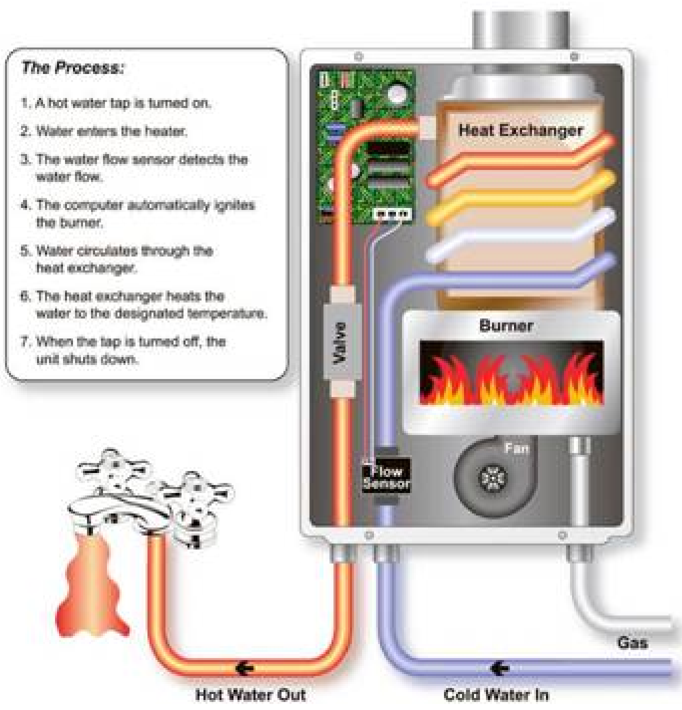
Final Report for Field Evaluation of PATH Technologies

March 2006

Evaluation of the Takagi Tankless Hot Water Heater for DHW & Space Heat



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Executive Summary

In 2004 Steven Winter Associates (SWA) performed a PATH field evaluation of a Takagi tankless water heater installed in a Gainesville, Florida model home in cooperation with the Florida Energy Extension Service (FEES). With a Home Energy Rating Score (HERS) of 90 and many "green" features, this prototype house could be characterized as a high performance custom home. In addition to providing domestic hot water on demand, the Takagi water heater, in combination with a Trevor Martin hydro-coil and Carrier air handler, was also used to meet the house's heating load. Hot water from the Takagi was supplied directly to the hydro-coil. For domestic hot water (DHW), a mixing valve was used to temper hot water from the Takagi to an acceptable supply temperature of 120 ^{o}F. By eliminating standby losses, this system results in a substantial improvement in water-heating efficiency compared to a conventional storage tank water heater. An improvement in water heating efficiency was especially important for this application since, as a result of the high performing thermal envelope house and the mild winter climate in Northern Florida, energy use due to domestic hot water accounts for a large fraction of total energy use. As part of the 2004 field evaluation, SWA investigated the performance of the Takagi system in DHW only, heating only and DHW/heating modes using a portable data logger system.

In 2005, SWA evaluated a new Takagi system that had been improved by the manufacturer based on lessons learned from the 200r evaluation. This 2005 evaluation was performed with ICI Homes in a Kissimee, Florida. ICI Homes may be characterized as a production builder and is implementing the Takagi on a community scale in a "Trafalgar Village" subdivision of homes. The new Takagi system includes an installation kit with all the necessary components and accessories for installing an instantaneous hot water heater for DHW and space heat. Simplifying the delivery of this technology in such a way was the next logical step to addressing the extra coordination between trades necessary with this integrated system. Shorter term performance testing of the system at Trafalgar indicated that:

- The DHW mixing valve effectively maintained constant DHW supply temperatures even with variable DHW loads.
- In heating mode, the system could deliver supply air temperatures of 100 ^{o}F, a condition judged by the manufacturers to be acceptable for Southern US markets.
- A decrease in heating duct supply air temperature was measured when there was also a simultaneous call for DHW. Installation of a higher head hydro-coil circulating pump minimized this issue.

From an installation standpoint, the least expensive system components were found to cause the most problems. In order to make the installation of this relatively new technology proceed as smoothly as possible, all necessary valves and plumbing accessories should be readily available to contractors and installed the same way on each job. The availability of parts to contractors has been addressed with Takagi's introduction of a standard installation kit. In a community scale application, assembling universal manifolds off-site that include all of the necessary valves and fittings should be considered by contractors to improve quality control and minimize system installation time.

Madera System Installation

In the Madera Model Center, the Takagi system was installed in a second floor mechanical closet and vented through the roof. The colored arrows in Figure 2, illustrate the flow of air through the forced air distribution system during heating mode. Cool return air is warmed as it passes through the hydro-coil and then is delivered throughout the house via the supply air plenum. The 150,000 Btu/hr output capacity of the Takagi was judged to be sufficient to meet the design space heating load for the house (30,000 Btu/hr) as well as hot water draws from two showers (2 x 50,000 Btu/hr).

Figure 1. Madera Model Center

Figure 2. Takagi System

Hot water that leaves the Takagi can either flow to open faucets for DHW or to the hydro-coil for space heating. The driving force for hot water flow to faucets is the city water pressure. The driving force for hot water flow through the hydro-coil is a circulating pump contained inside the hydro-coil enclosure. In heating mode, this pump continuously circulates water between the Takagi and the hydro-coil. The Takagi features a modulating firing rate that adjusts the heating capacity as necessary based on hot water loads for DHW and or space heat.

A plumbing schematic of the system is presented in Figure 3 on the following page.

