Testing For and Determining the Prevalence of Crossover in a Multifamily Central Domestic Hot Water Distribution System

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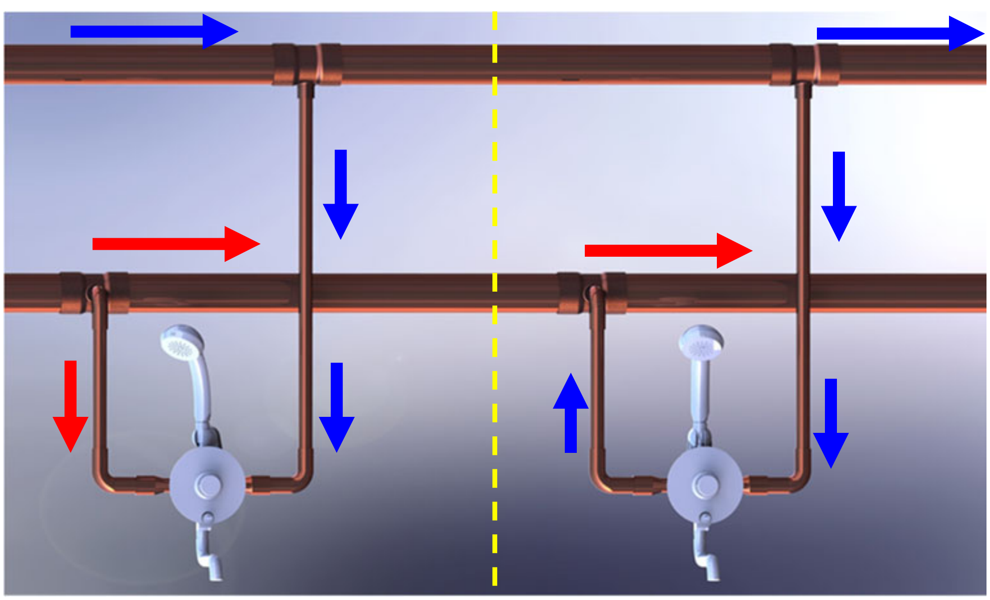
ABSTRACT

Crossover allows the unintended flow of hot water into the cold water system, and vice versa, and may have a significant impact on energy losses in the system, particularly in central DHW systems in multifamily and commercial buildings. In a CEC funded study of over 100 multifamily buildings throughout California, over 50% exhibited crossover failures in their central DHW distribution. This occurs most often when a cartridge in a shower or faucet's mixing valve wears out and is no longer able to effectively control the mix of hot and cold water at a fixture or point of use. Many times these issues are asymptomatic and the effects not readily felt by the user. The implication being that the problems will not receive proper attention or repair, and thus will persist over a long period of time. According to past CEC funded research into multifamily hot water energy use, approximately 1/3 of all energy use, on average, is lost in the distribution due to existing issues and conditions. Current efforts are underway to determine what impact that crossover failures have on these distribution losses and what the potential for energy savings are on a statewide level, given the pervasiveness of the problem.

Background

Crossover occurs in a DHW distribution system and is the result of a combination of a faulty fixture valve, or an uncontrolled open circuit at the point where cold water and hot water pipes join to mix, and a pressure imbalance between the hot and cold water subsystems. Crossover allows the unintended flow of hot water into the cold water system, and vice versa as shown in the diagram below (without crossover: left, with crossover: right):



It may have a significant impact on energy losses in the system, particularly in central DHW systems in multifamily and commercial buildings. Likewise, crossover may create issues that compromise hot water service that cause tenant complaints and discomfort, such as: Long hot water wait times, sudden and rapid temperature fluctuations (most common symptom), lukewarm water or no hot water. Changes to the system can impact the degree in which the symptoms are felt, such as adding recirculation pump controls or temperature reset strategies, and this increases the likelihood that controls measures for energy efficiency are bypassed and/or temperature set points are increased in an attempt to counteract the effects. In many cases, however, the symptoms are masked which cause the issues to go unnoticed and untreated, and energy losses persist over long periods of time, unabated.

