#5596

Computer Program for Sizing Residential Energy Recovery Ventilator

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ABSTRACT

Energy recovery ventilators offer the prospect of tighter control over residential ventilation rates than manual methods, such as opening windows, with a lesser energy penalty. However, the appropriate size of such a ventilator is not readily apparent in most situations. Sizing of energy recovery ventilation software was developed to calculate the size of ventilator necessary to satisfy ASHRAE Standard 62-1989, Ventilation for Acceptable Air Quality, *or a user-specified air exchange rate. Inputs to the software include house location, structural characteristics, house operations and energy costs, ventilation characteristics, and HVAC system COP/efficiency. Based on these inputs, the program estimates the existing air exchange rate for the house, the ventilation rate required to meet the ASHRAE standard or user-specified air exchange rate, the size of the ventilator needed to meet the requirement, and the expected changes in indoor air quality and energy consumption. An illustrative application of the software is provided.*

INTRODUCTION

Occupants of residential dwellings tend to rely primarily on infiltration for ventilation of the indoor air space. With an increasing emphasis on infiltration reduction as one aspect of energy conservation, infiltration alone is not always adequate to dilute humidity, odors, or other indoor contaminants to desired levels. It is possible to increase ventilation by opening windows, but the increase in ventilation through such manual methods cannot be easily controlled and usually carries some energy penalty. Energy recovery ventilators offer the prospect of tighter control with a lesser energy penalty. The appropriate size of such a ventilator, however, is not readily apparent in most situations, as it can depend on factors such as the size and tightness of the residence, the number of occupants, local weather patterns, and generally prevailing indoor air quality.

Sizing of energy recovery ventilator software (EPRI 1990) was developed to calculate the size of ventilator necessary to satisfy air-change requirements for a single-family residence. The program also estimates changes in indoor air quality (IAQ) that would result from operating the ventilator as well as the energy required for providing the supplemental ventilation during summer and winter seasons. Subsequent sections of this paper describe input screens, calculations by the program, and an illustrative application.

USER INPUTS

As summarized in Figure 1, five types of user input are required: (1) house location, (2) structural characteristics, (3) house operation and energy costs, (4) ventilation characteristics, and (5) HVAC system COP/efficiency. Based on these inputs, the software estimates the existing ventilation rate for the house, the ventilation rate required to meet *ASHRAE Standard 62-1989* (ASHRAE 1989a) or a user-specified air exchange rate, the size of the ventilator needed to meet the requirement, and the expected changes in indoor air quality and energy consumption (Figure 2). Further specifics on each type of input are provided below.

House Location

The first input screen (Figure 3) provides a list of 25 cities across the United States. Typically, the user of the software would select a city with climatic conditions similar to those in the geographic area for which installation of an energy recovery ventilator is contemplated. The choice of city determines (1) weather data for infiltration and energy calculations and (2) outdoor concentration data for carbon monoxide (CO) and nitrogen dioxide (NO_2) for IAQ calculations. These calculations are described later in the paper.

Structural Characteristics

The second input screen (Figure 4) requests information concerning (1) house leakiness and terrain sheltering, for calculation of air infiltration rates, and (2) floor area and ceiling height, for calculation of house volume. Floor area of the conditioned space is a summation of all floors including the basement. Values for house leakiness (L) are in the range of 1 to 5. Typically, a very tight house (L value of 5) would be one built recently with infiltration-reduction measures such as vapor barriers, double- or triple-pane windows, tight-fitting exterior doors, and no perceptible leaks or drafts around windows or electrical outlets. The sheltering factor (C) accounts for the effect of local terrain on the infiltration rate of a house. Values for C are in the range of 1 to 4. A highly sheltered home (C value

