of reading at rates lower than 1 FPS [0.3 MPS]
Response Time	0.3 to 30 seconds, adjustable
Protection	Reverse-polarity, surge suppression
Approvals	**Integral System** General Requirements: ANSI/ISA 582.01 Hazardous Locations: ANSI/ISA 12.12.01 Class I Div 2, Groups C & D CSA C22.2 No. 213, E79-15-95 (DTFXL3 & DTFXL4 models only) **DTTN Transducer** Standard: Ordinary Area Intrinsically Safe Option: General Requirements - C22.2 NO. 142; UL 916 Hazardous Locations - C22.2 No. 157; UL 913: 2002 Class I Div 2, Groups C & D

Product Specifications of the Dynasonics Transit-time Flow Meter (Dynasonics 2006)

4.2 HOBO Data Logger

HOBO U12 loggers contain internal sensors as well as accept a variety of external sensors and input cables, which enable users to monitor temperature, humidity, light intensity, and other measurements

required for indoor energy, HVAC/R, and industrial projects. Its 12-bit resolution allows for high accuracy measurements. Its USB connectivity allows for high-speed data offload and data viewing. (Onset 2006).

Image of the Hobo U12 Logger (Onset 2006)

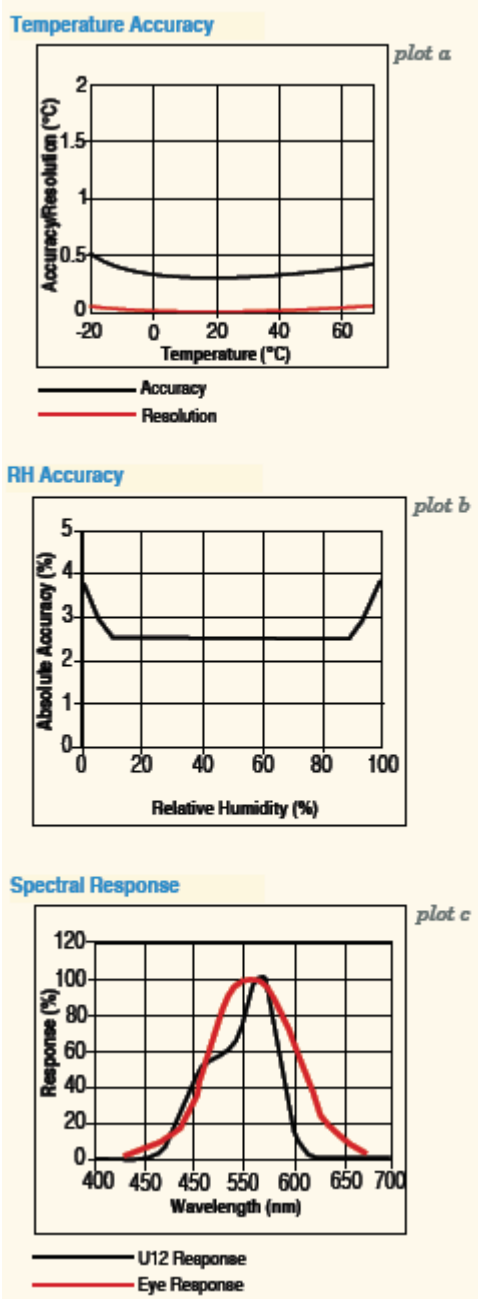
We relied on these dataloggers with Type T external thermocouples to monitor temperatures during this project. We also used these dataloggers with a 0-20 amp split-core AC current sensor to monitor the water heater and boiler burner duty. This split-core current sensor is shown below.

Split Core AC Current Sensor (Onset 2006)

4.2.1 Specifications

Time accuracy: ± 61 seconds per month at 25°C (77°F)
Temperature (see plot a)
Accuracy: ± 0.35°C from 0 to 50°C (± 0.63°F from 32° to 122°F)
Resolution: 0.03°C at 25°C (0.05°F at 77°F)
Drift: 0.1°C/year (0.2°F/year)
Response time in airflow of 1m/s (2.2mph): 6 minutes, typical to 90%
Relative Humidity
Accuracy: ± 2.5% RH from 10% to 90% over the range 10° to 50°C (50° to 122°F) typical; ± 3% RH from 5% to 95% (see plot b); conditions above 80% RH and 60°C (140°F) may cause additional error
Resolution: 0.03% RH
Hysteresis: 1% RH
Drift: <1% RH per year typical
Response time in airflow of 1 m/s (2.2 mph): 1 minute, typical to 90%
Light Intensity
Designed for indoor measurement of relative light levels 1 to 3000 footcandles (lumens/ft²) typical; maximum value varies from 1500 to 4500 footcandles (lumens/ft²)
Light wavelength response (see plot c)
External Input
(Accepts Temperature sensors, Split Core CTs for AC current, AC Voltage Transmitters, CO_2, 4-20mA and 0-2.5V DC input cables for use with third-party sensors (at right and page 8)
External Input Details*
Input range: 0 to 2.5 DC volts
Accuracy ± 2 mV, ± 2.5% of absolute reading
Resolution: 0.6 mV (12 bit)
Output power: 2.5 DC volts at 2mA, active only during measurements
Max. recommended source impedence: 2.5 KΩ

