New York State Energy Research and Development Authority

Investigation of a Simplified Method for Detecting Rogue Bypass in Buildings with CHP and Solar Thermal Preheat Systems

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Investigation of a Simplified Method for Detecting Rogue Bypass in Buildings with CHP and Solar Thermal Preheat Systems

Final Report

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Notice

Abstract

This study focuses on testing a simple method to detect a phenomenon called rogue bypass that affects numerous buildings with a hot water recirculation loop and has a negative impact on the performance of preheat systems such as solar thermal and cogeneration systems. It was determined in a previous study conducted at a building in The Bronx that rogue bypass was the cause of a 45% performance degradation of the solar thermal system. Since preheat systems such as solar thermal and combined heat and power (i.e. CHP or cogeneration) are becoming more and more popular in multifamily buildings, the goal of this study is to test a method that could potentially be implemented at a site as part of a feasibility study before installing a preheat system.

In the previous study, a costly flowmeter-based experiment was necessary to detect and measure rogue bypass, but a simplified methodology had been proposed to detect rogue bypass. In this study, we implemented the proposed simplified methodology on 12 recirculation loops at multifamily buildings in Manhattan and The Bronx. The methodology consists of measuring temperatures at four locations on the domestic hot water system and the status of the recirculation pump. Measurements were recorded for a period of two weeks. The advantage of this method is that it can easily be translated from one preheat system to another, since there is no measurement point on the preheat system itself.

The main metric used in this study is the temperature difference between the domestic hot water temperature and the recirculation loop temperature. One would expect this metric to be almost constant at all times, since no fluid is added to the loop between the supply and return temperature sensors in an ideal situation, and the only temperature drop is from radiative and conductive losses. Bright Power analyzed the ΔT data sets for each building and found various criteria that were identified in the previous study that would help determine the presence of rogue bypass at each building. Two tests were performed on these data sets: a visual screening and a statistical analysis.

The results of these two tests were combined to determine the probability of rogue bypass at each building. Out of the ten recirculation loops in the final data set, three of the buildings are probably experiencing significant rogue bypass. The methods described in this report appear to be promising ways to identify buildings potentially affected by rogue bypass.

# Keywords

Solar Thermal; Cogeneration; CHP; Multifamily; Cold Water Bypass; Rogue Bypass; Crossover Flow; Preheat Systems; Performance Degradation; DHW

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Summary

This study tests the hypothesis that a simple method can be used to detect a phenomenon called rogue bypass on a sample set of 12 New York City multifamily domestic hot water recirculation loops. It builds upon the results of "The Negative Impact of Cold Water Bypass On Solar Domestic Hot Water Systems"[1]study conducted at a building in the Bronx which showed that a solar domestic hot water preheat system's performance was reduced by 45% due to the presence of rogue bypass. Rogue bypass affects buildings with a hot water recirculation loop and has a negative impact on the performance of preheat systems. Rogue bypass is characterized by cold water by passing a preheat system by entering the DHW system elsewhere in the building via a pathway that was not intended. This study finds that 30% of buildings studied are likely to be affected by rogue bypass. While the sample size of this study is too small to draw statistically significant conclusions, we believe that rogue bypass affects the performance of the preheat system at some of the buildings identified in this study, and prevent system owners from realizing the savings projected when the systems were designed. This will become even more critical as solar thermal and combined heat and power (i.e. CHP or cogeneration) systems continue to become more popular. To that end, one goal of this study is to test a method that could be quickly implemented to test for the existence of rogue bypass at a site before installing a preheat system.

The most interesting metric from the resulting data is the difference between the domestic hot water temperature (T_{DHW}) and the return temperature at the end of the recirculation loop (T_{RCR}) as shown on Figure S-1 below. The difference between these two values (ΔT) should normally be relatively constant corresponding to heat losses (e.g., Archstone Chelsea Mid Loop). A system affected by rogue bypass has widely variable ΔT and T_{RCR} (e.g., 1472 Montgomery). This visual signature of rogue bypass is characterized by a generally large ΔT value[2] and a high degree of variability. We call the ability of the human eye to discern the signature of these wide temperature swings "visual estimation."

With data that is so widely variable, a histogram helps to visualize the shape of the ΔT distribution. In this study, many buildings suspected of exhibiting rogue bypass had a distribution which appeared to be bimodal[3]. A bimodal distribution is a combination of two symmetric distributions. In the case of rogue bypass, this manifests as a combination of a normal distribution centered on ΔT_{loss}, which is the ΔT associated with normal radiative losses in the recirculation loop, and another distribution with a peak centered towards a higher abnormal ΔT associated with rogue bypass, which we call ΔT_{RB}. In some extreme cases, the frequency of the ΔT_{RB} values is so high that the peak centered on ΔT_{loss} is barely visible. Figure S-2 below shows a building where the two peaks are easily visible.

1 See References.

2 A "large" a ΔT value is system dependent – in a building with a very long recirculation loop or one with uninsulated or exposed piping, we would expect a larger ΔT value. The definition of appropriate ΔT values based on building characteristics is a potential area for additional research and energy modeling.

3 Or potentially even multi-modal in some cases. See Table 6.

Figure S-1. T_{DHW} and T_{RCR} at Archstone Chelsea (Mid Loop) and 1472 Montgomery Avenue

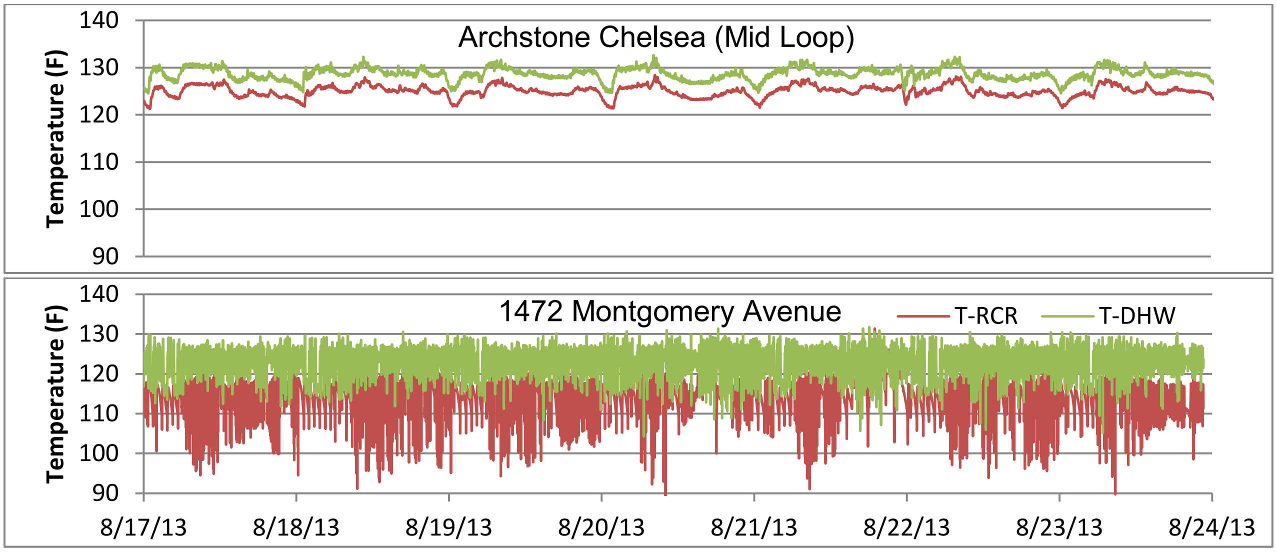
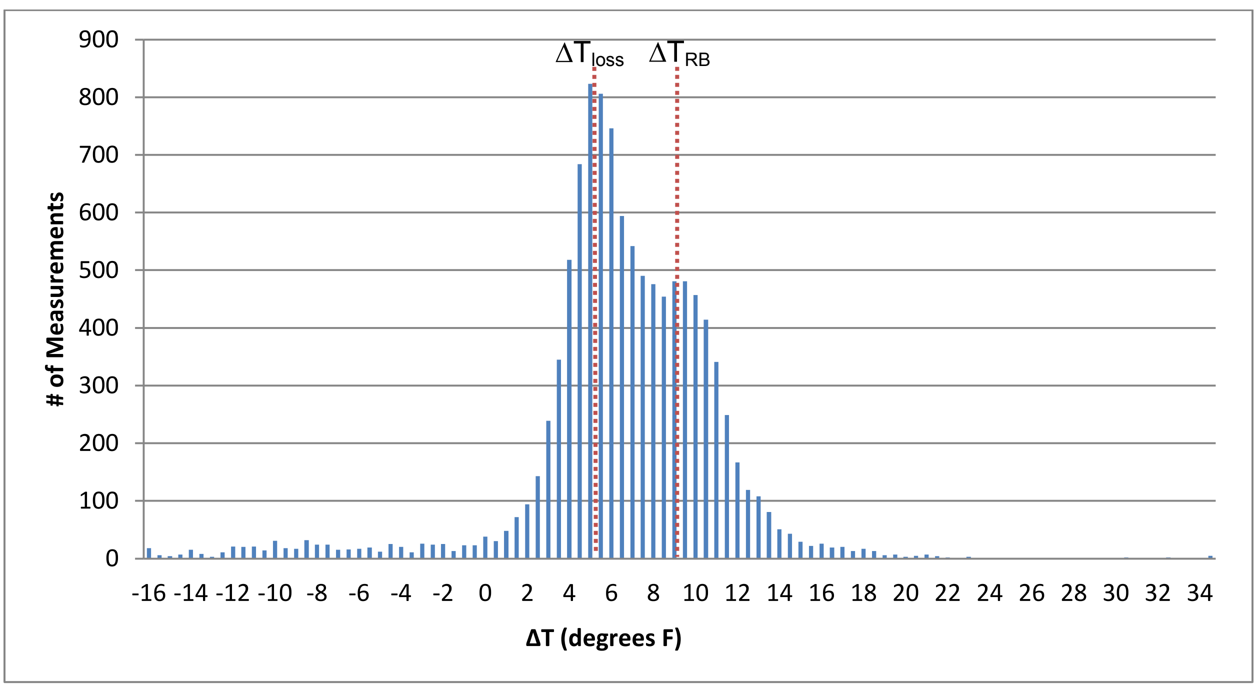


Figure S-2. Histogram of Delta T values at 1601 University Avenue

This data set does not follow a normal distribution and shows a shoulder towards the higher ΔT values. The left peak corresponds to ΔT_{loss}, and the second peak corresponds to ΔT_{RB} values when there is significant rogue bypass in the loop.



The existence of an abnormality in the distribution can be detected using a normality test, which compares the building's histogram to a normal distribution (our methodology is described in Section 4.2.3 of the report). However, in highly dysfunctional loops the ΔT_{RB} mode can "drown out" the ΔT_{loss} mode, and so we cannot rely solely on a test of normality[4]. As such, the results of the normality test are combined with the visual screening test shown in Figure S-1 to determine the probability of rogue bypass at each building, and can be found in Table S-3. Out of the 10 recirculation loops in the final data set, three of the buildings are probably experiencing significant rogue bypass. Three of the loops are probably experiencing low rogue bypass or another phenomenon. Four out of the eight loops flagged as probably experiencing rogue bypass have a solar thermal system and were built with similar water fixtures and characteristics. One interesting avenue for further study would be to look into what these buildings have in common exactly to pinpoint specific pieces of equipment that are particularly prone to rogue bypass.

Table S-3. Combined Analysis Results

Property Name	Test #1: Visual Screening	Test #2: Normality test	Hypothesis as to the presence / magnitude of rogue bypass	
	Probability of rogue bypass by visual estimation?	Possible abnormal behavior according to statistical analysis?	Rogue Bypass Presence?	Magnitude of Rogue Bypass?
1 - 120W 176th St	Probable	Low Rogue Bypass or other phenomenon	Probable	Low
2 - 1665 Andrews	Unclear	Moderate to High Rogue Bypass	**Probable**	**High**
3 - 1601 University	Probable	Low Rogue Bypass or other phenomenon	Probable	Low
4 - 1472 Montgomery	Probable	Moderate to High Rogue Bypass	**Probable**	**High**
5 - Archstone Chelsea - Low Loop	Unclear	Low Rogue Bypass or other phenomenon	Unclear	Low
6 - Archstone Chelsea - Mid Loop	Doubtful	No or Low Rogue Bypass	Doubtful	Low
7 - Archstone Midtown - Low Loop	Probable	Moderate to High Rogue Bypass	**Probable**	**High**
8 - Archstone Midtown - Mid Loop	Doubtful	No or Low Rogue Bypass	Doubtful	Low
9 - Avalon	Probable	Low Rogue Bypass or other phenomenon	Probable	Low
10 - Silver Towers	Doubtful	No or Low Rogue Bypass	Doubtful	Low

[4] Further statistical techniques, like the temperature at the mode of the distribution and the width of the standard deviation of the distribution hold promise as potential methods, but for various reasons described in the report need further research before they can be considered reliable determinants of rogue bypass.

The impacts of rogue bypass present significant risk to preheat system owners and the government entities that have invested heavily in these systems and depend on their energy savings. The New York State Energy Research and Development Authority (NYSERDA) has invested $114 million in over 174 cogeneration projects.

We are confident these results show that 1085 Washington Ave in the Bronx was not an isolated case and we appear to have found a detection method for rogue bypass. Without implementing a whole flowmeter-based study, it is unrealistic to make assumptions as to the performance degradation of the preheat systems in the buildings identified. An in-depth flowmeter-based analysis would also be necessary to confirm the presence of rogue bypass and to check for false positive and false negative cases.

The fact that hundreds of millions of dollars are being invested in preheat systems every year makes it urgent that rogue bypass – an effect which can reduce system performance by almost half if not more – be identified so that these systems can deliver the energy and economic savings they were designed to provide.[5]The methods described in this report appear to be promising ways to identify buildings potentially affected by rogue bypass.

[5] It is possible to design systems to mitigate the impact of rogue bypass, and Bright Power is currently piloting a technique using three-way diversion valves which shows promise.

1 Background

1.1 Findings from Previous Study

Combined Heat and Power (CHP) and Solar Domestic Hot Water (SDHW) systems are designed to preheat the domestic hot water for a building. These systems save fossil fuels or electricity by reducing the runtime required of the conventional domestic hot water (DHW) appliance, because the conventional appliance is not required to supply as much heat. The proper functioning of CHP and SDHW systems is predicated on the fundamental assumption that the vast majority of cold mains water to be heated for DHW will flow through the preheat system, and will not enter the conventional DHW appliance some other way.[6]

Post-installation monitoring of a24 collector SDHW system installed in The Bronx revealed that the overall performance of the system was far lower than expected. The initial hypothesis for the cause of the reduced performance posited that less water was being drawn through the preheat tanks than designed for, thereby impeding the distribution of the thermal energy collected and reducing the efficiency of the solar thermal system. To investigate this theory, a study was commissioned to analyze the internal dynamics of the system through a joint effort between Bright Power, the New York State Energy Research and Development Authority (NYSERDA), and the New York City Economic Development Corporation (NYCEDC). The results of this study were published in August 2011in "The Negative Impact of Cold Water Bypass On Solar Domestic Hot Water Systems."[7]

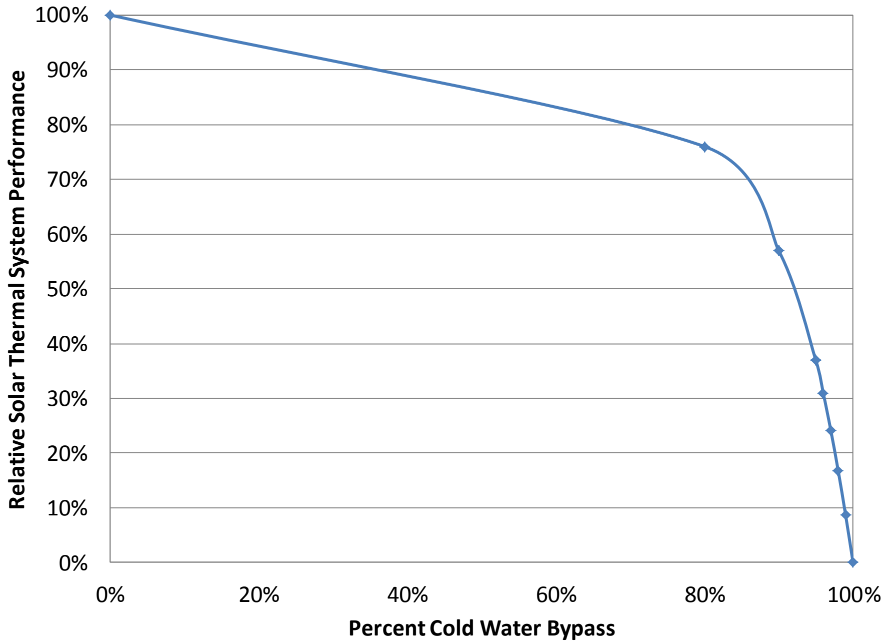
Using a 10-point temperature and 2-point flow sensor setup[8] for six months, together with hourly energy simulations, Bright Power analyzed the thermal and fluid dynamics of the domestic hot water (DHW) system. We found that the primary cause of the problem is cold water bypass, whereby cold water makeup from the mains plumbing line is circumventing the solar preheat tanks. The theoretical foundation for the effect of cold water bypass is shown in Figure 1 – as cold water bypass increases, the performance of the preheat system decreases.

[6] A small portion of the entering cold water is typically designed to flow through a tempering or mixing valve for scald protection.

[7] See References.

[8] These sensors were in addition to the temperature and flow sensors installed prior to this study on the solar collector and heat transfer portion of the system.

Figure 1. The negative effect of cold water bypass on solar thermal system performance[9]



As defined, cold water bypass has two components: mixing valve bypass and rogue bypass. Mixing valve bypass, whereby cold water enters the DHW system at the cold side of the mixing valve rather than through the solar preheat tanks, was intentional to the original design as a safety feature for summer months when the system is delivering higher temperature water than is safe for occupants. Rogue bypass is a phenomenon in which cold water bypasses a preheat system by entering the DHW system elsewhere in the building via a pathway that was not intended and is difficult to pinpoint. It was determined in the study that for this system the majority of the performance degradation is the result of rogue bypass. The negative impact of mixing valve bypass is a secondary effect that becomes significant only when rogue bypass is present. During the period of measurement, rogue bypass accounted for on average 82% of cold water entering the DHW system. This reduction of flow was found to result in a 45%.[10] average reduction in savings, both in energy and dollar terms. This means it would take nearly twice the time for the system owner to recoup the initial investment as was originally projected.

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9 This chart was specifically prepared for this particular solar thermal system, which has a projected annual solar fraction (percent of DHW provided by the solar system) of 11-12%. This chart would be different for other systems with other solar fractions.

