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Is it All a Lot of Hot Air?—Mechanical Ventilator Performance

by Michael Lubliner and Marvin Young

Whether to build homes airtight and then add mechanical ventilation has been hotly debated by energy-efficient builders since the 1970s. But much of the debate has overlooked two important underlying questions. Do ventilators work? And do people use them?

The Residential Construction Demonstration Project (RCDP) has collected a monumental amount of data from energy-efficient homes in the Pacific Northwest. One part of the monitoring focused on various types of mechanical ventilation systems, and has revealed two facts, one that is often taken for granted (but happily confirmed) and the other fairly surprising. First, mechanical ventilators—including heat recovery ventilators—*do* work. Secondly, residents of houses with ventilators did not run them as expected.

Since its inception in 1986, RCDP[1] has focused on the following ventilation innovations:

- air-to-air heat exchangers,
- air-to-air heat exchangers integrated with furnaces,
- air-to-air heat exchangers with duct heaters,
- exhaust-air heat pumps for domestic hot water, and
- exhaust-air heat pumps for hot water and space heat.

In addition to these heat-recovery ventilators, which recover a portion of the heat from exhaust air before expelling it, the project looks at:

- non-heat-recovery ventilators, and
- non-heat-recovery ventilators integrated with furnaces.

RCDP has focused the demonstration of these ventilation systems on the following housing types:

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- single-family site-built,
- single-family modular,
- single-family log,
- single-family manufactured (mobile home), and
- multifamily.

In 1986–87, RCDP cycle 1 constructed 165 single-family site-built and modular homes incorporating heat-recovery ventilators. In 1988-89, RCDP cycle 2 equipped 181 site-built homes with heat-recovery and non-heat-recovery ventilators. RCDP cycle 2 also built 149 manufactured homes with non-heat-recovery ventilators. RCDP cycle 3, which is presently underway, will demonstrate innovative ventilation systems in the multifamily sector. Via case studies, RCDP cycle 3 will also investigate 25 existing single-family ventilation systems in Super Good Cents homes.

RCDP homes have been extensively monitored and the performance of the RCDP ventilation systems reported in numerous research reports.[2] RCDP cycles 1 and 2 monitored:

1) Builder construction and equipment cost data; 2) Builder construction feedback surveys; 3) Occupant feedback surveys; 4) Weekly space heating and water heat electrical consumption; 5) Weekly ventilation system operation ontime; 6) Ventilation system flow rate; 7) Airtightness, using blower doors, perfluorocarbon tracer gas, and sulfur hexafluoride tracer gas; 8) Real-time ventilation system performance, using dataloggers; and 9) House doctoring. (Real-time ventilator performance and house doctoring were monitored only on a subsample of homes.)

Table 1. Non-heat-recovery exhaust and intake ventilation systems.

SYSTEM	EXHAUST TYPE	SUPPLY TYPE
Option 1	Designated bath or utility room exhaust fan	Fresh 80's or Aldes thru-wall vents
Option 2	Central Exhaust system	Fresh 80's or Aldes thru-wall vents
Option 3	Separate whole house exhaust fan	Fresh 80's or Aldes thru-wall vents
Option 4	Designated bath or utility room exhaust fan	Make-up air system via ducted heating system

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Non-Heat-Recovery Ventilators

Non-heat recovery systems were integrated into the program as a result of the high first costs associated with installing air-to-air heat exchangers in the Residential Standards Demonstration Program (RSDP). These systems incorporated devices to provide fresh air and expel stale exhaust air from the home. Table 1 provides the four approaches used in RCDP for non-heat-recovery ventilator systems.

Heat-Recovery Ventilators

Heat-recovery ventilators worked, that is, they recovered heat from ventilation exhaust air. In most cases they were limited not by their inherent performance, but by their operating time. Because residents did not feel a need for ventilation, many systems were not highly utilized.

