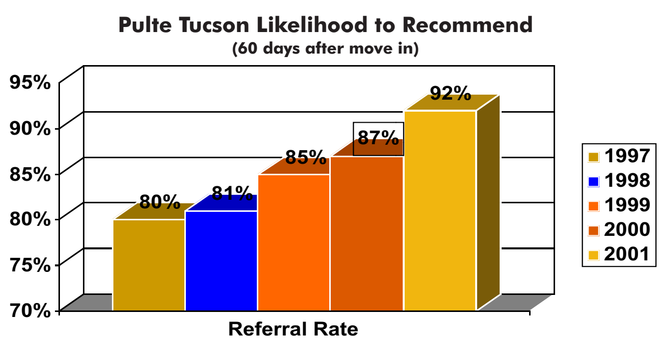
In 1986, Pulte Homes in Tucson was plagued by customer complaints and even law suits for construction and material defects in their homes. Today, customer satisfaction is above 90% and the Pulte division is the 2001 Energy Value in Housing Award (EVHA) Builder of the Year. What happened?

"We finally got the message from our buyers—value is as important as cost," says Vice President of Construction for Pulte Tucson, Alan Kennedy. Home buyer surveys revealed that energy efficiency, ease of maintenance, and builder reputation were topping the list of what home buyers wanted. Kennedy adds, "A large part of achieving these qualities has been our work with Building Science Corporation through the Building America program."

Pulte Tucson has changed an awful lot about the way they build—new design, new systems, new materials—all according to Building America performance criteria. Note how closely the key features listed at the right coincide with the Best Practices for the Hot/Dry Houses that Work. And the operative word here is performance: Pulte Tucson builds all of their homes to the BA performance standards, backs all of their homes with an Environments for Living™ energy guarantee, and has a full-time employee dedicated to performance testing and construction inspections.

Pulte Tucson has changed very little from their first Building America prototype home in 1996. They have switched from plywood to Thermoply (lighter, cheaper, easier) to define the attic conditioned space (backer for cellulose insulation installation), and have fine-tuned their mechanical ventilation system (see Discussion of moisture problems for technical discussion of ventilation systems for Pulte Tucson).

Kennedy continues: "This took a lot of work—we had to educate and train our staff, realtors, and even our building inspection department on some of the innovative systems. But if you take the same total systems approach with the industry as you take with your homes, it pays off." It certainly seems to—Pulte Tucson has 9 communities under full development, two-thirds of their customers are recommending Pulte three times or more, and call-backs and customer complaints are a fraction of their peak ten years ago.



The next step for Pulte Tucson is the Ultra-Efficient Home — total energy consumption, including appliances and plug loads, 50% more energy efficient than even their Building America homes. Better stay tuned to Pulte Tucson—blink and you will be left straining to see their back door!

See the Copper Moon Energy Analysis for more information about energy savings.

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Copper Moon Tucson, Arizona

Pulte Homes

1,332 - 1,618 sq. ft., 3 - 4 bedroom, 2 bath
$124,000 - 134,900

Key Features

- Post-tensioned slab foundation
- "In-line" framing with air barrier insulation
- Unvented cathedral attic
- Sealed ducts with mechanical ventilation
- Air returns in each bedroom
- Low-e spectrally selective windows
- Innovative "Cocoon" insulation
- Carbon monoxide detectors
- Reduced sizing of air conditioning equipment

Cost Summary for Building America Metrics

• Unvented roof	+	$ 750
• NOT installing roof vents	-	$ 500
• High performance windows	+	$ 300
• Controlled ventilation system	+	$ 150
• Downsize air conditioner by 2 tons	-	$1000
• Sealed combustion furnace	+	$400
TOTAL PREMIUM	**+**	**$100**

Key Partners/Products

- Milgard Windows (www.milgard.com)
- Cocoon insulation (www.greenstone.com)
- Thermoply insulating sheathing (www.simplex-products.com/pages thermoply.html)
- Hutchinson Insulation
- Knipp Brothers
- Environments for Living™ (www.environmentsforlivingonline.com)

