Energy Impact of Ventilation Air Distribution

Final Report

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NOTE

Funding for this project was provided by the Government of Canada under the Green Plan.

Abstract

The energy impact of various air distribution strategies for residential ventilation systems meeting CAN/CSA-F326-M91, *Residential Mechanical Systems*, were investigated using the HOT2000 computer program. Fifteen ventilation systems were evaluated through cost benefit analysis using two house types, five locations and three fuels. Low cost distribution strategies with low energy use were identified and recommended for field testing to evaluate their effectiveness at distributing ventilation air.

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Executive Summary

Continuous distribution of ventilation air as called for in the 1995 National Building Code and CAN/CSA-F326-M91, *Residential Mechanical Systems*, has a significant energy cost in many houses. These costs are not addressed by energy codes or the R-2000 program. This project investigated the cost of distributing ventilation air and the benefits of more energy efficient ventilation strategies.

Potential ventilation system configurations were identified and modelled using the HOT2000 computer program. Cost benefit analyses were done for various ventilation system strategies for two house types, five locations and three fuels.

The study found that differences in energy use were primarily a function of ventilation strategy; location and house type were not strong influences. In houses with forced air heating systems, the most significant cost savings (combined energy and system costs) can be realized by adopting ventilation strategies that do not require continuous operation of the furnace blower. If continuous furnace blower operation is necessary, replacement of PSC furnace blower motors with ECMs may have an attractive simple payback.

For houses without forced air heating, partially ducted HRVs with small, quiet axial (muffin) fans to circulate ventilation air between rooms were compared to fully ducted HRV systems. The muffin fan option would appear to be economical in some applications. Reliable fans (as proven in personal computer applications) are available at reasonable cost.

The report recommends research be undertaken to evaluate the effectiveness of distributing ventilation air via forced air heating system ductwork, without operating the furnace blower. It also recommends that two speed furnace fan operation be incorporated into HOT2000, and that power consumption relevant to discrete fan motor sizes be used in HOT2000, rather than estimating fan power at 20 watts/kW of furnace output.

Résumé

La distribution continuelle d'air de ventilation, préconisée dans le Code national du bâtiment du Canada 1995 et la norme CAN/CSA F326-M91 intitulée *Ventilation mécanique des habitations*, entraîne des coûts énergétiques substantiels pour les propriétaires de nombreuses maisons. Les codes énergétiques et le programme R-2000 n'abordent pas la question de ces coûts. Dans le présent projet, on a étudié le coût de la distribution de l'air de ventilation et les avantages que présentent les modes de ventilation plus éconergétiques.

On a déterminé les configurations possibles des systèmes de ventilation et réalisé leurs modèles au moyen du logiciel HOT2000. On a fait les analyses coûts-avantages de différents modes de systèmes de ventilation concernant deux genres de maisons situées à cinq endroits différents et utilisant trois combustibles différents.

L'étude a démontré que les différences constatées dans la consommation énergétique étaient avant tout causées par le mode de ventilation adoptée, et que le genre de maison, ainsi que l'endroit où elle se trouvait, n'influaient que très peu sur cette consommation. C'est dans les maisons munies d'un système de chauffage à air pulsé qu'on réalise les économies les plus importantes - sur le coût combiné de l'installation et de l'énergie consommée -, pourvu qu'on adopte des modes de ventilation n'exigeant pas le fonctionnement continuel du ventilateur de la chaudière. S'il est nécessaire de faire fonctionner ce dernier en permanence, remplacer les moteurs à condensateur permanent des ventilateurs de chaudière par des moteurs à commutation électronique peut s'avérer très rentable.

Dans le cas des maisons qui ne sont pas chauffées par un système à air pulsé, on a comparé les systèmes à ventilateurs-échangeurs de chaleur entièrement enveloppés à ceux qui utilisent des ventilateurs-échangeurs de chaleur partiellement enveloppés et munis de petits ventilateurs axiaux silencieux - des « moufflets » - qui font circuler l'air de ventilation d'une pièce à l'autre. Le système utilisant les ventilateurs du type moufflet semble être économique dans certains cas et, comme le prouve leur utilisation dans les ordinateurs personnels, il existe des ventilateurs fiables à prix raisonnables.

Les recommandations du rapport indiquent qu'il faudrait entreprendre des recherches en vue d'évaluer l'efficacité de la distribution de l'air de ventilation assurée par un réseau de gaines faisant partie du système de chauffage à air pulsé sans faire fonctionner le ventilateur de la chaudière. Il est également suggéré que l'on incorpore le fonctionnement de ventilateurs à deux vitesses dans le logiciel HOT2000 qui fera appel à des valeurs de consommation d'énergie correspondant aux différentes grosseurs de moteurs de ventilateurs plutôt que d'estimer la puissance des ventilateurs à 20 watts/kW de puissance de la chaudière.

1.0 OBJECTIVE

The 1995 National Building Code and the Canadian Standards Association F326 standard require that provisions be made to continuously distribute ventilation air throughout houses. For houses with forced air heating, the method of ventilation air distribution with the least first cost is to operate the forced air heating system circulation fan. The energy cost of continuously operating ventilation fans can be very significant but this energy cost has not been addressed by energy codes or the R-2000 program.

It is proposed that the energy required for ventilation air distribution be appropriately addressed in energy codes and by the R-2000 Program. The main purpose of the work reported herein was to evaluate the energy performance and cost of alternative ventilation strategies. Those responsible for setting R-2000 and energy code technical requirements can use this information to evaluate approaches which encourage more efficient ventilation strategies. A secondary purpose of this work was to identify energy efficient ventilation strategies for field testing. Field testing is needed to demonstrate whether or not the ventilation effectiveness of these low energy systems is equivalent to that of the prescriptive systems in the 1995 NBC.

2.0 METHOD

2.1 Identify Potential Ventilation System Configurations

A literature search was conducted by CANMET personnel of CMHC, EMR, AIVC and ASHRAE research. Based on this literature search and through discussions with persons knowledgeable in ventilation in Canadian homes, potential ventilation system configurations were identified for evaluation. Physical and energy model descriptions were prepared for each ventilation system.

Ventilation systems which are physically different may have the same energy performance, while systems which are physically the same may have very different energy performance. For example, a house with a fully ducted HRV will have the same energy performance as a house with the same HRV delivering ventilation air to a single central point. Conversely, the energy used to distribute ventilation air in a house with the HRV connected to forced air heating system ductwork will depend on whether the furnace fan is operated continuously or only on demand for heating.

The ventilation systems analyzed are described below in Section 3.3, Ventilation Systems Modeled.

2.2 Model Ventilation System Configurations Using HOT2000 7.0

Appropriate methods to model ventilation system fan operation within HOT2000 7.0 were developed for each ventilation system configuration. Fan powers and schedules for each configuration were selected from field measurements and product literature. Continuous ventilation at the minimum airflow rates required to meet R-2000 were modeled.

A matrix of HOT2000 Version 7 files was developed to facilitate the analysis of each ventilation system configuration identified in Task 1. Two houses were modeled in each of five locations for each ventilation system configuration identified as being appropriate for this project. The houses were a two storey and a bungalow. Insulation values and windows were varied for each location so that houses typically fell within 5% of the R-2000 energy target for each location.

Mid-efficiency gas and electric heat were modeled for locations in Ontario and west, mid-efficiency oil and electric for eastern locations. The heating systems modeled were 40,000 Btuh output systems in all cases, with 1/4 hp fan motors. Whereas furnace blower motors are often larger than this, modelling 1/4 hp fan motors resulted in conservative estimates of energy cost of the various ventilation distribution strategies. Two speed furnace fan operation was simulated by adding the continuous portion of fan power to the HOT2000 base loads, and inputting the incremental "high speed" fan power for demand for heating as automatic mode furnace fan power. Airconditioning was not simulated.

2.3 Analyze Data

Reductions in fan power consumption result in increased space heating loads, because less fan energy is available to offset heating loads during the heating season. The various HOT2000 simulations were compared to estimate the impact on fan energy and space heating energy consumption of each ventilation system strategy.

Relevant data was extracted from the HOT2000 output data files generated in Task 2 and imported into a spreadsheet. Some of the techniques used to simulate ventilation system fan operation in HOT2000 embed part of the fan energy in the electric base load. Thus, some data manipulation was required before the data could be properly analyzed.

Data from the various runs were sorted and graphed to assist in the analysis of the impact of ventilation system configuration on overall house energy consumption.

Incremental capital cost was estimated for each ventilation system configuration being evaluated, for each location. Current values of fuel and electric energy were used to determine the incremental costs for energy for each of the ventilation system configurations being analyzed.

For comparative studies, it is important to only modify one variable at each level of comparison. For primary comparisons in this study, house, location and space heating energy were fixed and ventilation systems changed. In secondary comparisons, house type, location, and space heating energy type were changed. At each level of comparison, total fan energy (HRV and other ventilation system fans plus furnace fan energy) and space heating energy for each ventilation system were examined.

Incremental energy usage was determined by subtracting the smallest energy consumption in a comparison group (as predicted by HOT2000) from the energy consumption for each other ventilation system in that group. As a result, incremental fan energy usage for the house using the least amount of fan energy in a group (i.e., a house with only an HRV fan) would be 0; all other ventilation system strategies in that group would have higher fan energy usage. The incremental space heating energy for the house using the least amount of space heating energy in a group (i.e., the house using the most fan energy had the smallest space heating load) would be 0; all other ventilation strategies in that group would have higher space heating energy usage.

Incremental energy usage was compared within these groups, and then against other locations, house types and energy sources, in order to identify the impact of each variable.

Incremental ventilation system costs and incremental benefits were analyzed to identify ventilation system configurations worthy of field study. To be considered worthwhile for field study, a configuration must have a favourable cost/benefit ratio compared to competing configurations offering equal or better performance with respect to ventilation effectiveness.

3.0 VARIABLES MODELED

3.1 Houses Modeled

Two houses were modeled. These were a 100 m^2, three bedroom bungalow with a finished basement and a three bedroom, two storey house with 175 m^2 living area and 90 m^2 unfinished basement. Where appropriate, data points on graphs are labelled by house style "1" and "2" for the bungalow and two storey respectively.

