Journal of the National Academy of Forensic Engineers®

http://www.nafe.org
ISSN: 2379-3252

Vol. XXIX No. 1 June 2012

Forensic Engineering Analysis of Building Depressurization Induced Product Re-Entry

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Abstract

With the advances in building materials and practices through the building expansions of the 1980's and 90's, along with the inherent benefits of these improvements, some unwanted side effects have resulted as well.

Indoor Air Quality (IAQ) issues ranging from mold and dust accumulations have become both a nuisance as well as, in some instances health issues to many homeowners who own houses with these inherent problems.

One such chronic building issue is the result of the failure to recognize the house – heating (or combustion) appliance as a "System". This problem is known as "Depressurization Induced Combustion Re-Entry".

Depressurization Induced Combustion Re-entry is the re-introduction of combustion emissions back into a structure as a result of negative air pressures developed by the structure as well as the location of the point of discharge of the emissions from the combustion appliance. Combustion appliances can be anything from a boiler, furnace or fireplace and this problem occurs regardless of the type of combustion fuel being consumed in the structure.

This paper will address the root causes of Depressurization Combustion Re-Entry using excerpts of cases investigated and assisted in litigation

The paper will also address house and system modifications that can be performed to reduce or eliminate the effects of Depressurization Induced Combustion Re-Entry.

Keywords

Ghosting Soot, Depressurization, Combustion Re-Entry, Backdrafting, Carbon Dioxide, Carbon Monoxide, Combustion Appliances, Backdraft, Downdraft, House Depressurization, House Tightness, Induced Draft Combustion Spillage, IAQ, Blower Door testing, Thermal Bridging, Negative Air.

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Advancements in Housing Material

House construction in the United States has increased significantly in the post World War II building boom through the 1950s and early 1960s. Advancements in the ability to increase the integrity of the standard housing building envelope in the 1980s and 1990's building boom that accommodated the growing World War II "Baby Boom Baby" generation allowed buildings to achieve thermal efficiencies far exceeding what was capable in the past.

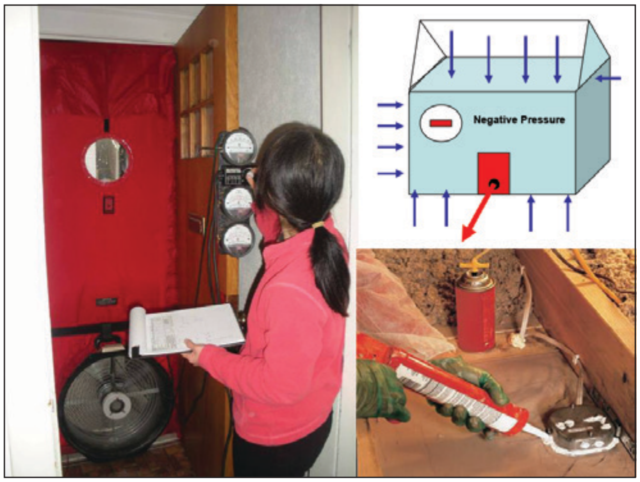
The drive and impetus for thermal efficiency and a tighter building envelope was born out of the energy crisis in the mid 1970s, which also saw an increase in the use of alternate energy sources, such as wood burning and solar heating systems.

At the same time as the advances in building materials developed, there was a "lag behind" regarding building codes being able to keep up with, as well as adjust, with the advances in not only building materials but also the alterations and modifications of how home heating appliances were constructed and installed.

Building Envelope Tightness

With an eye towards less air infiltration in an effort to increase the thermal integrity of a building, newer materials, such as heavier insulations, both of a batting and loose fill material have been introduced, as well as more advanced building wraps and vapor barriers.

Quantification as to the integrity of the building envelope was also a targeted and focused goal, with the introduction of blower door testing, which used a mechanical fan to pressurize the building envelope and to also measure and quantify the amount of air leakage from the structure.

