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Energy Impact of Residential Ventilation Norms in the United States

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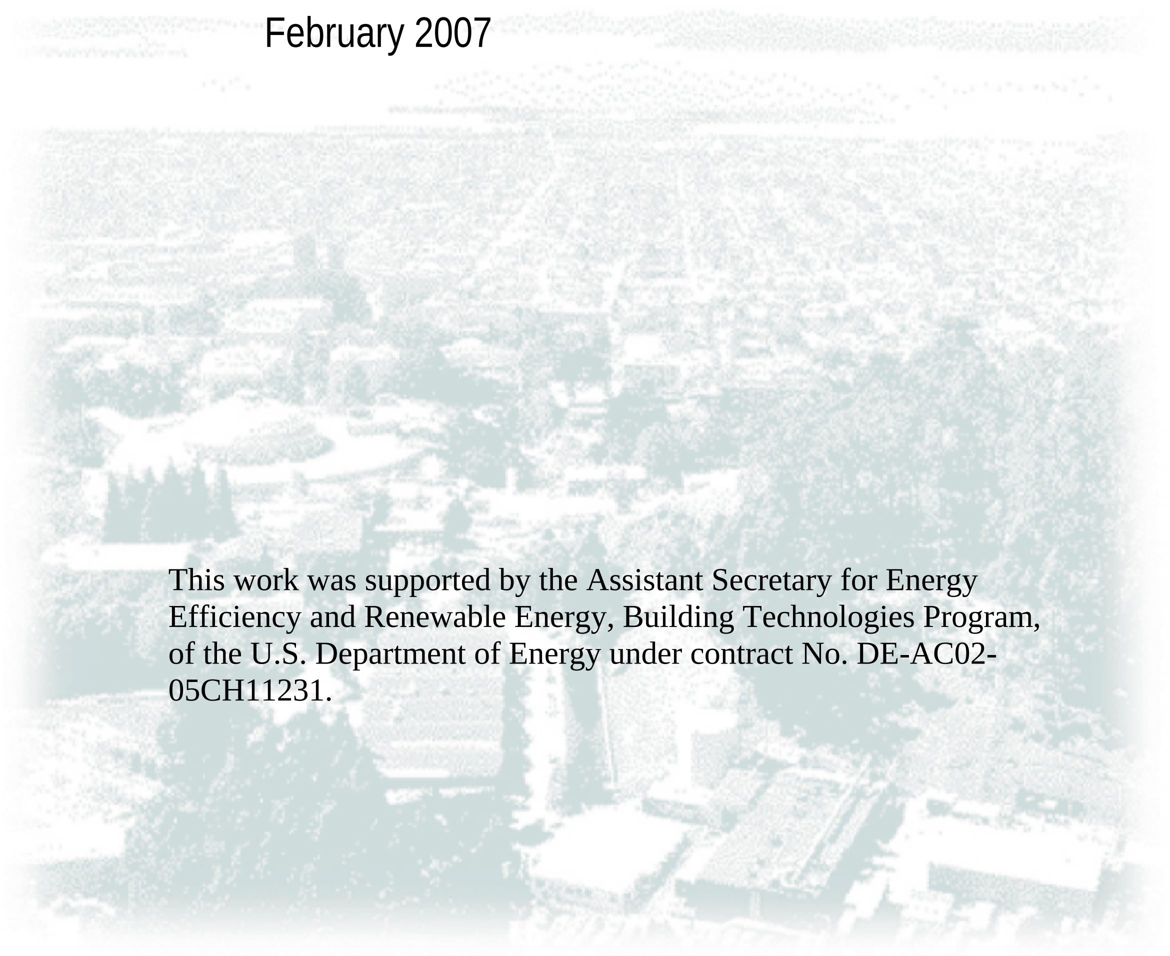

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SUMMARY

The first and only national norm for residential ventilation in the United States is Standard 62.2-2004 published by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). This standard does not by itself have the force of regulation, but is being considered for adoption by various jurisdictions within the U.S. as well as by various voluntary programs. The adoption of 62.2 would require mechanical ventilation systems to be installed in virtually all new homes, but allows for a wide variety of design solutions. These solutions, however, may have a different energy costs and non-energy benefits. This report uses a detailed simulation model to evaluate the energy impacts of currently popular and proposed mechanical ventilation approaches that are 62.2 compliant for a variety of climates. These results separate the energy needed to ventilate from the energy needed to condition the ventilation air, from the energy needed to distribute and/or temper the ventilation air. The results show that exhaust systems are generally the most energy efficient method of meeting the proposed requirements. Balanced and supply systems have more ventilation resulting in greater energy and their associated distribution energy use can be significant.