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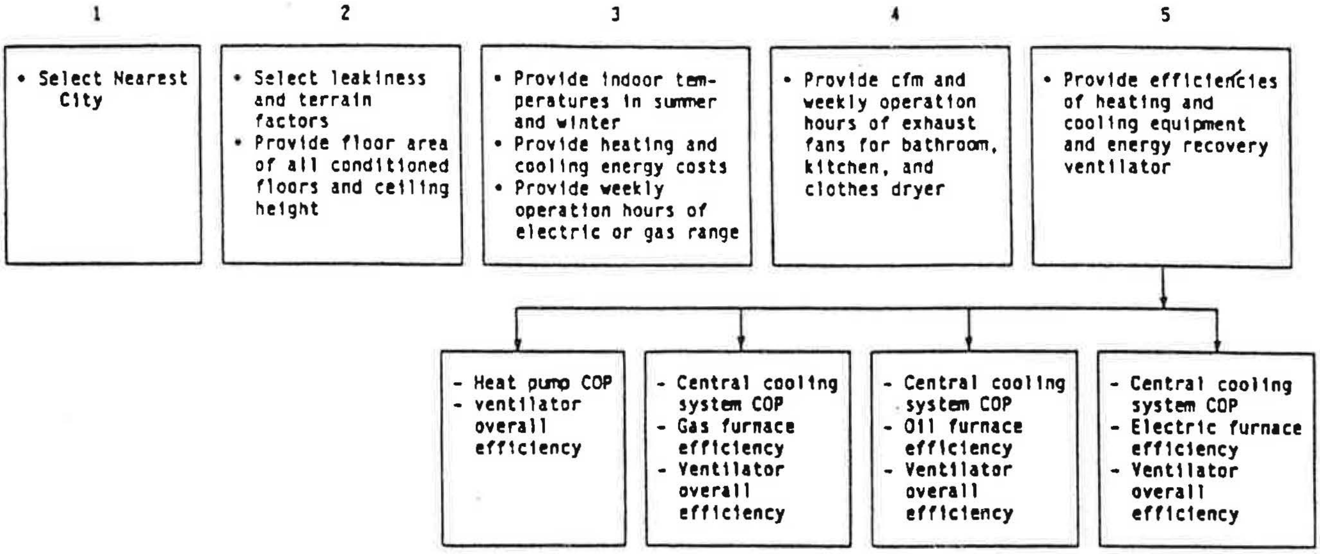

