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A Manufacturer's Guide to High Performance CSA P.9 Tested Combos

for packaged combination space and water heating systems that begin with condensing on-demand water heaters

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1. Executive Summary

The primary purpose of this document is to provide manufacturers of condensing on-demand water heaters with a route to developing combination systems that provide efficient home space and water heating, and getting the CSA P.9 test results to prove it.

On-demand condensing water heater based combination systems have the potential to be very energy efficient. One of their great advantages is that they can vary the supply water heating temperature in space heating mode to improve overall combination system performance by 10% or more. Engineered packaged systems that control water heating and air handling functions together can condense almost all the time.

This document is intended for managers and design engineers to 1) rapidly understand one approach to developing a high performance combination system 2) help de-risk the development process and use resources most effectively, and 3) set specifications for potential component suppliers. This approach can be customized to deliver a high performance combination system.

The report explains how performance weightings have been set in the standard for systems with different space heating outputs. Space heating part load performance is the key factor in the overall performance rating. For example, with a combo system with a rated 10 kW space heating capacity, space heating part load performance ratings form 74% of the total weighted performance of the combination system.

Table 1: Total energy use for 10 kW combination system

Operating Mode	Total energy use (kWh/yr)	Percentage of energy use (%)
Space heating: Full load	2,000	8%
Space heating: 40% of load	12,000	49%
Space heating: 15% of load	6,000	25%
Water heating	4,400	18%
Total	24,400	100%

Recognizing whether a demand is for space or water heating and responding differently is important. Water supply temperatures for space heating must be kept low whenever possible to keep return water temperatures low, and thereby maximize condensing.

The report discusses the components needed, potential controls approaches, and some issues that are anticipated in developing a cost effective and efficient combo using a condensing on demand water heater.

2. Zoned Systems

Intelligent residential combos may be one of the most attractive platforms for commercialization of reasonably priced zoned heating systems. Because they utilize hydronic fan coils, except for thermal comfort considerations that can be easily managed, there are no mandatory minimum or maximum air temperature rise issues that could impact on equipment performance or safety certification as there may be for other HVAC technologies. Therefore, no air bypass from the supply to the return of the air handler or supply air "dumps" into a common zone are needed to maintain a minimum air flow across the air handler. As well, an intelligent combo will have already incorporated much of the controls and the control logic design that is needed for the successful deployment of reasonably priced zoned HVAC systems.

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3. Background

3.1 Purpose

The purpose of this document is to provide manufacturers of modulating condensing on-demand water heaters with a route to developing combination systems that provide efficient home space and water heating, and get the CSA P.9 test results to prove it.

All water heaters that are being considered for use in combo applications must be specifically approved (certified) for use in combo applications and have a label indicating that the water heater is suitable for dual purpose hot water and space heating.

3.2 Audience

This document is intended to support:

- **Management** to rapidly understand one approach to developing a high performance combination system, and to help de-risk the development process and help use resources most effectively

- **Design Engineers** to select the water heater, speed the development of a controls approach for the combination system, and help set specifications for potential component suppliers.

3.3 Market

Combination systems have gained market share in Southern Ontario for small and efficient homes. While reliable statistics are not available, some industry sources estimate that a minimum of 30,000 combination systems are being installed annually in the Ontario new home market. Many of those systems are going into homes that typically have peak space heating loads of 15 kW or less (including a 40% oversize "safety" factor that is traditionally added to the calculated design space heating load).

ENERGY STAR for New Housing (ESNH) had an approximate market share of 20% of the builds in Ontario last year. Builders are looking for combination systems that have high performance ratings when tested and rated to the CSA P.9 Standard. In 2014, all combination systems used in ENERGY STAR for New Housing will be required to be rated to the standard.

3.4 Industry Practice

On-demand water heaters have been rapidly evolving to better meet North American domestic hot water heating needs and improve efficiency. They can now operate at a wider range of water flow rates, modulate over a wide range, and many now employ condensing technology.

Combination systems were first developed using traditional storage tank water heaters and an air handler fan coil to provide both space and water heating. Many such systems were site built and focused on meeting loads. Combo efficiency was not rated to any standard and received less attention as a result.

Condensing water heaters offer the potential to provide much more energy efficient combination systems. Combination systems can improve the payback on selecting a condensing water heater. Factory engineered combination systems make it possible to optimize combos and their controls to deliver high performance systems that condense in most operating modes.

Some manufacturers of on-demand water heaters are starting to develop better-matched components as well as packaged combination systems. They may be less familiar with high performance air handling and associated controls approaches that may be required to develop a high performance packaged system. This document is intended to provide a common baseline from which to start.

3.5 Evaluation Experience

Natural Resources Canada’s CanmetENERGY has been carrying out research on combination systems and components for many years. CanmetENERGY conducted research, and provided technical expertise and support for the development of the CSA P.10 standard for integrated mechanical systems and the subsequent CSA P.9 standard for combination systems. CanmetENERGY has also:

- evaluated the performance of site built and manufactured systems at laboratories, both their own and at third party laboratories.

- monitored and analyzed the performance of systems in the field and at the Canadian Centre for Housing Technology research homes. Many of these projects have been carried out in partnership with other government agencies and gas utilities.

- developed combination system components for specialty applications such as the Drake Landing Solar community.

This report builds upon the body of knowledge gained from those various works.

3.6 Key Challenge: Using Water heaters for Efficient Space Heating

On-demand water heaters can perform very well in domestic hot water heating mode with cool mains water temperatures and the fairly high peak system loading that occurs during hot water draws. They may perform particularly well when providing the large hot water draws that are used in current water heater test standards to rate their performance as water heaters.

Combination system performance is dominated by performance when providing space heating loads. Although the instantaneous thermal loads are considerably lower when providing space heating than when providing peak water heating loads, the duration of the space heating loads are much longer. It can be challenging to make the water heater condense in space heating mode because the return water temperature from the space heating coils will generally be much warmer than the city water inlet temperature that the system heats when providing potable hot water. Because only a small portion of the systems' annual space heating loads are actually provided when operating at design conditions, part load performance in space heating mode is particularly important to the overall system performance. Achieving excellent performance in part load space heating tests is far more important than at full rated output when calculating the overall system performance.

High performance results can be achieved where efficient components are well matched and the operating system intelligently controls both the water heater and air handler together.

3.7 Stepped Approach

This report supports manufacturers in taking the following steps to deliver a high performance combination system:

Step 1: **Understanding the design loads** driving all combination system decisions

Step 2: **Selecting a water heater** that can provide high performance in combination system applications

Step 3: **Selecting a controls approach** for the water heater and the air handler that minimizes manufacturer cost in providing high performance P.9 tested combination systems

Step 4: **Selecting other combination system components** (such as coils, and blower motors and their controls)

Step 5: **Using in house testing** to determining the performance of their combination systems so they can be upgraded as need be before sending to a third party laboratory for verification

Option: Considering testing implications of providing a combination system with multiple zones built into the air handler

4. Design Loads – CSA P.9 Performance

4.1 Thermal Performance Factor (TPF)

TPF is the key energy performance metric in the CSA P.9 standard.

It combines ratings for space heating and water heating performance and takes a load-weighted average of the two to generate this overall metric. Annex B of the CSA P.9 standard provides detailed explanations of how and why the weighting factors were developed.

This section highlights a few key factors and generates a chart that manufacturers can use to see what test results most heavily impact their products' TPF results.

As space heating is typically the dominant load in Canadian homes, the overall performance weighting for combination systems is dominated by space heating.
Part load space heating test results have the most important weighting in determining the composite space heating performance rating, and therefore TPF.

