# Design Methodology and Economic Evaluation of Central-Fan-Integrated Supply Ventilation Systems

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## ABSTRACT

Residential ventilation systems can be categorized as supply, exhaust, or balanced systems. This effort focused on establishing a design methodology for central-fan-integrated supply ventilation systems. Air flow measurements were taken for 7.6 m lengths of 12.7 cm through 22.9 cm diameter flexible ducts, with a 15.2 cm wall-cap, at duct pressures of -10 Pa to -120 Pa. Using these measurements and field experience, a five-step method was developed as a guide for sizing and installing the ventilation system. An economic evaluation was made by conducting hourly computer simulations to determine the impact on heating, cooling, and fan energy use for four U.S. climates. An effective ventilation system can be achieved using a filtered duct from outdoors to the return side of a central air distribution fan with a specialized fan control that automatically cycles the fan if the fan has been inactive for a period of time.

## INTRODUCTION

Energy efficient homes with low air leakage rates require mechanical ventilation for acceptable indoor air quality [1]. A number of residential mechanical ventilation system types exist. These systems can be generally categorized as follows:

- Supply ventilation, with either central-, single- or multi-point distribution
- Exhaust ventilation, with either single- or multi-point exhaust, and with or without passive inlet vents
- Balanced ventilation, with either single- or multi-point supply and exhaust, and with or without heat recovery or energy recovery (heat and moisture)

Recent related publications describing ventilation systems include [2], [3], [4], [5], [6]. Some economic analysis has been published, however, hourly computer simulations, with real buildings designed to meet national energy standards, and with properly sized heating and cooling equipment has not been published.

### Supply Ventilation

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 (heated, cooled, dehumidified, filtered, cleaned). If supply ventilation air is not pre-treated, it should be mixed with recirculated indoor air to mitigate discomfort effects of the outside air (at least 2 parts inside air with 1 part 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 around the building envelope. This strategy is advantageous in warm, humid climates to minimize moisture entry into the building structure from outdoors. Care should be taken with building envelope design and workmanship when using supply ventilation in climates with cold winters. In some cold climate houses, an exhaust fan may be advisable to balance supply ventilation air to avoid pressurizing the building.

Central-Fan-Integrated Supply Ventilation System

Ventilation systems that provide ventilation air through a duct that extends from outdoors to the return side of a central air distribution fan have an advantage in that they achieve full distribution of ventilation air using already existing ducts [2]. However, these systems only supply ventilation air when the central fan is operating. During mild outdoor conditions, the fan may not be activated by the thermostat for long periods of time, creating a problem for adequate distribution of ventilation air. Until the introduction of a specialized fan recycling control, the only options to remedy that problem were, 1) run the central fan continuously; or, 2) operate the fan in parallel with a separate timer that had no relation to the fan's operation due to thermostat demand, causing redundant and short-cycling operation. Both of these options are inefficient, and will shorten the life of the central fan. In addition, operating the central system fan continuously can lead to moisture related problems in humid cooling climates. A control [7], [8] can be set to periodically distribute ventilation air during periods when there is no thermostat demand to circulate air for purposes of heating or cooling. The specialized control periodically cycles the fan only if the fan has been inactive for a period of time. This is an energy efficiency strategy that utilizes the normal thermostat driven cycling of the fan for simultaneous distribution of ventilation air. The control can also operate a motorized outside air damper with operation of the central fan but limited to the time set for damper operation on the controller. This serves to disconnect outside air from the house when the fan is not operating, and to limit ventilation air flow if the fan is operating for long continuous periods. This type of central-fan-integrated supply ventilation system can also provide enhanced temperature and humidity comfort control, and air cleaning, through periodic whole house mixing.

As a prerequisite for energy efficiency in any forced air system, the entire air distribution system must be substantially airtight, including all ducts, dampers, fittings, and the air handler cabinet itself. If the air distribution system is leaky to unconditioned space, this will defeat the purpose of intentionally sizing an outside air duct to provide a controlled amount of ventilation air. A good alternative is to locate the entire air distribution system inside the conditioned space.

### Ventilation Requirements

Two code jurisdictions in the United States require whole house mechanical ventilation for homes. One is the HUD Manufactured Home Construction and Safety Standards [9], and the other, the Washington State Ventilation and Indoor Air Quality Code [10]. A new code requirement for residential ventilation will go into effect July 1999 in the State of Minnesota.