Air-to-Air Heat Exchangers

Air-to-air heat exchanger effectiveness was slightly better than 50%. Since effectiveness relates actual heat recovery to the theoretical maximum, it's clear that heat exchangers have their greatest potential in the coldest climates. Since air-to-air heat exchangers are "balanced" ventilation systems, mechanical ventilation is added directly to the natural ventilation rate. It is very important that the building envelope be tight and that distribution and utilization are good. The RCDP specifications require that in many cases homes with heat-recovery ventilators be tighter, with a target of 2.0 air changes per hour at 50 Pascal pressure difference (ACH_{50}), than those with non-heat-recovery ventilators, whose target is 7.0 ACH_{50}.

The tightest RCDP homes were those homes with air-to-air heat exchangers that received blower door diagnostic testing during construction. This "house doctoring" during construction (after sheet rock tape and before trim and carpet) assisted them in achieving the tighter Super Good Sense specification target. These homes were installed by builders who were familiar with the correct design and installation of heat-recovery ventilators, and who may have done a better job at explaining these systems to the homeowners. They had higher air-to-air heat exchanger utilization, which suggests that occupants had been briefed well.

Air-to-Air Heat Exchangers with Duct Heaters

Air-to-air heat exchangers with duct heaters warmed the supply air and no occupants complained about cold drafts. However, few occupants without duct heaters complained about cold drafts from air-to-air heat exchangers when the systems were well designed and commissioned. This suggests that although duct heaters work, they may be unnecessary with an otherwise well-designed and installed air-to-air heat exchanger supply air distribution system.

Table 2a. Ventilation System Material Costs ($)

System	Mean	Standard Deviation	Median	# in Sample
Air-to-air heat exchanger	919	417	863	96
Air-to-air heat exchanger with duct heater	1407	244	1481	19
Air-to-air heat exchanger with furnace	977	262	939	28
Exhaust-air heat pump	2188	326	2171	10

Table 2b. Ventilation System Labor Costs ($)

System	Mean	Standard Deviation	Median	# in Sample
Air-to-heat exchanger	329	266	360	96
Air-to-heat exchanger with duct heater	527	236	540	19
Air-to-heat exchanger with furnace	72	336	38	28
Exhaust-air heat pump	669	205	694	10

Table 3a. Ventilation System Total Costs ($)

System	Mean	Standard Deviation	Median	# in Sample
Air-to-air heat exchanger	1325	440	1223	95
Air-to-air heat exchanger with duct heater	1935	355	1871	19
Air-to-air heat exchanger with furnace	1049	384	1050	28
Exhaust-air heat pump	2857	330	2806	10

Table 3b. Ventilation System Material Costs ($) by Manufacturer

Air-to-Air Heat Exchange	Mean	Standard Deviation	Median	# in Sample
Air Changer 275	1018	104	1059	3
Airxchange 502	441	0	441	2
Boss Air	1074	0	1074	1
EMX-10	436	117	431	6
EMX-25	555	10	550	5
E-Z Vent 210	670	80	670	2
E-Z Vent 220	820	0	820	1
E-Z Vent 300	1100	0	1100	1
Nutone AE200	494	198	442	32
Star 165	512	17	512	2
Star 200	793	127	720	4
Star 300	973	38	1000	3
Vanee 2000	788	202	778	44

Table 4. Total Ventilation System Costs ($) by Ventilation System Type

AirType	# in Sample	Mean	Median
Option 1	13	393	408
Option 4	9	562	470
Air-to-air heat exchangers	2	1015	1015