The frequency of these issues is not sufficiently documented but may be the best explanation as to why recirculation pump controls, though part of CA Title 24 since 2005, still have a very low market acceptance. According to one report by engineering group HMG, most buildings do not have any type of controls (HMG 2005). This may be due, in part, to a lack of awareness of available energy saving hot water technologies, but it also may be due to controls being taken out or deactivated because of unrelated crossover issues that were misdiagnosed. This would have great consequence, as PIER funded research has shown that recirculation pump controls on their own can reduce total loop heat losses by over 50%, and total hot water gas use by 15% (Bonneville 2010)

Anecdotal data suggests that crossover may occur more frequently than previously thought. For example, in one article on PIER funded research in this area, the principal investigators noted that two of the three buildings monitored had shown signs of crossover (Howlett and Stone 2007). There is also anecdotal data on the energy impact of crossover in buildings, however there are varying degrees of crossover severity, and according to a report by ACEEE, crossover flows may account for 5-10% of total hot water energy use in multifamily buildings (Sachs et al. 2011). Another study that tracked the energy use of a multifamily community with 104 units where all the cartridges in every shower valve were replaced showed savings of $23,328 or 62% (Pfaff 2009). This high level of variation highlights the fact that there is too little data to make any conclusions and that more research and data collection must be performed. For this reason, Enovative Group has embarked on CEC funded research to help determine the frequency and energy impact that crossover has on buildings in California.

Project Goals and Tasks

- Determine the frequency and scale of crossover problems in multifamily buildings throughout California
- Determine the impact that crossover has on the energy performance of a typical CDHW system
- Determine potential energy savings for California
- Recommend changes to building codes and standards to help prevent crossover from occurring in buildings

Testing buildings for crossover

The first challenge in determining an estimate for the prevalence of crossover is that there is little documentation on how to detect crossover. A search on the internet yielded some instructions and methods for detecting crossover, but did not have data nor a detailed description of how and why the detection method worked. Oftentimes these would be buried deep, many pages from the first page of an internet search.

The research team identified a list of potential methods for detecting crossover via a paper study, internet research, and by way of interviews with various experts in the field of plumbing and hot water systems.

Crossover Detection Methods

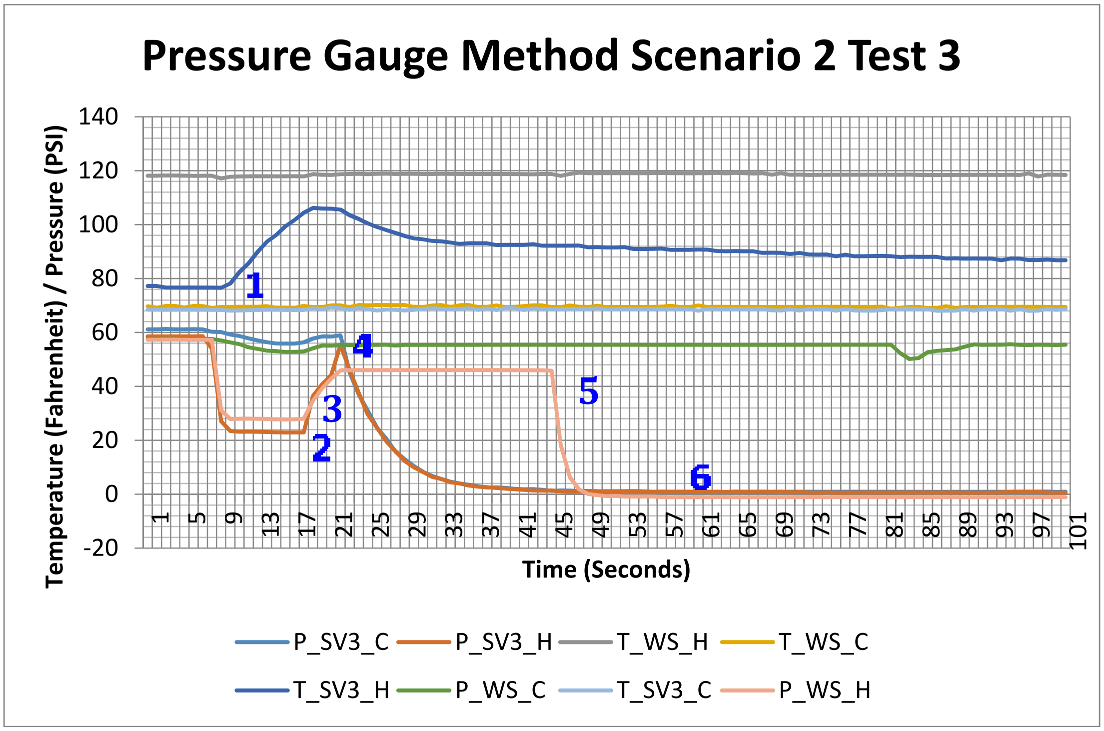
The following descriptions are of the detection methods gathered from the interviews.

