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Tankless and Solar Hot Water Heating Integration Research

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Abstract:

The combination of tankless hot water heating and solar hot water heating creates some challenges that we have been researching with our builder partner, Coastal Habitats/Coastal Green Building Solutions, Hilton Head Island, SC. Sending solar preheated water into a tankless water heater can cause wide temperature fluctuations at the domestic taps. The purpose of this research project is to design and install a solar hot water system that features a tankless water heater integrated with a solar hot water panel such that consistent temperature control can be achieved at the domestic taps.

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5. TANKLESS AND SOLAR HOT WATER HEATING INTEGRATION RESEARCH

5.1 Executive Summary

5.1.1. Solar Hot Water Research Overview

The combination of tankless hot water heating and solar hot water heating creates some challenges that we have been researching with our builder partner, Coastal Habitats/Coastal Green Building Solutions, Hilton Head Island, SC. Sending solar pre-heated water into a tankless water heater can cause wide temperature fluctuations at the domestic taps. The purpose of this research project is to design and install a solar hot water system that features a tankless water heater integrated with a solar hot water panel such that consistent temperature control can be achieved at the domestic taps.

5.1.2. Key Results

BSC worked directly with the builder and plumbing contractor at the Building America Prototype house (Bryant Park Cottages, Molly, Lot #8) to install a prototype system which integrated a solar hot water heater with a tankless water heater plus small storage tank and circulator. Temperature sensors, flow meters, valves, and bypasses were also installed accommodate monitoring of the system performance during short-term tests and long-term monitoring.

Short-term testing confirmed that the solar/tankless hot water heating system, without the small storage tank and circulator modifications suggested by BSC, would not reliably provide the expected hot water temperature to the domestic taps at low flow rates. Addition of the small storage tank successfully resulted in hot water reaching the taps at very low flow rates, and when the water temperature supplied to the tankless heater from the solar collector was elevated but still less than 130ºF. However, other unexpected temperature instability issues with the prototype design were observed and we are continuing to work toward the best resolution.

At a different test house, water quality issues, causing too frequent clogging of the tankless hot water heater inlet filter and mineral scaling of pipe fittings, were found to be the only problems in a prototype tankless/combination space and domestic hot water heating system. Electronic water conditioning and pre-filtering are solutions that were investigated and seem to be working well.

5.1.3. Gate Status

5.1.3.1. Source Energy Savings and Whole Building Benefits ("must meet")

This project meets the Gate 1B "must meet" requirement for source energy savings. The prototype system which couples a solar hot water heater with a tankless water heater plus small storage tank and circulator, is expected to save energy relative to the same solar hot water heater coupled with a standard storage type water heater. The prototype system is also expected to reduce inefficient tankless hot water heater cycling and reduce hot water use while improving temperature control at the domestic taps.

5.1.3.2. Performance-Based Code Approval ("must meet")

This project meets the Gate 1B "must meet" requirement for performance-based and safety, health and building code requirements for new homes. The solar hot water/tankless water heater integrated installation will be fully compliant with all relevant performance-based codes.

5.1.3.3. Prescriptive-Based Code Approval ("should meet")

This project meets the Gate 1B "should meet" requirement for prescriptive-based safety, health and building code requirements for new homes. The solar hot water/tankless water heater integrated installation will be fully compliant with all relevant prescriptive-based codes.

5.1.3.4. Cost Advantage ("should meet")

This project is expected to meet the Gate 1B "should meet" requirement for strong potential to provide cost benefits relative to current systems. The prototype system which couples a solar hot water heater with a tankless water heater plus small storage tank and circulator, is expected to provide energy savings, water savings, and increased temperature control at the domestic taps at a small incremental cost relative to the same solar hot water heater coupled with only a tankless water heater.

5.1.3.5. Reliability Advantage ("should meet")

This integrated product should meet the Gate 1B "should meet" requirement to meet reliability, durability, ease of operation and net added value requirements for use in new homes. Sensitivity to water quality resulting in too frequent clogging of the tankless heater inlet filter, and scaling inside pipe fittings, presents some reliability concerns that would be common to similar systems with or without the prototype modifications of a small storage tank and circulator.

5.1.3.6. Manufacturer/Supplier/Builder Commitment ("should meet")

BSC has discussed these system issues with technical staff at a major tankless water heater manufacturer (Rinnai America Corp.). They were more willing to discuss the water quality issues than the solar integration or the combination space and domestic hot water system integration (they said we were on our own with those systems). BSC will continue to conduct more research on this advanced subsystem in partnership with our builder partner and NREL before approaching a manufacturer about collaboration toward wider market solutions.

5.1.3.7. Gaps Analysis ("should meet")

Outstanding issues that our research aims to more fully determine include: 1) prototype system performance and occupant acceptance regarding temperature stability at the domestic water taps over a year of occupied monitoring; 2) the frequency of temperature instability at the taps if the small storage tank and circulator modifications were not used; and 3) annual energy, water, and cost savings.

5.1.4. Conclusions

BSC was successful in creating a prototype water heating system that merged an Integral Collector Storage (ICS) solar hot water heater with a tankless water heater plus small storage tank and circulator. The system achieved the goal of providing temperature control at the domestic taps regardless of very low flow, frequent on/off flow, or solar pre-heated water supply. The system is expected to provide energy savings, water savings, and increased temperature control at the domestic taps. An important but easy to implement improvement was already made. Another proposed improvement is scheduled to be implemented and retested. Long-term monitoring under normal operating conditions will begin once the house is sold and occupied.

5.2 Introduction

Tankless domestic hot water heaters are becoming standard practice for many high-performance homes. Domestic hot water heating amounts to 10 to 15 percent of total energy use in these homes. Upgrading from a standard tank/storage type gas water heater with an Energy Factor (EF) of 0.56 to a tankless hot water heater with EF between 0.82 (natural gas) and 0.85 (propane) can save 40 to 50 percent on hot water heating energy use, for a total energy use savings of around 5 percent.

The combination of tankless hot water heating and solar hot water heating creates some challenges that we have been researching with our builder partner, Coastal Habitats/Coastal Green Building Solutions, Hilton Head Island, SC. Sending solar pre-heated water into a tankless water heater can cause wide temperature fluctuations at the domestic taps. All gas-fired tankless hot water heaters have a minimum firing rate_usually not less than 15 kBtu/h. If the entering water temperature is too close to the outlet temperature setpoint, then the unit may not fire, causing wide temperature fluctuations at the domestic taps. One major manufacturer recommends that the water going into the unit be no warmer than 75°F because 15 kBtu/h will give a 50°F temperature rise at 0.5 gpm (the lowest flow rate to activate the heater) and 75+50=125, which is the highest recommended domestic hot water temperature.

Referring to Figure 5.1, at the minimum hot water draw rate of 0.5 gpm, the minimum firing rate will produce a 50ºF temperature rise. That means that if the water heater outlet set-point is 125°F, and the inlet water temperature is greater than 75°F, then the water heater will shut off, delivering water to the tap as low as 75°F. If the flow rate increases, or if the inlet water temperature falls, then the heater will fire again and start delivering 125°F water to the tap. Referring again to Figure 5.1, depending on the water flow rate (between the minimum and maximum allowed by the unit) this type of temperature fluctuation can occur with solar preheated water anywhere between 75°F (at 0.5 gpm) and 121°F (at 8.5 gpm). It is very likely that the solar preheated water will quite often fall within that range.

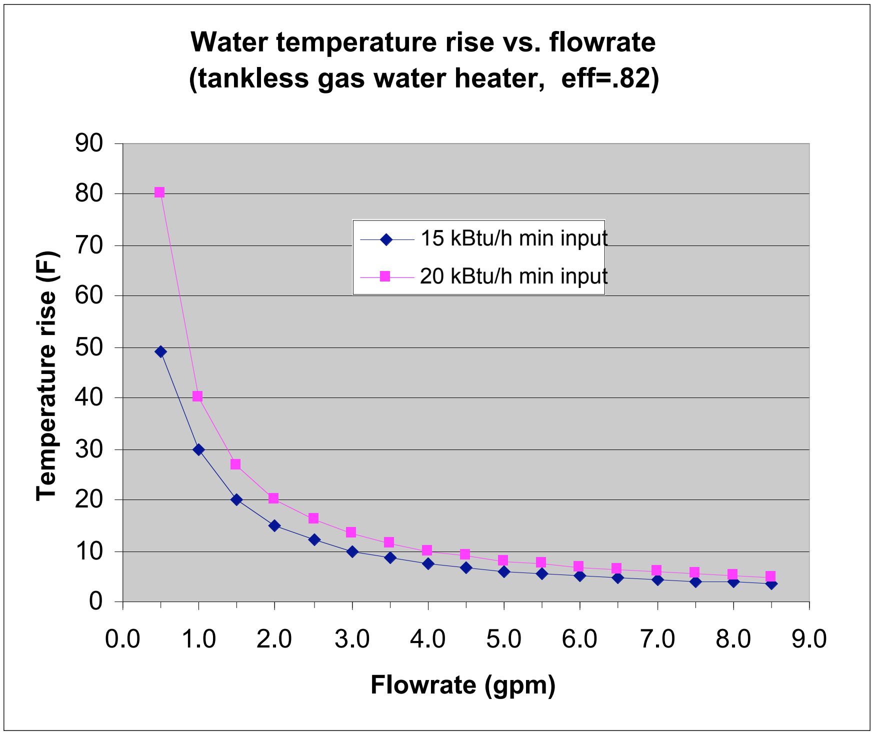


Figure 5.1: Water temperature rise versus flow rate for a typical gas tankless hot water heater

Tankless water heaters can cause annoying temperature fluctuations at the taps for other reasons as well:

1. Tankless hot water heaters are activated when water is drawn through the unit. If the water flow rate is below the typical 0.5 to 0.9 gpm minimum to activate the unit, the unit will not fire, delivering water to the taps at the water main temperature. That can cause occupants to increase the flow rate beyond what was needed in order to get hot water. Energy and water savings could be realized if that limitation was eliminated.