10 Percent degradation of SDHW system performance is defined as the percent difference between modeled and measured energy production. Hourly energy simulations were completed using TRNSYS software. Measured energy production was taken from the solar thermal controller output.

When large amounts of cold water bypass the solar preheat tanks, SDHW stored in the tanks is prevented from circulating to the DHW system. This causes heat produced by the solar thermal system to build up in the preheat tanks instead of being drawn out in response to occupant demand, to the extent that the preheat tank temperatures remain high even early in the morning. When preheated SDHW is not being used by the building, higher SDHW tank temperatures cause lower thermal transfer. The ultimate mechanism of performance degradation is the system's inability to collect and store additional heat when the SDHW tank is being bypassed.

Rogue bypass presents a compelling question: how could so much water be circumventing the domestic hot water system? With temperature and flow sensors on site taking readings at one minute intervals, we measured the flow rate of water entering the SDHW system; using the principles of conservation of mass and energy, we calculated rogue bypass flow and total DHW usage every minute for a three day period in March 2011.The data clearly show that a rogue bypass flow condition occurs below a threshold of 6 gallons per minute (GPM), meaning that all cold water bypasses the preheat system. Once flow exceeds this threshold, then water begins to flow through the conventional cold water inlet to the domestic hot water system. Remarkably, rogue bypass flow manages to account for 82% of total DHW usage even though rogue bypass flow never exceeds 10 GPM.

We believe that rogue bypass is caused by cold water entering the DHW system elsewhere in the building via crossover flow from the cold water line to the hot water line. Crossover flow is recognized in the plumbing community as the unintentional flow of water between the hot and cold water lines in a building, typically via faulty check valves or mixing valves, single-spout faucets or showers, dishwashers, washing machine hook-ups, and tenant modifications undetected by building management.[11] Because crossover flow is enhanced by pressure differences between the DHW and cold water lines, the numerous multifamily and commercial buildings that use a DHW recirculation pump are particularly susceptible.

The proliferation of solar thermal and other preheat systems, such as cogeneration, requires the formulation of a methodology for diagnosing the presence of rogue bypass and the development of best practices in design to minimize its impact. Initial analysis indicates that it may be possible to diagnose the existence of rogue bypass with three temperature sensors and one pump status sensor – a fairly simple apparatus to deploy prior to solar thermal installation.

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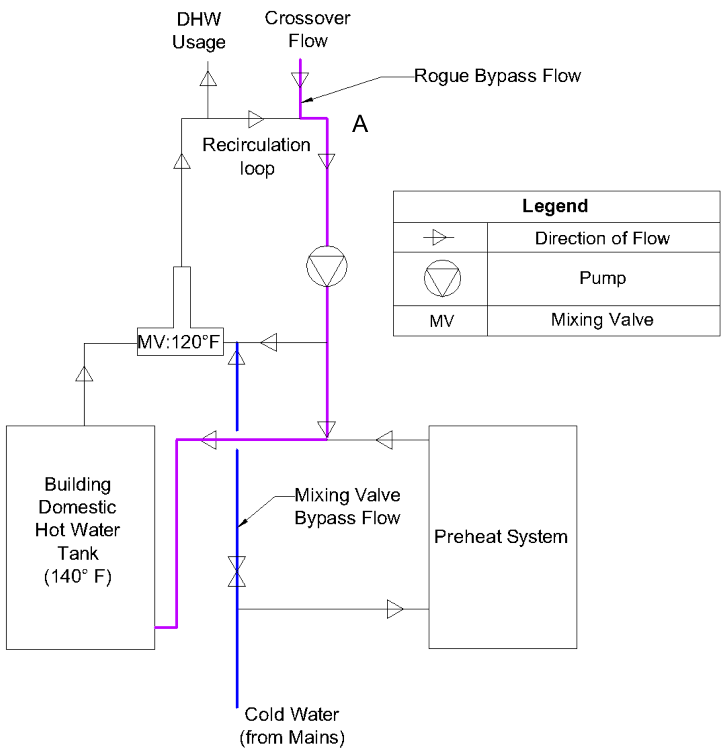
[11] Heschong Mahone Group, June 23, 2006. "Measure Information Template – Central Hot Water Distribution Systems in Multifamily Buildings."2008 California Building Energy Efficiency Standards.

1.2 Theoretical Model of Rogue Bypass

The amount of crossover flow contributing to rogue bypass can be theoretically quantified through a mass and energy balance. The following methodology can be applied to any DHW system with a recirculation pump. Figure 2 describes a generic building DHW system, including preheat system, mixing valve and a recirculation pump.

Figure 2. Two paths for cold water bypass

Cold water bypass has two components: mixing valve bypass and rogue bypass.



Consider point Aon Figure 2 at which the rogue bypass flow enters the system (e.g. on the cold side of a mis-plumbed faucet, approximately between 55 and 70 °F). At that point, we apply the concepts of conservation of mass and energy. These simply state that mass or energy cannot be created nor destroyed. Flow rates are simply a measure of mass delivered over time, so according to Equation 1, at this point:

$$F_{RCR} = F_{RCR}' + F_{RB} \qquad (1)$$

Where

- FRCR is the recirculation flow downstream of this point.
- F_{RCR}' is the recirculation flow upstream of this point.
- F_{RB} is the additional flow added to the recirculation loop at this point.

The flows into and out of the point must be equal for conservation of mass.

By a similar argument, conservation of energy requires that the energy flow into and out of this point must be equal. The amount of energy contained in water is determined by its specific heat capacity (mcΔT) and is proportional to flow multiplied by temperature. Thus, Equation 2 states:

$$T_{RCR}F_{RCR} = T_{RCR}'\, F_{RCR}' + T_{CW}F_{RB} \qquad (2)$$

Where T_{RCR}' is the temperature of the recirculation flow upstream of rogue bypass, T_{RCR} is the measured temperature of the return line, and T_{CW} is the measured temperature of the cold water mains. By rearranging Equation 1 to isolate F_{RCR}' we get Equation 3:

$$F'_{RCR} = F_{RCR} - F_{RB} \qquad (3)$$

which we can substitute into Equation 2 and solve for F_{RB} in Equation 4:

$$F_{RB} = F_{RCR}\frac{(T_{RCR} - T_{RCR}')}{(T_{CW} - T_{RCR}')} \qquad (4)$$

$F_{RCR,}$ T_{RCR} and T_{CW} are measured values while T_{RCR}'can be determined theoretically by considering what the return line temperature would be in the absence of rogue bypass. Radiative and convective losses in the recirculation loop mean that, even with no cold water added to the loop, the returning water arrives cooler than it was when sent to the building. During periods of no draw, no cold water is added to the loop and so the losses can be estimated by Equation 5:

$$\Delta T_{loss} = \min\,(T_{DHW} - T_{RCR}) \qquad (5)$$

Where T_{DHW} is the temperature at the outlet of the mixing valve.

This can then be used to estimate the upstream recirculation temperature in Equation 6:

$$T_{RCR}' \approx T_{DHW} - \Delta T_{loss} \qquad (6)$$

Similarly, this temperature difference between the domestic hot water temperature and output of the recirculation loop is noted ΔT and calculated as Equation 7:

$$\Delta T = T_{DHW} - T_{RCR} \qquad (7)$$

With measurements of $F_{RCR,}$ T_{RCR} and T_{CW}, we can calculate the predicted rogue bypass flow (F_{RB}). In this study we will be focusing on an experimental method of measuring the percentage of rogue bypass in the DHW system at any time by measuring T_{RCR}, T_{DHW} and T_{CW} and estimating ΔT_{loss}.

By reorganizing Equation 4 and substituting Equation 6, we calculate the percentage of rogue bypass as Equation 8:

$$\% \, RB = \frac{F_{RB}}{F_{RCR}} \approx \frac{(T_{RCR} - T_{DHW} + \Delta T_{loss})}{(T_{CW} - T_{DHW} + \Delta T_{loss})} \qquad (8)$$

1.3 Characteristics of Rogue Bypass

During the previous study summarized in Section 1.1, some of the characteristics of the rogue bypass phenomenon were identified. The most interesting metric is the temperature difference between the domestic hot water temperature and the output of the recirculation loop, which should be almost constant due to the heat losses in the loop. However, actual measurements show that the temperature of the recirculation loop output sometimes drops significantly while the domestic hot water temperature stays almost constant. The previous study showed that these significant temperature drops are due to cold water entering the recirculation loop when the usage in the building is highest, due to tenants using water fixtures, laundry machines and other devices where crossover flow is possible. These significant temperature drops are visible in Figure 3.

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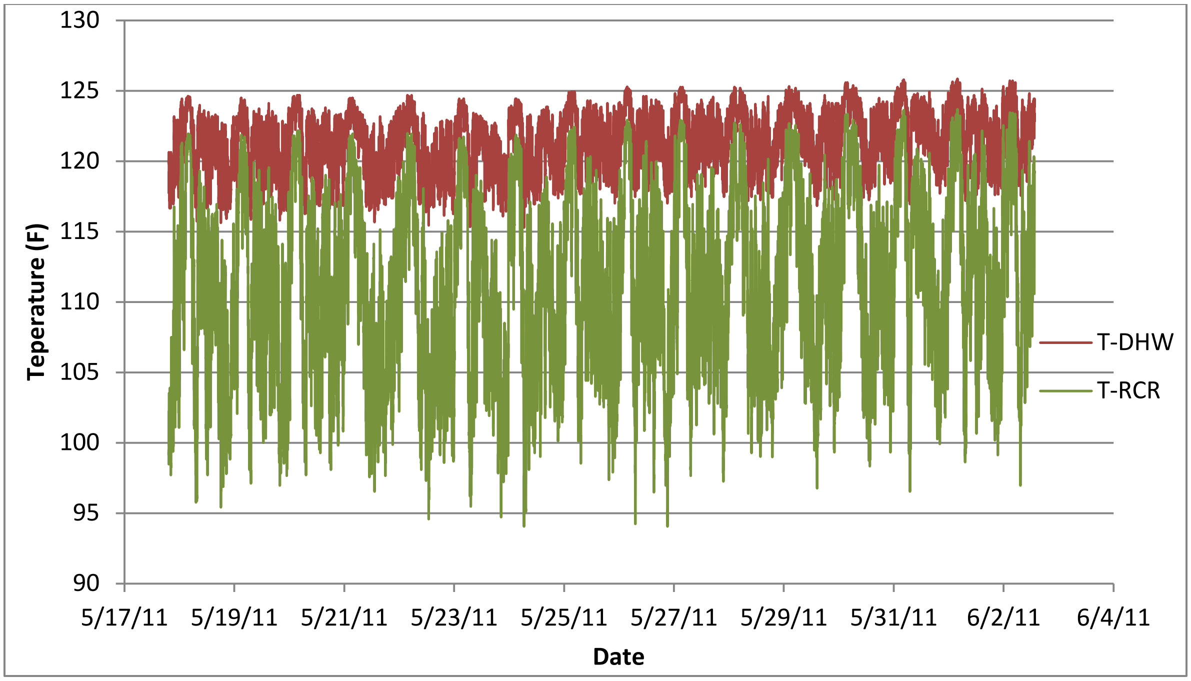
Figure 3. T_{DHW} and T_{RCR} at 1085 Washington

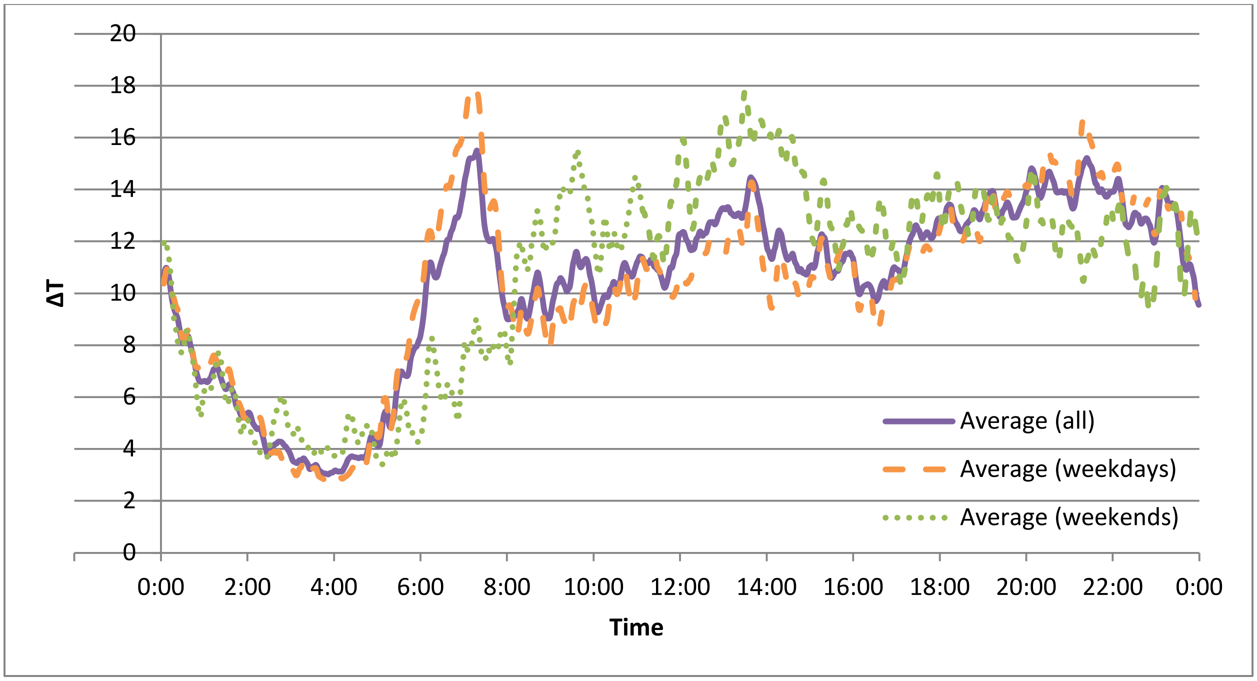
T_{RCR} varies significantly more than T_{DHW} and drops everyday by up to 20 degrees.



This temperature difference between the domestic hot water temperature and output of the recirculation loop is referred to as ΔT. At the time of a draw on the DHW system, the flow in the recirculation loop decreases; however, if there is no cold water bypass, the recirculation temperature should always be lower than the domestic hot water temperature by ΔT_{loss}, which is the temperature drop due to radiative losses in the recirculation loop. A graph of ΔT throughout the day should thus show a straight line. Figure 4 shows ΔT measured every minute for a period of two weeks and averaged depending on the type of day (weekend vs. weekday).

Figure 4. Average Delta T during the day depending on day type at 1085 Washington

ΔT varies significantly throughout the day and shows different behaviors depending on the type of day



This graph shows that ΔT is lowest at night, independent of the type of the day (weekend or weekday). The assumption is that the minimum ΔT happens when there is minimal or no draw in the building. During weekdays, ΔT increases significantly during the hours of 5 a.m. and 8 a.m., when usage increases in the building (tenants start their day with taking showers and using kitchen water fixtures). During weekends, ΔT increases significantly during the hours of 8 a.m. and 1 p.m., and this difference reflects different behaviors on the weekends.

1.4 Choice of Monitoring Points

The simplified formula for the percentage of rogue bypass flow is a function of temperatures in various locations on the domestic hot water system, as explained in Equation 8:

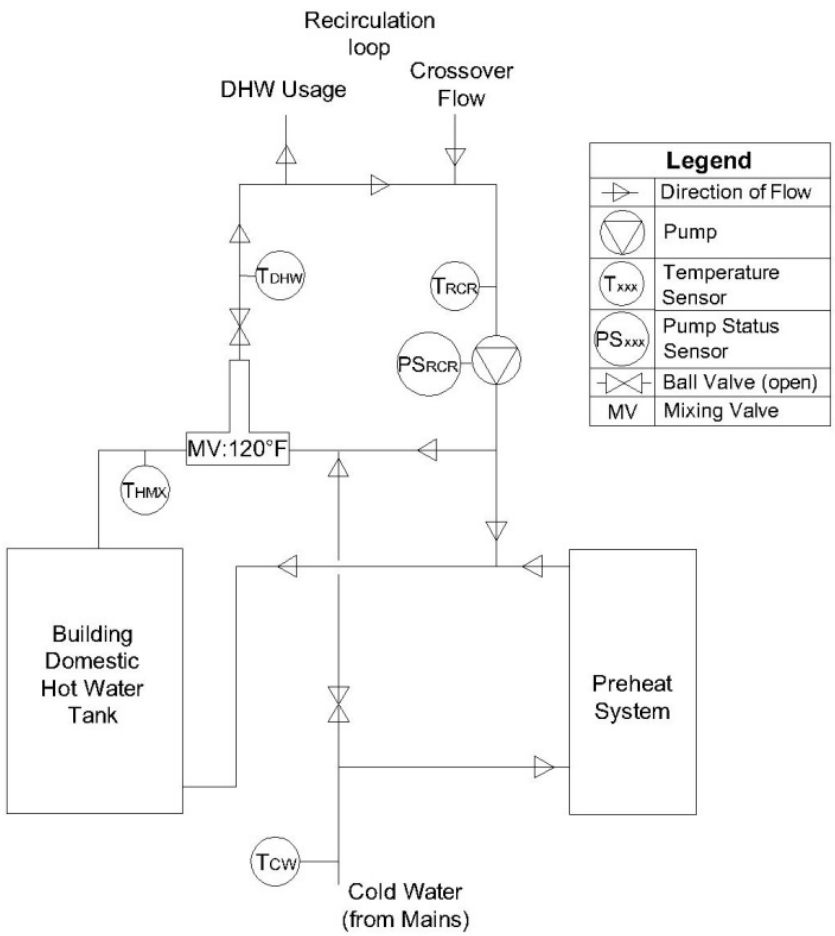
$$\% RB \approx \frac{(T_{RCR} - T_{DHW} + \Delta T_{loss})}{(T_{CW} - T_{DHW} + \Delta T_{loss})} \qquad (8)$$

In this formula, ΔT_{loss} is a constant value and the other temperatures vary. The locations of T_{RCR}, $T_{DHW,}$ and T_{CW} are shown in Figure 5.

As an additional check point, we decided to monitor the temperature on the hot side of the mixing valve (T_{HMX}). This temperature is not necessary for the calculation of the percentage of rogue bypass, but can potentially help understand variations in $T_{DHW,}$ since T_{DHW} is the result of the mixing valve mixing T_{CW}, T_{RCR}, and T_{HMX} . The location of the T_{HMX} sensor is shown in Figure 5.