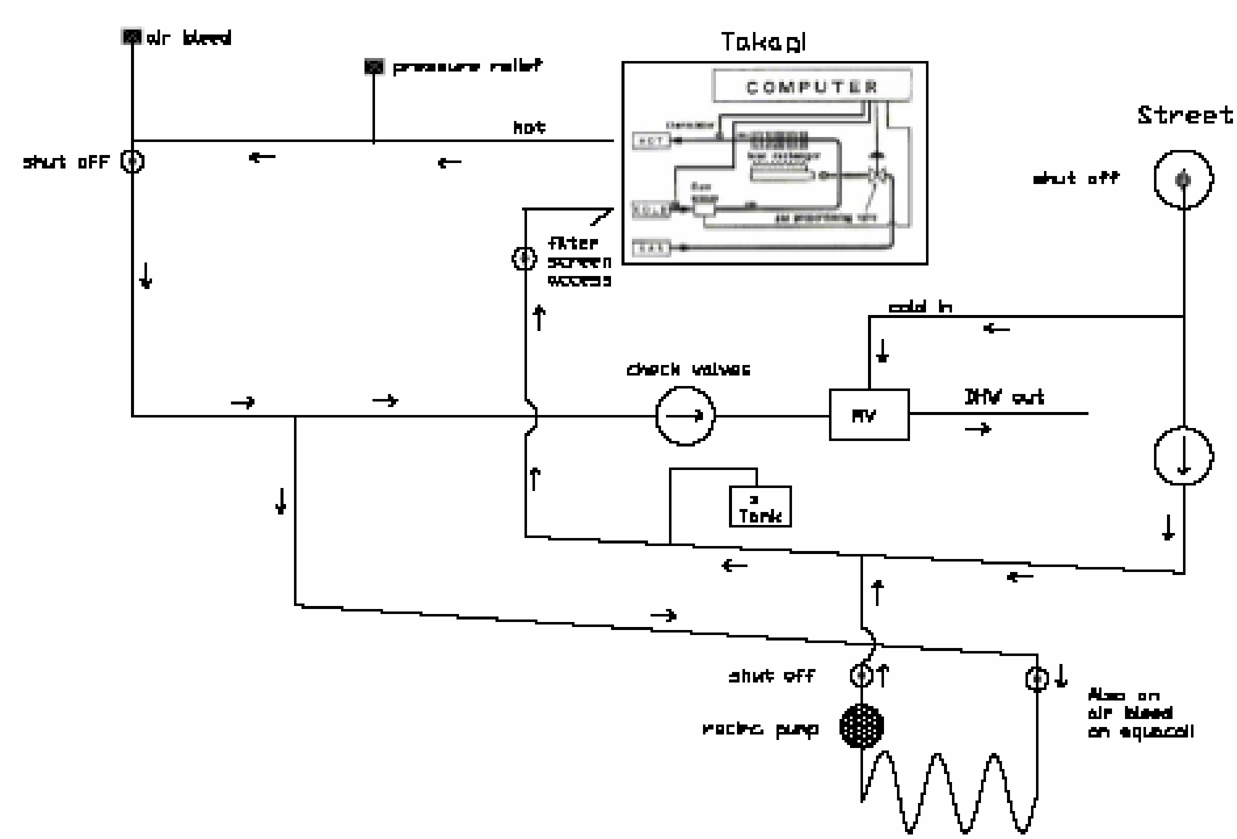


Figure 3. System Plumbing Schematic

It is important to note that in addition to the Takagi and hydro-coil, an assortment of valves, air bleeds and other plumbing accessories are necessary for the proper installation of the system. These extra plumbing accessories should be very familiar to any hydronic heating contractor. However, after observing the installation of the Takagi system at Madera, it soon became clear to SWA and to the Takagi representative that in the South, plumbing contractors are not necessarily plumbing / heating contractors. As a result, many of these components were installed incorrectly or not installed at all if the contractor's local supply house did not carry them. From a technical standpoint, using the Takagi for space heat makes a lot of sense in the South due to mild winter heat loads. However, the contractor infrastructure in the South may also result in a longer learning curve. Conventional heat pumps for space heating and gas or electric tank hot water heaters are certainly more forgiving technologies.

Madera System Performance Testing

Once the Takagi system had been installed to the manufacturer's satisfaction, SWA conducted short term performance testing in order to evaluate performance in three modes:

- DHW only mode
- Space heating mode
- DHW & space heating mode

Thermistor temperature sensors were temporarily installed in order to measure:

- Takagi inlet and outlet water

- Aquecoil inlet and outlet water
- Hot water supply immediately upstream of DHW mixing valve
- Cold water supply immediately upstream of mixing valve
- DHW supply immediately downstream of mixing valve
- Hot water supply temperature in the 2nd floor bathtub
- HVAC supply and return air plenum

Figure 4. Short Term Monitoring Sensors

Based on short term monitoring, the system was judged to perform acceptably in DHW only mode. The DHW mixing valve was capable of effectively tempering 140 F Takagi supply water down to 120 F over a wide range of DHW flow rates. Initially, some problems were observed when the system was tested in space heating mode. The first problem that was observed seems to be a design issue. At an outlet Takagi water temperature of 168 ^{o}F, the return temperature coming back from the hydro-coil is too high that the Takagi burner turns off. This is due to the hard wired control logic for the unit, which turns the burner off if return water temperature is above 133 ^{o}F. The burner will turn on again when the return water temperature drops to 123 ^{o}F. This operating scheme results in an unacceptable Takagi cycling frequency of ~ 1 minute. Similar results were noticed at the 158 ^{o}F set-point. When the Takagi outlet temperature was set to 140 ^{o}F, excessive cycling did not occur. In this case, there is a 20^{o}F temperature drop across the hydro-coil and the supply air temperature is approximately 104 ^{o}F. The visual display on the Takagi indicated that the hot water flow rate through the Takagi in heating only mode was between 2.6 GPM and 2.9 GPM. According to the performance curve for the hydro-coil circulating pump (GRUNDFOS Pumps Corporation UPS 15-42B7 circulating pump in high speed), a flow rate of 2.9 GPM corresponds with a head of 15 feet. The shut-off head (0 GPM) for this pump is 17 feet. Thus for this application, the circulating pump is just overcoming the flow resistance through the Takagi and hydro-coil in heating only mode.

In the case of simultaneous heating and DHW loads, DHW was consistently delivered at 120^{o}F, but the supply air temperature steadily dropped. Figure 5 presents supply and return air temperatures for the system, while Figure 6 presents hydro-coil water inlet and outlet temperatures. Before 1:30 PM the system was operated only in space heating mode. After 1:30 PM there were simultaneous calls for space heat and DHW. In the case of simultaneous demand for space heat and DHW, the path of least resistance for Takagi outlet water in the system is through the mixing valve and then through open faucets. When the first faucet was opened, the hydro-coil outlet temperature dropped from 120 ^oF to 113 ^oF while the hydro-coil inlet temperature remained at 140 ^oF. For the same airflow rate across the hydro-coil, a greater temperature difference between hydro-coil inlet and outlet temperatures indicates a lower flow rate of water through the coil. After the second hot water faucet was opened (bathroom tub), the hydro-coil inlet temperature dropped below the 140 ^oF Takagi outlet temperature. The decay of water temperature in the hydro-coil was unaffected by further increases in DHW draw. After this point, the hydro-coil temperature decay is solely dependent on time, the thermal mass of the hydro-coil, water in the hydro-coil, and the airflow across the hydro-coil.