2. With frequent on/off type water use, hot and cold water will be intermittently delivered to the tap due to water heating delay times as the burner cycles on and off. It can take 10 seconds after the beginning of a hot water draw for a tankless heater to prove proper draft and fire the gas burner. Rinnai now keeps the vent blower running for about one minute after the end of each hot water draw in order to reduce the re-firing time to a few seconds. So, delivery of cold water between on/off hot water demand can typically last from a few seconds to 10 seconds. Not only is frequent equipment cycling inefficient, but hot water waste could be significant as occupants leave the water on when it is not needed in order to avoid the temperature fluctuations.

Field research is being conducted to evaluate whether these situations are actuality a significant threat to the success of tankless hot water heating systems in high-performance homes, and whether or not there are cost effective solutions. In 2007, the systems shown in **Figure 5.8** and Figure 5.9 were proposed by BSC as solutions, with an initial focus on the integration of solar hot water heating with tankless hot water heaters.

The system of **Figure 5.8** adds a small, well-insulated storage tank that is backed up with electric heat to a setpoint approximately 10°F below the tankless hot water heater outlet setpoint. In that way, the temperature fluctuation delivery problem should be resolved for conditions when:

1. The hot water demand is below the minimum flow rate to fire the gas heater: and
2. The inlet water is warm enough that the water heating capacity needed is below the minimum firing capacity of the gas heater. The frequency and duration of this condition, and the heat loss from the tank will impact how often the electric heating element will need to come on.

The mixing valve shown in **Figure 5.8** and Figure 5.9 is required for when the solar pre-heated water is too hot for delivery to the domestic taps, and when the storage tank temperature needs to be high for space heating applications.

The system of Figure 5.9 goes further than the system of **Figure 5.8** by eliminating the short-cycling inefficiency of the gas heater and by eliminating the need for any electric heating. The system adds a pumped circulation loop from the side of the small, well-insulated storage tank to the tankless water heater, much like a typical boiler plus indirect water heater system. Whenever the thermostat switch on the storage tank closes, the circulator will be energized, moving water through the gas heater. Tankless hot water heaters have a relatively high flow resistance; the pump needed to force water through the unit will draw about 90 W—not an insignificant amount of pump energy. Therefore, while this system will provide the best operation in terms of supplying regulated temperature water to the taps, and it does not require an electric heating element, there will be circulator energy and storage tank losses that need to be better understood.

The system of Figure 5.9 also has the advantage of being easily adapted to combination space and domestic hot water heating applications as shown in Figure 5.2 In that configuration, the storage tank needs to have 2 additional side ports available for the pumped loop to the hot water coil in the space heating process air stream. Small, 12 gallon tanks of with 4 side ports and 2 top ports are readily available (such as Whirlpool md# E1F12US015V made by US Craftmaster, sold at Lowe's for about $210).

5.3 Prototype Testing Results for Integration Of Tankless Hot Water Heating With Solar Hot Water Heating

BSC worked directly with the builder and plumber at the Building America Prototype house (Bryant Park Cottages, Molly, Lot #8) to install the tankless domestic hot water heating integrated with solar hot water heating system shown in Figure 5.9. Temperature sensors, flow meters, valves, and bypasses were also installed according to Figure 5.2 to accommodate monitoring of the system performance during short-term tests and long-term monitoring.

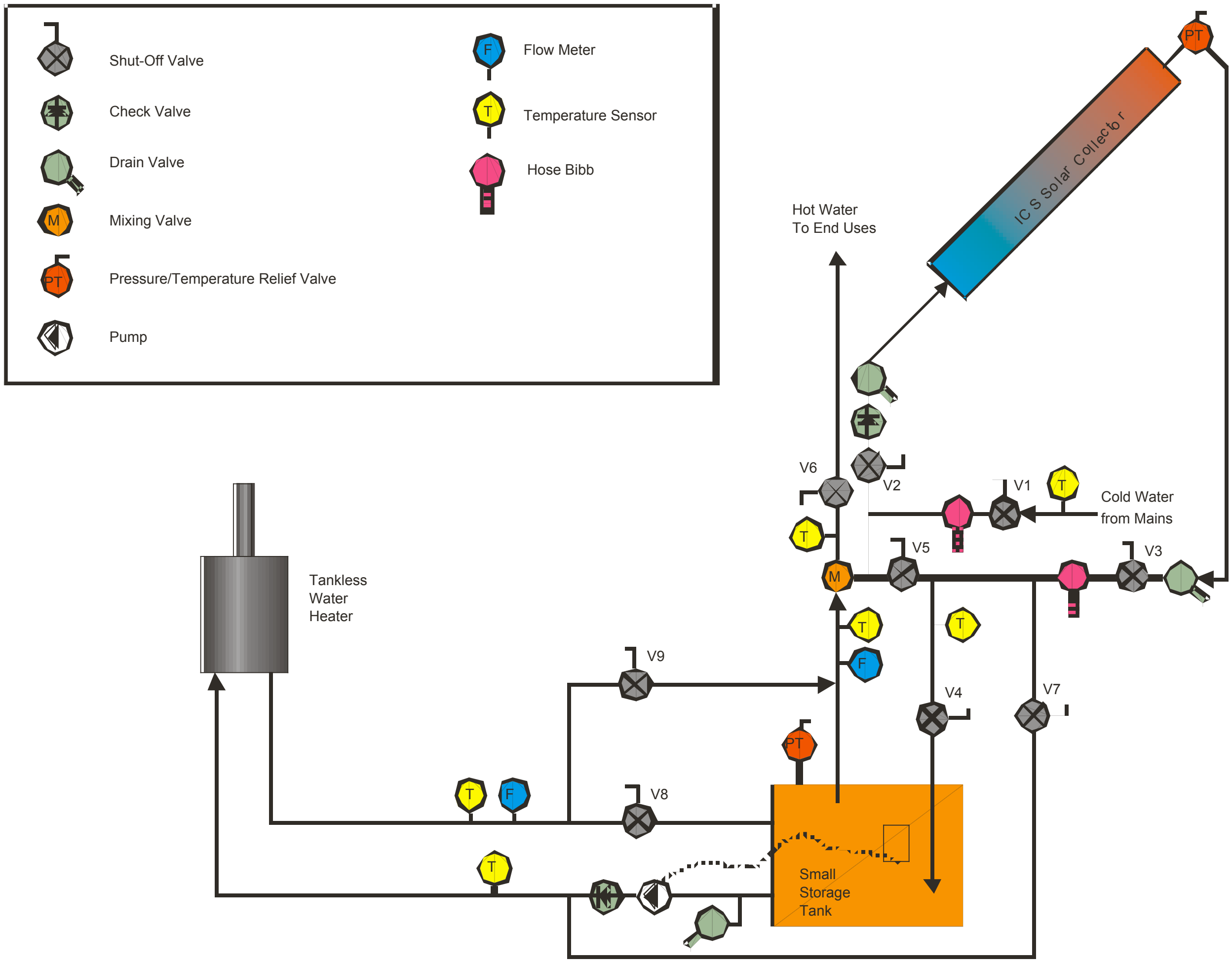


Figure 5.2: Locations of flow meters, temperature sensors, bypass loops, and hose bib connections for short-term testing

NREL researchers later installed the data monitoring system and conducted short-term tests, according to the test plan as described in Appendix A. Observations from the short-term testing were as follows:

1. The solar collector appears to be working well based on preliminary testing. The collector efficiency was 42% based on a test where the collector was drained at the beginning and end of the day, which is very consistent with our expectations given the system design and the weather conditions during the test. There is a section of PEX piping near the outlet of the solar hot water system inside the house that could see temperatures in excess of the PEX rating (peak temperature measured right after long-term stagnation of collector was 176°F). PEX is rated to 180°F, so that section of pipe should be replaced with copper to be sure that there will be no pipe failure if the collector should exceed 180ºF due to no domestic hot water use for long periods of sunshine.

2. The following issues were confirmed during short-term tests where the small storage tank was bypassed:

   - The tankless heater doesn't fire at low flow rates (<0.5 gpm). The Rinnai tankless water heater does not turn on when its internal logic determines that the combination of flow rate and inlet temperature would result in the outlet temperature exceeding the set-point even at the lowest burner setting.

   - The tankless water heater doesn't fire when there is an elevated supply temperature from the solar collector combined with slightly higher flow rates (0.5-0.8 gpm).

   - With solar pre-heated water, the tankless heater sometimes shuts off after turning on for a few minutes, probably caused by the tempering valve gradually decreasing the hot water flow rate, causing the maximum outlet temperature of the tankless heater to be exceeded.

3. Addition of the small storage tank successfully results in hot water reaching the taps at very low flow rates, and when the water temperature supplied to the tankless heater is too high.

4. The tempering/mixing valve seems to have a minimum cold water flow. It cannot maintain set point at 120°F when water entering the valve is below about 130°F . A different tempering valve without a minimum cold water flow or raising the storage tank thermostat setpoint should resolve that issue.

5. The hot water system exhibited some temperature stability issues when using the small buffer tank at higher hot water flow rates. With the storage tank thermostat set at 125ºF and the tankless heater outlet temperature set at the maximum of 140ºF for the residential heater, a temperature droop was observed at the domestic taps a minute or two after the water draw began. After the circulator started moving water through the tankless heater, the water temperature delivered to the taps increased more slowly than expected. Moving the storage tank thermostat set-point closer to the heater output set-point helped but not enough to resolve the problem. Unless the lower limit of the temperature droop response is above at least 105°F, this would likely result in comfort problems when the occupants take showers at high total hot water flow rates.

To resolve these temperature instability issues, BSC is working with the builder to replace the residential unit with the same size commercial unit which can be set for a higher outlet temperature (up to 180°F). That will allow the storage tank temperature to be increased such that the lower limit of the temperature droop will stay above a comfortable shower temperature. After that system change, some short-term tests will be repeated in cooperation with NREL.

Photographs of the installed system, showing the extensive extra piping, valves, and sensors required to conduct system testing in a number of operational modes, are shown in Figure 5.3.

