

Measured Air Change Rates and Distribution Ventilation Air in a Single Family Home

Conference Paper - 9907

1999

Armin Rudd

Abstract:

A single-story, single-family, 1350 ft² house located in Las Vegas, NV was outfitted with two separate ventilation systems. The systems were independent of each other, and were operated at different times to evaluate the relative difference in air change rate and distribution of ventilation air induced by their operation. One system was an intermittently operated central-fan-integrated supply ventilation system, wherein, 47 ft³ / min of outside air was ducted from a high wall location on the building exterior to the return air side of the central heating and cooling system blower. The other system was a continuously operated separate supply ventilation system, not connected to the central air distribution ducts, wherein, a separate fan drew 54 ft³ / min of outside air and 112 ft³ / min of re-circulated inside air from the master bedroom and delivered the resulting 166 ft³ / min of mixed air to the main living area of the house. During the testing, all interior doors were closed, and a computer controlled six-zone gas analyzer measured tracer gas concentration in the main living area and all closed rooms. Results showed that the intermittently operated central-fan-integrated supply ventilation system gave excellent uniformity of ventilation air distribution, while the installed outside air duct was undersized. The continuously operated separate supply ventilation system showed poor ventilation air distribution for closed bedrooms where there was no ventilation system ducting, while the air change rate for the main living area, and to a lesser extent the master bedroom, was adequate according to design.

Measured Air Change Rates and Distribution of Ventilation Air In A Single Family Home

Armin F. Rudd

ABSTRACT

A single-story, single-family, 1350 ft² house located in Las Vegas, NV was outfitted with two separate ventilation systems. The systems were independent of each other, and were operated at different times to evaluate the relative difference in air change rate and distribution of ventilation air induced by their operation. One system was an intermittently operated central-fan-integrated supply ventilation system, wherein, 47 ft³/min of outside air was ducted from a high wall location on the building exterior to the return air side of the central heating and cooling system blower. The other system was a continuously operated separate supply ventilation system, not connected to the central air distribution ducts, wherein, a separate fan drew 54 ft³/min of outside air and 112 ft³/min of re-circulated inside air from the master bedroom and delivered the resulting 166 ft³/min of mixed air to the main living area of the house. During the testing, all interior doors were closed, and a computer controlled six-zone gas analyzer measured tracer gas concentration in the main living area and all closed rooms. Results showed that the intermittently operated central-fan-integrated supply ventilation system gave excellent uniformity of ventilation air distribution, while the installed outside air duct was undersized. The continuously operated separate supply ventilation system showed poor ventilation air distribution for closed bedrooms where there was no ventilation system ducting, while the air change rate for the main living area, and to a lesser extent the master bedroom, was adequate according to design.

INTRODUCTION

Energy efficient homes inherently have low air leakage rates and therefore require mechanical ventilation for acceptable indoor air quality.

Supply ventilation systems draw outside air from a known location and deliver it to the interior living space. This known location should be selected to maximize the ventilation air quality. The air can be treated before distribution to the living space (one or more of: heated, cooled, dehumidified, filtered, cleaned). If supply ventilation air is not pre-treated, it should be mixed with re-circulated indoor air to mitigate discomfort effects of the outside air. Supply ventilation will tend to pressurize an interior space relative to the outdoors, causing inside air to be forced out through leak sites (cracks, holes, etc.) located randomly in the building enclosure. This strategy is advantageous in warm-humid climates to minimize moisture entry into the building structure from outdoors.

Supply ventilation systems can be powered and ducted in many different ways. How the system is powered, i.e. how fresh air is forced into the house, will effect the first cost and operating cost. How the system is ducted will affect the first cost and the capacity of the system to distribute ventilation air uniformly to all occupied spaces in the home.

The focus of this study was to evaluate the effectiveness of two different supply ventilation systems in providing adequate air change rates and uniform distribution of fresh air. Both of the ventilation systems tested have been used by production builders

as part of the USDOE Building America Program, Building Science Consortium. The central-fan-integrated supply ventilation system is being used extensively.