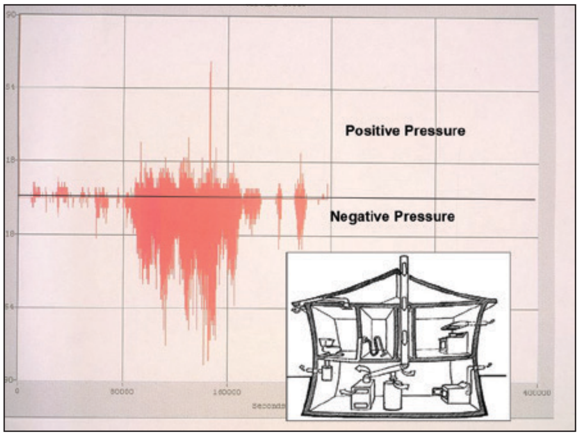


By knowing the "before and after" amount of air leakage and using the blower door testing apparatuses to measure and compare this leakage, home energy contractors have been able to decrease the amount of air leakage from a structure by sealing such air leaks around windows, attics, and other building openings that in the past would have allowed air infiltration into the building.

The goal of blower door testing and energy audit programs by State and Federal government organizations, as well as private contractors, is an effort to increase the long term energy savings of the structure and to reduce overall fuel consumption as well as increase the property value of these homes.

Creation of a Negative Pressure Within the Building Envelope

By reducing infiltration air openings into a building envelope, this also allows the building to develop and sustain a greater magnitude of negative air pressures in relation to the exterior of the home.



Negative air pressures are developed in homes during winter months as a result of many factors including mechanical air handling devices such as fans and blowers that remove air from the interior of the building and deposit them on the exterior of the home.

This photo of the differential pressure between the inside and outside of a house shows the existence of a negative pressure condition.

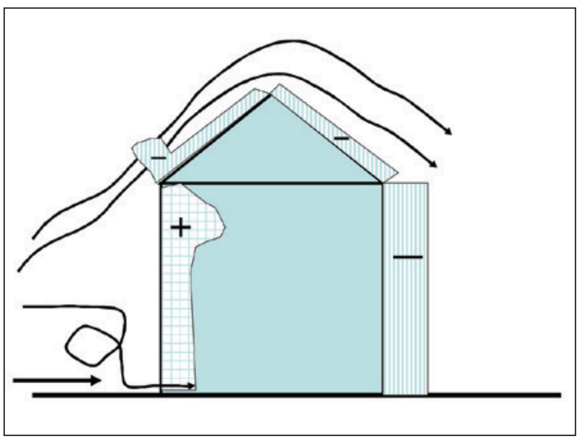


Illustration showing wind effects of pressure.
Reference ASHRAE Fundamentals.

House fixtures and appliances such as bathroom fans, clothes dryers, and kitchen exhaust hoods, as well as combustion appliances such as boilers and furnaces, many of which are outfitted with induced draft fans, contribute to the building's ability to develop a large negative pressure in relation to the exterior of the home while they are in operation.

Other factors also contribute to the building being capable of developing a negative pressure including wind flow over the structure. Air flow over a structure is unique since each individual house has its own unique topography around it, which in turn causes laminar and turbulent wind flow air currents over the structure, which also has the ability to affect the internal pressure within the structure.

Air density differences between the exterior and interior of the home also affect the structure's ability to develop a negative pressure during winter months.

Combustion Appliance Issues

Changes in design and installation practices of combustion appliances, such as boilers and furnaces, are another contributor to depressurization induced combustion re-entry problems.

In the event of an improperly operating boiler or furnace, the force in which products of combustion will pass in and then out of a chimney, known as a stack effect, will decrease.

It is generally accepted that depressurization of – 5 Pascals Pa (or .0200662991 inches of water) or more can cause interference with natural draft appliances and less harmful intermittent depressurization may be caused by exhaust fan, clothes dryers and other exhaust devices greater than 160 cubic feet per minute.

Additionally, an appliance that is installed in a room that is too small to provide adequate combustion air will also decrease the quality of combustion, which in turn allows the appliance to produce a heavier, more carbon particle laden product of combustion, which would require a comparatively stronger force to discharge the emissions not only from the chimney but also out of the chimney and away from the structure in which it is connected.