Exhaust-Air Heat Pumps

Exhaust-air heat pumps demonstrated great potential. They achieved coefficients of performance (COPs) in excess of 3 in favorable circumstances. The greatest COPs were achieved in space heating mode of the combined space heating and water heating systems. The exhaust-air heat pumps should work well in mild climates such as western Washington and Oregon, since, unlike air-to-air heat exchangers, the heat pumps' heat recovery is unrelated to outside temperature. No matter how warm it is outside, exhaust-air heat pumps still pull exhaust air temperatures down to about 35°F. Moreover the systems' ability to heat water provides a use for recovered heat even if space heating is not needed. The exhaust-air heat pumps eclipse some of the would-be natural infiltration by raising the neutral pressure level (the horizontal plane of a house where there is no difference between indoor and outdoor air pressure) to the ceiling. Unlike "balanced" ventilation systems, this means that some of the natural exfiltration is displaced with mechanical exfiltration with heat recovery. In theory this should relieve some of the necessity of building super tight, and partially offset the cost of the unit. The research on exhaust-air heating pumps has revealed good performance and potential for improving performance with optimum control. Unlike other RCDP ventilation systems, it is unlikely that the occupants will neglect to ventilate because the units are controlled by demand for space and water heat, and they are quiet. They are relatively trouble free for a new, sophisticated product. Although exhaust-air heat pumps are relatively costly, they offset the cost of water heating and potentially offset some house tightening measures. They not only save energy, but greatly reduce the burden on utility capacity since they produce hot water more slowly as well as more efficiently than standard water heaters.

Costs for Mechanical Ventilators

Builders reported a wide range of costs for the heat-recovery ventilation systems built in RCDP cycle 1. The cheapest heat recovery ventilation systems were heat exchangers integrated with the central heating system. This was due to the reduced ductwork requirements for these systems. The exhaust-air heat pumps were the most expensive. Costs for air-to-air heat exchangers—some integrated, some stand-alone—ranged from $431 to $1,150. The two most frequently used systems were the Nutone (average cost was $442) and the VanEE 2,000 (cost $778). Tables 2a and 2b provide a breakdown of the materials and installation costs of the ventilation system types or "options." Tables 3a and 3b provide the total cost by ventilation system option and materials cost by manufacturer.

Another smaller RCDP builder survey reported and compared air-to-air heat exchangers and non-heat recovery ventilation systems costs as presented in Table 4. Note the higher cost for an air-to-air heat exchanger as opposed to non-heat recovery systems option 1. Option 4 non-heat recovery systems averaged from $651 to $452 more respectively.

Ventilation System On-Time

In RCDP cycle 1, air-to-air heat exchanger operation was monitored on a weekly basis. Figure 1 provides the monitoring results from air-to-air heat exchangers in RCDP cycle I. Note that more than 50% of the occupants operate their air-to-air heat exchangers an average of less than 30% of the time. In RCDP cycle 2, air-to-air heat exchanger operation averaged 16 hours a day (roughly twice that of cycle 1), while the non-heat-recovery systems' average run times were all less than two hours per day as shown in Figure 2. Dehumidistats controlled many of these systems, turning the system on when the humidity of the building exceeds the setpoint. The second most common control strategy was to use a time clock, which can be set to operate for occupant-selected times of the day.

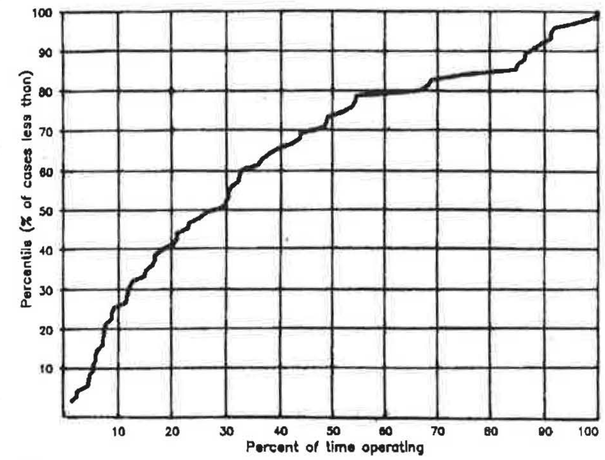

Figure 1. Distribution of air-to-air heat exchanger operating time.