Figure 5.3: Photos of installed hot water heating system at Bryant Park Cottages, Molly plan, Lot #8

Figure 5.4 through 5.9 show details of the system testing that exposed the temperature droop issue and identified an important but easy system improvement.

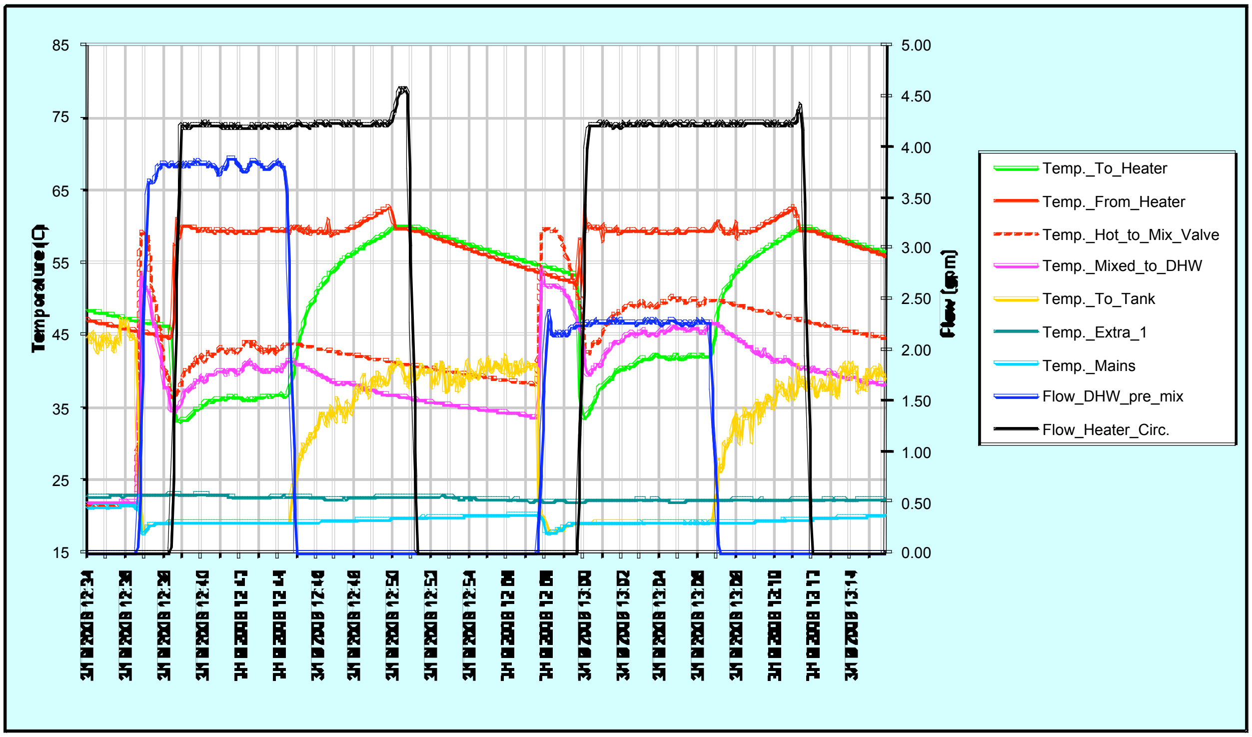


Figure 5.4; Temperature droop response at 4 and 2 gpm hot water flow rate

Two cycles of hot water draw, the first at 4 gpm and the second at 2.25 gpm, were made with the tankless hot water heater outlet set-point at 140˚F and the 6 gallon storage tank circulator set-point at 130˚F. This is shown in Figure 5.4. The data show a droop in water temperature delivered to the domestic taps (purple plot line) after the draw starts and slower than expected recovery after the pump starts circulating water between the small storage tank and the water heater. The droop occurs more quickly and more deeply at the higher flow rate than at the lower flow rate. The lower limit of the droop was 35 C (95ºF) at 4 gpm and occurred over the course of 1 minute. The lower limit was 40 C (104ºF) at 2.25 gpm and occurred over the course of 2 minutes. A person taking a shower using 2.25 gpm of hot water would have to adjust the shower valve to 100% hot sometime during the second minute to accommodate for the temperature droop. From the data, it appears that the thermostat activation point changes depending on the draw flow rate. It could be that mains water entering the tank is partially bypassing the thermostat, or that the thermostat response is slow enough that the water in the tank cools down too much before the thermostat activates the circulator.

Two solutions were postulated, one was to install a faster responding temperature sensor to control circulator activation, and the other was to change the circulator control method from temperature activation only to temperature and draw activation via an inline flow switch. The later meant that the circulator would be activated by either a drop in tank temperature or by a hot water draw event. Activating the circulator upon a draw event will push the room-temperature water in the pipes into the tank at the beginning of the draw eliminating the temperature dip that occurs later in the draw. Both solutions would require additional cost and neither solution was feasible to implement during the limited time scheduled for the short-term testing.

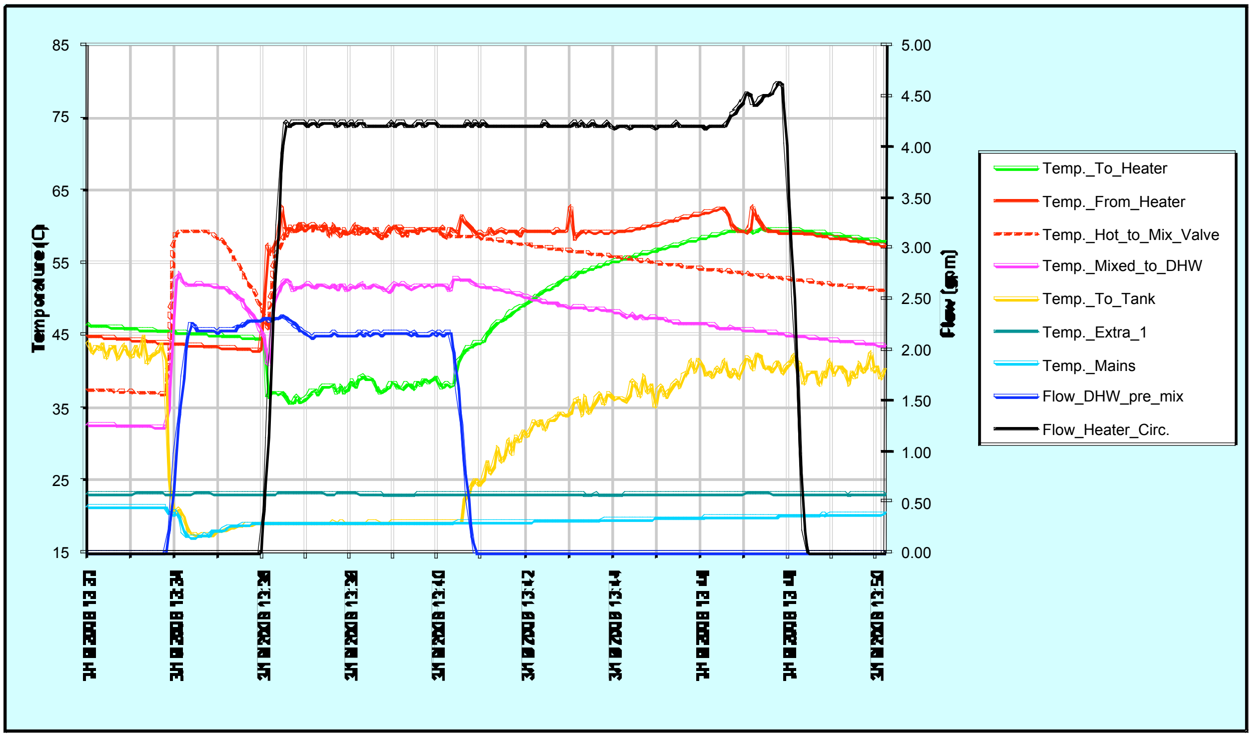


Figure 5.5: System response improvement by changing valve 8 and 9 positions

Further testing revealed an important but easy change to improve the system. Closing valve 8, shown Figure 5.2, and opening valve 9 worked much better than the original configuration of valve 8 open and valve 9 closed. Initially, valves 8 and 9 were installed in the system for testing purposes only-- to allow bypassing the small storage tank entirely. As it turned out, even when using the tank, piping hot water from the heater back to the tank hot water outlet pipe, instead of directly to the tank, sent hot water immediately to the taps after the circulator was activated. That is shown by the purple plot line in Figure 5.5.

For combination space and domestic hot water heating systems (discussed below), the valve change would also provide a built-in domestic hot water priority function. When domestic hot water is drawn, the hottest available water will go to the taps first before mixing in the tank. If no domestic hot water is drawn, hot water from the heater will flow back into the tank through the top port, instead of the side port, keeping the tank hot for space heating operation.