INTRODUCTION

In the United States (U.S.) residential ventilation was not traditionally a major concern because policy makers believed that between operable windows and envelope leakage, people were getting enough outdoor air. Over the past three decades, houses have become much more energy efficient and a key contributor was from reductions in envelope leakage. At the same time, the types of materials used in furniture, appliances, and building materials in houses have changed resulting in more indoor pollutants. People have also become more environmentally conscious not only about the resources they were consuming but about the environment in which they lived.

Historically, people have ventilated buildings to provide source control for both combustion products and objectionable odors [1]. Currently, a wide range of ventilation technologies is available to provide ventilation in dwellings including both mechanical systems and sustainable technologies. Recent residential construction has created tighter, energy-saving building envelopes that create a potential for under-ventilation [2,3]. As a result, new homes often need mechanical ventilation systems to meet current ventilation standards. These standards and related factors have been reviewed in previous studies [4].

ASHRAE Standard 62.2-2004 [5] is the U.S. standard for ventilation for acceptable indoor air quality in low rise residential buildings that (together with its companion Standard 62.1 for all other buildings) represents the current standard for setting ventilation rates. It is the objective of this study to evaluate the energy impacts of meeting this standard in U.S. houses.

ASHRAE Standard 62.2 has requirements for whole-house ventilation, local exhaust ventilation, source control and system requirements. The whole-house mechanical ventilation requirement of 62.2 is given by Equation 1:

$$Q\left(L/s\right) = 0.05 A_{floor}\left(m^2\right) + 3.5\left(N+1\right), \quad \textbf{(1)}$$

It is assumed that an additional 0.1 L/s/m^2 is supplied through infiltration. Standard 62.2 also requires local mechanical exhaust in kitchens and bathrooms. Kitchens must have the capacity to exhaust at least 50 L/s through a range hood or provide 5 kitchen air changes per hour. Bathrooms must have the capacity to exhaust 25 L/s intermittently or have 10 L/s of exhaust continuously.

METHOD

In order to evaluate the energy impacts of the ASHRAE 62.2 requirements, we used a simulation tool to perform minute-by-minute ventilation, heat and moisture calculations that allowed for the dynamic performance of buildings and Heating, Ventilating and Air Conditioning (HVAC) components. Details of the simulation tool can be found in [6] and a summary of model validation can be found in [7].

Climates Evaluated

Six locations were used that cover the major climate zones:

- **Hot humid**: This zone represents many tropical and semi-tropical areas and is represented by weather data for the U.S. city of Houston,
- **Arid**: This zone represents hot, dry (desert) conditions and is represented by weather data for the U.S. city of Phoenix,
- **Warm humid**: This zone may be typical of some warm temperate zones such as in southern Europe and is represented by weather data for the U.S. city of Charlotte,
- **Continental**: This zone is unmoderated by large bodies of water and has both heating and cooling loads; it is represented by weather data for the U.S. city of Kansas City,
- **Marine**: This zone is typically a cool zone with long, but mild winters; it is represented by weather data for the U.S. city of Seattle,
- **Cold**: This zone had severe winters and short or mild summers typical of Nordic climates; it is represented by weather data for the U.S. city of Minneapolis.

Houses Evaluated

The houses were chosen to be typical of new US homes and compliant with all relevant norms. Different sizes (from 93 m^2 2-bedroom to 372 m^2 5-bedroom) and air tightness levels were used, leading to mechanical ventilation rates from 15 to 40 L/s. Further details of the houses can be found in [8]. For brevity only results for a medium sized house of 186 m^2.

Heating and Cooling Equipment

Equipment sizing was based on ACCA Manuals J and S [10, 11]. Equipment sizing was important in this study because several ventilation systems used the furnace blower to distribute ventilation air. Further details of the equipment can be found in [7 and 8].

Systems Evaluated
We considered nine different ventilation systems derived from previous reviews [11] and rated performance. Fan energy use and HRV/ERV efficiencies were taken from the Home Ventilating Institute directory [12]. The following ventilation systems were simulated:

Standard House (no whole-house mechanical ventilation)
This was the base case for comparison to the other ventilation methods and was simulated for all six climates and three house sizes. This was the same house as the mechanically ventilated cases, except it had no whole-house mechanical ventilation, only bathroom and kitchen source control exhaust. This house was ***not*** 62.2 compliant.