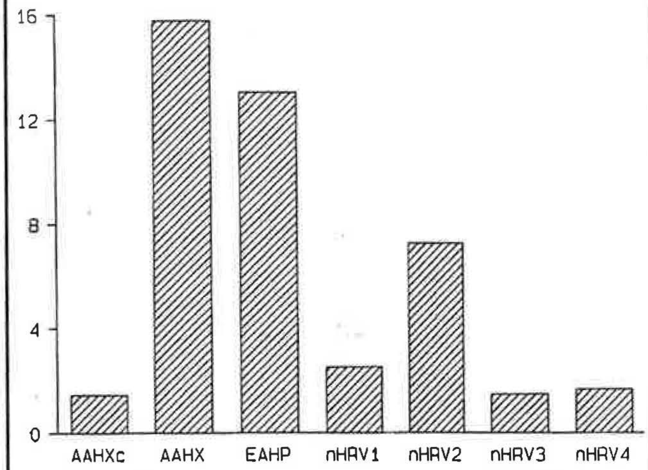

Figure 2. Average ventilation run time (hours/day).

Perfluorocarbon Tracer Gas and Blower Test

The fact that heat-recovery ventilator systems were operated more frequently than non-heat-recovery systems may have contributed greatly to the higher overall effective air change rates. Figures 3a and 3b show the difference in the perfluorocarbon tracer gas decay tests and LBL blower door test stack infiltration estimates. This "difference" can be used to estimate additional infiltration induced by the ventilation system. The air-to-air heat recovery systems appear to have contributed the most to the ventilation rates as compared to the non-heat-recovery systems.

Effects of Forced Air Systems

In RCDP cycle 2, as with other studies, forced air distribution systems have a significant impact on tracer-measured

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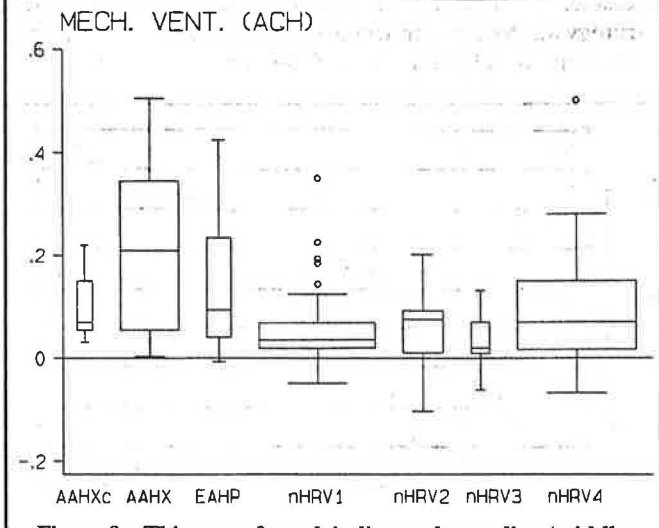

Figure 3a. This type of graph indicates the median (middle line in rectangle), quartiles (top and bottom of rectangle and top and bottom bars), and the sample size (the width of the rectangle). Circles are outliers.

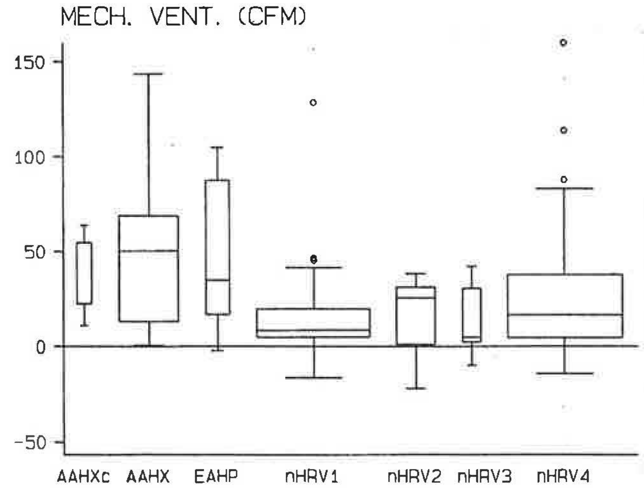

Figure 3b.

air change rates, but not as much as other similar studies conducted on pre-1980 current practice homes[3] (see Figures 4a and 4b). RCDP training encouraged builders to use systems with interior ductwork and better duct sealing practices. In older current practice homes this was not encouraged, which may provide an indication of the savings potential from these ductwork efficiency measures.

