Why Pay for Two Condensing Systems When One Will Do?

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ABSTRACT

As construction practices improve and people become more conscious of energy usage, space conditioning and water heating bills have declined in many residential homes. Under these circumstances it becomes harder to justify the added cost of two high efficiency mechanical systems. One solution is to use a single water heater or boiler for both space conditioning and water heating. While combined systems have been available for years, the design and installation must be optimized to achieve the expected efficiency for the new generation of systems that use condensing equipment. Installed efficiencies of greater than 90% and energy savings of 20% have been shown with combination systems. However, testing has shown that poorly chosen set points or undersized hydronic air handlers will reduce the system efficiency from 90% to 77%.

Guidelines for the implementation, installation and operation of these systems were generated from laboratory tests, a 200 home implementation project, and detailed field monitoring in 20 homes. An additional hurdle to implementation is the lack of a common rating method and or performance metric. A simple strategy has been developed to ensure quality installation and high performance of these systems, allowing for improved implementation. Following these guidelines and strategy would allow many homeowners the benefits of high efficiency space conditioning and water heating systems using only one heating plant.

Introduction

Improvements in insulation techniques and envelope construction reduce space heating loads and air infiltration rates for both new and existing homes. However, these improvements can increase the combustion safety risks associated with naturally drafted combustion appliances (D. Bohac and Cheple 2002; D. L. Bohac 2002). Replacing natural draft appliances with direct or power vented combustion systems will eliminate these risks, but the cost of upgrading both the space heating and water heating system to direct or power vented systems can be significant. High efficiency combination (combi) systems that use a direct vent burner can eliminate the safety issues associated with natural draft (ND) appliances and reduce the energy consumption for meeting the combined space and water heating loads.

Background

The term combination system refers to any system where the space heating and domestic hot water are supplied by a single heating plant. This concept has been available for many years, though not widely used. These older combi systems using non-condensing water heaters (WHs) could provide energy savings when they replaced older furnaces with efficiency less than 80%. Today 90%+ furnaces have become more common in the past 20 years (Comstock 2013) and laboratory testing (Thomas 2011) show that combi systems must utilize condensing heating plants to achieve similar or improved energy performance as that for a 90% efficiency furnace.

Combination systems can be used in both forced air and hydronic heating applications. Central forced-air space heating systems account for 70% of residential single family systems in the United States (EIA 2009). Combination systems provide a solution for forced air systems that require a combustion safety improvement. Hydronic combination systems (space heating boilers with indirect tanks are the most common type) were not analyzed for this project.

To be an effective solution for a home with central forced air heat and a tight, well insulated building envelope, combination systems need to be power or direct-vented, high efficiency, and work within the existing forced air distribution system. **Figure 1** shows a diagram of the two basic systems installed for the implementation study. Both systems use a high efficiency WH and a hydronic air handler. System (a) uses a condensing storage water heater (StWH). These WHs range from 34 to 80 gallons of storage capacity and have burner inputs between 100,000 and 199,000 Btu/hr. System (b) uses a condensing tankless water heater (TWH) or a hybrid water heater (HWH), which is a combination of a smaller storage tank (0.5 to 6 gallons) and a large tankless type burner (75,000 to 199,000 Btu/hr). These systems require a small amount of additional plumbing because they have a single set of water connections, as shown in the figure. Both systems use hydronic air handling units (AHUs). These AHUs consist of a hydronic coil, a circulation pump, and a fan. The hydronic AHUs are plumbed directly to a dedicated supply and return water tap on the StWH system (**Figure 1**a) and as a loop off the primary inlet and outlet for the TWHs or HWHs (**Figure 1**b). A call for heat from the thermostat activates the circulation pump in the AHU. Hot water from the WH enters the hydronic coil as the AHU fan blows air over the coil. Heat is transferred from the water to the air and the cooler water is returned to the WH through the space heating loop. Currently, all systems have constant flow pumps and fans and use a constant supply water set-point temperature.

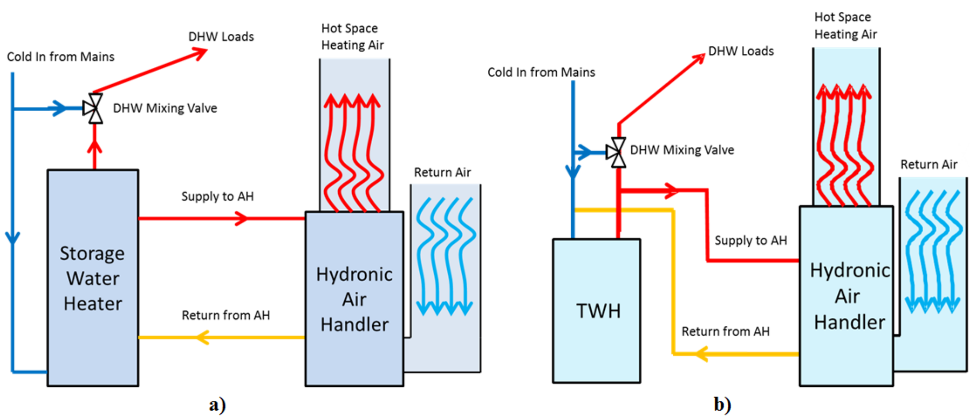

Figure 1. Forced air combination systems using high efficiency water heaters.

