ENERGY IMPACTS OF VARIOUS RESIDENTIAL MECHANICAL VENTILATION STRATEGIES

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ABSTRACT

The Building America program has been working with home builders for more than a decade using a variety of strategies for bringing fresh air into the homes. Many of these strategies utilize the central air handler fan from the HVAC system to ventilate when the system runs. Controllers can be purchased to force the air to enter for minimum periods of time or to shut off outside air dampers after some period of runtime.

EnergyGauge USA, a detailed hourly residential simulation program, has been modified to simulate the various runtime strategies, as well as supply- or exhaust-only ventilation strategies and an enthalpy recovery ventilation system. This paper compares simulation results for each of these ventilation strategies.

Runtime ventilation tends to bring in very little extra air. When forced to turn on for 25% of an hour, the typical HVAC fan uses significant energy making the overall energy penalty more than that from a continuous supply or exhaust fan supplying the same nominal air flow. Enthalpy recovery ventilation units tend to use more energy overall - despite the heat recovery - than supply or exhaust only ventilation systems, due to using twice as much fan energy.

This paper presents simulation results for eight ventilation strategies compared to no ventilation, and it presents the changes in energy use for each.

BACKGROUND

The U.S. Department of Energy's (DOE) Building America's contractors have worked with many builders over the last decade to favorably incorporate mechanical ventilation systems into home construction. Typical builder concerns include the ease of installation, maintenance, and first cost. The ability to maintain comfort and moisture control at low energy costs are additional concerns.

ASHRAE standard 62.2 (ASHRAE, 2007) requires that homes receive outdoor air each hour at no less than the rate specified in the following equation based on the floor area of the conditioned space and number of bedrooms:

Eq. 1 $$Q_{fan} = 0.01A_{floor} + 7.5(N_{br} + 1)$$

where

Q_{fan} = Fan flow rate (cfm)
A_{floor} = Floor area (ft^2)
N_{br} = Number of bedrooms; not to be less than one

For example, a three-bedroom house with 2,400 square feet would require at least 54 cubic feet per minute (cfm) of outdoor air.

Although ASHRAE standards may call for supplemental forced ventilation of homes, in practice few building departments are enforcing mechanical ventilation. In most Sun Belt states, only homes participating in "green" home or other beyond-code programs tend to have any mechanical ventilation other than spot exhaust systems. "Green" home programs put an emphasis on ventilation health aspects. For example, LEED for Homes® requires compliance with ASHRAE Standard 62.2-2007, with some exceptions for mild climates.

In humid parts of the country, the impact of adding fresh air must be properly evaluated in the HVAC design. Otherwise, the health benefits sought may be compromised since it could lead to increased moisture levels that contribute to mold growth and increased reproduction of dust mites or other allergens (Chandra, 2001). The moisture load of any fresh air design must be adequately accounted for in designing the home's comfort conditioning system with consideration for times when the sensible load is small and the air conditioner may not run.

A laboratory study looked at six strategies and resulting moisture loads [Moyer et al., 2004)]. This study quantifies the energy use and humidity impacts of six commonly implemented mechanical ventilation strategies – one exhaust system and five supply systems – compared to the base case of “no ventilation system”. One of these strategies incorporates energy recovery. The six systems were installed serially in a new, EnergyStar Manufactured home laboratory (MHLab) with typical whole house air tightness and simulated occupancy for 14-day periods. The MHLab, where these strategies using nominal 50 cfm airflow were implemented, is located in Cocoa, Fla. Measured air exchange for the home using tracer gases ranged form 0.20 to 0.32 air changes per hour with average outside wind speeds of two to four miles per hour. Without mechanical ventilation the home had 0.15 air changes per hour. Each of the systems tested maintained reasonable humidity control, and Moyer credits the properly sized cooling system with maintaining the control despite the outside air. The strategy with outside air brought in through the air handler with a dehumidifier maintained the humidity most consistently, but had a 200-watt energy penalty.

Humidity and cost considerations have led many builders to use a “runtime ventilation” scheme. This involves connecting a duct from the outside to the return side of the air handler where air is brought in by the air handler when it is activated. This allows the fresh air to be easily distributed to the various rooms. The potential downside of such a system is that at peak conditions excess air may be brought in when it is least needed, and during times of year when the air conditioning system may not need to run very often the fresh air goals will not be met.