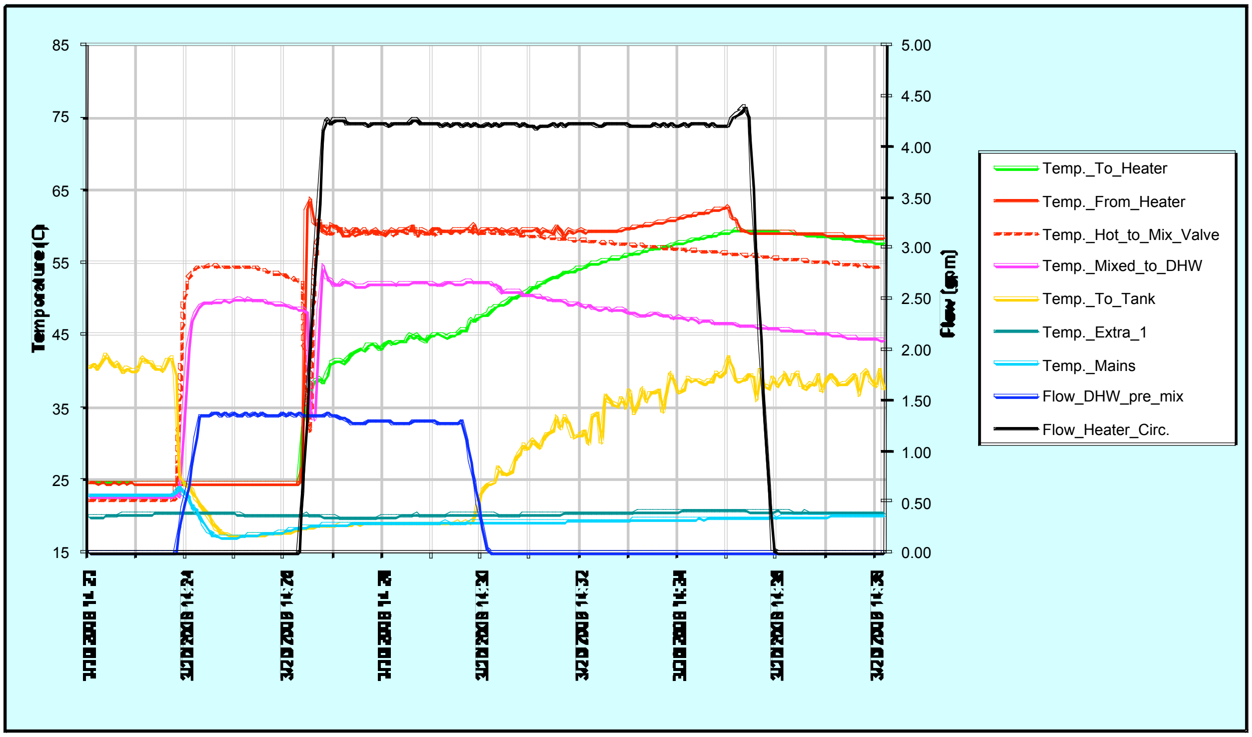


Figure 5.6: Temperature droop response at 1.5 gpm hot water flow rate

The test shown in Figure 5.6 was also run with valve 8 was closed and valve 9 open, but the draw rate was reduced to 1.5 gpm. At that lower draw rate, the temperature droop seen before after the draw started was nearly non-existent. When the circulator started, a sharp decrease in hot water temperature to the taps occurred for 10 seconds. The lower limit of that droop was 35 C (95˚F).

The tankless hot water heater that was already installed at this project was the Rinnai R85i (residential, 8.5 gpm max flow, internal mounting). It works the same as the commercial C85i except the C85i output temperature can be set as high as 185ºF instead of 140ºF max for the residential unit. The commercial versions apparently have a coating inside the heat exchanger to make them more durable. For that reason, Rinnai recommends using the commercial version whenever pumping water through the heater. Since the installed system (Figure 5.9) involves pumping through the unit, the R85i will be replaced with the C85i. That will also allow us to increase the water heater and storage tank set-points 10˚F, which will make sure that the temperature droop observed is always above a comfortable shower temperature.

The house is not sold or occupied yet, but once that happens, we will begin to get measured performance data based on actual system use. That data will provide valuable information on how the system responds and performs with naturally varied hot water draw rates and durations over the course of a year.

5.4 Prototype Testing Results for Integration Of Tankless Hot Water Heating With Space Heating

The system of Figure 5.2 was evaluated at an existing home having a tankless domestic hot water heater integrated with space heating (combination space and domestic hot water heating system). Figure 5.7 is a photo of the hot water heating side of the system.

Figure 5.7: Hot water heating side of combination space and domestic hot water heating system utilizing a sealed-combustion tankless water heater

This tankless heater for this system was the Rinnai commercial C53i (5.3 gpm max). Testing of this system also showed a similar temperature droop to that observed in the solar integrated system of Figure 5.9, but, in this case, the lower limit of the droop was always above the required domestic hot water delivery temperature because the water heater output setpoint was 160°F and the tank setpoint was 145°F. Therefore, we believe that the same settings will be the best solution for the system at the Hilton Head project.

Same as for the solar integrated system, the circulator that moves water from the tank through the tankless water heater is activated by the thermostat that comes with the electric water heater tank. However, in the combination space and domestic hot water heating system, another smaller circulator moves water from the tank through a hot water coil in the process air stream of the central heating system. Evaluation through the 2007-2008 heating season has shown the system to work well.

However, a problematic issue arose related to water quality. Mineral scaling in the piping system, especially in galvanized nipples and dielectric union fittings (Figure 5.12), and frequent clogging of the inlet filter to the tankless heater by crystallized mineral deposits was observed (Figure 5.10 and Figure 5.11).

The water heater manufacturer (Rinnai) states that the product warranty does not apply if the water supply exceeds chemistry or impurity limits as shown in the list below:

pH 6.5 to 8.5

TDS (Total Dissolved Solids) up to 500 mg/L

Total Hardness up to 11.7 grains/gallon

Aluminum up to 0.2 mg/L

Chlorides up to 250 mg/L

Copper up to 1.0 mg/L

Iron up to 0.3 mg/L

Manganese up to 0.05 mg/L

Zinc up to 5 mg/L

Water tested from the house taps showed that the water supply chemistry and impurity levels were within the required specifications. It is well known that mineral scaling and deposition is accelerated by the relatively high temperatures required for space heating. Based on recent discussions with our builder partner in Albuquerque, NM (Artistic Homes) who has thousands of combination space and domestic hot water heating systems installed, scale and mineral buildup in piping and hot water coils can be with a problem with these systems. The solution that seems to be working at this test site has been:

1) Installation of a large 80 mesh (175 micron) pre-filter before the small 60 mesh (238 micron) filter in the inlet of the tankless water heater (shown in Figure 5.14); and

2) Installation of an electronic water conditioner that keeps minerals such as calcium and manganese from collecting and sticking to surfaces (shown in Figure 5.15).

The larger surface area of the pre-filter has reduced the maintenance requirement from weeks to many months. As advertised, the electronic water conditioner seems to be clearing the system of mineral scale that had collected over time (Figure 5.13).

Understanding how and when to best apply these systems and solutions will increase the reliability and long-term successful performance of high-performance homes in the Building America program.

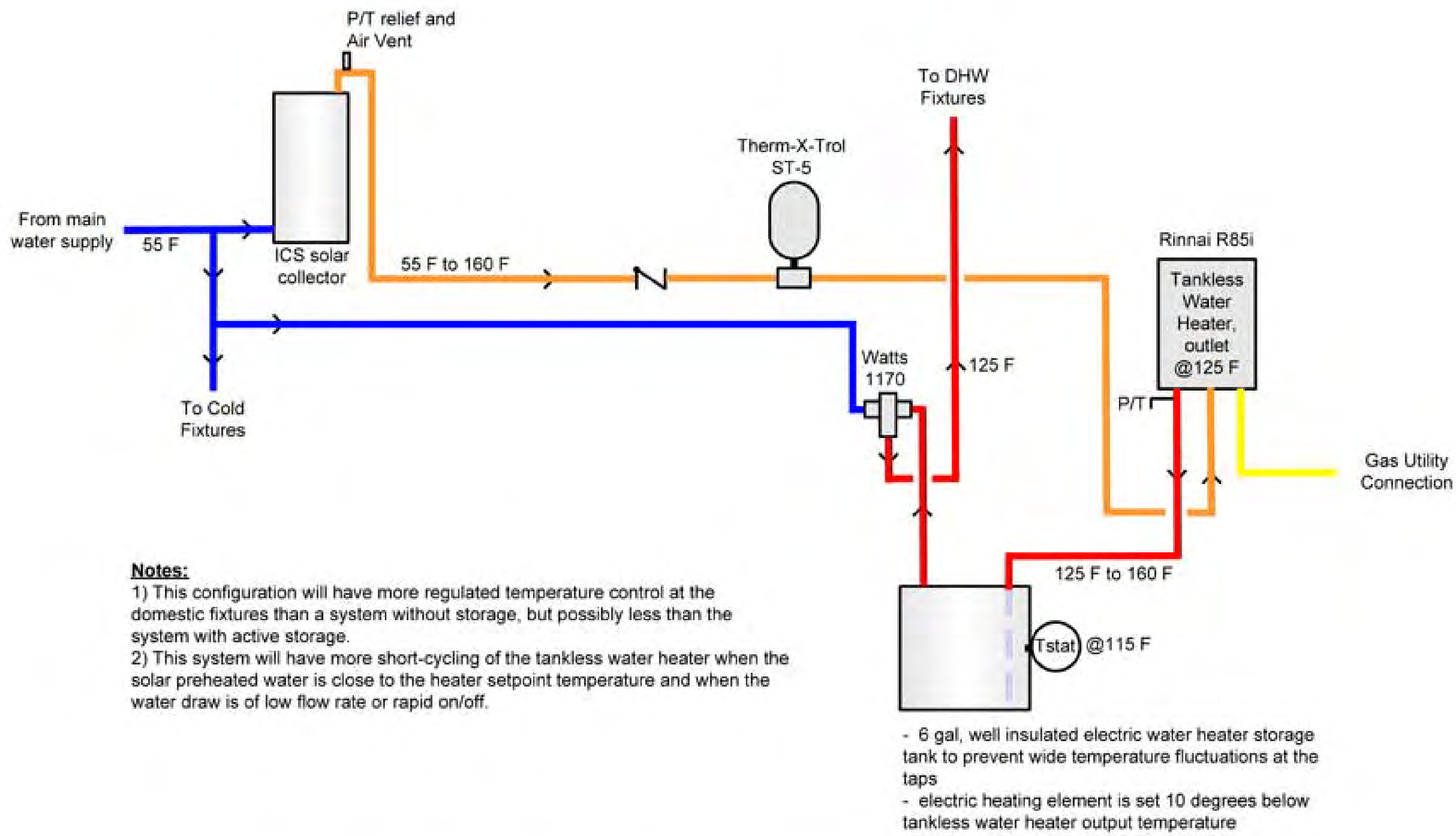
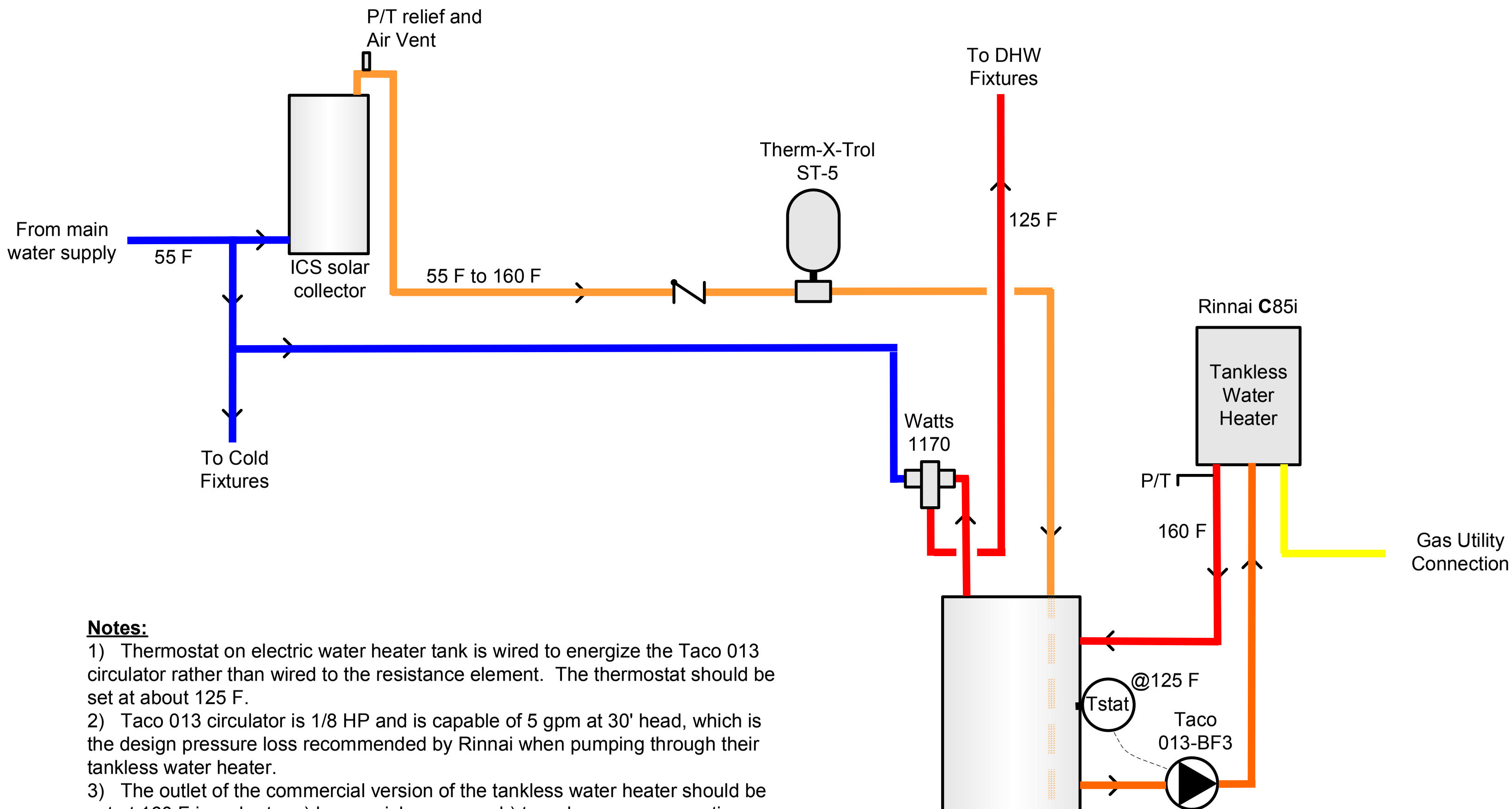


