VENTILATION AND COOLING
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Title: **Recommended Ventilatioan Strategies for New Energy-Efficient Production Homes**

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RECOMMENDED VENTILATION STRATEGIES FOR NEW ENERGY-EFFICIENT PRODUCTION HOMES

bijna nt beschouwd natural ventilation!

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SYNOPSIS

The U.S. Environmental Protection Agency is seeking to improve the thermal quality of new homes, most of which are being built in the sunbelt by large building development companies. Low-infiltration production (tract) homes need ventilation systems that satisfy the low-cost priority of the builders as well as the safety, health and low operating cost expectations of homeowners. We evaluated ten ventilation strategies in order to recommend the most suitable systems for four climates: cold, mixed, hot-humid, and hot-arid.

We recommend that builders in mixed (cold and hot), hot-humid and hot-arid climates use supply ventilation, which provides the safety and health benefits of positive indoor pressure and the ability to filter and dehumidify ventilation air. When ventilation is integrated with forced-air conditioning, we recommend that ductwork be installed within conditioned space and buyers be offered the option of an efficient, variable-speed fan. In cold climates we recommend that builders offer buyers the option of balanced heat recovery units, which significantly reduce operating costs. In hot-humid climates, we recommend that builders offer buyers the option of dehumidifying supply ventilation to control indoor humidity and improve occupant comfort.

≠ systemen geëvalueerd (10) →
jammer genoeg plaatjes
van ≠ systemen niet in
tabel

1. INTRODUCTION

The majority of new homes in the U.S. are built by large production building companies in fast-growing sunbelt cities from Florida to California. The Environmental Protection Agency (EPA), in its efforts to reduce greenhouse gas emissions, has introduced the Energy Star Homes program to encourage production homebuilders to voluntarily improve the energy-efficiency of their construction to beyond the levels required by the Model Energy Code. To achieve this, infiltration must be reduced to less than 0.20 (average annual) air changes per hour (ACH). This is below the level suggested to maintain indoor air quality (according to ASHRAE, the American Society of Heating, Refrigerating and Air Conditioning Engineers). These homes will need supplemental (active, mechanical) ventilation systems to provide fresh air and remove moisture and indoor pollutants.

Our task was to recommend the most affordable and effective ventilation systems in four climates. Suitable systems must meet or exceed ASHRAE ventilation and indoor air quality guidelines and be easy to implement by production residential builders and subcontractors. This is a challenging task because production builders' decisions are driven by cost, and though the Energy Star Homes program goal is to build efficient production homes at no additional cost, ventilation systems add to first-cost. Also, home ventilation systems currently available in the U.S. were developed for very cold climates, and even experienced HVAC contractors are unfamiliar with residential ventilation, and finally, unlike new custom homes, production home buyers have no input to the selection of their ventilation system.

2. SYSTEM DESCRIPTIONS

We determined that, at a minimum, ventilation systems must be able to deliver at least 0.35 ACH (daily average) ventilation and not cause or contribute to indoor depressurization. In order to account for the variation in effective ventilation rates, we normalized operating hours (operating costs) of all strategies to an effective rate of 0.50 ACH. Table 1 provides the name and description of the ventilation strategies evaluated.

Avoiding depressurization is a safety and health consideration. Negative indoor pressure can pull smoke from a fireplace, radon gas (if present) from the soil, auto exhaust from an attached garage, and pathogens from an attic, duct or building cavity into the home. It can also cause backdrafting (flue gas reversal) of combustion appliances that interact with indoor air. The Energy Star Homes program recommends that combustion appliances be direct-vent (sealed from indoor air), but it is reasonable to assume that most of these homes will have an attached garage, fireplace, and/or radon gas. Temporary depressurization can occur in any home (e.g., when a clothes dryer operates) but exhaust ventilation in a tight home without provision of supply air could intensify, prolong, or even sustain depressurization.

