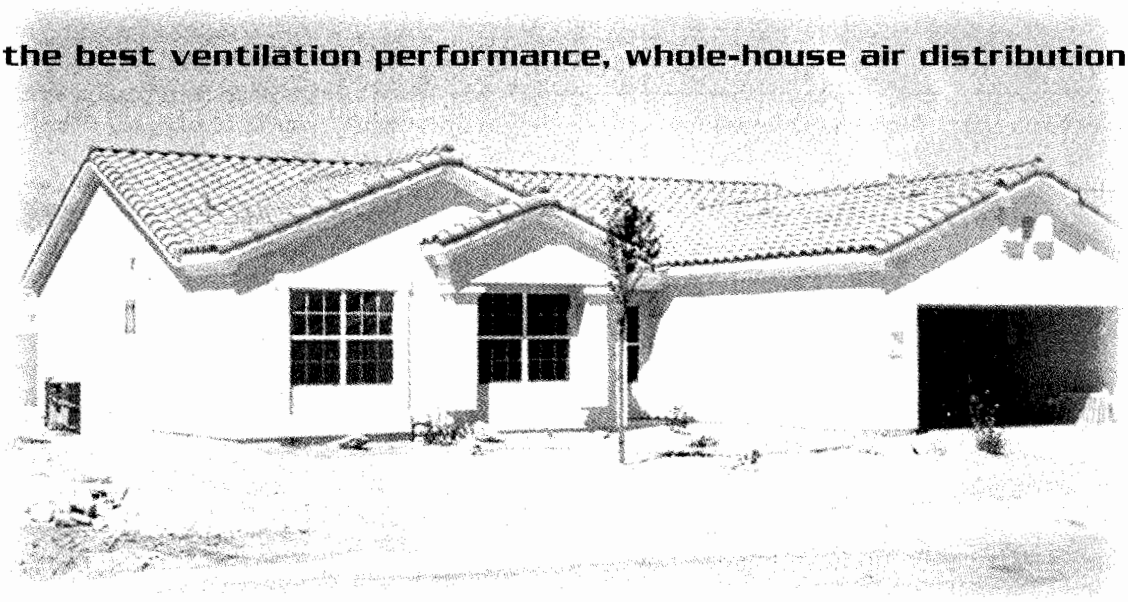
For the best ventilation performance, whole-house air distribution is key.



BUILDING SCIENCE CONSORTIUM

# Clean Breathing in Production Homes

by Armin Rudd and Joseph Lstiburek

With houses today being built with tighter and tighter envelopes, ventilation systems play a more important role than ever before. Indoor air quality (IAQ), comfort, and both first cost and operating costs have become top priorities for production housing. Through our experience building houses with the Department of Energy's Building America program, and its partner, the Louisiana Pacific Engineered for Life (EFL) program, we believe that the central-fan-integrated supply with fan cycling approach is the best value in basic ventilation strategies for production builders.

We know that, with single-thermostat systems, periodic whole-house mixing is critical to providing the best overall level of perceived IAQ and comfort. Distribution plays a large role in our ventilation strategies, not just for the dilution of pollutants that could harm residents, but for the dilution of pollutants that probably won't harm them—but will annoy them—pollutants such as stuffiness and odors. And just as important, our strategies often allow us to guarantee comfort, defined as a difference of no more than 3°F from the center of any room to the thermostat location. That is hard to do in two-story or large one-story plans without fan cycling. An alternative would be to parallel multiple temperature sensors, but the end result would still be to energize the central system.

Controlled mechanical ventilation has always been a cornerstone of systems-engineered building designs such as ours. Mechanical ventilation should first deal with removing the most offending pollutants where they are generated, and then deal with diluting the remaining pollutants. The removal of pollutants is typically accomplished with small spot exhaust fans in the kitchen, baths, and laundry. The dilution of pollutants is accomplished with supply, exhaust, or balanced whole-house ventilation fans, and with ducts that distribute less-polluted outdoor air throughout the living space, including closed rooms.