Pressure gauge method. The pressure gauge method requires a standard pressure gauge that is commercially available and relatively inexpensive. The pressure gauge can be attached to the domestic hot water system anywhere on the hot water subsystem (i.e. on a hot water pipe), however it is recommended to use a hose bib on a return line, which is commonly available.

To start, close the valve to the cold water supply that feeds into the water heater, while keeping the cold water supply to the cold water subsystem open. Then release hot water from the hot water subsystem via any fixture, thus relieving pressure on the hot water subsystem. After some or all of the pressure is released, the fixture should be closed so that water is no longer coming out.

If crossover is present, then the pressure gauge will show the pressure in the hot water subsystem slowly rebuilding to normal. If crossover is not present, the pressure gauge will continue to register at lower levels or even come to rest at zero pressure, but should not increase.

The temperature and pressure profiles monitored during the test procedure is displayed in the plot below against time:

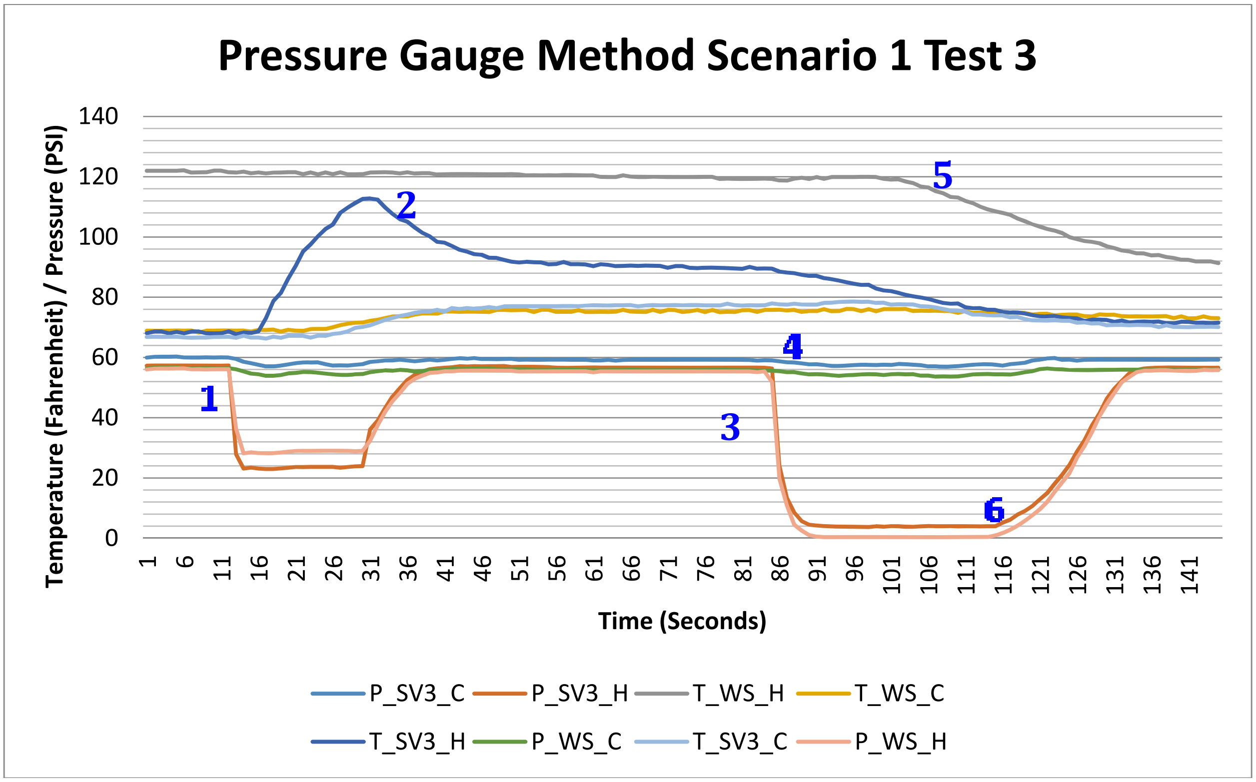


Annotations from the chart above (Without Crossover Scenario):

1. SV3 Hot section opened increasing temperature and dropping pressure.
2. SV3 Hot section turned off, regaining pressure
3. SV3 hot section isolated, dropping pressure but avoiding crossover
4. P_WS_H turned off preventing it from gaining full pressure and dropping P_SV3 fully.
5. Hose bib opened, relieving all pressure from hot sections of the system.
6. Pressure stays at zero indicating absence of crossover when the SV3_H was isolated.