This provides a significant opportunity for on-demand water heater based combination systems. These systems should be able to perform significantly better at part load space heating conditions than at full load conditions. (This is discussed in Section 4.)

During CSA P.9 efficiency tests, intelligent controls strategies are allowed to function. For instance, the control can start operating in space heating mode with a lower temperature supply to the air handler and a lower fan speed. These can be stepped up repeatedly if the load has not been met within a specific time period. Alternately, controls using load sensing approaches such as outdoor reset controls may provide similar performance improvements and can be simulated during tests. This is particularly important during part load space heating efficiency tests.

4.2 Water Heating

The annual water heating load represents a constant of 4400 kWh (~12 kWh per day) for each home. P.9 assumes that the daily domestic water heating load is the same as the standard water heating load that is currently used to determine the Energy Factor (EF) ratings for residential gas and oil fired water heaters in North America. In P.9, the performance rating for the combo as a water heater is called the Water Heating Performance Factor (WHPF). Although P.9 provides increased flexibility in control settings compared with standalone water heater standards, the WHPF rating is analogous to an EF rating and the numerical ratings should be similar.

4.3 Space Heating

While any space heating system must be capable of providing its rated space heating output when required by the controls, space heating systems only need to provide their peak heating output for at most, a few days during the year. The CSA P.9 standard recognizes that systems will operate under part load conditions most of the time and it generates space heating efficiency ratings based upon direct tests with full and part loads. Combination systems are tested under loads that equate to 100%, 40% and 15% of their space heating capacities. The results are combined to provide an overall Composite Space Heating Efficiency (CSHE) that weights the part load conditions most heavily. The related formula and corresponding graphic representation, taken from P.9 is as follows.

CSHE = 0.1*Net Efficiency at 100% + 0.6*Net Efficiency at 40% + 0.3*Net Efficiency at 15%

Figure 1 illustrates the amount of the annual heating load that can be attributed to different operating points.

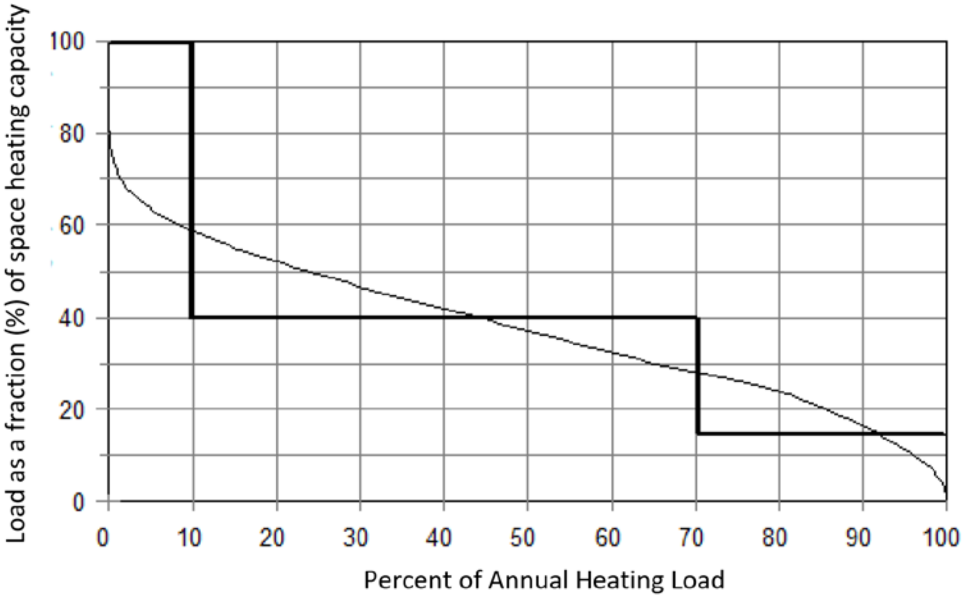

Figure 1: Space Heating Load-Duration Curve (Adapted from CSA P.9-11)

4.4 Relative Size of Space and Water Heating Loads

The combination system's controls are fully functional during all testing and are not manually adjusted once the first tests are under way. The manufacturer's choice of controls approach, temperature and air and water flow settings and components used will determine the peak space heating capacity and efficiency at full output. Systems with lower design heating capacities would typically be installed to serve homes with smaller design loads. As discussed previously, annual water heating loads are constant for all systems. Therefore the smaller the space heating capacity, the greater the relative importance of water heating on the TPF. This is illustrated in Figure 2. They show the relative annual space and water loads for combos with design space heating loads of 5kW and 10kW respectively.

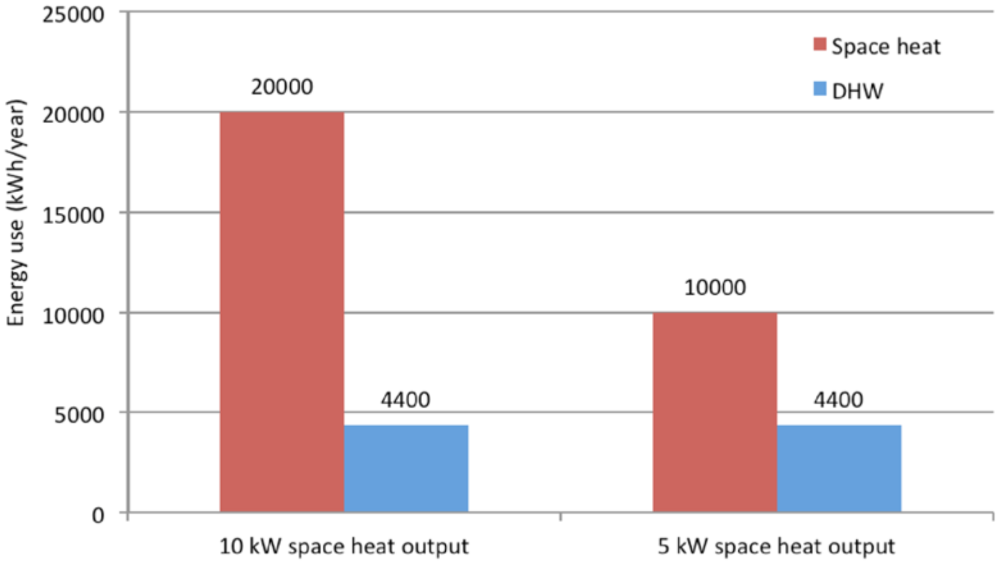

Figure 2: Comparison of heating and hot water energy use (kWh/year) for 10kW and 5kW combo systems

The weightings of the individual performance test results in the overall CSA P.9 thermal performance factor (TPF) for combos with three different space heating capacities are shown in Table 2.

Table 2: Annual energy consumption (kWh/year) in P.9 for combos with 5, 10 and 15 kW rated space heating outputs

Operating Mode	5 kW Space heating capacity	10 kW Space heating capacity	15 kW Space heating capacity
Space heating: Full load	1,000 kwh/yr	2,000 kwh/yr	3,000 kwh/yr
Space heating: 40% of load	6,000 kwh/yr	12,000 kwh/yr	18,000 kwh/yr
Space heating: 15% of load	3,000 kwh/yr	6,000 kwh/yr	9,000 kwh/yr
Water heating	4,400 kwh/yr	4,400 kwh/yr	4,400 kwh/yr
Total	14,400 kwh/yr	24,400 kwh/yr	34,400 kwh/yr

Table 3: Load weightings in P.9 for combos with 5, 10 and 15 kW rated space heating outputs

Operating Mode	5 kW Space heating capacity	10 kW Space heating capacity	15 kW Space heating capacity
Space heating: Full load	7%	8%	9%
Space heating: 40% of load	42%	49%	52%
Space heating: 15% of load	21%	25%	26%
Water heating	31%	18%	13%
Total	100%	100%	100%

It is important to look at this from a high level and understand the relative weightings of test results on the annual TPF. It is clear that the impact of the system's performance during the space heating test with 40% of rated space heating output has the largest contribution (42 to 52%) towards the annual rating, followed by the performance with 15% of rated space heating output (21 to 26%). The weightings of those test results increase even more as rated space heating output increases above the range shown in Table 3.