Building envelopes were modified for each location so that the houses modeled were near the R-2000 energy target. In some cases, envelopes for electrically heated houses were slightly modified compared to those for oil or gas heated houses to bring them closer to the target. In any case, only the ventilation system was changed between houses of a style and fuel type at a given location.

Specifications for electrically heated houses in the proposed National Energy Code for Housing (NECH) are approaching the performance requirements of the R-2000 program. Where inexpensive natural gas is available, R-2000 requirements are far more stringent than the NECH; however, use of low cost space heating energy improves the cost benefit of reducing electric consumption.

All houses were equipped with an HRV rated at 82% at 0°C, 75% at -25°C drawing 2 w/l/s of balanced airflow. Continuous ventilation rates and HRV power consumption simulated were 55 l/s and 110 watts for the bungalow, 70 l/s and 140 watts for the two storey, the R-2000 design ventilation rate.

Furnaces were mid-efficiency, 40,000 Btuh output with blower power draws of 250 watts on low, 350 watts on demand for heating for standard (PSC) blower motors (these values are typical for 1/4 hp PSC furnace blower motors); 75 watts on low, 300 watts on demand for heating for energy efficient (ECM) blower motors.

Default gas and electric DHW systems were modeled for gas and electrically heated houses. A tankless coil was modeled in oil heated houses.

3.2 Cities Modeled

The five cities modeled were Vancouver, Winnipeg, Toronto, Montreal and Halifax. The weather in most populated locations in Canada can be closely represented by the weather for one of these cities. The five selected locations cover the climatic range from 3000 to 6000 annual heating degree days. Where appropriate, data points on graphs are labelled with the initial of the city name.

3.3 Ventilation Systems Modeled

From an energy usage perspective, seven variations of ventilation systems were modeled using HOT2000 and compared in the data analysis. All seven systems included a continuously operating HRV. Data points for each ventilation system are labelled on graphs with a two letter code as appropriate. These codes are:

ae - forced air furnace; automatic furnace blower operation (i.e., fan only runs on demand for heat); blower has an energy efficient motor which draws 300 watts on demand for heat.

ap - forced air furnace; automatic furnace blower operation (i.e., fan only runs on demand for heat); blower has a standard efficiency motor which draws 350 watts on demand for heat.

bb - baseboard or radiant heat; other than the HRV, there are no fans distributing air throughout the house.

ce - forced air furnace; continuous, two speed furnace blower operation (i.e., high speed on demand for heat, otherwise low speed); blower has an energy efficient motor which draws 300 watts on high, 75 watts on low.

cp - forced air furnace, continuous furnace blower operation (i.e., high speed on demand for heat, otherwise low speed); blower has a standard efficiency motor which draws 350 watts on high, 250 watts on low.

mf - baseboard or radiant heat; HRV supplies ventilation air to a central location; small, quiet axial flow (muffin) fans circulate air between spaces not directly supplied or exhausted by the HRV to ensure compliance with the airflow requirements of CSA F326. Based on an evaluation of the house plans, the bungalow would require transfer fans from each bedroom (total 40 l/s, 35 watts fan power), the two storey would require transfer fans from two bedrooms and one other space (total 30 l/s, 30 watts fan power).

sm - similar to the mf option except that muffin fans operate only when the door to the room served by the fan is closed (i.e., controlled by a switch in the door jamb). For modelling purposes, it was assumed that doors would be closed (and so fans would operate) half the time.

Based on field test results for recent furnace installations across Canada, it was concluded that HOT2000 underestimates furnace fan energy consumption, particularly for small furnace sizes. For the current study, the estimates for furnace blower energy consumption were based on typical field test results for newer furnaces with a 1/4 hp blower motor, and a method to simulate two speed furnace fan operation was employed. Modelling 1/4 hp fan motors rather than the 1/3 or 1/2 hp motors found in most furnaces resulted in conservative energy cost estimates for ventilation distribution strategies.

3.4 Systems Considered But Not Fully Evaluated

Systems which utilize the HRV air supply to deliver space heat were studied. A limiting factor for this system type is the 70°C (160°F) maximum temperature for supply air being delivered into a space. The maximum allowable design heat loss (excluding ventilation air heating) for houses with this system type is determined by the ventilation airflow rate. Whereas this ventilation strategy may work for a house meeting the R-2000 energy target in Vancouver, houses in colder cities would have to be considerably more energy efficient than R-2000. Supplementary fans could be used to increase duct airflows and thus reduce delivery temperature. This system would be a small forced air furnace. Design of low flow forced air space heating systems would be complicated because space heating loads for different zones in the house are not likely to always be proportional to ventilation air requirements.

Systems with an HRV which delivers ventilation air to a central location plus a small, ducted fan system which recirculates house air to meet the requirements of CSA F326 were not evaluated. Because such a system would have ductwork to most rooms in a house, system costs and ductwork requirements would be similar to a fully ducted HRV system, while operation of the circulation fan would result in higher energy usage. The muffin fan strategy is a variation of this concept which minimizes ductwork by using multiple recirculation fans.

Systems using passive vents were not considered because both theory and field experience indicate they do not function satisfactorily, especially in cold climates.

Ventilation systems which do not incorporate heat recovery were not evaluated because ventilation systems without heat recovery will not practically meet R-2000 program requirements.

A system in which HRV exhaust air is continuously expelled through the draft induction fans on combustion appliances was considered. Air leakage performance of the house would be like that of a house with sealed combustion appliances. Feeding combustion appliance exhaust through an air-to-air heat exchanger would allow preheating the makeup air with waste heat in the flue gases when combustion appliances are operating, and with room temperature air when the furnace is not operating. The cost of such a system is not known, but its energy impact would be to significantly increase the effective thermal efficiency of fuel fired furnaces and DHW tanks while reducing the total air requirements for the house.

4.0 RESULTS AND OBSERVATIONS

In all, 140 house/ventilation system/city/fuel combinations were modeled. Using two houses in five locations is a sparse representation but experience tells us that the variation of architectural styles of houses across the country does not differentially impact the energy impacts of measures among the house types constructed at any one location. The selection of both a typical one storey and a typical two storey house covered a major portion of the detached R-2000 styles which are built in Canada. The five selected locations cover the climatic range from 3000 to 6000 annual heating degree days.

4.1 Description of Graphs

Data generated in the study is presented graphically in Figures 1 to 12. To help understand the graphs, refer to Figure 1, the graph for bungalows with electric space heat.

For each location/ventilation system strategy, incremental space heating energy and incremental fan energy are plotted, one above the other. The letters above the middle set of bars denotes the city order. The two letters under a group of bars represents the ventilation system strategy code. These codes are "ae" and "ap" for forced air systems with automatic fan operation and ECM and PSC motors respectively; "bb" for baseboard heated houses without any fans other than the HRV; "ce" and "cp" for forced air systems with continuous fan operation and ECM and PSC fan motors respectively; and "mf" for baseboard heated houses using small transfer fans (muffin fans) to circulate air between zones not directly served by the HRV and "sm" for muffin fans controlled by door switches.

Incremental space heating energy is measured relative to the system strategy in the same location with the lowest space heating energy. The system with the lowest space heating energy in each location is system "cp", a forced air system with a continuously operating fan with a PSC motor. For example, the energy provided for space heating by a baseboard heating system ("bb") in Winnipeg is just over 1400 kWh per year more than a "cp" bungalow in Winnipeg, while a "bb" house in Vancouver would require about 1200 kWh/yr more space heating energy than a "cp" bungalow in Vancouver.

Similarly, incremental fan energy is measured relative to "bb" systems, the strategy with the lowest fan energy consumption.

Figure 2 plots the same data for electrically heated two storey houses. Comparable data for gas heated houses are presented in Figures 3 and 4; Figures 5 and 6 present data for oil heated houses. In Figures 3 through 6, space heating energy is purchased energy (i.e., it is the heating value of the fuel delivered to the house, not the heat delivered by the furnace to the house).

In all six graphs, similar patterns emerge. The differences in incremental energy consumptions appear to be primarily a function of the ventilation system strategy selected. The influence of location on incremental energy consumption appears to be small.

In Figures 7, 8 and 9, average values of the data for the bungalows are compared to average values of the data for two storey houses. These graphs indicate that the differences due to house type are very small, at least for the houses modeled. Comparing these three graphs provides an indication of the influence of fuel type on incremental energies. HOT2000 predicts that oil and gas space heating requirements are higher than electric space heating requirements. This is primarily due to the combustion efficiency of the gas and oil furnaces modeled.

Figures 10, 11 and 12 plot the differences in total fan plus space heating energy for electrically heated houses. Theoretically "ae", "ap" and "bb" houses should have the same total energy requirements because the furnace fans only operate on demand for heating and this fan energy will simply displace energy that would otherwise be provided by the space heating elements. The differences in these data occur because different algorithms and look-up tables are used in HOT2000 for the different heating system types, and the fan energy also affects some of these algorithms.

Similar plots were not constructed for gas and oil heated houses because adding fuel energy directly to electrical energy is not particularly meaningful because of the difference in value between heating fuels and electricity.

4.2 Energy Consumption Differences

As one would expect, HOT2000 predicted that increasing fan energy during the heating season decreases the amount of energy needed to provide space heating. Because power consumption is highly dependant on the ventilation system strategy selected, and largely independent of location, house type and space heating energy source, general observations can be drawn from the graphs with combined data sets. Because different energy sources have different costs, cost benefit analyses need to differentiate between energy types.