TEST SETUP

Two ventilation systems were installed in the same 1350 ft² house, in Las Vegas, NV, to individually evaluate their effectiveness in providing adequate air change rates and uniform distribution of fresh air throughout the house.

One system was central-fan-integrated supply ventilation, wherein, outside air was ducted from a high wall location on the building exterior to the return air side of the central heating and cooling system blower (Rudd 1998). This system utilized the existing central heating and cooling system ducts and blower to provide ventilation air and conditioned air at the same time. A *FanRecycler*TM control (*The News*1998, *Builder* 1998, *EDU* 1997) is used to periodically cycle the central blower to distribute ventilation air and provide mixing during stagnant periods when there is no thermostat demand to circulate air for purposes of heating or cooling. A schematic of the central-fan-integrated supply ventilation system installed in the test house is shown in Figure 1. In this house, the attic was not vented, and the roof insulation was applied directly under the roof sheathing - called a "sealed-cathedralized" attic (Rudd, Lstiburek 1998). Hence, the attic mounted air handler and ducts were inside conditioned space, eliminating air distribution system losses. The outside air duct was a four inch diameter expanded aluminum duct connected to a four inch wall cap at the exterior wall and connected to a register box, modified to hold a standard 12"x12" filter, at the return plenum of the central heating and cooling air handler unit. The outside air duct was undersized for this house, allowing in only 47 ft³/min through the four inch duct. The target outside air flow for this house was 80 ft³/min according to **Eq. 1** and the following given parameters:

- 40 ft³/min continuous ventilation required for the occupants of the three bedroom house
- 33% central fan duty cycle
- 0.10 air changes per hour in-between central fan cycles
- house volume of 12,150 ft³

$$\dot{Q}_{cfan} = \frac{(\dot{Q}_{cont}) - (\frac{1}{60} V(1 - f))}{f} \text{Eq. 1}$$

where:

Q_{cfan} = intermittent outside air flow rate through the central fan (ft³/min)

Q_{cont} = continuous outside air flow rate required (ft³/min)

l = estimate of natural air change when central fan is not operating (1/h or ach)

V = volume of conditioned space (ft³)

f = fan duty cycle fraction

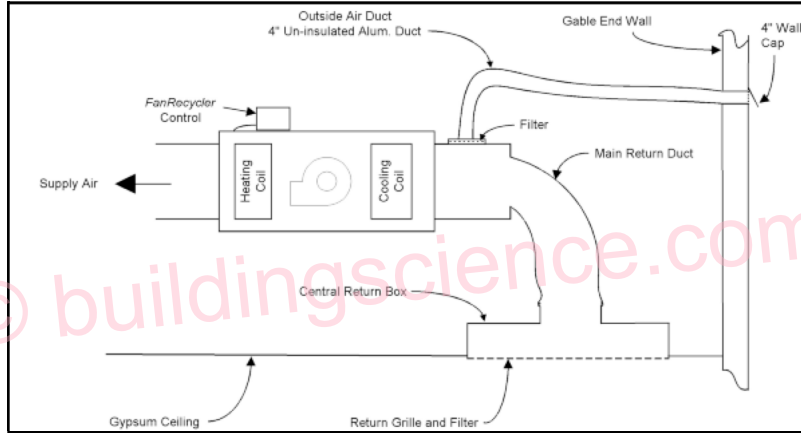


Figure 1 Schematic of central-fan-integrated supply ventilation as installed in the house tested

The actual outside air flow was measured two ways, using a calibrated fan and a velocity probe. The pressure in the outside air duct was -52 Pa with respect to outdoors. To achieve the target 80 ft³/min of outside air with this configuration, a five inch diameter insulated flex duct with a six inch wall cap and a balancing damper should be used. Outside air duct pressure should be adjusted with the balancing damper to obtain -30 Pa upstream of the balancing damper. A number of configurations have been used to conduct outside air to the air handler return for effective air flow and filter access. Recommendations are given in a further section of this paper.

