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Condensing Furnace Venting Part 1: The Issue, Prospective Solutions, and Facility for Experimental Evaluation

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OAK RIDGE NATIONAL LABORATORY
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Energy and Transportation Science Division

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ABBREVIATIONS AND DEFINITIONS

ΔP	test room (chamber) pressure minus outdoor pressure
ΔT	average bottom-to-top chimney temperature minus outdoor temperature
AFUE	annual fuel utilization efficiency
APGA	American Public Gas Association
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Category I	gas appliances, such as noncondensing furnaces, based on natural-draft combustion served by negative static pressure vents designed so that vent gas temperature remains high enough to avoid excessive condensate production in the vent
Category IV	gas appliances, such as condensing furnaces, based on forced-draft combustion served by positive static pressure vents
DFR	direct final rule
DOE	US Department of Energy
EPCA	Energy Policy Conservation Act of 1975
Furnace	for purposes of this report, a device that provides space heating through an air distribution system, is fueled by natural gas or propane, with a heat input rate of <225,000 Btu/h, but excluding special classes also covered by the standards such as mobile home furnaces or small furnaces (<45,000 Btu/h)
HDD	heating degree days (base 65°F)
HVAC	heating, ventilation, and air conditioning
NAECA	National Appliance Energy Conservation Act of 1987
ORNL	Oak Ridge National Laboratory
PID	proportional integral derivative (controller)
R&D	research and development

EXECUTIVE SUMMARY

In 1987, the National Appliance Energy Conservation Act prescribed the first federal minimum energy conservation standards for natural gas furnaces at an annual fuel utilization efficiency of 78%, effective January 1, 1992. One of the techno-economic issues that has prevented higher furnace efficiency standards since then is the lack of cost-effective, simple, and safe solutions that enable condensing furnaces and atmospheric combustion water heaters to vent through the same existing chimney.

This report is part 1 of a two-part series and documents the issue, prospective solutions, and a test laboratory established to evaluate prospective venting solutions. A subsequent part 2 report will document the updated prospective solutions (since they are evolving), the experimental evaluation methodology, and results of the evaluations.

The fundamental issue is that higher furnace efficiency standards would require use of condensing furnaces; and when existing noncondensing furnaces are replaced and costs to modify the venting systems considered, it is unclear whether this requirement is cost effective in all applications. It might be possible to reuse existing vertical vents as chases for new condensing furnace venting systems. If not, where physical constraints and codes allow, it might be possible to install new horizontal side-wall vent systems. Where these options are not feasible, running new vertical vents through buildings and roofs would be an alternative, albeit at additional cost.

The most challenging application is when existing noncondensing furnaces and draft hood–equipped atmospheric combustion water heaters are common-vented up the same chimney and a side-wall vent for the new condensing furnace is not an option. Cost-effective, commercially available solutions that enable condensing furnaces and atmospheric combustion water heaters to vent through the existing vertical chimney are needed.

In this study, a search for solutions was undertaken that included efforts devoted to inventing new solutions and monitoring developments by industry. Several prospective solutions were identified that appear to be simple and cost effective for retrofitting into Type B metal chimneys and/or masonry chimneys. Solutions for both metal and masonry chimneys are emerging from M&G DuraVent, the North American arm of M&G Group, believed to be the largest vent products company in the world. Another prospective solution is a minor adaptation of commercially available fan-assist kits for retrofitting draft hood–equipped water heaters. An additional prospective solution is known as EntrainVent, a precommercial invention by Oak Ridge National Laboratory. These prospective solutions are described in detail in this report.

A new furnace and water heater venting system test laboratory was established to implement an experimental program of evaluation for the prospective solutions. This new experimental facility is also described in detail in this report.

1. INTRODUCTION

In 1987, the National Appliance Energy Conservation Act (NAECA) prescribed the first federal minimum energy conservation standards for natural gas furnaces at an annual fuel utilization efficiency (AFUE) of 78%, effective January 1, 1992.

Research was undertaken at Oak Ridge National Laboratory (ORNL) to identify the technical issues preventing an increase in minimum AFUE and to find or develop solutions so that the AFUE level could be revisited and potentially raised. The approach to issue discovery was to conduct an exhaustive review of public comments submitted to the most recent furnace rule docket by the various stakeholders. It was determined that one of the techno-economic issues that has prevented higher furnace efficiency standards is the lack of cost-effective, simple, and safe solutions that enable condensing furnaces and atmospheric combustion water heaters to vent through the same existing chimney.

This report is part 1 of a two-part series, which together, documents the issue, prospective solutions, a test laboratory established to evaluate solutions, methodology for evaluating solutions, and results of the evaluations. Documented herein are the issue, prospective solutions, and test laboratory; the remaining topics are addressed in the subsequent part 2 report. In this report, Sect. 2 provides background on the minimum furnace efficiency standards, venting of noncondensing and condensing furnaces, issues raised by stakeholders preventing an increase in minimum AFUE, and, in general, the kind of solution needed to address the issues. Section 3 describes prospective solutions enabling venting of condensing furnaces and atmospheric combustion water heaters through the same vertical chimney. Section 4 describes the furnace and water heater venting system test laboratory established to experimentally evaluate the prospective solutions.

2. BACKGROUND

2.1 BRIEF HISTORY OF FURNACE MINIMUM EFFICIENCY STANDARDS

The US Congress enacted the Energy Policy Conservation Act (EPCA) of 1975, which directed the Federal Energy Administration to establish test procedures and voluntary energy efficiency improvement targets for certain home appliances (US Congress 1975). In 1978, the National Energy Conservation Policy Act amended the EPCA and directed the US Department of Energy (DOE) to establish energy efficiency standards to replace EPCA voluntary targets (US Congress 1978). The EPCA was further amended by the NAECA of 1987 and its amendments of 1988 (US Congress 1987).

The EPCA, as amended by the NAECA, established energy efficiency standards for twelve types of "consumer products," including residential furnaces. The function of a furnace is to combust fossil fuel for the generation of hot air, which is then forced through a ducted air distribution system, for space heating. Furnaces include burner(s), heat exchanger(s), blower(s), and connections to ducts. For the purposes of this report, "furnaces" refers to residential furnaces fueled by natural gas or propane with a heat input rate of less than 225,000 Btu/h but excluding special classes also covered by the standards such as mobile home furnaces or small furnaces (<45,000 Btu/h).

There are two main types of residential furnaces: weatherized (for outdoor installation, such as on rooftops) and nonweatherized. Nonweatherized furnaces are far more common and come in two forms: condensing and noncondensing. Noncondensing furnaces can achieve AFUEs as high as about 82%. No gas furnaces exist with AFUE ratings between 82–89% because problems arising from condensation occur within this range. Furnaces with 90% or greater AFUE are known as "condensing" products because they condense water out of flue gases to recoup heat to warm the home that would otherwise be vented to outdoor air. Condensing furnaces avoid problems arising from condensation through use of corrosion-resistant materials and other design features.

In 1987, the NAECA prescribed the first federal minimum energy conservation standards for furnaces at an AFUE of 78%, effective January 1, 1992. In November 2007, DOE updated the furnace standards and published a final rule setting a minimum AFUE of 80%, effective November 19, 2015. This immediately prompted a court challenge by states and environmental and consumer groups on the basis that virtually all furnaces on the market have an AFUE of 80% or better already and that an 80% AFUE requirement beginning eight years later was not stringent enough. In 2009, DOE filed a motion for voluntary reconsideration of the furnace final rule, and the motion was granted by the court.