In order to compensate for these potential drawbacks, control systems have been added to augment runtime ventilation. One control forces the system to turn on once per hour or every few hours in order to bring in outside air if the system has not run the required amount on its own thermostat control. The potential downside of this control scheme is that the air handler fan is used to bring in only a small amount of air and tends to draw much more power than a small supply or exhaust fan. Another control utilizes a damper that will shut off after a system has run for a specified period. This control alleviates the original downside of bringing in excess air during peak conditions and potentially reducing the size (or latent capacity in humid climates) of the air conditioning system. By itself this control system would still not bring in fresh air during times of low air conditioning operation.

Combining both of these control strategies allows a system to bring in sufficient outside air on a regular basis without excessive air during peak periods. Also, the excess power of using the air handler fan can be somewhat ameliorated by the use of a variable speed fan with a more efficient brushless DC motor.

ENERGY AND VENTILATION SYSTEMS

The energy use of the runtime ventilation system with and without the control systems will differ. Other mechanical ventilation options use small fans that use less energy when forced to run for ventilation purpose. An exhaust-only system, such as a bath fan that will run more frequently, is fairly easy to install. The potential downside is that the negative pressure created will lead to air movement through cracks, and potentially the made-up air will come from sources (e.g., an attached garage) where air is not desirable. A supply-only system could use a small fan and have positive pressure in the home. However, distributing the air throughout the house using just a small fan is a challenge. Balanced systems have to use two fans of similar size to the supply or exhaust only options, doubling the fan energy use and also being considerably more expensive to install. They allow the maximum control of entering and exiting air as both locations are determined by the designer. In comparison, an exhaust-only system will have the make-up air delivered from the paths of least resistance which may include holes between garages or attics and the conditioned space.

Balanced systems can also include a heat exchanger or enthalpy exchanger. A supply-only or exhaust-only ventilation system will tend to have less total air from the combination of the mechanical ventilation and infiltration due to the fact that unbalanced air flows are not additive. Balanced air flow results in larger ventilation rates due to the governing equation for combining forced and natural ventilation (Sherman and Modera, 1986):

Eq. 2 $$Q_{total} = (Q_{nat}^{2} + Q_{unbal}^{2})^{0.5} + Q_{Bal}$$

where Q represents volume of air flow (cfm or m/s).

SIMULATION TOOL

Recently, FSEC expanded EnergyGauge® USA ventilation control capabilities by adding a max-time damper control for ventilation systems. The simulation engine is DOE-2.1E Version 120. FSEC developed an algorithm in a private function of DOE-2.1E in order to model an HVAC fan running between a specified minimum and maximum portion of an hour. Building America teams, energy raters and energy analysts can now choose from a large number of potential mechanical ventilation strategies:

- No mechanical ventilation provided
- Supply air fan
- Exhaust air fan
- Both supply and exhaust air fan (Fully or partially balanced)
- Enthalpy recovery ventilation system
- Runtime ventilation where ventilation air is provided only when heating and cooling systems run (supply vent using the air handler unit)
- Runtime ventilation with a required minimum where the HVAC fan runs for a minimum amount of time each hour
- Runtime ventilation where the outside air damper will close if the air handler system has run a set amount of time during the hour
- A system that has a required minimum runtime and a closure for the outside air damper after a maximum amount of time run that hour
- A system that provides no outdoor ventilation air but does provide a set ventilation fan power (this is primarily for some reference building energy use rule sets).

DOE-2 reports the fan energy in report SS-L. The SS-L report allows for separate reporting of ventilation fan energy during non-heating and non-cooling hours. In order to process scoring requirements that consider the energy use of mechanical fans (HERS 2006 for instance), the ventilation fan energy used during heating and cooling hours is proportioned to heating and cooling in accordance with those energy uses in EnergyGauge USA. For allocation purposes, the fan energy used during non-heating and non-cooling hours, which DOE-2 reports on the SS-L report, is added to the total by the proportion of heating and cooling fan energy used that month. If no heating or cooling fan energy was used that month then 50% is added to each.

FSEC recently added the ability to separate out any mechanical fan energy each hour, including the extra time the air handler energy for runtime ventilation schemes. Another recent addition was TMY3 weather data which was used for this study.