The second system was a separate supply ventilation system, not connected to the central air distribution ducts, wherein, a separate fan drew 54 ft³/min of outside air and 112 ft³/min of inside air from the master bedroom and delivered the 166 ft³/min of mixed air to the main living area of the house. Figure 2 shows a schematic of this system. The flows used followed a 1:2 ratio of outside air to re-circulated air, based on the existing outside air flow of the central-fan-integrated system. Air flows were measured and balanced using a calibrated fan and velocity probe. Re-circulated inside air was drawn from the master bedroom instead of the main living area to test the hypothesis that fresher air from the main living area would tend to move back to the master bedroom to replace the re-circulated air. Depending on the house layout, this would likely raise the system first cost, but far less than a fully-ducted separate system.

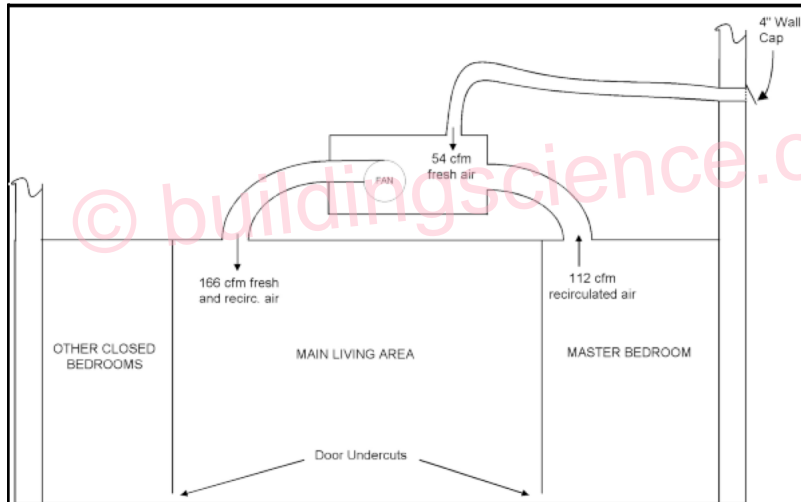


Figure 2 Schematic of separate supply ventilation system installed in the house tested

Air change rate and ventilation air distribution effectiveness was measured using a computer controlled multi-zone gas analyzer. Sulfur hexafluoride (SF₆) was the tracer gas. The gas analyzer was setup to measure SF₆ concentration at approximately two minute intervals in six locations: southeast bedroom, southwest bedroom, main living area hall, living room, master bedroom, and master bathroom. Decay of the tracer gas gives the air change rate according to Eq.

$$I = \frac{\ln (C_f / C_o)}{t} \text{ Eq. 2}$$

where:

I = air change rate (1/h or ach)

C_f = final concentration

C_o = initial concentration

t = time (h)

During the testing, all interior doors were closed to represent overnight sleeping conditions. It is during this time that effective distribution of ventilation air is most needed.

RESULTS

Testing commenced on 8 August 1998 at 2 pm and ended on 10 August 1998 at 9 am. To begin testing, the central heating and cooling system fan was turned on and SF₆ tracer gas was released into the return air grille. As the fan continued to operate, the tracer gas was mixed throughout the house until, after about 45 minutes, a uniform concentration of about 4 parts per million (ppm) was reached.

At this point, the first test period for the central-fan-integrated supply ventilation system began. The thermostat fan switch was left in the ON position, and the outside air duct was open. Since it was also hot outside, the thermostat system switch was left in the COOL position causing the compressor to cycle in response to thermostat demand.

Table 1 shows the air change results for tests of the central-fan-integrated supply ventilation system and the separate supply ventilation system. For the first central-fan-integrated ventilation test (Test ID 1), with the central fan operating constantly, a very uniform air change rate of between 0.33 and 0.34 was achieved in all six of the monitored spaces.