Building Science Corporation

Architecture and Building Science

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October 29, 2002

Pulte Home Corporation, Tucson Division
7493 North Oracle Suite 115 (North)
Tucson, AZ 85704
(520) 797-1100 / (520) 797-1420 fax
ATTN: Alan Kennedy, James Wilson, Len Utt

Gentlemen:

Enclosed are the results of our analysis of the plans submitted for Building America review at the Sonoran Moon and Sonoran Vista developments. This work includes calculation of design loads, Energy Star scores, energy guarantee figures, and testing goals.

Once you get a chance to look over this report, please feel free to call or email (phil@buildingscience.com) with any questions. I will assume that if you can receive the report and attachments without a problem, a hard copy by mail will not be necessary.

Sincerely,

Philip Kerrigan

cc: Brad Townsend (Environments for Living™)
Charlise Wood (Environments for Living™)
Margaret Aukamp (ComfortHome/EIC)

Building Characteristics

Building envelope	Building America
Ceiling	R-22 cathedral cellulose unvented
Walls	R-19 24 oc + R-4 EPS exterior
	R-19 24 oc to garage
Foundation	Slab, uninsulated
Windows	Sungate 1000
	U=0.35, SHGC=0.37
Infiltration	2.5 sq in leakage area
	per 100 sf envelope

Mechanical systems

Heat	Goodman Direct Vent Furnace
	GSMS Series 92.6% AFUE
Cooling	10 or 12 SEER A/C split system
DHW	0.62 EF high-efficiency water
	heater in garage
Ducts	R-4.2, conditioned sealed attic
Leakage	None (5% max to outside)
Ventilation	AirCycler™ Supply-only system
	10 minutes on; 20 minutes off; 50 CFM net

Utility Rates

Electric	Tucson Electric	May-Oct \$0.0909; Nov-Apr \$0.0790, + \$4.90 per month

The above is base rate from Residential Rate No. 1 (single phase service), effective September 1, 2000. The rates above do not include Franchise Tax, City Sales Tax, State Sales Tax, Arizona Corporation Commission Assessment, or Residential Utility Consumer Assessment.

Franchise Tax	2.0%
City Sales Tax (Tucson, Sahuarita)	2.0%
State Sales Tax	5.0%
Arizona Corporation Commission Assessment	0.22%
Residential Utility Consumer Assessment	0.07%
Total	9.29%

The rate schedule seems to have contradictory information on how these taxes are applied; instead, they were just totaled and added to the base rates above. The resulting rates are:

Electric	**Tucson Electric**	**May-Oct \$0.0994; Nov-Apr \$0.0863, + \$5.35 per month**

This rate (in bold) was used for the guarantee figures.

Natural gas	**Southwest Gas**	**May-Oct 0-20 $0.99515/therm; 20+ $0.91097/therm + $8.00/month 40+ $0.91097/therm + $8.00/month**

G-5 Residential Rate, 38th Revised Rate, Effective May 1, 2002

Due to the volatility in utility rates, please be sure that signage indicates that utility guarantees are based on the rates stated (and dated) as per above. Monthly service charges are not included in the above.

Test Requirements

Infiltration/air flow retarder (a.k.a. air barrier): The envelope is tightened to a target based on the surface area of the house (including floor slab). The Building America target is 2.5 square inches of equivalent leakage area per 100 square feet of envelope area.

The airtightness of these test houses will be measured with a blower door test. The targets are shown in the table below, in CFM 50 (cubic feet per minute at a test pressure of 50 Pascals) and in ACH 50 (air changes per hour at 50 Pascals). Note that ACH 50 is not the same as natural air changes per hour (nACH).

The airtightness goal is to be met with the attic scuttle (hatch) open, which will measure the airtightness of the complete building envelope shell, including the conditioned unvented attic.