It is believed that combos are typically being installed in homes that have design heating loads on the order of 7 kW to 10 kW. Based on heating system installation codes and industry recommended sizing guides, that would result in selecting combo systems with rated heating capacities of 10 kW to 15 kW. For combos in that capacity range, part load space heating test results have approximately a 75% weighting in the annual thermal performance rating.

Starting from a premise that the performance of the water heating component of the combo is already efficient (ref section 1.1 note), that weighting helps to identify where to invest the most effort in developing a high performance combination system.

Section 3.1 further expands on some of the implications of the load weightings.

5. Domestic Water Heating

The first step in developing a high performance combination system is selecting the right water heater. This section is intended to enable manufacturers to quickly find likely candidates.

This report focuses on how to provide efficient space heating when starting with a modulating, condensing on-demand water heater. For this approach to have potential, the heat generator must be able to perform efficiently at a wide range of operating conditions.

Required on demand water heater characteristics include:

- **Modulation** – efficient water heating performance across the full range from minimum to maximum rated water flow rates.
    - High turn down ratio
    - Ability to provide sufficient hot water for typical water heating needs.
    - Ability to operate with minimal hot water flow rates. Many current on-demand water heaters are rated by their manufacturers for use with hot water flows of 2 l/min (0.5 USGPM) or less. Some require higher flows.
- **Condensing Performance** – consistent condensing performance ratings across the full range of loads and fuel inputs
    - controls that properly manage the fuel to airflow ratio to maintain combustion efficiency independent of load
    - load-optimized control settings that identify size and types of loads and respond appropriately with best control settings for both the water heater and air handler functioning together
    - short pre and post purge cycles to minimize response times, “per cycle” losses and to reduce electricity consumption
    - low standby power consumption
    - direct venting of combustion products to avoid combustion spillage and depressurization risk

To quickly narrow down the base water heater selection, it will be easiest to start with data manufacturers will have (or can easily generate) for their own products in water heating mode. The goal is to start with a heat generator that has an energy performance rating of 90% or higher across a wide operating range.

If a water heater that is being considered for use as the thermal engine or heat generator for a combo package does not satisfy the above requirements, the choice of that unit should be carefully reviewed. In some cases, selection of different components, controls, or control settings may be able to overcome the performance deficiencies. The potential for significantly improving the water heating performance of an on-demand water heater without affecting its safety certification is limited. Because of this, selecting a different, more efficient, water heater may be the more expedient choice.

The Canadian CSA P.7 test and rating standard for on demand water heaters uses a common inlet water temperature of 14.4°C (58°F) and outlet temperature of 57.7°C (135°F) for its tests and performance ratings. Table 2 provides comparison “snapshots” of the energy performance of two hypothetical on-demand water heaters with the systems operating at several different water flow rates, using the same water temperature assumptions as P.7. While the peak performance rating for the first model is higher than the second (with water flow rates of both 11.4 and 7.6 l/min), the improved heating performance of the second model at lower water flow rates make it a much better candidate for a heat generator in a combo because of the high percentage of time during the year that a combo operates at low loads for space heating. That is further discussed in section 3 of this report.

Table 4: Comparison of P.7 energy performance characteristics for two hypothetical water heaters

Flow rate (l/m)	**Flow rate (USGpm)**	**Example Model 1**	**Example Model 2**
11.4	3	95%	92%
7.6	2	95%	90%
3.8	1	83%	92%
1.9	0.5	79%	92%
	Recommendation:	Poor choice for combo	Better choice for combo

Note that the energy performance ratings for the range of water flow rates used for illustrative purposes in Table 4 would not be interchangeable with the rated energy factors (EF) for the same water heaters, since the conditions in Table 4 are not identical to the setups, test procedures and water heating loads that are specified in the CSA P.7 rating standard for on demand water heaters. The hypothetical energy performance ratings in Table 2 are presented simply to illustrate that water heating performance for some types of water heaters can change as the flow rate (i.e. the water heating load) changes. Changes in water heating energy performance as a function of load are not fully captured within standardized EF performance ratings for water heaters. To avoid confusion, the terms “Energy Factor” or EF should only be used to identify standard water heater test ratings that are developed from tests and calculations that exactly follow the CSA P.7 rating standard for on demand water heaters, or the CSA P.3 standard for residential storage tank water heaters.

Having examined the energy performance of the candidate heat generators across their anticipated operating ranges for a combo, one can make an informed selection of a good water heater for the intended application. Once this has been done, the combination system manufacturer needs to decide on a controls approach before proceeding to selection of the other components for the combo system.

6. Designing Combination Systems

6.1 Implications of Load Weightings

Part Load Space Heating Conditions

The primary focus needs to be on part load space heating to get an excellent CSA P.9 test rating. Performance under part load space heating conditions will determine 90% of the composite space heating efficiency (CSHE) rating. For an installed combo with a design space heating output of 10kW, 75% of the TPF value will come from the results of part load testing, and for one with 15kW of space heating output, the part load space heating performance results will account for nearly 80% of the overall thermal performance factor.

Minimizing Supply and Return Water Temperatures

Water heaters that get excellent ratings with cold mains water supply temperatures will perform worse as the entry temperature increases. Warmer return water temperatures during space heating mode will reduce efficiency. Responding to space heating calls by utilizing control settings that minimize the supply and return water temperatures under part load conditions can help maximize combustion efficiency.

6.2 Design Approaches

One of the greatest advantages of an on-demand water heater is that, in principle, it can provide different supply water temperatures for water heating and space heating loads. It can also significantly vary the water temperature it supplies for different space heating loads. This is key to continuing to provide the same high efficiency water heating and providing very efficient part load space heating.

Two combination system design approaches will be examined:

- Approach 1 uses a constant water temperature for all loads

- Approach 2 varies the water temperature based upon the load

The first approach requires the fewest changes to current practice and is often thought of first. It is illustrated here primarily to show some of the inherent performance challenges.

The second approach is a much more cost effective way of achieving high performance levels both in the field and in testing to the CSA P.9 standard. Experience shows that it will provide a high performance level for less cost to the manufacturer.

Using a variable speed pump in the air handler can also improve energy performance. Approach 2 focuses on variable supply temperature because on demand water heaters can more readily provide this function. Variable speed pumps are uncommon in air handlers at present.

Context for Illustration examples

- **Water heaters**: Both combination system approaches will be illustrated using the same modulating condensing on demand water heater.

- **Space Heating Capacity**: The TPF performance weightings for a combination system with a 10 kW design space heating load will be used as a representative example to illustrate each of these approaches.

6.3 Approach 1: Constant Water Temperature

This combination system approach follows the status quo and only seeks to use better components to improve performance. It may often be thought of first because controls can remain exactly as they are in a system where one manufacturer supplies the on demand water heater and another supplies the air handler.

Water Heater and Air Handler Controls

The water heater does not identify whether a demand is for water heating or space heating. It senses a demand and provides hot water at a constant temperature. To meet the required peak space heating load, this is typically set to 60 °C (140°F). The air handler does little to stage the space heating output. It typically uses one or two blower fan speed settings. Since extended blower operation after a call for heat has been satisfied may cause cold draft comfort concerns, blower post run will either not be implemented or implemented using only short run times. Both scenarios will cause heat to be retained within the coil and piping that will subsequently be lost from the system during off time periods.