SIMULATION RESULTS

The ventilation options depicted in the previous section were run for three cities – Tampa, Dallas, and St. Louis, Missouri (Farmington weather data was used). A highly efficient, tax credit eligible, three-bedroom, 2,400 square-foot home was modeled with a natural air change per hour (ach) of 0.30 - ach 50 of 5.7 - infiltration rate. The St. Louis home had an additional unconditioned, windowless basement. The Tampa home had concrete block wall construction with R-5 ft^2-hr-^oF/Btu insulation. The Dallas and St. Louis homes had wood frame walls insulated to R-13 and conditioned by a SEER 14/ HSPF 8.0 Btu/Wh heat pump. Many other characteristics (note the exceptions described here) are described in a detailed report (Fairey et al., 2006). The decision was made to simulate the type of systems builders frequently use rather than systems that may be installed to guarantee the quantity and quality of air according to ASHRAE Standard 62. This study was done bringing a nominal design of 50 cfm of outside air into the home. For runtime systems that may mean far less than 50 cfm is actually added on an average basis, and examples of this will be shown in this paper.

The eight ventilation options produce the results shown in Tables 1 and 2 and increased energy penalty indicated in Figures 1 and 2. These results were obtained using EnergyGauge USA, version 2.8, release 1, and the *Calculate > Annual Simulation* menu option. These simulations were run with the following options:

- No mechanical ventilation during times of natural ventilation (EnergyGauge program shuts off all mechanical ventilation during times when algorithms indicate conditions are favorable for opening windows)
- Auto-sizing for the HVAC system set to on.

Table 1. Cooling season energy use for nominal 50 cfm ventilation strategies

	Tampa		Dallas		St. Louis	
Mechanical Ventilation Strategy	Mechanical Vent Fan kWh	Total Cooling kWh	Mechanical Vent Fan KWh	Total Cooling kWh	Mechanical Vent Fan kWh	Total Cooling kWh
None	0	3512	0	2680	0	1192
Supply Vent, 20W	120	3825	80	2900	46	1296
Exhaust Vent, 20W	120	3793	80	2878	46	1286
Balanced vent, 40W	236	4108	158	3103	90	1374
60% effective ERV, 40W	239	3923	160	2966	115	1325
Runtime Vent (RV)	0	3571	0	2740	0	1225
RV w 25% min. runtime	180	3805	170	2979	147	1426
RV with outside damper off at 25% runtime	0	3532	0	2700	0	1198
RV fixed at 25% runtime	165	3748	157	2922	137	1383

Table 2. Heating season energy use for nominal 50 cfm ventilation strategies

	Tampa		Dallas		St. Louis	
Mechanical Ventilation Strategy	Mechanical Vent Fan kWh	Total Heating kWh	Mechanical Vent Fan kWh	Total Heating kWh	Mechanical Vent Fan kWh	Total Heating kWh
None	0	293	0	2157	0	5028
Supply Vent, 20W	30	342	78	2327	100	5290
Exhaust Vent, 20W	30	346	78	2344	100	5318
Balanced vent, 40W	66	455	160	2774	206	6136
60% effective ERV, 40W	61	389	156	2485	194	5571
Runtime Vent (RV)	0	294	0	2164	0	5039
RV w 25% min. runtime	107	397	282	2429	368	5377
RV with outside damper off at 25% runtime	0	294	0	2160	0	5034
RV fixed at 25% runtime	102	393	265	2410	342	5350