## TEST FOR DETERMINING OUTSIDE AIR FLOW RATES

Measurements were made to establish ventilation air flow rates for central-fan-integrated supply ventilation systems having an outside air duct connected to the return side of a central air distribution fan. Outside air duct configurations included: 15.2 cm wall caps (outside air inlets), 12.7 cm to 22.9 cm diameter flexible duct sizes, and round to rectangular duct transitions with filter. Outside air duct pressures ranged from -10 to -120 Pa.

## TEST APPARATUS DESCRIPTION

All outside air ducts with the associated wall cap, balancing damper, transition, and filter were constructed using off-the-shelf components from local suppliers of HVAC or building products. All flexible ducts were uncut 7.6 m lengths. All joints between ducts and fittings were sealed with tape (for permanent field installations, fiberglass mesh and mastic should be used). A calibrated fan was used to create the range of negative pressures and to measure air flow. Digital pressure manometers were used to measure the outside air duct pressure upstream of the balancing damper, and to measure fan pressure to calculate the air flow rate from the fan calibration formulas.

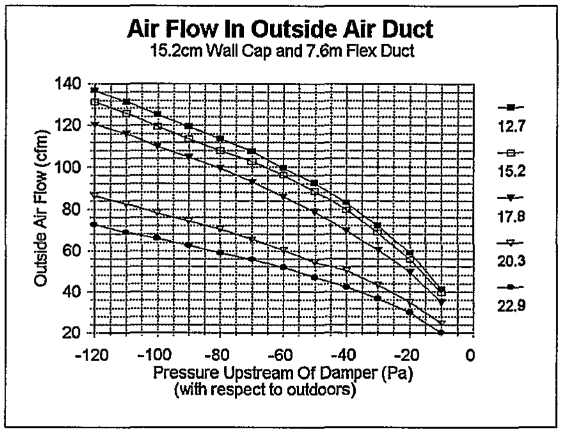


**Figure 1** Air flow rate in outside air duct versus outside air duct pressure, for flexible duct sizes between 12.7 cm and 22.9 cm diameter, using a 15.2 cm wall cap in all cases

## DISCUSSION

Figure 1 shows the measured relationship between air flow rate and negative pressure in the outside air duct for various duct sizes. A five-step procedure was created for designing, sizing, and installing a central-fan-integrated supply ventilation system. The procedure uses Eq. 1, Eq. 2, and Figure 1.

**Step 1**: Select the continuous outside air flow requirement for your house design. ASHRAE Standard 62-1989 recommends the greater of 7.1 L/s per person or 0.35 air changes per hour. Values can be based on personal choice, for example, if people have pets or want to smoke inside, they may want to choose 9.4 L/s per person. Or, if excellent hygiene is maintained, others may want to choose 4.7 L/s per person which will lower energy consumption and equipment size.

**Step 2**: Using Eq. 1, calculate the fan duty cycle fraction from the fan recycling control settings for Fan OFF time and Fan ON time.

$$\frac{(t_{on})}{(t_{on}+t_{off})} = f \qquad \text{....(1)}$$

**Step 3**: Using Eq. 2, calculate the intermittent outside air flow that will be equivalent to the continuous outside air flow selected in **Step 1**, for the fan duty cycle you chose in **Step 2.**

$$\dot{Q}_{cfan} = \frac{(\dot{Q}_{cont}) - (\frac{I}{60}V(1-f))}{f} \qquad \text{....(2)}$$

where: $Q_{cfan}$ = intermittent outside air flow rate through the central fan (L/s)
$Q_{cont}$ = continuous outside air flow rate required (L/s)
$I$ = estimate of natural air change when central fan is not operating, (1/h)
$V$ = volume of conditioned space (L)
$f$ = fan duty cycle fraction, from Eq. 1

The estimate of natural air change rate when the central fan is not operating may be difficult to predict since it changes with environmental conditions. To be conservative, it should be set to a low value (< 0.15 $h^{-1}$ ). If it is set to zero, the space may be over-ventilated resulting in higher energy consumption.

**Step 4**: Using Figure 1, select the outside air duct size that will give you the required intermittent outside air flow, calculated in **Step 3**, based on the expected negative pressure in the outside air duct upstream of the outside air balancing damper.