Space Heating Coil(s)

In an effort to increase efficiency in space heating mode, return water temperatures must be minimized. “Oversized” coils are specified to maximize the temperature drop across the heat exchanger when providing space heating.

Space Heating Part Load Conditions

The air handler cycles on and off to meet part load conditions, triggering related demand calls on the water heater.

P.9 Performance Illustration

Table 5 provides a hypothetical illustration of the kind of performance that would typically be expected using a single temperature set point approach.

Table 5: Performance of a hypothetical combo system with 10 kW space heating output using a simple single water temperature set point controls approach (space heating capacity offset by on-off cycling)

Operating Mode	Weighting	Supply water temp (ºF)	Return/ main water temp(ºF)	Air handler flow rate (CFM)	Energy In/Out Performance metric (%)	TPF contribution
Space heating: 100%	8%	140	120	800	85	.07
Space heating: 40%	49%	140	120	800	80	0.39
Space heating: 15%	25%	140	120	800	75	0.18
Water heating	18%	140	58	–	92	0.17
Total	100%					0.81

Comments on single temperature set-point approach:

- **Overall Performance:** A Total Performance Factor (TPF) rating of 0.81 is low for a system with a condensing on-demand water heater and shows that the system has not been effectively optimized.

- **Water Heating Performance:** The system condenses in water heating mode with a WHPF of 92%. However the WHPF weighting is less than 20% in calculating TPF.

- **Space Heating Performance:** Although the space heating performance at full output is "near condensing" at 85% efficiency, the water heater does not actually produce significant amounts of condensate in either full or part load space heating modes. Despite the use of a high performance coil, the return water heater temperature is simply too high to allow for much condensing to occur. Space heating performance becomes worse at part load settings due to shorter burner cycles and a greater percentage of run time spent in pre and post purge modes.

- **Blower Speed:** The blower will operate at the same speed used for full output to provide all heating loads. That will result in frequent cycling as well as increased noise levels and high electrical power use whenever the system is providing space heating. It may be difficult to properly distribute heated air during periods with low heating loads because of short cycling at full heating capacity that delivers "bursts" of hot air. That could create cold zones within the home and comfort complaints.

- **Indoor Air Temperature Control:** Modulating heating output through on-off cycling of any system that has an essentially fixed heating output while it is operating will produce more variation in indoor air temperature and larger temperature swings above and below the thermostat set point. That could lead to homeowners increasing the heating set point to achieve acceptable comfort conditions.

- **Zoning Impacts:** Zoning will be more difficult with a system with a fixed output and single blower speed.

Approach 1 can be improved by further increasing the size of an already oversized coil in the air handler. However, there are practical limits to this as even larger coils will require much more copper and forming and add to the overall cost, as will the related larger air handler cabinet. In addition, per cycle heat losses will increase, making it more difficult to achieve high part load performance. Using Approach 1 for high performance combination system may be too expensive to be worth following.

6.4 Approach 2: Variable Water Temperature

This approach is similar to that employed in multi-staged furnaces. Its goal is to have the water heater and air handler work together as a system to drive up efficiency while minimizing component costs and complexity.

Water Heater and Air Handler Controls

This approach takes advantage of the in-built capacity of the water heater to vary supply water temperature by changing the water heater set point based on demand. Low supply water temperature settings are used to meet part load space heating conditions. Air handler blower speeds are varied based upon an outdoor reset or a timer based approach to staging. After a call for heat has been satisfied blower operation is extended at reduced blower speeds to avoid cold comfort and noise related concerns. As a result, less heat is retained within the coil and piping and subsequently lost compared with the first example. The water heater and air handler must each recognize the demand they are being asked to meet. However, their controls do not need to be physically integrated in any way. This controls approach is discussed in more detail in Section 4.0.

Space heating Coil(s)

To simplify comparison, we will assume that the same “oversized” coils are used as in the first approach example so that the peak load space heating performance will be the same for both examples.

Space Heating Part Load Conditions

The water heater recognizes a call for space heating and starts by providing a low supply water temperature to the air handler. If the call for heat has not been satisfied within a given timeframe, the water heater incrementally increases the supply water temperature. The air handler monitors the supply water temperature and incrementally increases the blower speed when the supply water temperature is higher.

P.9 Performance Illustration

Table 6 provides a hypothetical illustration of the kind of performance that is possible using a simple controls strategy that employs variable water temperatures and blower speeds. The actual temperatures and blower air flow rates in table 6 were chosen for illustration only. They do not represent fully optimized settings for a combo.

Table 6: Performance of a hypothetical combo system with 10 kW space heating output using a variable water temperature and blower speed controls approach (space heat capacity variation by modulation of air flow and water temperature)

Operating Mode	Weighting	Supply water temp (ºF)	Return/ main water temp(ºF)	Air handler flow rate (CFM)	Energy In/Out Performance metric (%)	TPF contribution
Space heating: 100%	8%	140	120	800	85	0.07
Space heating: 40%	49%	110	102	600	92	0.45
Space heating: 15%	25%	90	87	500	94	0.23
Water heating	18%	140	58	–	92	0.16
Total	100%					0.92

Comments on variable supply temperature example

- **Overall Performance**: A Total Performance Factor (TPF) rating of 0.92 would put the combination system in the high performance range.

- **Water Heating Performance**: As with the single temperature set point scenario, the system condenses in water heating mode with a WHPF of 92%. A small improvement in water heating system efficiency might be achievable if a water temperature set point of less than the 140°F used in the first example were used. The P.9 standard allows for a set point as low as 120°F for potable water. The set point temperature no longer has to be the same as that required for maximum space heating load, so it can be reduced to the 120°F range. To simplify comparisons of the two systems in Table 3 and Table 4, a reduced potable water heater set point has not been included in Table 4.

- **Full Load Space Heating Performance**: Efficiency is lowest in this mode. The supply water temperature needs to be at its highest to meet the load so the return water temperature will also be highest in this mode. As the system will rarely operate in this mode, this poorer performance only accounts for a small fraction of the TPF weighting.

- **Part Load Space Heating Performance**: Water heating supply temperatures are set progressively lower to meet smaller part load demands. Temperatures can be set considerably lower than they need to be set for tap water heating. This also leads to lower return water temperatures than at full load. Both these factors lead to efficiency being higher at part load than at full load. The water heater will operate in condensing mode for both the 40% and the 15% space heating load points.

- **Blower Speeds**: As the heat output required lowers, so does the blower speed. This results in reduced noise and, longer blower operation with less frequent cycling, and a net reduction in power consumption. It may also reduce comfort complaints with longer operation at reduced air flows improving warm air distribution during shoulder seasons.

- **Indoor Air Temperature Control**: Modulating heating output through varying the water temperature and blower speed can provide a more consistent indoor air temperature with reduced temperature swings above and below the thermostat set points.

Approach 2 (variable water temperature) can lead to an efficient combination system that performs well when tested to the CSA P.9 standard and when installed in a real home. Performance levels will vary depending on the components selected and the specifics of the controls sequencing.

7. Controls

The generic controls required to implement the preferred variable temperature approach that was discussed in the last section can be relatively simple. A few on demand water heaters already provide reset temperature controls. However, temperature controls for typical on demand water heaters are not commonly configured to provide a load based temperature reset function. Essentially all of the currently available on demand water heaters include some provision for either built in or remote mounted temperature controls to enable the user to make manual adjustments to the supply temperature from the water heater.