In 2010, a field implementation project was started to assess the feasibility of using combination systems as a high efficiency space and water heating solution for weatherized homes. At the time very few high efficiency combi systems had been installed and most contractors were unfamiliar with their design and operation. As a result, a combi system laboratory was set up to support the planned field installations. A series of tests were conducted on nine heating plants and fifteen hydronic air handling units. The testing determined the best equipment, designs, and operating conditions to balance occupant comfort, safety, reliability, and energy performance. The field implementation began in 2011. Over 200 combi systems were installed in forced air retrofit applications in Minnesota. Ten percent of the systems were installed with detailed monitoring equipment to verify the installed performance. Laboratory test results, installation lessons learned, and monitoring data were completed to create guideline and best practices for the installation of combination systems.

Installation Best Practices

This section provides an overview of the best practices and installation guidelines developed and used for the implementation study mentioned previously. The high efficiency combi system installation procedure included a home assessment, selection of equipment (both heating plant and hydronic air handler), equipment installation, performance optimization, and installation verification. Each of these steps is necessary to ensure the system provides acceptable comfort, facilitates occupant safety, and minimizes energy consumption.

Home Assessment

A quality space heating and DHW installation should include an assessment of the space heating and DHW loads for the current and future occupancy. For this study, the assessment included a space heating design load calculation, a characterization of the domestic hot water load, and a water quality assessment.

The building envelope characteristics of each home were used to calculate the space heating design load. This load is a measure of the amount of energy necessary to heat the building during the coldest temperatures that occur at the building site. Air Conditioning Contractors of America's Manual J (Rutkowski and Air Conditioning Contractors of America 2006) and ASHRAE (2013) methodology was used to calculate the residential space conditioning load. This calculation can be done manually, but was calculated for the implementation project using the NEAT (Gettings 2003) software program. The calculation of the design heating load is complex and difficult to do accurately. To estimate the design load the calculations must estimate the heat transfer into and around a residential building, including the heat conduction and air flow through detailed and complex building assemblies. Inconsistencies in construction, limited access, and incomplete information can make it difficult to collect data about the buildings characteristics. In addition, occupant behavior, such as adjusting the thermostat or changing occupancy, can significantly change the load of a building.

The home's utility billing history and corresponding outdoor temperatures were used to verify the space heating load estimates. The utility billing analysis was used to estimate the actual energy use and space heating design load at design conditions. The NEAT software loads (the design heating load calculated by NEAT) and utility billing analysis were compared for the 19 homes in the field implementation study. The field study collected actual energy used for space heating in each home and adjusted for the weather conditions to determine the design loads of each home. **Figure 2** shows the comparison at each site. The NEAT load was an average of 10,000 Btu/hr higher than the measured design heating loads. The differences in the two methods of calculation were likely due to the methodology of the Manual J calculation, which was designed for sizing heating and cooling equipment. For an installer, it is unacceptable to undersize equipment, because it will result in customer dissatisfaction and call backs. Oversizing may lead to degraded performance, but the building will still be heated and/or cooled to acceptable levels. Therefore, the calculation methods and data entered into the Manual J calculation are typically more conservative, leading to over prediction of the load. In addition, Manual J does not account for specific occupant behavior or internal gains in great detail. Occupants, lights, and appliances generate heat and these internal gains reduce the home space heating load and defer greatly depending on many home and occupant specific variables. The monitored data includes these internal gains and no conservative estimates are added, leading to the lower design loads.

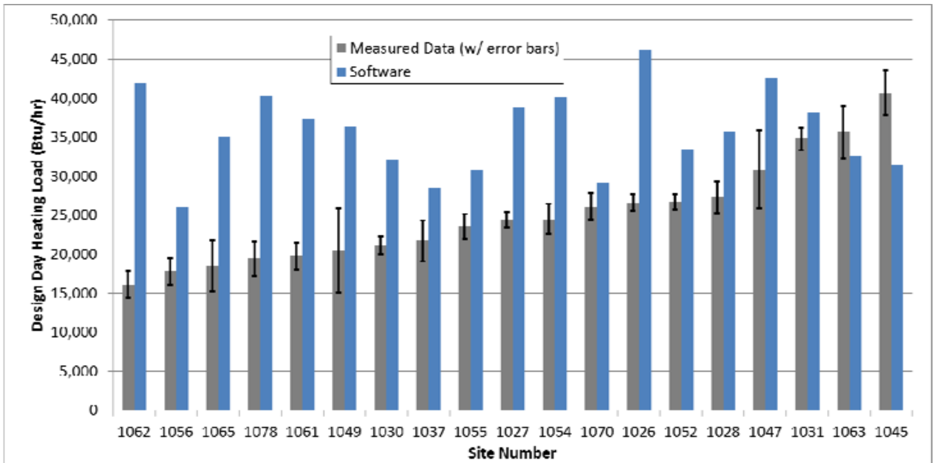

Figure 2. A comparison of the design load calculations from the measured data and a load calculation software.