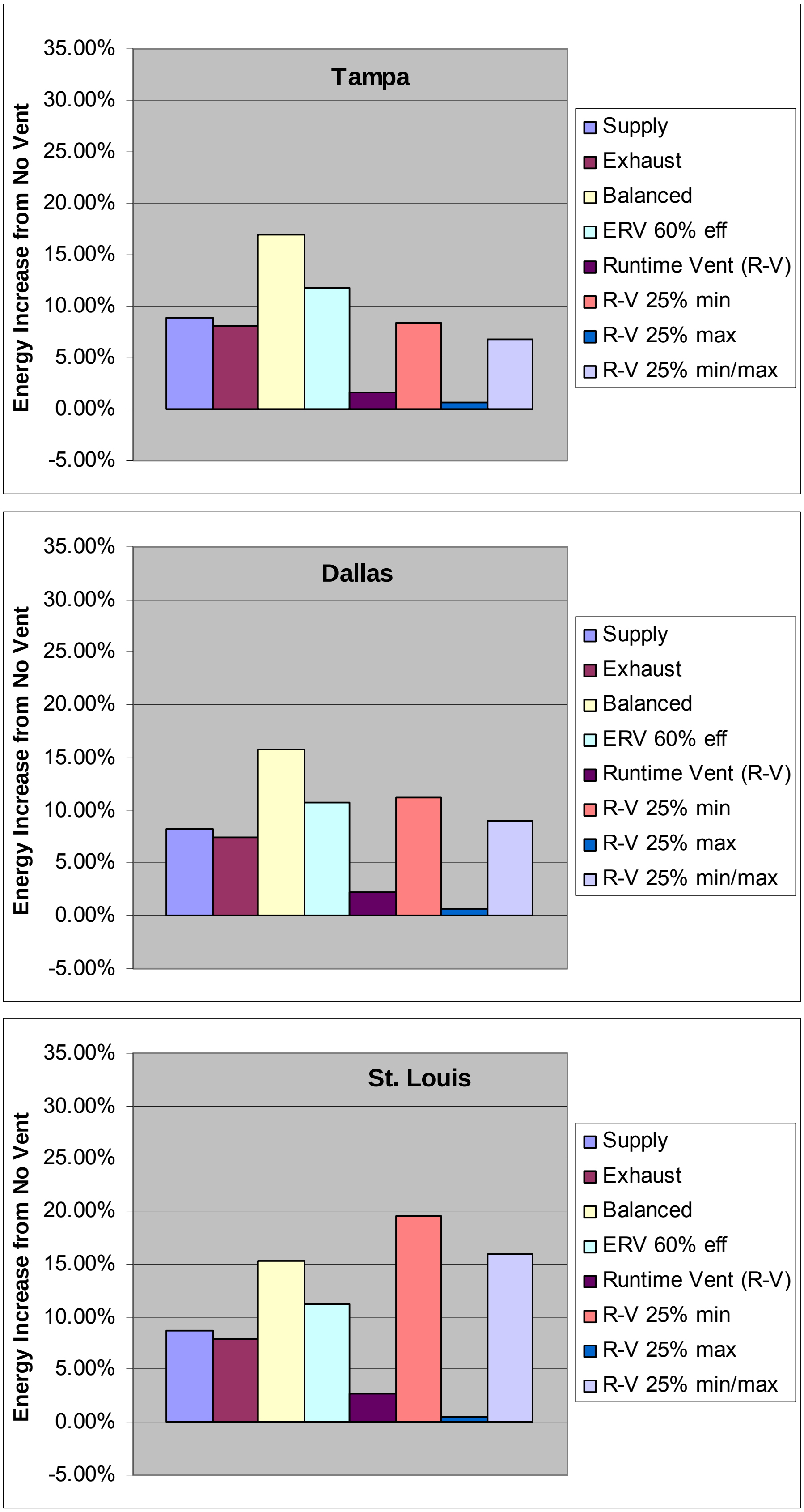

Figure 1. Cooling Season Increase in Energy Use with Eight Ventilation Strategies