Plan	Nominal floor area	Stories	Surface area	Volume (cu ft)	Goal CFM 50	Goal ACH 50
Plan 1576	1576	2	5,067	19,427	1270	3.9
Plan 1780	1780	2	5,903	22,031	1480	4.0
Plan 1951	1951	2	5,861	22,591	1470	3.9
Plan 1996	2253	2	5,938	23,504	1480	3.8

Duct system: The ductwork system will be tested for tightness in the completed house with a Duct Blaster® test. The goal is a CFM 25 (cubic feet per minute at 25 Pascals test pressure) equal to 5% of the high-speed air handler nominal flow, at 400 CFM per ton. For instance, a 3-ton unit has a nominal 1200 CFM flow, with a 60 CFM 25 goal. The requirement is for duct leakage to the outside, not total duct leakage.

Equipment sizing is not known at this time; duct leakage goals can be calculated from the equipment schedule.

Energy Performance Summary

The models built with the changes above provide the following performance on Energy Star scores and design heating and cooling loads. All houses meet Energy Star (86.0 or greater).

10 SEER Plan	Window area (sf)	Floor Glazing	Wall Glazing	Energy Star	Design Heating	Design Cooling
Plan 1332	215.2	16.0%	13.1%	87.7	16.4	17.9
Plan 1446	185.2	12.5%	10.5%	88.5	16.9	17.2
Plan 1575	245.5	15.6%	13.4%	88.0	18.2	20.7
Plan 1618	252.2	15.4%	14.1%	87.8	18.4	19.9

Adding a 12 SEER Air Conditioner increases the Energy Star Rating:

12 SEER Plan	Window area (sf)	Floor Glazing	Wall Glazing	Energy Star	Design Heating	Design Cooling
Plan 1332	215.2	16.0%	13.1%	89.0	16.4	17.9
Plan 1446	185.2	12.5%	10.5%	89.7	16.9	17.2
Plan 1575	245.5	15.6%	13.4%	89.3	18.2	20.7
Plan 1618	252.2	15.4%	14.1%	89.1	18.4	19.9

Design loads are in kBtu/hr; Tucson, AZ weather data (as below)
Winter design temperatures: indoor 72° F, outdoor 32° F, ΔT = 40° F
Summer design temperatures: indoor 75° F, outdoor 102° F, ΔT = 27° F

Detailed Energy Performance

The table below shows Energy Star scores, estimated heating and cooling costs, energy consumption, and design loads for the plans with the standard 10 SEER Air Conditioner.

Plan 1332

	[MMBtu=1,000,000 Btu]		Energy Star Score: 87.7 PASS
Space Heating	12.8 MMBtu	$125	
Space Cooling	13.4 MMBtu	$387	

Design loads: Heating		16.4	$512	Annual heating & cooling cost
(kBtu/hr)	Cooling	17.9	**$43**	**Monthly heating & cooling cost**

Reduced carbon emissions by 4000 pounds per year

Plan 1446

	[MMBtu=1,000,000 Btu]		Energy Star Score: 88.5 PASS
Space Heating	14.6 MMBtu	$142	
Space Cooling	12.8 MMBtu	$371	

Design loads: Heating		16.9	$513	Annual heating & cooling cost
(kBtu/hr)	Cooling	17.2	**$43**	**Monthly heating & cooling cost**

Reduced carbon emissions by 5000 pounds per year

Plan 1575

	[MMBtu=1,000,000 Btu]		Energy Star Score: 88.0 PASS
Space Heating	14.4 MMBtu	$140	
Space Cooling	15.2 MMBtu	$442	

Design loads: Heating		18.2	$582	Annual heating & cooling cost
(kBtu/hr)	Cooling	20.7	**$49**	**Monthly heating & cooling cost**

Reduced carbon emissions by 5000 pounds per year

Plan 1618

	[MMBtu=1,000,000 Btu]		Energy Star Score: 87.8 PASS
Space Heating	14.1 MMBtu	$137	
Space Cooling	15.0 MMBtu	$434	

Design loads: Heating		18.4	$571	Annual heating & cooling cost
(kBtu/hr)	Cooling	19.9	**$48**	**Monthly heating & cooling cost**

Reduced carbon emissions by 5000 pounds per year

The Energy Performance table below shows the Energy Star scores, estimated heating and cooling costs, energy consumption, and design loads for the plans with the 12 SEER Air Conditioner option.