The Energy Independence and Security Act of 2007 required DOE to evaluate the potential of regional heating, ventilation, and air conditioning (HVAC) standards. The same year Congress amended the EPCA to expedite the rulemaking process by authorizing DOE to issue direct final rules establishing new energy conservation standards upon receipt of joint stakeholders' proposals. In October 2009, furnace manufacturers led by the Air-Conditioning, Heating, and Refrigeration Institute and efficiency advocates (including consumer groups, environmental advocates, and some states), in turn led by the American Council for an Energy-Efficient Economy, negotiated a consensus agreement that, for the first time, included different standard levels for residential HVAC equipment (including furnaces) in three climate regions: the North, South, and Southwest.

DOE issued a direct final rule (DFR) in June 2011 reflecting the standard levels in the consensus agreement. The DFR became effective on October 25, 2011, establishing new standards that would become effective May 1, 2013. In the North (blue states on the map in Fig. 1), furnaces would be required to have an AFUE of 90%. The 80% AFUE standard for the South and Southwest (red and green states, respectively, in Fig. 1) would remain unchanged. This history is summarized in Table 1.

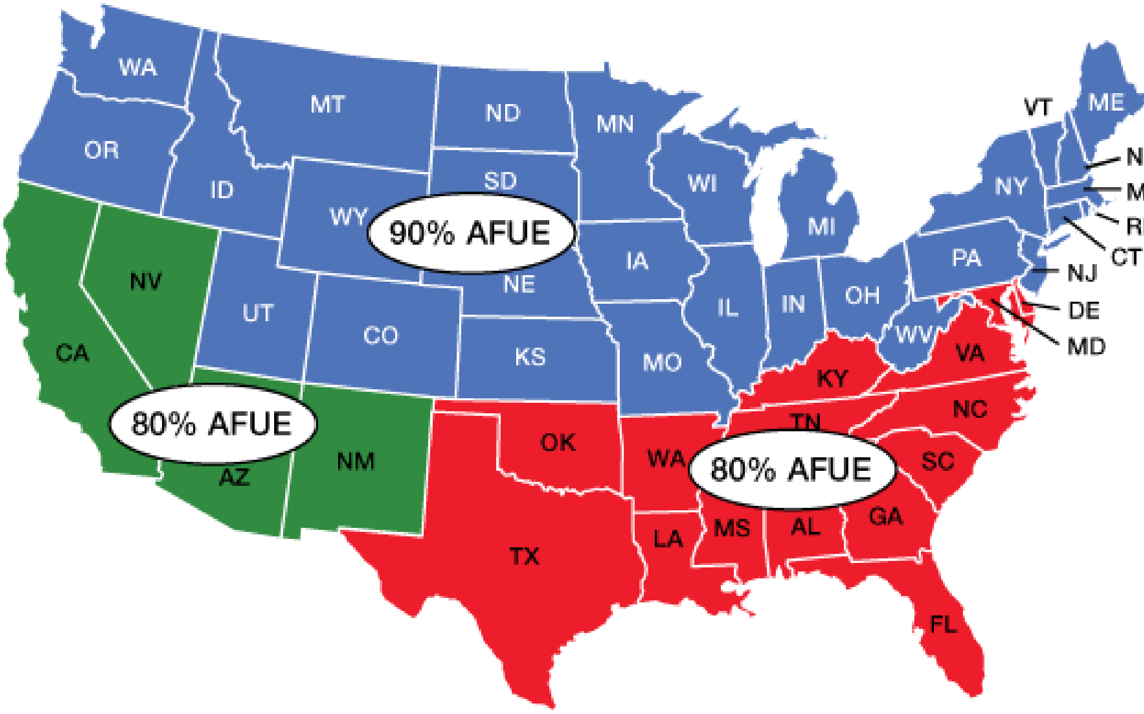


Fig. 1. Regions cited by DOE in the DFR issued in June 2011.

Table 1. Historical progression of standards and their effective dates for residential nonweatherized and weatherized furnaces (suitable for outdoor installation) (<225 kBtu/h)

			10/25/2011 DFR based on the consensus agreement between stakeholders		
	NAECA 1987	2007 update final rule	≥5,000 HDD[a]	<5,000 HDD	CA, AZ, NM, NV
AFUE: nonweatherized furnace	78%, effective 1/1/1992	80%, effective 11/19/2015	90%, effective 5/1/2013	80%, effective 5/1/2013	80%, effective 5/1/2013
AFUE: weatherized furnace	78%, effective 1/1/1992	81%, effective 11/19/2015	81%, effective 1/1/2015	81%, effective 1/1/2015	81%, effective 1/1/2015

[a]Heating degree days (base 65ºF).

On January 14, 2013, DOE proposed to settle a lawsuit brought by the American Public Gas Association (APGA), effectively suspending the October 25, 2011, DFR. Consequently, as of this writing, the furnace minimum AFUE remains at 78% but will rise to 80% on November 19, 2015. Some of the issues cited by the APGA and others on the furnace docket involve condensing furnace venting.

2.2 VENTING OF NONCONDENSING AND CONDENSING FURNACES

The venting codes refer to Category I, II, III, and IV gas appliances. Category I gas appliances, such as fan-assisted noncondensing furnaces and draft hood–equipped atmospheric combustion water heaters, are served by negative static pressure vents designed so that vent gas temperature remains high enough to avoid excessive condensate production in the vent. Category IV gas appliances, such as power burner condensing furnaces, are served by positive static pressure vents that are airtight, corrosion-resistant, and include a method of condensate disposal. Category II and III gas appliances are rare and are not addressed herein.

All Category I appliances should be vented using the manufacturers' installation instructions, which usually refer to the National Fuel Gas Code. Appliances in Category IV should also be vented according to the manufacturers' installation instructions. However, the National Fuel Gas Code does not contain any additional venting information for appliances in this category.

Manufacturers' instructions and codes permit Category I noncondensing gas furnaces to be vented vertically, through chimneys, and in common-venting arrangements with other Category I gas appliances. Per manufacturers' instructions, the venting systems for Category IV condensing gas furnaces are dedicated and cannot be used as part of another appliance's venting system (i.e., they cannot be common-vented with other gas appliances). Category IV gas furnaces cannot be directly vented into traditional clay tile–lined masonry chimneys or Type B double-wall metal chimneys, although an airtight, corrosion-resistant liner with condensate disposal can be routed through traditional chimneys.

Figure 2 shows a typical venting arrangement within a Category IV condensing furnace. The draft fan draws combustion air through the unit and provides the positive static pressure exhaust of combustion products to the vent. Illustrated in the figure is an elbow for horizontal venting, but vertical venting is also permitted by the manufacturer's instructions.

A Category IV condensing furnace can use either one or two pipes to the outside, depending on whether it is listed and installed as a central furnace (one pipe for exhaust) or a direct-vent furnace (two pipes, the second being for combustion air intake). Single-pipe installations use indoor air or air from a well-ventilated attic or crawlspace that complies with building code requirements for combustion air supplies. The two-pipe approach is more common in new construction, where the building envelope is generally more airtight, or in new or retrofit applications where the combustion air supply might be contaminated. Cited benefits include improved comfort and energy efficiency by reducing outdoor air infiltration (the source of draftiness), better indoor humidity control, and lower sound levels. In retrofit applications, since the combustion/dilution air requirement for the preexisting noncondensing furnace is greater than for the new condensing furnace, increased indoor depressurization (which could impact vent performance on remaining Category I appliances) as a result of the furnace retrofit is not a concern, and the single-pipe configuration is common. In lower cost applications—new construction or retrofit—the single-pipe configuration is more common.

