# Do forced air HVAC systems have a role in healthy homes?

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## SUMMARY
Most residential forced air systems do little to improve, and may actually degrade, indoor air quality. The use of forced air systems for air cleaning has serious limitations because air handler fans run infrequently and for short periods because of system oversizing, duct leaks introduce contaminants into indoor spaces, and filters are often low-efficiency and poorly installed. This paper explores these limitations as well as alternatives to centralized air cleaning. Decoupling the air cleaning and the conditioning equipment, or changing the types of conditioning equipment that we use, may improve the indoor air quality in many homes.

## KEYWORDS
Residential HVAC, air cleaning, energy use

## INTRODUCTION
Over 70% of Americans use forced air heating or cooling systems (HUD, 2005) and consequently, they are considered essential to comfort. In addition to providing comfort, central systems offer opportunities to clean air through the use of filters that are integrated into most forced-air systems. However, the use of forced air systems for air cleaning has serious limitations in most residential buildings because:

1. systems are oversized and therefore have short duty cycles,
2. most filters are ineffective at stopping particles of interest from a health perspective and are installed such that they have substantial bypass, and
3. duct leakage causes the introduction of contaminants from buffer spaces (such as attics and garages), as well as from outdoor air.

The goal of this paper is to explore these limitations as well as the strengths and weaknesses of alternative air cleaning systems.

## LITERATURE REVIEW
The ubiquity of central forced air systems make them an obvious choice for integration with an air cleaning function. Their design flow rate of 670 $m^3$/hr per 3.5 kW of cooling capacity (400 cfm per ton), typically several times the flow of effective portable air cleaners, allows them to achieve a very high clean air delivery rate (CADR), even with only a moderately efficient filter. Furthermore, their primary function as an air conditioning system ensures that cleaned air is distributed throughout a building.

Despite these advantages, central systems are also limited in their ability to clean air. The major limitation is one of oversizing. Systems are oversized for many reasons including to account for extreme weather conditions and for system maintenance and installation flaws such as insufficient air flow, excessive duct losses, and deviations from recommended amount of refrigerant charge (James et al, 1997; Walker et al., 1998; Siegel et al., 2000; Siegel and Wray, 2002), as well as higher profits for installers that are associated with larger systems (Lovins, 1991). The net effect of oversizing is that systems run infrequently. Many residential systems run less than 25% of the time (Ward et al., 2005; Stephens et al., 2009) even in the peak cooling period when they are anticipated to run the most. Considerably shorter run-times are likely during swing seasons and during less-extreme weather conditions.

Thus, a central forced air cleaning system has diminished capacity to remove any contaminants generated inside of a home simply because it does not run.

Even when a central forced air system is operating, it often has a very limited impact on reducing exposure to contaminants of concern. For gas-phase contaminants, a vanishing small number of residential buildings have any sort of filtration or other controls. For particulate contaminants, most homes use low-efficiency filters. Filters, typically labeled with a Minimum Efficiency Reporting Value (MERV) from ASHRAE Standard 52.2-2007 in the U.S., are tested for their ability to remove particles in three size ranges 0.3 – 1 µm, 1 - 3 µm, and 3 – 10 µm. Low efficiency furnace filters, typically MERV 1 – 4, are very porous and generally remove less than 10% of particles over this entire range (Hanley et al., 2004, ASHRAE, 2007). They are typically intended to protect HVAC equipment from large dust fibers and other very large particles. Even filters that are categorized as superior residential filters (MERV 11-12) in ASHRAE Standard 52.2-2007 are not tested/categorized for removal of particles in the 0.3 – 1 µm range. Such particles, and smaller, are generally of the greatest concern for human exposure. So even the best, albiet infrequently used, filters that are available for residential systems do little remove most particles of interest.

Adding to the problem of low filter efficiency is the fact that many filters are installed poorly and have air that bypasses the filter. Ward and Siegel (2005) simulated that this problem can seriously degrade filter efficiency, especially for high-MERV filters. VerShaw et al. (2009) measured bypass in residential and light-commercial buildings and found significant efficiency penalties for MERV 11 filters, even in homes with very small bypass gaps.