Figure 5.8: Tankless domestic hot water heater application with solar preheat and passive storage tank



Notes:

1) Thermostat on electric water heater tank is wired to energize the Taco 013 circulator rather than wired to the resistance element. The thermostat should be set at about 125 F.

2) Taco 013 circulator is 1/8 HP and is capable of 5 gpm at 30' head, which is the design pressure loss recommended by Rinnai when pumping through their tankless water heater.

3) The outlet of the commercial version of the tankless water heater should be set at 160 F in order to: a) have quick recovery, b) to reduce pump operation time, and c) to allow at least a 30 F temperature rise through the heater which occurs at the minimum firing rate at 1 gpm.

4) Electric water heater storage tank is available from Whirlpool at Lowe's, with all the ports neccessary.

5) This configuration will have the most regulated temperature control at the domestic fixtures. This system will also have the least short-cycling of the tankless water heater.

- 6 gal well insulated electric water heater storage tank to prevent wide temperature fluctuations at the taps and short-cycling of tankless heater;
- thermostat on storage tank controlled to 125 F minimum, but the water can get hotter depending on the solar input

Figure 5.9: Tankless domestic hot water heater application with solar preheat and active storage

Figure 5.10: Mineral deposition clogging the small tankless water heater inlet filter

Figure 5.11: Mineral deposition eventually clogging the large pre-filter installed before the water heater inlet

Figure 5.12: Scale buildup in galvanized steel dielectric union fitting and mineral deposition on large pre-filter

Figure 5.13: Scale being cleaned from a galvanized steel dielectric union fitting by the electronic water conditioner

Figure 5.14: Pre-filter installed in bypass loop before the inlet to the tankless water heater

Figure 5.15: Clearwave electronic water conditioner

5.5 Project Evaluation

5.5.1. Source Energy Savings and Whole Building Benefits

This project meets the Gate 1B "must meet" requirement for source energy savings. The prototype system which couples a solar hot water heater with a tankless water heater plus small storage tank and circulator, is expected to save energy relative to the same solar hot water heater coupled with a standard storage type water heater. The prototype system is also expected to reduce inefficient tankless hot water heater cycling and reduce hot water use while improving temperature control at the domestic taps.

5.5.2. Performance-based Code Approval

This project meets the Gate1B "must meet" requirement for performance-based and safety, health and building code requirements for new homes. The solar hot water/tankless water heater integrated installation will be fully compliant with all relevant performance-based codes.

5.5.3. Prescriptive-based Code Approval

This project meets the Gate1B "should meet" requirement for prescriptive-based safety, health and building code requirements for new homes. The solar hot water/tankless water heater integrated installation will be fully compliant with all relevant prescriptive-based codes.

5.5.4. Cost Advantage

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5.5.7. Gaps Analysis

Outstanding issues that our research aims to more fully determine include: 1) prototype system performance and occupant acceptance regarding temperature stability at the domestic water taps over a year of occupied monitoring; 2) the frequency of temperature instability at the taps if the small storage tank and circulator modifications were not used; and 3) annual energy, water, and cost savings.

5.6 Conclusions/Remarks

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At a different test house, water quality issues, causing too frequent clogging of the tankless hot water heater inlet filter and mineral scaling of pipe fittings, were found to be the only problems in a prototype tankless/combination space and domestic hot water heating system. Electronic water conditioning and pre-filtering are solutions that were investigated and seem to be working well.

BUILDING AMERICA FIELD TEST PLAN
MARCH 10, 2008

NREL / Building Science Consortium
Coastal Habitats
Hilton Head, South Carolina
Hot Humid Climate Region, 40% Energy Savings Level
Gate 2: Prototype House Evaluation
Expected Test Dates: March 13-23, 2008

Description: Coastal Habitats is constructing a series of Building America homes at the Bryant Park community in Hilton Head, SC. Based on analysis by Building Science Corporation (BSC), the homes will reach 30%+ source energy savings compared to the Building America (BA) Benchmark through the use of air-tight spray foam insulation, low-e windows, and high efficiency mechanical systems. The ventilation system features an innovative combination of central-fan-integrated supply (CFIS) and single-point exhaust methods. The Molly plan proposed here for detailed testing will also have solar domestic hot water (SDHW), resulting in projected source energy savings of 46% over the BA Benchmark. An additional Molly plan without solar hot water will be used for ventilation system testing. The test houses will be at Lot 8 and Lot 9. An elevation drawing of the Molly is shown in Figure 1, the community layout is shown in Figure 2, a schematic of the SDHW system is shown in Figure 3, and the first and second floor plans are shown in Figures 4 and 5. The key specifications are listed in Table 1. The preliminary BSC analysis results are summarized in Tables 2 and 3.

Figure 1: Molly test house front elevation.