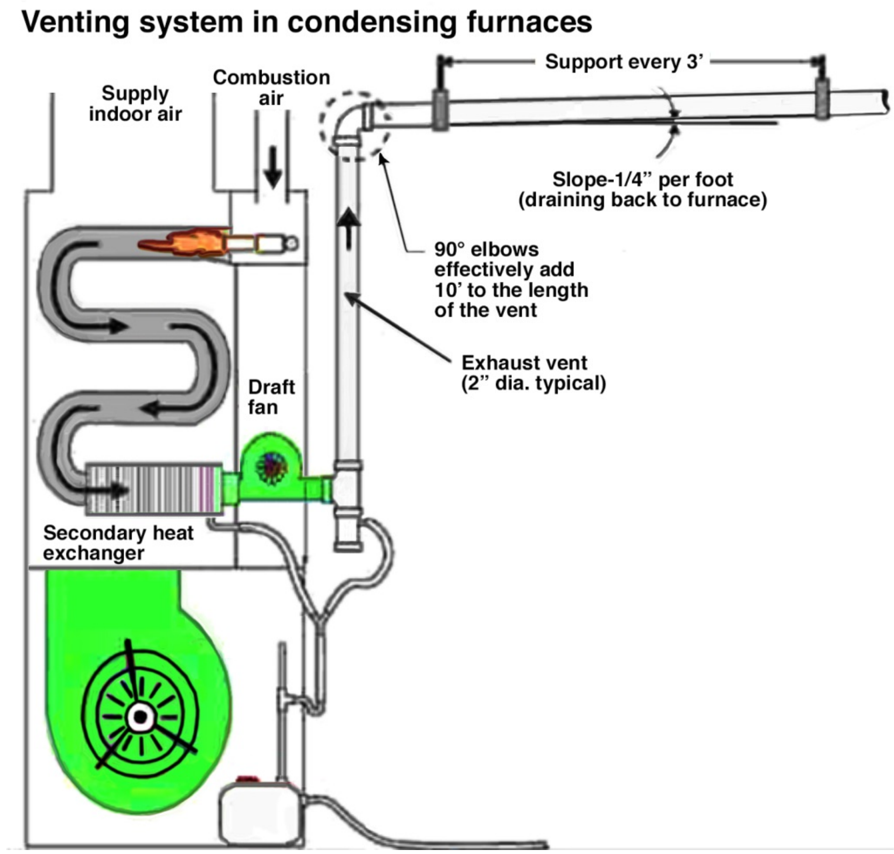


Fig. 2. Venting system in condensing furnaces. *Source*: InspectAPedia.com.

In retrofits where the furnace location changes or in new construction, prospective single-pipe condensing furnace locations, with or without water heaters, must be evaluated in terms of their ability to provide the proper quality and quantity of air for combustion. Some attics, crawlspaces, or equipment rooms, for example, might not have sufficient air supply to meet the building code requirements for combustion and dilution air. The installer should take care to determine that (1) there will be sufficient combustion air around the furnace and (2) there will be low levels of contaminants (such as detergents, cleaners, and aerosols) in the combustion air. If both criteria cannot be met, a two-pipe condensing furnace might be a more cost-effective alternative than relocating the furnace to an area that is free of contaminants.

Condensing furnaces with two-pipe vents have their advantages; however, home and building owners generally still prefer installations with only one wall or roof penetration. A commonly used vent for condensing furnaces is the concentric design (pipe in pipe), shown in Fig. 3. In this design, instead of two pipes penetrating the wall or roof (one for fresh air, another for flue gases), only one penetration is required. Flue gases are exhausted through the middle pipe, while fresh combustion air is drawn to the furnace through the outer pipe.

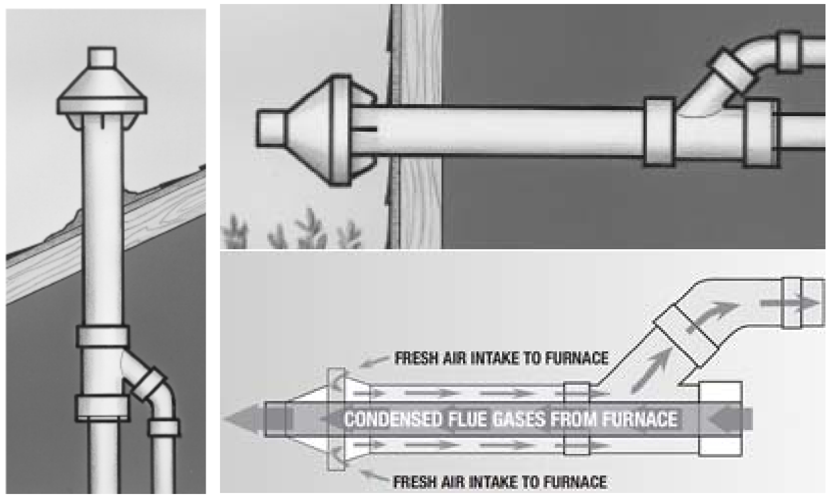


Fig. 3. Two-pipe condensing furnace vents requiring only one wall or roof penetration. *Source:* www.Bryant.com.

2.3 ISSUES RAISED BY STAKEHOLDERS CONCERNING CONDENSING FURNACE VENTING

The following subsections discuss the most frequently raised condensing furnace venting issues identified by a review of stakeholder docket comments received by DOE over the entire history of residential furnace rule development:

1. Inability to use existing venting systems in retrofit applications, resulting in extra costs.

2. Loss of venting performance by other gas appliances on common-vent systems in retrofit applications, resulting in extra costs.

3. Rules that restrict or outright prevent side-wall vents in new construction or retrofit applications, resulting in extra costs.

2.3.1 Inability to Use Existing Venting Systems in Retrofit Applications, Resulting in Extra Costs

In total, the installed base of noncondensing furnaces in existing residential buildings is larger than the number of condensing furnaces in existing residential buildings. Older homes in the North were originally designed and constructed for use with noncondensing furnaces. Those built since the mid to late 1980s were more and more frequently built to use condensing furnaces. Even with the many condensing furnaces installed as replacements in the North over the past 30 years, condensing furnaces will be replacing noncondensing furnaces in the majority of retrofits for the foreseeable future.

In every one of these upgrades, the existing Category I noncondensing furnace is served by a negative static pressure vent, which may be for example, a clay tile–lined masonry chimney or a Type B double-wall metal chimney terminating above the roof, and this existing vent cannot be used by the Category IV condensing furnace directly. It might be possible to reuse the existing vertical vent as a chase for the new condensing furnace venting system. If not, where physical constraints and codes allow, it might be possible to install a new horizontal side-wall vent system. Where these options are not feasible, running a new vertical vent through the building, though difficult and costly, would be the only alternative. In all of these cases, there are added costs compared with a like-for-like noncondensing furnace replacement because the preexisting negative static pressure vent cannot be used directly.

In townhouses and row houses, the technically acceptable or aesthetically allowable opportunities for side-wall vent installations are more limited than in single-family retrofit applications. If installing a liner in the existing masonry or metal chimney is not feasible, the alternate paths to the roof can be very expensive to implement.

2.3.2 Loss of Venting Performance by Other Gas Appliances on Common-Vent Systems in Retrofit Applications, Resulting in Extra Costs

Suppose two Category I gas appliances, a noncondensing furnace and an atmospheric water heater, are common-vented through a masonry or metal chimney in a single family home. The noncondensing furnace is then removed, and the chimney flue inlet previously used by the old furnace is sealed. The new condensing furnace is side-wall vented, as shown in Fig. 4. The water heater is now "orphaned" on the original negative static pressure vent and could experience a venting performance loss. The potential loss of performance stems from the fact that the chimney vent cross-sectional area was originally sized to vent both appliances but now serves only the water heater. Consequently, there could be insufficient draft to properly exhaust the flue gases from the water heater under some ambient temperature and wind conditions. This spillage of flue gases back into the basement through the water heater draft hood could result in dangerous levels of carbon monoxide and other pollutants in the home.