Another chronic problem with residential HVAC systems is duct losses due to ducts that are located outside of the conditioned space. In addition to energy concerns, duct leaks in return (negative pressure) ducts may also serve to degrade indoor air quality because the buffer spaces where ducts are located are often moist and have large amounts of biological activity (crawlspaces), dust including cockroach and other allergens (attics), and vehicle exhaust or solvent storage (garages). Thus an HVAC system may serve to increase contaminant loading in a space and may introduce contaminants after the filter in homes that have filters located at the return grille (VerShaw et al., 2009) or introduce contaminants that are not likely to be filtered by typical filters. Unbalanced leaks between the supply and the return side of the system can also increase infiltration of outside air, which can generally improve indoor air quality by diluting contaminants from indoor sources. However, because this infiltrated fresh air is not cleaned, it may be contaminated as it penetrates through the building envelope or buffer spaces.

Some newer homes combine ventilation and a forced air system with a dedicated fresh air supply (Russell et al., 2007). The fan energy consequences of using the central fan for ventilation purposes can be significant as typical fans draw 500-1000W (Proctor and Parker, 2000; Sachs, 2002). In addition to the direct electricity costs, the heat generated by the fan must also be removed by the cooling coil. To diminish the energy consequences of fans, there are some homes that use electronically-commutated motors (ECM) instead of more traditional fan motors (Kenty, 2007). ECM motors are much more efficient at part loads, but actually can consume more energy at typical flow rates required for cooling. This suggests that a simple change-out of ECM motor may not ameliorate the limitations of central systems for air cleaning and ventilation.

## DISCUSSION

Solutions to overcoming the limitations of conventional forced air systems for air cleaning are not immediately obvious. Many traditional weatherization approaches (reducing envelope air leakage, adding insulation, improving windows and other components) can actually diminish the filtration capacity because they decrease the size of the load relative to the size of the system, exacerbating the oversizing issues described above. Sealing duct leaks also decreases system on time and therefore reduces central air cleaning. Running fans continuously improves air cleaning but also increases the indoor air quality impacts of duct leakage and requires considerable energy expenditure associated with the fans. Improving filters and eliminating bypass increases pressure drop and reduces flow and thus can minimize benefits and even result in diminished air cleaning.

One potential strategy is to decouple the air conditioning and the air cleaning functions. This can be done with portable air cleaners. The advantage of such a strategy is that air cleaning can be located near sources and thereby operate at increased effectiveness (Novoselac and Siegel, 2009). However, there are numerous disadvantages including a limited number of technologies that are both energy efficient, such as ion generators, and also effective, such as HEPA filters (Offermann et al., 1985; Siegel and Waring, 2008). Another disadvantage with many air cleaning devices is the production of ozone (e.g., Waring and Siegel, 2008), the presence of noise, and the creation of undesirable indoor air flows (Novoselac and Siegel, 2009). For this strategy to be truly effective, we likely need to develop new portable air cleaning technologies and adapt passive strategies (Kunkel et al., 2009) to more pollutants of concern.

Another strategy is to change the way that we condition buildings. Many residential buildings in Europe and Asia, and increasingly those in the US, use ductless (mini-split) air conditioning systems. Ductless systems have the advantage of distributing refrigerant to evaporators in each zone and therefore not requiring ducts. They also can vary the refrigerant flow and therefore match the conditioning system output to the load. Although typically considerably more expensive than a traditional system, they often operate at higher efficiencies. There are limitations to this approach, including the fact that it is often prohibitively expensive to adapt such systems to existing buildings, more engineering has to be performed to make sure that appropriate air-cleaning components are integrated into the evaporator units, and providing adequate ventilation can be challenging in some buildings.

## CONCLUSIONS

Although traditional forced-air heating and cooling systems are robust and can provide exceptional comfort, the integration of air-cleaning equipment does not always result in improved indoor air quality. Alternative approaches that provide improved indoor air quality under all conditions should be explored.

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