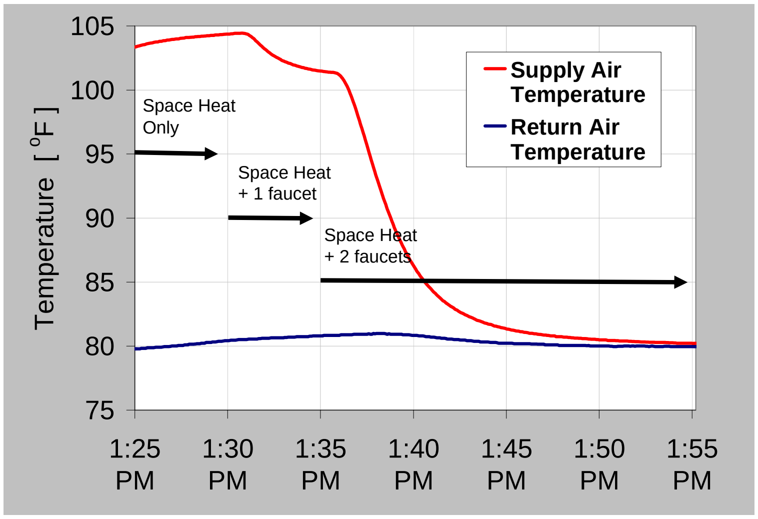


Figure 5. Supply and Return Air Temperature in Space Heat & DHW Mode

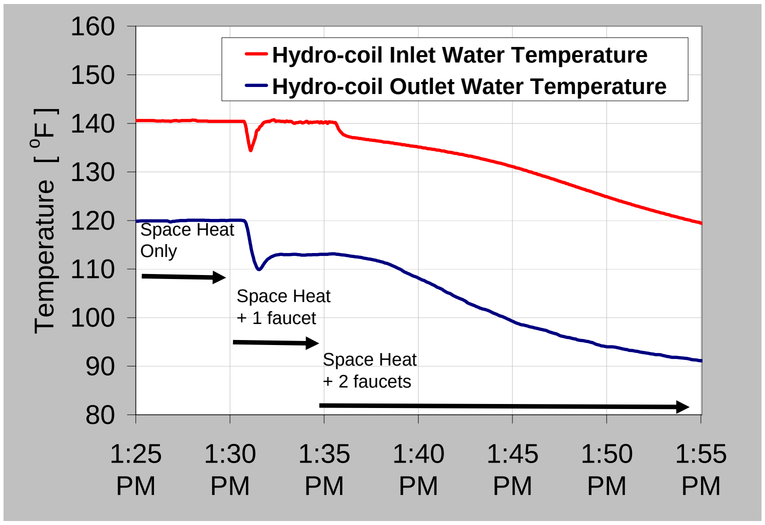


Figure 6. Supply Hydro-coil Inlet and Outlet Water Temperature in Space Heat & DHW Mode

As is evident in the plumbing schematic presented in Figure 3, the hydro-coil outlet meets cold street water at a "T" before returning to the Takagi inlet. While the cold street water is at street pressure, the hydro-coil outlet water is at street pressure minus the pressure drop through the Takagi (~20 psi) and minus the pressure drop through the hydro-coil (~15 psi). Thus in order to complete the loop between the hydro-coil and the Takagi, the circulating pump must fight against this ~35 psi pressure difference. Therefore the data indicate that in the system at Madera, if there is a simultaneous call for DHW at one fully open sink faucet and space heat, supply air temperature will decrease from an acceptable 104 ^oF to a still acceptable 99 ^oF and will remain stable at 99 ^oF. However, if there is a simultaneous call for DHW at a fully open bath tub and sink faucet and space heat, the supply air temperature will continue to drop (bottoming out only at return air temperature) as long as there is a DHW load. Thus while the firing rate of the Takagi (150,000 Btu/hr) was sufficient to meet simultaneous demands for space heat and hot water, the pumping rate of the hydro-coil pump was not sufficient to circulate hot water when there were open hot water faucets.

Trafalgar System Installation

In 2005, Steven Winter Associates conducted a field evaluation of the Takagi hydro-air system DHW and space heat in "Trafalgar Village," a subdivision of houses in Kissimmee, Florida built by ICI Homes. The ICI Homes evaluation represents a community scale implementation of the Takagi system by a production builder and was therefore a significantly different type of application than the single Takagi installation in the high performance Madera Model Center. In order to minimize mechanical room space and eliminate the need for a roof penetration, ICI choose to mount the Takagi on the outside of their houses. The air handler and hydro-coil were installed in an interior mechanical closet. As a direct result of experience with the 2004 Madera evaluation, the hydro-coils evaluated in the ICI subdivision incorporated a high head circulating pump. In addition, all of the installations with ICI homes were provided with an installation kit that included all of the necessary valves and fittings necessary to install the hydro-air system.

Despite the introduction of this installation kit, there were still many minor installation problems in the first batch of homes. SWA evaluated the installation of the first six systems during the initial March, 2005 site visit. Some of the systems were plumbed correctly; some of the systems were plumbed incorrectly. But the most striking observation was that all six of the systems evaluated were plumbed differently. Non-uniformity in system installation both increases the likelihood of installation mistakes and makes it more difficult to quickly inspect and troubleshoot systems. High turnover rates in plumbing and HVAC crews has meant that one-time training exercises are not enough to ensure that the systems are installed correctly. In addition, there were some problems associated with coordinating responsibilities of the plumbing and HVAC contractors.

The table below summarizes the problems encountered in the different houses. More detailed descriptions of the systems are presented in subsequent pages.