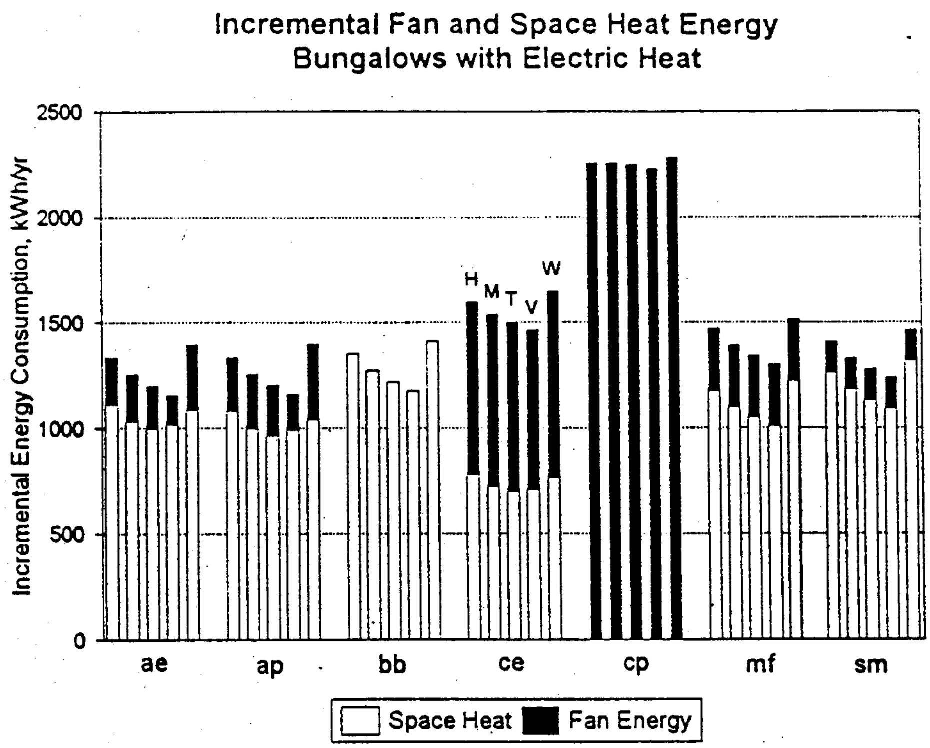

FIGURE 1

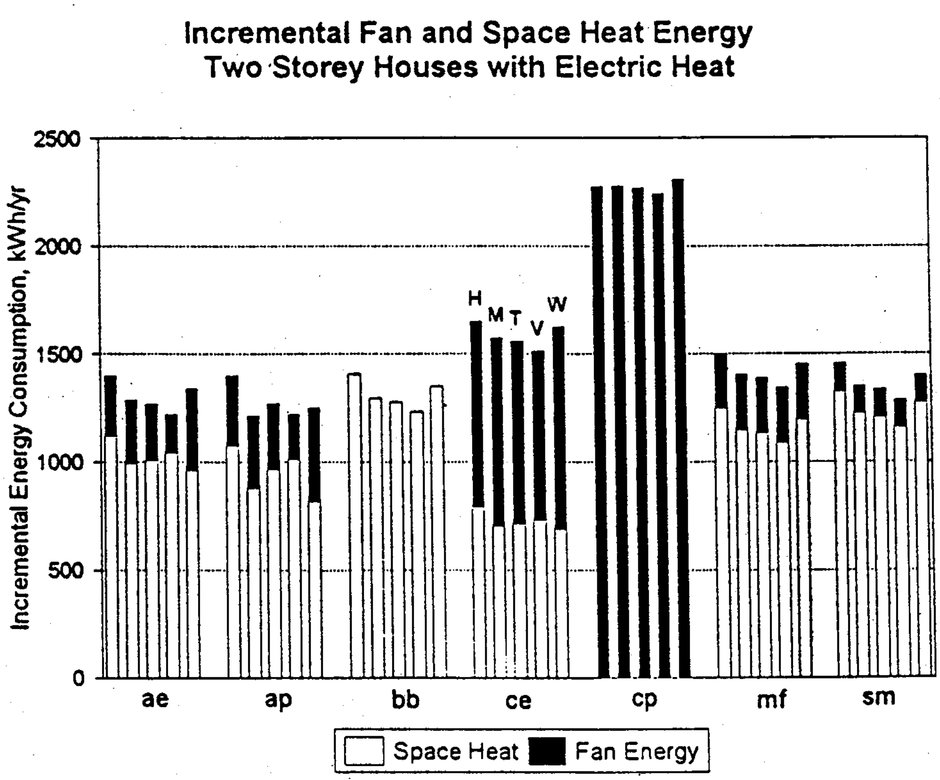

FIGURE 2

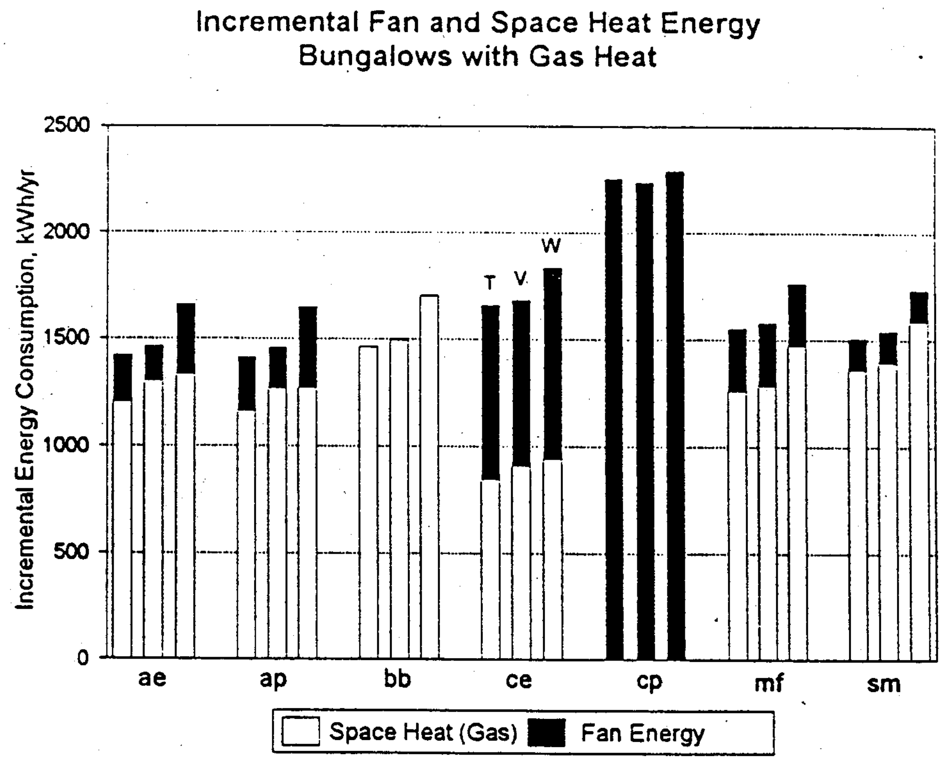

FIGURE 3

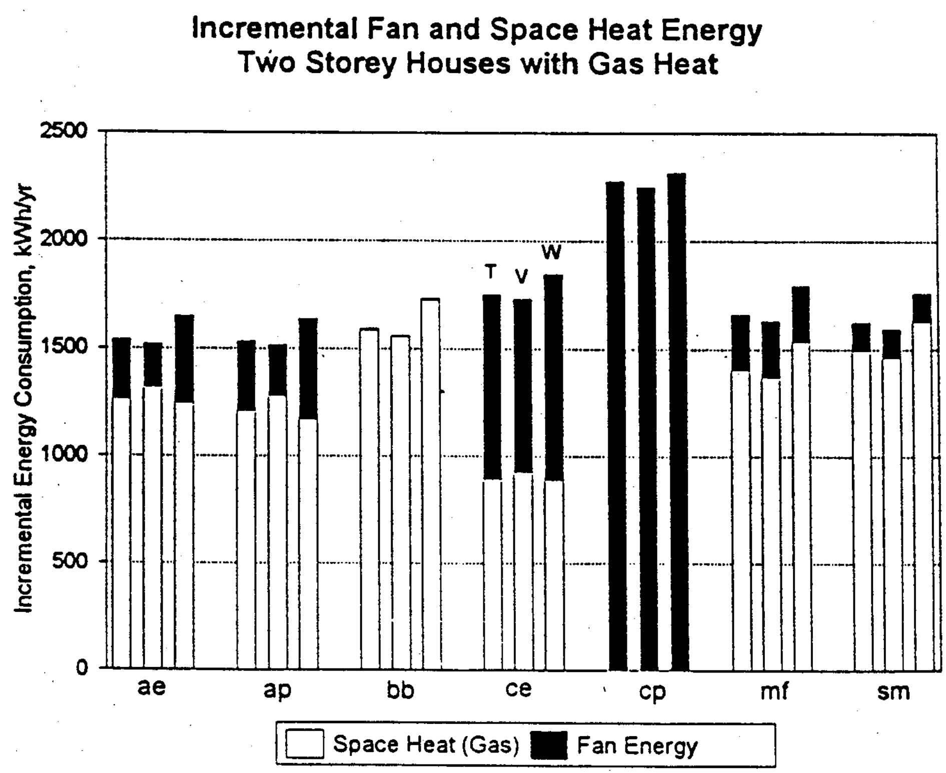

FIGURE 4

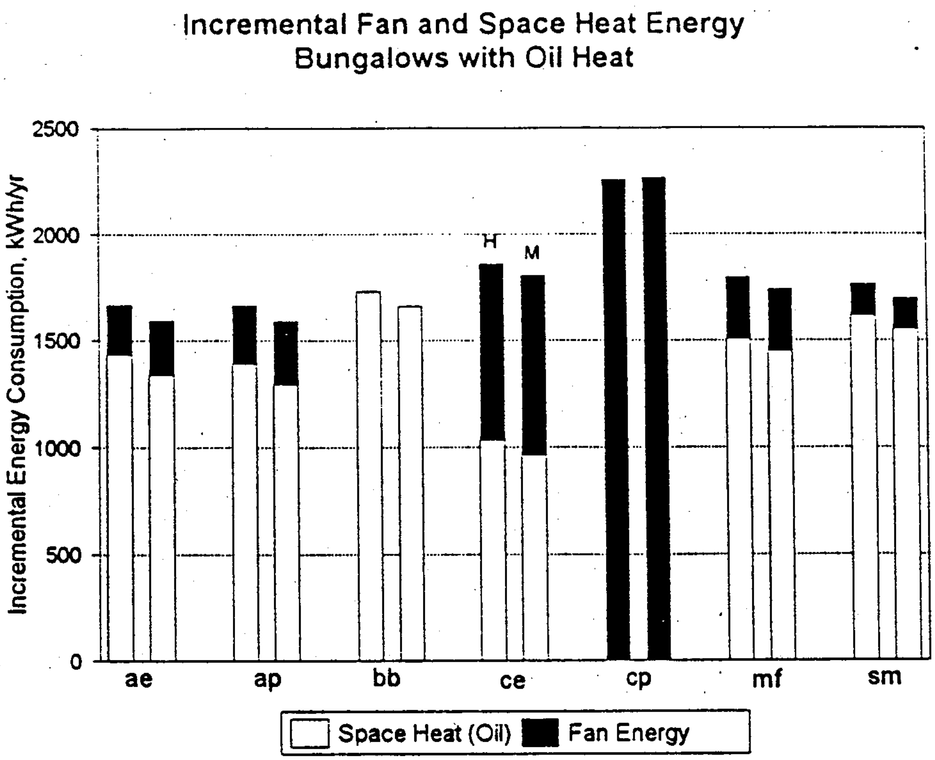

FIGURE 5

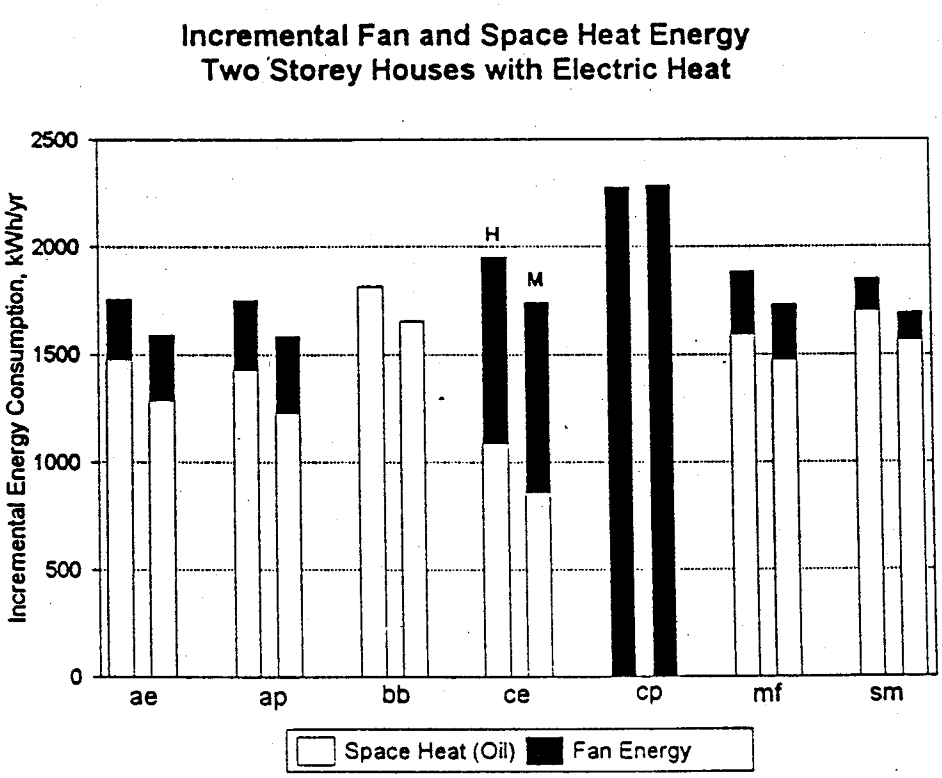

FIGURE 6

Avg. Incremental Energy for 5 Cities by System & House Type, Electric Heat

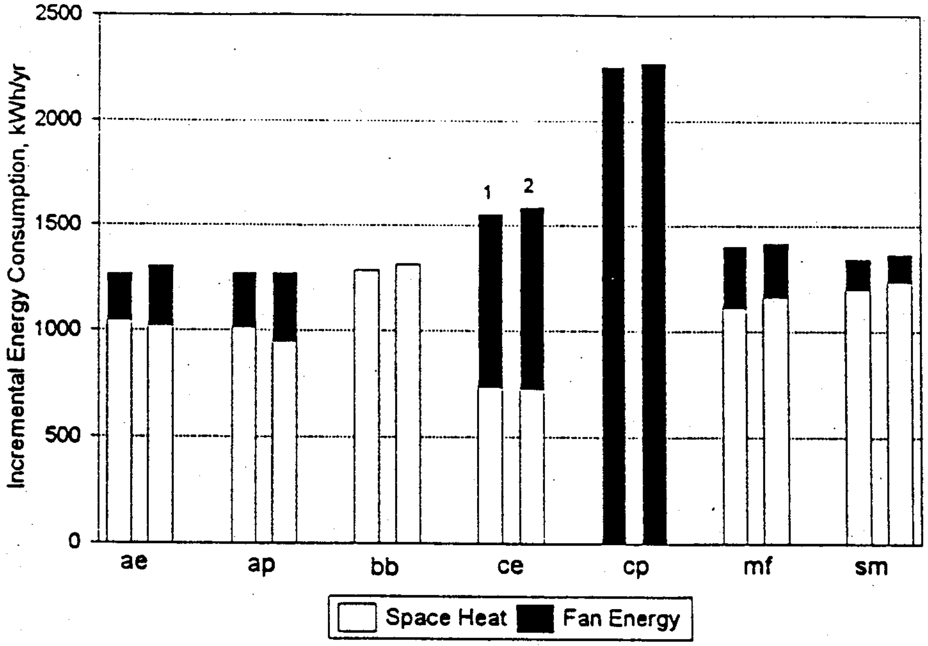

FIGURE 7

Avg. Incremental Energy for 5 Cities by System & House Type, Gas Heat

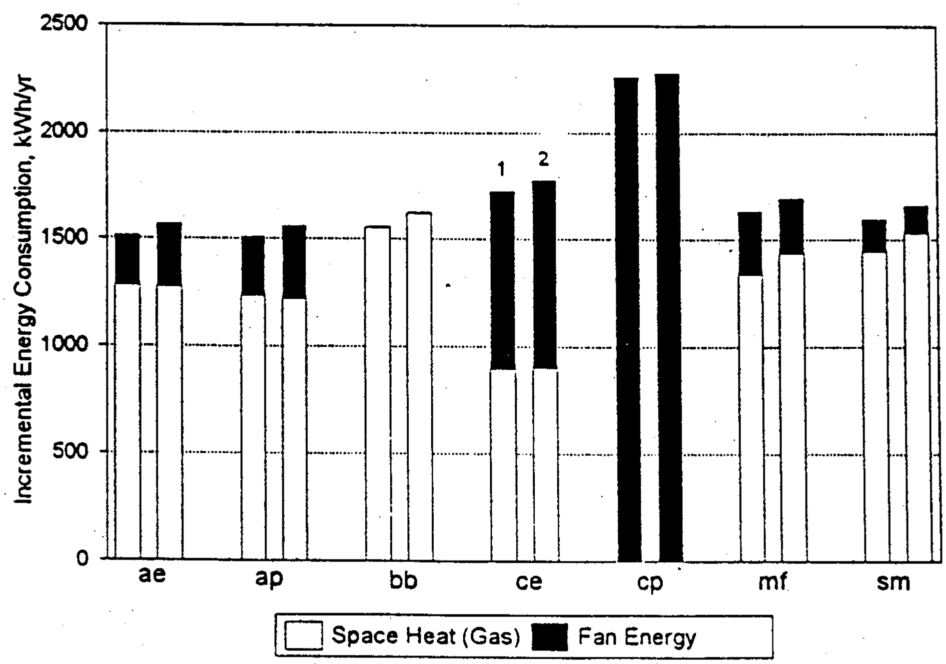

FIGURE 8

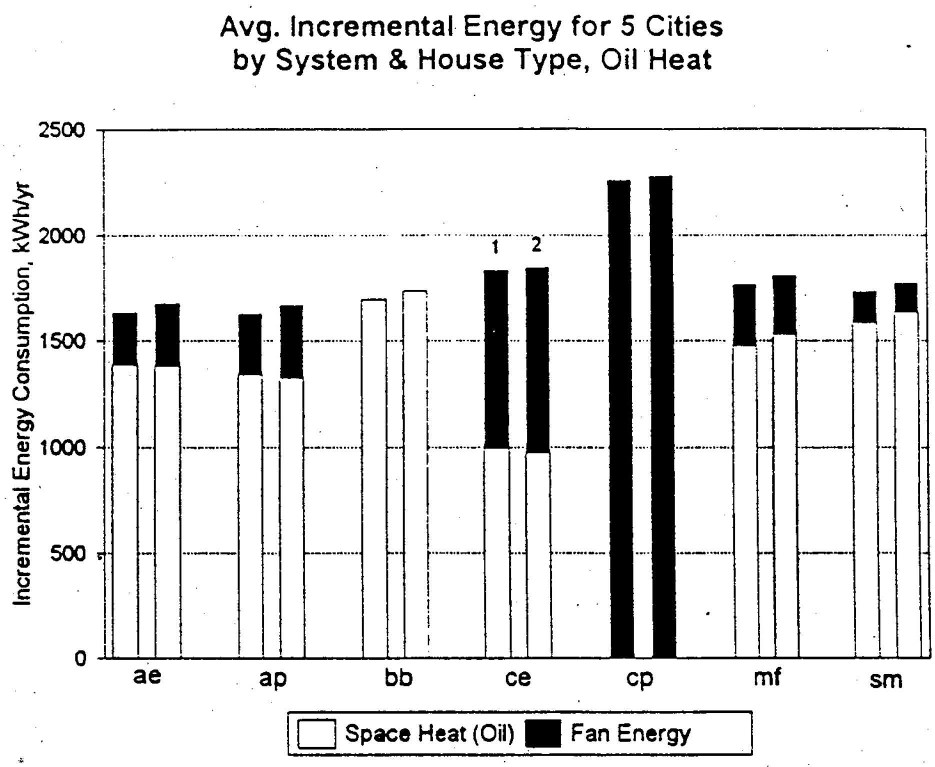

FIGURE 9

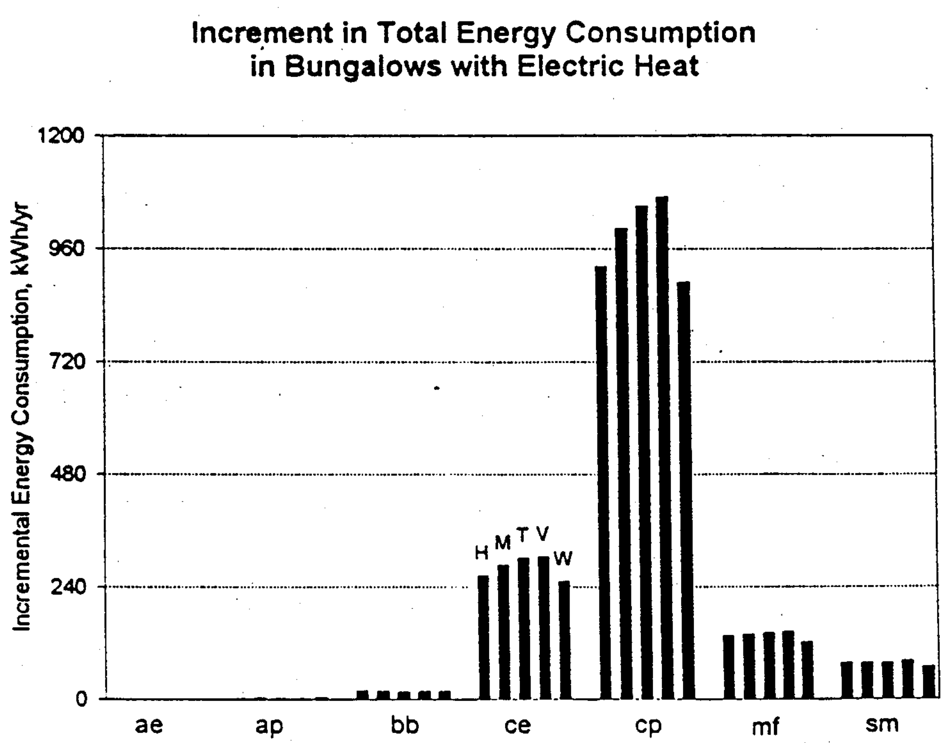

FIGURE 10

Increment in Total Energy Consumption in 2 Storey Houses with Electric Heat

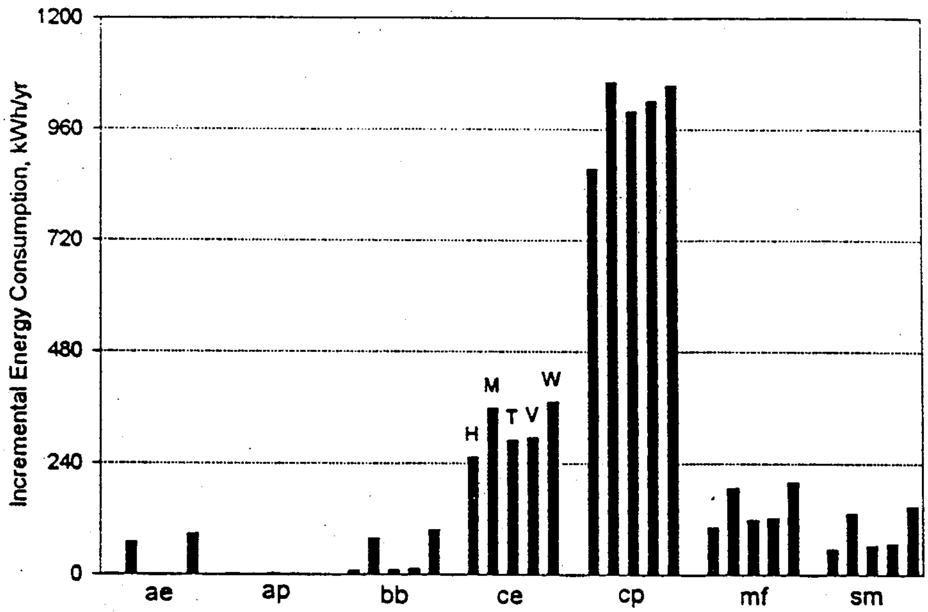

FIGURE 11

Five City Average Energy Increment by System & House Type, Electric Heat

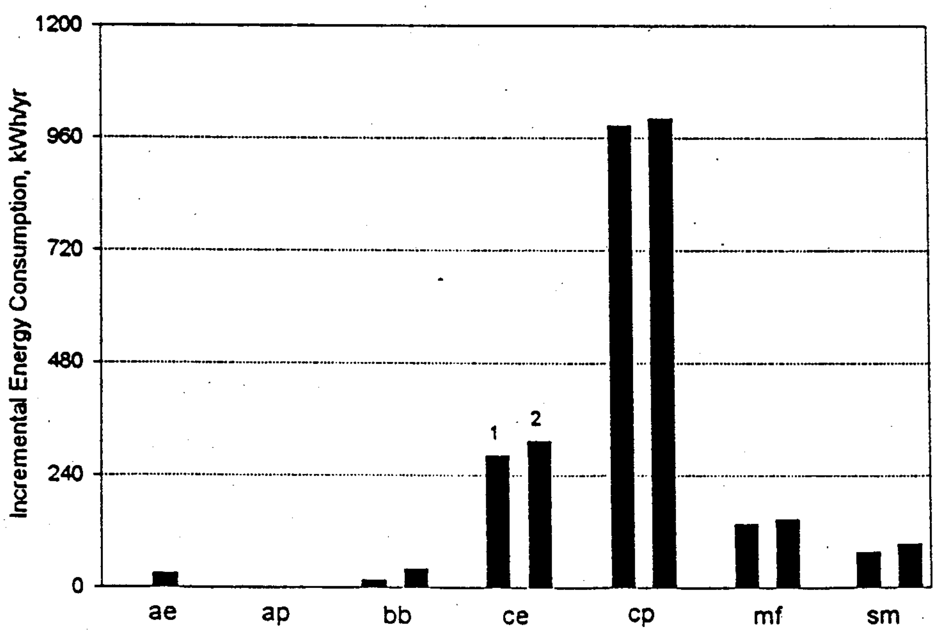

FIGURE 12

Electric Space Heating

"Ae", "ap" and "bb" systems in Figure 12 all have near zero incremental power, indicating that HOT2000 predicts that the energy consumed by a furnace blower on a call for heating in all electric houses simply displaces heating energy that would have to be otherwise supplied to the house. HOT2000 predicts that the incremental energy cost of running a 1/4 hp PSC furnace fan continuously in an all electric R-2000 house is about 1000 kWh/yr of electricity. Replacing the PSC fan motor with an ECM would reduce the incremental energy cost to about 300 kWh/yr. The muffin fan alternative would have an incremental energy cost of about 130 kWh/yr, 75 kWh/yr if the fans are controlled by door switches.

Gas Space Heating

Table 1 compares the energy performance and energy cost of the various ventilation systems modeled with gas space heating against the "bb" system, the system with the least electrical consumption. These five systems each have higher electrical consumption and lower fuel consumption than "bb" systems. The systems evaluated in the table can be compared with each other as well. For