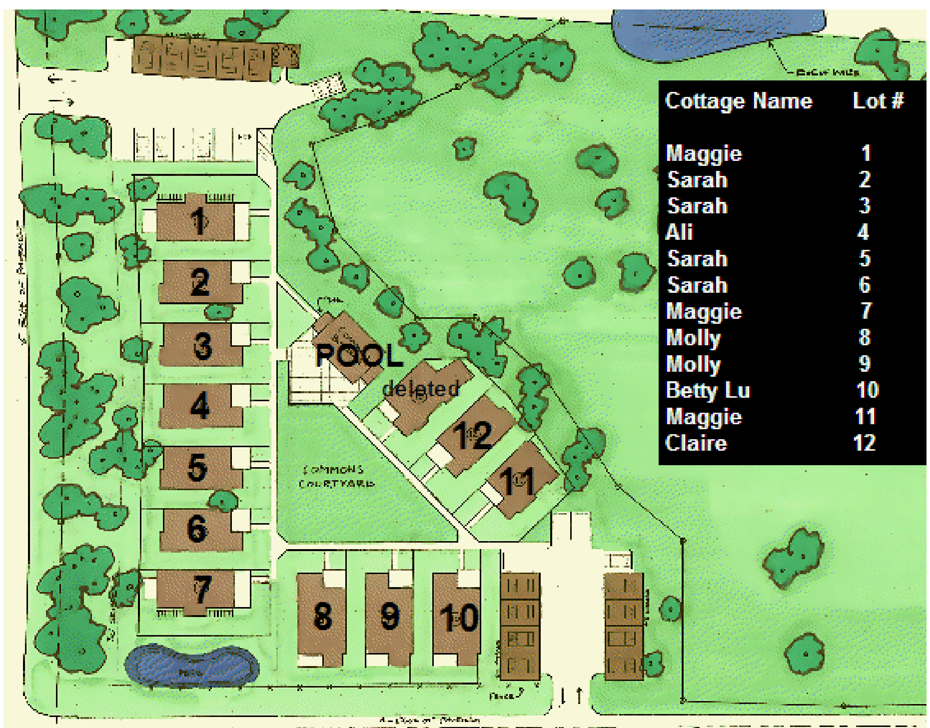

Figure 2: Bryant Park Cottages Site Plan

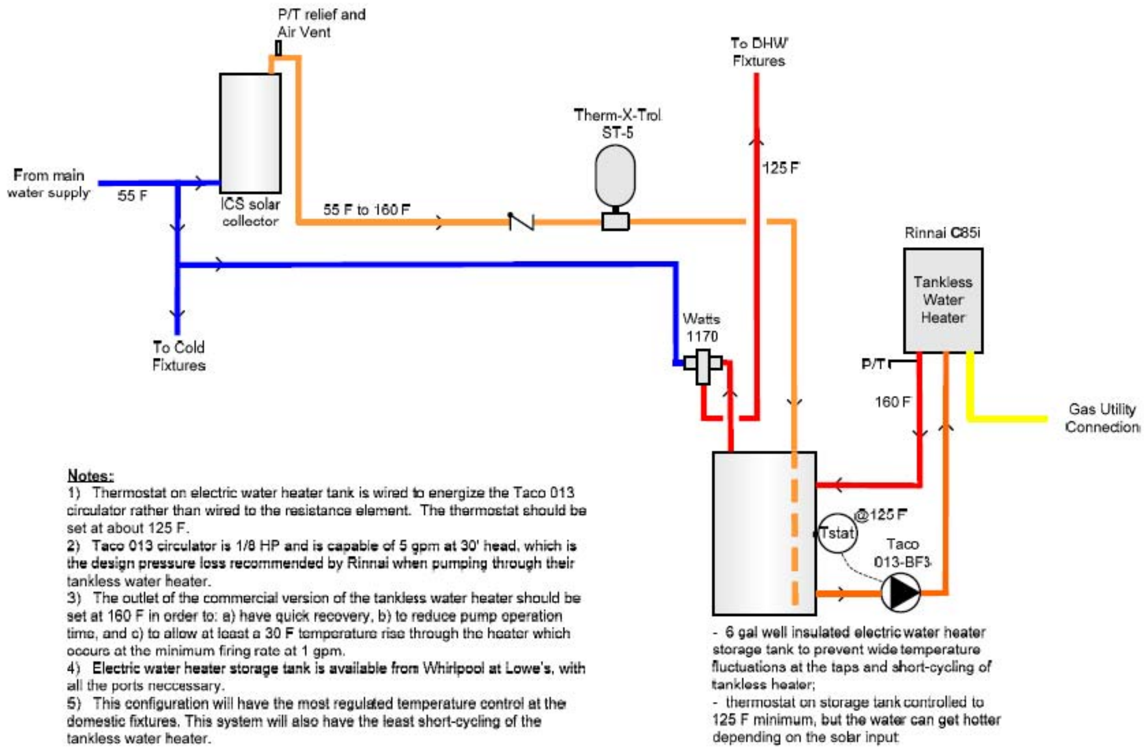

Figure 3. Schematic of the water heating system, in a hybrid configuration designed to avoid shortcomings of integrating a tankless hot water heater with solar pre-heat.

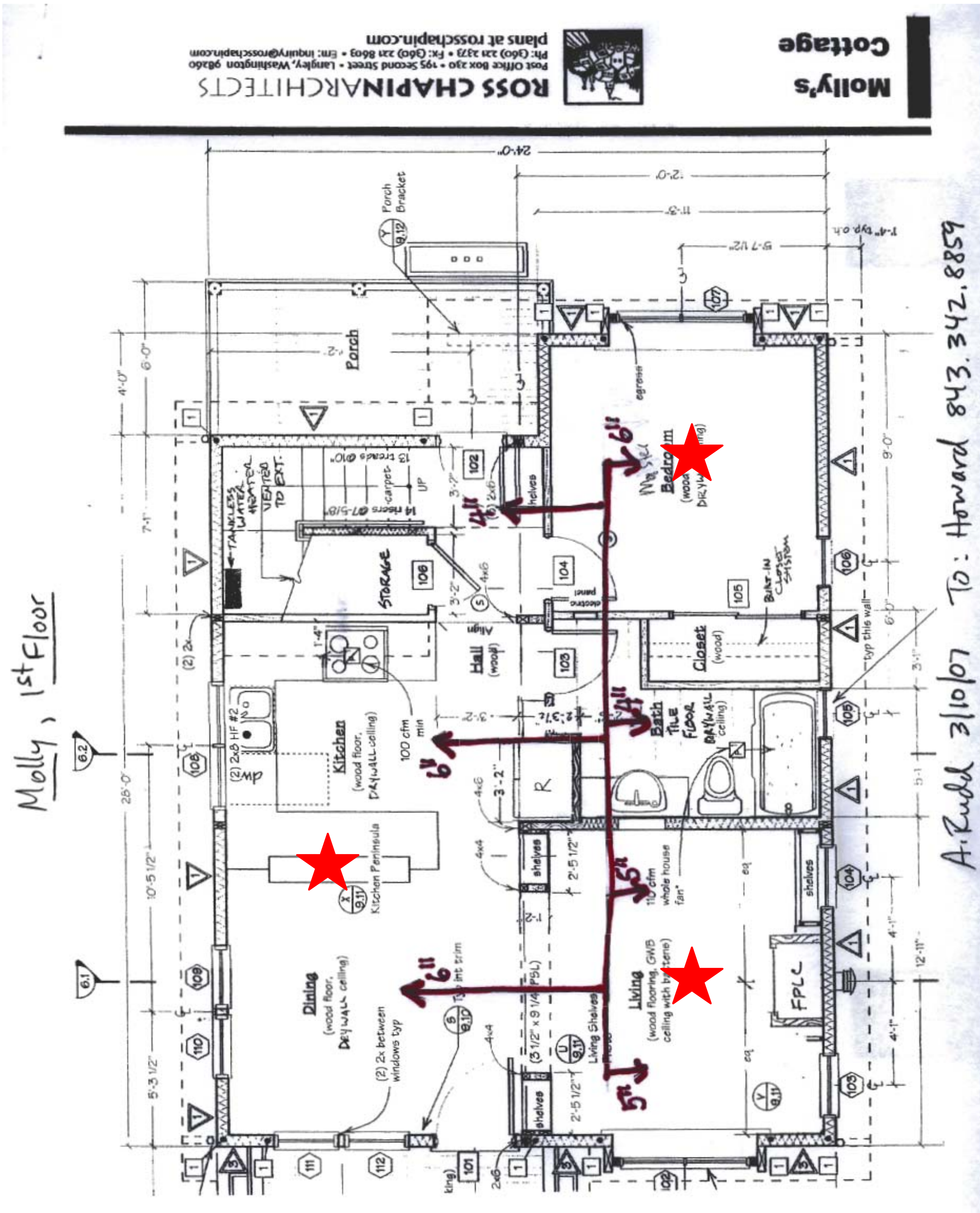

Figure 4. Molly 1st floor plan, with tracer gas measurement points indicated by stars.

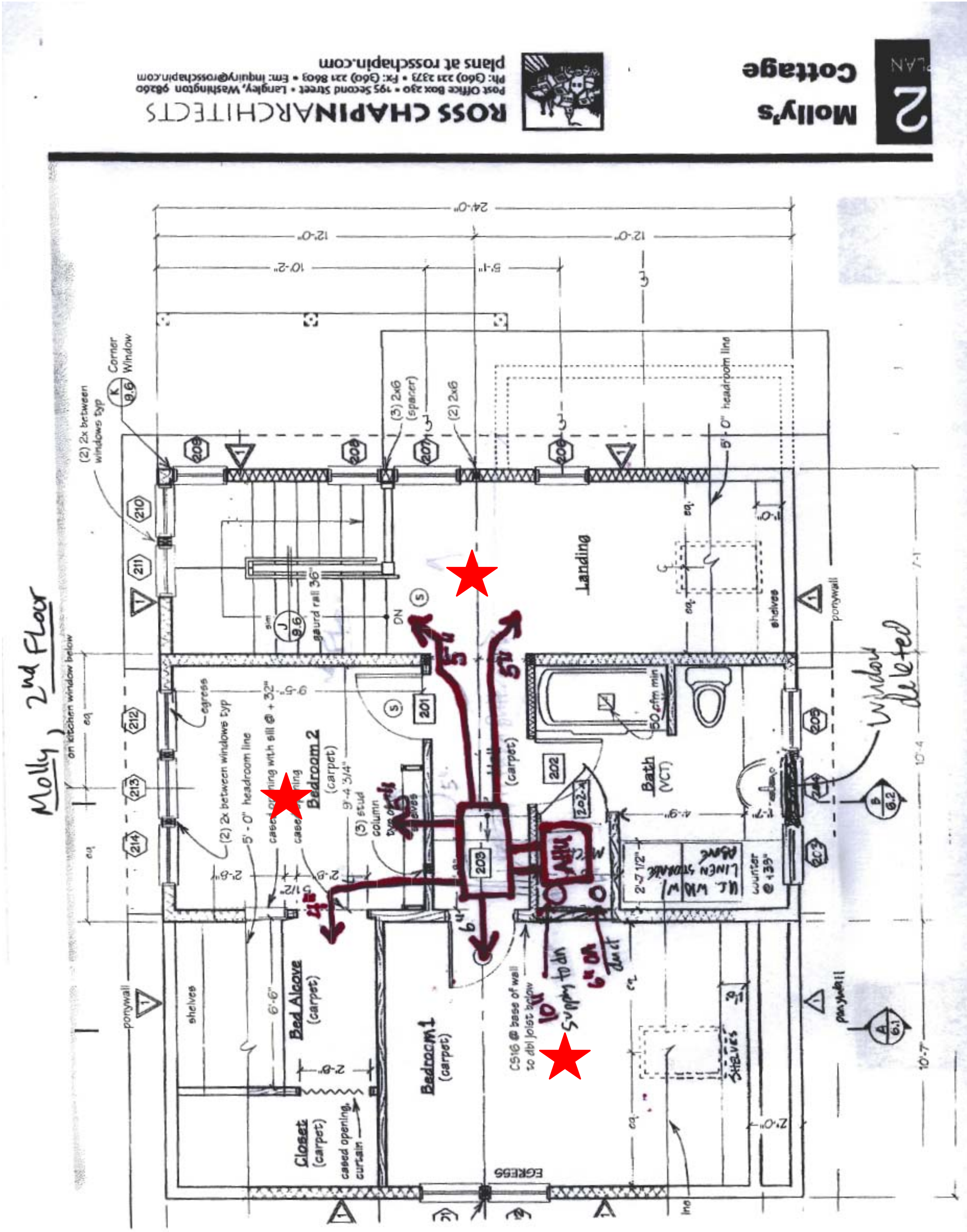

Figure 5. Molly 2nd floor plan, with tracer gas measurement points indicated by stars.