Plan 1332

[MMBtu=1,000,000 Btu] **Energy Star Score: 89.0 PASS**

Space Heating	12.8 MMBtu	$125
Space Cooling	11.1 MMBtu	$323

Design loads:	Heating	16.4	$448	Annual heating & cooling cost
(kBtu/hr)	Cooling	17.9	**$37**	**Monthly heating & cooling cost**

Reduced carbon emissions by 5000 pounds per year

Plan 1446

[MMBtu=1,000,000 Btu] **Energy Star Score: 89.7 PASS**

Space Heating	14.6 MMBtu	$142
Space Cooling	10.7 MMBtu	$309

Design loads:	Heating	16.9	$451	Annual heating & cooling cost
(kBtu/hr)	Cooling	17.2	**$38**	**Monthly heating & cooling cost**

Reduced carbon emissions by 6000 pounds per year

Plan 1575

[MMBtu=1,000,000 Btu] **Energy Star Score: 89.3 PASS**

Space Heating	14.4 MMBtu	$140
Space Cooling	12.7 MMBtu	$368

Design loads:	Heating	18.2	$508	Annual heating & cooling cost
(kBtu/hr)	Cooling	20.7	**$42**	**Monthly heating & cooling cost**

Reduced carbon emissions by 6000 pounds per year

Plan 1618

[MMBtu=1,000,000 Btu] **Energy Star Score: 89.1 PASS**

Space Heating	14.1 MMBtu	$137
Space Cooling	12.5 MMBtu	$361

Design loads:	Heating	18.4	$498	Annual heating & cooling cost
(kBtu/hr)	Cooling	19.9	**$42**	**Monthly heating & cooling cost**

Reduced carbon emissions by 6000 pounds per year

Guarantee Summary

10 SEER

Plan Name	Energy Star	Annual Cost	Monthly Cost	MMBtu Heating	MMBtu Cooling	Heating	Cooling
Plan 1332	87.7	$512	$43	12.8	13.4	128 therms	3928 kWh
Plan 1446	88.5	$513	$43	14.6	12.8	146 therms	3752 kWh
Plan 1575	88.0	$582	$49	14.4	15.2	144 therms	4455 kWh
Plan 1618	87.8	$571	$48	14.1	15.0	141 therms	4396 kWh

12 SEER

Plan Name	Energy Star	Annual Cost	Monthly Cost	MMBtu Heating	MMBtu Cooling	Heating	Cooling	Annual Savings
Plan 1332	89.0	$448	$37	12.8	11.1	128 therms	3253 kWh	$64
Plan 1446	89.7	$451	$38	14.6	10.7	146 therms	3136 kWh	$62
Plan 1575	89.3	$508	$42	14.4	12.7	144 therms	3722 kWh	$74
Plan 1618	89.1	$498	$42	14.1	12.5	141 therms	3664 kWh	$73

Discussion of ventilation systems for Pulte-Tucson homes

The following information is taken from a report by BSC engineer Armin Rudd on two ventilation strategies being employed by Pulte Tucson. Although the discussion by Rudd is specific to the homes and conditions in Pulte Tucson homes, it does reveal that system design, installation, and commissioning are all important in achieving proper ventilation in high performance homes.