Summary Table of Installation Problems with First Six Trafalgar Houses

	Plumbing	HVAC
Model Center	-No water flow through hydro-coil when there is a call for heat -Extremely high resistance of DHW piping resulted in flow at some bathroom sink faucets to be too low to trigger the Takagi to turn on -Pressure relief valve installed in wrong location -Air bleed not installed in highest point of system	
Lot 1	-Missing a check valve	n/a*
Lot 3		-T-stat not correctly wired
Lot 5		-Pump relay not correctly wired
Lot 25	-Air bleed not installed in highest point of system	n/a*
Lot 26	-Air bleed not installed in highest point of system	n/a*

* System had not yet been started up, so HVAC performance could not be verified.

In the first batch of installations, the HVAC contractor received the Takagi, air handler, hydro-coil and installation kit and was responsible for handing off the plumbing side of the installation to the plumbing contractor. Based on experience with these first few installations, the contractor responsibilities were rearranged. The HVAC contractor received the air handler. The plumbing contractor received the Takagi, hydro-coil and the installation kit. The plumbing contractor was then responsible for mounting the Takagi and hydro-coil, making all plumbing connections and installing all of the necessary valves and fittings. These tasks were performed in one site visit. After the plumber had done his job, the HVAC contractor was then responsible for installing the air handler and making the electrical relay connection between the air handler and the hydro-coil circulating pump.

There is not necessarily a “right” way to coordinate the installation of this system. The above described division of contractor responsibilities appeared to work for ICI Homes. According to a Takagi representative, ICI’s plumbing contractor has recently moved to assembly a universal plumbing manifold that includes all of the necessary fittings for installation on the exterior of the building along with the Takagi. In addition to improving quality control, this strategy saves time and site and makes a lot of sense in a community scale application, where the same basic installation is repeated many times.

However the system is installed, if quality control is ignored, there are countless potential installation problems when contractors are not familiar with hydronic heat as is illustrated by the figures and notes in the following pages from the first six Trafalgar installations.

Trafalgar Village Model Center

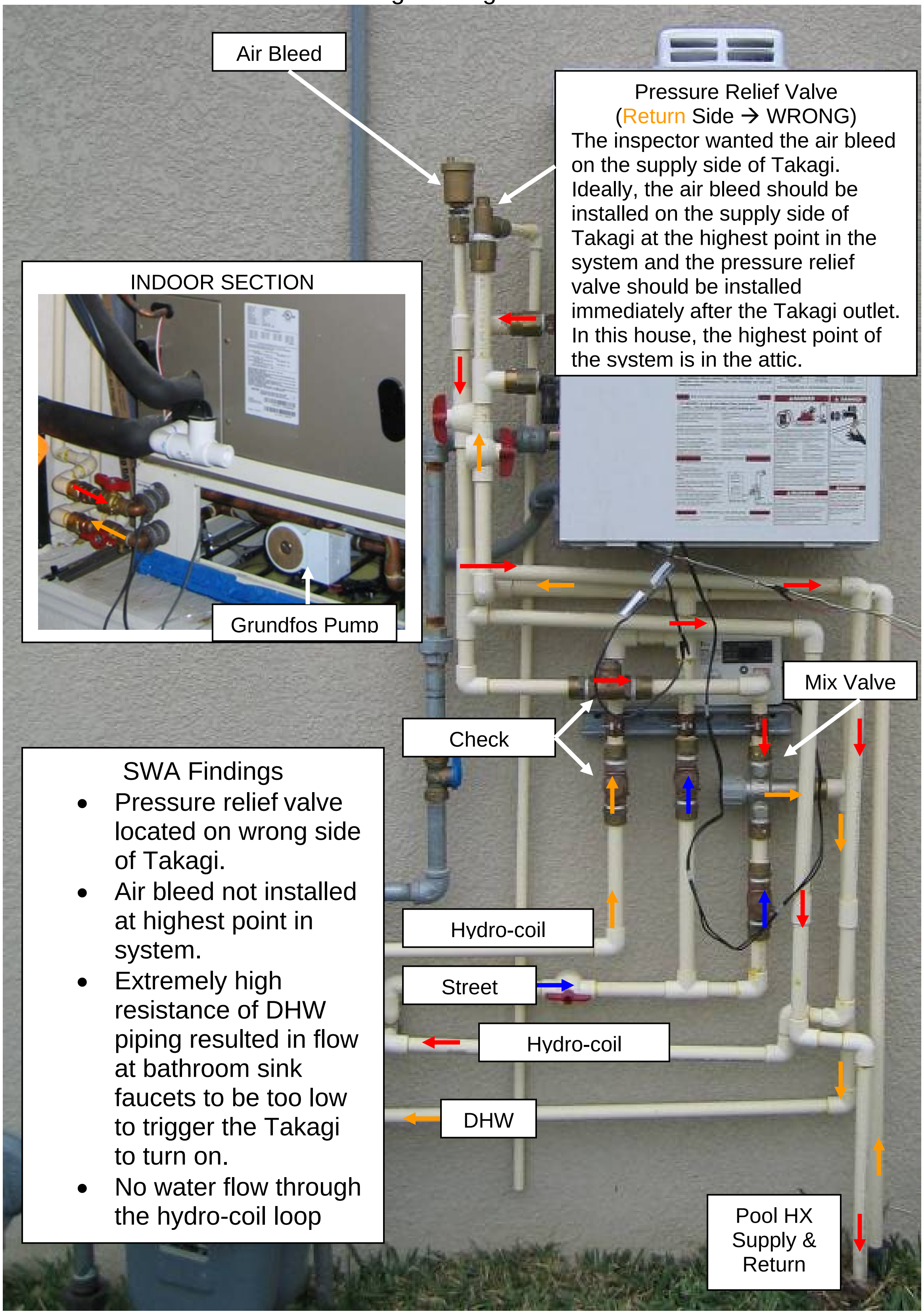
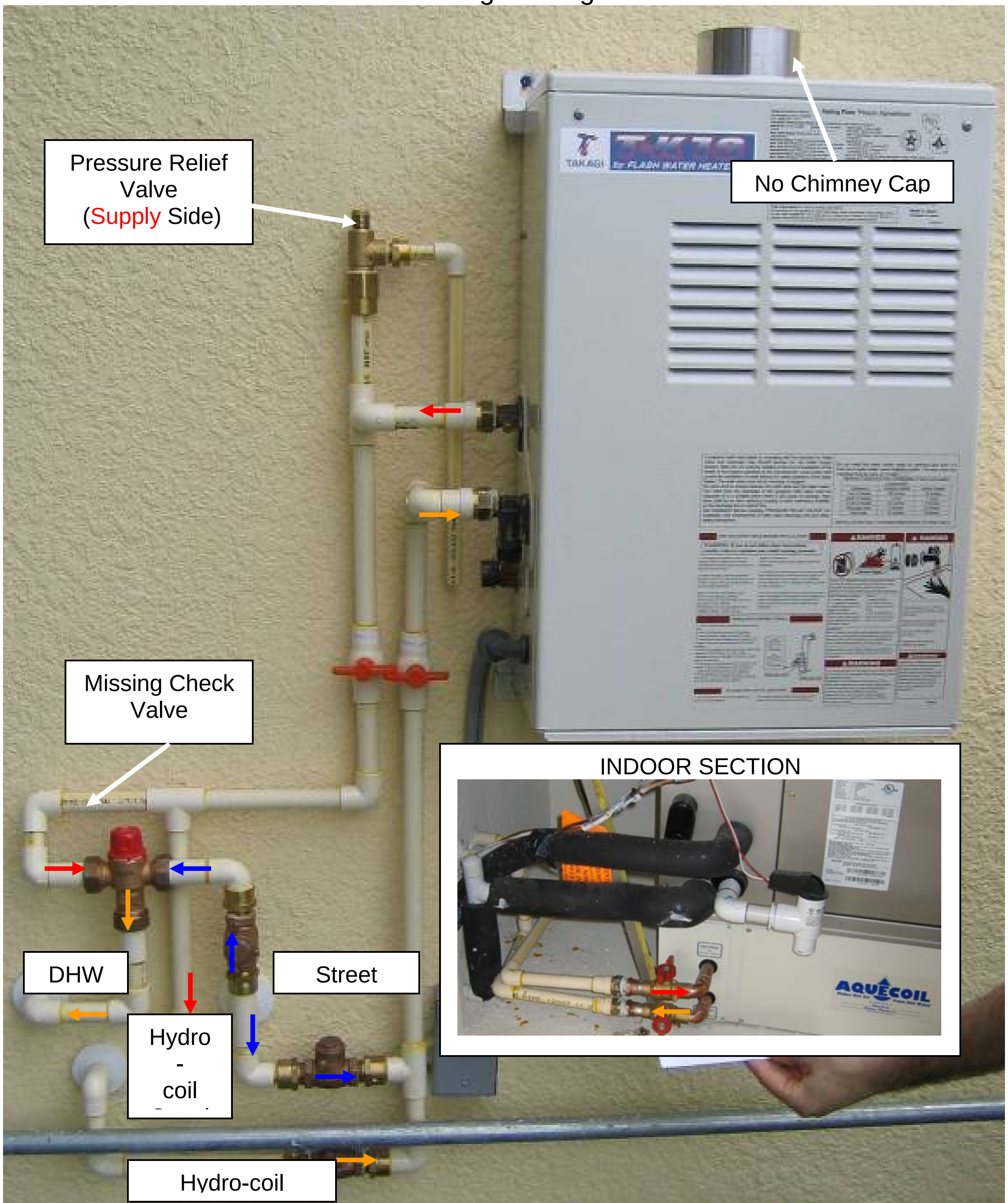