The above figure shows the pressure gauge method being tested on the test platform with the Scenario 2 treatment, a situation without crossover in the system.

Similarly the following chart displays the temperature and pressure profiles for the pressure gauge method for a scenario with crossover present:



Annotations from the chart above (With Crossover Scenario):

1. Shower Valve 3 turned on causing drop in pressure and spike in temperature.
2. Shower valve 3 closed off causing pressure stabilization and temperature loss.
3. Cold line water supply inlet to heater turned off.
4. Hose bib opened causing pressure drop and instant crossover at about 1.4 GPM
5. Hot water supply temperature starts to drop from cold water crossing over
6. Hose bib closed allowing pressure to slowly build up. Verified with P-gauge.

The above chart shows the data collected from the Pressure Gauge method being tested in scenario 1, a condition when crossover is present in the test platform system. The graph results confirm that there is crossover in the system. First, the needle on the pressure gauge attached to the hot water subsystem dropped to almost zero as the hot water was being released through an open fixture, and then slowly increased until reaching equilibrium with the cold water subsystem. In other words, the hot water pressure was reduced, and without adding more hot water to the hot water subsystem, pressure began to rebuild. This means that pressure was allowed to enter the hot water subsystem from somewhere within the test platform system. Since the cold water subsystem still had pressure, it is safe to conclude that the water was crossing over through the mixing valve and re-pressurizing the hot water subsystem. The corresponding data that was gathered by the data acquisition system on the lab test platform is shown by the line labeled "P_WS_H." The line curve matches up with what the research team observed when looking at the needle of the pressure gauge.

As expected, midway through the test, the chart line shows the hot water pressure dropping as a result of an open fixture emptying hot water from the hot water subsystem and then as soon as the research team had closed the fixture, the hot water pressure began to increase to the point where it was before the fixture was opened, as shown by the inclined curve on the chart.

The test data indicates that pressure was released from the hot water subsystem, but because crossover occurred, cold water had infiltrated the hot water system through the defective mixing valve of the opened fixture, thus restoring the lost pressure back to equal levels.

In addition to testing pressure, a temperature sensor was included on the hot water subsystem in order to deny or confirm the pressure sensor data. The chart line labeled "T_WS_H" represents the temperature in the hot water supply, which begins to drop at the time in the testing when cold water enters the hot water subsystem and cools it down.

Scoring positive results under Scenarios 1 & 2, the Pressure Gauge method was verified as an accurate way to detect crossover in a typical multifamily building. Though this distinction should be noted: while the Pressure Gauge method is the best method for detecting crossover's presence in a building, it is not an effective way to pinpoint the problem valve or valves responsible for creating crossover within a building.

Similar analysis were carried out for each of the following crossover tests detailed below. The charts and descriptions of which can be found via the reference section.

Water flow method. The Water Flow Method is the most widely recommended method as suggested and confirmed by multiple sources during the industry interviews. The Water Flow Method is preferred because it does not require extra equipment to perform

First, the cold water supplied to the hot water subsystem is shutoff via a valve on the cold water feed to the water heating system. Water supply to the cold water subsystem is not turned off. Next, open a fixture or hose bib to drain the water from the hot water pipes. If crossover is occurring, the water flow will not stop, even after the hot water has completely drained, and the water coming out of the fixture will eventually turn cold. If crossover is not occurring, then the hot water pipes will eventually drain and water will cease to flow.

Eatherton method. The Eatherton method, which is properly named after Mark Eatherton, the plumbing engineer who created this particular procedure, consists of testing each fixture individually, beginning with the shower valve in the housing unit that is experiencing hot water issues

The faceplate of the shower valve is removed, leaving the shower's mixing valve exposed. The hot side of the shower valve is heated by turning on hot water until the user gets the hottest water and then turning the shower valve back off. A nearby lavatory hot water faucet is then turned on, while the user feels the hot side of the exposed shower's mixing valve. If there is crossover, the shower mixing valve will rapidly cool down because the lavatory is pulling cold water through the shower mixing valve, thus rapidly cooling down the hot side of the shower mixing valve. If no crossover exists, the shower mixing valve will remain hot, because cold water is not crossing over, and thus the shower valve will remain heated.