## How the System Works

For production home builder designs, the most important aspect of our controlled mechanical ventilation system for pollutant dilution is central-fan-integrated supply ventilation. A nominal 6-inch diameter insulated duct with an outside air intake is connected to the return side of the central air handler unit, and a fan-cycling control unit automatically operates the blower when there is no thermostat demand and the blower has been inactive (see Figures 1, 2, and 3). With this system, the distribution of ventilation air is assured, regardless of the

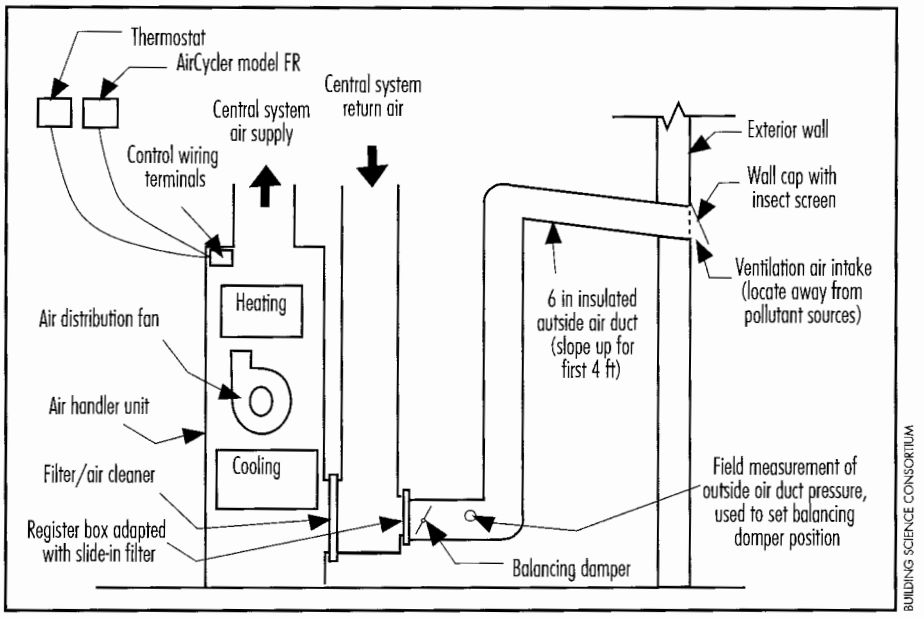



Figure 1. We believe that this ventilation system is best for houses in cold and mixed climates.

normal operation of cooling and heating.

This constitutes the core ventilation system. It can be adapted to various climates and situations, as follows:

1. In severe cold climates (>8,000 heating degree-days), continuous exhaust ventilation can be added to balance the supply ventilation flow.
2. Continuous-exhaust ventilation can be added to increase the supply ventilation flow above that which the supply ventilation system can reasonably provide by itself.
3. Both to close the outside air duct when the fan is not operating, and to limit the amount of ventilation air supplied if the fan has been on longer than needed for ventilation, a motorized damper in the outside air duct, and an AirCycler fan recycling and vent (FRV) control unit can be installed.
4. To reduce energy consumption an electronically commutated motor (ECM) fan can be installed. These fans are set to operate continuously on low speed, except in wet-coil climates, where they are set to operate with an off delay period after a cooling cycle. (An AirCycler fan recycling (FR) control unit is set for 6 minutes fan-off time and unlimited fan-on time.)

At times, we have used exhaust-only ventilation. In this case, the fan cycling control is used as a distribution and mixing tool and is set to operate the central system blower for 10 minutes, if it has been inactive for 50 minutes. We chose this 17% blower duty cycle to distribute ventilation air throughout the conditioned space after extensive tracer gas testing.