One focus of the field test will be the 50 gallon 32 ft^2 integrated collector-storage (ICS) solar hot water system, which will be coupled with a tankless water heater. A potential problem when using solar preheat with a tankless gas water heater is that the preheated water can be in a temperature range too low for use as hot water, but too high to be heated by the tankless water heater to a suitable temperature at its minimum firing rate. This issue is addressed in the design developed by BSC and illustrated in Figure 2. Mains water will first flow through the TCT ProgressiveTube® collector then into a small storage tank where the hot water will be topped off as needed by a pumped loop to the tankless water heater. Hot water is not provided directly by the tankless water heater. A larger than normal pump (5 gpm) is used to ensure that the water provided by the tankless heater is maintained near the 120ºF setpoint. A mixing valve will be installed on the outlet of the domestic water heater to prevent overheated water from going to fixtures when the solar collector heats the storage tank about 120ºF. This design should also avoid the possibility of hot water draws that are not met because the flow rate is too low for the tankless water heater.

We will also evaluate the performance of a next generation ventilation controller being developed by BSC and Lipidex Corporation. This controller will combine the operation of a separate exhaust ventilation fan with Central Fan Integrated Supply (CFIS) ventilation. The purpose of this coupling is to lower the ventilation costs and meet the recommendations of ASHRAE 62.2 by operating the exhaust ventilation fan when air handler operation is not called for.

Table 1: Molly test house characteristics. (Lot 8)

	Building America Version
Building envelope	
Ceiling	R-34 cathedralized attic
Walls	R-20 Icynene + 1" R-1.25 XPS
Foundation	Slab on grade exposed
Windows	Spectrally Selective LoE2 U=~0.32, SHGC=~0.33
Skylights	Spectrally Selective LoE2 U=~0.48, SHGC=~0.33
Infiltration	2.5 sq in leakage area per 100 sf envelope
Mechanical systems	
Heat	8.5 HSPF air source heat pump with AHU in conditioned space
Cooling	16 SEER air source heat pump with AHU in conditioned space
DHW	0.82 EF propane instantaneous water heater with solar preheat; 50 gallon 32 ft^2 integrated collector-storage (ICS) solar system; TCT ProgressiveTube® collector
Ducts	R-4.2 flex runouts in dropped ceiling or in floor joists
Leakage	none to outside (5% or less)
Ventilation	CFIS coupled with exhaust ventilation fan - Next generation controller, AirCycler at 33% duty cycle, ~50 cfm flow for both systems

Dehumidification	Aprilaire 1700 coupled with HVAC supply plenum
Return Pathways	jump ducts at bedrooms

Table 2: Annual site energy comparison predicted by BSC

	Annual Site Energy			
	BA Benchmark		**BA Prototype**	
End-Use	kWh	therms	kWh	therms
Space Heating	3666	0	1253	0
Space Cooling	6315	0	1810	0
DHW	0	164	212	38
Lighting	1830		608	
Appliances + Plug	7285	0	6981	0
OA Ventilation	35		17	
Total Usage	*19131*	*164*	*10881*	*38*
Site Generation	*0*	*0*	*0*	*0*
Net Energy Use	*19131*	*164*	*10881*	*38*

Table 3: Annual source energy comparison predicted by BSC

	Estimated Annual Source Energy		Source Energy Savings	
			Percent of End-Use	Percent of Total
	Benchmark	**Proto**	**Proto savings**	**Proto savings**
End-Use	10^6 BTU/yr	10^6 BTU/yr		
Space Heating	40	14	66%	12%
Space Cooling	68	20	71%	22%
DHW	17	6	63%	5%
Lighting	20	7	67%	6%
Appliances + Plug	79	75	4%	1%
OA Ventilation	0	0	51%	0%
Total Usage	*223*	*121*	***46%***	***46%***
Site Generation	*0*	*0*		*0%*
Net Energy Use	*223*	*121*	***46%***	***46%***

Research Questions:

1. What are the basic air leakage and flow characteristics of both test houses measured using a blower door, Duct Blaster®, and flow hood? (Short term testing)
2. What is the hourly air infiltration rate of Lot 9 during typical spring weather conditions, with and without the air handlers operating? With the outside air duct sealed and unsealed? (Short term testing)
3. Is the maximum room-to-room pressure differential below the design goal of 3 Pa? (Short term testing)

4. What is the projected fraction of total hot water load met by the solar hot water system? (Short-term testing and simulation) What is the actual fraction? (Long-term monitoring) What is the economic value of the solar hot water system in terms of annual energy cost savings? (Simulation)
5. What is the difference in annual energy use for the installed hot water system compared to a stand-alone tankless propane water heater using Benchmark operating conditions and TMY2 weather conditions for Savannah, GA? Compared to a condensing propane storage tank water heater? With and without the solar preheat system? Using a 1-gallon storage tank? Using a 2 gpm pump instead of 5 gpm for the tankless? (Short term testing and simulation)
6. Is there potential for unstable, fluctuating hot water supply temperatures when the hot water tank, the 5 gpm pump, and the mixing valve are removed from the system or de-activated? If so, across what combinations of flow rates, fixtures, and solar water heater delivery temperature does the problem occur (see test matrix in Table 4)? (Short-term testing) How large are the temperature fluctuations, and over what time period to they occur? How much damping of these fluctuations occurs at different distances from the water heater? (Short-term testing) How frequently are these conditions expected to occur assuming 2008 Benchmark event schedules and the expected solar hot water outlet temperature using TMY2 weather data? (Simulation) Does the addition of the tank and pump avoid or mitigate the problem? (Short-term testing) What alternative solutions are available (see Figure 9 of BSC Deliverable 15.C.3.c), and how does the annual energy use for those approaches compare to the tested system design? (Simulation)
7. At what flow rate are hot water draws unmet by the tankless system when the solar system, the hot water tank, the 6 gpm pump, and the mixing valve are removed from the system or de-activated? (Short-term testing) How frequently are such low flow rates expected to occur assuming 2008 Benchmark event schedules, and what would be the expected reduction in annual hot water volume? (Simulation) If it assumed that occupants will increase the flow rate as necessary to ensure hot water delivery, what is the increase in annual hot water volume and energy use caused by this effect? (Simulation) Does the addition of the tank and pump avoid or mitigate the problem? (Short-term testing)
8. What is the difference in air exchange and energy consumption with the Enhanced System Ventilation Controller in various settings (balanced vs. unbalanced and intermittent vs. continuous)? (Short-term testing and simulation) What is the predicted difference in annual energy use for the enhanced ventilation controller operating according to BSC recommendations compared to a continuous exhaust fan with the same nominal flow rate per ASHRAE Standard 62.2? Compared to a central-fan integrated supply ventilation system with the same average flow rate? (Simulation)
9. What are the air distribution characteristics of the CFIS, the stand-alone exhaust ventilation fan and the two combined using the intended control strategy during actual weather conditions and with bedroom doors closed? Are the decay curves sufficiently stable to accurately calculate reciprocal age-of-air? (Short-term testing)
10. How sensitive are the reciprocal age-of-air measurements to significantly different weather conditions at night and during the day? (Short-term testing)
11. What are the pros and cons of using the room mixing fans in the outside-air distribution test protocol? (a) How much does the age-of-air vary within a room during the decay test, when there is no mixing, with doors open and with doors closed? (b) How much do the room mixing fans change the amount of room-to-room variation in age-of-air? Does the shape of the decay curve vary within a room when there is no mixing? (Short-term testing)
12. What is the moisture removal rate of the dehumidifier compared to the heat pump over the course of a year? (Long term monitoring) What is the relative humidity in the house under various weather conditions? (Long-term monitoring)
13. What is the projected annual energy savings of the test house compared to the Benchmark, Regional Standard Practice, and Builder Standard Practice? (Simulation)

14. What is the energy use of the test house under occupied conditions? (Long term monitoring) How does the actual energy use compare to the simulations when actual weather and operating conditions are used? (Simulation)

Optional Questions if Time and Resources Permit:

15. How different are the reciprocal age-of-air measurements for nominally identical Molly floor plans on Lot 8 compared to Lot 9 under similar weather conditions?
16. What is relationship between outdoor weather conditions (temperature, wind speed, wind direction) and interzonal airflows for the test house? How large are the errors introduced into the reciprocal age-of-air calculations by the actual weather conditions during each test? (Short-term testing and simulation)
17. What is the predicted annual energy use of the dehumidifier? (Simulation) How frequently would the indoor relative humidity exceed 60% for more than 4 hours without the dehumidifier? (Simulation)

Table 4. Matrix for tankless hot water instability testing.