Figure 1 Overview of user input screens

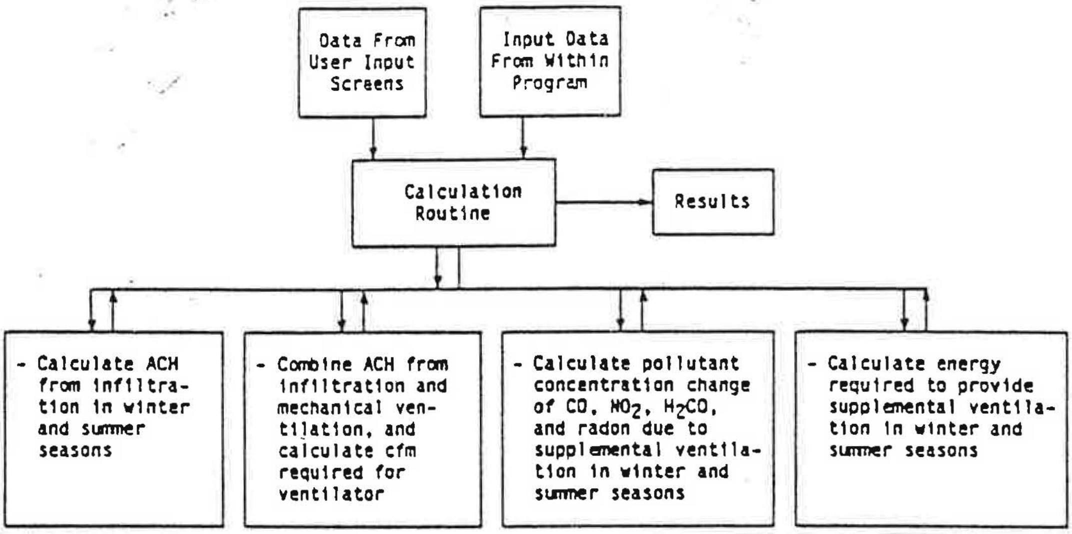

Figure 2 Overview of calculation routine

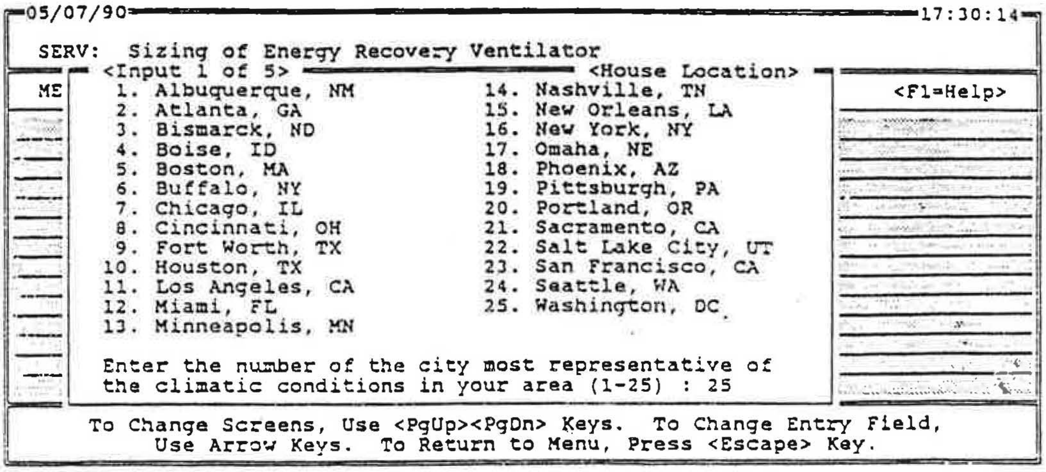

Figure 3 First input screen (house location)

```
05/07/90                                                              17:30:28
 SERV:  Sizing of Energy Recovery Ventilator
      <Input 1 of 5>                          <House Location>
 ME    1. Albuquerque, NM            14. Nashville, TN               <F1=Help>
      <Input 2 of 5>                <Structural Characteristics>

       Leakiness Factor, L           Terrain Sheltering Factor, C

       1. Very airtight              1. Open
       2. Moderately airtight        2. Lightly sheltered
       3. Average                    3. Moderately sheltered
       4. Moderately leaky           4. Highly sheltered
       5. Very leaky

       Enter Leakiness  Factor, L (1-5) : 2.0
       Enter Sheltering Factor, C (1-4) : 3.0

       Floor Area    (ft^2) : 1600
       Ceiling Height (ft)  :  9.0

    To Change Screens, Use <PgUp><PgDn> Keys.  To Change Entry Field,
         Use Arrow Keys.  To Return to Menu, Press <Escape> Key.
```

Figure 4 *Second input screen (structural characteristics)*

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05/07/90                                                              17:30:39
 SERV:  Sizing of Energy Recovery Ventilator
      <Input 1 of 5>                          <House Location>
 ME    1. Albuquerque, NM            14. Nashville, TN               <F1=Help>
      <Input 2 of 5>                <Structural Characteristics>

      <Input 3 of 5>      <House Operation & Energy Costs>

                  Number of Occupants in the House :      4

              Indoor Temperature for Winter (deg F) :   70.0
              Indoor Temperature for Summer (deg F) :   75.0

        Electric Cost for Heating/Cooling ($/kWh) :    .08
                Gas/Oil Cost for Heating ($/therm) :    .50
                  Annual House Energy Cost ($/year) :   1200

                  Weekly Gas Range Operation Hours :
              Weekly Electric Range Operation Hours :    6.0

