Performance and Costs of Air Sealing and Ventilation Measures for Home Decarbonization in the US

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ABSTRACT

In order to get to scale and rapidly decarbonize the energy use of homes, we need information on the performance and costs of potential home upgrade measures. The costs for different performance levels are vital for energy savings and decarbonization program planning and to focus R&D activities on measures that could achieve significant cost reductions. This study obtained data from over 1,700 projects that aimed to achieve advanced levels of energy use and related carbon emissions reductions. In this paper we examine the measures related to air sealing (for both the home building envelope and duct systems) and ventilation and present the relevant cost analysis. The results show that there are challenges to obtaining the envelope leakage levels appropriate for the energy and carbon savings we would like to achieve, that duct leakage reductions can be much greater than those for envelopes. From a cost perspective, envelops leakage can be substantially reduced with additional effort, but duct sealing results depend on parameters other than cost/effort. In addition, provision of adequate ventilation are rare and require additional emphasis or mandated requirements in future programs to ensure that indoor air quality (IAQ) is not compromised in decarbonized, energy efficient homes.

KEYWORDS

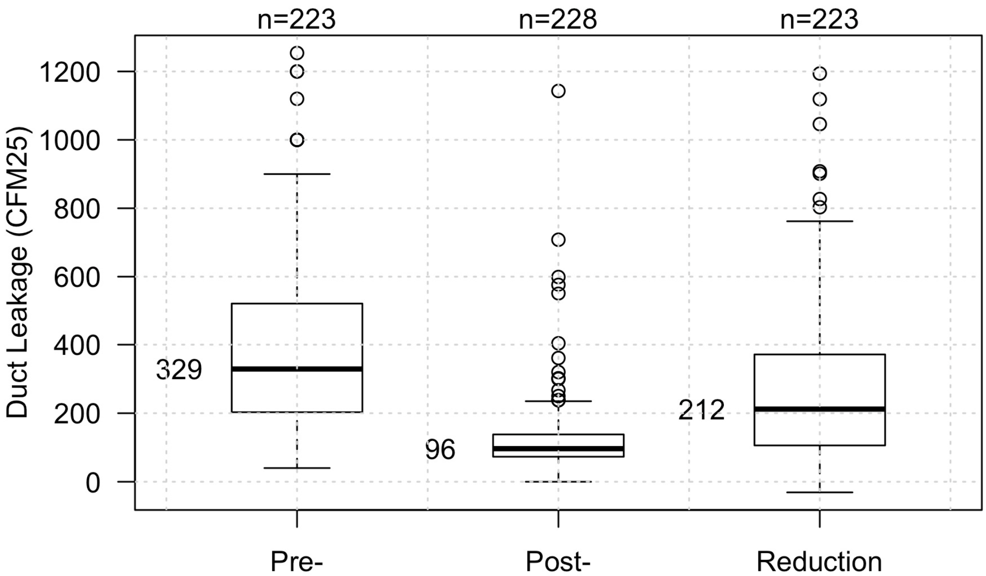
Air Sealing, Ventilation, Costs, Energy Retrofitting, Decarbonization, Residential Buildings

1 INTRODUCTION

Recent studies confirm that cost of energy upgrades in existing dwellings has been identified as one of the key barriers restricting the scaling of energy solutions and decarbonization strategies (Chan et al., 2021; Less, Walker, & Casquero-Modrego, 2021; Less, Walker, Casquero-Modrego, et al., 2021). It is known that measures like advanced insulation and air sealing reduce energy demand, including during a high-carbon and peak hours (Miller & Higgins, 2021). A study conducted by NYSERDA early in the 2010s addressing super-insulated deep energy upgrades (mostly in buildings about 100 years old), suggested that costs could exceed $100,000 per dwelling (Holladay, 2012). In a 2014 meta-analysis (Less & Walker, 2014) of projects across the US typical deep energy upgrade costs were about ($40,420 ± $30,358 (n=59)), or $22.11 ± $17.70 per ft^2 (n=57). This is about $28 per ft^2 in 2021 dollars. These high project costs, combined with relatively cheap retail energy costs, and a focus on cost-effectiveness, have limited the large-scale implementation of critical upgrades in the US housing stock. The cost of energy upgrades in the US has not been consistently or centrally tracked or organized by either industry, programs or government. To address this issue, a recent study (Less, Walker, Casquero-Modrego, et al., 2021) developed a database of US single family energy retrofits measures. Project data were obtained for 1,739 projects, from 15 states and 12 energy programs, with a total of 10,512 individual measures. The goal was to develop cost benchmarks and to guide future R&D efforts aimed at cost compression and scaling of the residential upgrade market. Each measure of the database was recorded along with its performance specifications (if available). The study compared the installed energy performance to determine if there is the capacity to do better from an energy standpoint. This paper used the database to asses the measures related to air sealing for a) building envelope and ducts systems; and b) ventilation, in order to show the cost analysis.