Table 1. Ventilation Strategies Evaluated	
Strategy Name	Description
1) *Forced-air Supply*	Outside air duct connected to the forced-air return
2) *Bath Exhaust w/ Vents*	An upgraded bath exhaust fan with passive vents
3) *Single-port Exhaust w/ Vents*	Ceiling- or remote-mount exhaust fan with passive vents
4) *Multi-port Supply*	Supply fan with ventilation ducts to living and bedrooms
5) *Forced-air Supply w/ Exhaust*	*Forced-air Supply* with a single-port exhaust fan
6) *Multi-port Supply w/Exhaust*	*Multi-port Supply* with a single-port exhaust fan
7) *Multi-port Exhaust w/ Vents*	Remote multi-port exhaust fan with passive vents
8) *Dehumidifying Forced-air Supply* (in Houston only)	Whole-house dehumidifying supply ventilation unit; ventilation air is distributed via forced-air ductwork
9) *ICM Forced-air Supply*	*Forced-air Supply* with an integrated-control motor[1]
10) *Balanced Heat Recovery*	Balanced heat-recovery ventilation unit with ductwork

3. MODELING

The following cities were selected to represent each of the four climates: Boston MA (cold), Washington DC (mixed), Houston TX (hot humid), and Phoenix AZ (hot arid). For modeling purposes, we assumed that the 2500 ft^2 Boston and Washington prototypical homes have 2-stories and basements. The 2000 ft^2 Houston and Phoenix homes are single story with a slab foundation.

Ventilation system performance was modeled using RESVENT software[2], hourly weather data, and the following assumptions:

- Energy Star homes have an annual average infiltration rate of 0.20 ACH.
- Mechanical ventilation systems are designed to provide, along with infiltration, a total annualized air change rate of 0.50 ACH.
- Windows remain closed, even in mild weather. [3]

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1 Integrated-control motors have variable speed controls at the motor (rather than remotely-located, like ECMs).

2 RESVENT was developed by the Energy Performance in Buildings Group of the Indoor Environment Program at Lawrence Berkeley National Laboratory (LBNL).

3 Reasons that people might not open windows even in mild weather include noise, security, allergy and infirmity.

flexible ducts → very leaky!
(geen luchtdichtheid meting in studie!)
ZUIVER THEOR. STUDIE

We used the ASHRAE 136 method to determine normalized leakage values corresponding to an annualized average infiltration rate of 0.20 ACH. We used DOE-2 to determine the hours of heating and cooling operation for forced-air integrated systems. Ventilation strategies were modeled with continual (24 hour) operation.

Modeling results show that, to provide an effective ventilation rate of 0.50 ACH, mechanical system design flow rates vary according to the climate, number of ventilation fans used, and whether the home is pressurized. The corresponding mechanical ventilation system design rates are given in Table 2. These results support the fact that ventilation contractors should take into account the climate, proposed ventilation system type and operating schedule when designing a residential ventilation system.

Table 2. Mechanical Ventilation System Design Rates (ACH)
(For 0.50 ACH Annualized Average Effective Ventilation Rate)

Ventilation Systems with:	two fans	one fan and vents	one fan, no vents
Strategies (from Table 1):	#5, #6, #10	#2, #3, #7	#1, #4, #8, #9
BOSTON	.23	.37	.41
WASHINGTON	.21	.36	.40
HOUSTON	.27	.40	.43
PHOENIX	.30	.43	.45

4. COSTS

Our installation (first) cost estimates include materials, labor and 25% overhead and profit. Costs were compiled from ventilation equipment manufacturers, distributors, contractors and consultants. Costs of all systems include a programmable timer with an on/off switch. For systems with passive vents, we assumed that one-story homes have five passive vents, and two-story homes have six passive vents. The heat recovery (HRV) system modeled has a 70% heat recovery efficiency. We assumed that installation costs are the same in each city (i.e., any variation is within the limits of our accuracy).

