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DESIGNS FOR NEW RESIDENTIAL HAC SYSTEMS TO ACHIEVE RADON AND OTHER SOIL GAS REDUCTION

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ABSTRACT

Most new houses in the U.S. are built with central forced-air systems for heating and/or cooling (HAC). Of the 838,000 new houses constructed in the U.S. in 1991, 88% had HAC systems (1). HAC systems have been shown to significantly impact the pressure-driven entry of soil gas into houses (2,3). Devising methods to minimize or eliminate the negative impact of the residential HAC system on soil gas entry is crucial to constructing houses with good indoor air quality.

Soil gas can contain a number of unhealthy contaminants, such as radon, volatile organic compounds (VOCs), pesticides, and biocontaminants. The poorly planned and installed HAC system can induce pressure differentials that drive the entry of soil gas into a building. The faulty HAC system also distributes the contaminated air to the living space. Conversely, a properly planned and installed HAC system can reduce soil gas entry, dilute any soil gas that enters a house, and increase ventilation rates to improve overall indoor air quality. This paper describes some recommended and proven techniques for HAC configurations that have lowered the entry rate of radon in new construction, and which could be applied to reduce the entry of other soil gas contaminants.

INTRODUCTION

Studies of residential HAC system operation on soil gas entry and indoor radon concentrations have shown that air leakage in HAC components contribute significantly to depressurization of the house interior, causing an increased potential for the entry of soil gas. Supporting research for the development of radon-resistant building techniques for new houses has provided some guidance for the installation of HAC systems that will lower radon entry. These recommendations include sealing of ducts and recommended locations for air handling units (AHUS) and air terminal devices. Another approach to control HAC-induced depressurization is to configure the system so that the groundcontact space (e.g., a basement) is pressurized, thus preventing the entry of soil gas. EPA research has shown that such a modified system can significantly reduce indoor radon levels to well below the EPA action level of 4 $pCiL^{-1}$ (148 Bqm^{-3}). This modified system also increases ventilation rates to meet current American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 62-1989 of 0.35 air changes per hour (ACH) in houses (4).

HAC systems have been shown to significantly impact pressure differentials between indoor and outdoors, leading to increased driving forces for radon-containing soil gas entry into houses. A study of 70 houses in Florida found that mechanical systems produced a greater pressure differential across the floor slab than the natural forces of wind and stack effect. Duct leaks, closed interior doors, and exhaust fans frequently created pressures greater than 4 Pa, while the naturally produced pressures were less than 2 Pa (5).

New construction offers the opportunity to plan and install HAC systems so that pressure relationships between the inside of the building and the outdoors reduce the entry of soil gas and so that fresh outdoor air is supplied to the living space (6). Efforts are currently underway at the EPA to develop model standards that can be used to construct radon-resistant houses. The State of Florida is also developing similar construction codes, and the

State of Washington has recently incorporated radon-resistant construction requirements into their building codes. All of these standards and codes contain configuration requirements for HAC systems.

The typical residential forced-air HAC system in U.S. houses consists of: (1) an AHU, (2) supply and return ducts, (3) cooling and/or heating devices, and (4) air terminal devices such as supply air diffusers and return air grilles. The AHU typically contains the fan, heat exchangers, and a condensate collector and drain. Filters are often installed in the return air grilles or in the return air section of the AHU. The supply air duct delivers conditioned air to the living space and the return air duct removes air from the living space to be conditioned by the AHU. A provision for outdoor air may also be installed in the return duct, though this has not been common practice in the U.S. Ducts are typically installed in a manner dictated by first-cost efficiency, without considering their effects on the dynamics of the house.

Depressurization caused by HAC systems occurs from air leakage in the AHU cabinet, air leakage in the ducts, imbalance of supply and return air delivery, and combustion air drawn from the house interior. Minimized air leakage in an air distribution system is necessary to prevent the depressurization of interior spaces, to reduce energy consumption, and to improve the performance of the HAC system. Sealing of ducts and AHUs is not always a good deterrent to air leakage, since sealants tend to fail over time and the application of sealants almost never achieves complete airtightness. AHU cabinets for residential use are constructed without gasketed panels which would reduce the cabinet air leakage. Sealing of AHU panels by any means other than gasketing cannot be done since the panels must be removable for servicing of the fan, heat exchangers, filters, and condensate drain. Since complete airtightness of HAC components is not economically achievable with current technologies it is necessary to locate the potentially leaky components so that the effects of their leakage are minimized. Location of the AHU, ducts, and air terminal devices must be considered when building a house that is resistant to soil gas entry.