To obtain a baseline air change rate for the house (Test ID 2) without heating or cooling or ventilation operation, the thermostat system mode switch was turned to OFF, the thermostat fan switch was turned to AUTO, and the *FanRecycler* was turned OFF. As shown in Table 1, the baseline infiltration was very low, between 0.01 and 0.06, and not very uniform across the six zones. However, within each zone, the air change rate was consistent. The master bedroom and master bath, which were one zone, had the lowest air change rate (0.01), similar to the southwest bedroom (0.02). The main living area zone, which was represented by the hall and living room sampling locations, and had the highest air change rate (0.05 to 0.06), along with the southeast bedroom (0.05).

The second central-fan-integrated ventilation test (Test ID 3) represented normal operating conditions. The thermostat system switch was set to COOL, the thermostat fan switch was set to AUTO, and the *FanRecycler* was turned ON. The *FanRecycler* was

set to operate the fan for 10 minutes if it hadn't operated for 20 minutes, giving a 33% duty cycle. During this 12.46 hour test period (overnight), the air change rate averaged between 0.10 and 0.11 for all of the monitored locations. This demonstrates that very uniform distribution of ventilation air can be achieved by central-fan-integrated ventilation with normal cycling of the central fan. However, as stated in the previous section, the volume of ventilation air flow was too low due to an undersized outside air duct.

Before the beginning of the separate supply ventilation tests, tracer gas was again injected into the house with the central fan operating continuously. However, this time it was injected into the outside air duct wall cap on the exterior of the building, not into the central return air grille. Referring to Figure 3, plotting of the tracer gas growth in all six monitored locations graphically shows how uniformly ventilation air is distributed with the central-fan-integrated ventilation system.

Test ID	Test Period (h)	Test Period Description	Air Change Rate (1/h)						Comments
			Ch1 SE bedrm	Ch2 SW bedrm	Ch3 Hall	Ch4 Living	Ch5 M bedrm	Ch6 MBath	
1	3.16	Central-fan-integrated ventilation System COOL Fan ON	0.04	0.04	0.04	0.03	0.03	0.03	Good air change if fan on continuously, for intermittent fan, the flow needs to be increased.
2	1.94	Central-fan-integrated ventilation System OFF Fan AUTO	0.05	0.02	0.05	0.06	0.01	0.01	Baseline house infiltration with no mechanical ventilation—very low.
3	12.46	Central-fan-integrated ventilation System COOL Fan AUTO	0.11	0.11	0.10	0.10	0.10	0.10	Overnight, nice uniform distribution of fresh air to all rooms, but volume of fresh air is too low.
4	3.92	Supply fan ventilation System OFF Fan AUTO	0.19	0.09	0.24	0.24	0.25	0.23	Continuous supply fan operation with 54 cfm outside air gives better overall air change but closed SW bedroom get little distribution. The 2:1 mixing ratio with master bedroom air works well.
5	0.75	Supply fan ventilation System COOL Fan ON	0.09	0.04	0.26	0.24	0.29	0.29	With central fan operation the fresh air gets evenly distributed again as shown by the greater air change in the closed bedrooms.
6	16.15	Supply fan ventilation System OFF Fan AUTO	0.12	0.10	0.19	0.20	0.14	0.14	Overnight, with no central fan operation, the closed bedrooms get less fresh air. FanRecycler would correct this problem.

Table 1 Multi-zone air change rate measurements for central-fan-integrated supply ventilation and separate supply ventilation

Once the tracer gas concentration was uniform throughout the house, the first test of the separate supply ventilation system was begun (Test ID 4). The outside air duct to the return air side of the central fan was blocked off. The thermostat system switch was turned to OFF, the thermostat fan switch was turned to AUTO, and the *FanRecycler* was turned OFF. This kept the central fan from operating. The separate supply fan was turned on, drawing 54 ft³/min from outdoors and 112 ft³/min from the master bedroom, and supplying the resulting 166 ft³/min of mixed air to the