example, compared to gas heated houses with system "cp" ("cp", continuously operating PSC furnace blower motor, is the status quo for R-2000 houses with forced air systems), houses with system "ce" are predicted to save 1421 kWh/yr (i.e., 2269-848 kWh/yr) electricity and use 901 kWh/yr (i.e., 1589-688 kWh/yr) more gas.

From the data, it can be seen that compared to "cp" type systems, significant energy cost savings can be realized by using fans which draw less power or adopting strategies in which fans operate less. (If 1/3 hp or 1/2 hp blower motors were modeled, bigger savings would have been predicted.) For houses with forced air heating systems, any ventilation system which allows the furnace blower to run in the automatic mode will be the preferred option. If continuous air circulation is necessary in order to achieve proper distribution of ventilation air, the annual increases in energy cost predictions indicate that system types "ce" (ECM furnace blower), "mf" (muffin fan) and "sm" (switched muffin fan) should be evaluated.

Table 1 - Gas Heat

	increase in electricity (kWh/yr)*	decrease in gas (kWh/yr)*	annual increase in energy cost**
ae	263	311	$ 13.58
ap	306	362	15.79
ce	848	688	51.33
cp	2269	1589	143.38
mf	275	201	17.18
sm	138	101	8.62

* increases and decreases measured relative to "bb" system
** relative to "bb" system, using electricity at $0.08/kWh and gas at $0.024/kWh

Oil Space Heating

Table 2 presents the same data for oil heated houses as was presented in Table 1 for gas heated houses. The increases in electrical consumption, decreases in oil consumption energy and increases in cost are similar to those predicted for gas heated houses, and the observations made are similar.

Table 2 - Oil Heat

	increase* in electric	decrease* in oil	annual increase in energy cost**
ae	268	331	$ 10.25
ap	312	379	12.25
ce	852	728	48.80
cp	2270	1715	141.25
mf	283	210	17.80
sm	141	105	8.85

* increases and decreases measured relative to "bb" system
** relative to "bb" system, using electricity at $0.10/kWh and oil at $0.05/kWh

5.0 COST - BENEFITS ANALYSIS