Leaky Envelope that meets 62.2 (no whole-house mechanical ventilation)
This represented existing homes and was simulated for all six climates and three house sizes. This house was 62.2 compliant because of its leaky envelope.

Continuous exhaust
Continuous exhaust was simulated using a bathroom exhaust fan.

Intermittent Exhaust
Intermittent exhaust was simulated using bathroom fans that were on for 20 hours and off for 4 hours during peak space conditioning load. The fan flow was increased from the continuous exhaust case to account for the intermittent operation using algorithms from 62.2.

Heat Recovery Ventilator (HRV) & Energy recovery Ventilator (ERV)
An HRV was used in the cold, marine, continental and arid climates. The hot humid and warm humid climates used ERVs. The HRV and ERVs were connected to the forced air duct system and the air handler fan operated at the same time to distribute the air. Listed recovery efficiencies were applied to the air flow through the unites when calculating the energy use.

Continuous Exhaust plus Air Distribution
The continuous exhaust system was augmented with a central fan integrated (CFI) supply that used the furnace blower to intentionally draw outdoor air through a duct into the return and distribute it throughout the house using the heating/cooling supply ducts. The outdoor air duct was only open to outdoors during heating and cooling blower operation and had a damper that closed when the blower was off. The flow through the outdoor air duct into the return was the same as the continuous exhaust fan flow.

Continuous Supply
The continuous supply system used a fan to supply filtered air from outside to the duct system that then distributed the air throughout the house without using the furnace blower. The supply fan was sized to be four times the ASHRAE Standard 62.2 outdoor air requirements to allow for a 3:1 mixing ratio of indoor air to outdoor air for tempering.

RESULTS

In order to focus on the impacts of the ventilation system and not the details of the house, we have elected to show the results relative to a base case. This approach subtracts out common factors, allowing the results to reflect the difference due to the ventilation treatment chosen. We have elected to use the *unvented house* as the base case, but it is important to remember that that case is a non-compliant one.

The figures are stacked bar charts where we have broken up the total energy use into a piece that represents the energy to induce the desired ventilation (Ventilation), the energy to distribute air (Distribution) and the energy to condition the air (Space Conditioning that combines heating and cooling). The energy use data was converted to dollars ($) using current local energy prices for the US cities chosen.

Figure 1 shows the results for the Hot humid climate where the total energy use for the standard house was 16,500 kWh (cost was $1125). The exhaust systems had the least energy increase of about 800 to 1000 kWh (5% of the total space conditioning) and the intermittent system saved 200 kWh ($18) relative to the continuous system. Both the ERV and Continuous Supply systems used significant distribution energy that made them the least energy efficient. The higher ventilation rates of the continuous supply and continuous exhaust plus intermittent supply lead to greater space conditioning energy use.

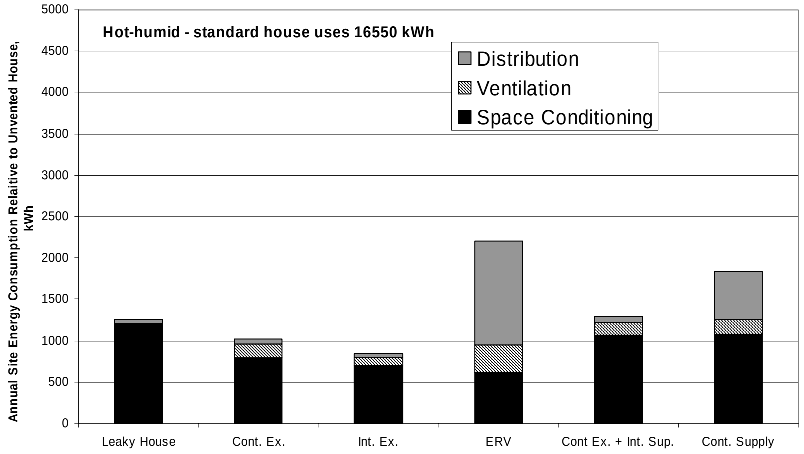

Figure 1: *Energy use of ASHRAE 62.2 compliant ventilation systems relative to standard unventilated house in Hot humid climate.*

Although the ERV had the greatest air change rates, the recovery of energy was shown by the having the least space conditioning energy use. However the distribution energy requirements and ventilation fan power made the ERV the greatest energy user (costing an additional $240 compared to the standard house). If the ERV had not used the central fan for distribution the energy use would be between the continuous and intermittent exhaust cases. In comparison to the leaky house, both the exhaust only systems actually used less energy despite providing greater effective ventilation. The leaky house suffers from having higher ventilation rates when indoor outdoor temperatures are greatest leading to excess energy use.