In principle, it should be feasible to develop a simple control interface package that would connect to the existing temperature control connections. The new control would simulate the action of the standard manually adjusted temperature controller to provide an automatic temperature reset function for the water heater. All safety controls would remain functional.

A simple controls approach is capable of providing high performance. The key elements are:

- Knowing whether a demand includes a need for domestic hot water heating
- In space heating only mode, using a timer or an outdoor reset (or similar inferential load sensor) to progressively stage up supply water temperature
- An air handler that varies air flow based upon the water temperature coming into the unit, the length of time that a call for heat is present, or a direct load-control sensor input

It is important to note that the water heater and the air handler do not need to have direct communications or common controls to implement some of these control approaches.

When the system controls determine that a call for heat has been satisfied, the air handler should continue to operate for a long enough time period to extract all of the residual heat from the coil and transfer it to the air stream. To avoid thermal comfort concerns, reducing the blower speed during this fan-delay time period is desirable. Continuous blower operation using a low speed setting would automatically provide this functionality without requiring any controls intelligence. That would have a side benefit of providing more uniform temperature distribution inside the home. It would also be useful for distribution of fresh air if the combo is installed together with a heat recovery ventilator (HRV) or other type of ventilation system.

Intelligent controls will ultimately make or break combination system efficiency. Controls should be able to identify whether there is a call for space heat, for water heating or both. They will need to be able to identify the magnitude of each load and respond appropriately by varying parameters for both the space heat delivery system (i.e. the air handler) as well as the heat generator (particularly if a on demand water heater is the heating source) . Under conditions of high water heating demands, some form of DHW priority control approach may be the better option. Controls can infer the magnitude of space heating loads through various mechanisms, including monitoring of thermostat duty cycles, and direct inputs from an inferential load control such as an outdoor reset control.

Figure 3 shows a simplified generic controls algorithm for the water heater section of a combo system that uses four steps of water temperature settings for space heating and one for water heating.

The control logic illustrated in Figure 3 is intended only as one example of a rudimentary controls approach that could be used to produce high performance in space heating modes without requiring expensive components. The control algorithm could be improved if the controller had sufficient intelligence to enable it to “learn” the required heating stages based on monitoring the durations of space heating calls over several recent heating cycles.

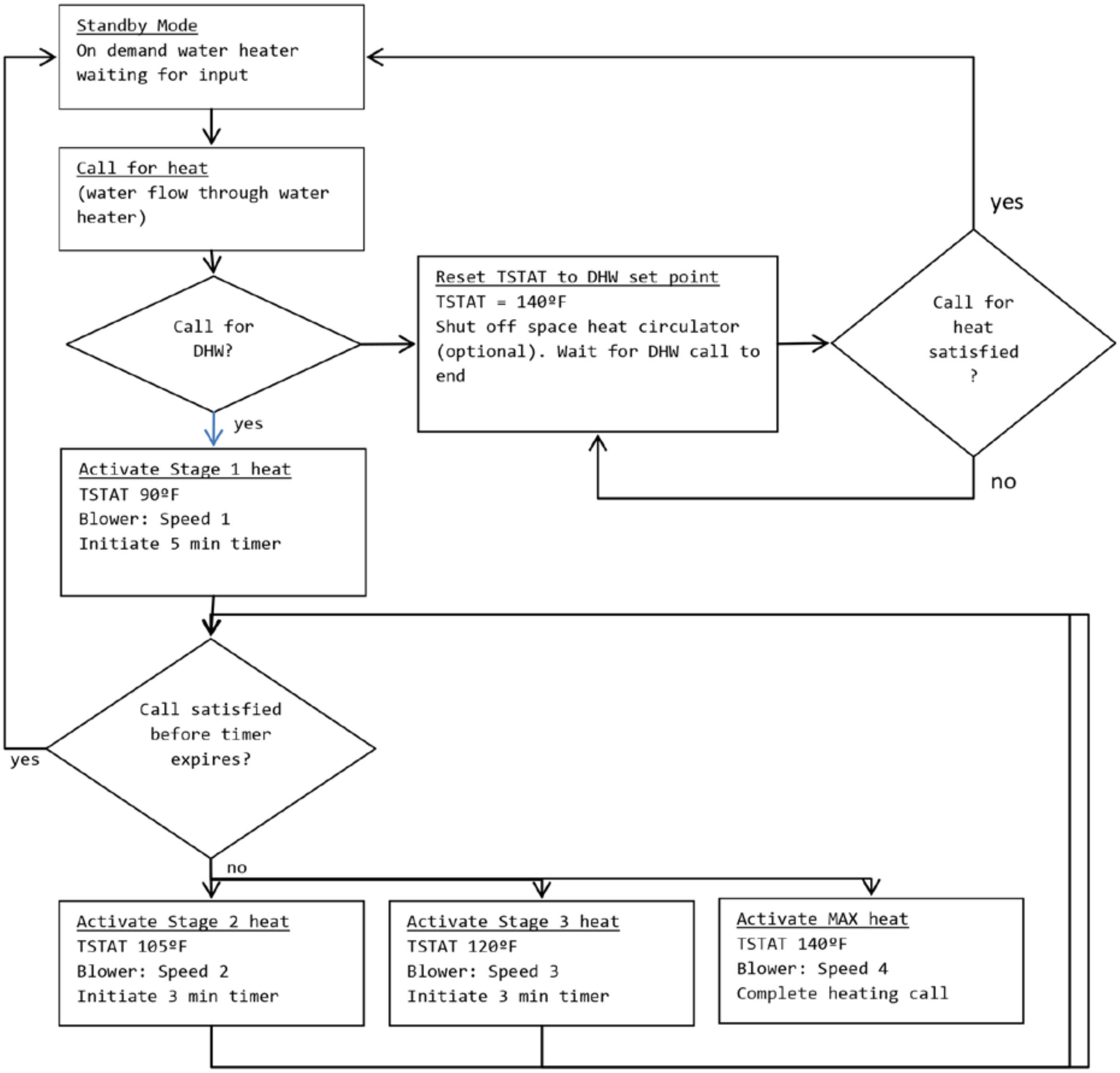

Figure 3: Simplified water heater control algorithm logic for four stage heating scenario

Here are three options for control of the air handler blower speed to accompany the water heating approach shown in Figure 3:

Indirect temperature based control

- **Controls Connection:** Water Heater and Air Handler Controls are completely separate from each other but function in a complimentary way.

- **Approach:** The air handler senses the temperature of the incoming hot water. The higher the water temperature is, the more the air handler controls increases the airflow.

- **Discussion:** The water heater controls increase the supply water temperature when the demand has not been satisfied within a given period of time. The air handler recognizes the increased temperature and blows more air across the coils to utilize it.

- **Mechanics:** A temperature well is installed in the incoming supply water pipe within the air hander. The blower air flow setting would be adjusted based on installing an air handler control module that measures the water temperature being supplied to the air handler from the water heater during a call for space heat to the air handler. The call for heat would be indicated through a control signal from the HVAC thermostat to the control board of the air handler.

Indirect timer based control

Controls Connection: Water Heater and Air Handler Controls are completely separate from each other but function in a complimentary way.

Approach: The air handler air flow is varied based on the length of the call for heat to correspond with the temperature control timings identified in Figure 5.

Discussion: The water heater controls increase the supply water temperature when the demand has not been satisfied within a given period of time. The air handler recognizes the duration of the call for heat and blows more air across the coils to correspond with the programmed temperature steps.

Mechanics: The blower air flow setting would be adjusted based on installing an air handler control module that steps the air flow based on the duration of the call for heat. The call for heat would be indicated through a control signal from the HVAC thermostat to the control board of the air handler.