** The grounds of all voltage and/or current sources must be at the same voltage potential before you connect them to the logger to avoid inaccurate readings or damage to the logger and input cables.*



Product Specifications of the HOBO Data Logger (Onset 2006)

4.3 SmartReader Plus 7

The SmartReader Plus 7 is a data logger capable of recording common process signals. With seven input channels, the logger is able to monitor through commercially available transducers and thus record a wide variety of measurement parameters. (Onset 2006)
We purchased two loggers configured with all external channels set to accept a 0-25 mA signal. This logger recorded the 4-20 mA output signals from each of the three flowmeters installed at each building.

Figure 17. ACR SmartReader Plus 7 (ACR Systems 2006)

4.3.1 Specifications

GENERAL SPECIFICATIONS

Size:	107 mm x 74 mm x 22 mm (4.2" x 2.9" x 0.9")
Weight:	110 grams (3.75 ounces)
Case Material:	Noryl® plastic
Battery:	3.6 volt Lithium
Battery Life:	10 years with normal use (factory replaceable)
Resolution:	12-bit (1 part in 4096)
Mounting:	Magnetic backing or locking eyelet
Clock Accuracy:	+/- 2 seconds per day
Sampling Methods:	Continuous (First-in, First-out)*, Stop When Full (Fill-then-stop) **Not available with sample rates faster than eight seconds*
Operating Limits:	-40 to 70°C (-40 to 158°F) and 0 to 95% RH (non-condensing)
PC Requirements:	IBM PC or 100% compatible with at least one free serial port, 2 MB of RAM memory, and 2 MB of hard disk space
Software Requirements:	TrendReader® Standard 2 *(compatible with Windows® 2000, and XP)*
Memory Size:	32KB *(capable of storing up to 21,500 readings)* 128KB *(capable of storing up to 87,000 readings)* 1.5MB *(capable of storing up to 1,048,000 readings)*
Sampling Rates:	User selectable rates from 25 per second to once every eight hours *(BP-101 battery pack or PS-201 power supply required for sampling rates faster than eight seconds)*
Number of Channels:	Eight *(one for the internal temperature sensor and seven external channels for analog voltage and curent loop signals)*

SENSOR SPECIFICATIONS

Temperature Sensor	NTC Thermistor - 10,000 Ohm @ 25°C (77°F)
Range:	-40 to 70°C (-40 to 158°F)
Accuracy:	+/- 0.2°C (+/- 0.3°F) over the range 0 to 70°C (32 to 158°F)
Resolution:	0.03°C (0.05°F) @ 25°C; better than 0.07°C (0.12°F) between -25 and 70°C (-13° and 158°F); better than 0.13°C (0.23°F) between -40 and -25°C (-40°F and -13°F)

Standard Model* *(SRP-007)*	**Other Models***
0 to 2.5 VDC (1 channel)	All external channels: 0 to 2.5 VDC (SRP-007-0-2.5V)
0 to 5 VDC (2 channels)	All external channels: 0 to 5 VDC (SRP-007-0-5V)
0 to 10 VDC (1 channel)	All external channels: 0 to 10 VDC (SRP-007-0-10V)
0 to 200 mV DC (1 channel)	All external channels: 0 to 25 mA (SRP-007-25mA)
0 to 25 mA DC (2 channels)	

Maximum Protection

Voltage channels: +/- 40V *(reverse-polarity protected)*

Current channels: +/- 70mA *(reverse-polarity protected)*

Accuracy

+/- 0.5% of full scale

Input Impedance

Greater than 1M Ohm (200mV channel)

Greater than 1M Ohm (0 to 2.5V channel)

Greater than 1M Ohm (0 to 5.0V channels)

Greater than 1M Ohm (0 to 10V channel)

20 Ohm (0 to 25mA channels)

**Transducer restrictions: The use of a single power supply is recommended to avoid ground loops or use loop isolators*

Product Specifications of Smart Reader Plus7 (ACR Systems 2006)