During the previous study, one of the experiments showed that by replacing an oversized recirculation pump with a pump of the appropriate size, the average percentage of rogue bypass dropped from 93% to 82%, indicating a possible correlation between over-pressurization in the recirculation loop and the percentage of rogue bypass. We monitored the status of the recirculation pump during this study to determine whether this correlation could be verified in other buildings. This sensor is shown as PS_{RCR} on the diagram in Figure 5.

Figure 5. Location of monitoring points on a typical Domestic Hot Water System with a Preheat System



2 Experimental Setup

2.1 Pilot Phase

2.1.1 Goal

We conducted a preliminary pilot phase during which the proposed diagnostic approach was implemented on three buildings in Manhattan and the Bronx. This phase was conducted to test the experimental methodology and monitoring equipment before deploying the experiment on the larger set of buildings identified for study.

Bright Power installed monitoring equipment on two sites with CHP systems and one site with a solar domestic hot water system:

Table 1. Site Locations for Pilot Phase

Site	Building Type	System	Heat Recovery Use
120 West 176th Street	Multifamily	SDHW	DHW
Archstone Chelsea	Multifamily	CHP	DHW
Jewish Home and Hospital Greenwall Pavilion	Assisted Living Center	CHP	DHW & Cooling

Before deployment, the temperature sensors and pump run-time sensors were calibrated, installed, and programmed to ensure proper function. They were determined to be in good working order and provided accurate readings. The accuracy of the temperature sensors was a critical factor in the equipment choice because the goal was to measure a temperature difference that could be as low as 2 ºF. The temperature sensors used were Onset Hobo TMC-6HD sensors with an accuracy of ±0.25ºCand a 2-minute time response.

The monitoring equipment was deployed at all sites over the same two-week period and programmed to collect data at 1-minute intervals. Monitoring points included the pump status and run-time of the recirculation pump, the return water temperature in the recirculation loop (T_{RCR}), domestic hot water temperature (T_{DHW}), water temperature on the hot side of the mixing valve (T_{HMX}), and the temperature of cold mains (T_{CW}). All sensors were successfully deployed at each site with the exception of the T_{CW} sensor at JHH due to access problems.

2.1.2 Lessons Learned from Pilot Phase

Two of the sites had multiple mixing valves with multiple recirculation loops, which we did not anticipate, and we therefore did not have enough data monitoring equipment to install sensors on all of them. During the second phase, we took this factor into account and decided to identify the number of monitoring points per site as part of our pre-visit data collection and then to monitor each loop as a separate system. We were particularly attentive to the possibility of interactions between different loops in these cases and made sure the monitored loops were independent.

Some buildings had a DHW night time turn down control which created large T_{DHW} variations towards the end and beginning of the day, which had to be compensated for in our analysis. This was another piece of information we subsequently included in our pre-visit data collection.

Some sites utilized the pre-heat systems for purposes other than DHW, such as cooling, or had usage profiles that made it difficult to detect rogue bypass with our current strategy. We decided to prioritize those sites that used the heat during the monitoring period for DHW only and tied to anticipate complications in usage patterns.

We also found that there could be access issues with the cold water piping, which created difficulties to monitor T_{CW}. If T_{CW} could not be obtained, we found it was possible to estimate it using data from other recirculation loops.

2.2 Monitoring Phase

Bright Power deployed temperature sensors and pump status sensors on 12 recirculation loops in 9 different buildings in Manhattan and The Bronx. The loops were programmed to collect data on all loops from August 17, 2013 through September 1, 2013 (two weeks). Before installing the sensors on each of the recirculation loops, each sensor was tested and calibrated.

At the end of the logging period, all monitoring equipment was collected and the mechanical rooms were restored to their original conditions.

In total, data was collected from eight cogeneration recirculation loops and four solar domestic hot water recirculation loops. A summary of the loops that were monitored is provided in Table 2 and Table 3.

Table 2. Summary of Solar Thermal Loops

#	Name	Address	Solar Capacity	End Use	Dates of Monitoring
1	120 W 176	120 W 176th St. Bronx	15 SunEarth EC-40 collectors	DHW	Aug 17 - Aug 31
2	1665 Andrews Ave.	1665 Andrews Ave. Bronx	28 SunEarth EC-40 collectors	DHW	Aug 17 - Aug 31
3	1601 University Ave.	1601 University Ave. Bronx	28 SunEarth EC-40 collectors	DHW	Aug 17 - Aug 31
4	1472 Montgomery Ave.	1472 Montgomery Ave. Bronx	21 SunEarth EC-40 collectors	DHW	Aug 17 - Aug 31

Table 3. Summary of Cogeneration Loops

#	Name	Address	kW Rating	Type	Dates of Monitoring
5	Archstone Chelsea Low Loop	800 6th Ave. Manhattan	75	DHW	Aug 17 - Aug 31
6	Archstone Chelsea Mid Loop	800 6th Ave. Manhattan	75	DHW	Aug 17 - Aug 31
7	Archstone Midtown LowLoop	250 West 50th St. Manhattan	150	DHW	Aug 17 - Aug 31
8	Archstone Midtown MidLoop	250 West 50th St. Manhattan	150	DHW	Aug 17 - Aug 31
9	Avalon	1 Morningside Dr. Manhattan	150	DHW	Aug 17 - Aug 31
10	Silver Towers	620 West 42nd St. Manhattan	300	DHW Space Heating	Aug 17 - Aug 31
11	Seaside Loop A	20 Father Capodanno Blvd. Staten Island	100	DHW	Aug 17 - Aug 31
12	Seaside Loop B	20 Father Capodanno Blvd. Staten Island	100	DHW	Aug 17 - Aug 31

2.3 Data Collection

At the end of the two-week period, the data collected by the sensors was exported from the data loggers. All temperature sensors were still working and the data loggers had stored data during the specified timeframe.

After the two-week monitoring period, the sensors were tested again at ambient temperature and in an ice/water mixture, and one sensor was found to be significantly more sensitive to temperature changes than the rest of the sensors. This particular sensor was the one measuring T_{DHW} at Seaside Apartments for both recirculation loops. We decided to omit those recirculation loops in the rest of the study. Table 4 below shows for which loops we considered the data to be acceptable to be used in the rest of the study.

Six out of the 12 pump status sensors stopped working or became damaged from overheating. For these six recirculation loops, we assumed that the pump was running 24 hours a day for the purpose of this study, which is what we had noticed during the sensor installation and collection at these particular sites. In the buildings where the pumps were controlled, the control was typically an aquastat that was set in such a way that the pump never turned off.

Two of the pump status sensors seem to have malfunctioned, only measuring that the pump was ON about 2 minutes every hour, which is inconsistent with what we saw while installing the sensors onsite. Out of the four remaining recirculation loops, two had recirculation pumps that ran 24 hours a day for the duration of the study and the pumps at the other recirculation loops ran for 23% and 51% of the time. In a future study, measurement of current flow might be more reliable, but was beyond the scope of this study.

Table 4. Post Monitoring Data Summary

#	Name	Pump On/Off Data?	Temperature Sensor Data?	Data considered acceptable?
1	120 W 176	No (overheated sensor)	Yes	Yes
2	1665 Andrews Ave.	Yes	Yes	Yes
3	1601 University Ave.	Yes	Yes	Yes
4	1472 Montgomery Ave.	Yes	Yes	Yes
5	Archstone Chelsea - Low Loop	No (overheated sensor)	Yes	Yes
6	Archstone Chelsea - Mid Loop	No (overheated sensor)	Yes	Yes
7	Archstone Midtown - Low Loop	No (overheated sensor)	Yes	Yes
8	Archstone Midtown - Mid Loop	No (overheated sensor)	Yes	Yes
9	Avalon	No (overheated sensor)	Yes	Yes
10	Silver Towers	Yes	Yes	Yes
11	Seaside - Loop A	Yes, but unreliable data	Yes, but unreliable data	No
12	Seaside - Loop B	Yes, but unreliable data	Yes, but unreliable data	No

3 Observations

T_{RCR}, T_{DHW}, and ΔT showed multiple behaviors which had not been encountered during the previous study.

3.1 Delta T Variations from Building to Building

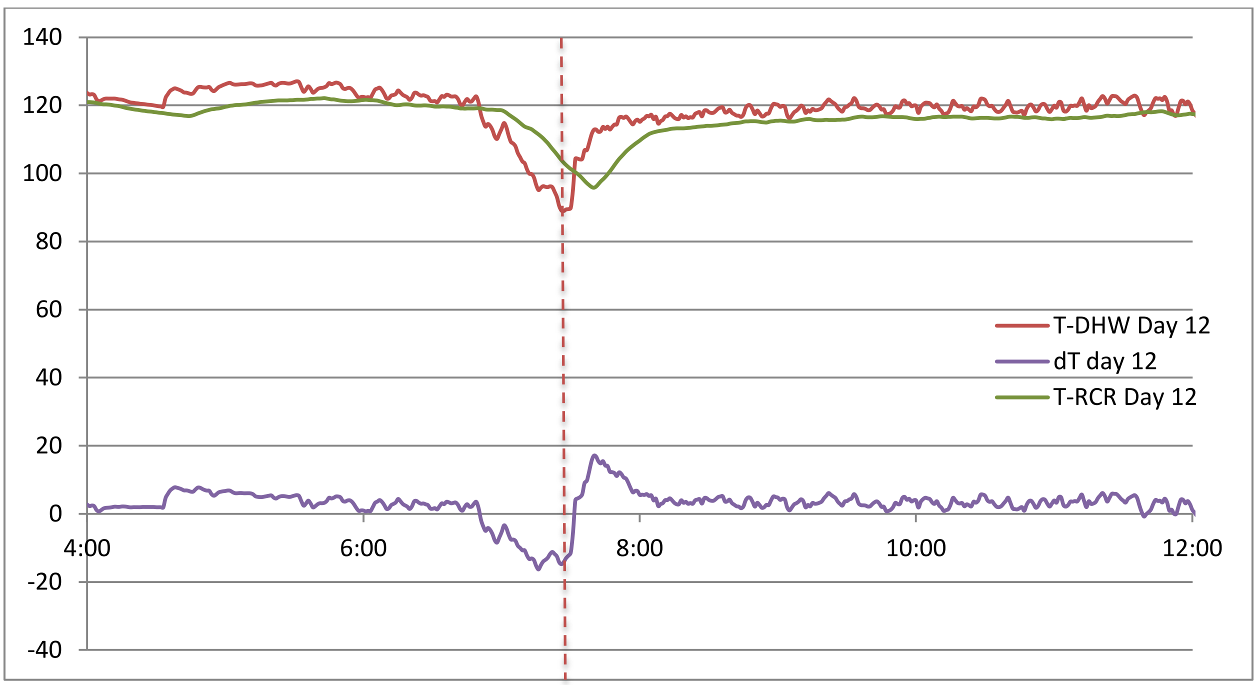
The average ΔT varied significantly from site to site. Similar buildings in terms of number of units and height showed average ΔT as low as 3 and as high as 20.

3.2 T_{DHW} Variations Due to System Shutoff

In more than one building, isolated and sudden significant T_{DHW} drops appeared as negative ΔT values. However, ΔT cannot be negative, since this would mean the water comes out of the loop hotter than it entered it. This could only happen if there was a heat source somewhere along the loop. In those specific cases with isolated and sudden T_{DHW} drops, these variations were interpreted as the DHW system turning off for a short period (for maintenance purposes, for example). The variations in ΔT were not due to rogue bypass.

Figure 6.Delta T and T_{DHW} variation at Archstone Midtown Mid Loop on 8/28/13

A sudden 30-degree T_{DHW} drop shows as a negative ΔT drop (while T_{RCR} is higher than T_{DHW}) followed by a sudden ΔT increase.

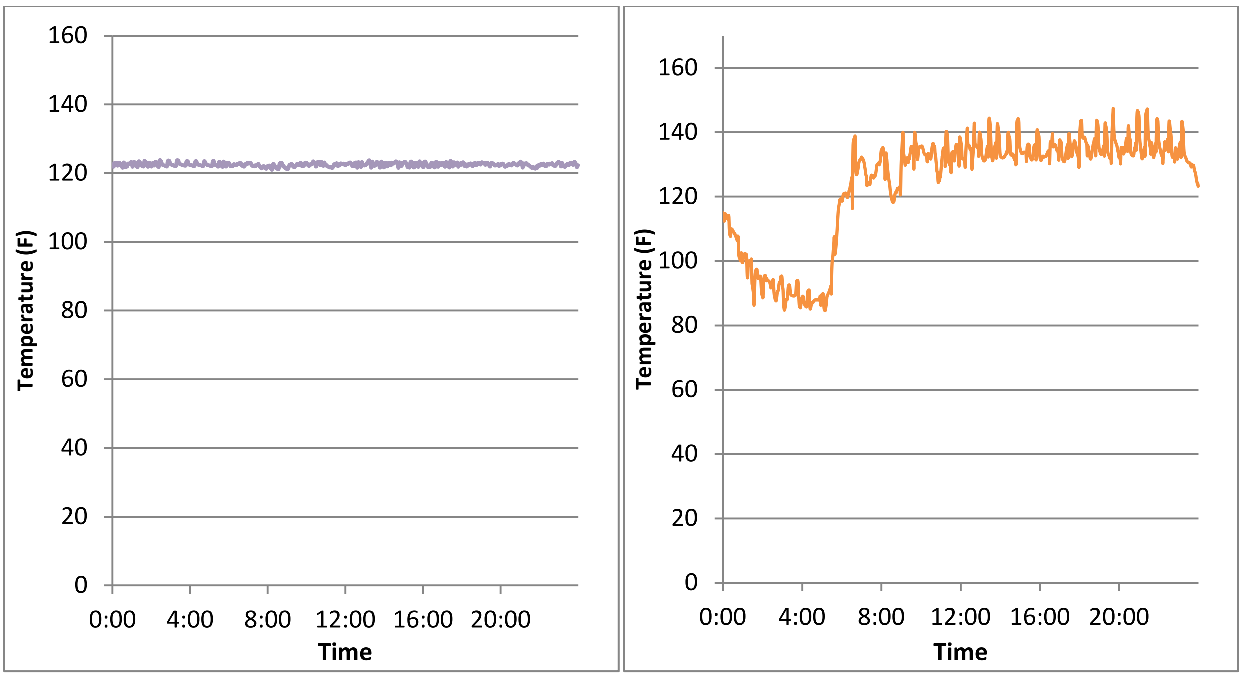


3.3 T_{DHW} Variations Due to Mixing Valve Response Time

When observing the data with more granularity, some buildings show a very smooth T_{DHW} profile, whereas other buildings show a very irregular T_{DHW} profile. This difference is shown in Figure 7.

Figure 7. T_{DHW} profiles at Silver Towers and Archstone Chelsea (Low Loop)

The left graph on the left shows a smooth TDHW profile at Silver Towers on Day 10 of the study, with a relative standard deviation of 0.4%. The graph on the right shows the irregular TDHW profile at Archstone Chelsea (Low Loop) on Day 12 of the study, with a relative standard deviation of 14.1% (calculated over the two-week period).



One of the possible reasons for this behavior is the reactivity of the mixing valve where the water from the domestic hot water heaters is mixed with cold water. When the temperature of the domestic hot water heaters vary, the mixing valve adjusts how much flow of cold water is added to obtain T_{DHW}. If the mixing valve does not react quickly enough, the output temperature can be significantly different from the set temperature. The assumption is that Silver Towers (left) has a very reactive mixing valve with a short response time, and that the mixing valve at Archstone Chelsea (Low Loop) has a significantly longer response time.

This assumption can create issues when analyzing the data, especially when calculating ΔT as the difference between T_{RCR} and T_{DHW} measured at the same moment in time. In reality, when measuring T_{DHW} at the beginning of the recirculation loop, we are measuring the temperature of a certain quantity of water that is circulating in the recirculation loop. This quantity of water does not instantly reach the location where T_{RCR} is measured; it takes some

time for the fluid to travel through the recirculation loop. In the previous study, the assumption was that T_{DHW} was constant enough that we could neglect the effect of the recirculation loop travel time. In this study, we will be taking into account a delay when calculating ΔT to avoid the effect of the T_{DHW} variation. This delay is calculated to minimize the standard deviation of the entire data set for each building. A graphical explanation and the time offsets calculated for each building can be found in the Appendix.

3.4 Recirculation Pump Effect

When filtering the ΔT data sets to keep only the values when the recirculation pump is running, we realized that some of the negative values considered physically impossible were filtered out. The assumption is that when the pump is not running, there is conduction in the pipes that is not counteracted by the fluid circulating, which results in the high temperature at the mixing valve propagating in the pipes around the mixing valve. The behavior described in this assumption results in a higher T_{RCR} than when the pump is running. In extreme cases, this assumption also explains why T_{RCR} is higher than $T_{DHW,}$ resulting in a negative ΔT. These negative ΔT values are eliminated when filtering out the period when the pump is off.

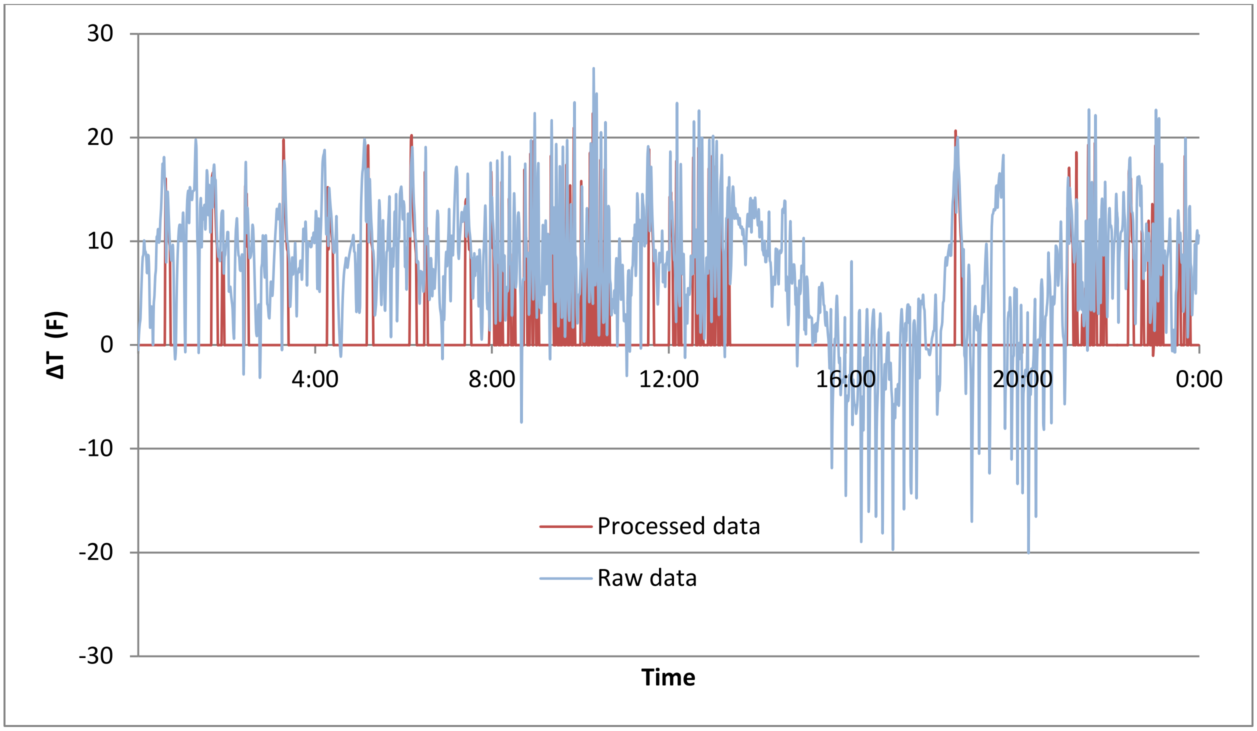
To obtain Figure 8, we calculated the optimized time offset between the measurement of T_{DHW} and T_{RCR}. The length of the recirculation loop means the fluid takes a certain amount of time to go from the first measurement point T_{DHW} to the second measurement point T_{RCR}. If T_{DHW} is constant, this is not a problem, but if T_{DHW} varies significantly from one minute to the next, and T_{RCR} also varies from one minute to the next, that means the difference between those two temperatures measured minute-to-minute do not reflect the actual temperature variation of a certain quantity of fluid travelling through the loop. The time it takes for the fluid to travel through the loop creates noise in the data set. We chose to minimize this noise by offsetting the T_{RCR} data by a determined offset for each building. This offset was determined by seeking the offset for which the standard deviation of the ΔT data set was minimal. For most buildings, this offset was determined to be between 0 and 15 minutes, which is a reasonable loop travel time.