Backdraft- Depressurization Re-entry at the appliance

One path of product of combustion re-entry is caused by the changes in air flow when the appliance is in operation or shut down.

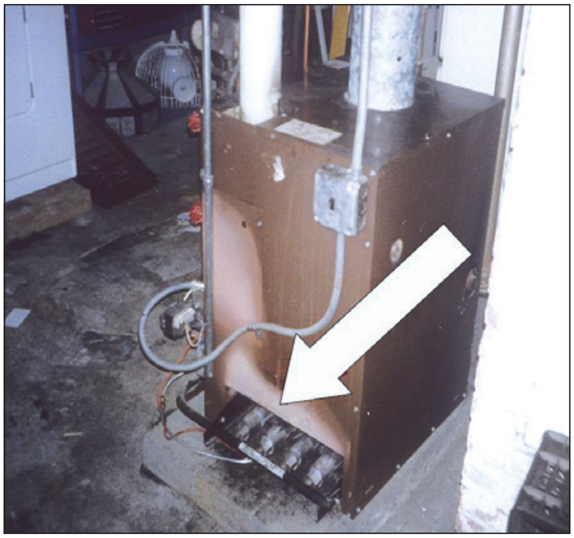
If a naturally vented combustion appliance is located in an area of depressurization difficulties in establishing or maintaining a proper draft is likely.

A firing appliance develops draft in the chimney and a resulting higher force known as the stack effect. This stack effect will be great enough to overcome any building air pressure differences allowing adequate operation of the heating appliance without combustion product spillage.

Upon the appliance shutting down however, when there are emissions in the chimney flue between the appliance and the peak of the chimney, upon the termination of combustion, the negative air pressure effects within the structure will reverse the flow direction of these emissions. This causes these products of combustion to back out of the chimney flue and appliance and into the home until the building air pressure differences are equalized.

This type of problem manifests itself as emissions being seen backing out of heating system components such as barometric dampers and draft hoods as well as out of combustion chambers and fireplace dampers.

Oftentimes this phenomenon is known as “Rollout” in gas fired appliances.



Depressurization Re-Entry due to the Proximity of Discharge

When a building is developing a negative pressure and the products of combustion are discharging from a chimney or direct vent appliance discharge hood that is exhausting products of combustion adjacent to the structure, these two conditions together create a situation where products of combustion, although discharging from the system adequately, will be re-drawn into the structure.

This results in a condition where, over time, products of combustion accumulate to the point where they become more noticeable.

In houses that have "tighter" construction, in the event of higher differential-negative pressures being developed, the localized building "leak" air flow velocity and quantity will increase in comparison to if the house could not achieve these pressures. This facilitates the re-entry of outside air and entrained particles if the boundary layer of air is contaminated with products from any internal combustion sources.

Proximity of Discharge – The Chimney

The design of chimneys is crucial in thinking of the heating appliance and house structure as a "system" and many problems with product of combustion re-entry into homes is the result of chimney construction and design.

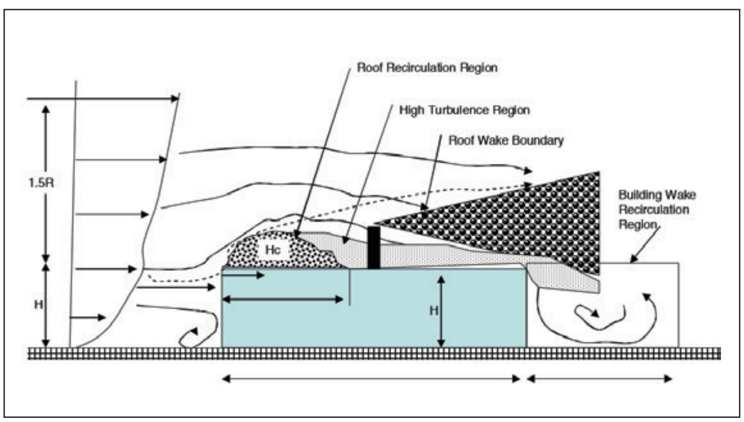


Illustration from ASHRAE Fundamentals.