Sulfur Hexafluoride Tracer Gas Test

A small sub-sample of RCDP homes with air-to-air heat exchangers, exhaust air heat pumps, and non-heat-recovery ventilator option 1 systems had tracer gas decay testing conducted. In each home, sulfur hexafluoride tracer gas decay tests indicated the home overall air change rate with and without the ventilation systems operating. Figure 5 shows how in all cases the operation of the ventilation system increased the overall air change rates to about 0.35 ACH. These case study homes demonstrate that the mechanical ventilation systems can work as intended when operated sufficiently.

Ventilation System Flow Testing

RCDP flow-rate specifications were based on ASHRAE Standard 62-81R. This typically results in whole-house design flow-rate capacities of 0.35 air changes per hour (ACH). Spot ventilation fans were to provide 50 cfm per bathroom and 100 cfm per kitchen. Eighty-four percent of non-heat-recovery ventilator option 1 systems in RCDP cycle 2 had measured ventilation rates not meeting 0.35 ACH. This was largely due to bathroom fans being used as whole house ventilators that incorporated long runs of three-inch ductwork or highly restrictive exhaust flow outlets. These bath fans are typically rated to operate at ductwork pressure drops of about 0.1 inches of water. In RCDP, as in most new

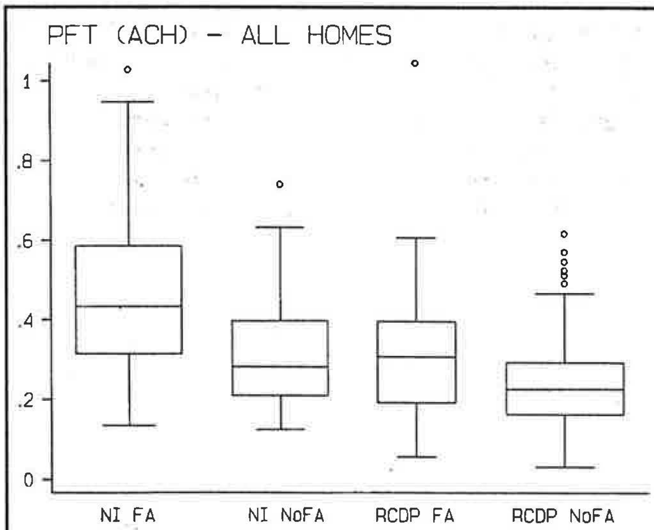

Figure 4a.

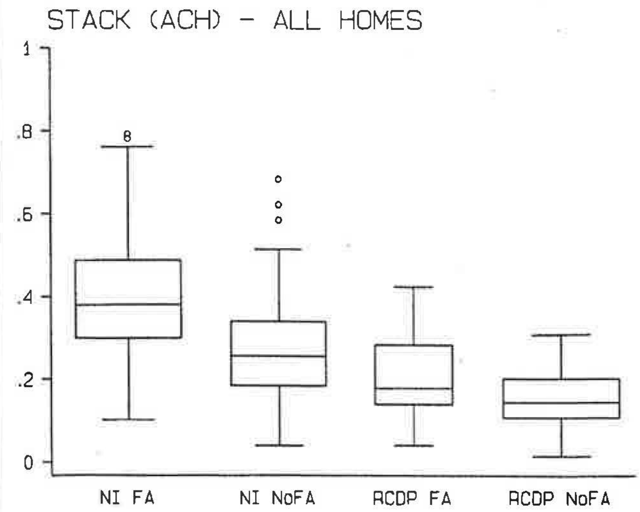

Figure 4b.

homes, many bath fans are ducted with significantly more pressure drop than 0.1 inches of water.

Heat recovery ventilation systems had higher installed flow rates, although in RCDP cycle 2, 26% were still not meeting 0.35 air changes per hour. Exhaust fans in the heat-recovery ventilator systems are typically of greater capacity and ductwork diameters larger than the non-heat-recovery ventilator bath fans. Most air-to-air heat exchangers exhaust and supply flow rates were found to be within 30% of each other, although there were a few serious outliers (statistical anomolies). Most of the time the exhaust flows were higher than the supply flows, which would tend to depressurize these homes and draw in unconditioned air from the outside.