The configuration of a residential HAC system is controlled by the type of foundation used. Three types of house foundations are common to the U.S.: (1) concrete slab-on-grade, (2) basement, and (3) crawlspace. Concrete slab-on-grade construction provides no underground living space, as does a basement; however, cracking of the concrete and unsealed penetrations for plumbing and electrical services provide pathways for soil gas entry. Basement foundations consist of floor and walls that are, at least partly, located underground. The crawlspace foundation consists of foundation walls supporting a raised floor over an enclosed, passively vented space. In crawlspace houses there is a great potential for soil gas entry into the living space due to the presence of floor penetrations and house depressurization.

HAC systems are installed in areas of new houses that are architecturally or aesthetically pleasing to the home builder or homeowner. This generally means in a location that is out of sight, which includes the basement, crawlspace, or attic. The typical configuration of the HAC system in slab-on-grade housing has the AHU on the floor of a closet near the center of the house, and ducts routed through the attic or placed in or under the concrete slab. In houses with basements, the AHU is generally located on the floor of the basement, with ducts routed throughout the basement, penetrating the first floor with supply diffusers and return grilles. In crawlspace houses the AHU is often located in the crawlspace along with the supply and return ducts that penetrate the first floor to condition the living space. Table 1 summarizes typical practices for HAC installations that result in increased soil gas entry and recommended practices that decrease soil gas entry.

Table 1.
Examples of HAC system component locations and the effects on indoor depressurization for various foundations[a]

Component	Common Installation	Effect on Entry	Improved Installations
Air handling unit (AHU)	Placed on slab inside building shell or in crawlspace	Leaking AHU cabinet depressurizes house interior and increases driving forces for soil gas entry	Install AHU outside of building shell; e.g., in the attic or outdoors (S,C). Install AHU with outdoor air capability (S,B,C) or modify configuration to pressurize space (B)
Supply and return ducts	Installed in floor slab or buried beneath the floor slab (S), routed throughout basement or crawlspace	Leaking ducts draw soil gas into HAC system and distribute it throughout house	Install ducts outside of building shell, such as in the attic (S,C), and seal ducts thoroughly
Return grilles	Grille located centrally in hallway	HAC system operation depressurizes zone where the return is located	Install a return system or a door grille in every room that has a supply diffuser
Gas/oil-fired furnace	Combustion air taken from inside house shell (S and B), or from crawlspace	Operation depressurizes zone and increases driving force for soil gas entry	Install a duct to outdoors to provide combustion air directly to the unit. Also locate AHU in attic

[a] Foundations: S = Slab-on-grade; B = Basement; C = Crawlspace

METHODS

Research was begun in the summer of 1990 to evaluate whether a typical residential HAC could be easily modified to pressurize the basement of a house to prevent the entry of radon-containing soil gas (7). This research was not directly related to the code development for new residential construction but was significant in further development of an optimal HAC system for soil gas control. It was believed that radon entry could be minimized by using the AHU and the air distribution system to pressurize the basement and slightly depressurize the upper floor. This modified system would prevent the entry of soil gas and increase ventilation rates in the upstairs living area by slightly increasing the infiltration of outdoor air. The modified HAC system is illustrated in Figure 1.

The house chosen for the study is near Allentown, Pennsylvania. It is a two-story house with a basement under all but the living room. The living room was built as slab on-grade. The house was constructed with the knowledge that high radon levels existed in other neighboring houses, thus the builder incorporated several radon resistant techniques during its construction, including the use of poured concrete walls and floor, sealing of all concrete joints, and a polyethylene vapor barrier under the slab. In addition, an active soil depressurization (ASD) system was installed in the building, which consisted of a 10 cm layer of DOT #2 stone, an interior perimeter loop of 10 cm drain pipe, and a 10 cm PVC pipe routed through the building and out the roof with an in-line centrifugal blower. The ASD system was disabled and capped for the basement pressurization project.