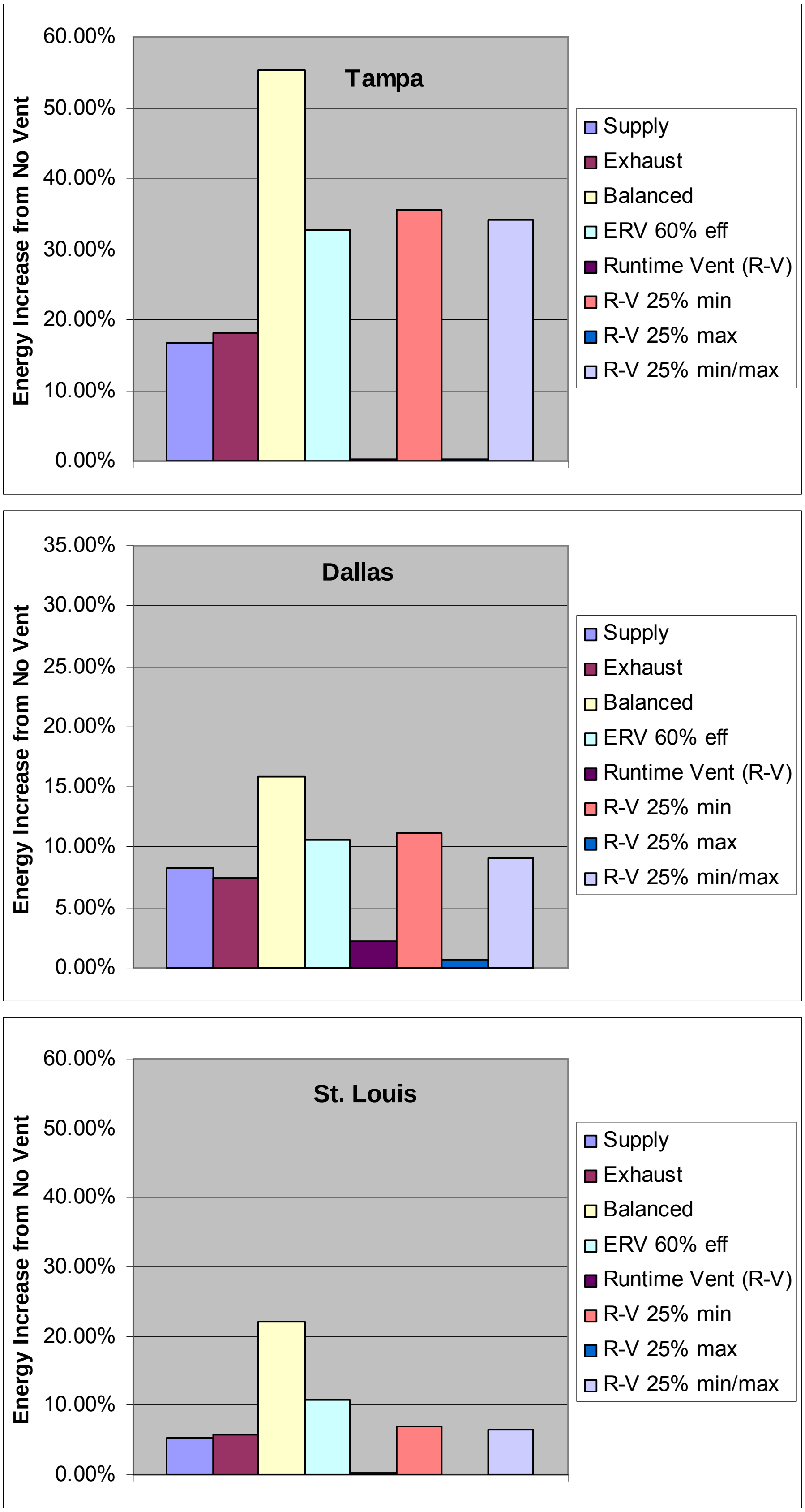

Figure 2. Heating Season Increase in Energy Use for Eight Ventilation Strategies

DISCUSSION

Below, we help interpret the results shown in Tables 1 and 2.

Continuous Ventilation Systems

When an exhaust system is employed we assume that the heat from the fan's motor is also exhausted. For supply systems, we assume the heat of the fan motor is delivered to the space. Thus, the exhaust vent option uses slightly more energy for heating, but slightly less energy for cooling than the supply only system

We also assumed that balanced flow required twice the fan power of unbalanced flow (40 watts vs. 20 watts) since both a supply and exhaust fan are required. Even when a 60% enthalpy recovery ventilator (ERV) is added, the energy use is greater than for an unbalanced simple supply or exhaust system. Another reason for the greater energy use is that a balanced system delivers more air as explained above in Equation 2.

Runtime Ventilation Systems

The runtime vent method uses the heating and cooling system fan and a purposeful, ducted return leak with a damper to bring in outside air when the system runs. Without any other controls, it only brings in fresh air during periods when heating or cooling is required. For the Dallas home, the runtime vent option only slightly increased heating and cooling energy use. Considering that we were only adding 50 cfm when the system runs, this was not surprising. For the Dallas-Fort Worth climate, the home's mechanical systems were only turned on 13% of the time. The net effect when combined with the envelope ach 50 leakage of 4.0 is vanishingly small. Computing the difference between straight natural infiltration and the total from the runtime ventilation run requires looking at the difference between the flow calculated from equation 1 and what would have otherwise occurred.