Pulte Tucson has employed both central-fan-integrated supply ventilation with AirCycler™ controls as well as a locally-patented passive-stack, heat-recovery ventilation system. The lattter system consists of an 10" diameter duct extending from conditioned space up through the roof, and within that 10" duct, a 3" uninsulated aluminum duct which goes from outside to the return of the air handler. The principle of this system was to increase air exchange with outdoors while exchanging some heat between air moving in the 10" duct and air moving in the 3" duct. This system increases air exchange with outdoors, thereby diluting interior moisture buildup with drier outdoor air.

The passive stack system was substituted for the originally specified central-fan-integrated system due to moisture and odor buildup in some homes. The following discussion is an analysis of the problem with recommendations.

Point #1

Problems with moisture and odor build-up with the central-fan-integrated system were related to improper installation and commissioning or inexact specifications for both.

The specified system was central-fan-integrated supply ventilation with fan cycling. This system was comprised of:

1. A 6" insulated outside air duct connecting the return side of the airhandler to a fresh air location outdoors. The fresh air locations was to be selected for a high standard of air quality (not near the ground, not near operating cars, and not from the roof where gases from other exhausts and vents could be re-entrained or where asphalt shingle odors could be picked up).

   The outside air duct pressure was to be between –15 Pa and –20 Pa with respect to outside to achieve between 65 cfm and 75 cfm of outside air flow, based on an air handler duty cycle of 33%.

2. A fan cycling control to assure the 33% air handler duty cycle.

According to reports from the field (Bill Irvine and Len Utt), the outside air duct pressures were usually between –5 and –10 Pa with respect to outside, giving at least one-third less outside air flow than required. The low outside air duct pressure was likely due to how the duct was connected to the air handler return system. The system was specified to have a single ceiling return filter grille box with the outside air duct connected to the box, with a washable hog-hair-type filter held in place by a Z channel. Refer to Figure 1.