CSA F326 allows ventilation air to be supplied directly or indirectly to spaces in houses. Indirect ventilation is when ventilation for a space is provided by drawing or pushing air through the space from another space. Utilization of this concept permits a reduction in the amount of supply air ductwork. This approach was assumed for some of the ventilation systems costed in this study.

5.1 Description of Systems Integrated with Forced Air Heating

Various configurations of integrated force air heating/ventilation systems were considered and costed. These were:

Minimum HRV ductwork, through the wall exhausts in wet rooms - HRV supply and exhaust ducts are hard connected to the forced air heating system ductwork. Washrooms and kitchen are served by intermittent, through the wall exhaust fans. If the furnace fan operates continuously, this system would be represented by energy model "ce" or "cp", depending on the type of furnace fan motor. The furnace fan could operate on automatic if a backdraft damper were located in the furnace ductwork between the points where the HRV supply and exhaust are connected. Systems with automatic furnace fan operation would be represented by energy model "ae" or "ap", depending on the type of furnace fan motor. HOT2000 modelling did not account for bathroom and kitchen exhaust fan energy.

Typical integrated system - HRV supplies fresh air to the furnace ductwork and continuously exhausts from washrooms and kitchen. If the furnace fan operates continuously, this system would be represented by energy model "ce" or "cp", depending on the type of furnace fan motor. The furnace fan could operate on automatic if the HRV supply were connected to the furnace supply side ductwork. (It may be necessary to install a backdraft damper in the furnace ductwork to prevent supply air from backdrafting out furnace return air grilles.) Systems with automatic furnace fan operation would be represented by energy model "ae" or "ap", depending on the type of furnace fan motor.