Temperature differential method. The temperature differential method involves adding temperature sensors to the hot water supply from the water heating system and then on the return line of the hot water system. The temperatures are then logged.

If the logged data shows fluctuations in temperature due to cold water coming down the return line, which is usually easier to determine by logging the minimums for a given interval and comparing to the temperature averages for the same interval period, then this may indicate crossover. Alternatively, if there is an excessive temperature differential between the hot water supply and the hot water return, this could also be indicative of crossover.

Pump control method. The pump control method relies on controlling (i.e. turning on and off) a recirculation pump with a temperature sensor on the return line, which can be achieved with an aqua-stat or demand controller.

If problems arise from ceasing to recirculation of the hot water, then a tenant will complain because the return may have hot water, keeping the recirculation pump off, but within the building the cold water is crossing from one faulty valve and feeding the next fixture. Since the pump control is on the hot water return, which is normally the coolest point on the hot water subsystem, it means that there is an even cooler point within the building, which could mean crossover.

Water meter method. The water meter method required a water meter be installed on both the hot and cold water pipes that are feeding an individual unit.

If there is crossover, one of the water meters will spin forward, while the other water meter is spinning backwards during a crossover event. If crossover is not there, then the water meters should both only spin forwards when someone is using water in the dwelling unit.

Controlled Test Platform

After compiling a list of potential methods for detecting crossover, the research team built a scaled down replica of a central domestic hot water system to be used as a test platform for testing various shower valves and cartridges, both new and used, until crossover was simulated. Crossover was simulated when a suspected bad cartridge taken from a local multifamily building was used in the test platform and then tested under a series of different hot water draw events.

The research team was able to verify the crossover via a flow meter that only detects flow in one direction, which was installed backwards on the hot water side of a shower valve. In other words, this flow meter would only show flow if there was crossover, as the cold water would have to flow from the cold water side, through the shower valve, and backwards through the hot water pipe, triggering the flow meter. This was further verified by temperature, where the hot water side would be heated up with a temperature sensor attached to the hot pipe, followed by opening a different fixture, which induced crossover through the bad cartridge allowing cold water to rush into the hot water pipes and cool down the spot where temperature was being measured along with backwards water flow.

After the successful simulation of crossover on the test platform, the research team devised a method of easily eliminating the crossover from the test platform and created two known scenarios, a test platform with crossover, and a test platform without crossover.

To be certain of which methods for detecting crossover worked, and which ones did not, as well as the pros and cons of each method, each method was run through the test platform in both scenarios. The research team logged and video recorded each test. If the method worked, it would detect crossover when the test platform was setup with crossover simulated, and would not detect crossover when crossover was removed from the test platform. By testing the detection method in this way, the research team could identify if a test had a proclivity towards false positives or false negatives.

The only weakness was that the tests were done in a controlled lab environment, which would be different than in live buildings of various ages and plumbing setups. For example, in the test platform the research team knew if a fixture was turned on or off, but in the field in a large building there may be occupants using hot water during the testing which could affect results.

The end result of the testing of detection methods is shown in the table below.

Table 1. Results of crossover testing methods

Method	Results with Crossover	Results without Crossover	Verification	Notes
Pressure Gauge Method	Detected	Not Detected	Method Validated	Quickest, building-level test
Water Flow Method	Detected	Not Detected	Method Validated	Building-level and pinpointing detection possible
Eatherton Method	Detected	Not Detected	Method Validated	Pinpointing detection possible, non-invasive
Temperature Differential Method	N/A	N/A	Invalid	Can be indicative of crossover

Pump Control Method	N/A	N/A	Invalid	Discarded, but may reveal crossover symptoms
Water Meter Method	Detected	Not Detected	Method Validated	Only possible in some buildings

The research team concluded that using the pressure gauge method was the most practical and reliable method for detecting crossover in buildings and would be the standard test used for the existing buildings in order to determine the frequency of crossover and other discernable patterns that may potentially relate.

Determining the Frequency of Crossover in Multifamily Buildings

One of the primary goals of the study was to estimate the prevalence of crossover in multifamily buildings. Secondary to this goal was to attempt to determine patterns or common building characteristics that correlate to whether or not crossover exists in the building. Research funding allowed for one hundred buildings to be included in this study.