There are practical solutions to prevent the loss of water heater venting performance from creating a health and safety issue. For example, a Type B chimney liner could be installed that is properly sized for just the water heater. Alternatively, a powered draft inducer with backflow preventer could be installed. However, both of these solutions result in extra costs.

2.3.3 Rules that Restrict or Outright Prevent Side-Wall Vents in New Construction or Retrofit Applications, Resulting in Extra Costs

Comments to DOE include a litany of reasons why side-wall vents are restricted in certain applications, including the following:

- Local codes governing placement of side-wall vents:
  - Exhaust pipe must be a minimum of 2 ft from a window, door, or decking.
  - Exhaust and intake pipes must be above the highest anticipated snow level, including possible drifting snow.
  - Exhaust and intake pipes must be out of reach of children.
  - Exhaust pipe should not be installed above a walkway.
  - Intake pipes must be a minimum of 2 ft from dryers or power-vented water heater exhaust vents.
  - Exhaust pipes cannot be pointed in the direction of prevailing winds.
  - Exhaust pipes cannot be pointed in the direction of neighboring homes.
  - Exhaust and intake pipes must be on the same wall so that they experience the same wind dynamic and static pressures.
- Condominium or homeowner association covenants governing the architectural and aesthetic appearance of exteriors of buildings:
  - The most cost-effective means of satisfying some local code placement requirements would be to penetrate walls where feasible and then run the required distances along outside walls, but this is often in violation of aesthetic covenants.

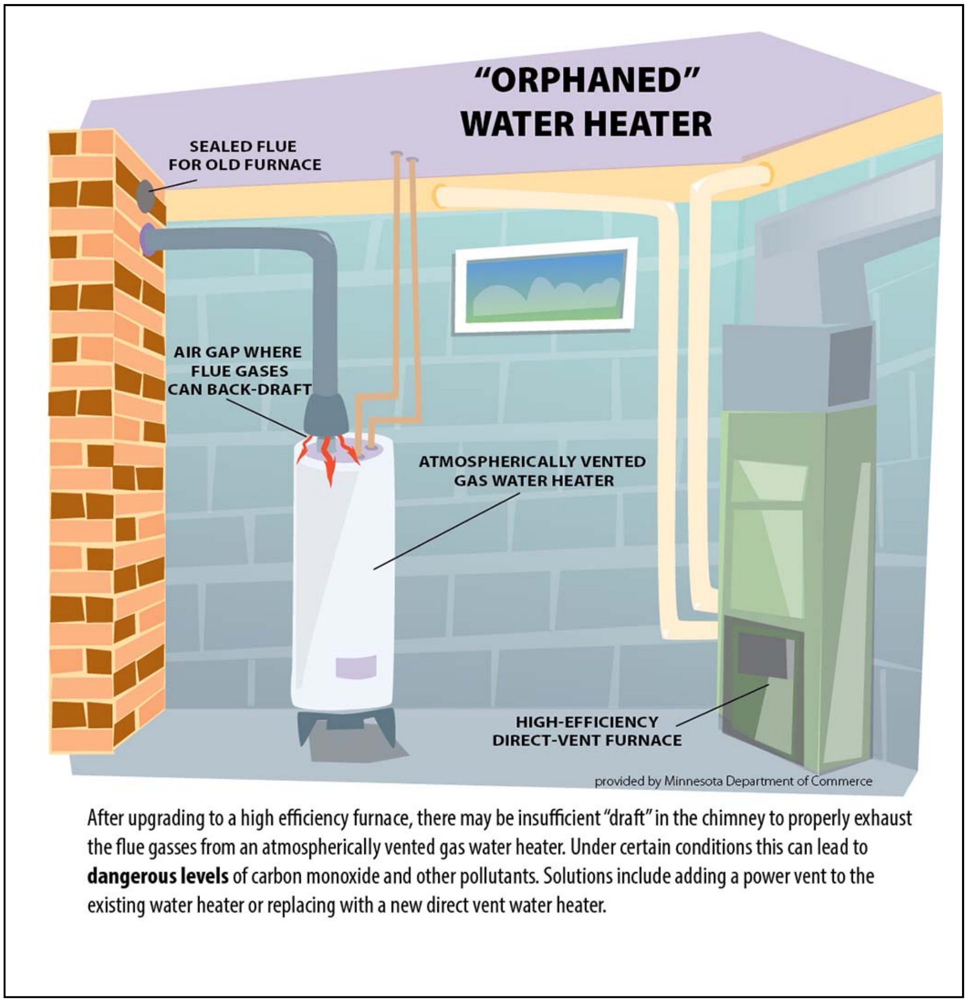


Fig. 4. "Orphaned" water heater. *Source:* Structure Tech.

2.3.4 General Description of Solution Needed to Address Venting Issues

To have the greatest impact, condensing furnace venting solutions should simultaneously address all three issues just described, with a focus on applications where condensing furnaces replace existing noncondensing furnaces. This suggests that efforts should be targeted toward solutions that somehow enable the Category IV condensing furnace to vent using the same preexisting vertical construction through the building and roof as the replaced Category I noncondensing furnace. Further, if the old furnace was common-vented with a Category I water heater, then the solution must enable the new Category IV condensing furnace and the remaining Category I water heater to vent using the same preexisting vertical construction. The common-vented solution must simultaneously provide an airtight positive pressure vent for the condensing furnace and a negative pressure vent with sufficient draft for the atmospheric water heater. If such solutions were commercially available, they could be used in cases where physical constraints or codes prevent new side-wall vents and, in some applications, could even be lower cost than new side-wall vents. Such solutions could also be used in new construction, enabling new buildings to cost effectively deploy a mix of Category I and IV gas appliances and avoid unintended consequences such as fuel switching to options with a larger environmental impact.

In summary, this project seeks solutions that enable condensing furnaces and atmospheric combustion water heaters to vent through the same vertical chimneys previously serving noncondensing furnaces and atmospheric water heaters. Such solutions are needed where physical constraints and/or codes prevent the installation of new horizontal side-wall vents and where running a new vertical vent through the building and roof is cost prohibitive. Since the combustion/dilution air requirement for preexisting noncondensing furnaces exceeds that for new condensing furnaces, increased indoor depressurization (which could negatively impact atmospheric water heater vent performance) as a result of the furnace replacement is not a concern. Therefore a solution that provides a single-pipe vent for the condensing furnace and sufficient natural draft for the water heater is all that is needed.

3. PROSPECTIVE VENTING SOLUTIONS

3.1 ENTRAINVENT DEVELOPED AT ORNL

Invention disclosure #201303220 filed December 10, 2013, at 9:06 a.m. eastern standard time describes EntrainVent. This invention potentially provides a low-cost solution for venting both the Category IV condensing furnace and the Category I natural-draft water heater through the original vertical chimney. EntrainVent leverages the same physical phenomenon that has been widely and successfully applied in ejector, vacuum jet, and carburetor technologies.

Theoretically, when a jet discharges to a larger space, the flow shear stress causes entrainment of the ambient flow into the jet stream. Consider the case of concentric pipes of diameter D1 and D2, as shown in Fig. 5. The flow in the inner pipe having diameter D1 is the powered exhaust of gaseous combustion products from the condensing furnace. The inner pipe flow acts as a jet, and the resulting entrainment causes a negative pressure, which induces a secondary flow in the annular space between the inner and outer pipes serving as the vent for the natural-draft water heater.