2 AIR SEALING IN BUILDING ENVELOPE AND DUCTS

Building envelope and duct air sealing are a key part of energy retrofits in existing buildings in the US. Duct sealing is particularly important in US homes due the prevalence of using forced air duct systems for heating and cooling. The database developed for this study found that house and duct sealing were among the most common measures recorded, with 555 homes with envelope sealing and 306 with duct sealing. The pre- and post-leakage measurements, along with the measured reductions in leakage for the building envelope and for ducts are summarized in Figure 1. Building envelope leakage results.



and Figure 2. The median percent reductions in leakage were lower for the building enveloped than for the ducts (27% vs 64% respectively). The limited reduction in envelope leakage, with a median post-retrofit value of over 8 ACH_{50} indicate that more effort could be put into envelope air sealing to further reduce uncontrolled air infiltration loads and resulting energy use and carbon emissions. For comparison, in the US, the target for much new construction is 3 ACH_{50} (ICC IECC, 2021). Similar requirements are also used in other countries (for a summary see (Leprince et al., 2017)).

The sealing measures recorded in the database were referred to as: the *House_Envelope* (the exterior envelope of the dwelling), the *HVAC_Ducts* (the duct system leakage) and *Attic_All* (for projects that separated attic leakage measures from other envelope leakage measures). When normalized by dwelling floor area (ft^2), the median air sealing costs were \$0.53/ft^2 (\$5.7/m^2) for the HAVC ducts, \$0.41 (\$4.4/m^2) for the house envelope and \$0.16 (\$1.7/m^2) for the attic. There was considerable variation from home to home with about a factor if two covering the 25 to 75th percentile, Figure 3.

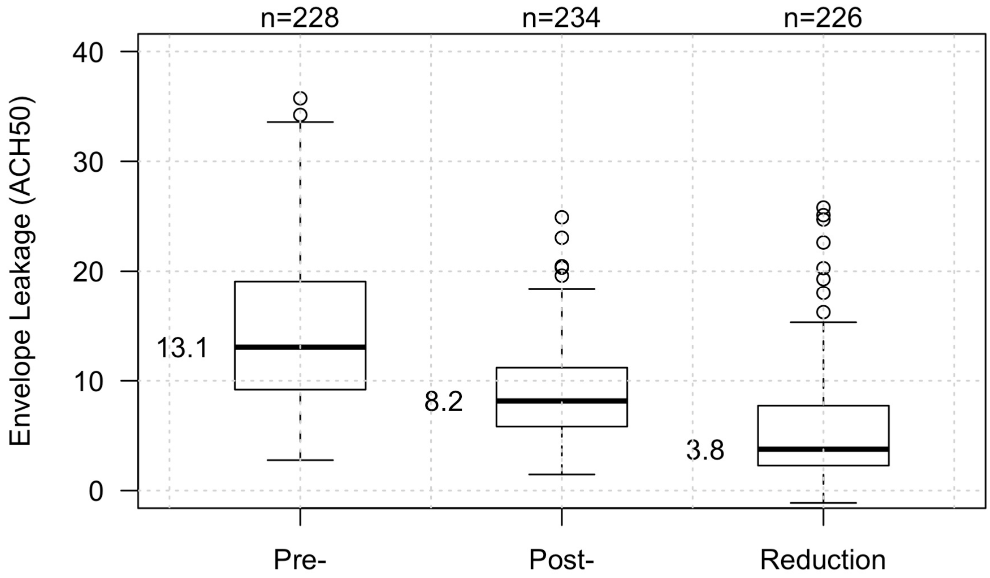


Figure 1. Building envelope leakage results.