We then filtered out the times when the recirculation pump was off, according to the assumptions made previously. The result is the elimination of all negative ΔT values that were considered as physically impossible, except for one building with an odd behavior toward the end of the afternoon.[12]

[12] See Appendix A.

Figure 8. Delta T at 1472 Montgomery on Day 9 (Raw data and after processing)

The processed data filtered when the recirculation pump was off does not include any negative ΔT values.



3.5 Determination of Delta T_{loss}

To calculate the percentage of rogue bypass flow for each recirculation loop, the radiative losses in each loop must be determined. As explained in Section 1.2, ΔT_{loss} can be estimated by Equation 5:

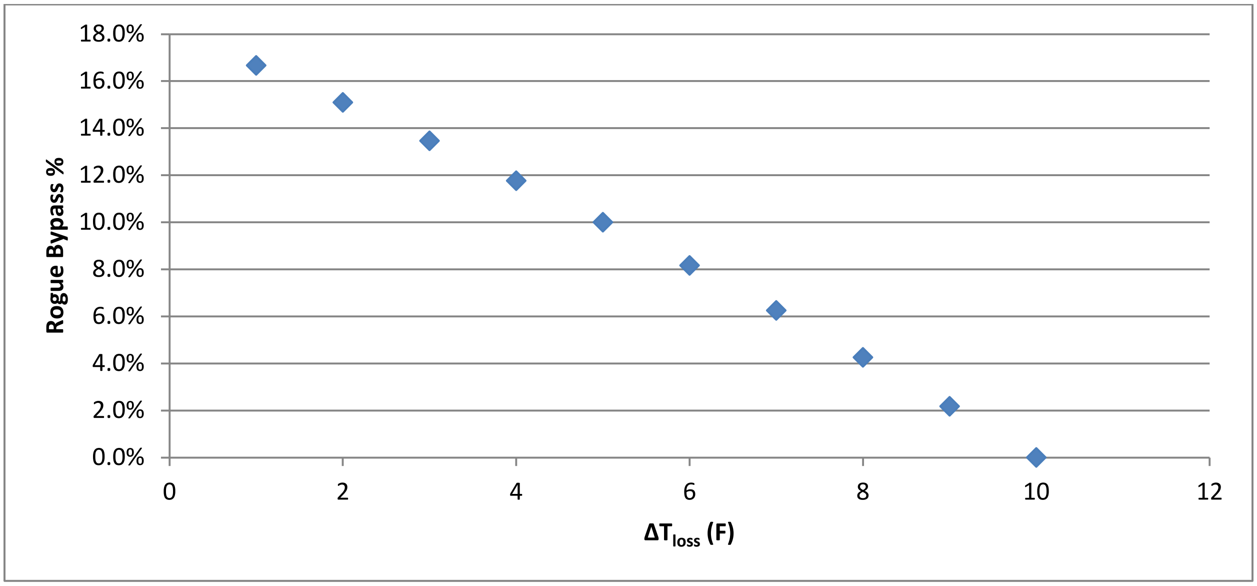
$$\Delta T_{loss} = \min\,(T_{DHW} - T_{RCR}) \qquad (5)$$

During the previous study, as shown on Figure 5, minimum radiative losses were visibly occurring at night, when ΔT_{loss} was lowest. ΔT_{loss} was determined as the minimum ΔT value over the length of this study. This method cannot be applied to the 12 buildings in this study because the vast majority of them show a negative ΔT at least once over the two week study length (even after applying the time offset and filtering the data when the pump was off). A negative ΔT is impossible, as this value would mean that the water is heated at an undetermined location on the recirculation loop.

Another solution is to determine an approximate ΔT_{loss} value by graphing ΔT over two weeks and choosing a value that is repeated often at night (when usage is minimal or nonexistent, which is when rogue bypass cannot happen). The issue with this solution is that the calculated rogue bypass percentage is heavily correlated with ΔT_{loss}. Figure 9 shows the variation of the rogue bypass percentage depending on the ΔT_{loss} value, all other factors being equal in a typical building situation (T_{DHW} = 125 F, T_{RCR} = 115 F, ΔT = 10 F, T_{CW} = 70 F). A one degree error in ΔT_{loss} induces up to a two percent point error in rogue bypass percentage, especially when ΔT is close to ΔT_{loss} itself (which is the case in most buildings).

Figure 9. Effect of Delta T_{loss} on Rogue Bypass Percentage

A one degree error in ΔTloss can induce up to a two percent point error in rogue bypass percentage.



Due to the difficulty of determining ΔT_{loss} and the uncertainty created by the error in ΔT_{loss}, we decided not to present ΔT_{loss} and RB% values in this report, as we are not confident enough in these results to draw conclusions from them. Instead, we chose quantitative methods to determine whether rogue bypass is present in a building. Section 4 describes these various methods.

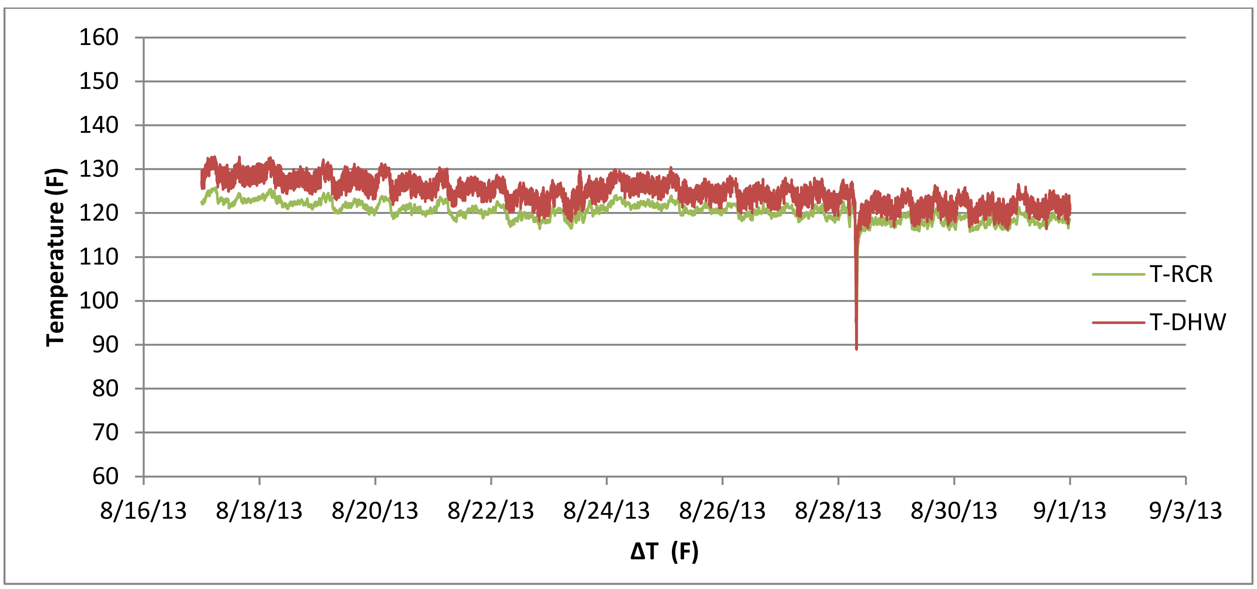
4 Analysis

4.1 Visual Analysis

An initial visual analysis of the profile of T_{DHW} and T_{RCR}, without any calculations, proved to be a valuable screening tool for how to interpret the data. These profiles can be compared to the same profiles for 1085 Washington (Figure 3), where rogue bypass was proven to be significant. If the variations of T_{RCR} seem to follow the variations of T_{DHW} with an almost constant offset between the two temperature profiles (e.g., ΔT is close to constant), it can be assumed that rogue bypass is minimal in the building. The absence of variation in ΔT can rule out rogue bypass; however the presence of variation is not conclusive evidence and demands further study. This is why we recommend a visual analysis as a screening method. Figure 10 shows an example of a building where rogue bypass is unlikely to be happening.

Figure 10. T_{DHW} and T_{RCR} at Archstone Midtown Mid Loop

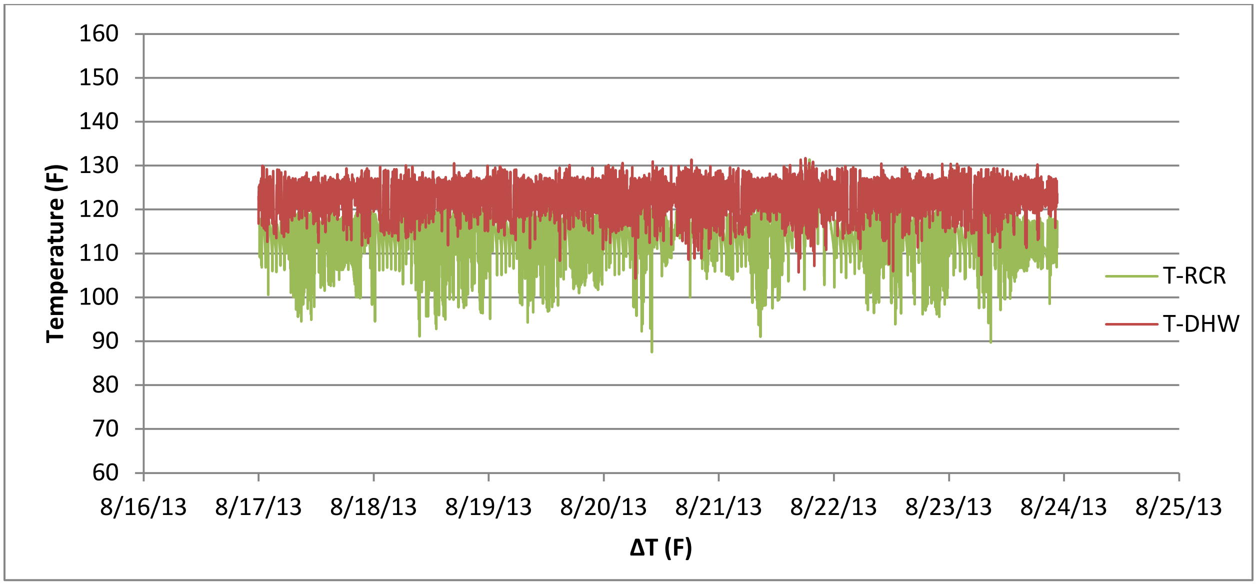
The two temperature profiles are almost parallel, which can be considered a sign that rogue bypass is minimal in this building.



If, on the contrary, the profiles are very different, with T_{RCR} variations significantly different from TDHW variations and a large temperature difference between T_{RCR} and T_{DHW}, there is a chance that rogue bypass is happening in this building.

Figure 11. T_{RCR} and T_{DHW} at 1472 Montgomery

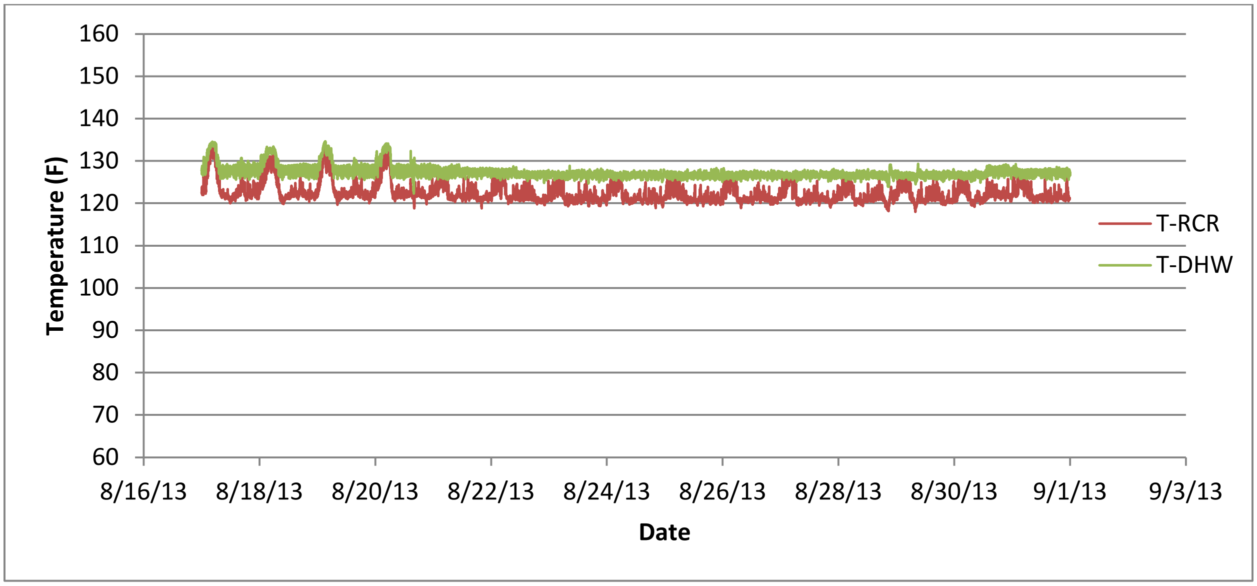
This building shows a similar behavior as 1085 Washington Ave, and we should consider that there is potential rogue bypass occurring at this site.



Figures 10 and 11 show very obvious cases of buildings with either a significant rogue bypass or no rogue bypass at all. Some other buildings are not as clear. Figure 12 shows the temperature profile from Avalon.

Figure 12. T_{RCR} and T_{DHW} at Avalon

T_{DHW} is very constant and T_{RCR} varies slightly during the day. On this building, it is probable that the daily variations are due to rogue bypass but since the temperature drop is small, this may not affect the preheat system significantly.



By looking at the same temperature graphs for the ten recirculation loops, we estimated the probability of rogue bypass in each building. Graphs for each building are shown in Appendix A. The estimates are shown in Table 5 below. In the next section we will focus on confirming these visual estimates through a statistical analysis.

Table 5. Probability of Rogue Bypass at Each Site (Visual Estimation)

Property Name	Probability of rogue bypass (by visual estimation)
1 - 120W 176th St	Probable
2 - 1665 Andrews	Unclear
3 - 1601 University	Probable
4 - 1472 Montgomery	Probable
5 - Archstone Chelsea - Low Loop	Unclear
6 - Archstone Chelsea – Mid Loop	Doubtful
7 -Archstone Midtown – Low Loop	Probable
8 - Archstone Midtown – Mid Loop	Doubtful
9 - Avalon	Probable
10 - Silver Towers	Doubtful

4.2 Statistical Analysis

Due to the presence of negative ΔT values at most buildings and the risk of visually estimating ΔT_{loss}, the potential error in calculating rogue bypass percentage was estimated to be very high. Therefore, we decided not to quantify rogue bypass but to conduct a statistical analysis to detect it. This analysis was performed on the 10 recirculation loops with acceptable temperature and pump sensor data, as shown in Table 4. Post Monitoring Data Summary.

To ensure the accuracy of the data for the following statistical analysis, we processed the data as described in Sections 3.3 and 3.4, by finding the optimal time offset between the measurements of T_{DHW} and T_{RCR}, and by filtering the data when the pump was off. When no pump data was available, the pump was assumed to be running 24 hours per day over the length of the study. The processed versions of the data sets are used in the rest of this study.

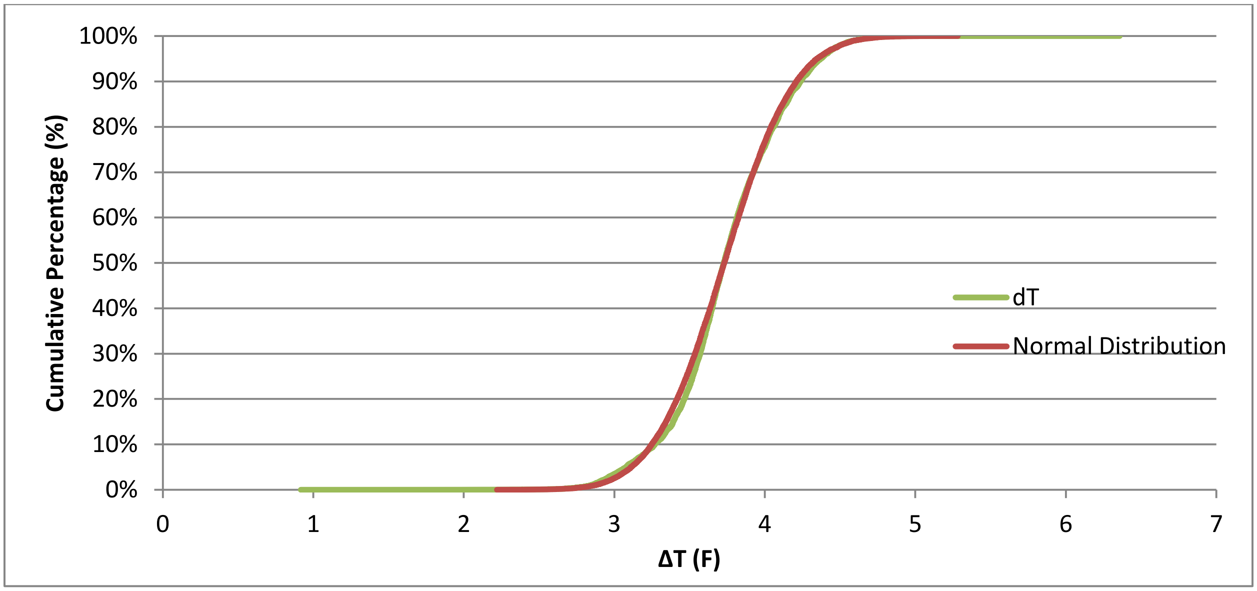
4.2.1 Distributions

Rogue bypass is an abnormal phenomenon happening in undefined locations along the recirculation loop, which causes T_{RCR} values to be lower than expected if losses were normal. In a building where no rogue bypass is present, the distribution of T_{RCR} should follow a similar distribution to T_{DHW}, which would mean that ΔT should have a symmetric distribution. Once other factors have been controlled for, rogue bypass is the only non-random source of variation in ΔT. Thus, for a sufficiently large sample of ΔT, we can test for rogue bypass by testing the normalcy of ΔT for a given confidence interval. It is interesting to look at the distribution of ΔT in the buildings to see if it follows a normal distribution.