The combi system design also considered the expected DHW load. Hot water usage is widely variable, both from home to home and hour to hour within a single residence (Thomas 2008; Schoenbauer 2012), which made estimating the load difficult. Also, water heating equipment is traditionally sized by the expected daily usage, but due to the combined demands on the combi system heating plants, short term hot water peaks were more important for sizing than the daily DHW load. The shower events were typically the largest loads and had the greatest impact on occupant satisfaction with DHW delivery (Schoenbauer 2012). The actual shower hot water flow rates would provide more reliable sizing estimates, but person-to-person variances of flow, cold water temperature into the home, and shower temperature selection necessitated the use of typical values. For the field portion of this project, low flow shower heads were recommended to replace shower heads with flow rates greater than 2.0 gpm to avoid excessive shower flow rates that could cause occupant dissatisfaction. For most homes, the rate of heat required for the peak DHW load was much greater than the space heating design load. For example, in Minneapolis the average space load was 35,000 Btu/hr at design conditions (-18 °F outdoor air temperature). The typical inlet water condition at design was around 38 °F, which corresponds to a load of 85,000 Btu/hr DHW for a two gallon per minute single shower.

The DHW load was best estimated by counting the number of showers and the number of occupants. The number of showers defined the maximum short term capacity of the home and the number of occupants estimated daily usage (Mayer and Deoreo 1999; Lutz 2012).

The water quality of the home was also assessed prior to installation. WH warranties often require specific water quality levels. A water softener was used in areas with hard water to improve water quality, but these systems required maintenance to achieve the necessary water quality. A community, city, or water utility report typically provided enough information to ensure the warranty was met or that a softener was needed.

Equipment

The two major components of a combi system are the heating plant and the hydronic air handler. Each piece of equipment has several types available with different benefits and drawbacks. For this study, the equipment was sized and designed together to ensure acceptable performance.

Three primary types of heating plants were used for the high efficiency forced air combi systems: condensing StWHs, condensing TWHs, and condensing HWHs. The condensing StWHs had a large volume of stored hot water that was controlled by the temperature dead band, typically set between 3 and 7 °F. The dead band determined the allowable reduction in water temperature before the burner fired to reheat the tank. StWHs achieve condensing by increasing the surface of the venting inside the unit to transfer more heat from the air being exhausted into the stored water. The condensing TWHs had no storage capacity and worked on demand by using flow sensors to measure water flow and modulate the rate of fire to supply just the amount of heat required for the current hot water demand. TWHs use several different techniques to increase the burner efficiency by extracting more heat out of the exhaust air. The most common is to use two heat exchangers, which increases the total surface air for heat exchange and the effectiveness of the heat exchange. The condensing HWHs were a hybrid of a StWH and a TWH. They use small storage tanks (less than 5 gallons) and large burners. The intent of this type of WH is to have a small volume of hot water for use at all times, but keep the stand-by loses low. Two basic approaches are used for hybrid units. Some units are essentially TWHs with temperature controlled buffer tanks that are typically less than 1 gallon, while the larger storage capacity HWHs use the water tank as the unit's heat exchanger.

Combi boilers were also tested in the laboratory and used in a limited number of installations. These combination boilers are primarily designed for hydronic heating applications. They were tested in forced air systems, but were more difficult to install and optimize than the WHs described previously. These difficulties led them to be excluded from the full program.

There are several areas that differentiated the three heating plant choices. **Table 1** summarizes the benefits and drawbacks found with each heating plant type. The storage for the StWHs and HWHs allowed those WHs to immediately generate hot water for DHW or space heating uses. The TWHs did not store hot water so there was a time delay between the start of hot water use and hot water production, while the burner and heat exchanger came up to temperature. TWHs and HWHs can be wall mounted and have a smaller footprint than conventional WHs and condensing StWHs. Therefore, a combination system using a TWH or HWH reduces the mechanical foot print in some installations. This may be ideal for situations with limited space.