Figure 7. SWA Installation Observations – Model Center

Trafalgar Village Lot 1



SWA Findings

- **Missing check valve between Takagi outlet and mixing valve.**
- Chimney cap was left off allowing rain water to enter Takagi.
- Air handler was not fully wired yet so space heating operation could not be verified.

Figure 8. SWA Installation Observations – Lot 1

Trafalgar Village Lot 3

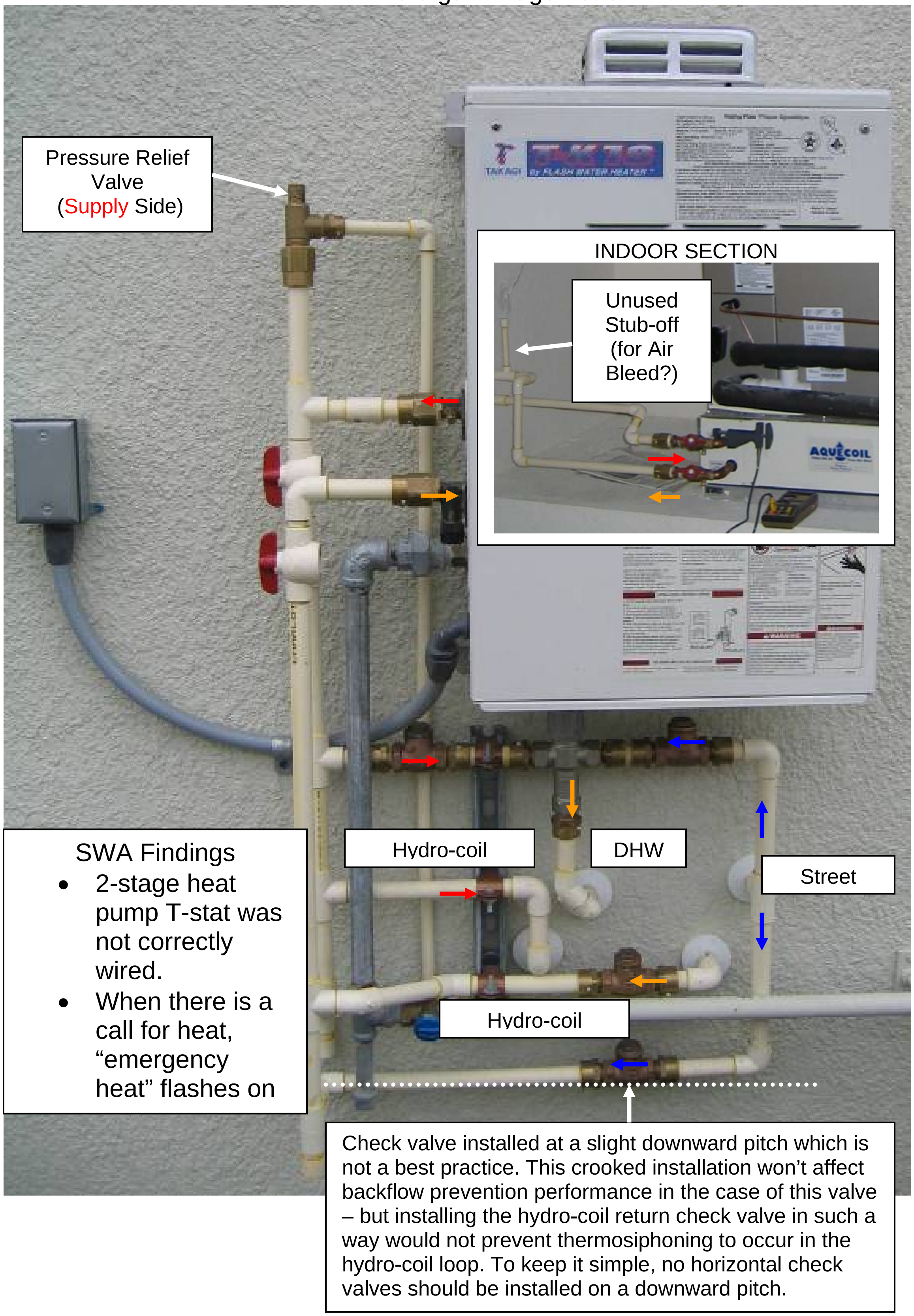
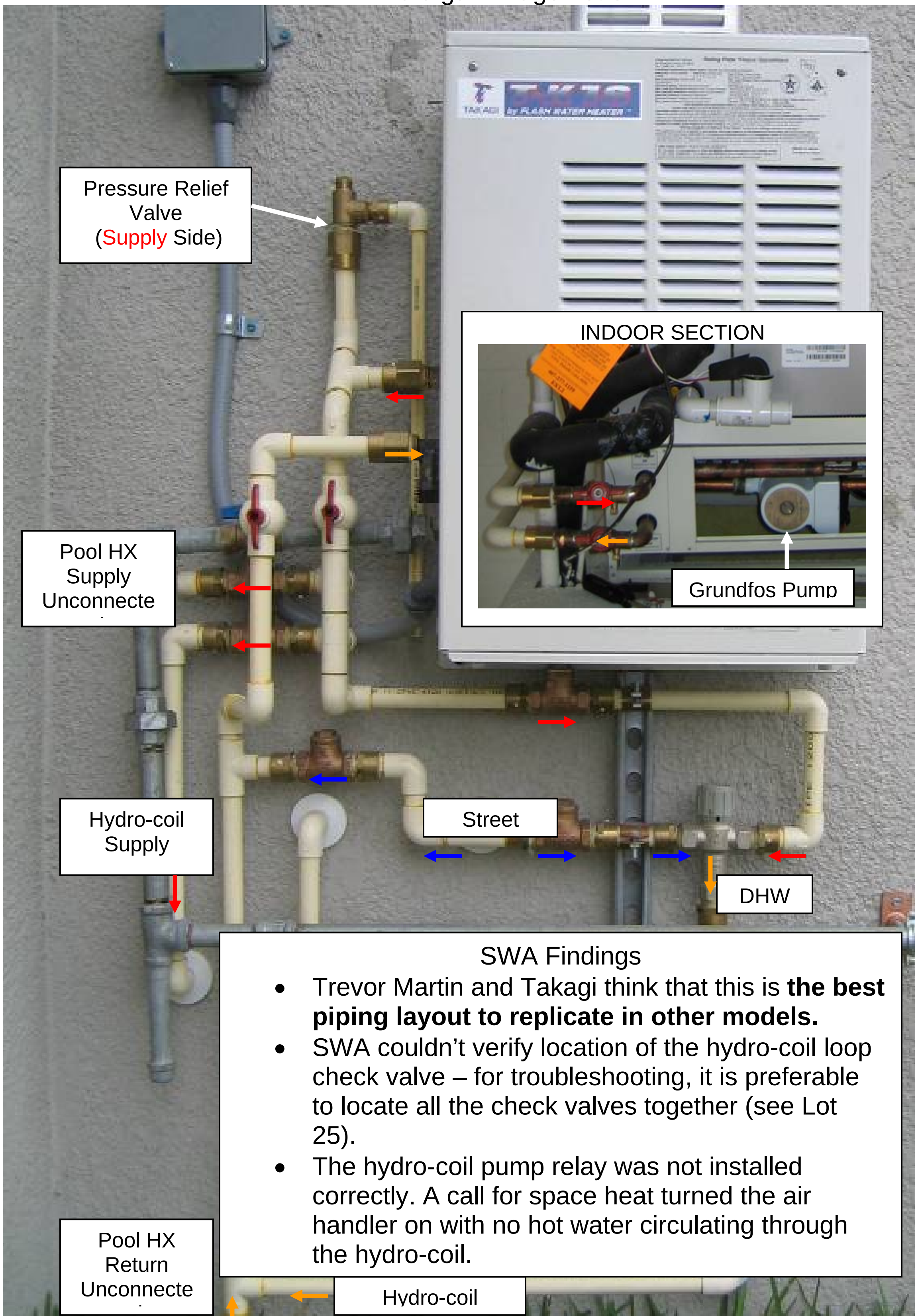


Figure 9. SWA Installation Observations – Lot 3

Trafalgar Village Lot 5



SWA Findings

- Trevor Martin and Takagi think that this is **the best piping layout to replicate in other models.**
- SWA couldn't verify location of the hydro-coil loop check valve – for troubleshooting, it is preferable to locate all the check valves together (see Lot 25).
- The hydro-coil pump relay was not installed correctly. A call for space heat turned the air handler on with no hot water circulating through the hydro-coil.