**Step 5**: After installation of the air distribution and ventilation system, measure the pressure in the outside air duct upstream of the balancing damper, with respect to outside. Adjust the balancing damper until the combination of the duct pressure and the duct size match with the required outside air flow in Figure 1. Then lock the damper in place.

Furnace manufacturers often require that the furnace heat exchanger not be exposed to air below a minimum air temperature to protect the heat exchanger from excessive thermal expansion and contraction and unintended condensation of combustion gases. For cold outdoor conditions, for a central-fan-integrated supply ventilation system with a 7% outside air fraction, if the outdoor temperature was -31.7 C, and the indoor setpoint temperature was a low 18.8 C, the mixed air temperature at the furnace heat exchanger would be 15.6 C. This mixed air temperature would not negatively impact a furnace heat exchanger.

During the heating season, under part load conditions, the specialized recycling control may operate the central fan between heating cycles to distribute ventilation air. Depending on the location of supply registers, and the supply air velocity, and the sensitivity of the occupants to essentially room temperature air being circulated, thermal comfort may be a concern [3]. This can be mitigated with reasonable care to avoid introducing air directly on sedentary people.

## ECONOMIC EVALUATION

An economic evaluation was made by conducting hourly computer simulations to determine the impact of central-fan-integrated supply ventilation on heating, cooling, and fan energy use for four U.S. climates: cold (Chicago), mixed (Charlotte), hot-dry (Las Vegas), and hot-humid (Orlando).

### Simulation Model Setup

The hourly simulation program used was DOE2.1E. A special subroutine was written so that the duty cycle of the central fan could be specified, such that, if the heating and cooling system did not operate enough to meet the specified duty cycle, the fan alone would operate. By running the model both ways – with and without the duty cycle specified – a comparison of fan operational hours and the associated impact on heating, cooling, and fan energy use was made. All fan power was calculated at 74 W/L/s (based on a combined fan and motor efficiency of 0.23 and external static pressure of 169 Pa), and 188.8 L/s per 3516 W of cooling.

The modeled house was 139.4 $m^2$, single-story, with three bedrooms, two bathrooms, and two-car garage. The building envelope characteristics for each city were taken from the prescriptive requirements listed in the ASHRAE Standard 90.2-1993 [11]. For each of the four cities, a determination of the heating and cooling system size was made using a software that calculates the system capacity requirement based on a room-by-room ACCA Manual J approach.

## Simulation Results

Net annual heating, cooling and central fan operation costs ranged from $US 3 to $US 27 more for the central-fan-integrated system when comparing the Cen Fan1 case (ducts in unconditioned space) to the Base1 case (no mechanical ventilation system). Although there is a small energy consumption cost for the Cen Fan1 case over the Base1 case, the argument against relying on random natural infiltration for acceptable ventilation is well known– over-ventilation in winter and under-ventilation in summer.

Net annual heating, cooling and central fan operation costs ranged from $22 to $47 less for the Cen Fan2 case (ducts in conditioned space) compared to the Base1 case. This highlights the benefit of locating the air distribution ducts inside conditioned space.

Net annual heating, cooling, and central fan operation costs ranged from $36 to $54 more for the Cen Fan1 case compared to the Base2 case (19 L/s continuous supply ventilation, separately ducted and fully distributed), and ranged from $50 more to $33 less for the Cen Fan2 case compared to the Base2 case. The installed cost increment of the Base2 case, relative to the Cen Fan1 or Cen Fan2 cases, is approximately $500. Thus, it would take at least ten years to cover the first cost of the separately ducted supply ventilation system. In addition, the Base2 case does not include the important advantage of periodic whole house mixing during stagnant periods, to re-average temperature and humidity conditions, to improve occupant comfort especially in closed rooms.

## CONCLUSION

Effective and economic residential ventilation can be achieved with the central-fan-integrated supply ventilation system approach. This approach entails using a 12.7 cm to 22.9 cm diameter insulated duct from outdoors to the return side of a central air distribution fan with a specialized fan recycling control to ensure that fresh air will be periodically distributed throughout the house if the central fan has been inactive for a period of time. The outside air should be filtered before it enters the air handling unit, and a balancing damper should be used for setting the delivered outside air flow rate.

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