All WHs are impacted by hard water. In the condensing StWHs, the stainless steel tank StWH helped prevent damage from hard water. TWHs require heat exchangers with large surface areas to heat water on demand. Surface area can be increased by reducing the size of the water pipes and increasing the number of paths in the heat exchanger. However, these smaller passage ways are more susceptible to damage and blockage from scaling buildup. Another temperature control method for TWHs is to overheat the water in the heat exchanger and mix in cold water to meet the desired set point. These smaller passage ways and increased temperatures increased the risk of hard water fouling for TWHs. Because of this, TWH manufacturers require either good water quality in a home as part of the warranty or annual flushing and maintenance of the WH.

The relative simplicity of a StWH's design and the ease in which it is installed were benefits for long term maintenance and durability and also reduced the installation and optimization time. StWHs have simple designs and include four water taps, making the installation simple and straight forward. The complex design of many TWHs and HWHs make maintenance difficult; specialized training is often necessary to trouble shoot and repair these units. As these units become more common these drawbacks may diminish, but need to be considered at this time.

Table 1. Heating plant drawbacks and benefits by model type

	Condensing Storage WH	Condensing Tankless WH	Condensing Hybrid WH
Hot water delay time	Benefit	Drawback	Benefit
Unit size (footprint)	Drawback	Benefit	Benefit
Operation with hard water	Benefit	Drawback	Drawback
Simplicity of design	Benefit	Drawback	Drawback
Ease of installation	Benefit	Drawback	Drawback

Codes handle sizing for WHs and space heating systems differently and manufacturers often use their own proprietary software. At the time of the implementation project, neither codes nor manufacturers adequately addressed combi appliance sizing. Contractors traditionally sized systems using their own rules of thumb or guidance from local manufacturer representatives. Project staff developed sizing guidelines for expected shower load and estimated space heating load. The natural gas burner input rate, storage capacity, and heating plant controls (DHW priority) were considered for sizing.

The heating plants were sized by the short term peak loads. The space heating and DHW loads (e.g. number of simultaneous showers) were compared to the burner firing rate and the storage capacity of each heating plant. **Figure 3** shows sizing guidelines used for high efficiency combi systems by heating plant type. The guidelines were developed based on equipment specifications and laboratory testing. Each line in the figure represents a single heating plant model. For a home with an expected DHW load of one simultaneous shower **Figure 3** shows the relationship between the homes design heating load (x-axis) and the minimum burner input rate (y-axis) to meet the load. The guidelines were modified to meet the shower load of each home. A separate relationship was used for systems with DHW priority controls, which prioritize DHW use so that space heating could not be active while a DHW event was active. This control methodology prevents a simultaneous DHW and space heating load. As a result, the required burner input rate is only a function of the DHW load (see **Figure 3** for the TWH). DHW priority was deemed unnecessary to meet the load, but could improve temperature consistency that was noticed with simultaneous events with some TWH systems.

A conservative thermal efficiency of 85% was used to determine the output capacity of the heating plant burner. The output capacity of the hot water storage volume was computed from the rate of energy output for a 30°F temperature drop in the storage volume for a typical shower draw of 20 minutes. It was also assumed that the inlet water temperature was 60°F and the mixed shower temperature was 105°F. The storage capacity calculations were verified with measured data in the laboratory for simulated shower events.

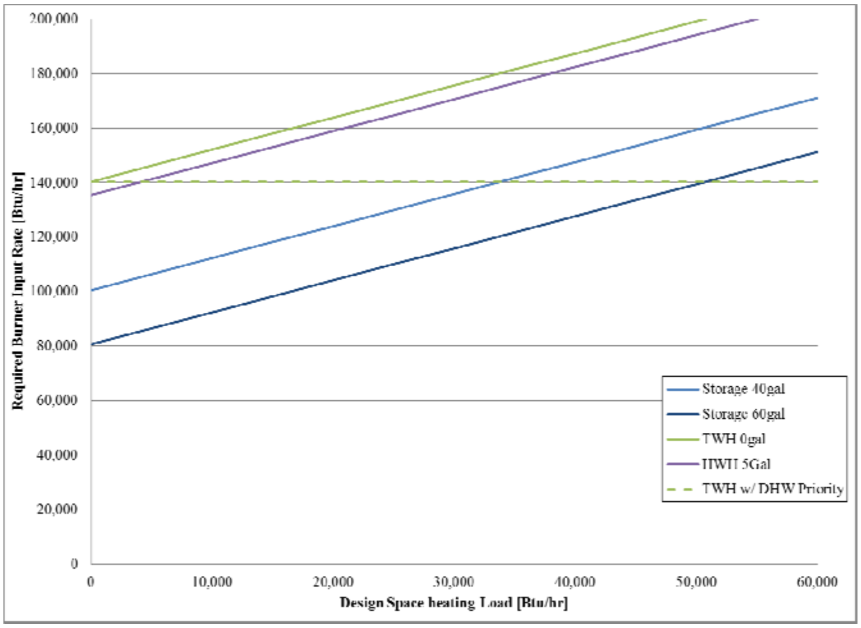

Figure 3. Heating plant sizing guidelines for one shower.