However, our production home-building clients like the central-fan-integrated supply ventilation system for the following reasons:

1. Ventilation air comes in from one known location, and that location is selected for its air quality. (For example, ventilation air does not come from the garage, the attic, or the subslab.) The outside-air intake is usually on a gable end, or if the roof is full hip, we often drop a small soffit inside the garage just far enough to get to the outside wall. (If the roof is full hip, the insulated and sealed duct goes through the soffit and the wall to a wall cap on the outside, far away from the driveway and its accompanying fumes.)
2. Unlike exhaust ventilation systems, the supply ventilation system provides filtered air. The air is also preconditioned when the heating-and-cooling system is operating.
3. The house is slightly positively pressurized with conditioned air, which acts against any infiltrating air. (The house may be depressurized if the sum of the intermittent

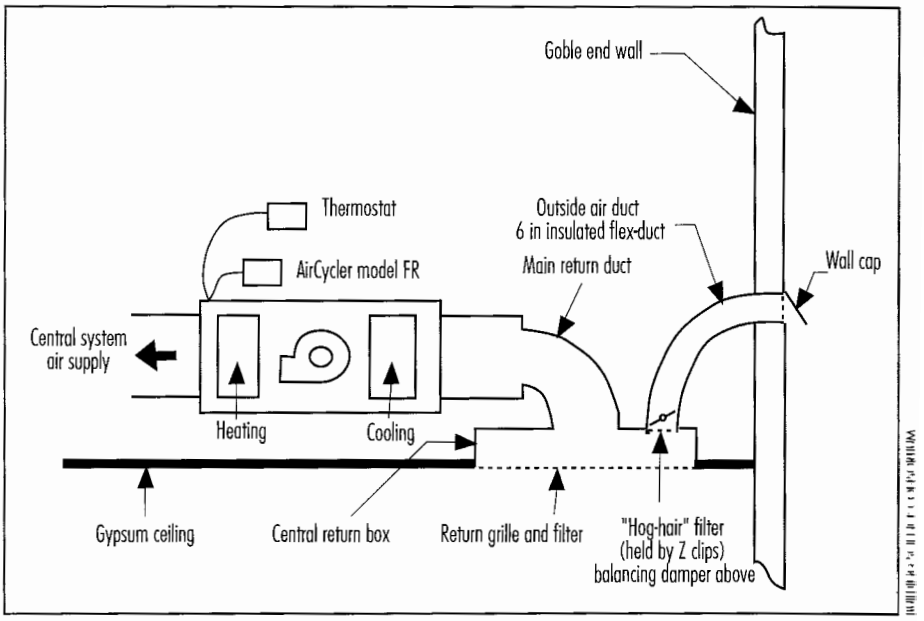



Figure 2. This ventilation system was designed for houses in hot-dry and hot-humid climates with unvented-cathedralized attics (conditioned space).

exhaust flow is greater than the supply flow. However, since we don't have any natural draft combustion appliances inside conditioned space, and most exhaust flows are only for short bursts, this is not a concern.)

4. When we use the central air handling system to draw in and distribute ventilation air, we are using a system that will be operational, and will be maintained, over the long term; the motor, bearings, and so forth are designed for continuous duty.