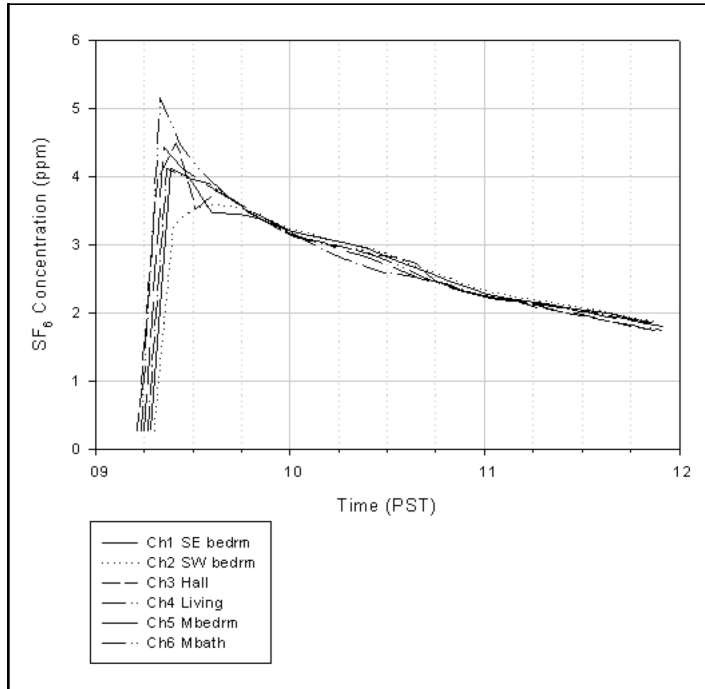


Figure 3 Tracer gas injection into outside air inlet of central-fan-integrated supply ventilation system shows how uniformly ventilation air is distributed throughout the house

main living area. Air change rates for the 3.92 hour test varied widely from 0.09 to 0.25 among the six monitored locations. The master bedroom, master bathroom, hall, and living room locations all averaged closely between 0.23 and 0.25, showing that drawing re-circulated air from the master bedroom zone did indeed induce fresh air distribution to that zone. However, the southeast and southwest bedrooms received inadequate fresh air as evidenced by the much lower air change rates, 0.19 and 0.09, respectively.

The next test period for the separate supply ventilation system test (Test ID 5) began with turning the thermostat system switch to COOL and the thermostat fan switch to ON. This allowed

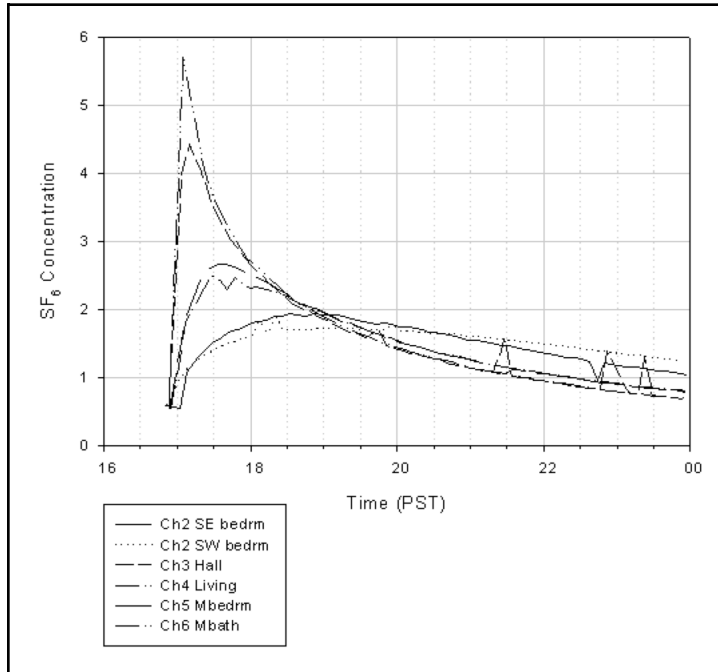


Figure 4 Tracer gas injection into outside air inlet of the separate supply ventilation system shows how non-uniformly ventilation air is distributed throughout the house

cooling of the house while also re-averaging the tracer concentration throughout the house. This showed the beneficial effect of central fan operation along with the separate supply ventilation fan operation. As shown in Table 1, the concentration of tracer gas did not change much in the main living area and master bedroom zones, but it increased a lot in the other closed bedrooms as fresh air from the main living area was distributed to the bedrooms. This was especially true for the southwest bedroom which had previously had the lowest air change rate.