Often times, although a chimney may conform to building code or NFPA 211's guidelines for chimney construction, in that the peak of the chimney be two feet over the top of the roof ridge where it is installed, (when the chimney is within ten feet of the peak), the plume of emissions may come into contact with the building, which in turn allows negative air pressures to draw smaller amounts of these products of combustion back into the structure over time.

A chimney that is properly built on a 1-story portion of the home may have its discharge plume strike a portion of the building that is higher than the 1-story addition, which in turn allows products of combustion to come into contact with and then re-enter the structure.

Proximity of Discharge – The Direct Venting Appliance

Another contributing factor to depressurization induced combustion re-entry problems is the use of direct venting appliances.

Direct vent appliances became popular in the 1980's era of the building boom in that their use allowed significant cost savings in construction by eliminating the cost of chimney construction.

Contrary to chimneys that discharge products of combustion into the air stream above the boundary layer of air around a structure, mechanical and direct vent appliances deposit these emissions adjacent to the building at or just above grade level in homes.

By discharging product of combustion emissions in a location allowing them to come into contact with the structure either by poor chimney placement and design or the use of a direct venting appliance, depending on the installation's unique features such as wind flow, negative pressures developed and topography, these situations enhance the likelihood of a structures ability to re-introduce these substances into the structure.

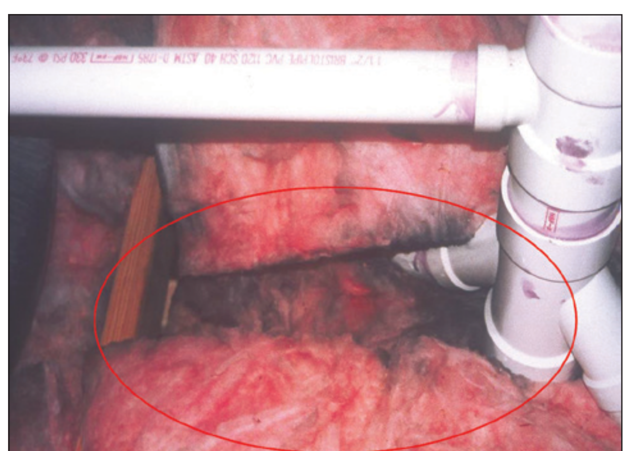
Paths of re-entering emissions flow

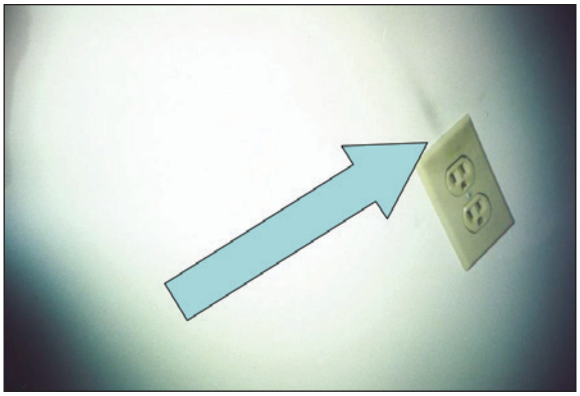
Paths of combustion product re-entry into structures can be a simple as reversal of flow down chimney flues exiting from the appliance's combustion chamber area or dampers.

In Combustion Re-Entry conditions where the emissions discharge from a direct vent or chimney and then re-enter the structure, tell-tail evidence of combustion re-entry is evident firstly in concentrations of "soot" laden material in areas further AWAY from the appliance as opposed to in direct contact with that appliance.

Accumulations of soot within attics on insulation materials is the result of emissions exiting the structure and reentering through ridge and soffit vents into the attic space.

As negative air pressures draw these emission particles into the attic space, the particles are "filtered" through the insulations fiberglass strands leaving a blackened deposit on the insulation





Negative pressures can also draw emission laden re-entry air from attic locations, through pathways created for house wiring allowing emission particle re-entry into the lower floors as seen by stained electrical outlets. Staining of carpeting adjacent to wall framing is also indicative of a leakage path through interior wall framing.