**Table 1. Ventilation Run Time Data for Three Chicago Homes**

| | Cool On (%) | Heat On (%) | Fan Cycling Vent On (%) | Fan Cycling Cost ($)* |
|---|---|---|---|---|
| Centennial Crossing, Lot 179** | | | | |
| Oct | 0 | 5 | 24 | 4.97 |
| Nov | 0 | 15 | 14 | 2.81 |
| Dec | 0 | 25 | 9 | 1.81 |
| Jan | 0 | 34 | 3 | 0.68 |
| Feb | 0 | 26 | 6 | 1.18 |
| Mar(1–8) | 0 | 31 | 3 | 0.17 |
| Centennial Crossing, Lot 176*** | | | | |
| Aug | 21 | 0 | 17 | 3.52 |
| Sep | 10 | 0 | 21 | 4.24 |
| Oct | 0 | 5 | 20 | 4.12 |
| Nov | 0 | 15 | 12 | 2.33 |
| Dec | 0 | 27 | 6 | 1.35 |
| Jan | 0 | 35 | 3 | 0.54 |
| Feb | 0 | 24 | 5 | 1.00 |
| Centennial Crossing, Lot 22**** | | | | |
| Apr (27–30) | 0 | 12 | 12 | 0.24 |
| May | 1 | 2 | 15 | 3.06 |
| Jun | 7 | 1 | 10 | 2.05 |
| Jul | 10 | 0 | 12 | 2.58 |
| Aug | 10 | 0 | 13 | 2.72 |
| Sep | 5 | 0 | 15 | 2.96 |
| Oct | 0 | 4 | 15 | 3.07 |
| Nov | 0 | 13 | 10 | 1.99 |
| Dec | 0 | 20 | 6 | 1.31 |
| Jan | 0 | 31 | 3 | 0.60 |
| Feb | 0 | 23 | 5 | 0.95 |
| Mar (1–9) | 0 | 25 | 4 | 0.23 |

*at 8¢/kWh. ** The fan cycling control was set for 20 minutes off and 10 minutes on (33% duty cycle). ***The fan cycling control was set for 20 minutes off and 8 minutes on (29% duty cycle). ****The fan cycling control was set for 25 minutes off and 6 minutes on (19% duty cycle).

5. The periodic air circulation, even with no thermostat demand, improves overall comfort control.
6. The system first cost is low, and the operational cost has been consistently below the low budget guaranteed by the Engineered for Life program. (The operating cost of our system is more than that of a simple exhaust fan, but a fan alone would not provide whole-house distribution and mixing, which we know is needed to avoid stuffiness and temperature variations.)
7. The HVAC contractor is responsible for everything. We don't have to cross trades, with electricians installing fans and ducts, as usually happens with other ventilation systems.

## Hesitations Resolved

Our experience creating ventilation systems has given us answers to some frequently asked questions from builders and homeowners.

### *Humidity*

In hot humid climates, our clients sometimes ask, "Won't bringing in hot-humid outside air make the house feel uncomfortable?" The answer is, No. We are simply trading controlled ventilation for random and uncontrolled air leakage.

However, to maintain year-round humidity control for clients (some production home-building clients and almost all our custom-home clients) in hot humid climates, we have been installing a stand-alone dehumidifier that removes moisture even when the thermostat is satisfied. For noncustom homes, the dehumidifier we use is a standard 40-pint-per-day unit that installs under the air handler unit in an interior closet with a louvered door. These dehumidifiers have a built-in dehumidistat and a condensate collection pan that can be plumbed directly to the cooling system condensate line. The dehumidifier, with its dehumidistat, is in the return air path (air from outside the interior closet passes through the louvered door), where it can sense the level of humidity in the recirculating air. The fan cycling control ensures that the dry air is periodically distributed throughout the house, even when there is no thermostat demand.

### *Fan Noise*

Some housing professionals involved with mobile homes have suggested that noisy air-handling systems would be a barrier to the success of central-fan-integrated ventilation in these homes. After well over 1,000 installations in the Building America Program and the EFL program that have gone through at least one heating and cooling season, no contractor or customer has voiced any complaint about system noise. In fact, when inside many Building America houses, with normal background noise, you have to strain