Figure 13 shows the cumulative distribution of ΔT values at one of the buildings compared to a normal distribution. Visually, ΔT follows a normal distribution, and the mean ΔT falls into the expected range.

Figure 13. Cumulative Distribution of Delta T at Archstone Chelsea (Mid Loop) Compared to a Normal Distribution

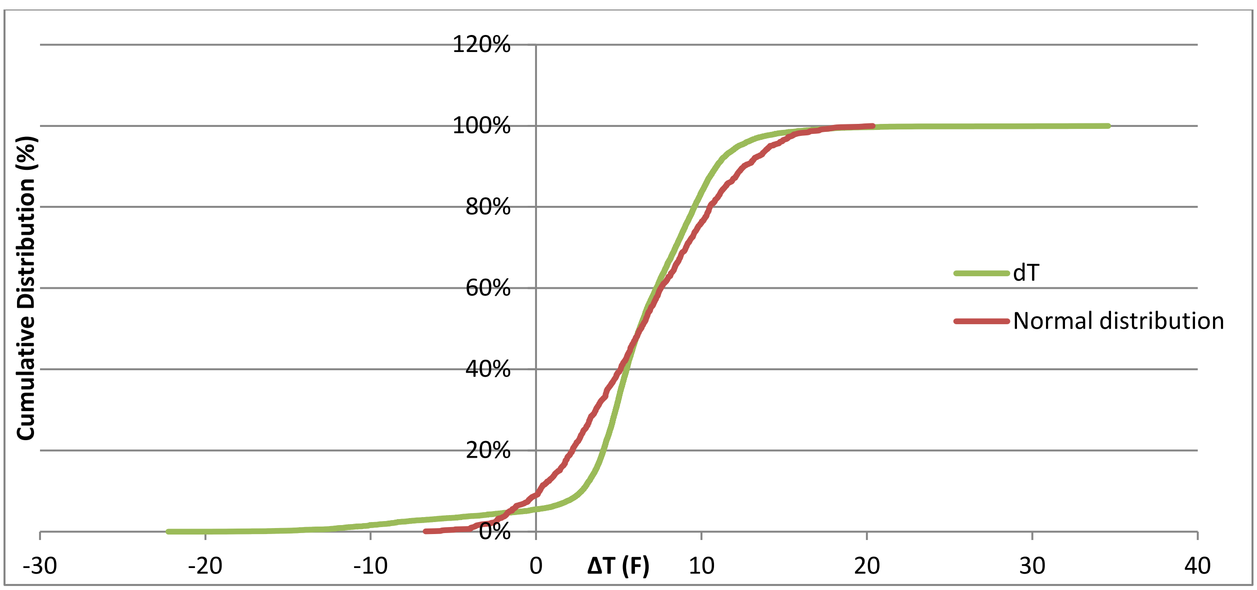
The cumulative distribution of ∆T is very close to a normal distribution with the same 50th percentile and standard deviation.



This same analysis was performed on the nine other buildings. Figure 14 shows a ∆T distribution that is significantly different from a normal distribution.

Figure 14. Cumulative Distribution of Delta T at 1601 University Ave compared to a normal distribution

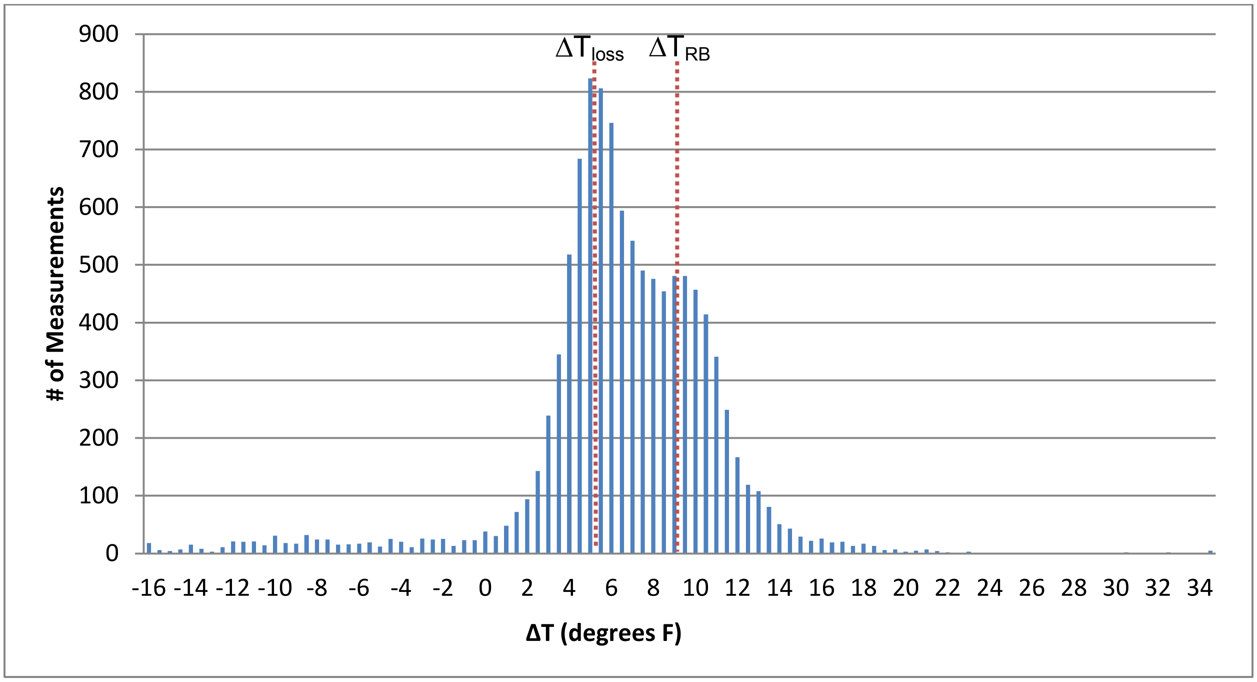
The cumulative distribution of ∆T is significantly different from a normal distribution with the same 50th percentile and standard deviation.



When looking at the same data as a histogram (see Figure 15), a "shoulder" is visible on the right side of the peak of the distribution. This shoulder can be interpreted as an abnormal number of high ΔT values, which is indicative of rogue bypass. We call this second peak corresponding to rogue bypass ΔT_{RB}. This distribution is typical of bimodal distributions, which are basically two normal distributions overlaid. In this case, the main distribution peaks at 5 degrees, and the secondary distribution peaks at 9.5 degrees.

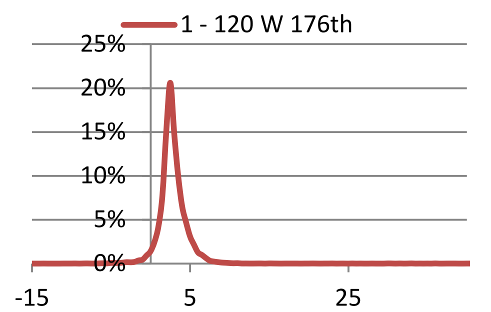
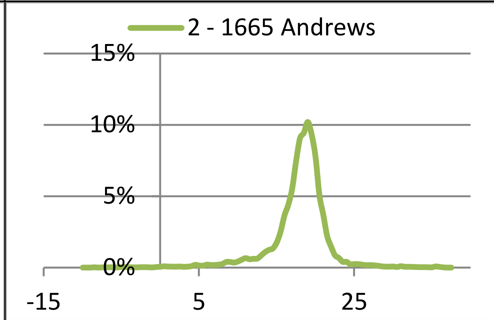
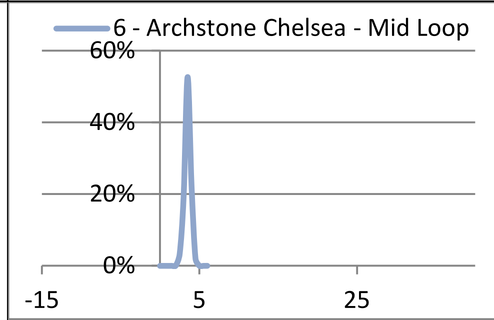
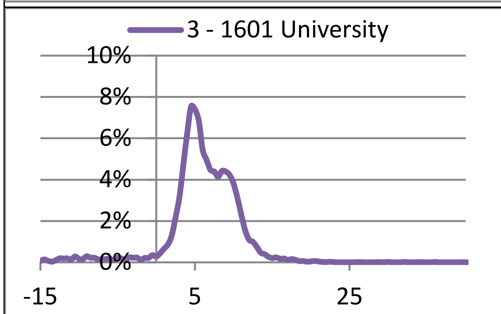
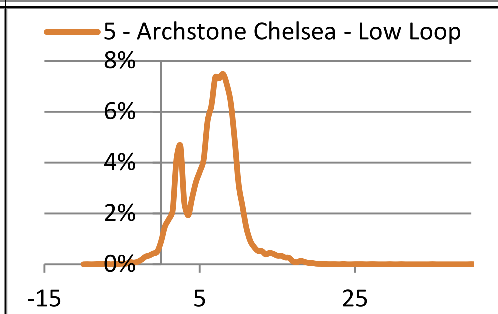
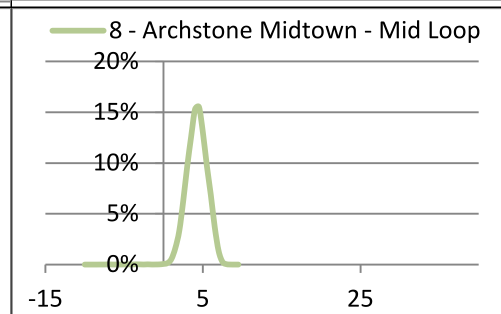
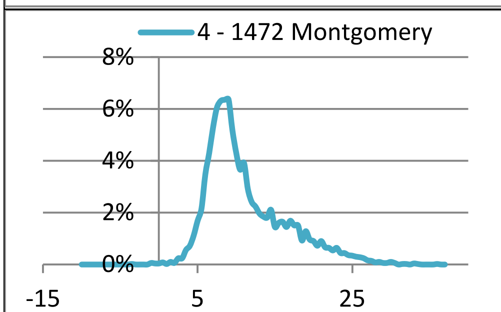
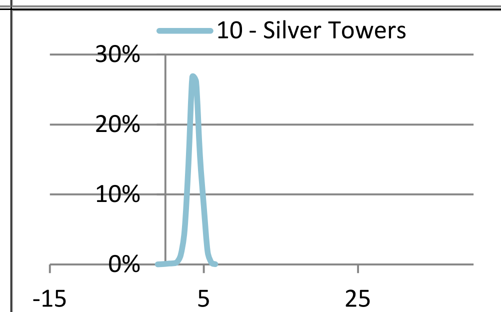
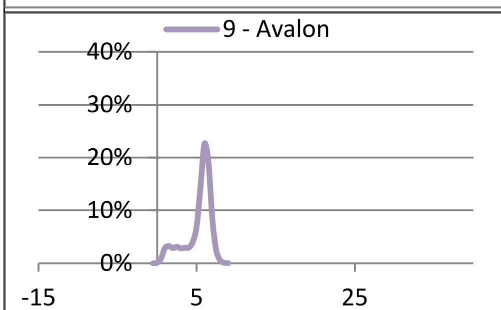
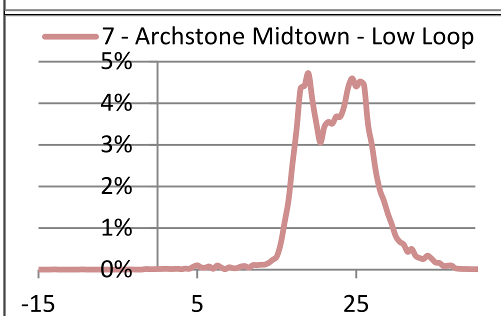
Figure 15. Histogram of Delta T values at 1601 University

This data set does not follow a normal distribution and shows a shoulder towards the higher ΔT values.



Histograms for each building can be found in Table 6.The buildings are sorted by the result of the visual screening test. Buildings without rogue bypass tend to have a much narrower distribution with on peak, while buildings with rogue bypass tend to have a wider distribution with multiple peaks. Some of them are similar to bimodal distributions, while others may even be multi-modal.

Table 6. Delta T distribution for each building

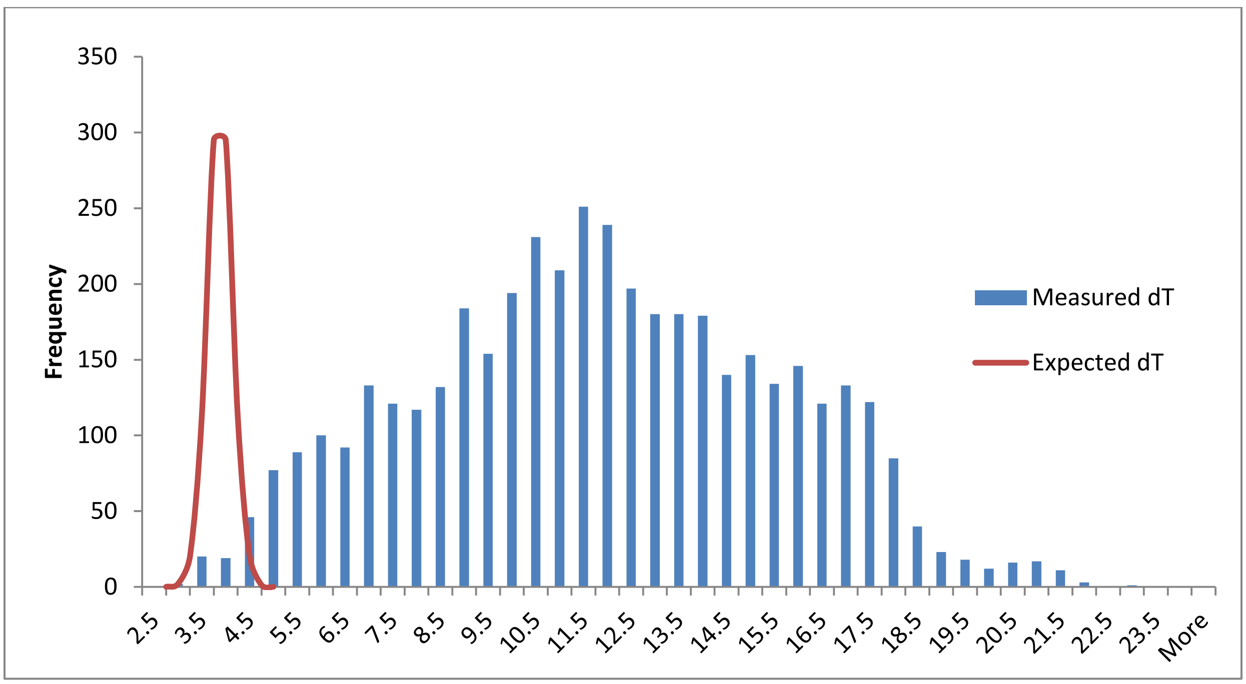
Buildings with "Probable" rogue bypass according to visual screening test	Buildings with "Unclear" rogue bypass according to visual screening test	Buildings with "Doubtful" rogue bypass according to visual screening test
		
		
		
		
		

4.2.2 Comparison to 1085 Washington Ave

In the previous study, the presence of rogue bypass was demonstrated by measuring flows in various locations of the recirculation loop. By running a statistical analysis on the data collected during this study, the distribution of ΔT can be obtained. If this building had no rogue bypass, we would expect to see a normal distribution around a ΔT value of approximately 2 to 5 °F, which is the range of values seen at night. Figure 16 shows the distribution of ΔT at 1085 Washington, as well as a normal distribution describing a situation with no rogue bypass (i.e., the expected normal distribution centered around ΔT_{loss} measured at night). The measured ΔT distribution is not symmetrical and shows a significant shoulder towards ΔT_{RB} values. The abnormal ΔT_{RB} values are overtaking the distribution and hiding the expected values in red. By comparing the peak and the width of the measured distribution to the expected distribution, it is clear that even though the measured distribution may look symmetric and close to normal, it is closer to a bimodal or perhaps multi-modal distribution with various peaks. In the case, the main peak corresponding to the expected average ΔT (approximately 3 degrees) is almost invisible next to the secondary peak ΔT_{RB} (approximately 11.5 °F).

Figure 16. Histogram of Delta T values at 1085 Washington (expected and measured values)

The blue data set almost looks like a normal distribution, but is actually closer to a bimodal distribution with the expected peak centered on the ΔT values measured at night (in red) hidden by the peak due to rogue bypass (in blue).