Annualized installation costs assume a 7% real discount rate. Installation costs were amortized assuming a 20-year lifetime for all ventilation systems, replacement after ten years of standard air-handler fans used intermittently for ventilation , and a 20-year lifetime for HRVs and other fans designed for continuous operation.

Table 3 lists the installation, operating and total annualized costs of ventilation systems in homes with two types of heating and cooling equipment – a furnace and air conditioner, and an electric heat pump.

alleen energy?, no mainten

opvallend : operating cost altijd >> annuel install. cost

Table 3. Ventilation System Costs

			Operating Costs by Heating & Cooling Equipment			
			Furnace/Air Conditioner		or Electric Heat Pump	
	Installation or First Cost ($)	Annualized Installation Cost ($)	Annual Operating Cost ($)	Total Annualized Cost ($)	Annual Operating Cost ($)	Total Annualized Cost ($)
BOSTON - cold climate						
1) Forced-air Supply	300	25	436	461	435	460
2) Upgraded Bath Exhaust with Vents	463	23	395	418	346	369
3) Single-port Exhaust with Vents	613	31	395	426	346	377
4) Multi-port Supply	650	33	388	421	342	375
5) Forced-air Supply with Exhaust	663	43	504	547	499	542
6) Multi-port Supply with Exhaust	763	38	419	457	370	408
7) Multi-port Exhaust with Vents	1063	53	395	448	346	399
8) ICM Forced-air Supply	1550	78	376	454	325	403
9) Balanced Heat Recovery	1838	92	324	416	289	381
WASHINGTON - mixed climate						
1) Forced-air Supply	300	25	323	348	290	315
2) Upgraded Bath Exhaust with Vents	463	23	290	313	290	313
3) Single-port Exhaust with Vents	613	31	290	321	220	251
4) Multi-port Supply	650	33	287	320	220	253
5) Forced-air Supply with Exhaust	663	43	364	407	184	227
6) Multi-port Supply with Exhaust	763	38	303	341	231	269
7) Multi-port Exhaust with Vents	1063	53	290	343	220	273
8) ICM Forced-air Supply	1550	78	282	360	212	290
9) Balanced Heat Recovery	1838	92	237	329	184	276
HOUSTON - hot humid climate						
1) Forced-air Supply	300	25	280	305	324	349
2) Upgraded Bath Exhaust with Vents	463	23	231	254	226	249
3) Single-port Exhaust with Vents	613	31	231	262	226	257
4) Multi-port Supply	650	33	227	260	223	256
5) Forced-air Supply with Exhaust	663	43	324	367	367	410
6) Multi-port Supply with Exhaust	763	38	252	290	247	285
7) Multi-port Exhaust with Vents	1063	53	231	284	226	279
8) Dehumidifying Forced-air Supply	1463	73	338	411	338	411
9) ICM Forced-air Supply	1550	78	228	306	220	298
10) Balanced Heat Recovery	1838	92	186	278	182	274
PHOENIX - hot arid climate						
1) Forced-air Supply	300	25	308	333	354	379
2) Upgraded Bath Exhaust with Vents	463	23	255	278	246	269
3) Single-port Exhaust with Vents	613	31	255	286	246	277
4) Multi-port Supply	650	33	249	282	240	273
5) Forced-air Supply with Exhaust	663	43	363	406	409	452
6) Multi-port Supply with Exhaust	763	38	283	321	274	312
7) Multi-port Exhaust with Vents	1063	53	255	308	246	299
8) ICM Forced-air Supply	1550	78	252	330	244	322
9) Balanced Heat Recovery	1838	92	206	298	201	293

Note: Total annualized cost is the sum of annualized installation cost and annual operating cost.