Test #	DHW Configuration	Fixture	Flow Rate	Temperature Entering Tankless
1	No solar, no tank	Kitchen Sink	~0.7 gpm	70ºF
2	No solar, no tank	Kitchen Sink	~0.7 gpm	80ºF
3	No solar, no tank	Kitchen Sink	~0.7 gpm	90ºF
4	No solar, no tank	Kitchen Sink	~0.7 gpm	100ºF
5	No solar, no tank	Kitchen Sink	~0.7 gpm	110ºF
6	No solar, no tank	Kitchen Sink	~0.7 gpm	120ºF
7	No solar, no tank	Bath 2 Shower	~0.7 gpm	70ºF
8	No solar, no tank	Bath 2 Shower	~0.7 gpm	80ºF
9	No solar, no tank	Bath 2 Shower	~0.7 gpm	90ºF
10	No solar, no tank	Bath 2 Shower	~0.7 gpm	100ºF
11	No solar, no tank	Bath 2 Shower	~0.7 gpm	110ºF
12	No solar, no tank	Bath 2 Shower	~0.7 gpm	120ºF
13	No solar, no tank	Bath 2 Shower	~2.5 gpm	70ºF
14	No solar, no tank	Bath 2 Shower	~2.5 gpm	80ºF
15	No solar, no tank	Bath 2 Shower	~2.5 gpm	90ºF
16	No solar, no tank	Bath 2 Shower	~2.5 gpm	100ºF
17	No solar, no tank	Bath 2 Shower	~2.5 gpm	110ºF
18	No solar, no tank	Bath 2 Shower	~2.5 gpm	120ºF
19	No solar, with tank	Kitchen Sink	~0.7 gpm	70ºF
20	No solar, with tank	Kitchen Sink	~0.7 gpm	80ºF
21	No solar, with tank	Kitchen Sink	~0.7 gpm	90ºF
22	No solar, with tank	Kitchen Sink	~0.7 gpm	100ºF
23	No solar, with tank	Kitchen Sink	~0.7 gpm	110ºF
24	No solar, with tank	Kitchen Sink	~0.7 gpm	120ºF

Table 5. Matrix for single and multi-zone tracer gas testing in Lot 9.

1. Single Mixed Zone Tracer Gas Ventilation Bump Testing (2 days) a. Deploy destratification and mixing fans with the aim to create a single well-mixed zone in the whole house. Position sampling points on each floor of the home as shown in Figures 4 and 5. Perform standard tracer gas tests with ventilation off, with exhaust ventilation on, and with the air handler operating (supply ventilation on). Check the data to see if a single mixed zone was achieved. If a single mixed zone is achievable, proceed with tracer gas decay testing. b. Evaluate whether a single mixed zone is achievable and the home is sufficiently tight to proceed with the age-of-air testing outlined below.
2. Air-of-air Tracer Gas Testing – all six sample points in one zone (2 days) a. Master bedroom zone – exhaust ventilation - bedroom doors open - mixing fan off b. Master bedroom zone – exhaust ventilation - bedroom doors open - mixing fan on c. Master bedroom zone – exhaust ventilation - bedroom doors closed - mixing fan off d. Master bedroom zone – exhaust ventilation - bedroom doors closed - mixing fan on (if necessary based on results of (b))* e. Repeat (a) with outside air damper open*
3. Air-of-air Tracer Gas Testing – Multi-zone (4 days) a. Exhaust ventilation - bedroom doors closed - mixing fans on (overnight) b. Repeat (a) during the day in different weather c. Exhaust ventilation - bedroom doors open - mixing fans on d. Exhaust ventilation - bedroom doors open - mixing fans off e. Exhaust ventilation - bedroom doors closed - mixing fans off (if necessary based results of (2a-d))* f. Supply ventilation @ 33% duty cycle - bedroom doors closed - mixing fans on (overnight)* g. Ventilation controls operating as recommended by BSC - bedroom doors closed - mixing fans on h. Repeat (a) in Lot 8 overnight in similar weather*

* Lower priority tests if time runs out

Preliminary Time Frame: The test house should be available for testing on March 13, 2008.

Day #1 (March 13)	Arrive at site and meet with Coastal Habitats representative for keys to house. Transport equipment from NREL to test house.
Days #1-10	Hot water system testing at Lot 8. Multi-zone tracer gas testing of Lot 9. Long-term monitoring installation at Lot 8.
Day #10 (March 22)	End test and transport equipment back to NREL.

Requested Action Items for Team and Builder:

1. Let NREL know with as much advance notice as possible when this house will be available for testing.
2. Have the house fully finished prior to testing if possible.
3. Install instrumentation and additional piping to DHW system in accordance with Figure 6.
4. Have any building commissioning activities deemed necessary by the team performed prior to testing (i.e., balance air distribution system).

5. Conduct full battery of performance testing including. This includes blower door, Duct Blaster®, HVAC static pressures, register flows, and ventilation measurements.
6. Inform NREL test engineer if builder or sales personnel require access to the house while testing is underway.

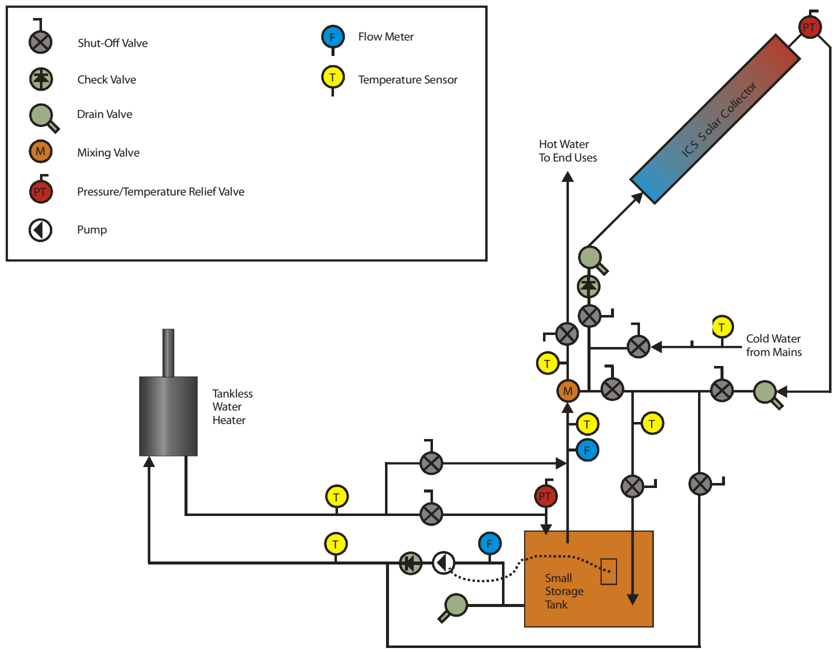

Figure 6. Locations of flow meters, temperature sensors, and bypass loops.

Directions

Jobsite: 625 Spanish Wells Road, Hilton Head, SC 29926. (See Figure 7)

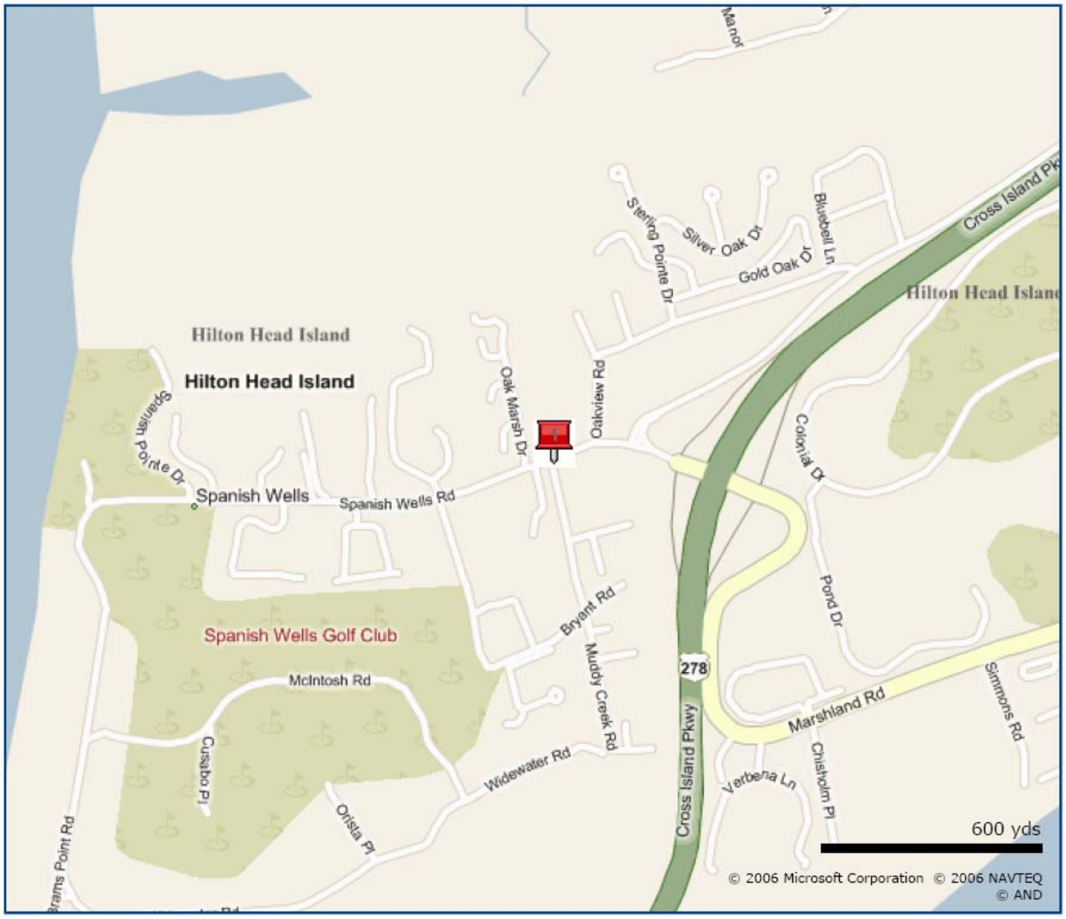

Figure 7: Bryant Park Cottages Site Location

Contacts:

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DEVELOPMENT WEB SITE HTTP://WWW.BRYANTPARKCOTTAGES.COM/

BUILDER WEB SITE HTTP://WWW.COASTALHABITATS.NET/

About this Report

This report was prepared with the cooperation of the U.S. Department of Energy's, Building America Program.

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