Impacts of HVAC Filtration on Air-Conditioner Energy Consumption in Residences

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SUMMARY

The use of high-efficiency filtration is a common strategy to control exposure to particulate matter in buildings. However, filters are perceived to be associated with large energy penalties. This research explores the potential energy impacts of higher efficiency filters in residential forced-air cooling systems. A literature review of the likely impacts of filters on energy use, including changes in fan power draw, air-conditioner compressor power draw, cooling capacity, and duct leakage suggests small energy consequences and potentially even energy savings. The magnitude of filter impacts is especially insignificant when compared to other common air-conditioner operation and maintenance issues.

KEYWORDS

Filters, residential energy use, particulate air cleaning, forced-air systems

INTRODUCTION

High-efficiency particle filtration in forced air heating, ventilating, and air-conditioning (HVAC) systems is used to protect building equipment and occupants, but can also influence building energy usage. Filters with a high MERV (Minimum Efficiency Reporting Value) typically have a greater pressure drop than filters with a lower MERV (ASHRAE, 2007). In large commercial HVAC systems, where fan and motor controls typically maintain required airflow rates, a greater pressure drop will generally lead to increased energy consumption (e.g., Fisk et al., 2002). This relationship between energy use and filter pressure drop is widely assumed to hold true for smaller residential air-conditioning systems, but differences between small and large systems suggest very different energy consequences. This paper surveys literature and explores the magnitude of the likely effects of filters on residential air-conditioning systems.

BACKGROUND

The energy consequences of a higher-pressure drop filter depend on the pressure drop of the filter relative to that in the rest of the return side of the HVAC system, the fan curve, the fan efficiency curve, and the location of the intersection of the fan and system curves. To illustrate the effects of varying filter pressure drop, Figure 1 represents a typical static pressure distribution through the different components in a residential system with two levels of filtration efficiency installed (low-MERV and high-MERV).

The central difference between small and large systems is that an increased pressure drop in most residential systems will typically diminish airflow rates because smaller systems typically do not have flow controls. The magnitude of flow reductions likely to be seen due to higher pressure drop filters depends on the intersection of the fan curve and system curve. Figure 2 shows the system curves and fan curve for theoretical medium, high, and low efficiency filters (Points A, B, and C, respectively).

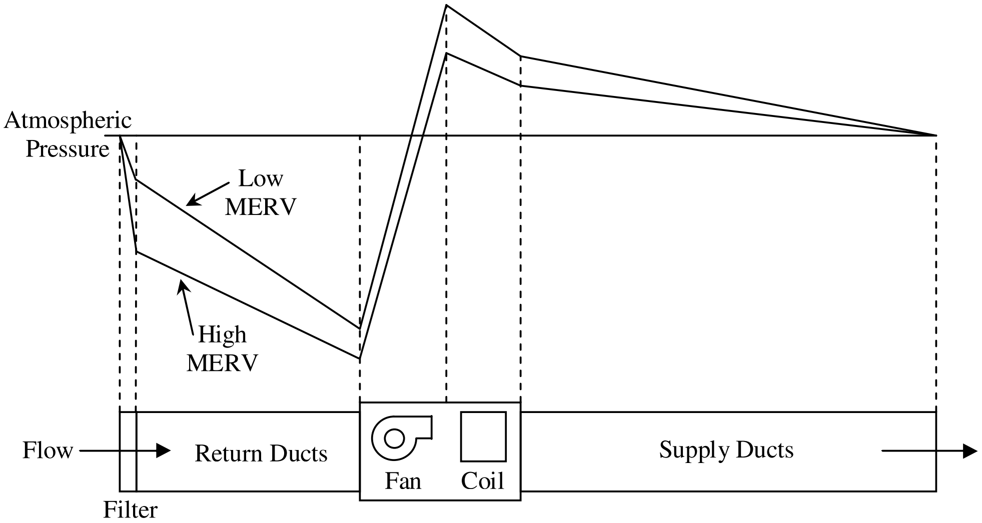

Figure 1. Example static pressure distribution for a typical residential system with low and high efficiency filters.

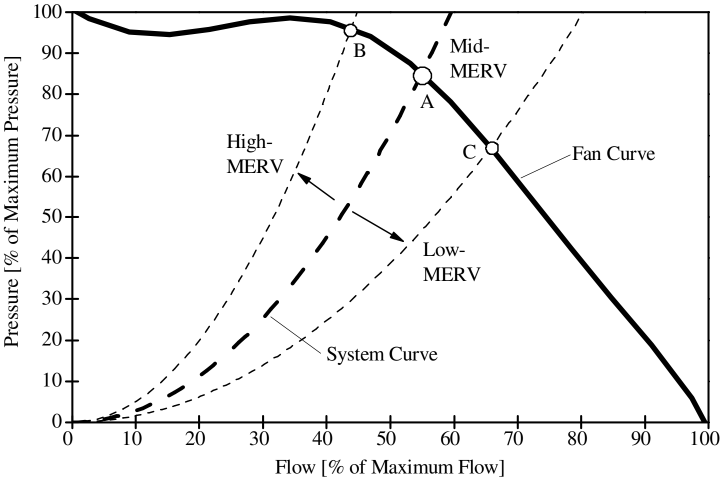

Figure 2. Example fan and system curves for low, medium, and high pressure drop filters.