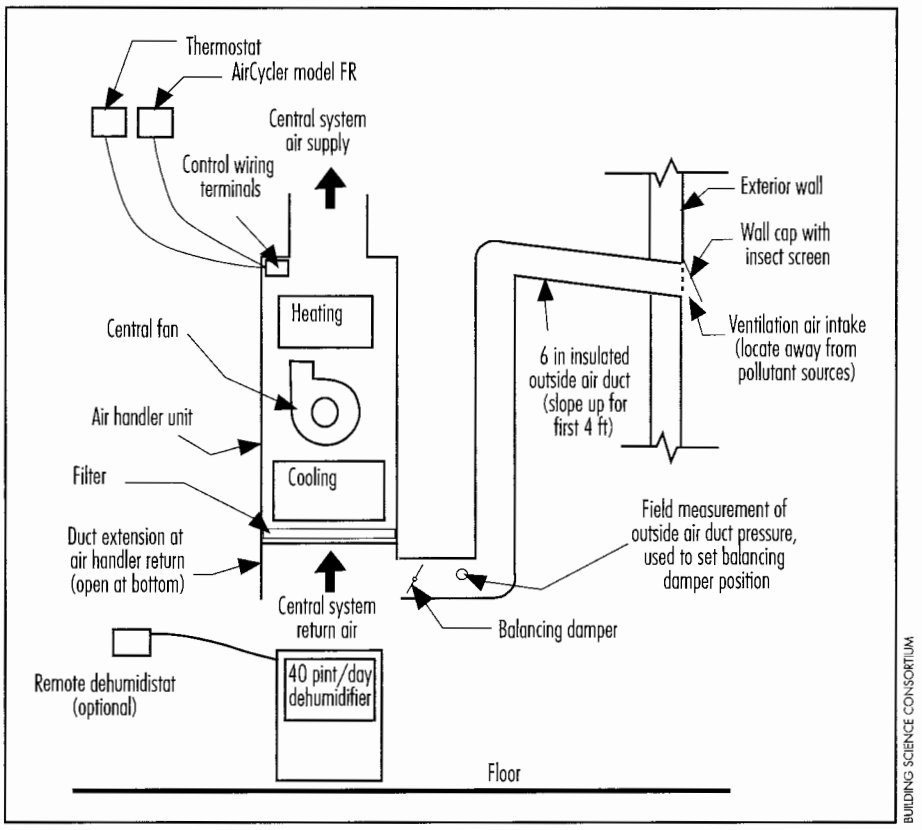



Figure 3. The ventilation system for a hot-humid climate includes a dehumidifier in the return air path.

your ears, or put your hand to a register, to be sure the system is on. We don't think that air handler noise would be a problem in mobile homes either, as long as extra care is taken in the HVAC system design.

### *Room Temperature Air Distribution*

Some people have suggested that operating the air-handling system during the heating season, without the heat being on, would be a barrier to the success of central-fan-integrated ventilation. In one Las Vegas subdivision, despite our advice to the engineer about sizing the cooling equipment, the air handling systems in Building America homes were oversized by at least 40%. This caused excessive air flow from the supply registers, which evoked some complaints about cool air in the bedrooms the first winter. The short-term solution was to explain to the occupants how the ventilation system worked, and to adjust supply registers to avoid blowing air directly on sedentary people. The long-term solution was to reduce the size of the equipment.

## Making the Best Choices Possible

The central-fan-integrated supply ventilation system is our basic design choice for production builders. Upgrades to that basic system will follow in time, including a motorized outside air damper with FRV control and ECM motors. Our choices give our clients the best overall value considering moisture control, air distribution performance, ventilation air quality, first cost and operating cost, equipment longevity, and unattended (no fuss for the client) operation.

Assuming that the air handler unit (AHU) is in conditioned space (if the unit is a furnace, then a forced-draft or sealed-combustion furnace); and assuming that the ducts are either in conditioned space or leak to the outside less than 5% of high-speed flow, then we make the following choices, depending on the climate. (Each scenario assumes 10 CFM of conditioned air per person in the house.)

#### *Severe-Cold Climate (>8,000 HDD)*

First choice: continuously operating single-point exhaust with intermittent central-fan-integrated supply limited to 7% of AHU flow. The percentage of AHU flow is smaller for severe-cold and cold climates than it is for hot or mixed climates to prevent cold air from lowering the mixed-air temperature when the heat is not on.

Second choice: continuously operating single-point exhaust with central fan cycling for distribution and mixing (sealed-combustion space and domestic hot water heating).

Third choice: balanced heat recovery ventilation with central fan cycling for distribution, or fully ducted to all rooms.