The house is heated and cooled using a standard residential-grade heat pump system with the AHU located in the basement. All supply and return ducts were also located in the basement. Investigations of the extent of air leakage, in what had been identified initially as carefully installed ducts, revealed that the ducts had a high rate of leakage. This leakage was evidenced by operation of the HAC system, which, when operating, produced a negative pressure in the basement. To accomplish pressurization it was necessary to minimize the leakage in the return duct, which was accomplished on a temporary basis with tape and caulk. A 9.4 cm^2 opening was made in the main trunk of the supply air duct. These modifications resulted in the pressurization of the basement, with respect to outdoors, of an average 4 Pa. Infiltration in the upstairs living area also increased, to make up the air lost through the basement. The modified system produced ventilation rates in the upstairs living space of between 25 and 41 Ls^{-1}, or 0.53 ACH for this house.

RESULTS AND CONCLUSIONS

The effects of the modified operation on indoor radon were studied by monitoring radon continuously in the basement and on the ground floor with the AHU operating both continuously and off. The results, illustrated in Figure 2, show that, with the AHU off, the average basement-to-outdoor pressure is -1 Pa with an average radon concentration of 714 Bqm^{-3}. With the AHU on, the average basement-to-outdoor pressure is +4 Pa, and the indoor radon concentration averages 60 Bqm^{-3} in the basement, which is well below the EPA recommended action level of 148 Bqm^{-3} (8). For this house, the average radon level compares favorably with operation of the ASD system which, in previous studies, had reduced basement radon levels to 41 Bqm^{-3}. With the AHU off, the basement air pressure quickly drops, and there are radon spikes each time the basement becomes negative relative to outdoor air.

Total energy consumption of operating the HAC system to pressurize the basement was compared to that for operating an ASD system. The amount of electricity used to power the ASD system continuously is 90 W . For 1 year of operation this amounts to 788 kWh. Operating the HAC system continuously on low speed adds 1002 kWh (174 W for 5760 hr) to the normal operation required for cooling and heating. The modified HAC system will thus require only 214 kWh per year more than operating the ASD system which, at 0. 10 \$(U.S.) kWh^{-1}, is only slightly more than \$21 (U.S.) annually. Installation costs associated with the modified HAC system are favorable when compared to the costs of installing an ASD system. The modified HAC system is estimated to cost \$200 to \$300 (U.S.) which includes the cost of sealing the ducts and modifying the AHU control wiring so that it runs continuously on low speed (and changes to high speed on a call for cooling or heating). The estimated cost for the ASD system in this house was \$730.

DISCUSSION

Proper installation of a HAC system can provide for significantly reduced soil gas entry. Theoretically, the modified HAC and other properly configured HAC systems could significantly reduce the entry of soil gas contaminants such as methane from landfills or benzene from leaking underground storage tanks. The modified HAC system can also control the ventilation rates for living areas, thus improving the overall quality of residential indoor air.