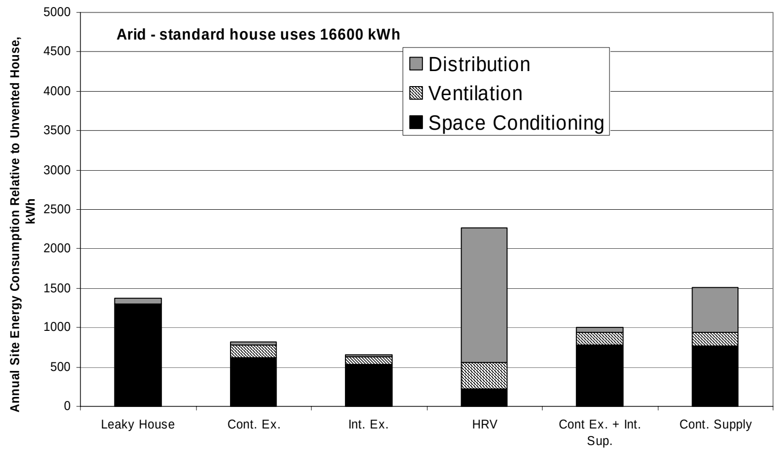

Figure 2: *Energy use of ASHRAE 62.2 compliant ventilation systems relative to standard unventilated house in an Arid climate.*

Figure 2 shows the results for the Arid climate where the total energy use for the standard house was 16,600 kWh (cost was $1170). Although this is considered a cooling dominated climate (with almost four times as much cooling operating time than heating), the energy used for heating (9600 kWh) is still greater than that used for cooling (5500 kWh). The Arid climate results had the same general trends as the Hot humid climate, but the milder climate meant that the space conditioning energy use related to ventilation is lowered. The exhaust system used 800 kWh ($60). The intermittent exhaust saved 160 kWh ($14) relative to the continuous system. With less space conditioning energy, the distribution energy use was even more dominant for the HRV and continuous supply than in the Hot humid climate and made them the least energy efficient. The higher ventilation rates of the continuous supply and continuous exhaust plus intermittent supply lead to greater space conditioning energy use.

Although the HRV has the greatest air change rates the recovery of energy is shown by the having the least space conditioning energy use. However the distribution energy requirements and ventilation fan power make the HRV the greatest energy user: requiring an additional 2250 kWh compared to the standard unvented house (costing an additional $240 compared to the standard house). If the HRV did not use the central fan for distribution the energy use would be between the continuous and intermittent exhaust cases. As with the Hot humid climate, the leaky house used more energy than either of the exhaust systems.

Figure 3 shows the results for the Warm humid climate where the total energy use for the standard house was 24,750 kWh (cost was $1410). For the Warm humid climate, the less benign climate led to the energy for space conditioning increasing significantly - in particular for the higher ventilation rate systems and the leaky house.

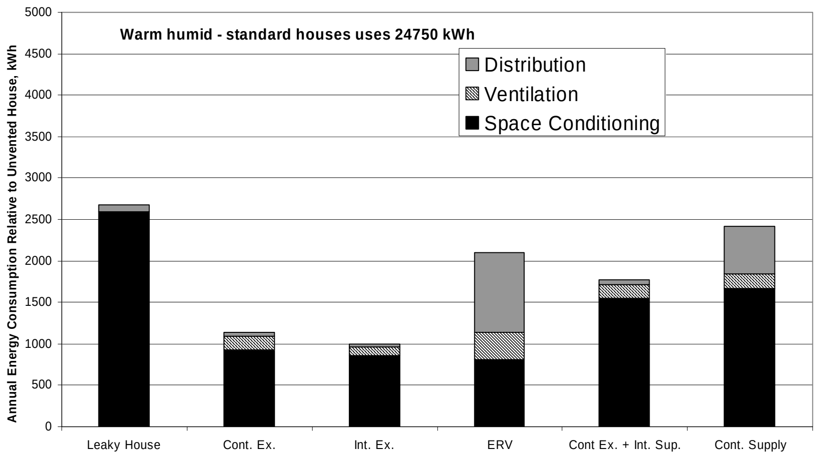

Figure 3: *Energy use of ASHRAE 62.2 compliant ventilation systems relative to standard unventilated house in a Warm humid climate.*