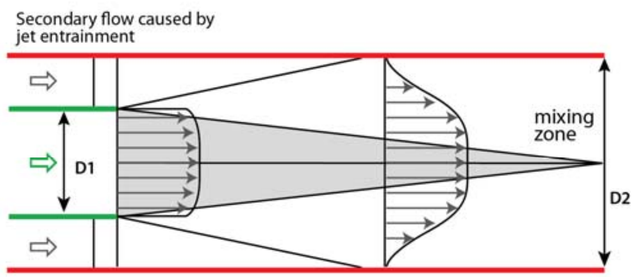
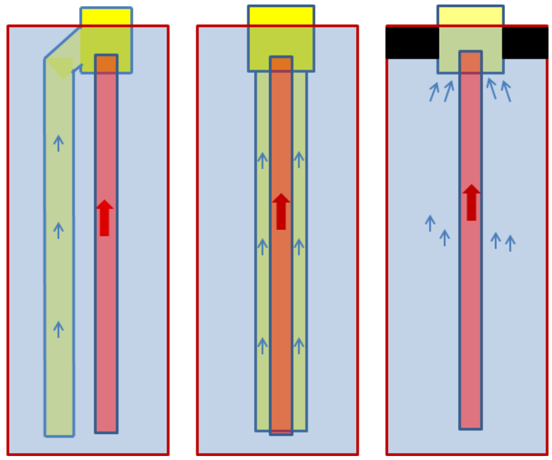


Fig. 5. Illustration of secondary flow caused by jet entrainment.

In a nutshell, the concept uses a fraction of the kinetic energy of the high-velocity, power-vented condensing furnace flue gases to induce flow entrainment negative pressure (or suction) on the water heater vent. The flow entrainment produces negative pressure at the top of the water heater vent, theoretically causing flue gases to rise and discharge from the top of the chimney under any ambient temperature and wind conditions. It is believed that this solution might not increase the load on the condensing furnace fan. Instead, it might only exploit the kinetic energy of the condensing furnace flue gas, which would otherwise be dissipated to the atmosphere.

With EntrainVent, establishing the draft for the water heater vent is no longer a problem whenever the condensing furnace is operating. At other times, a controls interconnect between the water heater and condensing furnace is required that essentially prevents fuel flow to the water heater until the condensing furnace power vent is operating.

Three different EntrainVent configurations, illustrated conceptually in Fig. 6, have been considered. In all cases the mixing chamber is installed at the top of the chimney, where ease of access for installation is greatest. The mixing chamber is completely passive, and no sensors, controls, or dampers with actuators are required. The thick red arrows denote power-vent flow motivated by the vent fan in the condensing furnace. The thin blue arrows denote induced and/or natural-draft flow from the water heater vent hood. In the configuration on the left (a), inside the masonry chimney, separate liners are installed for the water heater and the condensing furnace. In the center configuration (b), the separate liners inside the masonry chimney are arranged concentrically. In the right-hand configuration (c), only a liner for the condensing furnace is installed, and the original masonry chimney liner, for example a clay-tile liner, serves as the vent for the water heater. It is believed that each of these configurations could have advantages and be most appropriate depending on the application (in terms of building, climate, chimney condition, etc.); however, the configuration on the right (c) would likely have the lowest cost.



(a) (b) (c)

Fig. 6. Conceptual illustrations of three possible EntrainVent configurations.

More than 500 bench-top experiments were conducted to optimize the key dimensions for the mixing chambers in configurations (a), (b), and (c) shown in Fig. 6. For example, the dimensions for configuration (a) are shown in Fig. 7. L1 is the distance from the mixing chamber exit to the condensing furnace vent exit. L2 is the distance from the mixing chamber exit to the center line of the water heater vent as it enters the chamber. D1 is the inside diameter of the condensing furnace vent. D2 is the inside diameter of the mixing chamber. Mixing chamber optimization involves finding the L1/L2 and D1/D2 combination that maximizes negative pressure (suction) on the water heater vent.

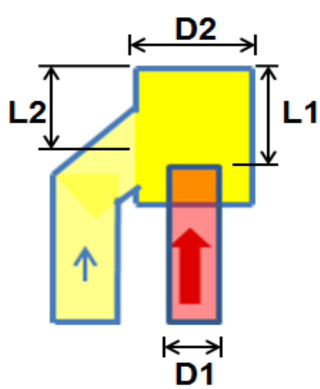
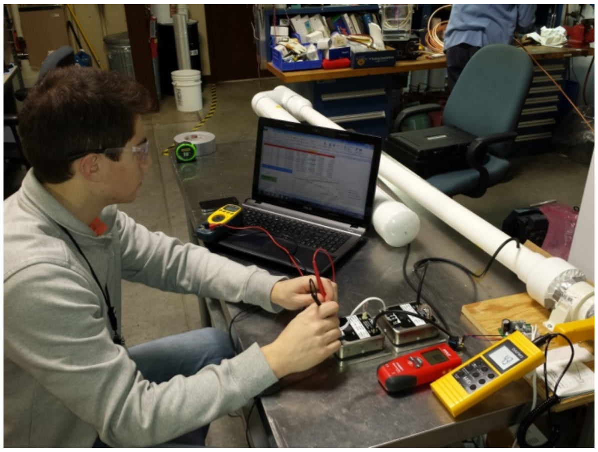
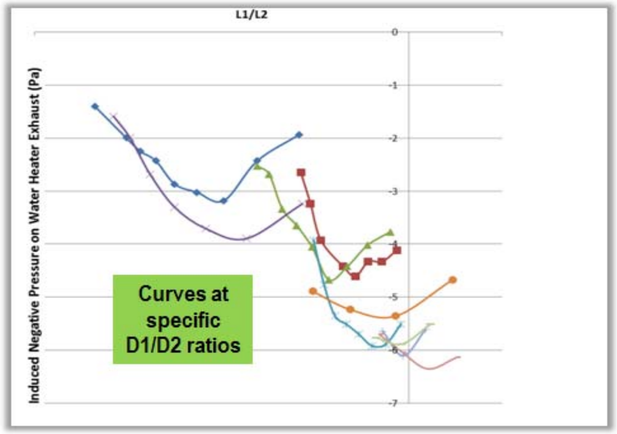


Fig. 7. Illustration defining the key dimensions of the mixing chamber for Fig. 6(a).

The bench-top test rig used to optimize the mixing chamber for configuration (a) (left-hand side of Fig. 6) is shown in Fig. 8(a), along with some typical results in 8(b). The L1/L2 scale and the D1/D2 curve labels were intentionally removed from the figure to protect the data. Measurements were taken for several hundred unique combinations of L1/L2 and D1/D2 to complete the optimization process. The optimal dimensions are identified in the patent application. The configuration shown in Fig. 6(c) is the EntrainVent common-venting option that was evaluated at full scale in the masonry chimney using the experimental venting facility. This option was selected because it is expected to have the lowest cost in cases where the clay tile–lined masonry chimney is in good condition. Figure 9 shows the full-scale design (a), prototype attached to a clay liner tile (b), and the bench-top apparatus used to optimize the dimensions of the prototype's mixing chamber (c).



(a)



(b)

Fig. 8. Bench-top test rig used to optimize configuration (a) and typical results (b).

To install this configuration in a real masonry chimney, the liner serving as the condensing furnace vent is lowered into the chimney from the roof, braced to the vent cap to hold its weight, and connected to the flue inlet near the bottom of the chimney that serves the condensing furnace. The preexisting clay liner serves as the flue vent for the water heater. The mixing chamber is simply a pipe penetrating an inexpensive concrete block with a diameter larger than that of the liner. Since the design induces a significant draft from the clay liner out through the top of the chimney, it does not matter that the cross-sectional area of the clay liner vent is too large for the water heater according to conventional Category I vent design principles.

Measurements were taken for several hundred unique combinations of L1/L2 and D1/D2 to complete the optimization of this solution applied to the full-size clay-tile chimney liner using the apparatus shown in Fig. 9(c). The optimal dimensions are identified in the patent application.