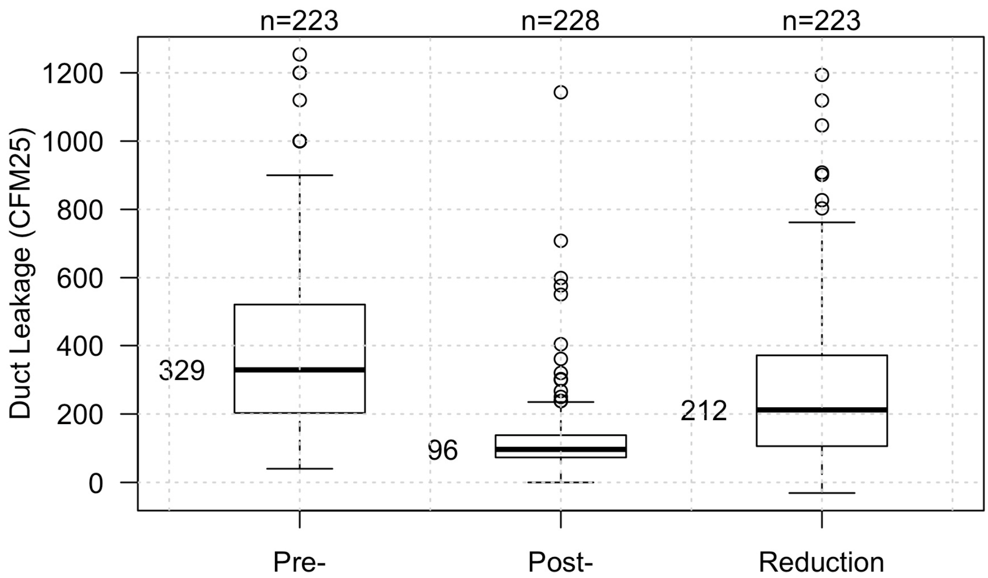


Figure 2. Duct leakage results.

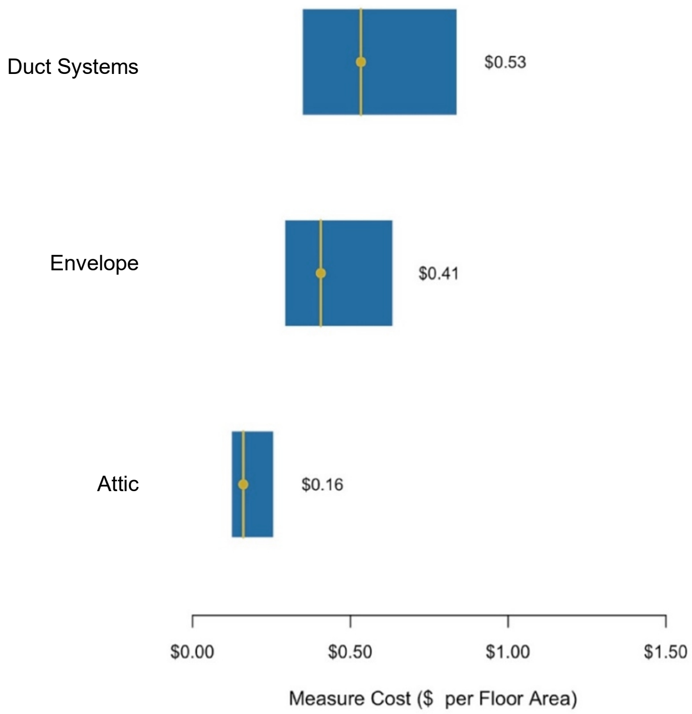


Figure 3. Sealing measure cost normalized by home floor area (ft^2), showing the median and 25th/75th percentiles.