Direct control

Controls Connection: Water Heater and Air Handler Controls are both controlled using a new integrated combo controller that directly interfaces with both the water heater and air handler.

Approach: The air handler air flow and water temperature are varied by the new controller to optimize heating performance.

Discussion: This direct approach requires development of a new control component . The controller can utilize more sophisticated operating settings to improve performance in all operating modes.

Mechanics: The blower air flow setting and water temperature to the air handler would be directly controlled by a new integrated combo controller. The call for heat would be indicated through a control signal from the HVAC thermostat to the controller.

Water Heater – Tap Water Heating Mode

Tap water heating algorithms do not change from what is in the standard controls package. The only change is that the water heater uses a flow switch or flow meter to identify a draw of hot water (or an inflow of cold water) to recognize that a demand has been made for water heating. If space heating demand is concurrent, it could serve both concurrently at the tap water required outlet temperature setting. Another option would be to default to the water heating mode setting. A more sophisticated control could potentially delay space heating when and if necessary to meet high water heating demands, or to enable provision of space heating using more optimum temperature settings. This is illustrated in Figure 4.

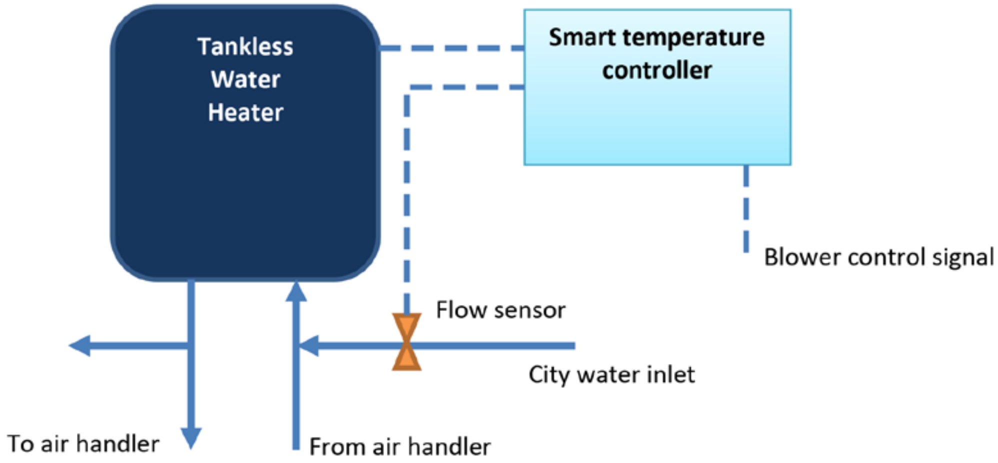

Figure 4: Illustration of the use of a water flow sensor to identify a portable water heating load

Safety Certification Implications

Since the indirect controls approaches discussed in this document do not require connection to or modification of any of the safety related components or controls (gas valve, ignition controller, pre and post purge control, burner sensors and modulation controls, venting, temperature limit controls etc.) of the water heater, there should be no safety related issues from using the water heater in an advanced combo with an indirect controls approach. That may not be the case if a direct controls approach is used. As noted at the beginning of this report, all water heaters that are being considered for use in combo applications must be specifically approved (certified) for use in combo applications and have a label indicating that the water heater is suitable for dual purpose hot water and space heating.

8. Components

Combination systems require high performance components to perform well, both “as-installed” and “as-tested” to the CSA P.9 standard. This section is intended to help on-demand water heater manufacturers:

- develop their own air handler, or
- partner with another manufacturer to provide an air handler for their system by identifying
    - component needs
    - how little or how much an existing air handler model need to be refined to meet their needs
- identifying changes that need to be made to the total packaged system to improve performance

8.1 Air Handler

The air handler needs to include the components needed to provide heat and circulate air. Items that need to be considered include space heating coils, blower motor, pump and temperature well. These items are explained in further detail below.

8.2 Space Heating Coils

The space heating coils must be sufficiently sized to allow for space heating to take place with low enough supply water temperature and sufficient water temperature drop to promote condensing in the heat generator when the system is operating under part load conditions (and ideally full load conditions too).

Typically space heating coils that extract heat from water are designed and selected based on a water temperature drop of about 11°C (20°F) across the coils at the design heating conditions. Preliminary coil selection can be made based on software that is readily available from various coil suppliers. In most cases, the software model calculates the heating output for a hydronic heating coil based on air conditioning performance measurements for coils with similar construction and geometries. Because of this, the actual heating output for a given design condition may be somewhat different from what is predicted by the software.

The actual performance of the selected coil (heating output, water temperature drop, static pressure drop on the air and water side) should be verified through in house tests. Once that has been done, the software model can provide invaluable assistance for the coil selection and it should provide fairly reliable indications of changes in coil performance at different design conditions. That information will be useful in developing and refining more advanced control approaches and settings to optimize the system performance in part load heating conditions.

Elements to consider include:

Water coil diameter & number of passes – a larger pipe diameter will minimize the water pressure drop and minimize the energy used by the water circulator. A smaller pipe diameter will enable a less expensive coil because less copper will be required in the coil. However, smaller tubes will require more pumping energy and increase the wear and erosion of the tubes, if sufficient pump power is applied to deliver the design water flow rate. In reality, using a coil with tubes that are too small will reduce the heating output from the coil, since the same standard circulator will likely be used regardless of the coil selection. The TECA hydronic and combo guideline[1] (section 8.14) specifies that the velocity of water passing through the heating system must not exceed 4 feet per second.

Number of fins per inch (fpi) – more fins per inch increase the heat transfer area and heat output but also create a higher pressure drop on the air side of the coil. A certain amount of pressure drop across the coil is useful in providing more even air flow across the coil, especially in a “blow through” configuration that is commonly used in combo fan coils for space heating. Heating coils can be specified with fins per inch ranging from about 6 fpi to 14 fpi. Typical hydronic heating coils use 12 or 14 fpi. Coils with higher numbers of fins are more readily fouled by dust or debris. Based on the results from coil modelling software, 12 fpi or even 14 fpi appear to be a reasonable choice for a high performance space heating coil, provided that the coil is selected with a large enough area to keep the air face velocity low at the design heating output.

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[1] Thermal Environmental Comfort Association (TECA); Surrey BC; Hydronic & Combo Guidelines for the Design and Installation of Hot Water Heating Systems and Combination Hot Water & Space Heating Systems, 8th Edition, August 2009 [www.teca.ca]

Figure 5: Example of an “oversized” space heating coil used for a hydronic air handler application

8.3 Blower Motor

The air-handler should use an electronically commutated motor (ECM) blower motor and be operated using a multi-speed or variable speed control system. This will enable modulation of the air flow as well as the supply water temperature when the system is operating at less than its maximum rated heating output. The ability to use a low speed low power continuous circulation mode will be particularly useful when operating at the 15% and 40% rating points, where it is essential to collect and distribute all of the residual heat from the heating coils, since P.9 only credits heat that is actually transferred into the air stream.

Modulating both airflow and supply water temperature will enable comfortable delivered air temperatures as well as high heating efficiencies.

An ECM that incorporates constant air flow programming will likely outperform one that uses constant torque programming, since the system will at least partially compensate for differences between the rated static pressures and the actual installed static pressures. It may be essential for ensuring that combustion performance in varying real world conditions matches performance testing in the lab.

Constant air flow programming will likely be essential to obtain acceptable performance for any zoned combination system.

8.4 Circulator/Pump

The right circulator must be selected to deliver the correct amount of flow against the installed static pressure that will be in effect. The pressure drops across different on-demand water heaters vary. Using a circulator that provides too much flow will lead to a small temperature drop in the water circuit through the coil and high return water temperature to the water heater. Too little flow leads to low heating capacities. Hydronic circulators are available with three selectable “speeds” and rated pump capacities. However, the motors that are used in typical multi speed circulators are not as efficient as EC motors. Variable speed circulators with EC motors are starting to become available, but they are not yet commonly used in combo applications.