4.4 SMARTlogger

We used these loggers to record the recirculation pump duty:

Figure 18. SMARTLogger (Dent Instruments 2006)

4.4.1 Specifications

SMART*logger*™ Specifications	
Logger Types	LIGHTING: Internal photo-sensor MAG: Internal Magnetic Sensor CT: External Current Transformer CONTACT: External Switch or Relay
Display	5 digit LCD showing Total On-Time, Percent On, Annunciator
Time Stamps	Month, Day, Year and Hour, Minute, Second
Time Resolution	One second
Sampling Rate	One per Second (1Hz)
Data Analysis	Statistics, summaries, graphs and data export using SMART*ware*™
Memory	8,000 records, ring memory *plus* Separate On-Time Totalizer
Communication	USB with SMART*logger*™ communications cable
Sensitivity	LIGHTING*logger*™: Adjustable MAG*logger*™: 40 mGauss min CT*logger*™: 0.25 amp min CONTACT*logger*™: Dry Contacts
Internal Clock	Real-Time, Crystal controlled, true calendar, 20 ppm accuracy (<1 min/month)
Battery Life	5 years
Operating Temperature	0 to 60° C (32 to 140° F)
Operating Humidity	5% to 95% non-condensing
Dimensions	6.3 x 3.8 x 1.9 cm (2.5 x 1.5 x .75")
Weight	40 gm (1.5 oz)
Mounting	Magnets, Velcro®, or Mounting Hole
Warranty	Three years

Figure 2. Specifications for SMARTLogger (Dent Instruments 2006)

5 Supporting Reports

5.1 Multifamily Construction Practices

The survey responses for Task 1A – Survey of Developers, Architects, Plumbing Engineers, Energy Consultants, and Building Departments – were consolidated with responses from Task 1B – Survey of Plumbing Contractors and Plumbing Distributors – to present a statewide picture of the current market for central domestic water heating systems with controls on the recirculation loops. The respondents were selected based on their experience with central water heating systems in multifamily buildings. Only respondents with direct experience with the systems were chosen for the surveys. The response sample is not as large as we would have hoped because many of the sources to be interviewed could not spare the time for a survey. It typically required multiple attempts to obtain the responses that we did get. Even though the results represent a fairly wide spectrum, a deeper set of data would help refine these results further.

5.1.1 Response Sample

Number of Units

The results presented here are based on a response by Architects, Plumbing Engineers, Energy Consultants, Developers and Building Departments, representing 118,000 units(rounded to the nearest 1000); and Contractors representing installation in 23,000 units and maintenance in 2000 units (rounded to the nearest 1000). This sample size however cannot be used directly to represent a certain percentage of the total multifamily housing stock of 167,000 units built in the state of California in the last three years as the number of units represented by the categories mentioned above are not mutually exclusive (e.g., an architect and an energy consultant may have worked on a common building).

Number of Systems

The response represents 292 central domestic water heating systems with recirculation loops and controls specified or modeled in the last 3 years by the Architects, Plumbing Engineers, Energy Consultants and Developers; 134 systems installed and 94 systems maintained in the last 12 months by the Plumbing contractors; and 1525 recirculation pumps and 1055 recirculation controls sold by the Distributors in the last 3 years (with 177 central water heating systems sold in the last 12 months).

5.1.2 Response Distribution

Location and Building Type – Building Departments & Developers

In the case of Building Departments where they had not had any central water heating systems in their multifamily projects in the last 3 years, the response was simply recorded as the fact that there was no such installation activity in those areas. In the case of Building Departments that did permit projects with central water heating systems in the last 3 years, staff were unable to provide quantified data on the number of buildings and units with central water heating systems, or details about the systems. This was primarily because it is not part of the information the Building Departments collect or maintain in their databases. The Building Department databases typically provide information such as Number of permits issued for multifamily units, (typically without distinguishing between new construction and renovation) and the Valuation of the jobs permitted. In the absence of quantifiable data from the Building Departments, it was not possible to estimate the number of total central water heating systems installed during the last three years across any jurisdictions