#### *Cold Climate (>4,500 HDD and <8,000 HDD)*

First choice: central-fan-integrated supply limited to 10% of AHU flow.

Second choice: continuously operating single-point exhaust with central fan cycling for distribution and mixing (sealed-combustion space/DHW heating).

#### *Mixed Climate (<4,500 HDD, <45°F Minimum Monthly Average Temperature)*

First choice: central-fan-integrated supply limited to 13% of AHU flow.

#### *Hot Dry/Hot Humid Climate (>45 F Minimum Monthly Average Temperature)*

First choice: central-fan-integrated supply limited to 15% of AHU flow.

Optional year-round humidity control for hot humid climate: air handler unit located in a closet with a louvered door in conditioned space, placed on platform high enough to place dehumidifier underneath. Dehumidifier controlled by dehumidistat in conditioned space. Normal thermostat-driven cycling of air handler, together with fan cycling, distributes both ventilation air and dry air to the whole house.

With proper design and installation, the problem evaporated. The central-fan-integrated supply ventilation system is still the ventilation system of choice for the builder and the mechanical contractor, and in that market, the Building America/EFL houses are outselling the competition almost two to one.

### First Cost

For our production builder clients, the costs of materials and installation for the basic central-fan-integrated supply ventilation system, with fan cycling control, has ranged from $125 to $200. A rule of thumb for new construction ventilation is that every duct pickup or duct drop costs about $75. Since the fan cycling control costs about the same as one pickup or drop, the entire central-fan-integrated supply system costs about $150. That compares very favorably to a separately ducted, multipoint supply ventilation system that has a total cost of at least $550, with two pickups (outside air inlet and house recirculation inlet), four drops, and a minimum $100 blower.

### Operating Cost

Some critics have suggested that operating the relatively large air handler unit blower for ventilation would not be energy efficient. Those suggestions were based on computer simulations that made one or more of the following assumptions:

- The blower would be operated continuously rather than intermittently with the fan cycling control.
- The building envelope would not be the superior envelope designed and used by Building America, which allows for smaller cooling and heating equipment (all of which meet or exceed Energy Star performance); this equipment, when properly sized, does not short-cycle. In the shoulder months, the properly sized system may have short run times to meet the thermostat setpoint, but there will be long periods between cycles with no thermostat demand. Therefore, it will run for short periods infrequently.
- The air distribution system would not be well sealed or not be installed inside conditioned space, or duct performance and duct location would not be considered important enough to account for.

Our own DOE-2 computer simulations for several climates estimated blower operating cost to be $50–$60 per year on average. We then monitored several of our Building America homes for actual system run times to determine the electrical energy consumed to operate the central system blower for ventilation only. Results for three homes in the Chicago area showed that blower run times for ventilation hit a maximum in the swing season months of May and October, when little heating or cooling was occurring, and slid to minimums in the peak winter and summer months, when the blower was operating often for space conditioning, which required little blower operation for ventilation only (see Table 1). For a 350W blower (nominal 2.5 ton cooling system) and at 8¢/kWh, the cost to operate the blower for ventilation during the swing season months was less than $5 per month, and it went down to less than $1 per month in the center of the heating and cooling seasons. Even if it stayed at $5 per month every month, the annual operating cost would still be only $60—hardly excessive.

*Joseph Lstiburek is principal and Armin Rudd is principal engineer of the Building Science Corporation in Westford, Massachusetts. Armin Rudd is the developer of the AirCycler.*

### For more information:

Wray, Craig P., Nance E. Matson, Max H. Sherman. 2000. "Selecting Whole-House Ventilation Strategies to Meet Proposed Standard 62.2: Energy Cost Considerations." *ASHRAE Transactions* 2000, MN-00-10-1.

Armin F. Rudd
Building Science Corporation
726 Maple Street
Annville, PA 17003
Tel: (717)867-0123
Fax: (717)867-0124
E-mail: armin@buildingscience.com
Web site: www.buildingscience.com

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