5 evaluative criteria

5. EVALUATION

Strategies were compared to each other according to five "priority" criteria: 1) installation cost, 2) operating cost, 3) indoor pressure, 4) effective distribution of ventilation air within the home, and 5) the potential for ventilation-related condensation in exterior walls. For each of our five evaluation criteria, we quantified the cost and effectiveness of ventilation strategies by assigning each a score (from –3 to 3) for each climate. Installation costs, indoor pressure and distribution scores are based on system types, and therefore, the same for each climate. Total score (overall cost and effectiveness) is the sum of the five scores. Finally, in each climate, we ranked strategies (with 1 as best), based on the total scores. Scores and ranking results are provided in Table 4. The scoring criteria is described below.

5.1. Installation Cost:

First Cost	$300-400	$401-500	$501-600	$601-700	$701-800	$801-1200	> $1200
Score	3	2	1	0	-1	-2	-3
Strategies	#1	#2	none	#3, 4, 5	#6	#7	#8, 9, 10

5.2. Annual Operating Cost

Average of the annual ventilation system operating costs for furnace/AC and electric heat pump:.

Score	Boston	Washington	Houston	Phoenix
3	$300-325	$200-225	$175-200	$200-225
2	$326-350	$226-250	$201-225	$226-250
1	$351-375	$251-275	$226-250	$251-275
0	$376-400	$276-300	$251-275	$276-300
-1	$401-425	$301-325	$276-300	$301-325
-2	$426-450		$301-325	$326-350
-3	>$450		$326-350	>$350

5.3. Indoor Pressure, from a safety and health perspective:

Score	Indoor Pressure	Strategies
3	positive	#1, 4, 8, 9
0	neutral, balanced	#2, 3, 5, 6, 7, 10
-3	negative	none evaluated

Table 4. Ventilation Systems Ranked by Cost and Effectiveness

Systems are Sorted by Rank Rank is based on Total Score	Rank	Total Score	EVALUATION CRITERIA Installation Cost score	Operating Cost score	Indoor Pressure score	Distribution of Air score	Moisture Problems score
BOSTON - cold climate							
Multi-port Supply	1	3	1	1	3	1	-3
Balanced Heat Recovery	1	3	-3	3	0	3	0
Forced-air Supply	2	2	3	-2	3	1	-3
Multi-port Supply with Exhaust	2	2	0	0	0	2	0
ICM Forced-air Supply	3	0	-2	1	3	1	-3
Upgraded Bath Exhaust with Vents	3	0	2	1	0	-3	0
Single-port Exhaust with Vents	3	0	1	1	0	-2	0
Forced-air Supply with Exhaust	3	0	1	-3	0	2	0
Multi-port Exhaust with Vents	4	-1	-1	1	0	-1	0
WASHINGTON - mixed climate							
Multi-port Supply	1	6	1	1	3	1	0
Forced-air Supply	1	6	3	-1	3	1	0
ICM Forced-air Supply	2	4	-2	2	3	1	0
Forced-air Supply with Exhaust	2	4	1	1	0	2	0
Balanced Heat Recovery	3	3	-3	3	0	3	0
Multi-port Supply with Exhaust	3	3	0	1	0	2	0
Single-port Exhaust with Vents	4	0	1	1	0	-2	0
Multi-port Exhaust with Vents	5	-1	-1	1	0	-1	0
Upgraded Bath Exhaust with Vents	5	-1	2	0	0	-3	0
HOUSTON - hot humid climate							
Multi-port Supply	1	10	1	2	3	1	3
Forced-air Supply	2	8	3	-2	3	1	3
ICM Forced-air Supply	3	7	-2	2	3	1	3
Multi-port Supply with Exhaust	4	3	0	1	0	2	0
Balanced Heat Recovery	4	3	-3	3	0	3	0
Forced-air Supply w/ Dehumidifier	5	2	-2	-3	3	1	3
Forced-air Supply with Exhaust	6	0	1	-3	0	2	0
Upgraded Bath Exhaust with Vents	7	-1	2	1	0	-3	-1
Single-port Exhaust with Vents	7	-1	1	1	0	-2	-1
Multi-port Exhaust with Vents	8	-2	-1	1	0	-1	-1
PHOENIX - hot arid climate							
Multi-port Supply	1	7	1	2	3	1	0
Forced-air Supply	2	5	3	-2	3	1	0
ICM Forced-air Supply	3	4	-2	2	3	1	0
Balanced Heat Recovery	4	3	-3	3	0	3	0
Multi-port Supply with Exhaust	5	2	0	0	0	2	0
Upgraded Bath Exhaust with Vents	6	0	2	1	0	-3	0
Single-port Exhaust with Vents	6	0	1	1	0	-2	0
Forced-air Supply with Exhaust	6	0	1	-3	0	2	0
Multi-port Exhaust with Vents	7	-1	-1	1	0	-1	0