Eq. 3 $$Q_{difference} = Q_{total} - Q_{nat}$$

Figure 3 represents the hourly Q_{nat} and $Q_{difference}$ for the runtime ventilation case. The average $Q_{difference}$ value is 0.8 cfm. Thus, runtime venting is hardly any different, on an annual basis, than no mechanical venting. Peak summer hours for this case were as high as 12 cfm added, so for some select hours the mechanical ventilation may make a significant difference, but not on an annualized basis.

Runtime ventilation is highly dependent on system size. The system size calculated yielded moderate winter runtimes as shown on the top of Figure 3. Obviously, system size will have a large impact on the impact of runtime ventilation, although the modeled systems are quite a bit smaller than what might be expected in many newer homes where systems are chronically oversized.

When forced to turn on for 25% of an hour, the typical HVAC fan uses significant energy so that the overall energy penalty is more than a continuous supply or exhaust fan that, although sized for the same nominal flow, would provide more fresh air, albeit not distribute it as well. This study is a simulation study and does not evaluate the quality of a given ventilation strategy, and in practice, energy used will depend on the components and the resistance of the distribution system.

On the other hand, if the runtime vent is limited with a damper to be no greater than 25% of the hour, the model predicts almost no difference in cooling or heating energy use. This is expected because the system will supply even less outside air than the simple runtime vent case shown in Figure 3, where for some hours it is adding ventilation air for much more than 25% of the hour. Finally, a sophisticated controller that maintains exactly 25% minimum and maximum runtime each hour results in a 6% (Tampa) to 16% (St. Louis) increase in cooling and a 6% (St. Louis) to 34% (Tampa) increase in heating energy use compared to no venting, or slightly less energy penalty than the simpler 25% minimum runtime.

Fan Energy Use Explains Overall Energy Use Changes

Examining the breakout between actual cooling, heating and fan energy use, it is apparent that most of the added energy is from the fan. Actual cooling load is only slightly larger, which is not surprising since buildings require cooling many times, such as at night when it is more comfortable outside and the added air may actually reduce cooling loads. This occurs because internal gains and solar gains create cooling loads but reduce heating loads.

Fan Heat Energy is Extra Load

The heating value column in Table 2 is slightly misleading as the extra fan runtime also provides heat from its motor. Table 3 shows more details for the Dallas case.

Thus, the 25% minimum runtime case shows less heating (excluding fans) than the no-vent case, but the software models the extra 295 kWh of fan energy as heat. In this case, with minimal added outside air, that more than makes up for the added heating load due to extra outside air.