(a) **(b)** **(c)**

Fig. 9. EntrainVent configuration: design (a), prototype (b), and bench-top rig (c).

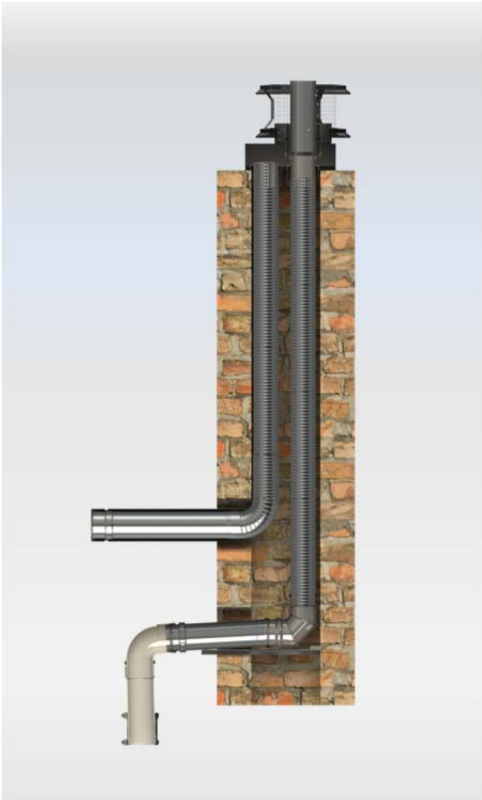
3.2 VENTING SOLUTIONS EMERGING FROM INDUSTRY

3.2.1 M&G DuraVent Solutions

The International Air-Conditioning, Heating, Refrigerating Exposition, held in conjunction with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Winter Conference in New York City, was held January 21–23, 2014, at the Javits Convention Center. At the expo, a large number of venting products were exhibited, but none of them could accommodate the venting of Category I and IV gas appliances in the same chimney. However, M&G DuraVent announced and distributed literature for a product currently in development that would provide such a solution. Shown in Fig. 10, the M&G DuraVent product is a patent-pending vent upgrade system that can exhaust a 90+ AFUE condensing furnace and atmospheric combustion water heater in the same chimney. The upgrade system enables reuse of the existing metal or masonry chimney and is composed of a new vent cap and appropriate liner(s).

If the existing chimney is Type B double-wall metal, as depicted in Fig. 10(a), the retrofit involves replacing the existing vent cap with a new one that supports a flexible stainless steel liner, which is inserted down the metal chimney to serve as the flue for the new condensing furnace. The annular space between the liner and the original Type B inner chimney wall serves as the flue for the water heater. The two flue streams remain separated and are exhausted individually to the atmosphere.

If the existing chimney is masonry, as depicted in Fig. 10(b), but in poor condition, the retrofit involves replacing the existing vent cap with a new one that supports separate liners for the two appliances. The left-hand liner is flexible aluminum and serves as the flue for the water heater, and the right-hand liner is flexible stainless steel and serves as the flue for the new condensing furnace. The two flue streams remain separated and are exhausted individually to the atmosphere.



(a) **(b)**

Fig. 10. Products emerging from M&G DuraVent for common-venting of a 90+ AFUE condensing furnace and an atmospheric combustion water heater.

3.2.2 Minor Adaptations of Commercially Available Fan-Assisted Products

Category I noncondensing fan-assisted furnaces supplanted draft hood–equipped furnaces many years ago, enabling reduced off-cycle losses and AFUE ratings of noncondensing furnaces as high as 82%. The vent pressure in a fan-assisted furnace is still negative (hence the Category I designation) because the draft action in a properly sized Category I vent will be stronger than the fan pressure rise. In addition, the vent gas temperature of these appliances is in the same range as traditional, draft hood appliances since the higher flue exit temperatures of draft hood appliances are moderated with greater amounts of dilution air.

Fan-assist kits for retrofitting draft hood–equipped water heaters are also commercially available (e.g., http://www.tjernlund.com/Tjernlund_CSA1_Chimney_Stack_Assist_Fan_Kit_8500605.pdf). These products are designed to ensure that orphaned water heaters will vent properly in a preexisting chimney after the old Category I furnace is removed and the new Category IV condensing furnace is separately side-wall vented. The kits come with safety interlocks that essentially prevent gas flow to the water heater unless the fan is operating. Relatively minor modifications to existing fan-assist kits could also provide a solution to the orphaned water heater problem in applications where the old Category I furnace is removed and the new Category IV condensing furnace must be vented through the existing chimney because venting through a side-wall is not possible.

One option along these lines was built and will be tested. For the case of a preexisting clay tile–lined masonry chimney, a fan-assist was installed on the vent connector between the water heater and chimney inlet. The version built has a stronger fan-assist than the typical water heater kit, akin to those built into condensing furnaces or into packaged units with gas heating, so that dilution air would be sufficient to keep flue temperatures low enough to enable use of lower cost chimney liner materials for the water heater. A separate low-cost liner was installed in the masonry chimney for the condensing furnace. In this configuration, the low concentration of water vapor from dilution air minimizes the condensation in the water heater liner. The fan-assisted water heater option is shown in Fig. 11.

Fig. 11. Fan-assisted water heater option.

4. EXPERIMENTAL VENTING FACILITY

4.1 EXPERIMENTAL FACILITY DESCRIPTION

This section describes the experimental venting facility constructed for acquiring the data necessary to evaluate the prospective condensing furnace and atmospheric water heater venting solutions.

The facility consists of a near airtight room (or chamber) and an indoor masonry chimney with clay-tile liner, an outdoor masonry chimney with clay-tile liner, and an outdoor Type B double-wall metal chimney. Together the three chimneys represent a large share of what exists in the existing building stock, and the outdoor metal chimney bay provides an easy means to change to any conceivable venting configuration. Two Category I gas-fired appliances—an atmospheric water heater and a fan-assisted noncondensing furnace—and one Category IV gas-fired appliance—a condensing furnace—reside inside the room.

Figure 12 shows the indoor masonry chimney foundation before the concrete was poured (a), the indoor masonry chimney under construction (b), the outdoor masonry chimney under construction (c), and the near airtight room in the process of being assembled (d).

(a) (b) (c) (d)

Fig. 12. Construction of the experimental venting facility.

The room is equipped with multiple and/or flexible natural gas, vent, electric power, and air duct connections. All three gas-fired appliances are mounted on wheels so that components can easily be moved to enable vent experiments using any of the three chimneys and any combination of appliances. For example, the facility can be configured to operate the atmospheric water heater and noncondensing furnace using any of the three chimneys. It can then be reconfigured by swapping out the noncondensing furnace, replacing it with the condensing furnace, and installing one of the prospective solutions in the chimney for evaluation. Experiments can also run the furnace only, water heater only, furnace and water heater simultaneously, or sequences of these states to fully examine venting performance under steady-state and dynamic operating conditions.

Figure 13 shows the appliances on rollers with flexible utility connections inside the room (a) and the completed facility from a distance with the door to the room open and indoor masonry chimney on the right (b).

(a) **(b)**

Fig. 13. Images of appliances inside the near airtight room (a) and the completed experimental venting facility (b).