Because attic air sealing as a separate measure was rare and insufficiently documented for the analyses presented here, we will focus on the building envelope and duct leakage only. The median costs for each measure were very similar at $730 for the building envelope air sealing and $789 for the ducts. For similar costs, duct leakage was able to be reduced two-fold more than envelope leakage, which likely makes it much more cost-effective in dwellings with ducts outside of conditioned space. Building envelope reductions and associated air sealing costs normalized by dwelling floor area (ft^2) are shown in Figure 4. Spending more on air sealing results in significant improvements: a doubling of costs from $\$0.34/ft^2$ to $\$0.68/ft^2$ ($\$3.7/m^2$ to $\$7.3/m^2$) increased the leakage reduction by a factor of three. Part of this study summarized the published literature associated with deep energy retrofits in the US (Less, 2021) and found that a range of factors determine the determining air sealing cost for the building envelope. The most important factors were: a) the Energy Program the project participated in; b) the leakage reduction; c) the climate zone; and d) the post-retrofit CFM_{50} value. The costs of air sealing reported here are for direct air seal actions only, and do not include the costs of other measures that might also contribute to leakage reductions (e.g., window replacement, dense pack insulation, etc.). As a result, these costs might underestimate the expense of air leakage reductions when used in isolation from other upgrade measures.

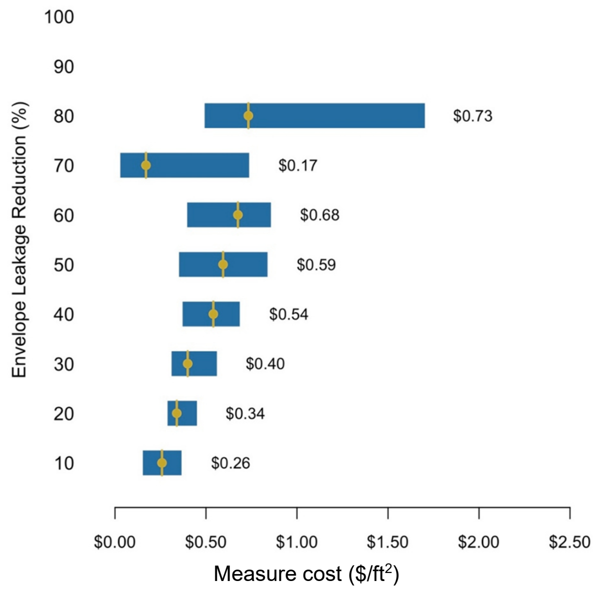


Figure 4. Building envelope reductions and associated air sealing costs normalized by dwelling floor area (ft^2) showing the median and 25th/75th percentiles.

Unlike the envelope leakage, duct sealing costs did not vary as much with increasing leakage reduction. As shown in Figure 5, median costs only increased from $0.46/$ft^2$ ($5/$m^2$) to $0.57/$ft^2$ ($6.1/$m^2$) as duct leakage reductions increased from 10% to 80% This suggests that most duct sealing work is more dependent on factors other than simply sealing the leaks. This may include broader range of access to duct leaks compared to envelope leaks or that sealing large ducts leaks is relatively easier than sealing small ones.

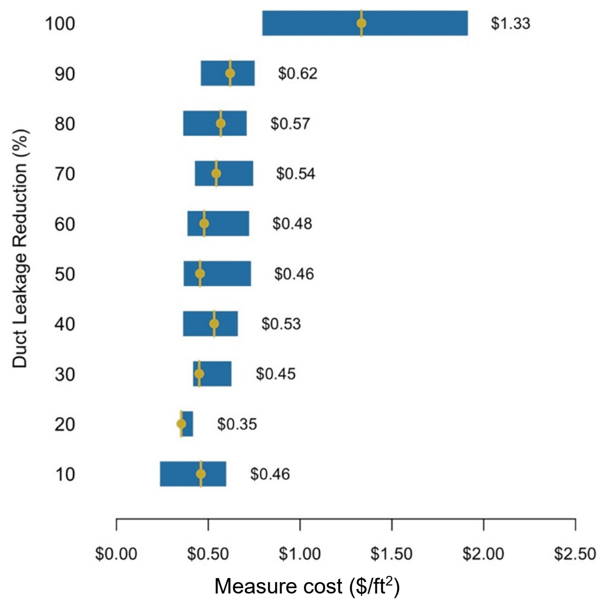


Figure 5. Duct sealing measure costs by dwelling floor area (ft^2) by leakage reduction percentage showing the median and 25th/75th percentiles.