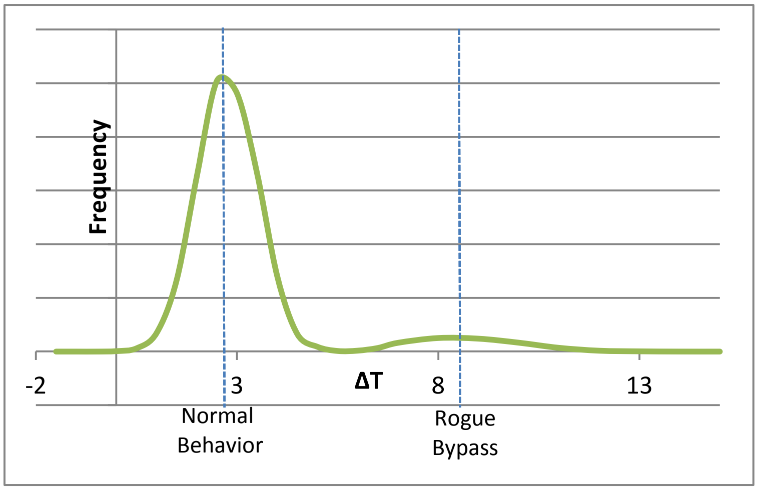
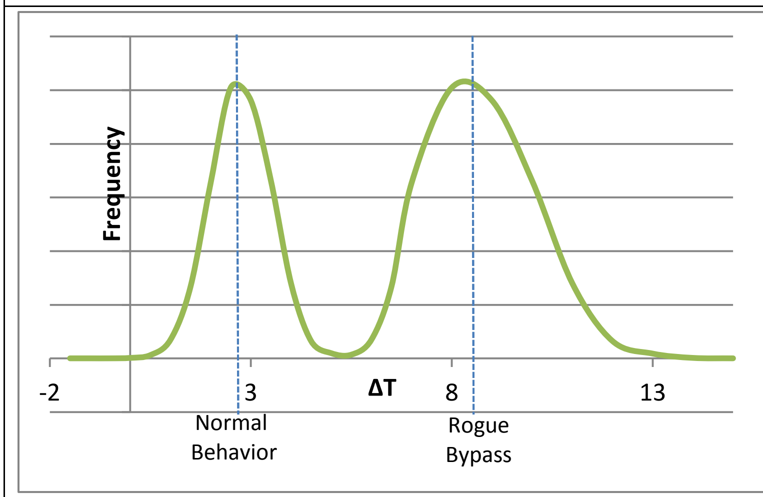
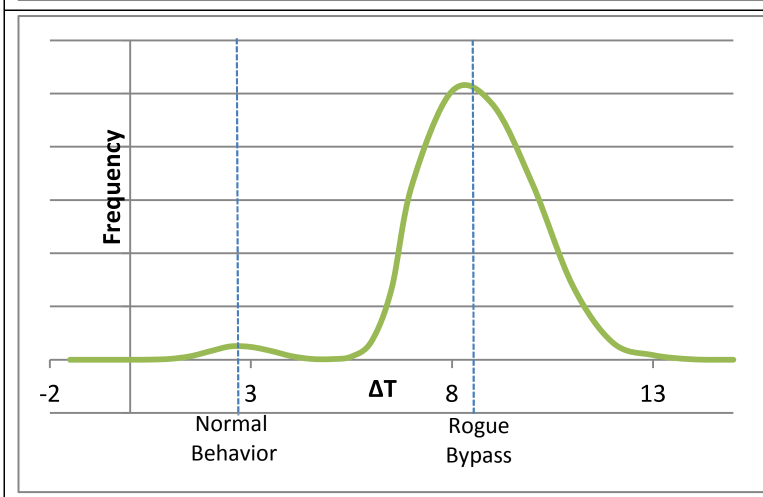
4.2.3 Normality Test

The Kolmogorov-Smirnov (KS) test is a nonparametric statistical test that can be used to compare two distributions together or one distribution compared to a reference probability distribution. The result of the KS test is a number called the D-value, which gives an indication as to whether a data set was extracted from a distribution following the reference distribution. For this statistical analysis, we used a one-sample version of the KS test that compares the data set to a normal distribution with the same mean and standard deviation as the data set. For these tests, we used "H_0: the data set follows a normal distribution" as the null hypothesis.

The rest of the Kolmogorov-Smirnov test is a number called the D-value. This D-value is compared to a critical D-value to calculate the probability of rejecting the null hypothesis. If the calculated D-value is greater than the critical D-value, the null hypothesis is rejected. The critical D-value is a function of the sample size N. Since the various data sets had different sample sizes, with different critical D-values, the KS test results are presented as the D-value divided by the critical D-value (D/D_{cr}). The higher this ratio gets, the further the data set is from a normal distribution.

There are three possible situations found in our sample buildings, depending on the magnitude of rogue bypass affecting each building. Table 7 explains which result can be expected from the KS test in each situation.

Table 7. Typical Distributions and KS Test Interpretation

ΔT Distribution	KS Test Interpretation
	<u>Building with **low or no rogue bypass**</u> The distribution is similar to a normal distribution with ΔT_{loss} as the mean value. If there is some rogue bypass happening but not enough to impact the overall distribution, the KS test may reject the null hypothesis but will return a **low D/D_{cr} ratio** (because the distribution is so close to a normal distribution).
	<u>Building with **significant rogue bypass**</u> The distribution is similar to a bimodal distribution with two “peaks” at ΔT_{loss} and ΔT_{RB}. The mean of the distribution in this case is between ΔT_{loss} and ΔT_{RB}, depending on the amount of rogue bypass. Rogue bypass is present and affects the recirculation temperature significantly (approximately half of the ΔT values are higher than normal due to rogue bypass). The KS test will most probably reject the null hypothesis will return a **high D/D_{cr} ratio** (because the distribution is so different from a normal distribution).
	<u>Building with **very high rogue bypass**</u> The distribution is similar to a normal distribution with ΔT_{RB} as the mean value. Rogue bypass is affecting the recirculation temperature that ΔT is higher than normal almost all the time. The KS test may reject the null hypothesis but will return a **low D/D_{cr} ratio** (because the distribution is so close to a normal distribution).We believe that 1085 Washington Ave is similar to this case.

According to the interpretation in Table 7, we can detect rogue bypass by looking at two pieces of information: the KS test result and the mean value of the distribution. Table 8 shows how to interpret this information.

Table 8. Detection of Rogue Bypass from Kolmogorov-Smirnov test and Delta T mean value

		Kolmogorov-Smirnov test result	
		Low KS D-value	High KS D-value
Mean ΔT value	Low mean ΔT value (close to ΔT_{loss})	No or Low Rogue Bypass	Low Rogue Bypass or other phenomenon
	High mean ΔT value (close to ΔT_{RB})	High Rogue Bypass	Moderate to High Rogue Bypass

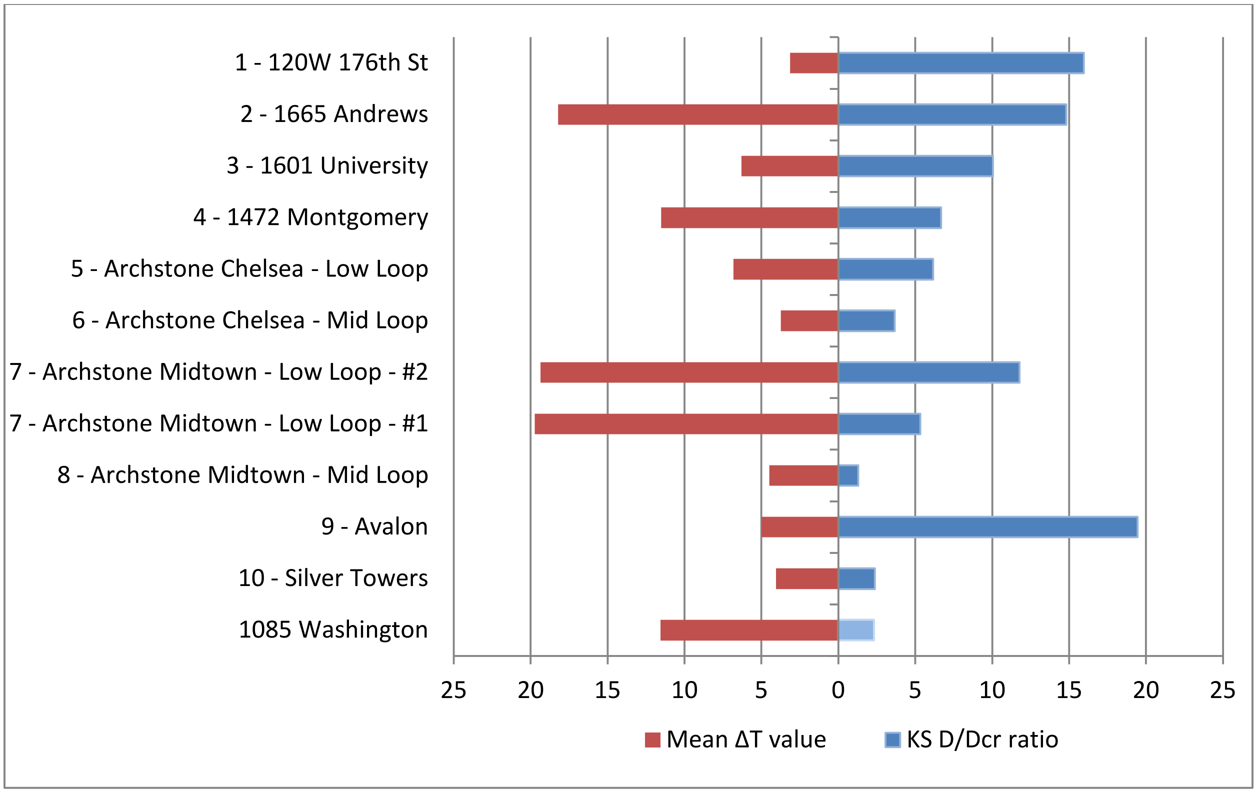
A Kolmogorov-Smirnov test was performed on the processed data set for each of the ten recirculation loops that presented acceptable data as well as the reference site (1085 Washington). All tests were run with a significance level of 5%.Since the various data sets had different sample sizes, with different critical D-values, the KS test results are presented as the D-value divided by the critical D-value (D/D_{cr}). The higher this ratio gets, the further the data set is from a normal distribution. The results are presented in Figure 17. Test results and critical values can be found in the Appendix.

An interesting thing to note is that the Kolmogorov-Smirnov tests predict that none of the distributions are following a normal distribution, as reflected by the fact that all D/D_{cr} ratios are larger than 1. We believe this is due to a variety of factors, including the imperfection of the time offset method, the possible data noise induced by the mixing valves on some loops, as well as other unknown factors (such as the phenomenon creating negative ΔT values at 1601 University, for example). The D/D_{cr} are therefore used to indicate how different the observed results are from a normal distribution, instead of indicating if the observed results are normally distributed.

When performing these Kolmogorov-Smirnov tests, we observed the temperature variations in details and realized that Archstone Midtown Low Loop showed two different behaviors. An unknown event affected the temperature patterns around August 22, 2013, and the measurements after this date show a significantly larger ΔT. For the statistical analysis, we considered this loop to have two different data sets and processed them separately.

Figure 17. Normality Test Results Per Building with Mean Delta T Value

The light blue bar is the reference site where rogue bypass has been verified in a previous study.



The mean ΔT value is influenced not only by the presence of rogue bypass, but many different building characteristics including length of the loop, recirculation pump size, and presence of insulation on pipes. We judged this value by comparing similar buildings or different loops in the same buildings together. For example, buildings 1 through 4 are approximately the same height and have similar plumbing setups, so we would expect to see similar mean ΔT values. 1665 Andrews has a significantly higher meant ΔT than the other three buildings, which is why we hypothesized that rogue bypass was "Moderate to High" in this building. Similarly at Archstone Midtown, both the Low and Mid loops are approximately the same length, with the same level of insulation and similar plumbing setups, but the mean ΔT values and D/D_{cr} ratios for the Low Loop are more than five times higher than in the Mid Loop, so we hypothesized that rogue bypass was "Moderate to High" in this particular loop. However, since we did not open up the walls to see the level of insulation, or run our analysis according to the various flow rates in the loops, we cannot say with certainty whether the low or high ΔT values were caused by rogue bypass.

The interpretation of the KS test according the principles put forth instable, for each building, can be found in Table 9.

Table 9. Statistical Analysis Result

Property Name	Statistical Analysis Result
1 - 120W 176th St	Low Rogue Bypass or other phenomenon
2 - 1665 Andrews	Moderate to High Rogue Bypass
3 - 1601 University	Low Rogue Bypass or other phenomenon
4 - 1472 Montgomery	Moderate to High Rogue Bypass
5 - Archstone Chelsea - Low Loop	Low Rogue Bypass or other phenomenon
6 - Archstone Chelsea - Mid Loop	No or Low rogue bypass
7 - Archstone Midtown - Low Loop	Moderate to High Rogue Bypass
8 - Archstone Midtown - Mid Loop	No or Low rogue bypass
9 - Avalon	Low Rogue Bypass or other phenomenon
10 - Silver Towers	No or Low rogue bypass

According to this analysis, three buildings are experiencing rogue bypass, while another four may be experiencing rogue bypass or another disturbing phenomenon causing either a high ΔT or abnormal ΔT distribution.

5 Conclusions

5.1 Result Combination

In Sections 4.1 and 4.2 of this study, a visual screening and a statistical analysis were performed on the data collected on 10 recirculation loops during a two-week monitoring period (two loops were removed from the study due to unreliable temperature data). The combined results of these analyses can be found in Table 10. If both tests concurred in that there was a probability of rogue bypass presence at the building, we hypothesized that there was in fact a probability of rogue bypass presence.

Table 10. Combined Analysis Results

Property Name	Test #1: Visual Screening	Test #2: Normality test	Hypothesis as to the presence / magnitude of rogue bypass	
	Probability of rogue bypass by visual estimation?	Possible abnormal behavior according to statistical analysis?	Rogue Bypass Presence?	Magnitude of Rogue Bypass?
1 - 120W 176th St	Probable	Low Rogue Bypass or other phenomenon	Probable	Low
2 - 1665 Andrews	Unclear	Moderate to High Rogue Bypass	**Probable**	**High**
3 - 1601 University	Probable	Low Rogue Bypass or other phenomenon	Probable	Low
4 - 1472 Montgomery	Probable	Moderate to High Rogue Bypass	**Probable**	**High**
5 - Archstone Chelsea - Low Loop	Unclear	Low Rogue Bypass or other phenomenon	Unclear	Low
6 - Archstone Chelsea - Mid Loop	Doubtful	No or Low Rogue Bypass	Doubtful	Low
7 - Archstone Midtown - Low Loop	Probable	Moderate to High Rogue Bypass	**Probable**	**High**
8 - Archstone Midtown - Mid Loop	Doubtful	No or Low Rogue Bypass	Doubtful	Low
9 - Avalon	Probable	Low Rogue Bypass or other phenomenon	Probable	Low
10 - Silver Towers	Doubtful	No or Low Rogue Bypass	Doubtful	Low

The data collected allows us to say that rogue bypass is probably present at sites 1, 2, 3, 4, 7 and 9, and that there is an abnormal behavior at site 5.The magnitude of rogue bypass most likely varies from one building to another, but it is likely that three of the sites are experiencing significant rogue bypass, while the other could either be experiencing low rogue bypass or another phenomenon causing a temperature drop in the recirculation loop, which would be interesting to investigate but would require a flowmeter-based analysis.

We are confident these results show that 1085 Washington was not an isolated case, and that we appear to have found a detection method for rogue bypass. An in-depth flowmeter-based analysis would be necessary to confirm the presence of rogue bypass and to check for false positive and false negative cases.

The other aspect to consider is the actual impact of rogue bypass on the performance of the preheat system. In the previous study performed at 1085 Washington, rogue bypass represented 82% of the cold water entering the domestic hot water system, and this lowered the performance of the solar thermal system by 45%. The impact on the performance is highly dependent on the actual plumbing setup and system controls. The recirculation loop return input into the DHW system is a very important factor as to whether rogue bypass could impact the performance of the preheat system or not. In this study, we deemed the uncertainty in the rogue bypass percentage too high and decided not to present these calculations. The results obtained through the two tests do not give quantifiable information about the magnitude of rogue bypass and the potential effect on the performance of the preheat system.

One interesting thing to note is that the results of the visual test matches the hypothesis presented at the end of the overall study; all buildings that came up as “Doubtful” in the visual screening also came up as “Nor or Low Rogue Bypass” in the statistical analysis. Even though this method is non-numerical and cannot help quantify rogue bypass at a building, it is quite reliable. This method could easily be implemented before installing a solar thermal or CHP system. The fact that a human can visually detect rogue bypass means that there should be a mathematical way of quantifying this effect that is accurate for all types of buildings (independently of the length of the recirculation loop and the mixing valve type).

5.2 Factors Impacting the Results

We decided to present the results for all buildings together, without making a distinction between buildings with solar thermal systems and buildings with cogeneration systems. The reason is that all the measurements were taken on the hot water system itself, not on the pre-heat system, and the theoretical model of rogue bypass does not factor in variables from the pre-heat system. The impact on different pre-heat systems may be different but the pre-heat system itself does not influence rogue bypass in the recirculation loop.

Other factors could have a significantly larger impact on rogue bypass. For example, the year the building was designed impacts the type of fixtures as well as the design best practices followed at the time. Whether the building is for affordable housing or market rate housing could impact the quality of the fixtures used. The building developer and Mechanical Electrical Plumbing engineer impact the best practices used for the system design. These factors could potentially be detected on a larger sample.

5.3 Opportunities for Further Research

In this study, we found that, out of the small sample of 10 recirculation loops, 30% of recirculation loops studied are likely to be affected by a significant rogue bypass. NYSERDA has already invested over $114 million into cogeneration and solar thermal systems. While the sample size of this study is too small to draw statistically significant conclusions, if rogue bypass exists at the rate identified in this study[13], and depending on the actual performance degradation of the systems, the lost savings may be as high as millions of dollars. This figure would only grow as solar thermal and combined heat and power (CHP) systems continue to become more popular.

Our methodology provides a rubric by which DHW temperature data can be evaluated to provide strong evidence for or against the occurrence of rogue bypass. However, while temperature data can be a powerful diagnostic tool in the identification of rogue bypass, our conclusion is that on its own it is not reliable enough to provide a single metric – percent rogue bypass – which is applicable to all buildings in all circumstances. While the lack of a single, easily quantifiable metric is frustrating, we believe that this study can serve as the basis for a testing procedure that will provide valuable cautionary feedback prior to the installation of SDHW or CHP systems, with substantially lower cost and mobilization requirements than a full, flowmeter-based analysis. It can also serve as the basis for further research to quantify the effect of rogue bypass.

[13] With a conservative assumption that the performance degradation is 50% of the degradation seen in the previous study conducted at 1085 Washington Ave in the Bronx.

Possible further investigation paths include:

- Implementing a flowmeter-based study on the buildings analyzed in this study to quantify the performance degradation of the preheat systems, predict this degradation based on temperature measurements only, and correlate whether the methods used in this report accurately predict the presence of rogue bypass.
- Instrumenting a larger set of buildings for a longer time period to research a mathematical method to reproduce the results given by the visual screening test. The tests used to detect rogue bypass in this study are not fully developed and a bigger data set in terms of number of buildings and monitoring period would be necessary to fully define the mathematical method that could have the same results as the human eye,
- Instrumenting a larger set of buildings to detect trends in different types of buildings and define a methodology to calculate the effect of rogue bypass that would be applicable to all types of buildings, independently of the adverse effects of the mixing valve response time and recirculation pump effect. Looking at the mode and spread of the ΔT distribution depending on the type of building in particular should be fruitful.
- Studying the effectiveness of three-way diversion valves as a rogue bypass mitigating feature installed on existing preheat systems.
- Studying the seven recirculation loops where rogue bypass was detected and look at what these buildings have in common, including drawing and analyzing exact plumbing details, to pinpoint specific pieces of equipment or piping configurations that are particularly prone to rogue bypass.