The sample size of one hundred buildings was a relatively arbitrary number, and not a statistically significant sample size. With budget limitations, the research team believed that one hundred buildings would be a great enough sample size to be indicative of the crossover problem, and would be a litmus test on whether crossover was a problem at all and worthy of attention.

, Our 100-building sample was meant to represent a cross section of the existing buildings in California. To do this, statistics regarding the building sizes, building ages, and regions where the buildings resided were gathered from sources such as the US Census. Then buildings were selected that would result in a close match to the statistics. For example, 27% of multifamily buildings were between five units and nine apartment units per building, and therefore the sample aimed at having twenty-seven buildings that were between five and 9 units in size. The end result was a sample that represented existing buildings in California.

With the sample selected, the research team hypothesized about what potential building characteristics or other qualities could relate to crossover. A list of building characteristics was created to gather during the site visit during the crossover test in order to identify further crossover occurrence patterns. This information included:

- Type of Shower Valve
- Single Handle Shower Valve versus Dual Handle
- Water Sample which yielded:
  - pH
  - Salinity
  - Conductivity
  - PPM of particulate
- Type of Pipe Material

- Condition of Pipe
- Material of Wall where shower valve was located
- Water Pressure

It was the hope of the research team that by gathering the above information a pattern would reveal itself. This way the team would not only have an indication of the prevalence of crossover, but would also potentially have leads as to the source or cause of crossover.

Conclusion of Crossover Field Tests

During a series of site visits of the selected buildings, the research team conducted crossover tests and gathered building data. After which the data was analyzed. The analysis yielded the result that crossover occurred in 52% of the 100 multifamily buildings tested.

The result of the analysis of building characteristics did not provide any apparent patterns that would connect a building characteristic with crossover. There was a slight correlation in regard to building size. This makes sense as the more shower valves in the building, the higher the chance one of the valves would degrade or be faulty and cause crossover. One shower valve failure in a 100-unit building was considered the same as one in a 5-unit building even though the percent energy impact would be significantly less.

It was originally hypothesized by the research team that water quality could relate to crossover, as the lower the water quality the faster a shower valve might deteriorate. However, no conclusive result was obtained from the water quality analysis. Another step of analysis that was performed, considered all the surveyed building by the age or the decade in which it was built in. This analysis summarizes all of the buildings that tested positive for crossover. A table of results are shown below as an example:

Table 2. Vintages of buildings tested for crossover and results

Age	Total Buildings	Crossover	No Crossover	Unknown CxO	Crossover %
1900-10	1	1	0	0	100.00%
1910-20	3	1	1	1	33.33%
1920-30	3	0	2	1	0.00%
1930-40	0	0	0	0	0.00%
1940-50	5	0	5	0	0.00%
1950-60	7	3	4	0	42.86%
1960-70	21	10	8	3	47.62%
1970-80	5	2	2	1	40.00%

1980-90	7	4	3	0	57.14%
1990-00	4	0	4	0	0.00%
2000-10	3	1	0	2	33.33%
2010+	2	0	0	2	0.00%
Unknown	43	23	20	-	53.49%
TOTAL	61	22	29	10	43.14%

The primary goal of getting an indication of crossover was achieved, and with the result coming in at 52% of buildings, the research team concludes that crossover is very prevalent. The percentage of buildings with crossover is higher than expected, and does warrant further attention and investigation.

Citations and References

HMG, "*Measure Information Template- Central Hot Water Distribution Systems in Multifamily Buildings,*" June 2005

Bonneville, Charlotte. 2010 *Central Domestic Hot Water Systems in Multifamily Buildings*. ACEEE Hot Water Forum presentation session 3C

Howlett and Stone, "*Improving Hot Water Delivery in Multifamily Buildings," 2007*

Sachs, et al. ACEEE, "*Emerging Hot Water Technologies and Practices for Energy Efficiency as of 2011*," October 2011

Pfaff, Terry. 2009, "Crossover Historical Analysis the Effect on Energy Efficiency and Hot Water System Operation", ACEEE Hot Water Forum presentation, June 2009

Ayala, Gabriel; Zobrist, Derek; Enovative Group Inc. 2015. *Detecting Crossover*. California Energy Commission. Publication number: CEC-500-YYYY-XXX.