Figure 10. SWA Installation Observations – Lot 5

Trafalgar Village Lot 25

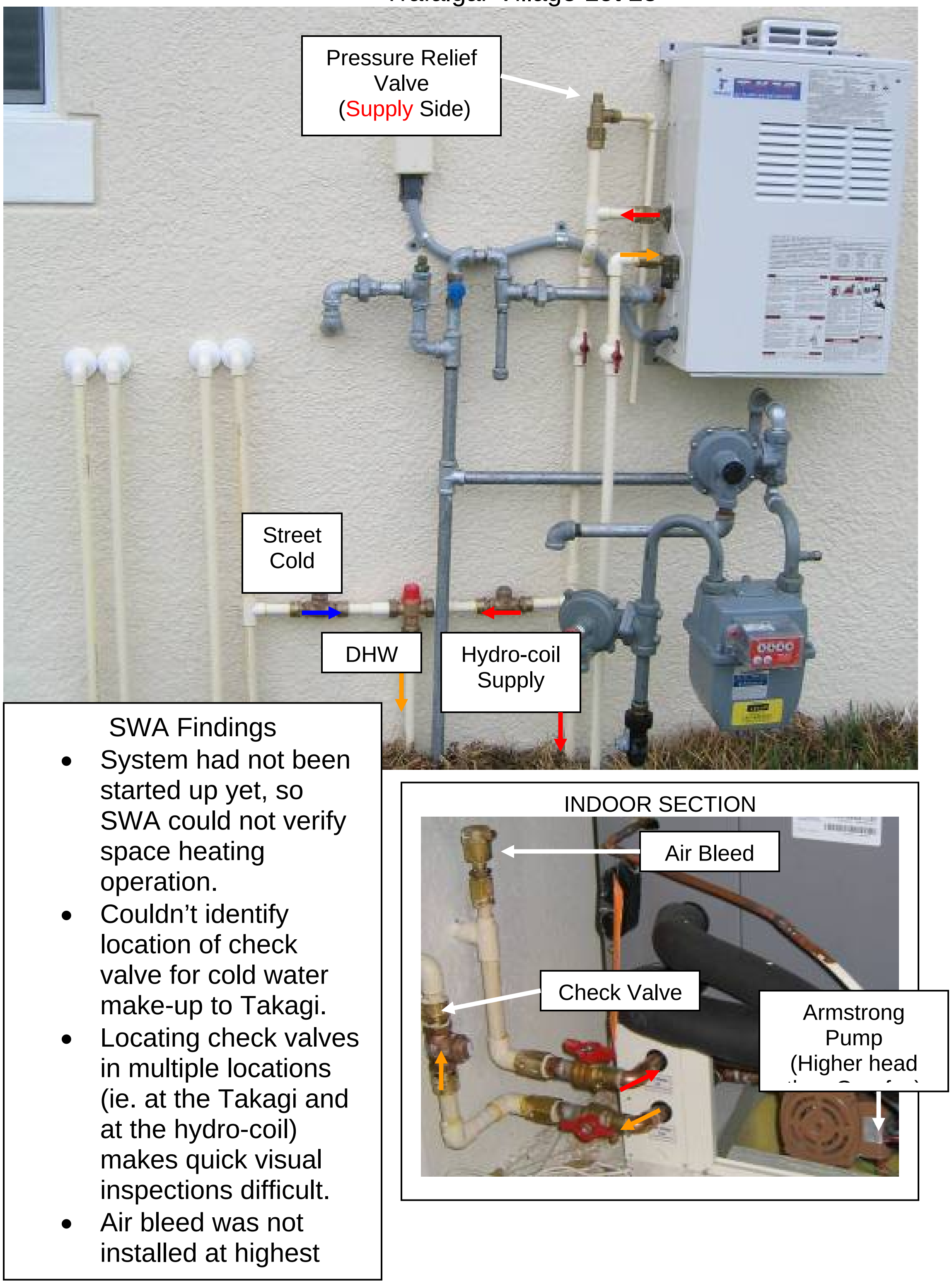
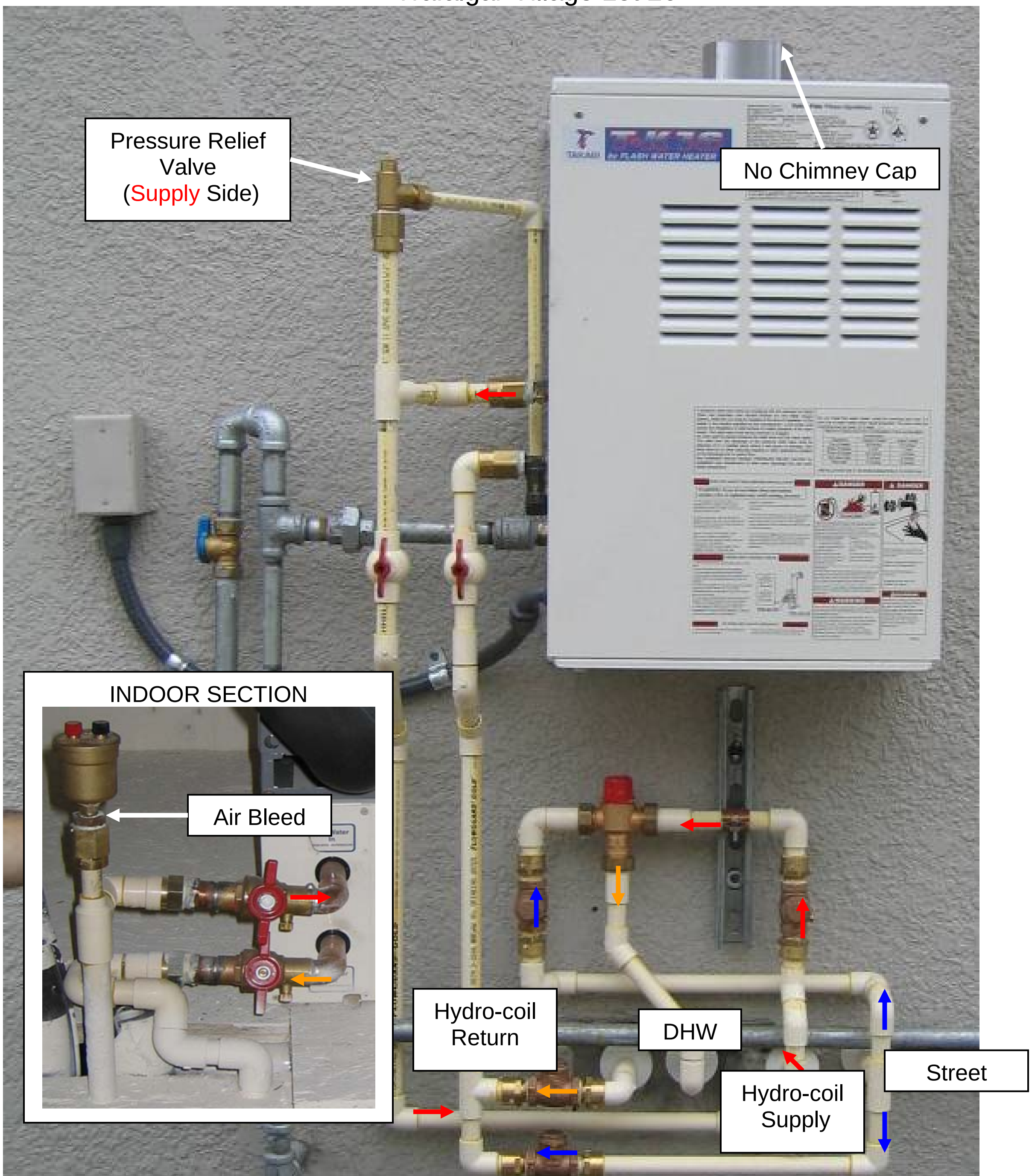