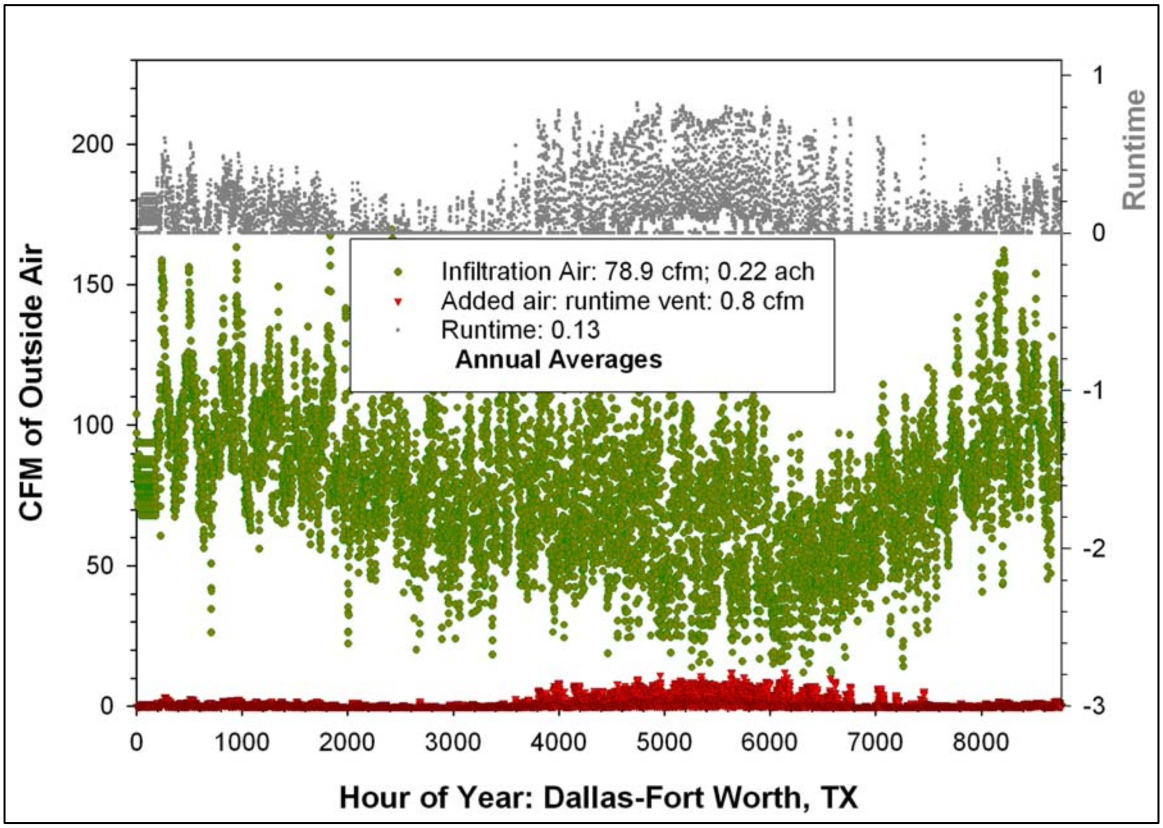

Figure 3. Hourly natural and added ventilation rates for runtime vent case. Inputs were 50 cfm mechanical and 0.3 ach leakage (natural). Natural infiltration is adjusted hourly by DOE2 based on natural driving forces (e.g., wind speed).

Table 3. Runtime Vent Dallas case

	Heating	Heating Fan	Mech. Vent Fan	Total Heating	% increase from no vent case
No Vent	1860	287	0	2157	0
RV with 25% minimum	1852	295	282	2429	12.6

SUMMARY

Simulation runs demonstrate that using typical mechanical ventilation control systems in highly efficient homes, with nominal 50 cfm ventilation, may increase overall cooling season energy use by 15% or more and heating season energy use by 25% or more. The fan energy use can be significant as a percentage for climates with mild seasons. Balanced ventilation systems, simulated using 40 watts of continuous energy have the highest energy use by far

since balanced systems increase the amount of air more than supply or exhaust only systems and use more power. Enthalpy recovery ventilation units tend to use more energy overall, despite the heat recovery, than supply or exhaust only ventilation systems due to using twice as much fan energy. Runtime ventilation systems sized for bringing in 50 cfm of air actually bring in very little air on an average basis. For instance, there was only a 1% increase in outdoor air in a simulation for a home in Dallas. When forced to turn on for 25% of an hour, the typical HVAC fan uses significant energy so that the overall energy penalty is more than a continuous supply or exhaust fan

This paper presents simulation results and does not evaluate the quality of a given ventilation strategy. The distribution of air, the actual quantity of air delivered and potential humidity levels will vary. However, this study does provide useful information for designers regarding the comparative energy use of systems.

REFERENCES

ASHRAE. 2001. ANSI/ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality, Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Chandra, S., & Beal, D. (2001). “Preventing House Dust Mite Allergens in New Housing.’ ASHRAE IAQ Conference Proceedings, San Francisco, CA.

Neil Moyer, Dave Chasar, Subrato Chandra and David Hoak, “Assessing Six Ventilation Techniques in Hot Humid Climates,” Proceedings of the 2004 Summer Study on Energy Efficiency in Buildings, Vol. 1, American Council for an Energy Efficient Economy, Washington D.C.

Sherman, M.H. and Modera, M.P.,1986., "Comparison of Measured and Predicted Infiltration Using the LBL Infiltration Model," Measured Air Leakage of Buildings, ASTM STP 904, H.R. Treschel and P.L. Lagus, Eds., American Society for Testing and Materials, Philadelphia, p. 325-347

Fairey, Philip, Carlos Colon, Eric Martin, Subrato Chandra, “Comparing Apples, Oranges and Grapefruit: An Analysis of Current Building Energy Analysis Standards for Building America, Home Energy Ratings and the 2006 International Energy Conservation Code,” FSEC_CR_1650-06, September, 2006.

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