Ideally the circulation pumps in advanced combos would be variable speed modulating designs to improve efficiency and compensate for different piping configurations. This design option is now available and it could be implemented now or it could be deferred until the next generation of advanced combination systems are developed. Early laboratory test results have shown that it is possible to achieve good performance results to CSA P.9 without using expensive variable speed circulation pumps and ancillary controls. In the future, as the cost of variable speed circulators with EC motors comes down and more integrated controls become more accepted, their use in combo heating applications will be more cost effective.

8.5 Measurement Ports (Temperature Wells & “Pete’s Plug” Pressure Measurement ports)

Designing the plumbing layout to accommodate measurement ports for water temperature and pressure will simplify in-house testing and commissioning measurements and also make it easier to purge air from the hydronic circuits. Externally mounted temperature sensors can be used for field commissioning measurements if strategically located copper pipe sections are included in the designs.

8.6 Identifying Space or Tap Water Heating Demand for Water Heater

Some “boiler-like” on-demand water heaters have separate set points and control algorithms for space heating and water heating. Others will need to identify whether the load is associated with space heating or potable water heating. This can be done using various sensors, including monitoring signals from a water flow meter installed in the potable water system or a flow meter installed in the space heating circuit. Many on demand water heaters utilize such sensors as part of their burner control circuits to match the firing rates to the loads. In combo applications, use of load differentiating controls relate to DHW priority control logic.

8.7 Valves, Water Piping and Related Restrictions

Water piping between the heat generator and combination system should be sufficiently sized to avoid excessive pressure drops.

All external copper piping must be insulated with a minimum of the industry standard. The benefits from insulation of interconnect piping may be small if pipe lengths are short and use PEX or a similar type of piping that has less heat loss than copper pipe.

9. Generic guide to manufacturer in-house integrated mechanical or combination system space heating testing

This section is intended to provide guidance and some commentary for combo manufacturers to assist them to undertake “in-house” testing of their combos. In house testing using a simplified setup will enable them to better understand how their prototype designs and controls will perform when tested in a third party facility to the CSA P.9 standard (P.10 for IMS manufacturers). In house testing does not necessarily need to be designed to produce 100% accurate performance results, but it is considered indispensible in the product development and optimization cycle, because the benefits of improved system design and operation can be readily identified through comparisons of “before” and “after” test results.

It is typically not cost effective to pay a third party test lab to do the first evaluation of a complete combo system. The lab fees and the challenge with design engineers specifying adjustments when they are not on site makes it problematic. Simple testing in the manufacturers own facility can ensure the results are in the right range first.

A sketch of a suggested test setup for performing measurements to the CSA P.9 standard is provided in the standard. A simplified version of that is shown below in Figure 6.

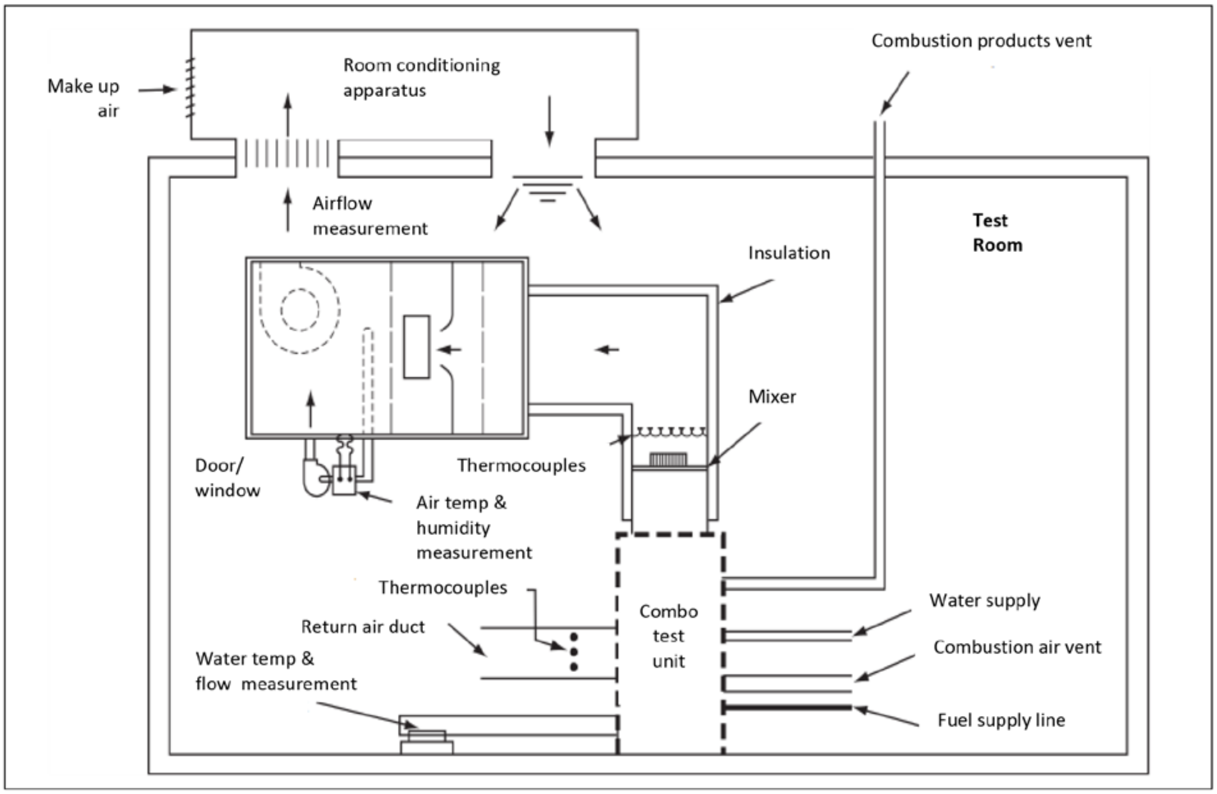

Figure 6: Simplified schematic to illustrate setup for P.9 Tests (individual combo components not shown)

The figure illustrates a tunnel air enthalpy measurement setup that is based on the ASHRAE 37 standard. The air measurement apparatus shown in the standard figure uses a flow nozzle and a balancing fan to allow the use of an air flow measurement technique that requires a high differential pressure (~ 1 to 4 inches of water) across the nozzle. Used with accurate manometers, this apparatus provides high measurement accuracy on the order of 1 to 2% of air flow, and it also provides a well mixed air flow to allow for accurate temperature measurement of the supply air flow.

The P.9 standard identifies the flow nozzle incorporated in the tunnel air enthalpy apparatus as an acceptable method of measuring air flow, but it explicitly (clause 6.3) permits other air flow measuring procedures provided that the accuracy limits specified in the standard are satisfied. This provides an opportunity to use a more straightforward air flow measurement technique that does not require a balancing fan apparatus. In some cases, the use of an flow measurement chamber with a balancing fan to adjust the static pressure of the supply air duct has been linked to stability issues with EC motors that have been programmed for constant airflow, so avoiding the need for balancing fans is advantageous.

9.1 Electrical & Gas Consumption Measurements

It is assumed that any manufacturer who is developing advanced combos already has instrumentation to measure electrical energy use, fuel consumption, combustion performance, temperature, and pressure (gas manifold pressure, duct static pressure etc.). If that is not so, such routine measurement equipment should be procured. Gas and electrical utility billing meters should provide sufficient accuracy and resolution for product developmental tests.