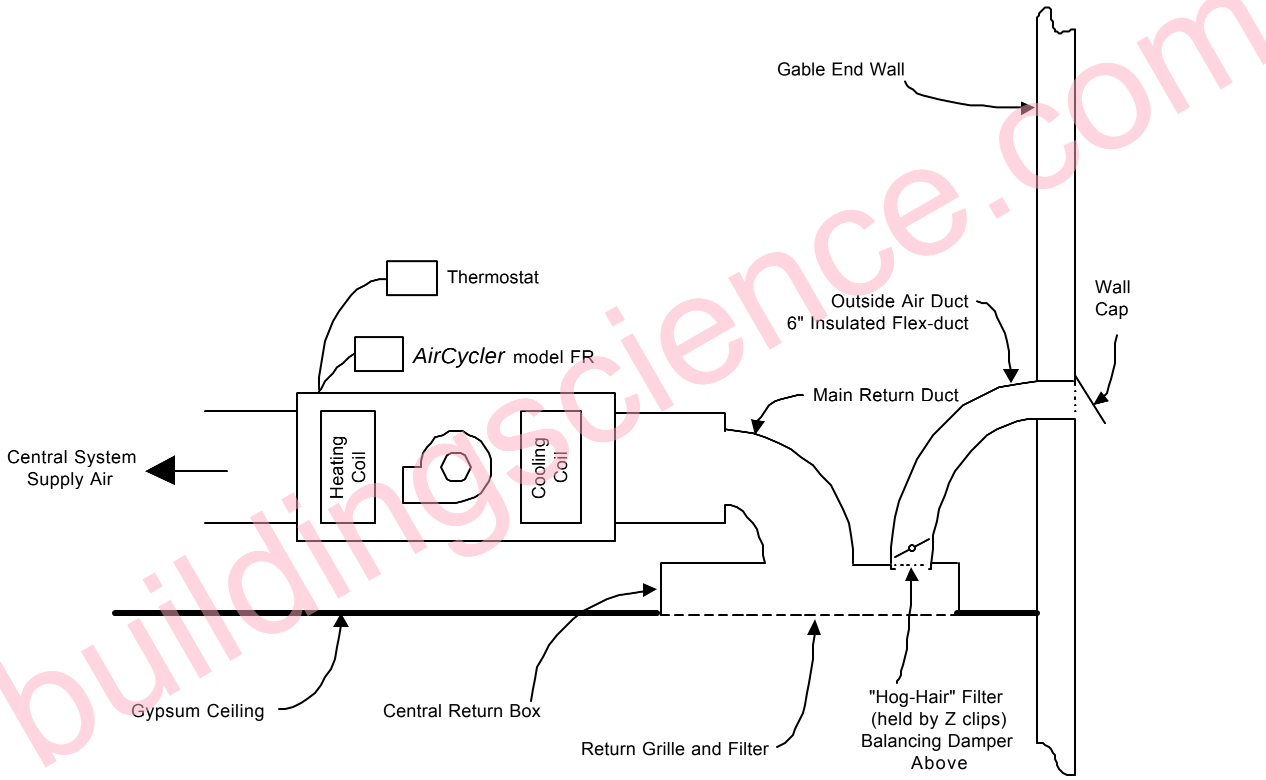

Figure 1 Central-fan-integrated supply ventilation; outside air duct into ceiling return box

It appears that, in some cases, up to three return grilles were being installed. This leaves less flow, and hence, less available negative pressure available at the main return grille where the outside air duct is connected. Further, the return grille should be sized for 350 ft/min. Sizing the return for more than 350 ft/min could lead to noise problems, and sizing for less reduces the available negative pressure to draw in outside air.

An alternative connection point that would always assure enough draw for outside air would be to connect the outside air duct to an extended collar where the main return flex duct connects to the return box. Refer to Figure 2.

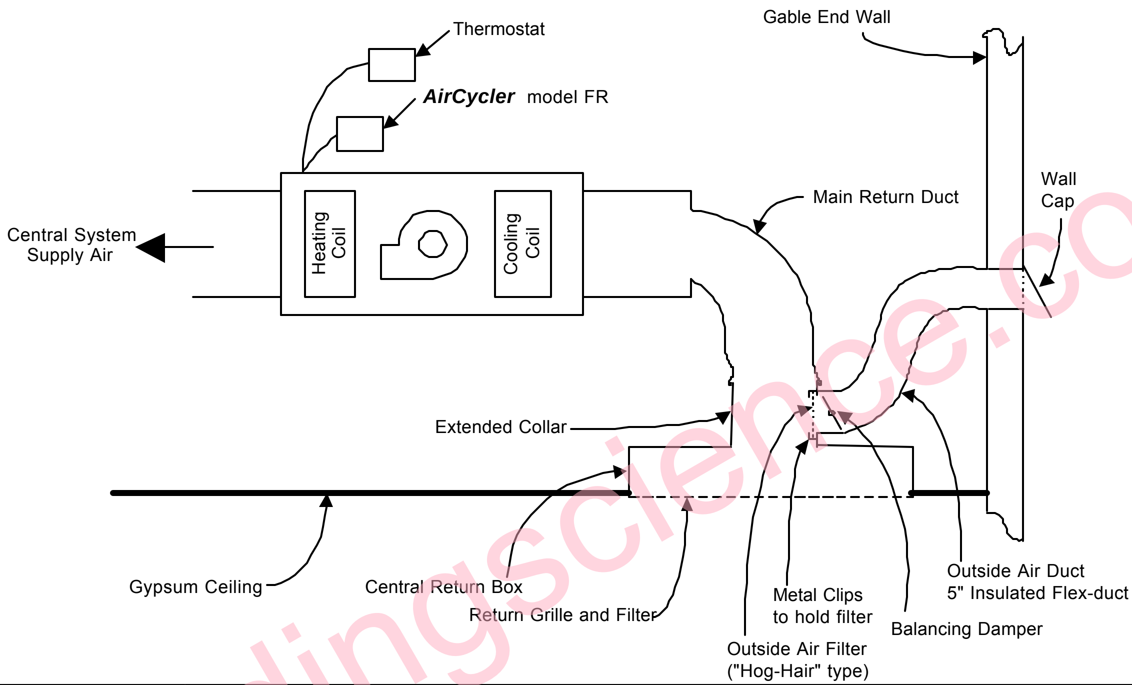

Figure 2 Central-fan-integrated supply ventilation; outside air duct into extended collar