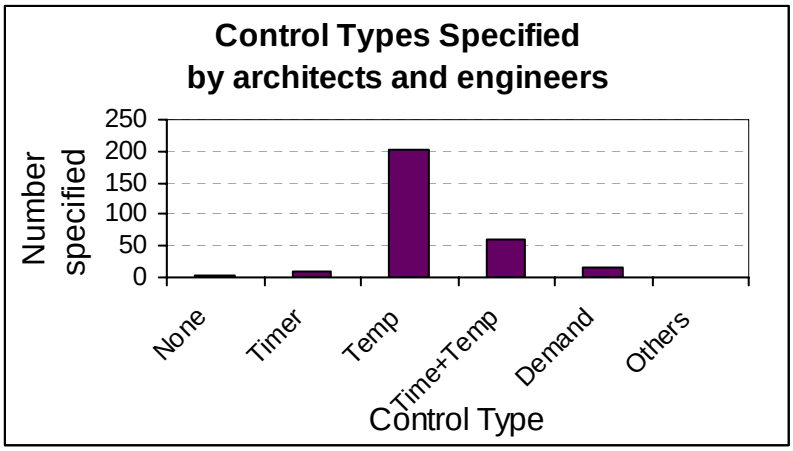
However, conducting the survey provided useful information regarding the general distribution of central water heating systems across the state of California.

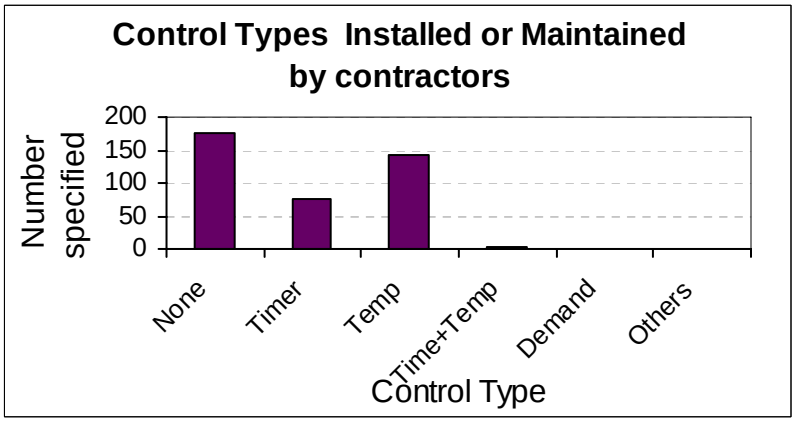
5.1.3 Results

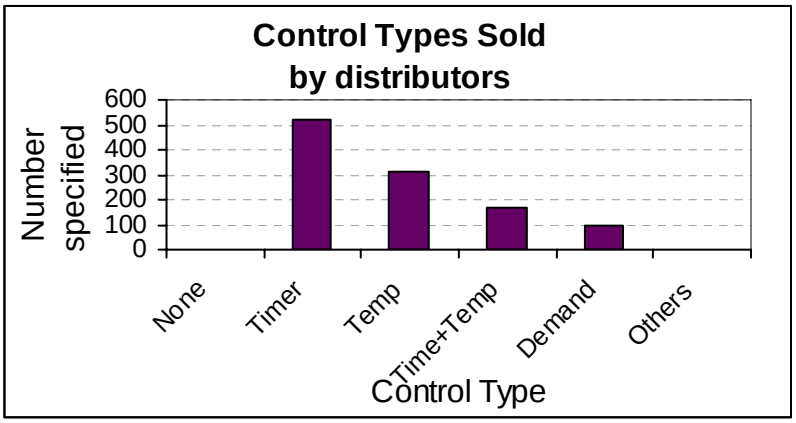
RECIRCULATION SYSTEM CONTROLS

Control Types

Data gathered from the Architects, Plumbing Engineers, Energy Consultants, and Developers shows that Temperature controls are the most commonly specified of all the control systems. Data gathered from Contractors shows the same trend – that Temperature controls are more commonly installed compared to other types of controls. Data gathered from Distributors however indicates that Timer Controls are the most commonly sold. This could either mean that a large number of Timer Controls are purchased after construction and installed without professional help, or that this data set is not large enough to draw a firm conclusion.







Availability of Controls

The respondents indicated that most recirculation controls were readily available, with a lead time of 1 day to a maximum of 3 days in case of an unusually busy time. According to the Contractors, this was true for the Timer, Temperature and the Timer + Temperature controls. They were unable to comment on the Demand or other controls (such as ProTemp). The Distributors however indicated that Demand controls were just as readily available. This applies to markets that have a demand for central water heating systems and controls and distributors that deal in these.

The following manufacturers and plumbing suppliers were mentioned as sources for the controls for the recirculation loops in the central water heating systems by the plumbing contractors and design team professionals we surveyed:

Johnston
Howard Industries
Raypak
Rheem
Pace Supply
HK Ferguson
Todd
Slakey Brothers
Hajoca

Cost of Controls – Parts

There is no fixed cost for the controls as it depends on the size and location of the job. It became obvious that asking for the cost of a temperature modulating control, for example, was a bit like asking "how long is a piece of string?" The cost quoted for a timer control ranged from $35 to $100. Temperature controls ranged from $23 to $100 each. Time + Temperature controls ranged between $58 and $200. One source quoted a Demand Control at $100 while other sources could not provide a value for it. One plumber told us that demand controls are essentially free because recirculation pumps with a demand control are the same price as those without it. Temperature Modulating controls for the ProTemp model PT-64 suitable for a small building (up to approximately 30 units) cost $750 and the ProTemp model PT-76 suitable for larger buildings costs $1902.