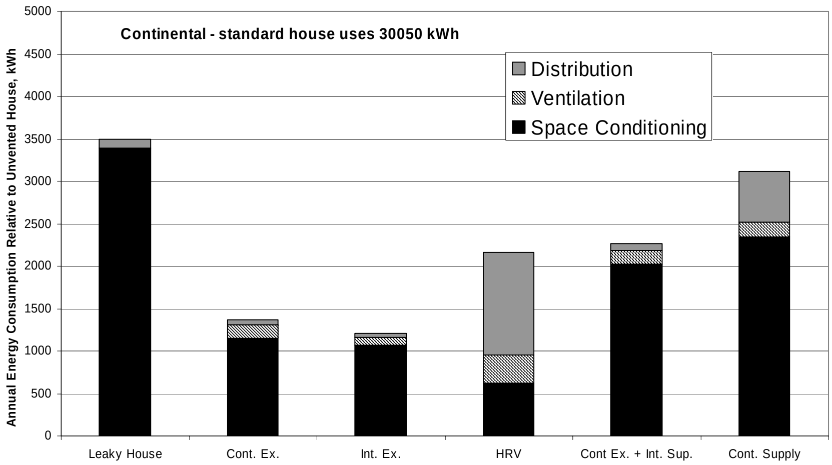

Figure 4: *Energy use of ASHRAE 62.2 compliant ventilation systems relative to standard unventilated house in a Continental climate.*

The exhaust system used 1150 kWh ($75) more than the unvented house. The intermittent exhaust saved only 45 kWh (less than $10) relative to the continuous system. The leaky house was the greatest energy user, followed by the continuous supply. The ERV had the lowest space conditioning energy use that made it more energy and cost competitive with the other systems.

The Continental climate is more heating dominated and cooling energy use is reduced to about 5% of the total. The colder climate is reflected in the space conditioning energy use that in increased relative to the distribution and ventilation fan components. The same trends are seen as for the Warm humid climate, with the leaky house requiring the most additional energy (3500 kWh ($190)) and the continuous exhaust system the least (1365 kWh ($85)).

The marine climate has very little air conditioning - compressor energy was less than 1% of the gas energy used. However, the milder winter climate compared to the Continental climate led to less total energy use and less difference between the unvented standard house and the ventilation systems.

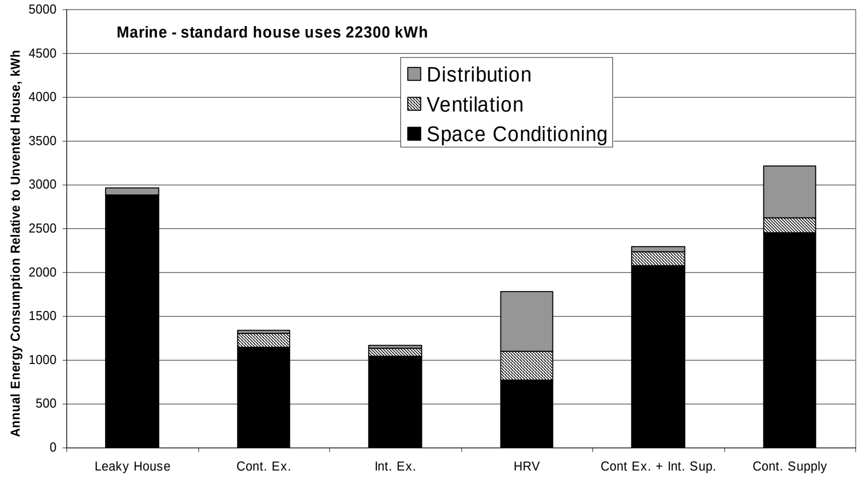

Figure 5: *Energy use of ASHRAE 62.2 compliant ventilation systems relative to standard unventilated house in a Marine climate.*