Besides having a low outside air flow rate as described above, the fan cycling control used by Pulte-Tucson also plays into the problem of too little outside air exchange. The control used was the Totaline thermostat part number P374-1100. This thermostat is capable of automatically operating the air handler fan for a programmed number of minutes per hour (between 0 and 60). The way the control achieves that capability is to operate the fan for the programmed number of minutes beginning at the top of each hour. (As an aside, it is not energy-smart in that it operates the fan at the top of the clock hour regardless of whether the fan had already run enough prior to the beginning of the clock hour.) Another setting on the control sets the clock hours that the automatic fan operation will be active. The factory default is 7 am to 9 pm, which eliminates the night hours.

The Totaline thermostat fan control had been set to operate the fan between 5 and 10 minutes out of every hour, which was one-quarter to one-half the design time of 20 minutes per hour. (Twenty minutes of fan operation at the top of each hour would likely elicit comfort complaints. That is why the AirCycler control was designed to divide the fan operation into smaller intervals.) The Totaline control was also left at the factory default setting for not being active during the night hours, hence, it was active only 58% of the time.

Putting it all together, if the flow rate was 66% of design, and the fan on time was 50% of design, and the active time was 58% of design, then the outside air exchange was only 19% of design. This could well explain what originally went wrong, such that the specified controlled mechanical ventilation system did not provide adequate air exchange.

<u>Point #2</u>
Based on the characterization of the problem in Point #1, it is recommended that the original central-fan-integrated supply ventilation with AirCycler controls should be used.

As it's name implies, the passive stack ventilation system is essentially an uncontrolled leakage area in the building envelope. Uncontrolled leakage is what we are trying to eliminate in favor of controlled mechanical ventilation. The passive stack is similar to a fireplace flue with the damper left open. The air flow rate, and flow direction, in the stack is subject to forces of the environment. It all depends on the wind speed, wind direction, and temperature differential across the building envelope.

When ventilation supply air being drawn in through the 3" duct is sufficient to pressurize the building, house air will likely be flowing up the stack to relieve the pressure. In cold weather, there will also be an unknown amount of warm house air flowing up the stack due to the buoyancy of warm air, increasing air exchange. In windy weather, an unknown amount of air will be going up or down the stack, increasing air exchange, and possibly allowing the direct entry of unfiltered outside air.

It is as yet unknown how the ventilation air drawn in by the 3" duct is connected to the return plenum, or what the flow rate is, or how the air is filtered, and it is unknown if condensation potential on the uninsulated 3" duct has been considered.

Fan Cycling Control Specification
To avoid future problems such as those discussed above, a fan-cycling control specification is recommended for the Building America/EFL program that is both energy-smart and will not create indoor moisture problems.

> Fan cycling is required for all Building America and EFL houses for ventilation air distribution and whole-house mixing, improving indoor air quality and comfort. The fan cycling control shall have the following capabilities and these capabilities must be enabled:
>
> 1. The fan cycling control shall stop the air handler unit fan at the same time the cooling compressor stops and it shall be capable of not energizing the fan for fan cycling for at least 10 minutes after the cooling compressor stops. This will enhance moisture control.
>
> 2. The fan cycling control shall not operate the air handler unit fan unless the fan has not already operated for a sufficient amount of time to provide ventilation air distribution and whole-house mixing.
>
> 3. The fan cycling capability shall be enabled 24 hours per day that the house is occupied for providing the specified amount of fan operation time required for ventilation air distribution and whole-house mixing.