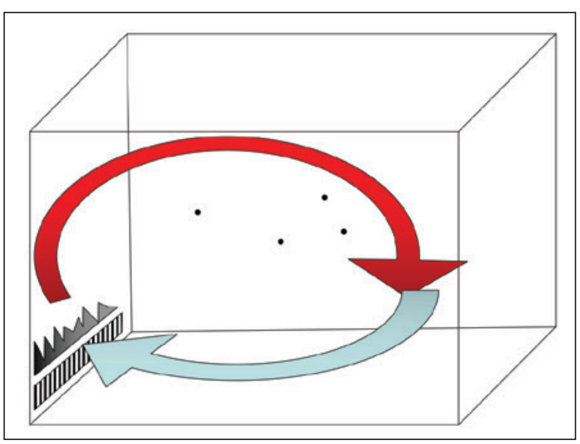
Other common pathways of re-entry emissions from an attic location is along vertical penetrations in the building envelope such as plumbing stack vent piping and attic hatch entryways.

Ghosting Soot Accumulations

Once within the interior conditioned space, carbon particles from the combustion appliance source will accumulate in common locations and is known as “Ghosting Soot”.

Particle staining on stud framing members within walls are an indication of poor indoor air quality within the structure.

Precipitation of these particles onto the wall at the framing locations is the result of thermal bridging and cooler temperatures at these frames allowing localized condensation which attracts airborne particles.



Particle accumulation above forced hot water baseboards are also common due to the air particles within the room being re-circulated in the convection air current flow within the room due to the heating action of the baseboard.

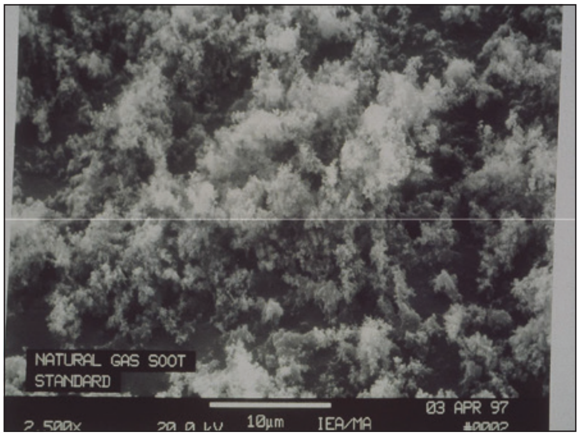
These particles will pass through the baseboard and concentrate these onto the adjacent wall due to moisture and temperature differences as well.

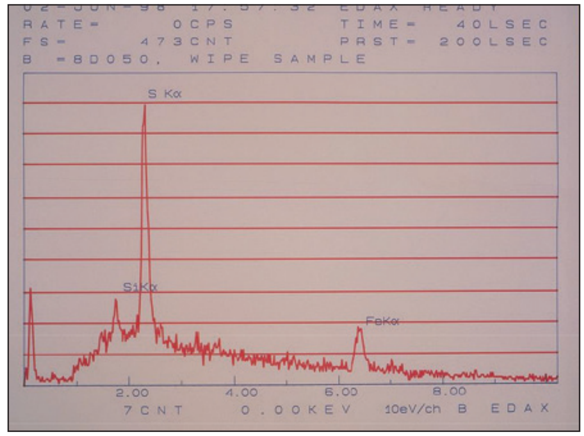
Common emission particle accumulations and deposits are often found on surfaces such as:

- Plastic Toys or Plastic Cookware
- Walls Shading the Locations of Studs Behind Sheetrock
- Above Hot Water Baseboards
- Glass Television or Computer Monitor Screens

Don't assume too quickly that the offending "soot" particulate is from the suspected source

In the event of a soot like substance within the home, care must be taken to ensure that the suspected origin of this product of combustion, being emissions from the heating system, are in fact from that source. Laboratory services are available that allow collected deposits to be analyzed and verified as to their origin.