Basic hydronic air handlers included a fan, a hydronic coil, and a circulator pump. Some AHUs contained additional features, such as energy recovery ventilators and packaged air conditioning coils. These extra features could provide additional integration benefits to the home, but were not assessed by this project. The AHU selection was based on the required space heating load of the home. The capacity range of a properly installed AHU for a high efficiency combi system was found to be at least 1.5 times greater than the home space heating demand plus a safety factor. Oversizing of the AHU allows for flexibility in delivery capacity and proper system optimization for high efficiency operation (see *Optimization* section).

Installation

Upgrading to a high efficiency WH requires some changes in the installation, whether the system is being used as a combi system or as a WH alone. These changes may include modification to the gas supply lines, installation of additional electrical service, addition of a condensate line or pump, and installation of a new intake air and combustion vent exhaust system. These changes are described in the system installation manuals and these procedures should be followed.

Both a DHW mixing valve and AHU circulation flow control were added to all combi systems. The DHW mixing valve was added near the outlet of the WH. This mixing valve allowed the hot water from the WH to be tempered with cold water and allowed greater flexibility for space heating optimization. WH supply water temperatures could be increased without the risk of scalding users. A balancing valve was installed on the return water pipe between the AHU and the WH. This valve was used to manually adjust the water flow rate during optimization. Ideally this valve would be replaced by a modulating AHU circulation pump, but these pumps were not available for these units.

Optimization

After the combi system was selected, properly sized, and installed, it was optimized to maximize efficiency and occupant satisfaction. Extensive laboratory testing was conducted to determine the optimized operating performance of combi systems (Schoenbauer et al. 2012). The WHs are set up for optimal DHW operation by the manufacturer. For combi operation the space heating optimization was prioritized over DHW optimization. Systems were optimized by adjusting the WH set-point temperature, the water circulation rate through the AHU, and the airflow rate of the AHU. The water temperature returning from the AHU to the WH is the most important parameter in maximizing space heating efficiency. Figure 4 shows the relationship between return water temperature and system efficiency. Each curve represents performance for a specific heating plant under a single set of operating conditions. The curves should not be used to determine the exact performance of all systems, but are presented here to show the general trend in efficiency with return water temperature. Lower return water temperatures improved the space heating efficiency of the systems. The efficiency of most systems started to reach diminishing improvements of efficiency for return temperatures below 100 °F to 105 °F, with large reductions in efficiency for some units resulting at water temperatures greater than 120 °F. At these non-optimized conditions the systems operated just around 80% efficiency, which was the rated efficiency of the furnaces they were replacing. A maximum return water temperature of 105°F was selected to provide a good tradeoff between higher efficiency, reasonable hydronic air handler coil size, and cost.

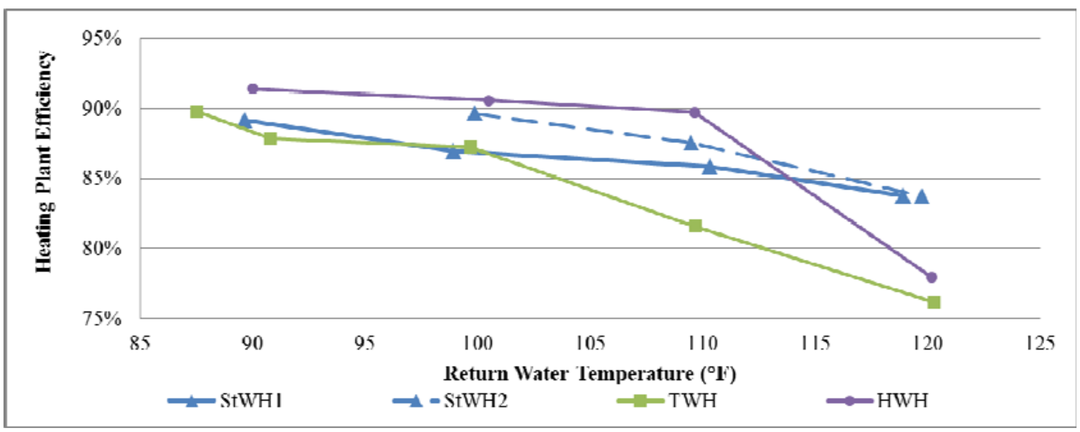

Figure 4. The impact of return water temperature on combi system efficiency under space heating operation (1000 CFM and 4 GPM).

Optimizing heating plant operation required an AHU coil large enough to transfer sufficient heat to meet the design load and reduce the water temperature enough to achieve high efficiency. It was important to deliver warm enough supply air to provide comfort in the living space. In retrofit applications where duct design was difficult to alter, reducing the temperature of air that was blown onto occupants increased the chance of dissatisfaction by "cold blow". In retrofit applications 115 °F was an acceptable minimum supply air temperature (SAT). This temperature was comparable to the delivered SAT of condensing furnaces (Brand and Rose 2012) and air source heat pumps (Johnson 2013), which are commonly installed in retrofit applications. If the air distribution system was installed, or could be modified to discharge air from the diffusers that would not blow directly on people, then air temperatures could be reduced to 100 °F or lower. Discomfort from cold blow only occurs when the movement of air is felt on skin. A lower supply air temperature would allow for lower return water temperature and improved efficiency.