6 References

Heschong Mahone Group, June 23, 2006. *Measure Information Template – Central Hot Water Distribution Systems in Multifamily Buildings.*2008 California Building Energy Efficiency Standards.

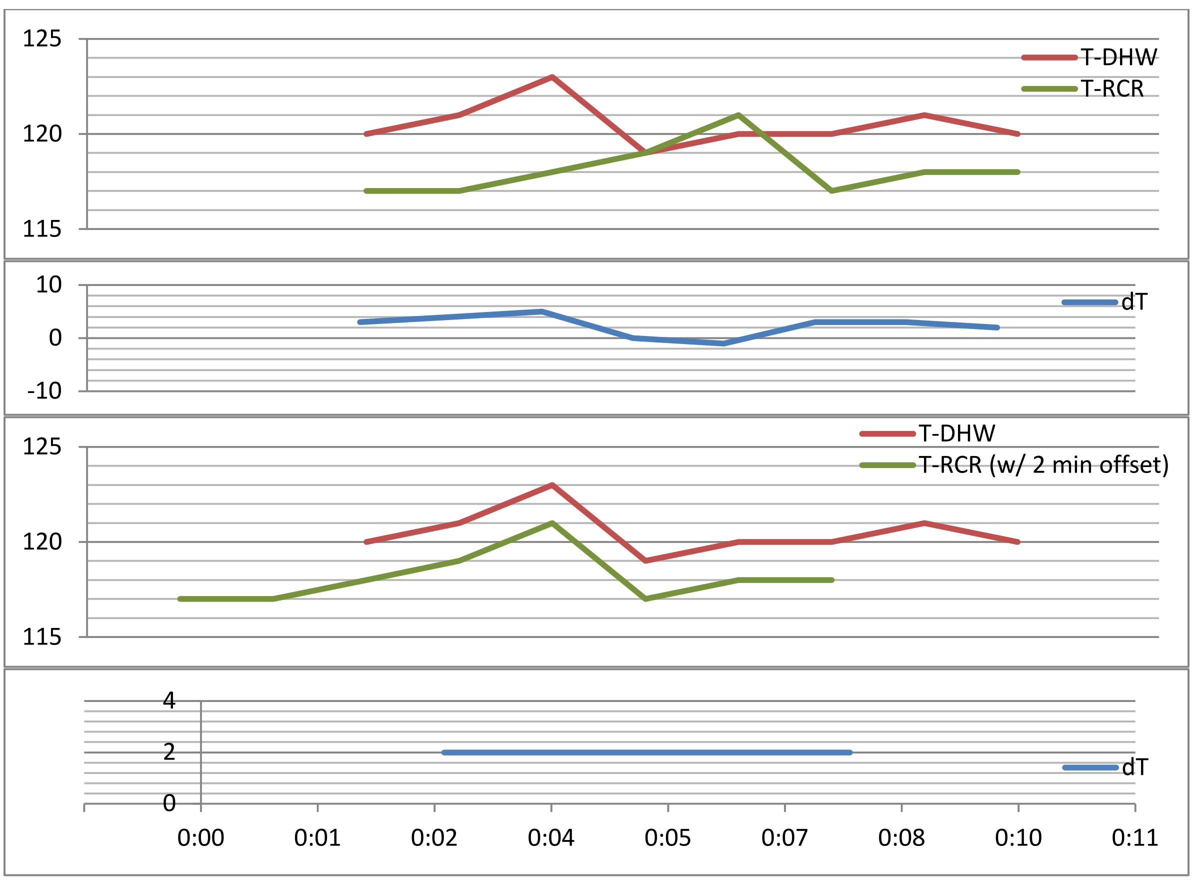
McNamara, A., Gruen, S., Laver, C., Perlman, J., August 2011. *The negative impact of cold water bypass on solar domestic hot water*. New York State Energy Research and Development Authority and New York City Economic Development Corporation.

Appendix A

A.1 Time Offset

For the purpose of this explanation, let us consider a simplified version of our experiment with 8 measurements. The first graph below shows the variation of TDHW and TRCR over 8 minutes. The second graph shows the difference between TDHW and TRCR (i.e. ΔT) if calculated minute-to-minute. ΔT varies between -1 and 5 degrees and its standard deviation is 1.99. The following graph shows the same measurement with a 2-minute time offset on the TRCR data, which corresponds to a 2 minute loop time (the time it takes for the fluid to travel from one measurement point to another). The last graph shows ΔT calculated with the time offset. ΔT is constant, with a standard deviation equal to zero.

Figure A-1. Delta T Calculated With and Without a Time Offset



When analyzing the ΔT data shown in the second graph, there is a high probability of seeing a false negative for rogue bypass since ΔT varies so much. The rogue bypass percentage of this data series is as high as 5%, without any rogue bypass actually happening.

Taking into account a time offset allows to eliminate erroneous ΔT values that are not representative of a physical condition.

The method employed to find the time offset for each building was to calculate the standard deviation for the ΔT dataset, and then to find the optimal time offset to minimize the standard deviation. Most buildings came back with a time offset between 0 and 15 minutes. For anything above that, we considered this method inconclusive and decided not to use a time offset. Results are shown in A-1 below.

Table A-1. Time offset calculated and used for each data set

Only time offsets between 0 and 15 minutes were used.

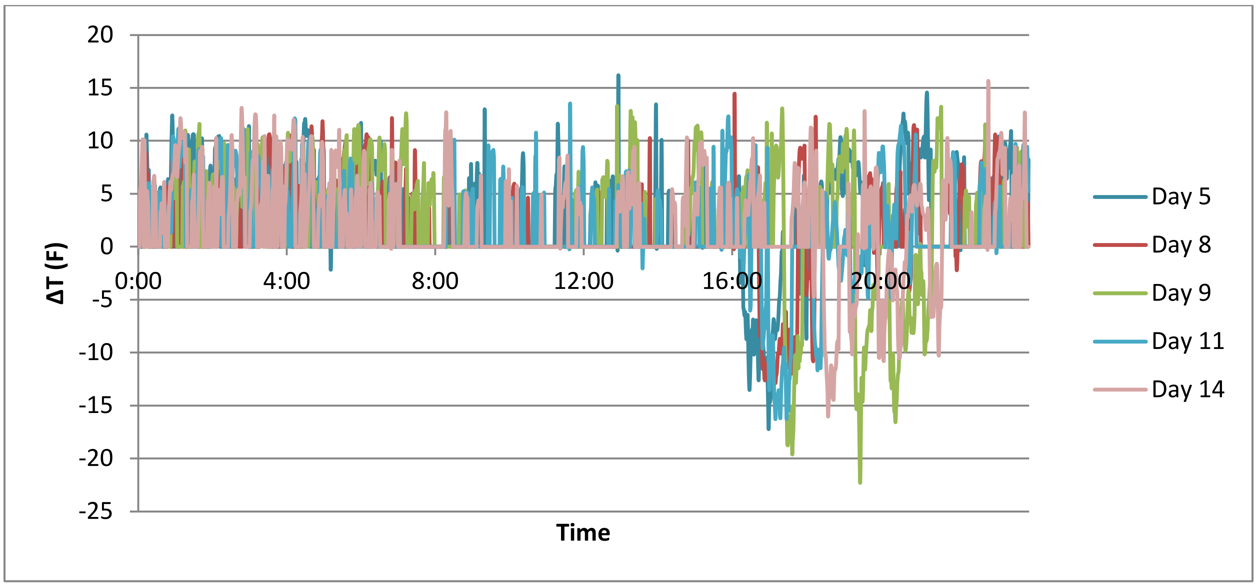
#	Name	Calculated Time offset (minutes)	Time Offset used for analysis (minutes)
1	120 W 176	7	7
2	1665 Andrews Ave.	3	3
3	1601 University Ave.	3	3
4	1472 Montgomery Ave.	1	1
5	Archstone Chelsea - Low Loop	25	0
6	Archstone Chelsea - Mid Loop	15	15
7	Archstone Midtown - Low Loop	13	13
8	Archstone Midtown - Mid Loop	56	0
9	Avalon	13	13
10	Silver Towers	41	0
11	Seaside - Loop A	Not calculated due to poor data quality	
12	Seaside - Loop B		

A.2 Negative Delta T values at 1601 University

In one building, the recirculation loop showed periods longer than 30 minutes where T_{RCR} is higher than T_{DHW}, with no obvious explanation. This resulted in periods with a negative ΔT, which would mean the fluid comes out of the loop hotter than it went in, which is impossible except if an external heating source is present on the recirculation loop. We have not been able to find an explanation for this behavior. These negative values represent a negligible portion of the data set (less than 3%). Figure A-2 below shows the ΔT over the length of the day for various days when ΔT was negative for prolonged periods of time. This figure only shows times when the recirculation pump was on.

Figure A-2. 18. Delta T variation at 1601 University on days 5, 8, 9, 11 and 14

The inexplicable behavior always happens between 4pm and 10pm.



A.3 T_{DHW} and T_{RCR} Visualizations

All graphs in this section show raw data, including data when the recirculation pump was off.