    To Change Screens, Use <PgUp><PgDn> Keys.  To Change Entry Field,
         Use Arrow Keys.  To Return to Menu, Press <Escape> Key.
```

Figure 5 *Third input screen (house operation and energy costs)*

of 4) would be one in very close proximity to other houses and with a dense array of surrounding trees or tall shrubs.

House Operation and Energy Costs

Among the inputs to be provided on this screen (Figure 5) are the number of house occupants and typical indoor temperatures during the summer and winter seasons. The number of occupants is used together with house volume to determine the minimum air exchange rate needed to provide 15 cfm/person of outdoor air. Typical indoor temperatures would be the thermostat setpoints for heating and cooling; the program does not consider temperature setback. The user also is asked to provide the cost of electricity for both the heating and cooling seasons and the cost of oil or natural gas for the heating equipment. These values are used by the program in determining the cost of supplemental ventilation provided by the energy recovery ventilator. The user's estimate of annual house energy costs is used by the program in estimating the percent increase in energy costs due to operation of the ventilator. The user's choice of an electric or gas range has no effect on energy calculations but will affect IAQ calculations (the gas range is an indoor source of CO and NO_2).

Ventilation Characteristics

The program sizes the energy recovery ventilator for the house using 0.35 air changes per hour (ach), 15 cfm/person, or a user-specified air exchange rate, whichever is greater (Figure 6). A value below 0.35 ach is not accepted by the program, as such a value is not consistent with the intent of *ASHRAE Standard 62-1989*. The user is also asked to provide inputs on weekly operation hours and airflow rates for any vented exhaust fans that are used intermittently. Although included in the program, these fans typically have only a small impact on existing ventilation, relative to the impact of infiltration. Operation of any of these fans can be suppressed by entering zero as the number of weekly operation hours.

HVAC System COP/Efficiency

Four heating and cooling system options are available in the program (Figure 7). It is assumed that each option satisfies the entire heating and cooling load. The options are heat pump (default), central cooling/gas heating, central cooling/oil heating, and central cooling/electric heating. For the option selected, the user is asked to provide information on (1) COP of the heat pump or central system; (2) efficiency of the oil furnace,

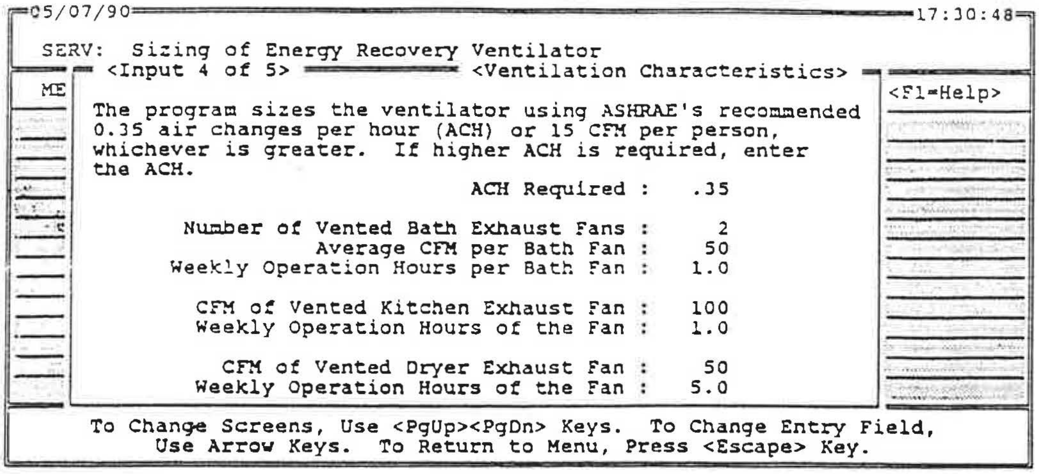

Figure 6 Fourth input screen (ventilation characteristics)

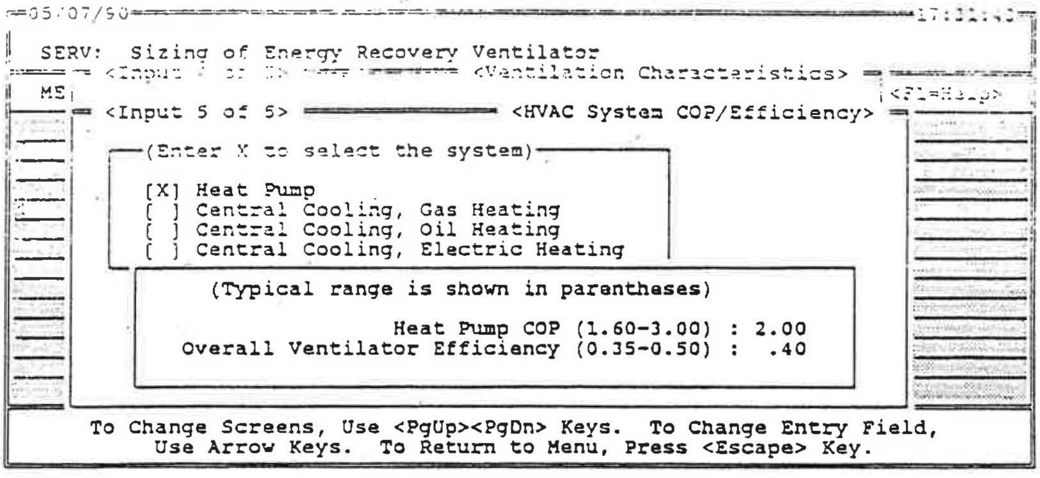

Figure 7 Fifth input screen (HVAC system COP/efficiency)

gas furnace, or electric furnace; and (3) overall efficiency of the energy recovery ventilator. The efficiency of the energy recovery ventilator takes into consideration any energy used by its supply and exhaust fans. A typical efficiency for an energy recovery ventilator would be 60% to 70%, which would be reduced to 40% to 50% after accounting for the energy required to operate its supply and exhaust fans.

PROGRAM CALCULATIONS

The program calculates the air exchange rate for the house due to air infiltration and mechanical ventilation, the size of the energy recovery ventilator (if needed) to satisfy air-change requirements, heating and cooling energy associated with the supplemental ventilation, and expected changes in pollutant concentrations. Each of these calculations is described below.

Air Exchange Rate

A variety of mathematical models for air infiltration exist. Such models, however, cannot be readily used here because the inputs required (e.g., leakage areas, crack lengths) cannot be easily gathered by the typical user (e.g., utility representative) of this program. Another approach to estimation of air infiltration rates is through empirical models, which rely on collection of infiltration measurements under a variety of weather conditions for estimating the relationship to wind speed and temperature. However, the model user typically will not have the resources to develop the regression estimates needed for these predictions.