5.2 Description of Independent Ventilation Systems

Several system configurations in which ventilation air was not distributed through the forced air heating system ductwork were considered and costed. These include:

Fully ducted ventilation system - HRV distributes ventilation air directly to most rooms in the house through a dedicated ductwork system, and continuously exhausts from washrooms and kitchen. Some rooms were indirectly ventilated in accordance with CSA F326, as described below.

In the two storey house, 20 l/s continuous exhaust was assigned to the ensuite bathroom. Because the ensuite bathroom was only connected to the master bedroom, it was assumed that the master bedroom was indirectly ventilated by withdrawal of exhaust from the ensuite.

In the bungalow, ventilation air was supplied indirectly to the rec room in the basement via the exhaust from the basement washroom.

In both houses, a single ventilation air supply, assisted by the kitchen exhaust, served the living, dining and kitchen areas.

The "bb" energy model represents fully ducted ventilation systems for houses without forced air heating systems. The "ae" and "ap" energy models predict the energy consumption for houses with forced air heating systems, in which ventilation air is distributed through dedicated ductwork.

Partially ducted ventilation system with muffin fans - HRV supplies fresh air to the living area of the house and continuously exhausts from washrooms and kitchen. Small, low power fans circulate air between rooms, through partition walls or floors, indirectly supplying ventilation air to areas not directly supplied or exhausted by the HRV. In the two storey house, ventilation air could be supplied to the unfinished basement and to the foyer at the front door. The master bedroom was assumed to be ventilated indirectly via the 20 l/s continuous exhaust from the ensuite bathroom. Muffin fans exhausting from the other two bedrooms and the laundry room indirectly ventilated these rooms.

In the bungalow, ventilation air was assumed to be supplied to a central location on the main floor and to the laundry room in the basement. Muffin fans in each bedroom exhaust air down into the basement, indirectly ventilating the bedrooms. Exhaust from the basement washroom and from the bedroom muffin fans indirectly ventilates the basement.

The "mf" energy model results represent this ventilation system option for houses without forced air heating systems. The "sm" system was a variation of this system in which the muffin fans only operated when doors to rooms served by the fan were closed. These configurations were not modeled for houses with forced air heating systems.

5.3 Ventilation System Capital Costs

Capital costs for the various ventilation systems being considered were estimated using a computer spreadsheet program. Basic ventilation system component costs and regional cost indices were input into the master spreadsheet. The type and number components in each ventilation system were specified and the spreadsheet calculated system costs.

Cost data do not include cost of the heating system, however, modifications made to the heating system, such as ECM furnace fan motors or a backdraft damper in furnace ductwork to control the direction of ventilation or exhaust airflow in the furnace ductwork, were included as ventilation system cost options.

Ventilation systems were costed for a base city. Montreal was chosen as the base city because its cost index was at the midpoint between the least expensive city (Winnipeg) and the most expensive (Toronto). The multipliers to estimate system cost for the other study locations relative to Montreal, derived from "Life Cycle Cost Analysis for Selection of Prescriptive Requirements for the Energy Code for Buildings and Houses" (IRC January 27, 1994), are: Winnipeg, 0.97; Halifax, 0.99; Vancouver, 1.02; Toronto, 1.03.

System cost estimates for Montreal and the applicable energy model codes are presented in Table 3. Sample costing spreadsheets, which include component cost data, are appended to this report.

5.4 Incremental Cost and Benefit

The cost of each ventilation system is compared to the cost of ventilation systems with the least first cost (i.e., systems vi and ix for the bungalow and system ii for the two storey).

For systems vi and ix, the furnace has a PSC blower motor, the HRV supplies ventilation air to the furnace ductwork and exhausts from the kitchen and bathrooms. Whether the furnace fan operates continuously (i.e., system vi) or on automatic (i.e., system ix) does not affect installed cost.

For system ii, the kitchen and bathrooms are exhausted by conventional exhaust fans, the HRV supplies fresh air to and withdraws exhaust air from furnace ductwork and the furnace has a PSC blower motor which operates continuously.

Table 3

	Ventilation System Option	System Retail Cost, Montreal		Energy Model
		Bungalow	Two Storey	
	HRV Supply and Exhaust to Furnace Ductwork, Individual Wet Room Exhausts			
i	Cont. ECM Furnace Fan	2587	2703	ce
ii	Cont. PSC Furnace Fan	2350	2466	cp
iii	Auto ECM Furnace Fan, bd damper	2794	2910	ae
iv	Auto PSC Furnace Fan, bd damper	2557	2673	ap
	HRV Supply to Furnace Ductwork, HRV Exhausts from Wet Rooms			
v	Cont. ECM Furnace Fan	2585	2871	ce
vi	Cont. PSC Furnace Fan	2347	2634	cp
vii	Auto ECM Furnace Fan	2585	2871	ae
viii	Auto ECM Furnace Fan, bd damper	2792	3078	ae
ix	Auto PSC Furnace Fan	2347	2634	ap
x	Auto PSC Furnace Fan, bd damper	2555	2842	ap
	Forced Air Heating, HRV Not Integrated			
xi	Fully ducted HRV, ECM Furnace Fan	3158	3484	ae
xii	Fully ducted HRV, PSC Furnace Fan	2921	3247	ap
	Non Forced Air Heating (e.g., Baseboard or Radiant)			
xiii	Fully ducted HRV	2921	3247	bb
xiv	Partially ducted HRV and muffin fans	2759	3157	mf
xv	Partial duct HRV, door switched muffin fans	2849	3247	sm

The ventilation system costs presented in Table 4 are system costs in excess of the cost of these least cost systems. The marginal energy costs, from Section 4.2 in this report, are also presented in Table 4.

5.5 Cost - Benefit Analysis of Blower Operating Mode and Motor Type

The cost of ECMs over PSC motors for furnace blowers was estimated at $237, retail in Montreal. Energy cost savings for ECMs over PSC furnace fan motors in forced air heating systems with continuous fan operation were estimated at ($143.38 - 51.33 =) $91.99 for gas heated houses, $92.45 with oil and $56 in all electric houses. Thus, in gas or oil heated houses with continuous furnace fan operation, ECMs are estimated to have a simple payback under three years. In electrically heated houses, the payback would be over four years. These paybacks would improve if the ECM were credited for reductions in air-conditioning loads or electric demand.

Table 4

Ventilation System Option	Energy Model	Incremental System Cost (Montreal)		Incremental Energy Cost ($/yr)		All Electric*
		Bungalow	Two Storey	Gas	Oil	
HRV Integrated with Forced Air Heating						
HRV Supply and Exhaust to Furnace Ductwork, Individual Wet Room Exhausts						
i Cont. ECM Furnace Fan	ce	240	237	51.33	48.80	24.00
ii Cont. PSC Furnace Fan	cp	3	0	143.38	141.25	80.00
iii Auto ECM Furnace Fan, bd damper	ae	447	444	13.58	10.25	0
iv Auto PSC Furnace Fan, bd damper	ap	210	207	15.79	12.25	0
HRV Supply to Furnace Ductwork, HRV Exhausts from Wet Rooms						
v Cont. ECM Furnace Fan	ce	238	405	51.33	48.80	24.00
vi Cont. PSC Furnace Fan	cp	0	168	143.38	141.25	80.00
vii Auto ECM Furnace Fan	ae	238	405	13.58	10.25	0
viii Auto ECM Furnace Fan, bd damper	ae	445	612	13.58	10.25	0
ix Auto PSC Furnace Fan	ap	0	168	15.79	12.25	0
x Auto PSC Furnace Fan, bd damper	ap	208	376	15.79	12.25	0
Forced Air Heating, HRV Not Integrated						
xi Fully ducted HRV, ECM Furnace Fan	ae	811	1018	13.58	10.25	0
xii Fully ducted HRV, PSC Furnace Fan	ap	574	781	15.79	12.25	0
Non Forced Air Heating (e.g., Baseboard or Radiant)						
xiii Fully ducted HRV	bb	574	781	0	0	0
xiv Partially ducted HRV and muffin fans	mf	412	691	17.18	17.80	10.40
xv Partial duct HRV, door switched muffin fans	sm	502	781	8.62	8.85	6.00

* Based on electric costs of $0.08/kWh.

Energy cost savings for ECMs in systems with automatic fan operation were estimated at ($15.79 - $13.58) $2.21/yr for gas heated houses, $2.00/yr. for oil heated houses and 0 for electrically heated houses. The price used for ECMs in the costing is at the low end of the range of expected retail costs. In the absence of a major price reduction for ECMs or credit for other benefits of ECMs (e.g., significant reductions in air-conditioning loads or electric demand), system options which include ECMs and automatic fan operation (i.e., options iii, vii, viii and xi) can be excluded from further consideration.

In some jurisdictions (e.g., Minnesota) it is common practice to hard connect the HRV ventilation air supply to the forced air heating system ductwork and operate the furnace blower on automatic. Utilizing the furnace ductwork to distribute ventilation air minimizes capital costs while operating the furnace blower in automatic mode minimizes energy consumption. The writer is not aware of any research done to evaluate the effectiveness of this method of ventilation air distribution.

A backdraft damper must be installed if both the HRV supply and exhaust are connected to the forced air ductwork and the furnace fan operates on automatic (i.e., systems iii and iv). Backdraft dampers may also be desirable in systems in which only the HRV supply side is connected to the forced air ductwork. In the following discussion, it is assumed that furnace blowers operating on automatic would use PSC motors, and backdraft dampers would only be installed in furnace ductwork if automatic fan operation is intended.

PSC blower motors operating on automatic have lower energy costs than ECM blowers operating continuously. Backdraft dampers cost $207 in Montreal, $30 less than an ECM. Thus, a forced air system with a PSC blower motor operating on automatic (e.g., systems iv and x) is both less expensive to install and to operate than the comparable system with a continuously operating ECM blower (i.e., systems i and v), even if a backdraft damper is required. Integrated ventilation systems in which the furnace blower operates in the automatic mode (i.e., systems iv, ix and x) deserve further investigation.