The near airtight room resides inside a large high-bay laboratory area, which is space conditioned to a set indoor temperature by a separate preexisting HVAC system. When a furnace inside the room operates, it generally draws return air from the high-bay area through a duct penetration in the room wall and then blows the warm supply air outdoors through a duct that penetrates both the room wall and the surrounding high-bay laboratory wall. However, an additional high-bay wall duct penetration and a set of slide dampers is provided so that the furnace can draw return air from either the high-bay area or outdoors. The source of combustion air is the inside of the room, and the gaseous products of combustion are vented to the atmosphere through one of the chimneys. When the atmospheric water heater inside the room operates, as with the furnace, the source of air for combustion and dilution air for draft is the inside of the room and the gaseous combustion products and dilution air are vented to the atmosphere through one of the chimneys. Supply water for the water heater originates from a water temperature control loop in the adjacent equipment research and development (R&D) laboratory. The plant for the loop includes a variable-speed water chiller and an electric resistance immersion heater for precise proportional integral derivative (PID) control of supply water temperature.

As mentioned previously, the source of combustion/dilution air is the inside of the near airtight room. Since the furnace supply and return airflows are sealed from the room interior by airtight ducts and wall penetrations, the only air exiting or entering the room must be through the chimney, with the exception of controlled airflows and leakage through the room walls, ceiling, and floor, which are discussed later. When a furnace and/or water heater is firing, combustion/dilution air is vented up the chimney, and makeup air to the room must be provided. This is accomplished with the use of two round ducts between the room and outdoors with fan-controlled airflows, both with dampers that seal to zero flow when desired. One duct is set up to inject air into the room and the other to exhaust. During experiments, a steady pressure is maintained in the room by manually adjusting the volumetric flow of air through the two round ducts. Both ducts are outfitted with precise pulse-width modulated fans and flow instrumentation to control and measure volumetric flow when dampers are open.

Figure 14 shows one of the room-to-outdoor round ducts that provide control and volumetric flow measurement of makeup air for the combustion/dilution air vented up the chimney.

Fig. 14. Round duct for control of pressure in the room and measurement of combustion/ dilution makeup air.

The experiment room is near airtight but not perfectly airtight. The round duct volumetric flow measurements must be corrected for leakage through the room walls, ceiling, and floor to arrive at the experimental determination of volumetric flow up the chimney. This is accomplished by sealing off the chimneys from the appliances in the room and using the precise flow instrumentation on the round ducts to experimentally generate a leakage vs. pressure difference correction curve. The driving force for leakage is the pressure difference between inside the room and outside the room. The high-bay area is outside the room but has a large, poorly sealed overhead door in proximity to the near airtight room; hence, the pressure difference between the high-bay area and outdoors cannot be distinguished within the accuracy of practical instrumentation. Therefore, the leakage correction curve is based on the room-to-outdoor pressure difference.

The primary measurements necessary to characterize vent performance are pressure difference between the room and outdoors, temperature difference between the chimney (volumetric average over length) and outdoors, volumetric flow up the chimney, temperature and humidity in the room, temperature in the high-bay area, temperatures at intervals along the inside vertical length of the chimney, and the presence or absence of flue gas condensation at several intervals along the inside vertical length of the chimney. All of these measurements can be captured with this facility.

Since ORNL is located in a mixed/humid climate with a heating season of modest duration and harshness, the experimental facility was equipped with several features to enable useful experiments year round and to broaden the operating conditions for experiments beyond those provided by natural weather. These special facility features include the capability to independently control the temperature inside the near airtight room and the room-to-outdoor pressure difference, as well as the capability to create conditions in the indoor masonry chimney that might cause condensation on the vent walls.

An independent, precise, uniform, and steady temperature inside the room is achieved through the use of PID control of portable resistance heaters and fans to mix the room air. This feature enables elevated room temperatures so that experiments can be run at room-to-outdoor temperature differences typical of climates colder than Oak Ridge, Tennessee.

An independent, precise, uniform, and steady pressure inside the room is achieved by manually adjusting the volumetric flow of air into or out of the room using the pulse-width modulated fans on the two room-to-outdoor round ducts. This feature enables elevated or suppressed room pressures so that experiments can be run at room-to-outdoor pressure differences typical of a variety of equipment room airtightness values or other real-world application parameters.

This facility also has the capability to use the chilled water temperature control loop in the adjacent equipment R&D laboratory to route chilled water through copper tubing wrapped around the clay liner in the indoor masonry chimney. The loop, plus buffer tank, provides independent, precise, and steady control of the chilled water temperature through PID control of the variable-speed water chiller. This feature, along with the previously described independent ΔT and ΔP control, enables researchers to impose cold-climate operating conditions associated with flue gas condensation on the vent walls in a controlled manner, independent of actual weather occurring in Oak Ridge, Tennessee. The same capability enables researchers to reset the thermal mass in the indoor masonry chimney to a known condition, preventing disparate thermal histories from introducing noise to the data.

Figure 15 shows the copper tubing wrapped around the clay liner of the indoor masonry chimney. The external piping that distributes chilled water to the copper tubing can be seen in the background in Fig. 14. Poured concrete was used to fill the voids between the clay liner, cement block, and copper tubing.

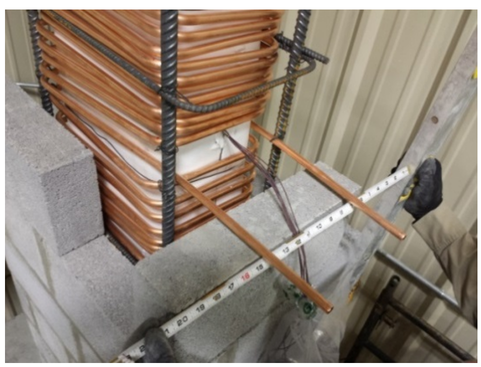
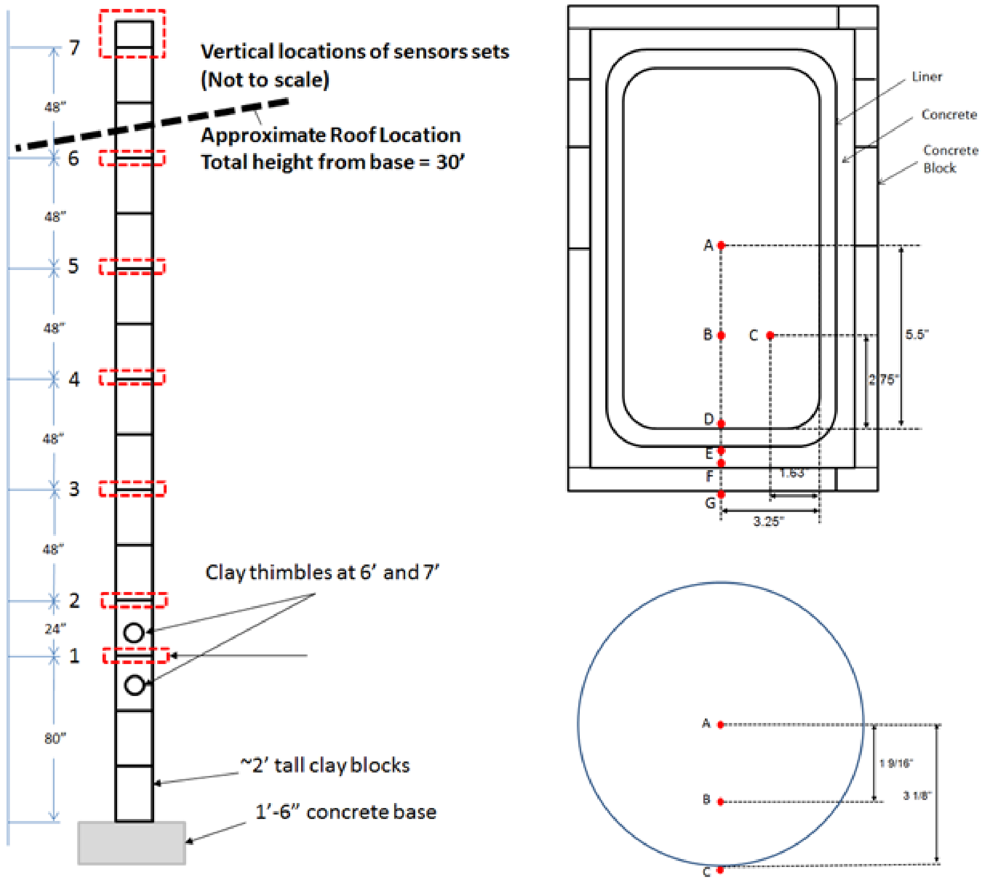


Fig. 15. Water-chilled copper tubing wrapped around clay liner to achieve operating conditions conducive to flue gas condensation or to reset thermal history.