The space heating optimization process used a return water temperature no greater than 105 °F, while maintaining an SAT of 115 °F. In order to meet acceptable operating parameters (especially the 115°F SAT), combi system heating capacities often exceeded the required capacity to meet the home load.

The optimization process required the use of a surface mount thermocouple, or similar device, for measuring the temperature of the water pipes and a second temperature measurement device to measure the supply air temperature. The process was simplified through the use of an air flow measurement device and would have been further simplified by a water flow measurement, but neither was required.

An iterative process was used to complete the optimization. The initial air flow was calculated from the target delivered air temperature and the design heating load, using equation (1), where $T_{supply\ air}$ is the target air temperature of 115 °F.

$$CFM= (Design\ Heat\ Load+Safety\ Factor\ (Btu/hr))/(1.08*(T_{supply\ air} - 68)) \qquad (1)$$

Once the initial operating CFM was calculated the iterative process shown in **Figure 5** determined the optimized operating conditions. If the optimization called for changing the airflow rate, equation 1 was solved for the supply air temperature (equation 2) and used to determine the new target supply air temperature to ensure the design load was met.

$$T_{supply\ air} = ((Design\ Heat\ Load+Safety\ Factor\ (Btu/hr))/1.08*(CFM)) +68 \qquad (2)$$

The new target air temperature would replace the old target of 115 °F and the optimization continued until three conditions were met:

- The AHU output was equal to or greater than the design heating load plus a safety factor.
- The delivered air temperature at the outlet of the AHU was greater than 115 °F.
- The water temperature returning from the AHU was less than or equal to 105 °F.

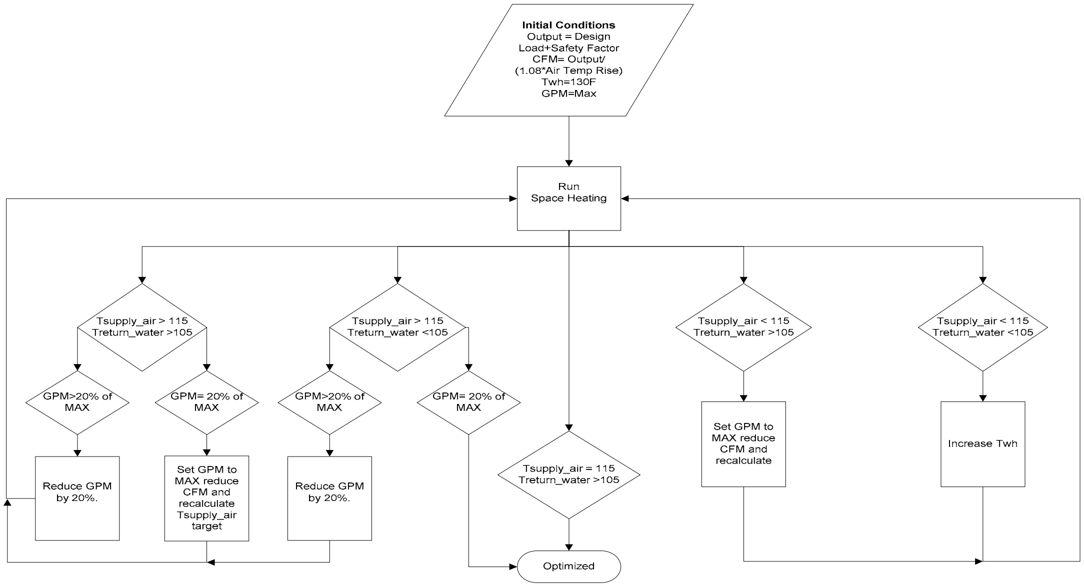

Figure 5. AHU optimization process.

Verification

High efficiency combination systems are an emerging technology and many installers were unfamiliar with the installation and optimization of the systems. Verification of proper installation was necessary to achieve the desired results of a safe, comfortable, and efficient space and water heating system. After training contractors, installing systems, and verifying installations, the following process was developed to verify future installations. **Table 2** outlines the three step process that could be used to verify performance of combi systems. Each step of verification increases the expected performance from the system. The first step would be to ensure that the correct equipment is being installed. All combi systems should use approved air handlers and heating plants. Equipment can be approved by an equipment list or a set of specifications, such as:

1. All equipment must be approved for use in combined space and water heating systems.
2. All heating plants should have an efficiency rating (AFUE, EF, or thermal efficiency) greater than 90%.
3. All air handlers should have a rated capacity of at least 175% of the design heating load of the home.