For the purpose of verification of these sources, laboratory samples should be taken for analysis. Typical tests performed to verify these sources include Energy-dispersive X-ray spectroscopy and morphology analysis through certified laboratories.

Whenever this type of loss is being encountered, care must be taken to not to quickly assume that its origin is from a suspected appliance without independent confirmation through laboratory analysis.

There have been cases where the contaminating substance has been analyzed and found to be from combustion sources outside of the structure such as local power plants and neighboring property activities.

Re-Cap of Symptoms of Depressurization Induced Combustion Re-Entry Damage to Homes

Typically, depressurization induced combustion re-entry conditions are characteristic in the form of only a small amount to no soot at all discharging directly from the appliance, as would be found in a conventional heating or combustion appliance malfunctions.

Although small amounts of soot may be seen from oil fired appliances at areas such as the barometric damper or perhaps other openings, typically, depressurization induced combustion re-entry homes show the characteristic heavier concentrations of soot like substances further away from the appliance and on higher floors and not a direct discharge of soot into the home from the appliance itself.

Typically, homes that are being damaged from product of combustion re-entry have concentrations of a soot like substance in the attic, especially around vertical penetrations through the building envelope, such as vent pipes, as well as holes drilled in the wall sill plates to accommodate wiring paths.

More extensive testing of the potential backdrafting of appliances has been suggested in documents such as the ASTM Designation E1198-11 Standard Guide for Assessing Depressurization Induced Back-drafting and Spillage from Vented Combustion Appliances.

Modifications to Reduce Effects of Depressurization

The problem with depressurization induced combustion re-entry occurs as a result of two factors being present. The first is due to the building developing a negative pressure, coupled with the proximity of discharge of the appliance venting—be it a chimney or power venter termination point. There is, however, the possibility that the chimney itself will backdraft, especially during times of the burner turning itself off at the end of a heating cycle.

Although each house is unique upon itself and a blanket statement cannot be made that will address all structures, in our experience, the most cost effective, as well as effective way to address this problem is with chimney height extension or abandonment of direct venting appliances.

By increasing the chimney height, this increases the stack effect of the chimney which contributes to the appliance being capable of overcoming any negative air pressures within the building, and additionally, it deposits these products of combustion up in the air stream where they are more capable of being removed from the immediate vicinity of the building, allowing any infiltration air to be free of these substances.

The development of negative air pressures, the second factor in this problem, is more difficult to address, since there are many sources of this negative air pressure, other than internally operating fans.

With that said, companies such as Tjernlund and Fields market heat recovery ventilators that are fans that bring air from the outside into the building's structure at times when the combustion appliance is in operation in an effort to reduce the negative air pressure developed, thereby reducing or eliminating this problem.

Conclusion

The coordination of a building's ability to develop a negative pressure as a result of increased building envelope integrity, as well as conventional combustion appliance design and installation practices, must be embraced to prevent interaction between the house and these appliances in the future.

The industry must develop a heating system - house system concept as opposed to approaching the construction and installation of these different portions of the home as separate entities.

Depressurization induced combustion re-entry went from a little known phenomenon identified by Canadian HUD builders in the early 1980s to one which now has resulted in being recognized by Code officials, such as the Uniform Building Code, Standard Building Code, National Building Code, and other State Codes.

In addition to allowing products of combustion to re-enter a home causing damage to interior surfaces, the physical effects of carbon particle re-introduction and its contribution to poor indoor air quality is also a concern.

There have also been instances where an appliance that is being effected by combustion reentry due to depressurization has resulted in injury and death to the occupants within.

The effects of depressurization induced combustion re-entry are a shining example of how builders must approach a "whole house system approach" to building design and construction and not allow the "compartmentalization" approach by the various designers and subcontractors involved with the project.

With the proper understanding of the potential for depressurization induced combustion reentry, unsubstantiated causes of the incident, which may benefit to serve as a scapegoat to heating contractors or other individuals, can be avoided and the true underlying cause of this problem be understood and corrected.

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ASTM E631 Terminology of Building Constructions

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ANSI Standard Z21.47 Gas Fired Central Furnace

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