4.2 DATA ACQUISITION SYSTEM AND EXAMPLE MEASURED DATA

A National Instruments data acquisition system is used for data collection from the experimental venting facility. This includes a “compactDAQ” chassis (cDAQ-9178), three 16-channel thermocouple measurement modules (NI 9213), one 8-channel analog input module (NI 9201), one 8-channel analog output module (NI 9263), and one 4-channel counter module.

Thermocouples are installed at seven different levels along the vertical height of each chimney, as shown by the red dotted lines in Fig. 16(a). At each level, seven thermocouples are installed at different locations of the chimney cross section, as shown in the upper half of Fig. 16(b-top). Thermocouples labeled as “A” measure the temperature of flue gas along the central axis of chimney. Thermocouples labeled as “B-D” measure the temperature of flue gas at different cross-sectional locations. Thermocouples labeled as “E-G” have been installed inside the chimney and on the outside wall. In addition to the preceding, there are three thermocouples at different cross-sectional locations of each of the two clay thimbles (aka, vent inlets), as shown in the lower half of Fig. 16(b-bottom).



(a) (b)

Fig. 16. Location of thermocouples at different heights along the chimney (a), at each cross section of the chimney (b-top), and at thimble (aka, vent inlet) cross sections (b-bottom).

LabView programming software is used for data collection. A screenshot of LabView as implemented for this project is shown in Fig. 17. A schematic diagram of the near airtight room and active chimney (only one can be active at a time) has been added to make the program more understandable and user friendly for the operator of the experimental venting facility.

Preliminary testing has been performed on the baseline noncondensing furnace. In this experiment, a 15 min cycle where the furnace was on for 5 min and then off for 10 min was repeated 14 times. The total test duration was 210 min, or 3.5 h.

A variety of measured temperatures are presented in Fig. 18. On the left (a), flue gas temperatures at the chimney inlet centerline (furnace thimble discharge centerline) and chimney centerlines at heights 1, 3, and 7 (see Fig. 16, locations 1A, 3A, and 7A) are displayed. On the right (b), the flue gas temperature at height 1 centerline (Fig. 16, location 1A) and inside the masonry chimney wall (Fig. 16, location 1F) are shown.

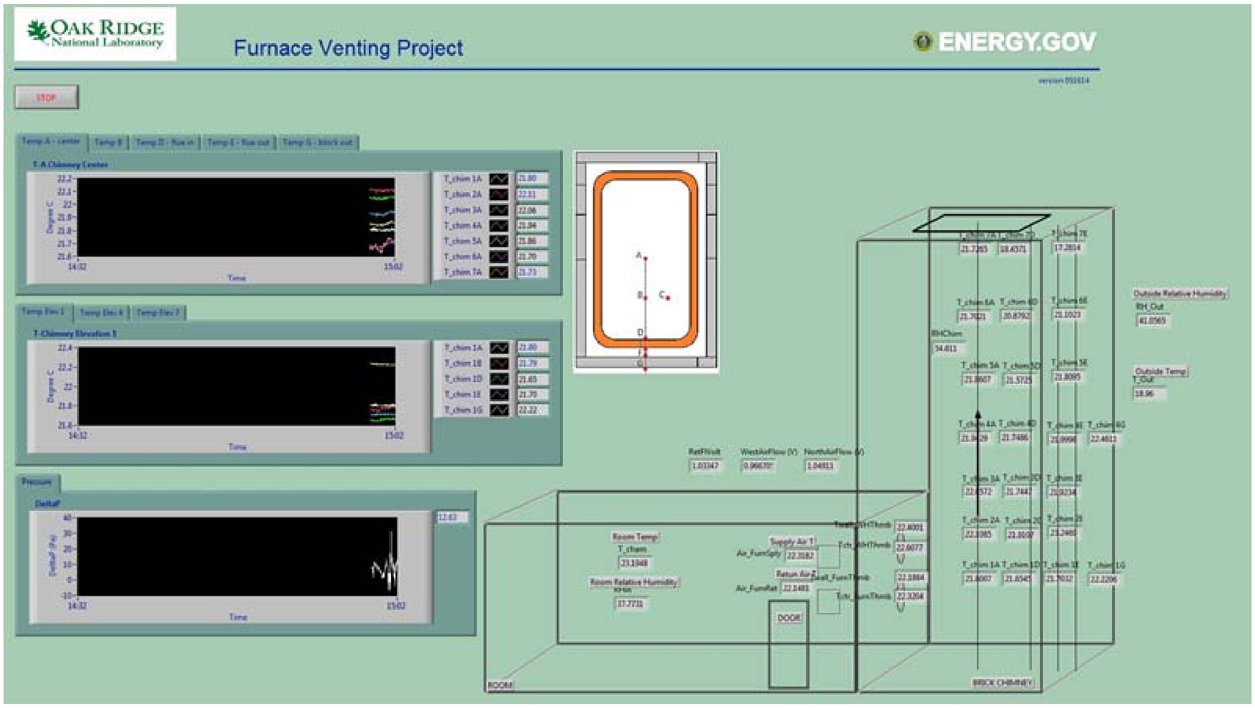
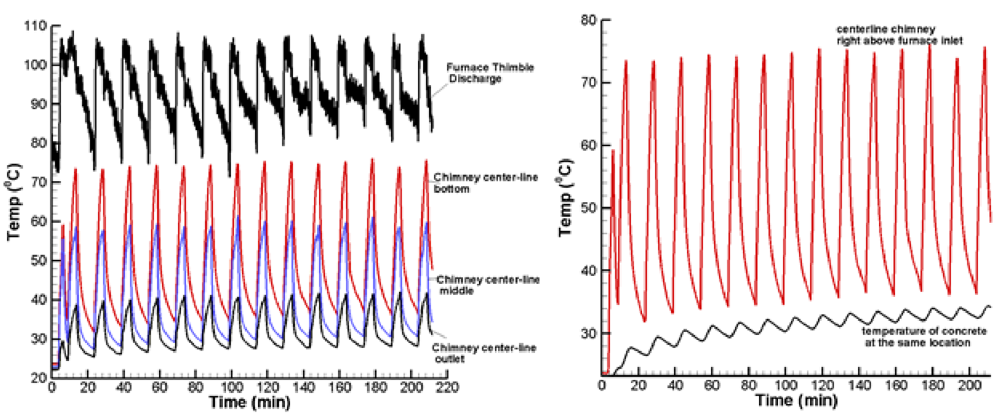


Fig. 17. Screenshot from LabView during data collection from experimental vent facility.



(a) **(b)**

Fig. 18. Example noncondensing furnace test results: (a) temperatures at centerline of chimney inlet (furnace thimble) and locations 1A, 3A, and 7A in Fig. 16 and (b) temperatures at locations 1A and 1F in Fig. 16.

A few observations are noted. The flue gas temperature at the chimney inlet centerline (furnace thimble discharge centerline) can reach as high as 108°C. Also, the comparison of temperatures at locations 1A and 1F in Fig. 18(b) highlights the significant thermal mass of the masonry chimney.

5. REFERENCES

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