Other additional costs are very small compared to the project budget. The relatively low-cost additional items could include additional valves, regulators, pipe fittings, or a different size/type of pump, among others.

Cost of Labor to install controls

We obtained data for installing Timer, Temperature and Timer + Temperature controls. The average time quoted for the job was 1 hr to 2 hrs, and the cost was $95 to $190. One plumber told us that there is not additional labor cost for installing demand controls. It appears that installing controls as a retrofit may incur a cost as indicated above, whereas installing the control as part of a new system installation may not incur the additional cost.

Additional Savings from Controls

Data from manufacturers shows savings but some plumbing contractors dispute whether any savings actually materialize. Often the controls are not set up correctly, or are (intentionally or unintentionally) modified. When this causes tenant complaints, the controls are decommissioned. More hard data is required on additional savings from the controls and the persistence of these savings.

Calibration Required for Controls

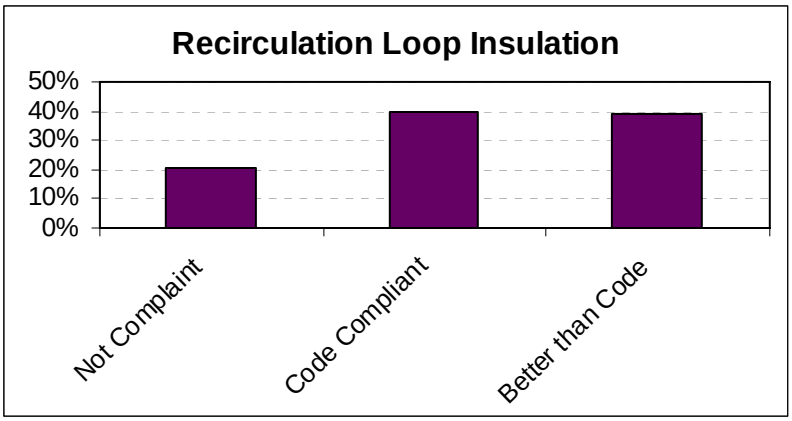
Once the time or temperature, or time/temperature schedule has been set on the controls, no further calibration is usually required for the Timer, Temperature or the Timer + Temperature controls, according to the respondents. Similar data could not be obtained for the Demand control, but sources at one control manufacturer that makes and installs temperature modulation controls, and also installs remote monitoring of system performance, indicated that they will reset schedules and/or temperatures when usage patterns so indicate.

Maintenance Required for Controls

According to most respondents, the controls do not require maintenance. One source stated that controls should be checked once every 6 to 12 months. Another source stated that temperature controls typically do not require maintenance, but timer controls need to be checked, and reset every spring and fall according to the changing time table of the residents. Time required for a typical maintenance call is 1 to 2 hours according to the Contractors. The cost to the owner was quoted variously as $85 or $180.

As mentioned above, operation of one type of temperature modulation control is monitored remotely by the manufacturer. This data allows the manufacturer to pinpoint when there is a system failure – even if the failure is in a portion of the system (e.g., the boiler or pump) that they do not manufacture. The manufacturer then dispatches recommendations for system maintenance to the property owner or his/her designee so that the failing equipment can be fixed or replaced.

RECIRCULATION LOOP INSULATION

Data collected from Architects, Plumbing Engineers, Energy Consultants, and Developers shows that recirculation loop pipes are usually insulated either to code or better than code, depending on the location of the pipes. The cost to insulate pipes was quoted as 25 cents to 47 cents per linear foot by one source.

In some cases, the pipes are not insulated, which is a violation of the code. However, prior to the 2005 revisions to the Building Energy Efficiency Standards, this code requirement was arguably ambiguous. None of the Building Departments surveyed have kept a copy of the plumbing drawings for MF buildings after a project has passed its final inspection. Some Building Departments check the plumbing drawings set at the time of processing the permit, but even this is not always the case. As a result, if there is a code violation, such as lack of the mandatory minimum insulation in the recirculation pipes, it is practically impossible to check it once the project has been built and the pipes are buried. Knowledge of this fact, resulting in a degree of complacency among the developers and plumbers regarding pipe insulation, was evident during the surveys.