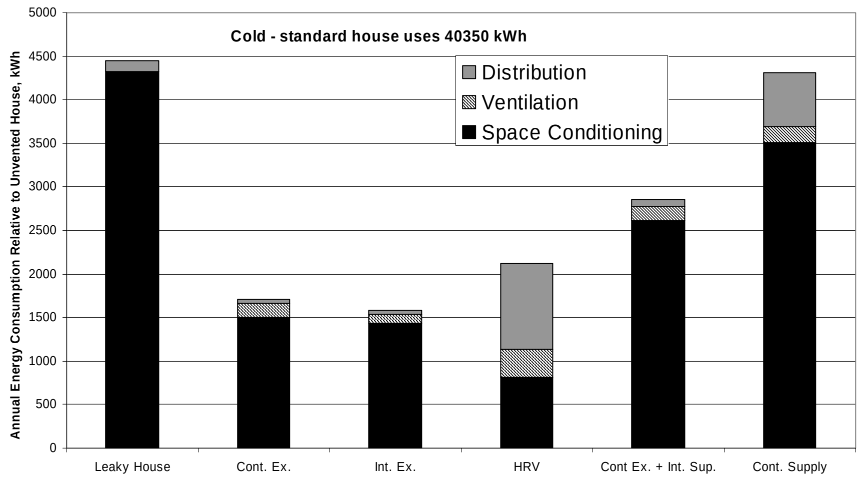

Figure 6: *Energy use of ASHRAE 62.2 compliant ventilation systems relative to standard unventilated house in a Cold climate*.

The distribution energy for the HRV and Continuous exhaust with intermittent supply were reduced due to the small capacity furnace and air conditioner required in the Marine climate with their smaller blower.

The Cold climate was the harshest climate investigated in this study and used the most energy. The low outdoor temperatures in winter make the leaky house a big energy user - requiring 4400 kWh ($240) more than the standard house. Although the space conditioning energy use for the HRV is about half that for the exhaust systems, the blower energy used to distribute the air is such that it requires 400 kWh ($60) more energy. As stated previously this could be reduced if the central furnace blower was not used to distribute the air, in which case the HRV would use the least energy. The higher air change rates of the continuous exhaust plus intermittent supply and the continuous supply lead to much more energy use than the exhaust only cases in this extreme climate.

Exhaust systems were found to be more energy efficient for several reasons: they had the lowest ventilation rates, they used the least ventilation fan power and they did not use fans to mix or distribute air. The most important reason was that requirements of 62.2 do not account for the differences in combining of infiltration with balanced and unbalanced mechanical ventilation.

Air distribution systems are used to distribute heating and cooling, to distribute fresh air, and to filter, clean and recirculate indoor air. As such they can be seen as a separate building function from the rest of the ventilation system and could be treated separately both in regulation and design. One advantage of treating distribution as a separate function is that it will allow efficiency advances in distribution to be made independently from, for example, cooling systems. Other studies [13, 14] have shown that using more efficient variable speed motors at low speed to circulate and mix air in a house results in significant energy savings relative to the blowers in most systems like the ones used in this study. Other options include using the HRV/ERV fans to also distribute the air in the house either through a dedicated duct systems or using the existing forced air system ducts.

CONCLUSION AND RECOMMENDATIONS

In this study we used a simulation approach to determine the likely energy impacts of residential ventilation requirements associated with ASHRAE Standard 62.2 and ventilation strategies for six different climates. The energy to provide such minimally acceptable ventilation was in the range of 800 to 1700 kWh per year ($50 to $100) for the most efficient options, which typically represented about 5% of the heating and cooling energy. The space conditioning energy associated with the extra ventilation provided by the ASHRAE 62.2 ventilation systems was much larger than the fan energy needed to supply or exhaust the air. In every climate the intermittent exhaust system proved to be the most energy efficient system for meeting the proposed requirements—followed by the continuous exhaust system.

Homes with leaky envelopes paid a significant energy penalty without necessarily providing more ventilation then a house with a better envelope and mechanical ventilation. Exhaust systems were found to be more energy efficient than the alternatives because the requirements of 62.2 do not correctly account for the addition of infiltration and mechanical ventilation. Since the exhaust system had a lower impact on the total air exchange, its space conditioning impact was smaller and it was the more energy-effective approach by virtue of producing fewer air changes.

Although the ventilation related energy requires changed by about a factor of three between mild and harsh climates, the general trends for relative energy use between systems was consistent.

Finally, systems that used the furnace or air conditioner blower to distribute air used substantially more energy than other systems. In particular for HRVs and ERVs, the use of the central blower counteracted the space conditioning energy savings of these devices such that they used more energy than a simple exhaust system. This energy penalty may be acceptable if mixing of air is considered desirable for thermal or health concerns.

ACKNOWLEDGEMENTS

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