Next, to begin the last test of the separate supply ventilation system (Test ID 6), the thermostat system was turned to OFF and the thermostat fan switch was turned to AUTO, precluding any central fan operation. Tracer gas was then injected into the outside air inlet to the separate supply ventilation fan. Referring to Figure 4, plotting of the tracer gas growth in all six monitored locations graphically shows how non-uniformly ventilation air is distributed with the separate supply ventilation system. Over the next 16.15 hours (overnight), average air change rates ranged between 0.10 for the southwest bedroom to 0.20 for the living room. During this test, air change rates in the master bedroom zone were not as close to those in the main living area zone as they were for Test ID 4, and air change rates in the other bedrooms were significantly lower. Based on these data, the ventilation air distribution performance of the separate supply ventilation system is poor relative to the central-fan-integrated supply ventilation system. However, as shown by the re-distribution effect of central fan operation (Test ID 5), a *FanRecycler* control installed on the central heating and cooling system blower would correct this problem.

DISCUSSION AND RECOMMENDATIONS

While the focus of this study was not cost, it is useful to layout the basic cost issues that inevitably will be considered by production builders (Rudd 1998). Central-fan-integrated supply ventilation systems provide the lowest first cost, since the only additional cost is the outside air duct and the *FanRecycler* control to periodically operate the central fan during mild weather when there is no thermostat demand. However, since the power to

force air through ducts is directly proportional to the volume flow, it is more costly to operate a large central fan designed to move at least 10 times more air than a small separate supply ventilation fan. Yet, since the central fan will already operate in response to thermostat demand to distribute heated and cooled air, the extra energy cost is only for that time which the fan is caused to operate by the *FanRecycler* control to provide ventilation and mixing in-between normal heating and cooling cycles. Conversely, a separate supply ventilation system will have the highest first cost but lower operating cost. A fully-ducted separate supply ventilation system is probably cost prohibitive for production builders, hence, the modified system used here whereby re-circulated air is drawn from the master bedroom to induce greater fresh air distribution to that space. To achieve uniform ventilation air distribution the cost of the *FanRecycler* control should be added to the cost of the separate supply ventilation system.

The following recommendations are given for the central-fan-integrated supply ventilation system to better achieve adequate outside air flow and filter access. Figure 5 shows an attic mounted air handler with an outside air duct connected to an extended collar above the main return air filter grille assembly. This configuration allows enough available negative pressure to draw in outside air with a 5 inch or 6 inch duct, and the outside air filter is also accessible from below for regular maintenance. The design air flow should always be set with a balancing damper. Figure 6 shows an attic mounted air handler with the outside air duct connected to the top of the main return air filter grille assembly. While this location provides less available negative pressure than the configuration in Figure 5, a larger duct can be installed to compensate for the lower pressure, and the outside air filter is still accessible for regular maintenance.