Because the first step only ensures the correct equipment is used and does not address installation and optimization, this step is not sufficient to assure optimal space conditioning performance. The second step of the verification process is to have contractors complete combi system installation training and require that all installations be performed by trained contractors. The training should cover the installation, optimization, and operation of high efficiency combined systems. Using the second step will result in at least 90% of optimal efficiency. To be sure of an optimal installation, the performance should be measured and verified, either through a documented measurement by the contractor or independent quality control personnel. This is the final step and includes a measurement of the space heating return water temperature or the combustion efficiency during a normal space heating event. This measurement will verify that a quality installation was completed and the optimal performance of the system should be expected.

Table 2. Steps of a quality install verification process

Verification measures		Expected Performance	
		Space Heat	DHW
1	Combi system installed using approved equipment list	80% of Optimal	Optimal
2	Combi system installed using approved equipment list Installer must have received combi system training	90% of Optimal	Optimal
3	Combi system installed using approved equipment list Installer must have received combi system training Field verified system performance	Optimal	Optimal

Operation

The combi system delivers the same type of service as individual furnaces and WHs, but there are several minor differences the homeowner should know about regarding operation, maintenance, and performance.

For a traditional system, the occupant had two control points: the thermostat for space heating and the water temperature set point for DHW. The combi system thermostat operates exactly the same as a traditional furnace, and in retrofit applications the thermostat did not need to be replaced or modified. The DHW temperature control changed from a WH set point control to a mixing valve control installed near the WH outlet. The thermostatic mixing valves have an element inside the valve that expands and contracts in response to changes in water temperature. The expansion and contraction controlled the mixture of hot and cold water maintaining the desired water temperature. The mixing valve also reduced the variance in water temperature coming from the WH. **Figure 6** shows the impact of the mixing valve for a StWH. The figure shows the temperature delivered by the WH (in black) and the mixing valve (in blue) for a series of DHW events in a typical home. The water events started at a time of zero seconds and the temperature delivered from the StWH varied from about 135 °F to 145 °F. This variance was due to the dead band on the storage tank. The figure also shows a slight delay of about 10 seconds until the mixing value came up to temperature. This was because it was installed downstream of the WH outlet. Once tempered there was little variance in water temperature. Additionally, the event-to-event variance was reduced from about 10°F at the StWH outlet to about 5°F at the mixing valve outlet.

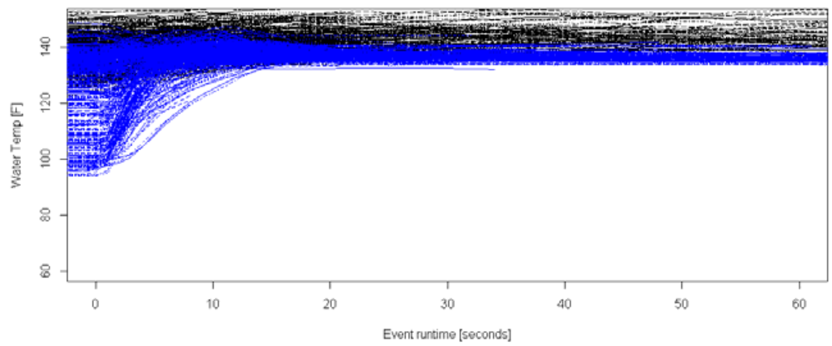

Figure 6. Hot water temperatures delivered by the WH (black) and mixing value (blue).

The maintenance and durability for these combi systems is expected to be an improvement over traditional systems. The single heating plant for combi systems is expected to require less annual maintenance than a separate furnace and WH. Manufacturers typically recommend a small package of maintenance for both the furnace and WH. This typically includes an annual furnace inspection and cleaning that includes the burner, fan, vent system, and heat exchanger. Additionally, the furnace air filter must be changed regularly. WH manufacturers usually recommend annual burner and venting inspections, as well as a flushing of the unit to clear debris and buildup. The maintenance of a WH based combi system will be reduced; the WH will have the same recommended maintenance as a typical system. The air handler is a much simpler system than a furnace and will have reduced maintenance and up keep. The air handler only requires an annual fan inspection and regular replacement of an air filter.

All equipment used in this project was supported by the manufacturer's warranty for use in combi systems and was rated for this purpose. The equipment described had warranties comparable to other high performance equipment and are expected to have good durability in delivering their intended performance. It is not advisable to install WHs not intended by the manufacturers for this type of installation. Some WHs are not designed for the load profile required of a combi system.