A good compromise between the theoretical and empirical approaches has been struck in the model, specified by Dietz et al. (1986):

$$ACH = L(0.006 \times \Delta T + 0.03/C \times U^{1.5}) \quad (1)$$

where ACH = average air changes per hour or infiltration rate (h^{-1}), L = generalized house leakiness factor ($1 < L < 5$), C = terrain sheltering factor ($1 < C < 10$), ΔT = average inside-outside temperature difference (°C), and U = average wind speed (m/s). It is possible for the user to develop reasonable estimates for L and C, given limited guidance, and appropriate values of average outdoor temperature and wind speed in various geographic areas have been developed from historical data. For these reasons, the above model was chosen for infiltration calculations. Separate infiltration estimates are provided by the program for summer and winter seasons, based on user inputs for L, C, and indoor temperature combined with seasonal-average temperature and wind speed values for a test reference year.

Mechanical ventilation through exhaust fans (e.g., bathroom, kitchen, clothes dryer) further contributes to the residential air exchange rate. The incremental air exchange due to any exhaust fan, in ach, is determined by dividing its exhaust rate (ft^3/h) by the house volume (ft^3). Letting $ACH_{SUP,J}$ represent the air exchange rate from all supply fans in combination J and $ACH_{EXH,J}$ represent the air exchange rate from all exhaust fans in combination J, the effective air exchange rate from infiltration and from mechanical ventilation in combination J ($ACH_{I,M,J}$) can be obtained from the relation:

$$ACH_{I,M,J} = [ACH_I^2 + (ACH_L - ACH_S)^2]^{0.5} + ACH_S \quad (2)$$

where ACH_I is the infiltration rate from Equation 1, ACH_L is the larger of $ACH_{SUP,J}$ and $ACH_{EXH,J}$, and ACH_S is the smaller of $ACH_{SUP,J}$ and $ACH_{EXH,J}$. Assuming that there are K fan combinations in a week, the effective air exchange rate for each combination is given by Equation 2. The total effective air exchange rate from infiltration and mechanical ventilation ($ACH_{I,M}$) during a weekly period is then given by the relation:

$$ACH_{I,M} = 168/\sum_{J=1}^{K} (WOH_J/ACH_{I,M,J}) \quad (3)$$

where 168 is the number of hours in a week and WOH refers to the weekly operation hours of fans in combination J. For calculational convenience, none of the exhaust fans is assumed to operate at the same time.

Size of Energy Recovery Ventilator

ASHRAE Standard 62-1989 is the most widely recognized reference on ventilation requirements for acceptable IAQ. Therefore, this standard was used as the basis for establishing required air exchange rates. The standard provides two alternative procedures to obtain acceptable indoor air quality: the ventilation rate procedure (VRP) and indoor air quality procedure (IAQP). The IAQP achieves acceptable air quality within a space by controlling known contaminants. The use of the IAQP may result in increased ventilation requirements, depending on the strength of a particular contaminant source in the space.

The program uses the VRP of *ASHRAE Standard 62-1989* to assess the impact of providing outdoor air to the space. IAQ is considered acceptable if the outdoor air is delivered to the occupied space at the rates specified in Table 1. These rates are specified both in terms of cfm per person and air changes per hour because the level of contamination may be related to factors such as emissions from building materials or furnishings, as well as to building occupancy. If the existing air exchange rate calculated by the program is not sufficient to meet the ASHRAE standard or the user-specified air exchange rate, then a ventilator is used to satisfy the required ventilation. The size of the ventilator, in cfm, is calculated by an iterative procedure involving Equations 2 and 3.

Heating and Cooling Energy for Supplemental Ventilation