Conclusions and Recommendations

(1) Investigations on design flow rates should be conducted, based on the different ways that balanced and exhaust-type ventilation systems interact with the homes' neutral pressure level and ability to exfiltrate passively. It may be that exhaust systems will require higher installed capacities to achieve similar ventilation rates as balanced systems.

(2) Performance testing requirements for house tightness using blower door tests are recommended for homes with balanced ventilation systems such as air-to-air heat exchangers.

(3) In-field performance measurements to determine the installed flow-rate capacities of ventilation systems are recommended. This will ensure that the homeowners have an installed ventilation system that can provide adequate mechanical ventilation if the occupant decides to use it, and possibly reduce utility, local government, or builder liability for indoor air quality problems.

(4) Occupant education efforts by manufacturers of ventilation systems, builders, utilities, and local governments are crucial to the operation of these systems.

(5) Continued research and development into better ventilation control strategies (i.e., occupancy sensors, continuous operation) should be evaluated.

RCDP has shown that mechanical ventilation systems can work to achieve effective ventilation, but only if systems have adequate capacity and are operated sufficiently. This qualifier, though seemingly obvious, can be easily forgotten. It has implications for building codes and other programs promoting conservation or enhanced air quality. These codes or programs must ensure that systems achieve intended installed capacity and are "user friendly" enough-in terms of noise, drafts, and controls for people who actually use them. Even if systems are well designed, installed, commissioned, and meet the above criterion, the ultimate decision to operate any ventilation system lies with the individual homeowner. People perceive the relative severity of health and safety risks very idiosyncratically (e.g., they are often willing to drive cars while fearing air travel, etc.). Since environmental effects from indoor air pollutants are not well understood, it is likely that many people will not perceive a need to operate these devices very frequently. This means that homeowner education regarding the need to operate ventilation systems—either to maintain minimum ventilation standards, or to improve indoor air quality—is crucial. ■

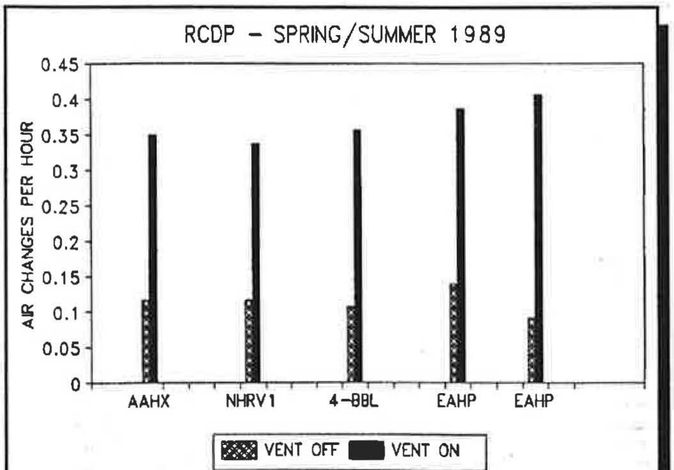

Figure 5. SF_6 Tracer Decay test results.

Endnotes

1. The Residential Construction Demonstration Project (RCDP) is a research and demonstration effort developed and funded by the Bonneville Power Administration (BPA) and implemented by staff at the Washington, Oregon, Idaho, and Montana energy offices. RCDP investigates energy efficiency in new electrically heated residences and provides technical support and research to utilities and BPA's Super Good Cents program, an energy rating system for new homes. RCDP also tracks the effectiveness of the Super Good Cents specifications through its cost and energy monitoring studies. Monitoring data collected from RCDP homes helps guide decisions on resource policy and refinement of specifications.
   RCDP's objective is to increase the capacity of the new home building industry to provide cost-effective, energy-efficient housing, by demonstrating the effectiveness of new innovative construction techniques and products.

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