Figure 11. SWA Installation Observations – Lot 25

Trafalgar Village Lot 26



SWA Findings

- Air bleed not installed at highest point in system.
- Chimney cap was left off allowing rain water to enter Takagi.

Figure 12. SWA Installation Observations – Lot 26

Trafalgar Performance Testing Results

SWA returned to the Trafalgar site in July of 2005 in order to conduct short term performance testing of the Takagi system. Figure 13 below presents system temperatures in DHW only mode. From this figure, it is evident that both the outlet Takagi water temperature and the outlet mixing valve temperature is maintained at a constant temperature over a wide range of DHW water draws.

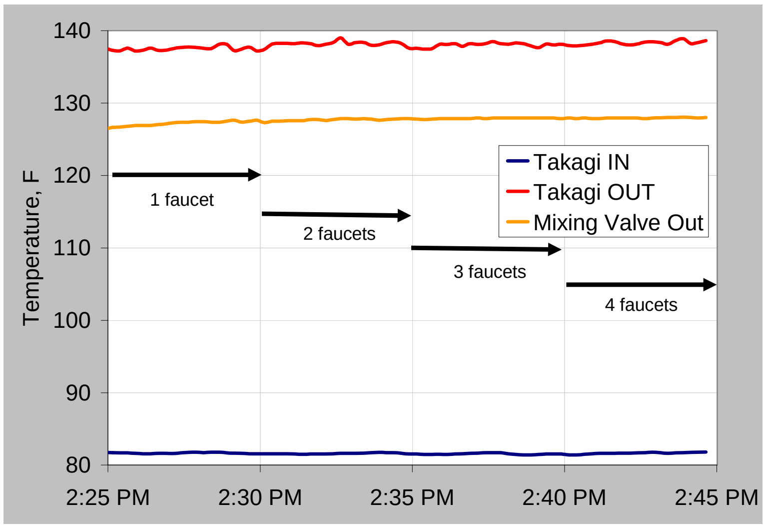


Figure 13. System Water Temperatures in DHW Mode

Figure 14 presents supply and return air temperatures for the system. Before 6:20 PM the system was in space heating mode only. After 6:20 PM there was a simultaneous demand for space heat and DHW. As in the Madera house, the supply air temperature drops after there is a demand for DHW. However compared to the Madera house, it is clear that the higher head hydro-coil circulating pump results in a much less significant drop in supply air temperature during simultaneous demands for space heat and DHW.

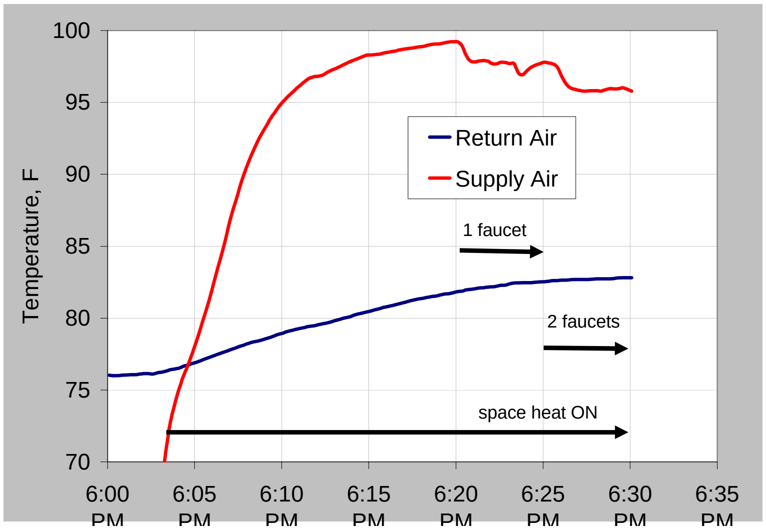


Figure 14. System Air Temperatures in Space Heating & DHW Mode

Summary and Conclusions

SWA evaluated the installation of the Takagi hydro-air system in a high performance model home and in a community scale production builder application. Shorter term performance testing of the system indicated that:

- The DHW mixing valve effectively maintained constant DHW supply temperatures even with variable DHW loads.
- In heating mode, the system could deliver supply air temperatures of 100 ^{o}F, a condition judged by the manufacturers to be acceptable for Southern US markets.
- During a simultaneous call for heat and DHW, the path of least resistance for hot water leaving the Takagi was found to be through open faucets and not through the hydro-coil. Thus the system configuration results in a built in priority control ensuring that supply DHW temperatures are not affected by a call for heat. At the same time, a decrease in heating supply air temperature was measured when there was also a call for DHW. Installation of a higher head hydro-coil circulating pump minimized this issue.

From an installation standpoint, the least expensive system plumbing components were found to cause the most problems. In order to make the installation of this relatively new technology proceed as smoothly as possible, all necessary valves and fittings should be readily available to contractors and installed the same way on each job. The availability of parts to contractors has been addressed with Takagi's introduction of a standard installation kit. In a community scale application, assembling universal manifolds off-site that include all of the necessary valves and fittings should be considered by contractors to improve quality control and minimize system installation time.