5.4. Distribution of Ventilation Air:

Score	Strategies	Distribution Effectiveness
3	#10	air is supplied to and exhausted from several rooms
2	#5, 6	air is supplied to several rooms, exhausted from a central location
1	#1, 4, 8, 9	air is supplied to several rooms
-1	#7	air is exhausted from each bath, closed doors can disrupt circulation
-2	#3,	air is exhausted from a central location, closed doors disrupt circulation
-3	#2	air is exhausted from one bath, closed doors definitely disrupt circulation

5.5 Moisture Problems:

Score	Potential for indoor pressure to cause condensation in exterior walls
3	ventilation-induced indoor pressure prevents moisture problems
0	indoor pressure is neutral, or there is no potential moisture problem
-1	indoor pressure may cause humid outdoor air to enter walls via infiltration
-3	ventilation-induced indoor pressure will push humid indoor air into walls

6. RECOMMENDATIONS

gevaar depressie
x open haard
x C.V. niet
onttrekken → onderdruk

6.1. Cold Climate

In cold climates, we recommend production builders use exhaust ventilation with passive vents, or supply ventilation combined with measures to prevent condensation in exterior walls, or offer home buyers the option of paying for balanced heat recovery ventilation, which reduces operating costs.

→ voor verwarm.

For builders who use exhaust ventilation in cold climates, we recommend *Single*-or *Multi-port Exhaust with Vents*. *Single-port Exhaust with Vents* is less expensive to install; however *Multi-port Exhaust with Vents* provides better distribution of ventilation air. In multi-level homes, we recommend installing passive vents on the lower floor only, with the exhaust ventilation fan in the ceiling of the upper floor, and operating the system continuously, to help ensure that air enters the vents and exits via the fan.

In cold climates, we recommend supply ventilation only when combined with measures to prevent condensation in walls: 1) use a dehumidistat to control at least one bathroom exhaust fan and maintain indoor relative humidity ≤ 50% and 2) install insulative vapor-permeable sheathing on exterior walls to keep wall temperature above the dew point of indoor air and facilitate drying. Builders using *Forced-air Supply* should also install ductwork in conditioned space and offer buyers the option of paying for a forced-air fan with a variable-speed integrated-control motor (ICM).

6.2. Hot Humid Climate

In hot humid climates, we recommend production builders install *Multi-port Supply* We recommend that builders using *Forced-air Supply* ventilation install ducts within conditioned space and offer buyers the option of paying for a dehumidifying supply ventilation unit to improve comfort.

6.3. Mixed and Hot Arid Climates

In these climates, we recommend production builders use *Multi-port Supply* ventilation. For builders using *Forced-air Supply* ventilation, we recommend installing ducts in conditioned space and offering buyers the option of paying for a forced-air fan with a variable-speed integrated-control motor (ICM).

7. CONCLUSION

Incorporating energy-efficient construction in U.S. production homebuilding is a task that requires the development of affordable and effective residential ventilation systems. Our investigation estimates the costs of residential ventilation systems in the U.S, offers a method to evaluate ventilation systems and their impact on the indoor environment, and provides usable information to the building community.

8. ACKNOWLEDGMENTS

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