The incremental energy due to the loss through supplemental ventilation during heating and cooling seasons is calculated separately for each season using the incremental air exchange rate, indoor and outdoor climatic conditions, heating degree-days, cooling degree-hours, equipment efficiencies, and the volume of the house. The energy estimation method described in *ASHRAE Fundamentals* (ASHRAE 1989b) is used in the analysis. The density and specific heat of air used in the analysis are 0.075 lb/ft^3 and 0.24 Btu/lb·°F, respectively. Latent loads during a cooling season are calculated using an average indoor humidity ratio of 0.011 lb water/lb dry air. An energy recovery ventilator recovers a fraction of the energy required for the supplemental ventilation. A typical value for the overall efficiency of an energy recovery ventilator is 40%, which takes into account the energy used by the supply and exhaust fans of the ventilator. The net energy used for providing the supplemental ventilation is the difference between the heating season incremental energy and the energy recovered by the ventilator.

Pollutant Concentrations

The following steady-state version of a mass-balance model (Nagda et al. 1987) is used to estimate the impact of supplemental ventilation on indoor concentrations of CO, NO_2, formaldehyde, and radon:

$$C_{in} = (S/V + aPC_{out})/(a + k) \quad (4)$$

where C_{in} = indoor concentration (mass/volume), S = indoor generation rate (mass/time), V = indoor volume (volume), a = air exchange rate (1/time), P = penetration rate (1 − fraction of outdoor concentration intercepted by the building envelope), C_{out} = outdoor concentration (mass/volume), and k = rate constant for chemical decay (1/time). Indoor concentrations with and without supplemental ventilation are calculated, and the percent difference between the two conditions is then computed.

For CO and NO_2, outdoor concentrations for each of the 25 cities have been estimated from data compiled by the U.S. Environmental Protection Agency's National Air Data Branch. A penetration factor of one is appropriate for CO because it is chemically inert. For NO_2, previous regression estimates (Drye et al. 1989) indicate that a value of 0.65 can be assumed; for the outdoor NO_2 brought indoors through the ventilator, however, the penetration factor can be assumed to equal one. The only potential indoor CO/NO_2 source considered in the program is a gas range. A decay rate constant of 0.8 is assumed for NO_2; CO is chemically nonreactive (i.e., k = 0).

Both radon and formaldehyde are assumed to be nonreactive, and outdoor concentrations for these pollutants are

TABLE 1
Outdoor Air Requirements for Ventilation of Residential Buildings (*ASHRAE Standard 62-1989*)

Application	Outdoor Air Requirements
Living Areas	0.35 ACH but not less than 15 cfm (7.5 L/s) per person
Kitchens	100 cfm (50 L/s) intermittent or 25 cfm (12 L/s) continuous, or openable windows
Baths, Toilets	50 cfm (25 L/s) intermittent of 20 cfm (10 L/s) continuous, or openable windows for each bath and toilet

assumed to equal zero. In this case, C_{in} is inversely proportional to the air exchange rate. Thus, for example, if the base infiltration rate is doubled, then the average radon concentration will be reduced by half. For formaldehyde, previous research has shown that the concentration reduction is less than proportional to the increase in the ventilation rate. Based on an empirical relationship developed in previous research (Nagda et al. 1985), the ventilation rate raised to the power of 0.38 is used in calculating the percent difference.

ILLUSTRATIVE APPLICATION

Figure 8 shows the results of program execution for Washington, DC, using defaults that were displayed in previous figures. The required air changes per hour are 0.35 ach because the user did not override this default value and the calculated ach based on the number of occupants did not exceed 0.35 ach. The size of the energy recovery ventilator to satisfy the required air exchange rate is 62 cfm. This is the size of a balanced system with supply and exhaust fans of equal capacities.