9.2 Data Logger

It is also assumed that the manufacturer will also have access to a data logger system for the work. If not, one should be procured that has sufficient accuracy and number of measurement channels for the intended work. It is estimated that about eight channels will be needed for temperature measurements plus a few analog or digital channels to suit the outputs from flow meters, pressure transducers etc (either analog or digital depending on the measurement instruments that are selected). Data loggers are widely available from many suppliers. Campbell Scientific, Fluke Instruments, Omega, and Measurement Computing (personal DAQ) are a few suppliers of small scale data logger systems that could be considered. Software support for the selected data logger should be considered at the time the equipment is being evaluated. If the manufacturer does not wish to commit resources to purchase a datalogger, rental may be an option, although the expected cost savings from short term rental are likely to be small.

9.3 Air Flow

For air flow measurements during in-house testing, an averaging air flow grid installed in the supply air duct is recommended, in conjunction with a precision differential pressure manometer. Averaging air flow measurement stations are available in a wide range of sizes from a variety of suppliers and they are relatively inexpensive because they are often used within commercial Variable air Volume (VAV) heating and cooling systems. A Google search using the term “Air Flow Measurement Station” identifies numerous suppliers and links to obtain further information. Nailor Industries Inc. and Dwyer Instruments both provide averaging air flow measurement stations in a wide range of duct sizes.

9.4 Manometers

Differential pressure manometers are also widely available, ranging from incline manometers to precision digital transducers. Care must be taken to properly match the measurement range of the transducer or manometer to the pressure provided by the measurement station over the anticipated range of air flows. For digital transducers, capacitance based instruments are known to work well in the low differential pressure range that would normally be specified (~ 0.5 inches of water column differential). Suitable capacitance based low range differential pressure transducers are available from Setra Instruments, MKS Instruments (Baratron), Dwyer Instruments, and others.

9.5 Temperatures

Inlet and outlet air temperatures can be measured using thermocouples, thermistors or averaging duct sensors. Because of their low cost, ease of use and broad availability, thermocouples are likely the instrument of choice for this application. An array of thermocouples can be fabricated from a spool of thermocouple wire and connected together in parallel to provide a single reading that represents the average value. Thermocouple grade wire is available from a number of suppliers, including Thermo Electric Company Inc, Omega Inc. Watlow Inc. and others. Temperature sensors to monitor other parameters such as water temperatures can also be fabricated from the same thermocouple wire. Care should be taken to ensure that thermocouple grade wire is used rather than similar but less accurate extension grade wire.

9.6 Water Side measurements

For water side measurements across the coils, a flow meter and temperature sensors are needed. These measurements could be made using discrete sensors (i.e. a water flow meter and separate temperature probes). Care must be taken to ensure that inserting a flow meter into the water loop does not change the flow rate of the circulation pump. That is particularly important with low power circulators that are typically used for combo applications, where installing a conventional high pressure drop turbine flowmeter may choke the water flow. Accurate flow meters without high pressure drops are available. Some can be purchased already packaged with temperature sensors as “Energy meters”. They simultaneously measure the supply and return water temperatures and the water flow rate and they directly calculate the energy flow from those measurements. Energy meters are used in district heating and cooling applications and they are fairly common in Europe. They are available from a number of suppliers that include Kamstrup, Siemens, Badger Meters, Elster Metering, ABB Meters and others. Packaged energy meters are normally configured with some means to read the individual parameters as well as the calculated energy flows. Most provide some internal data storage and/or digital outputs that can interface with external data loggers.

9.7 Variations from P.9 Standard for in-house work

The CSA P.9 standard requires that the space heating be determined using two measurements (air side and water side) with agreement within an acceptable tolerance for the steady state full capacity space heating test. For in house measurements undertaken by a manufacturer in the context of focussed product development work, agreement between air side and water side measurements is not necessarily required. It is suggested that the manufacturer concentrate on those measurements that target the specific component or controls approach that is being investigated. For example, if different fan delay or "after-run" approaches are being evaluated, the air side measurements are far more important than attempting to achieve balance between the air side and water side. Depending on the amount of energy left within the water coil when the blower fan shuts down and other energy losses from the system, it is possible that there will not be an energy balance between the air-side and water-side measurements even with "perfect" instrumentation, measurements and calculations.

The CSA P.9 requires measurement of air flow and temperatures at least every five seconds. For in-house tests, this measurement frequency could likely be relaxed for some tests. In addition, full compliance to the P.9 standard requires precise temperature control of the test room where the combo is installed for testing as well as precise control of city water temperature. For in house developmental testing those requirements may also be relaxed, provided that the temperatures do not vary much during tests. A reasonably sized conditioned commercial space will likely be adequate, at least for initial testing and development.

9.8 Instrumentation Layout

A simplified schematic to illustrate a general layout of the measurement locations and parameters for in house testing of a condensing tankless water heater combo is shown in Figure 7. The air flow through the air handler supply duct will be monitored using an averaging air flow station and manometer (not shown) as described in section 7.3.

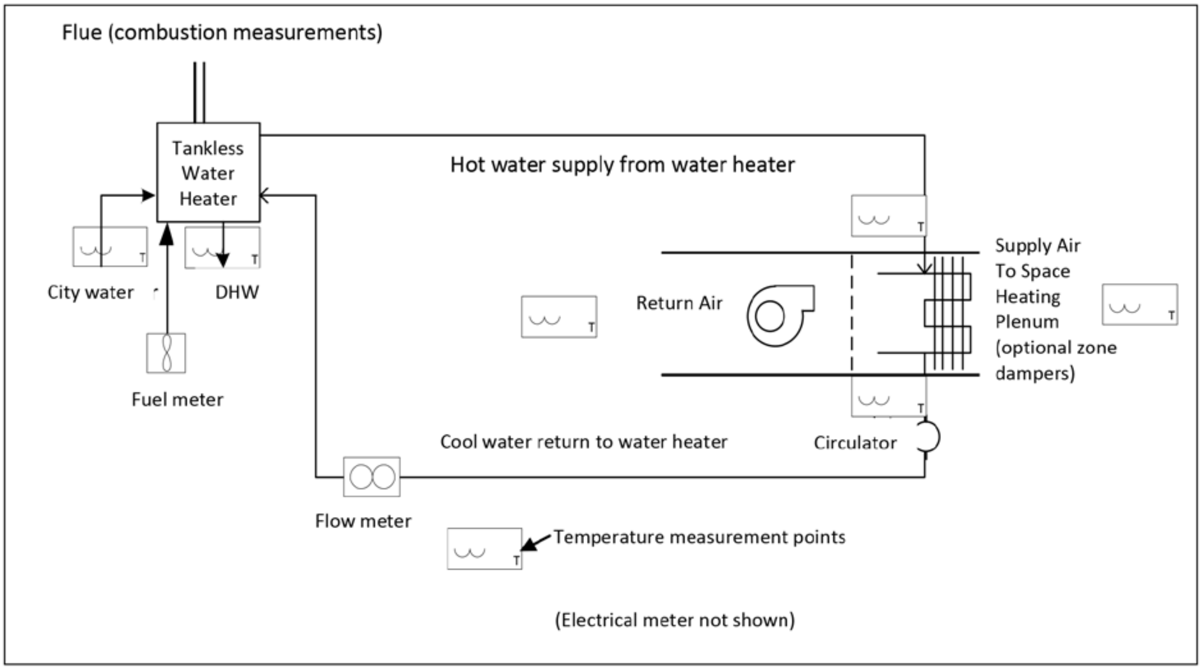

Figure 7: Simplified measurement schematic for in house testing of a tankless water heater based combo

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