Performance

When properly installed and optimized the high efficiency combination systems provided significant savings over the systems they replaced (an 80% AFUE furnace and a 0.58 Energy Factor (EF) natural draft water heater). **Figure 7** shows the percentage annual savings measured at 12 sites using WH based systems. The WH based combination systems saved an average of 17%. The site with the highest, savings of about 34% had an older existing furnace with a 70% AFUE rating. The site with the lowest savings (about 3%) replaced a condensing furnace with a 91% AFUE rating. The ratio of DHW load to space heating load accounted for most of the variance in savings. The load ratio was a significant factor because of the difference in the space and DHW efficiencies for most systems. Analysis was not completed at two sites where occupancy issues prevented sufficient data collection. Additionally, 5 homes wither boilers were also monitored, but the complexity of installation and optimization yielded lower savings and these systems were not recommended.

Table 3 shows the average installed and rated efficiencies for each type of system. The winter efficiencies are dominated by space heating and summer efficiencies are only DHW use.

The table illustrates the measured difference in DHW and space heating efficiencies. Despite high rated efficiencies, the measured DHW efficiencies were around 60% for the StWH and the HWH, due to actual DHW loads that were lower than that used for the efficiency rating tests.

The efficiencies measured from the installed combi systems were lower than the equipment's rated efficiencies (**Table 3**). This reduction between rated and measured efficiencies has been measured for conventional space and water heating systems both in this project and others (D. Bohac et al. 2010; Brand and Rose 2012). The combi systems installed performance was the same as separately installed high efficiency furnaces and high efficiency water heaters.

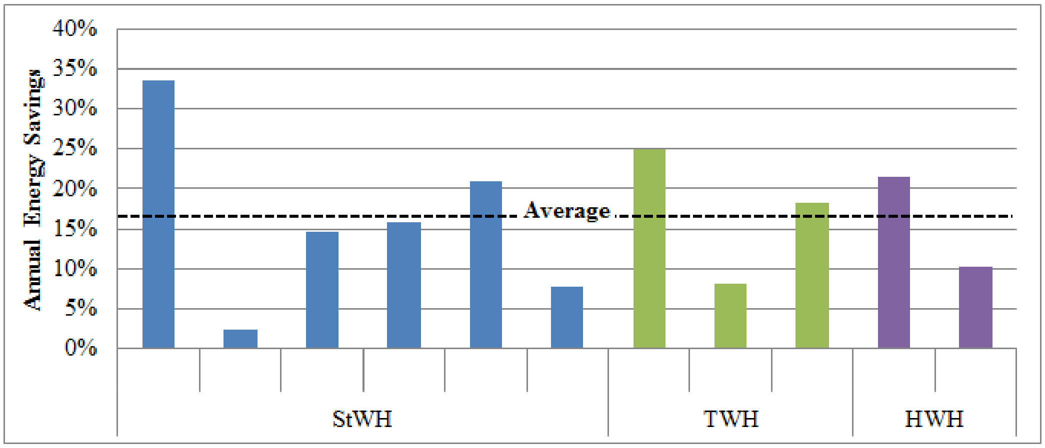

Figure 7. Energy savings from combi systems monitored in real homes.

Table 3. Average installed performance of combi systems in 11 homes

Heating Plant	Installed Efficiency			Rated Efficiency	
	Annual	Winter Space Heat	Summer DHW	Rating Method	Rating
StWH	86%	87%	60%	Thermal Efficiency	95%
TWH	86%	85%	85%	Energy Factor	93%
HWH	90%	92%	61%	Energy Factor	95%
Existing[1]	71%	72%	47%	AFUE/Energy Factor	79% / 59%

1. Existing system efficiencies were not measured directly, but were estimated from measured energy consumption data.

Conclusions

The field research demonstrated that forced air natural gas combination systems can be used to provide at least the same level of capacity, efficiency and comfort for both space and water heating as traditional systems. In some cases the delivery can be improved for either or both types of heating. In addition, combi systems can provide space and water heating safely with power or direct vent combustion and also provide measures to prevent water scalding. Combi systems are capable of providing this heat with high efficiency in both residential new construction and retrofits. Combi systems provided a measured 17% natural gas savings over ND forced air furnaces and ND SWHs (AFUE ~80% and EF ~58%) in 11 field installations. Combi systems provided annual space heating at 85%–92% efficiency and improved domestic water heating efficiency at every site. Summer DHW efficiencies ranged from 45%–90%, depending on water usage and system type. Several homes in the study had very low usage, resulting in storage tanks operating almost totally in standby mode.

Despite good savings and occupant comfort, there are initial hurdles to widespread implementation. The biggest hurdle is that contractors are unfamiliar with high efficiency combi systems and often are not able to properly install and optimize systems to ensure good performance. The installation of these systems does not require skills that are above typical HVAC technicians and plumbers, but they need to be made aware of the requirements of a good installation and verify performance. The guidelines in this paper for equipment selection, installation, optimization, and operation were developed during the successful installation of over 200 high efficiency combi systems. These guideline and best practices are intended to provide information to facilitate successful installations, programs, and emergence of combi systems.

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