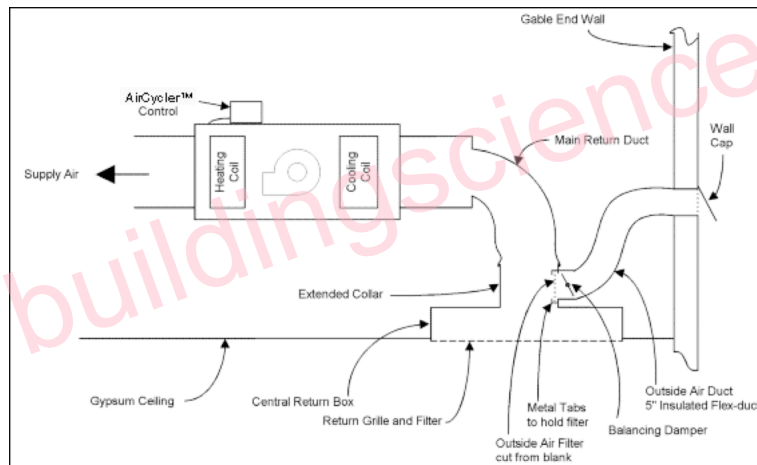


Figure 5 Central-fan-integrated supply ventilation system with attic mounted air handler and outside air duct connected to extended collar above the main return air filter grille assembly

CONCLUSIONS

Multi-zone tracer gas measurement was used to evaluate the effect on air change rate and ventilation air distribution for two ventilation systems installed in the same house. The intermittently operated central-fan-integrated supply ventilation system showed excellent uniformity of ventilation air distribution, while the installed outside air duct was undersized. The continuously operated separate supply ventilation system showed poor ventilation air distribution for closed bedrooms where there was no ventilation system ducting, while the air change rate for the main living area, and to a lesser extent the master bedroom, was adequate according to design.

ACKNOWLEDGMENTS

This work was sponsored by the U.S. Department of Energy, Office of Building Technologies, Building America Program. Sincere appreciation is expressed for the valued support from George James, USDOE Program Manager, and Betsy Pettit and Joseph Lstiburek of the Building Science Consortium. Thanks to Ren Andersen of the National Renewable Energy Laboratory for his participation in the testing.

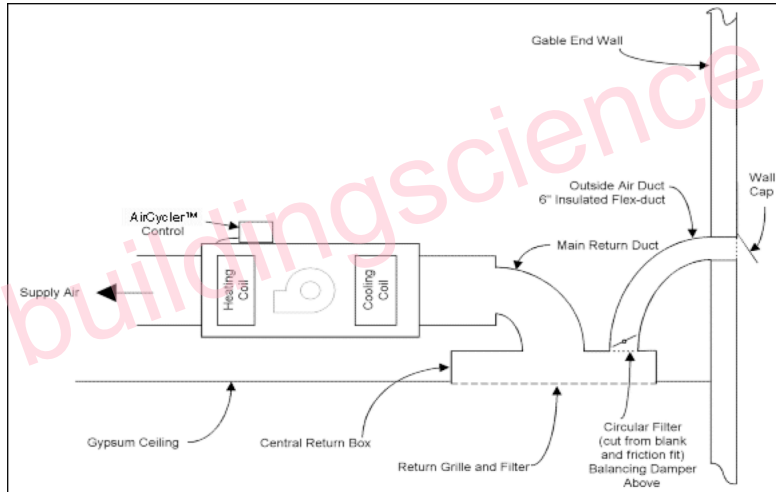


Figure 6 Central-fan-integrated supply ventilation system with attic mounted air handler and outside air duct connected to the top of the main return air filter grille assembly

About the Author

Armin Rudd is a principal engineer at Building Science Corporation in Westford, Massachusetts. More information about Armin Rudd can be found at www.buildingscienceconsulting.com.

Direct all correspondence to: Building Science Corporation, 30 Forest Street, Somerville, MA 02143.

Limits of Liability and Disclaimer of Warranty:

Building Science documents are intended for professionals. The author and the publisher of this article have used their best efforts to provide accurate and authoritative information in regard to the subject matter covered. The author and publisher make no warranty of any kind, expressed or implied, with regard to the information contained in this article.

The information presented in this article must be used with care by professionals who understand the implications of what they are doing. If professional advice or other expert assistance is required, the services of a competent professional shall be sought. The author and publisher shall not be liable in the event of incidental or consequential damages in connection with, or arising from, the use of the information contained within this Building Science document.