Figure A-3. Loop #1 - T_{DHW} and T_{RCR}at120 W 176th

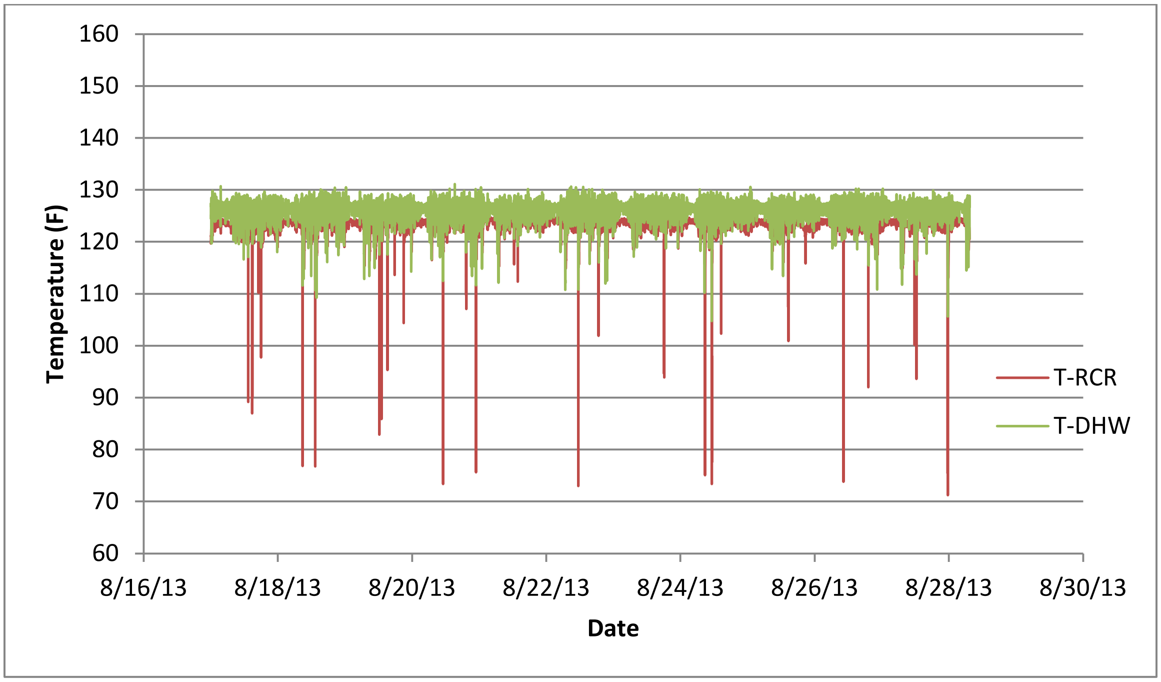


Figure A-4. Loop #2 - T_{DHW} and T_{RCR} at 1665 Andrews

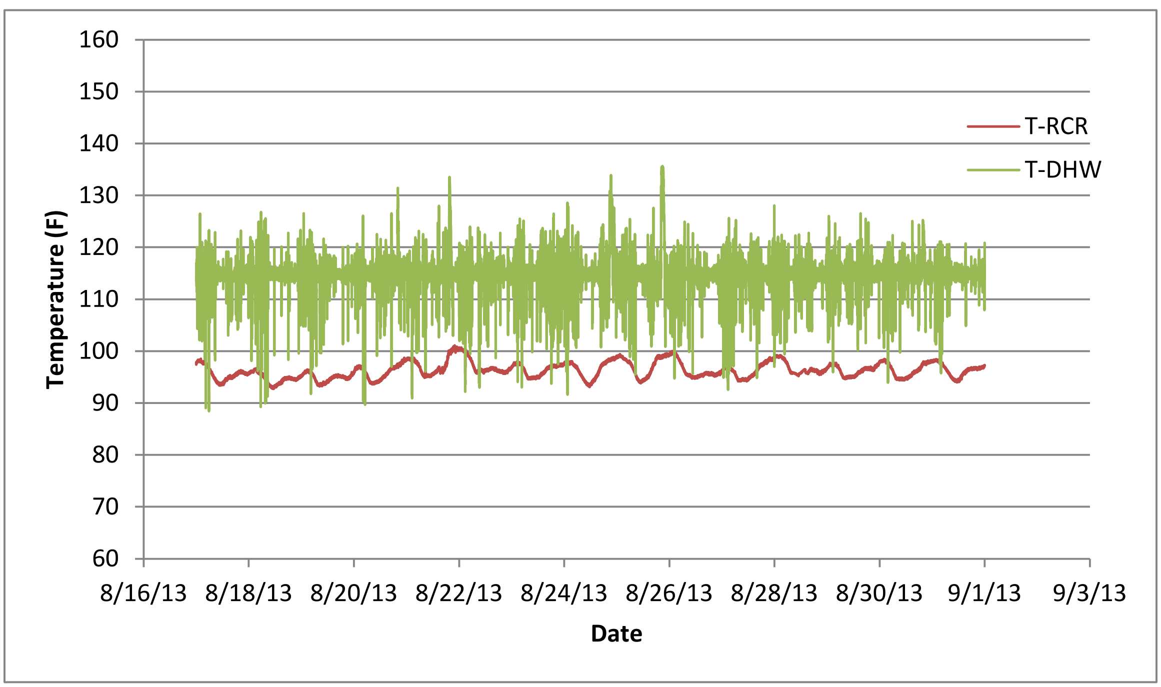


Figure A-5. Loop #3 - T_{DHW} and T_{RCR} at 1601 University

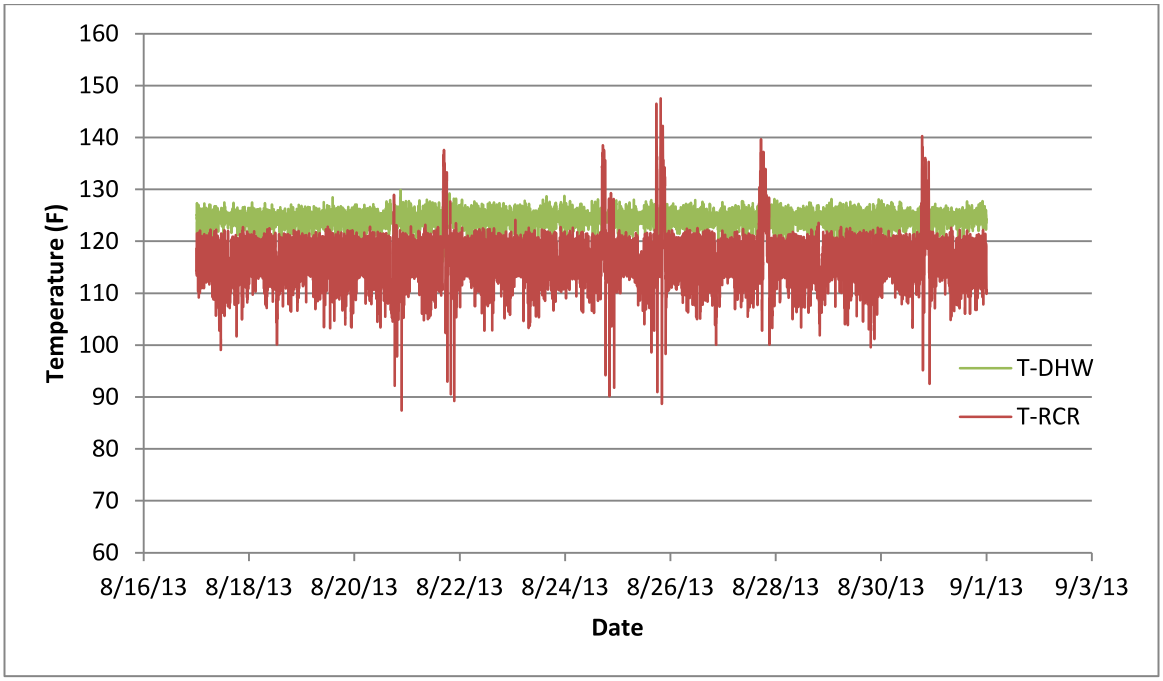


Figure A-6. Loop #4 - T_{DHW} and T_{RCR} at 1472 Montgomery

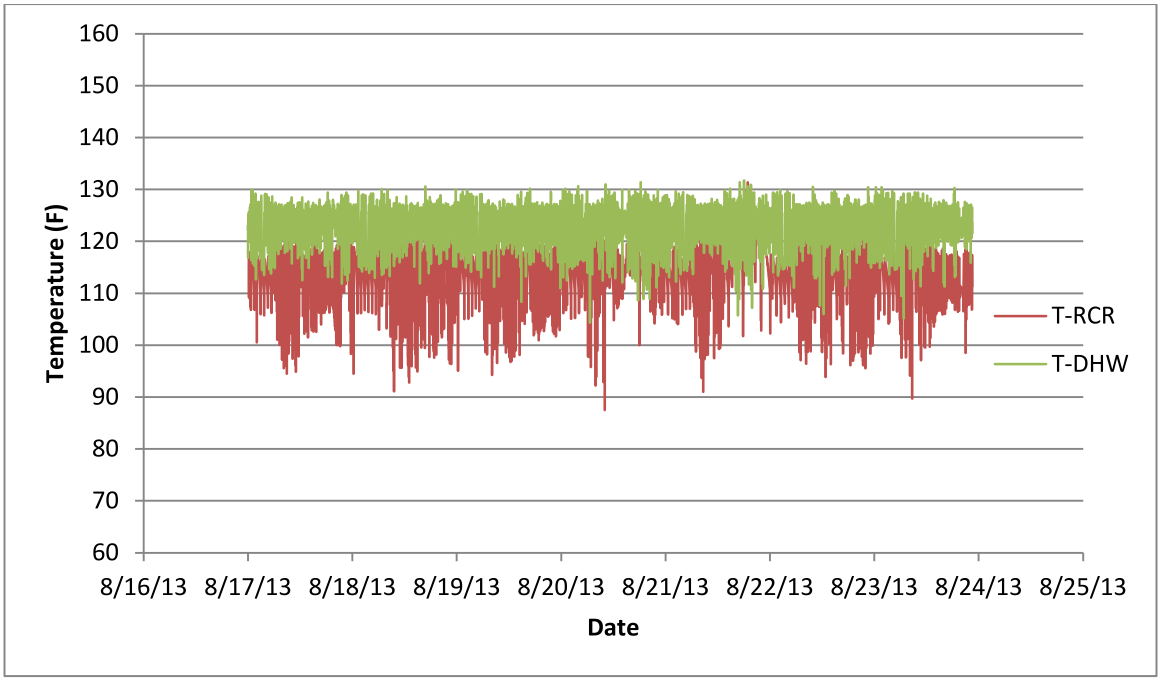


Figure A-7. Loop #5 - T_{DHW} and T_{RCR} at Archstone Chelsea – Low Loop

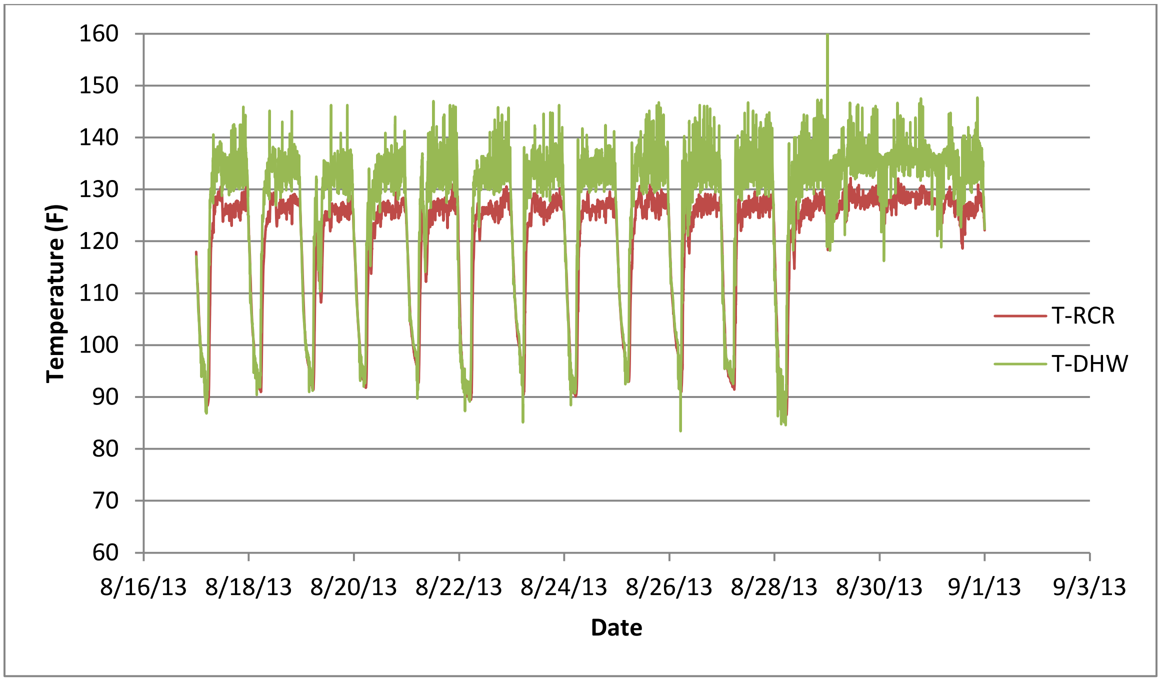


Figure A-8. Loop #6 - T_{DHW} and T_{RCR} at Archstone Chelsea – Mid Loop

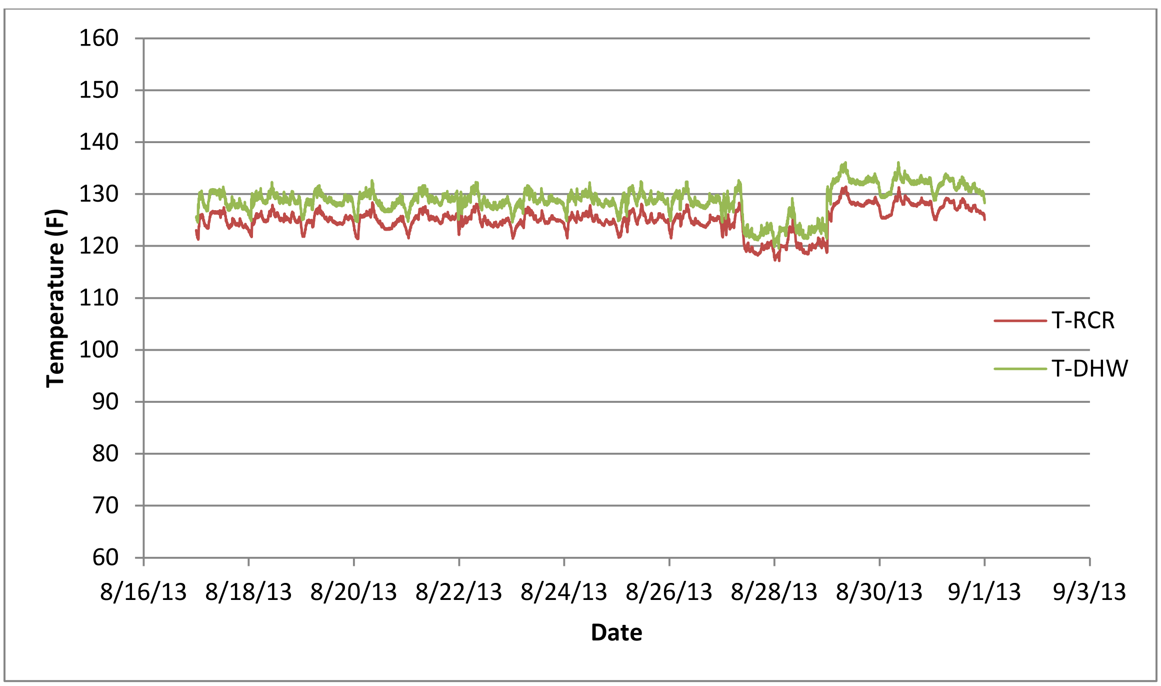


Figure A-9. Loop #7 - T_{DHW} and T_{RCR} at Archstone Midtown – Low Loop

The blue lines show the limits of the data sets used for the statistical analysis. Data set #1 includes data collected between 8/17/2013 and8/22/2013, and Data set #2 includes data collected between 8/23/2013 and 8/30/2013.

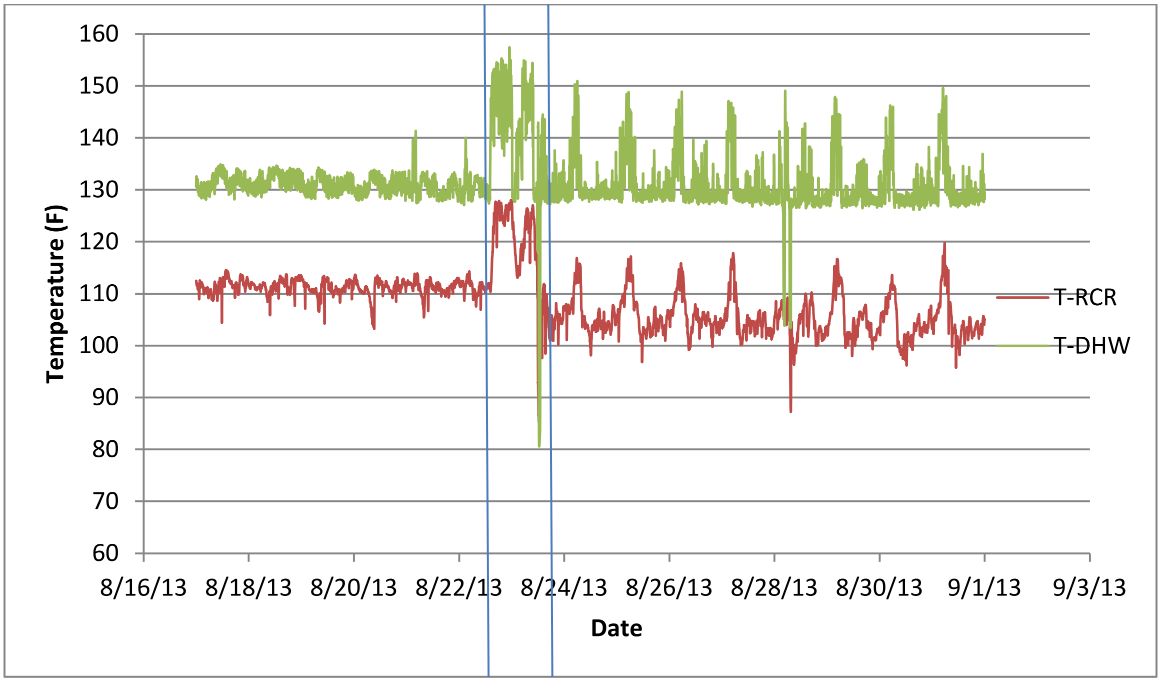


Figure A-10. Loop #8 - T_{DHW} and T_{RCR} at Archstone Midtown – Mid Loop

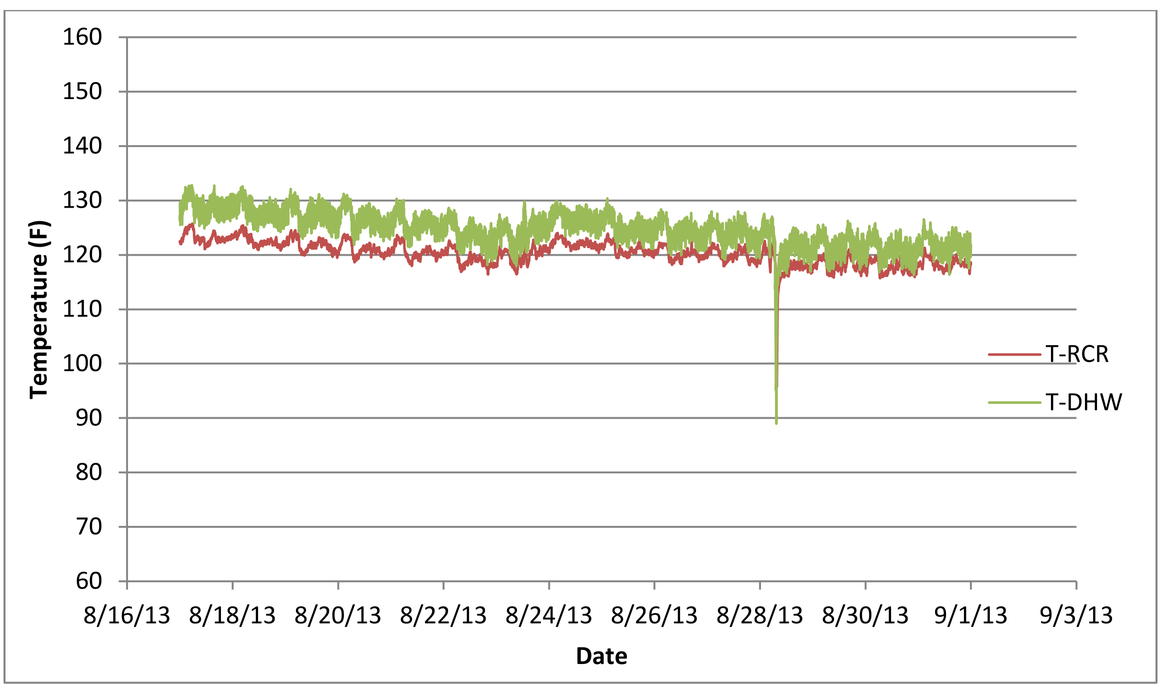


Figure A-11. Loop #9 - T_{DHW} and T_{RCR} at Avalon

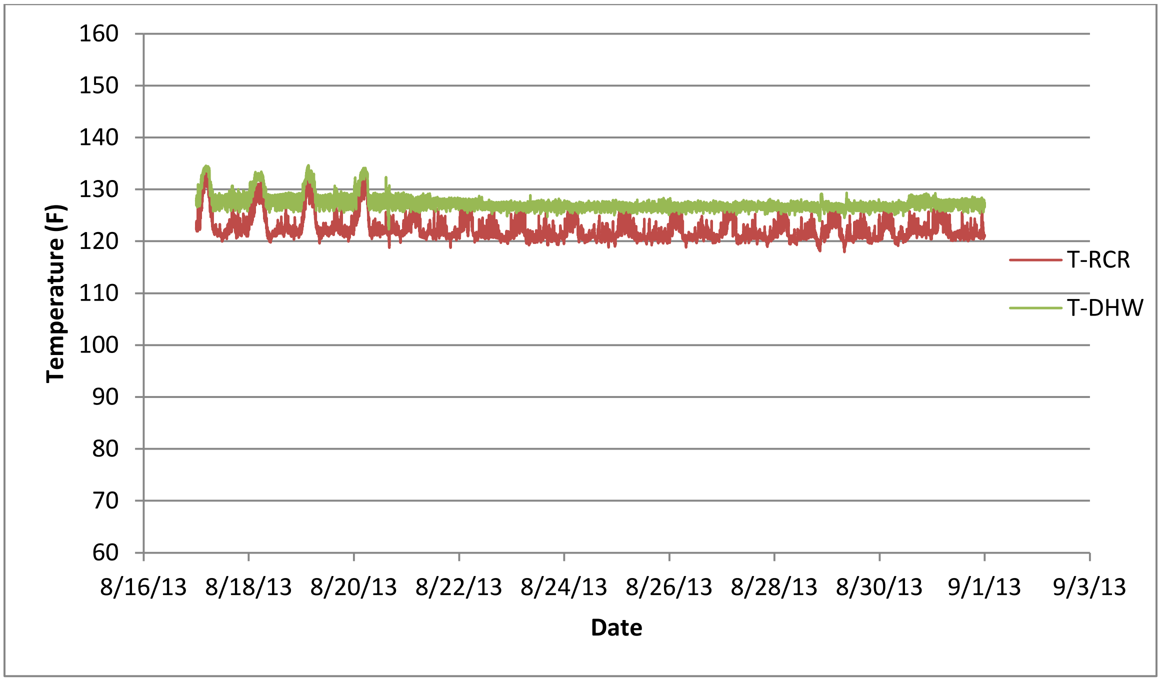
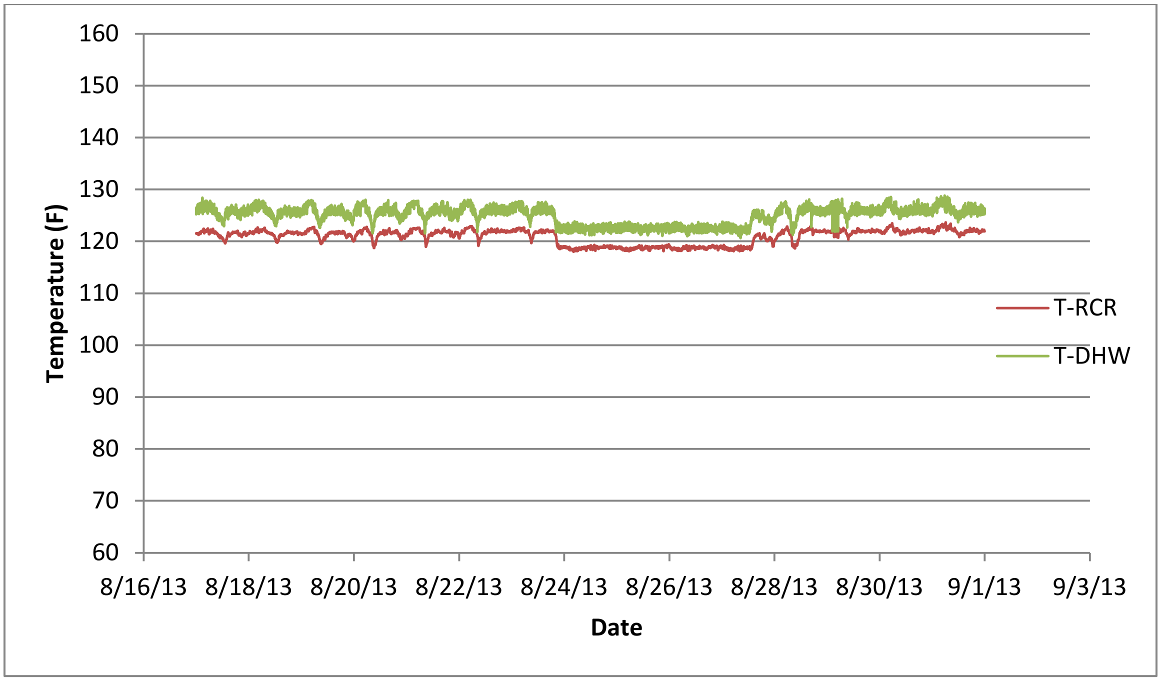


Figure A-12. Loop #10 - T_{DHW} and T_{RCR} at Silver Towers



A.4 Kolmogorov-Smirnov Test Results

Table A-2. KS test results, critical value and sample size for each building

Property Name	KS D-value	Critical D-value	D/D_{cr}	Sample Size
2 - 1665 Andrews	0.137	0.009	14.805	21600
3 - 1601 University	0.131	0.013	10.061	10910
4 - 1472 Montgomery	0.129	0.019	6.691	4976
5 - Archstone Chelsea - Low Loop	0.057	0.009	6.160	21600
6 - Archstone Chelsea - Mid Loop	0.034	0.009	3.674	21600
7 - Archstone Midtown - Low Loop - #2	0.144	0.012	11.769	12282
7 - Archstone Midtown - Low Loop - #1	0.082	0.015	5.335	7888
8 - Archstone Midtown - Mid Loop	0.012	0.009	1.297	21600
9 - Avalon	0.18	0.009	19.452	21600
10 - Silver Towers	0.022	0.009	2.377	21600
1085 Washington	0.048	0.021	2.320	4321

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Investigation of a Simplified Method for Detecting Rogue Bypass in Buildings with CHP and Solar Thermal Preheat Systems

Final Report
May 2014

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State of New York
Andrew M. Cuomo, Governor

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