5.6 Analysis of Independent Ventilation System Options

Fully ducted ventilation systems in houses with forced air heating (i.e., system xii) were compared to integrated ventilation systems with continuously operating ECM furnace blowers (i.e., systems i or v). The fully ducted systems were estimated to cost at least ($574 - 240) $335 more in the bungalow and at least ($781 - 405) $376 more for the two storey than the integrated systems. The incremental costs for a fully ducted HRV system over an integrated system would be even higher if a PSC furnace blower motor were specified rather than an ECM.

The incremental energy cost to continuously operate the ECM blower was estimated at ($51.33 - 15.79) $35.54/yr for gas heated houses, $36.55 for oil heated houses and $24 for electrically heated houses. This indicates best-case simple paybacks in the order of 10 years for fully ducted ventilation systems in houses with forced air heating. (Higher ECM prices would reduce the cost difference, resulting in shorter paybacks.)

An integrated system in which the furnace blower operates on automatic would have the same energy use as a fully ducted ventilation system in a house with forced air heating (i.e., continuous HRV and furnace fan operation only on demand for heating or cooling). However, the integrated system with automatic blower operation would have a significantly lower capital cost.

For houses without forced air heating, the partially ducted HRV system with muffin fans to circulate ventilation air (i.e., "mf" option) was less costly to install than the fully ducted ventilation system, but energy costs were higher. Capital cost differentials are very house dependant; for the study houses, the cost difference was $162 for the bungalow, $90 for the two storey. Adding door switches (i.e., "sm" option) reduced the energy costs but also reduced the cost differential relative to fully ducted systems to $72 and $0 for the bungalow and two storey, respectively.

Based on energy savings relative to the "mf" option ($17.18 for gas heat, $17.80 for oil heat, $10.40 for electric heat), the incremental cost for the fully ducted HRV system would be paid back in 5 to 14.5 years depending on the house and space heat energy source. The payback periods of 8 to 13 years were estimated for the incremental costs of a fully ducted system versus the "sm" option for the bungalow. For the two storey, "sm" systems and fully ducted systems were estimated to have the same capital cost. Because the fully ducted system would have lower energy cost, the "sm" option should not be considered.

The muffin fan option appears to be economical in some applications, if reliable hardware were available at the estimated cost (i.e., $95 installed, retail in Montreal for the "mf" option, $125 for the "sm" option).

6.0 CONCLUSIONS AND RECOMMENDATIONS

For the houses and systems modeled, incremental energy use is primarily a function of ventilation strategy; location and house type were not strong influences. Furthermore, differences between the energy requirements for the three space heating energies modeled appear to be primarily a function of space heating appliance efficiency.

The differences in total energy requirements did not vary significantly with space heating energy type. However, energy cost savings did vary significantly with space heating energy source. Cost savings related to energy efficient ventilation air distribution strategies were greater for houses with gas or oil space heat than electrically heated houses. The reductions in electric utility winter peak load will also be greater in gas and oil heated houses than electrically heated houses.

In houses with forced air heating systems, the most significant energy cost savings can be realized by adopting ventilation strategies that do not require continuous operation of the furnace blower. If continuous furnace blower operation is necessary, replacement of PSC furnace blower motors with ECMs may have an attractive payback.

Fully ducted HRVs in houses with forced air heating do not appear to be economically attractive. The muffin fan option may be economically attractive when compared to fully ducted HRV systems.

Research should be undertaken to evaluate the effectiveness of distributing ventilation air via forced air heating system ductwork, without operating the furnace blower. If distribution through furnace ductwork without operating the furnace blower provides unsatisfactory ventilation, methods to improve distribution of ventilation air without operating the furnace blower should be evaluated, including the use of discharge configurations which direct ventilation air in the furnace ductwork and the use of backdraft dampers. The research should consist of a series of trials designed to determine if simple duct arrangements can effectively distribute ventilation air throughout the house. Prior to undertaking this work, contact should be made with equipment suppliers and housing/energy agencies in Minnesota to evaluate their experience with these types of systems.

Two speed furnace fan operation should be incorporated into HOT2000. This can be done with only minor modifications to the program.

HOT2000 should use power consumption data for discrete fan motor sizes. The current practice of estimating fan power at 20 watts/kW of furnace output underestimates furnace fan power for small furnace sizes. Default values based on the rated horsepower of the furnace fan motor can be derived from the data base generated for the CEA furnace blower study.

Residential ventilation system manufacturers should be informed of the concept of "mf" and "sm" type systems. One or more manufacturers should be asked to estimate the retail prices and market potential for these systems.

The concept of an HRV which uses combustion appliance exhaust gasses as well as house exhaust to preheat ventilation air should be evaluated by one or more HRV or furnace manufacturers. Such a system would increase the effective efficiency of furnaces and DHW tanks connected to it.

APPENDIX

EXAMPLES OF VENTILATION SYSTEM COSTING WORKSHEETS

VENTILATION SYSTEM COSTING WORKSHEET

DATE OF ANALYSIS: 21-Feb-95

DIRECTIONS: Enter data in shaded areas only, erase entries in shaded areas using "/EE".

1. HOUSE AND SYSTEM DESCRIPTION	Upgraded system = mid efficiency HRV with 3 exhausts, 1 supply (to furnace) and backdraft damper.
HEAT DISTRIBUTION SYSTEM	Forced air
NUMBER OF FLOORS	1
LOCATION	ENTER "1"
Halifax	
Montreal	
Toronto	
Winnipeg	1
Vancouver	

2. REFERENCE COSTING DATA (modify only if necessary)			
REFERENCE LOCATION	Winnipeg		
REFERENCE DATE:	April 1, 1994		
REGIONAL COST MODIFIERS **			
1. Halifax	1.02		
2. Montreal	1.03		
3. Toronto	1.06		
4. Winnipeg	1.00		
5. Vancouver	1.05		
CITY (DO NOT TOUCH!)	4		
INFLATION MODIFIER (from Ref. Date)	1.00		
RETAIL/BUILDER INDEX	1.15		
COST DATA	REFERENCE COST*	BUILDER COST	RETAIL COST
Kitchen exhaust fan & D/W	$144.00	$144.00	$165.60
Bathroom exhaust fan (main floor or bsmt.) & D/W	$98.00	$98.00	$112.70
Bathroom exhaust fan (2nd floor) & D/W	$98.00	$98.00	$112.70
Central exhaust fan & duct from fan to outside	$205.00	$205.00	$235.75
Exhaust duct from bsmt. to bsmt. mech. room	$94.00	$94.00	$108.10
Exhaust duct from main floor to bsmt. mech. room	$137.00	$137.00	$157.55
Exhaust duct from 2nd floor to bsmt. mech. room	$168.00	$168.00	$193.20
Vent. supply duct from bsmt. mech. room to furnace R/A	$30.00	$30.00	$34.50
Vent. supply duct from bsmt. mech. room to bsmt.	$94.00	$94.00	$108.10
Vent. supply duct from bsmt. mech. room to main floor	$137.00	$137.00	$157.55
Vent. supply duct from bsmt. mech. room to 2nd floor	$168.00	$168.00	$193.20
Muffin fan	$80.00	$80.00	$92.00
Make-up air duct from outdoors to furnace R/A	$51.00	$51.00	$58.65
Heating return (main floor)	$44.00	$44.00	$50.60
Heating return (2nd floor)	$55.00	$55.00	$63.25
Mid-efficiency HRV & cold-side D/W	$1,584.00	$1,584.00	$1,821.60
High-efficiency HRV & cold-side D/W	$2,015.00	$2,015.00	$2,317.25
Furnace backdraft damper	$175.00	$175.00	$201.25
ECM furnace motor	$200.00	$200.00	$230.00

* "Reference Cost is defined as a) the "Builder Cost" for the location b) Winnipeg calculated c) for the "Reference Date".

** Regional cost modifiers are from "Life Cycle Cost Analyses for Selection of Prescriptive Requirements for the Energy Code for Buildings and for Houses" (IRC January 27, 1994).

3. BASE CASE HOUSE		
ROOMS (USED FOR DOCUMENTATION ONLY)		LOCATION (-1, 1 or 2)
Kitchen		1
Living		1
Dining		1
Utility		
Bedroom (master)		1
Bedroom #2		1
Bedroom #3		1
Bedroom #4		
Bathroom #1		1
Bathroom #2		-1
Bathroom #3		
Basement		-1
Other #1	laundry	-1
Other #2	mech./storag	-1

-1 = Basement
1 = Main floor
2 = Second floor

VENTILATION SYSTEM	LOCATION (-1, 1 or 2)	SYSTEM COST BUILDER	SYSTEM COST RETAIL
UNITARY EXHAUST FANS (FAN & D/W)			
Kitchen	1	$144.00	$165.60
Bathroom #1	1	$98.00	$112.70
Bathroom #2	-1	$98.00	$112.70
Bathroom #3		$0.00	$0.00
MAKE-UP AIR DUCT		$0.00	$0.00
VENTILATION SYSTEM COST (BASE CASE)		$340.00	$391.00

4. DESCRIPTION OF UPGRADED VENTILATION SYSTEM			
COMPONENT	LOCATION (-1, 1 or 2)	SYSTEM COST BUILDER	RETAIL
UNITARY EXHAUST FANS (FAN & D/W)			
Kitchen		$0.00	$0.00
Bathroom #1		$0.00	$0.00
Bathroom #2		$0.00	$0.00
Bathroom #3		$0.00	$0.00
CENTRAL EXHAUST FAN & DUCT FROM FAN TO OUTSIDE		$0.00	$0.00
MID-EFFICIENCY HRV & COLD-SIDE D/W	-1	$1,584.00	$1,821.60
HIGH-EFFICIENCY HRV & COLD-SIDE D/W		$0.00	$0.00
EXHAUST DUCT TO BSMT. MECH. ROOM FROM:			
Kitchen	1	$137.00	$157.55
Bathroom #1	1	$137.00	$157.55
Bathroom #2	-1	$94.00	$108.10
Bathroom #3		$0.00	$0.00
VENTILATION SUPPLY DUCT FROM MECH. ROOM TO:			
Furnace R/A plenum	-1	$30.00	$34.50
Basement		$0.00	$0.00
Main floor		$0.00	$0.00
Second floor		$0.00	$0.00
Bedroom (master)		$0.00	$0.00
Bedroom #2		$0.00	$0.00
Bedroom #3		$0.00	$0.00
Other (laundry)		$0.00	$0.00
Other		$0.00	$0.00
Other		$0.00	$0.00
MAKE-UP AIR DUCT FROM OUTDOORS TO FURNACE R/A		$0.00	$0.00
MUFFIN FANS			
Bedroom (master)		$0.00	$0.00
Bedroom #2		$0.00	$0.00
Bedroom #3		$0.00	$0.00
Other		$0.00	$0.00
HEATING RETURNS FROM:			
Living		$0.00	$0.00
Dining		$0.00	$0.00
Bedroom (master)		$0.00	$0.00
Bedroom #2		$0.00	$0.00
Bedroom #3		$0.00	$0.00
Other		$0.00	$0.00
FURNACE BACKDRAFT DAMPER	-1	$175.00	$201.25
ECM FURNACE MOTOR		$0.00	$0.00
OTHER ITEM (DESCRIBE)			
VENTILATION SYSTEM COST (UPGRADED)		$2,157.00	$2,480.55