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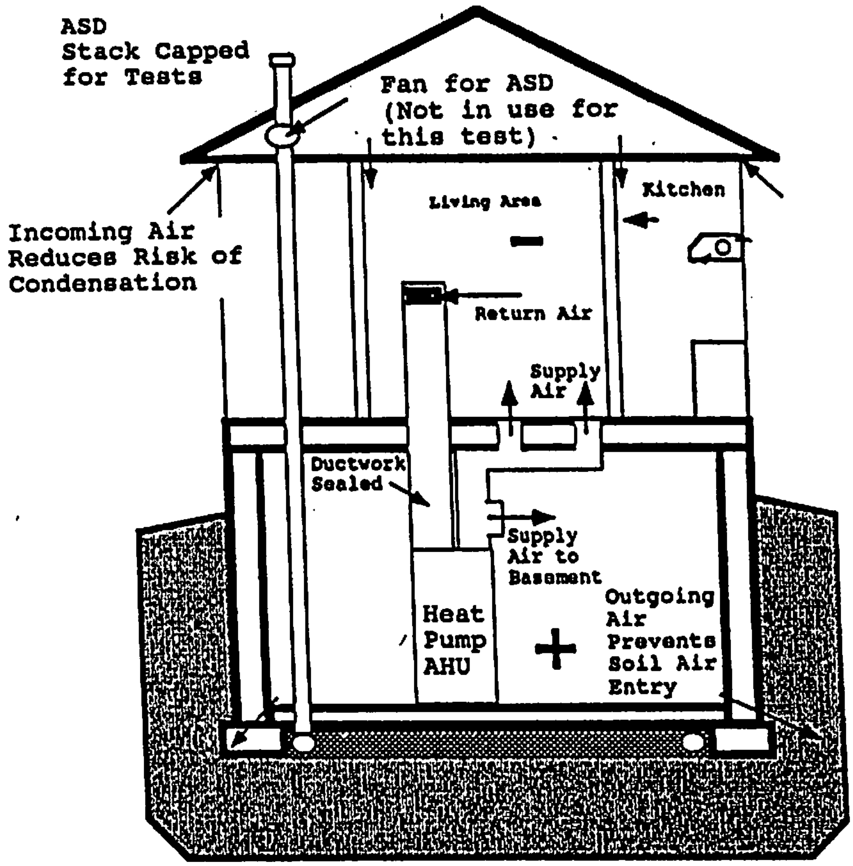

Figure 1. Showing the use of the HAC system to control radon entry, and provide recommended ventilation rates.

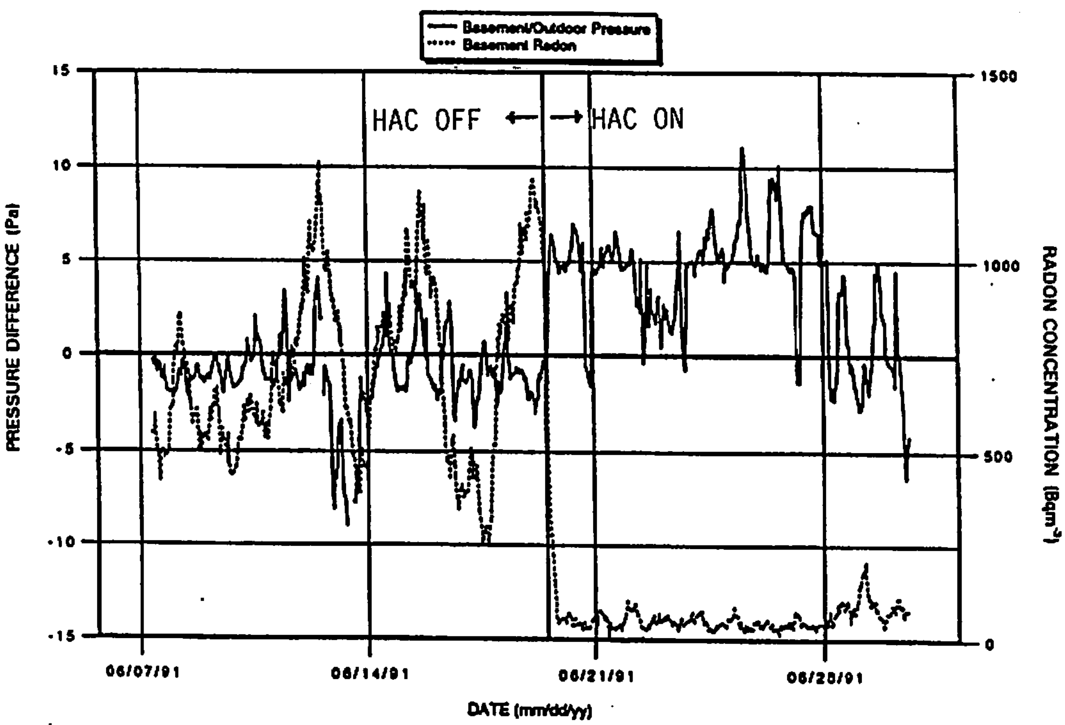

Figure 2. Radon and pressure differences for the modified HAC system on and off