Air infiltration rates due to temperature and wind forces for winter and summer seasons are 0.22 ach and 0.09 ach, respectively. When an energy recovery ventilator is added, the air exchange rates for winter and summer seasons resulting from the combined effect of air infiltration, existing exhaust fans, and the ventilator are 0.49 ach and 0.35 ach, respectively. The ventilator is sized by calculating the supplemental ventilation needed to increase the lower of the two existing seasonal values to the required air changes per hour. In most cases, the summer value will be lower than the winter value. The net air exchange rate supplied by the ventilator during either season is 0.26 ach.

The supplemental ventilation did not change the indoor CO concentration because there was no indoor source (an electric range was specified). The added ventilation increased NO_2 because outdoor NO_2 is partially removed by the building envelope, but the supplemental ventilation provided by the ventilator bypasses this building-removal process. Both formaldehyde and radon decreased because their sources are exclusively indoors.

The estimated incremental energy values in winter and summer, due to energy not recovered in providing supplemental ventilation, are 1,741 kBtu and 624 kBtu, respectively. The annual incremental energy of 2,365 kBtu/year is the summation of these two values. The annual cost of added ventilation is $55/year, which is 4.6% of the baseline annual energy cost of the house. This number does not include the initial costs for purchase and installation of the energy recovery ventilator.

Figure 9 shows the result of increasing the required air exchange rate from 0.35 to 0.50 ach. Default values were retained for all other input parameters. A comparison of the results with those in Figure 8 indicates that the size of the ventilator

05/07/90 17:37:14

<Results> City: Washington, DC

Required Air Changes per Hour (ACH)		.35 ACH	
Calculated Size of Energy Recovery Ventilator		62 CFM	
HVAC System: Heat Pump			

		Winter	Summer
Air Infiltration Rate	(ACH)	.224	.090
Air Change Rate with Exhaust Fans Added	(ACH)	.227	.093
Air Change Rate with Fans and Ventilator	(ACH)	.486	.354
Net ACH Supplied by Ventilator	(ACH)	.259	.261
Incremental Energy for Added Ventilation	(kBtu)	1741.0	624.3
Change in Carbon Monoxide	(%)	.0	.0
Change in Nitrogen Dioxide	(%)	70.9	195.0
Change in Formaldehyde	(%)	-25.1	-39.9
Change in Radon	(%)	-53.3	-73.8

User-estimated Annual Energy Cost	1200.00 $/year
Annual Incremental Energy for Added Ventilation	2365.3 kBtu/year
Annual Cost of Added Ventilation	55.00 $/year
Annual Cost Increase for Added Ventilation	4.6 Percent

Press Any Key to Return to Menu

Figure 8 Program output with defaults for all inputs

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<Results> City: Washington, DC

Required Air Changes per Hour (ACH)		.50 ACH	
Calculated Size of Energy Recovery Ventilator		97 CFM	
HVAC System: Heat Pump			

		Winter	Summer
Air Infiltration Rate	(ACH)	.224	.090
Air Change Rate with Exhaust Fans Added	(ACH)	.227	.093
Air Change Rate with Fans and Ventilator	(ACH)	.632	.500
Net ACH Supplied by Ventilator	(ACH)	.405	.407
Incremental Energy for Added Ventilation	(kBtu)	2722.3	974.7
Change in Carbon Monoxide	(%)	.0	.0
Change in Nitrogen Dioxide	(%)	99.6	270.2
Change in Formaldehyde	(%)	-32.2	-47.3
Change in Radon	(%)	-64.1	-81.4

User-estimated Annual Energy Cost	1200.00 $/year
Annual Incremental Energy for Added Ventilation	3697.0 kBtu/year
Annual Cost of Added Ventilation	87.00 $/year
Annual Cost Increase for Added Ventilation	7.2 Percent

Press Any Key to Return to Menu

Figure 9 Program output with required air exchange rate changed from 0.35 to 0.50 ach increased from 62 to 97 cfm. Air exchange rates due to the combined effect of infiltration, vented exhaust fans, and the ventilator increased from 0.49 to 0.63 ach for winter and from 0.35 to 0.50 ach for summer. Annual incremental energy for added ventilation increased from 2,365 kBtu/year to 3,697 kBtu/year. The annual incremental energy cost increased from $55 to $87. Indoor NO_2 concentrations further increased and formaldehyde and radon concentrations further decreased with the higher supplemental ventilation.

ACKNOWLEDGMENT

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