3 VENTILATION

Mechanical ventilation is an important element of energy retrofits that reduce air leakage. In order to dilute or remove contaminants of indoor origin it is necessary to maintain minimum ventilation flows and use local exhausts in kitchens and bathrooms. The US Ventilation Standard (ASHRAE 62.2, 2019) sets minimum ventilation rates for dilution of about 0.3 Air Changes per Hour, as well as minimum exhaust air flow rates for kitchens and bathrooms. The calculation of the required air flow rate for mechanical ventilation systems can include a reduction based on measured envelope air leakage (together with climate and building geometry). Many US weatherization programs allow homes that are leaky enough to not require the use of mechanical ventilation - mostly as a cost-saving measure. Homes need to be very leaky to meet this criterion - at least 10 ACH_{50} or greater and the vast majority of homes in this study are tighter than this post-retrofit, and we expected that many would have had ventilation systems installed. However, we found that installation of mechanical ventilation was infrequent, with only 65 installations recorded in 1,739 projects, and almost half of these were local exhausts and not whole dwelling ventilation. If those systems intended for whole dwelling ventilation, they were roughly split between low-cost exhaust fan units and higher-cost units with heat recovery (both energy recovery ventilation (ERV) and heat recovery ventilation (HRV)). Overall, installation of mechanical ventilation added $733 to a project. When disaggregated by ventilation fan type, the costs varied substantially. Exhaust fan median costs were $748, while heat recovery unit median costs were $2,835, as shown in Figure 6.

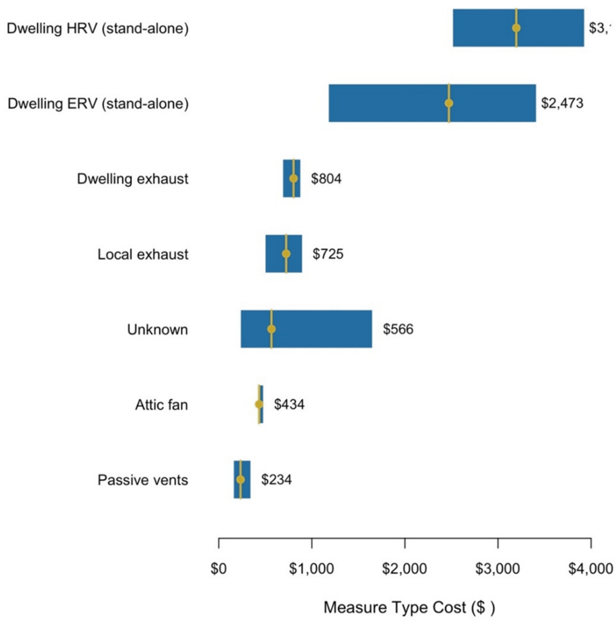


Figure 6. Ventilation system installation costs showing the median and 25th/75th percentiles.

4 CONCLUSIONS

This study examined over 1,700 projects intended to save significant energy and carbon in US homes. Air sealing was one of the most common measures indicating that air sealing is a key technique for improving home performance. In terms of leakage reductions, air sealing of ducts had bigger improvements than for envelopes - this is important in US construction where forced air HAVC systems are common. Given that the median envelope leakage improvements were only 27% we believe there is a need to substantially increase air sealing of envelopes if we want to meet energy and carbon savings goals, particularly because the additional costs are moderate compared to the improvement in leakage. Both envelope and duct sealing had moderate costs of about $750 per home indicating that they are high-value approaches when reducing energy use and carbon emission in homes. Unfortunately, we found that provision of adequate ventilation was rare and requires additional emphasis or mandated requirements in future programs to ensure that indoor air quality (IAQ) is not compromised in decarbonized, energy efficient homes.

5 ACKNOWLEDGEMENTS

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