SUMMARY OF VENTILATION SYSTEM COSTS FOR DIFFERENT LOCATIONS
USING WINNIPEG AS THE REFERENCE CITY

HOUSE AND SYSTEM DESCRIPTION	Upgraded system = mid efficiency HRV with 3 exhausts, 1 supply (to furnace) and backdraft damper.
HEAT DISTRIBUTION SYSTEM	Forced air
NUMBER OF FLOORS	1

BASE CASE SYSTEM	BUILDER COST	RETAIL COST
1. Halifax	$346.80	$398.82
2. Montreal	$350.20	$402.73
3. Toronto	$360.40	$414.46
4. Winnipeg	$340.00	$391.00
5. Vancouver	$357.00	$410.55

UPGRADED SYSTEM	BUILDER COST	RETAIL COST
1. Halifax	$2,200.14	$2,530.16
2. Montreal	$2,221.71	$2,554.97
3. Toronto	$2,286.42	$2,629.38
4. Winnipeg	$2,157.00	$2,480.55
5. Vancouver	$2,264.85	$2,604.58

INCREMENTAL COSTS (UPGRADED - BASE CASE)	BUILDER COST	RETAIL COST
1. Halifax	$1,853.34	$2,131.34
2. Montreal	$1,871.51	$2,152.24
3. Toronto	$1,926.02	$2,214.92
4. Winnipeg	$1,817.00	$2,089.55
5. Vancouver	$1,907.85	$2,194.03

VENTILATION SYSTEM COSTING WORKSHEET

DATE OF ANALYSIS: 21-Feb-95

DIRECTIONS: Enter data in shaded areas only, erase entries in shaded areas using "/EE".

1. HOUSE AND SYSTEM DESCRIPTION	Upgraded system = mid efficiency HRV with 4 exhausts, 1 supply (to furnace) and backdraft damper.
HEAT DISTRIBUTION SYSTEM	Forced air
NUMBER OF FLOORS	2
LOCATION	ENTER "1"
Halifax	
Montreal	
Toronto	
Winnipeg	1
Vancouver	

2. REFERENCE COSTING DATA (modify only if necessary)			
REFERENCE LOCATION	Winnipeg		
REFERENCE DATE:	April 1, 1994		
REGIONAL COST MODIFIERS **			
1. Halifax	1.02		
2. Montreal	1.03		
3. Toronto	1.06		
4. Winnipeg	1.00		
5. Vancouver	1.05		
CITY (DO NOT TOUCH!)	4		
INFLATION MODIFIER (from Ref. Date)	1.00		
RETAIL/BUILDER INDEX	1.15		
COST DATA	REFERENCE COST*	BUILDER COST	RETAIL COST
Kitchen exhaust fan & D/W	$144.00	$144.00	$165.60
Bathroom exhaust fan (main floor or bsmt.) & D/W	$98.00	$98.00	$112.70
Bathroom exhaust fan (2nd floor) & D/W	$98.00	$98.00	$112.70
Central exhaust fan & duct from fan to outside	$205.00	$205.00	$235.75
Exhaust duct from bsmt. to bsmt. mech. room	$94.00	$94.00	$108.10
Exhaust duct from main floor to bsmt. mech. room	$137.00	$137.00	$157.55
Exhaust duct from 2nd floor to bsmt. mech. room	$168.00	$168.00	$193.20
Vent. supply duct from bsmt. mech. room to furnace R/A	$30.00	$30.00	$34.50
Vent. supply duct from bsmt. mech. room to bsmt.	$94.00	$94.00	$108.10
Vent. supply duct from bsmt. mech. room to main floor	$137.00	$137.00	$157.55
Vent. supply duct from bsmt. mech. room to 2nd floor	$168.00	$168.00	$193.20
Muffin fan	$80.00	$80.00	$92.00
Make-up air duct from outdoors to furnace R/A	$51.00	$51.00	$58.65
Heating return (main floor)	$44.00	$44.00	$50.60
Heating return (2nd floor)	$55.00	$55.00	$63.25
Mid-efficiency HRV & cold-side D/W	$1,584.00	$1,584.00	$1,821.60
High-efficiency HRV & cold-side D/W	$2,015.00	$2,015.00	$2,317.25
Furnace backdraft damper	$175.00	$175.00	$201.25
ECM furnace motor	$200.00	$200.00	$230.00

* "Reference Cost is defined as a) the "Builder Cost" for the location b) Winnipeg calculated c) for the "Reference Date".

** Regional cost modifiers are from "Life Cycle Cost Analyses for Selection of Prescriptive Requirements for the Energy Code for Buildings and for Houses" (IRC January 27, 1994).

3. BASE CASE HOUSE				
ROOMS (USED FOR DOCUMENTATION ONLY)		LOCATION (-1, 1 or 2)		
Kitchen		1		
Living		1		
Dining		1		
Utility				
Bedroom (master)		2		
Bedroom #2		2		
Bedroom #3		2		
Bedroom #4				
Bathroom #1		1		
Bathroom #2		2		
Bathroom #3		2		
Basement		-1		
Other #1	laundry	1		
Other #2	family room	1		
VENTILATION SYSTEM		LOCATION (-1, 1 or 2)	SYSTEM COST BUILDER	SYSTEM COST RETAIL
UNITARY EXHAUST FANS (FAN & D/W)				
Kitchen		1	$144.00	$165.60
Bathroom #1		1	$98.00	$112.70
Bathroom #2		2	$98.00	$112.70
Bathroom #3		2	$98.00	$112.70
MAKE-UP AIR DUCT		-1	$51.00	$58.65
VENTILATION SYSTEM COST (BASE CASE)			$489.00	$562.35

-1 = Basement
1 = Main floor
2 = Second floor

4. DESCRIPTION OF UPGRADED VENTILATION SYSTEM			
COMPONENT	LOCATION (-1, 1 or 2)	SYSTEM COST BUILDER	RETAIL
UNITARY EXHAUST FANS (FAN & D/W)			
Kitchen		$0.00	$0.00
Bathroom #1		$0.00	$0.00
Bathroom #2		$0.00	$0.00
Bathroom #3		$0.00	$0.00
CENTRAL EXHAUST FAN & DUCT FROM FAN TO OUTSIDE		$0.00	$0.00
MID-EFFICIENCY HRV & COLD-SIDE D/W	-1	$1,584.00	$1,821.60
HIGH-EFFICIENCY HRV & COLD-SIDE D/W		$0.00	$0.00
EXHAUST DUCT TO BSMT. MECH. ROOM FROM:			
Kitchen	1	$137.00	$157.55
Bathroom #1	1	$137.00	$157.55
Bathroom #2	2	$168.00	$193.20
Bathroom #3	2	$168.00	$193.20
VENTILATION SUPPLY DUCT FROM MECH. ROOM TO:			
Furnace R/A plenum	-1	$30.00	$34.50
Basement		$0.00	$0.00
Main floor		$0.00	$0.00
Second floor		$0.00	$0.00
Bedroom (master)		$0.00	$0.00
Bedroom #2		$0.00	$0.00
Bedroom #3		$0.00	$0.00
Other		$0.00	$0.00
Other		$0.00	$0.00
Other		$0.00	$0.00
MAKE-UP AIR DUCT FROM OUTDOORS TO FURNACE R/A		$0.00	$0.00
MUFFIN FANS			
Bedroom (master)		$0.00	$0.00
Bedroom #2		$0.00	$0.00
Bedroom #3		$0.00	$0.00
Other laundry		$0.00	$0.00
HEATING RETURNS FROM:			
Living		$0.00	$0.00
Dining		$0.00	$0.00
Bedroom (master)		$0.00	$0.00
Bedroom #2		$0.00	$0.00
Bedroom #3		$0.00	$0.00
Other		$0.00	$0.00
FURNACE BACKDRAFT DAMPER	-1	$175.00	$201.25
ECM FURNACE MOTOR		$0.00	$0.00
OTHER ITEM (DESCRIBE)			
VENTILATION SYSTEM COST (UPGRADED)		$2,399.00	$2,758.85

SUMMARY OF VENTILATION SYSTEM COSTS FOR DIFFERENT LOCATIONS
USING WINNIPEG AS THE REFERENCE CITY

HOUSE AND SYSTEM DESCRIPTION	Upgraded system = mid efficiency HRV with 4 exhausts, 1 supply (to furnace) and backdraft damper
HEAT DISTRIBUTION SYSTEM	Forced air
NUMBER OF FLOORS	2

BASE CASE SYSTEM	BUILDER COST	RETAIL COST
1. Halifax	$498.78	$573.60
2. Montreal	$503.67	$579.22
3. Toronto	$518.34	$596.09
4. Winnipeg	$489.00	$562.35
5. Vancouver	$513.45	$590.47

UPGRADED SYSTEM	BUILDER COST	RETAIL COST
1. Halifax	$2,446.98	$2,814.03
2. Montreal	$2,470.97	$2,841.62
3. Toronto	$2,542.94	$2,924.38
4. Winnipeg	$2,399.00	$2,758.85
5. Vancouver	$2,518.95	$2.896.79

INCREMENTAL COSTS (UPGRADED - BASE CASE)	BUILDER COST	RETAIL COST
1. Halifax	$1,948.20	$2,240.43
2. Montreal	$1,967.30	$2,262.40
3. Toronto	$2,024.60	$2,328.29
4. Winnipeg	$1,910.00	$2,196.50
5. Vancouver	$2,005.50	$2,306.33