In Figure 2, increasing the filter pressure drop increases the total system pressure drop, which decreases the airflow rate at the intersection point. The magnitude of the decrease depends on the nature of the fan curve. Systems operating at the higher range of airflow on this graph will be more sensitive to changes in pressure drop than systems operating at the lower range. The effect that these changes have on fan power draw depends on the fan efficiency curve.

IMPACTS OF FLOW REDUCTION

Diminished airflow can have negative energy consequences in residential air-conditioning systems by reducing cooling capacity and system efficiency, which will theoretically cause a system to run longer to meet the cooling load. However, reduced airflow can also have potentially positive energy consequences by reducing the power draw of the air handler fan. A reduction in fan power draw also increases sensible capacity because the fan adds less heat to the air stream that the cooling coil must remove. A reduction in airflow also means that the refrigerant does not absorb as much heat from the air stream, diminishing sensible capacity and generally decreasing the power draw of the outdoor compressor. Diminished airflow often increases the sensible heat ratio as well, providing more dehumidification and potentially affecting thermostat operation.

An increased pressure drop can change return and supply side duct leakage by altering the pressure distribution in the duct system. The direction and magnitude of the impact on duct leakage due to changes in flow and pressure drop depends on the locations of the filter and the leaks. In a system like Figure 1, increasing the filter pressure drop can decrease the pressure differential in both the supply and return ductwork and decrease the amount of leakage. Since most ductwork in U.S. residences is located outside conditioned space, reducing duct leakage achieves energy benefits by potentially increasing both sensible and latent capacity.

Measured values of these interacting effects in the literature are scarce. Previously, a 4-5% reduction in airflow was measured when replacing standard disposable filters with high-efficiency pleated filters in residential air-conditioner field tests (Parker et al., 1997). In three previous studies, a 5-10% reduction from recommended airflow rates (the range of airflow reductions likely due to filters) has been shown to diminish total capacity, sensible capacity, and system efficiency by approximately 2-6%, increase latent capacity by approximately 1-3%, and diminish total power draw (fan + compressor) by less than 1%, all at steady-state operation (Parker et al., 1997; Rodriguez et al., 1996; Palani et al., 1992). Residential systems generally cycle on and off and often operate at unsteady-state conditions, thus the real implications of filters may be less predictable. In a recent field study of 17 residential and light commercial systems, changing from a low-efficiency (MERV<4) to a high-efficiency (MERV 11-12) caused fan power draw to decrease by an average of 4% and daily system energy consumption to decrease by 0.8 kWh per ton of installed cooling capacity (Stephens et al., 2009). Although there was considerable variation in the results, this small savings is consistent with earlier work that suggests very small energy impacts from the use of high-efficiency filters in small systems.

DISCUSSION

It is important to evaluate the magnitude of potential energy implications of filters relative to the impacts of other parameters. Duct leakage, refrigerant charge, and extremely low airflow are air-conditioner installation and maintenance issues that have a large impact on system performance. The prevalence of excessive duct leakage has been reported in numerous residential field tests and a modelling study showed that an increase in supply and return duct leakage from 0% to 11% decreases capacity by approximately 34% (Walker et al., 1998). The same study combined the effects of a 30% undercharged unit with 30% duct leakage and predicted a capacity decrease of over 50%. A 5-14% decrease in system efficiency was measured with a 30% undercharged air-conditioning unit in laboratory tests (Proctor, 1998). An extreme reduction in airflow of 50% from the recommended rate has been shown to cause total capacity to decrease by approximately 25% (Rodriguez et al., 1996). A recent study of residential air-conditioners reported that over half of the systems in the sample had low refrigerant charge levels and approximately 19% had low airflow that warranted repair (Downey and Proctor, 2002).

Equipment size is an important design parameter that has a large impact on capacity and efficiency. A large field study of homes reported that annual energy consumption increased 3-10% in homes with oversized systems and that over half of the systems were oversized (James et al., 1997). Outdoor temperature also plays an important role in cooling system capacity and efficiency. For example, typical system efficiency has been shown to decrease approximately 2.1% for each °C increase in outdoor temperature (Bain et al., 1996). In addition, occupant thermostat settings have straightforward and substantial energy consequences as systems run longer to meet lower set points.

The potential effects of higher efficiency filters on energy consumption in residential air-conditioning systems are small in comparison with the typical impacts of higher outdoor temperatures, thermostat settings, and prevalent problems of duct leakage, refrigerant charge, severely restricted airflow, and equipment over-sizing. This suggests that the perception that high-efficiency filters have large energy penalties associated with their use is unlikely in residences.

CONCLUSIONS

The goal of this research was to explore the energy consequences associated with higher-efficiency filtration in residences. The results herein suggest that the energy consequences of higher-efficiency filters in residential air-conditioning systems are likely small and that other factors should govern filter selection.

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