Whole House Mechanical Ventilation

A South Chicago Case Study

Background

Claretian Associates, a non-profit community development organization, and South Chicago Workforce, a non-profit builder and contractor, have teamed to create 26 efficient, healthy, sustainable, affordable homes in South Chicago, IL. These homes are constructed with structural insulated panels (SIPs), are heated with condensing furnaces, utilize sealed-combustion water heaters, and contain efficient lights and appliances. The first 10 homes also feature 1.2-kW solar electric systems. Many of the energy improvements were financed by an energy grant from the Illinois Department of Commerce and Economic Opportunity under its *Energy Efficient Affordable Housing Construction Program*. Claretian Associates' and South Chicago Workforce's commitment to high-quality affordable housing earned the project the Chicago Neighborhood Development Award for "2005 Outstanding Non-Profit Neighborhood Project."

Because the homes are so air-tight (blower door tests showed 300-350 CFM_{50}), providing adequate ventilation is a special concern of the builder. David Sullivan of South Chicago Workforce and Paul Knight of Domus PLUS – an architect consulting on the project – approached SWA about monitoring the performance of several ventilation systems in the first three homes. SWA was able to perform the monitoring with funding from the Department of Energy's (DOE's) Building America program and from the Department of Housing and Urban Development's (HUD's) PATH program (Partnership for Advancing Technology in Housing). The goal of the study was to evaluate the ventilation systems' performance with respect to fresh air distribution effectiveness and to energy consumption and operating costs.

In mid-October of 2004, monitoring systems and ventilation systems were completely installed and commissioned in the first three South Chicago homes. The three ventilation systems installed in the homes were:

House 1: Energy Recovery Ventilation (ERV)
House 2: AirCycler™ supply ventilation
House 3: Exhaust only (bath fans on timer control)

To examine ventilation effectiveness, in each home SWA monitored:

- Temperature, humidity, and carbon dioxide concentrations outdoors, in two bedrooms, and in the living room;
- Fresh air supply flow rate, temperature, and humidity;
- Exhaust air flow rate, temperature, and humidity.

All sensors in the homes were connected to Campbell Scientific datalogger systems. Data were collected every 10 seconds and recorded at 15-minute intervals. SWA finished collecting data at the end of April 2005; six full months of data were collected. SWA would have preferred to evaluate these homes operating side-by-side for a full year. Only one of the three homes has central air conditioning installed; the others do not have cooling and make use of natural ventilation (open windows) during summer months. Comparisons under these circumstances have very limited usefulness.

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Ventilation Systems

Energy Recovery Ventilation

The first home completed features a RenewAire™ energy recovery ventilator (ERV) ducted into the central supply and return ducts in the basement. Initially, the ERV operated constantly – 24 hours a day – while the central air handler operated very infrequently (because of the low-heat load and city-mandated, oversized equipment).

Even with the ERV operating continuously, carbon dioxide levels were almost always above the 1000-ppm ASHRAE-recommended maximum and often reached above 2000 ppm. SWA alleviated this condition by installing a controller that engages the central air handler fan whenever the ERV operates. When ventilation systems were commissioned in October 2004, the outdoor air flow was measured at 80 CFM. ERV duty cycle was set to 75% to achieve the equivalent of 60 CFM continuous as required by ASHRAE 62.2.

The sensible effectiveness of the ERV was measured at 70-75% during the winter months. The ERV consumes 102 Watts when operating; the air handler, which operates whenever the ERV operates, consumes 712 Watts in fan-only mode.

Air Cycler™

The second home features an Air Cycler™ supply ventilation system. The Air Cycler™ is a timer control that operates the central air handler at programmed intervals. A 6” duct runs from the return plenum to the outdoors, so some fresh air is introduced to the central air system and distributed through the homes’ heating ducts. A motorized damper is installed in the outside air duct which opens only when it receives a call for fresh air from the Air Cycler™.

During commissioning in October 2004, outside air flow through the duct was measured at 80 CFM. The Air Cycler was programmed so that the central air handler would operate 75% of the time (15 minutes on, 5 minutes off) to achieve the 60 CFM effective continuous rate (per ASHRAE 62.2). The central air handler draws 712 Watts when operating in fan-only mode to provide ventilation.

Exhaust Only

The third house contains two efficient, bathroom exhaust fans (Broan model S80-UE) connected to two Tamarack Airetrack™ controllers. When operating, the first- and second-floor fans draw 56 and 59 CFM, respectively. The Airetrack™ timers operate both fans at full speed for 35 minutes each hour to achieve the effective continuous rate of 60 CFM. The Airetrack™ controller also allows occupants to turn the fan on at any time. Both fans operating together draw 45 Watts.

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Results

Flow Rates

SWA installed flow stations in both the exhaust and fresh air ducts of the ERV system as well as in the outside air duct in the Air Cycler™ system. Flow rates of the exhaust fans were measured when the bath fans were installed with an Alnor Low-Flow balometer; these rates are assumed to be constant throughout the six-month test period.

When ventilation systems were commissioned in mid-October 2004, all were programmed to provide approximately 60 CFM of effective, continuous ventilation as required by ASHRAE 62.2. Because the Airetrack™ controller can only be programmed to operate in 5-minute increments each hour, the exhaust fan flow is slightly higher. SWA's flow monitoring, summarized in Table 1, shows that these flow rates were not maintained over time.

	Average, Effective, Continuous Flow Rates [CFM]		
Month	1 - ERV	2 - Air Cycler	3 - Bath Exhst
October Commissioning	60	60	67
Nov	80	44	67
Dec	80	35	67
Jan	80	33	67
Feb	74	36	67
Mar	70	34	67
Apr	70	32	67
Average	76	35	67

Table 1. Ventilation flow rates over the monitoring period. Target flow rate is 60 CFM (shown in the commissioning line). Bath exhaust flows are not monitored and are based on commissioning measurements.

During commissioning, operating outdoor air flows in both the ERV and Air Cycler™ systems were measured at 80 CFM. Measurements from the flow stations agreed well with flow hood measurements taken at the inlet and outlet hoods. Duty cycles for both systems were set to 75% to obtain an effective rate of 60 CFM. Over time, the data show higher flow rates for the ERV system and lower flow rates for the Air Cycler™ system.

Part of this flow rate discrepancy could have been caused by wind during commissioning affecting measured flow rates. In the Air Cycler™ system, however, a steady decrease was observed in the first three months after commissioning. In the second half of October, effective continuous flow was 51 CFM (not shown in Table 1). In November it fell to 44 CFM, and during the rest of the monitoring period effective continuous flows were 32-36 CFM. SWA suspects that fouling of the intake screen is partly responsible for this decline.

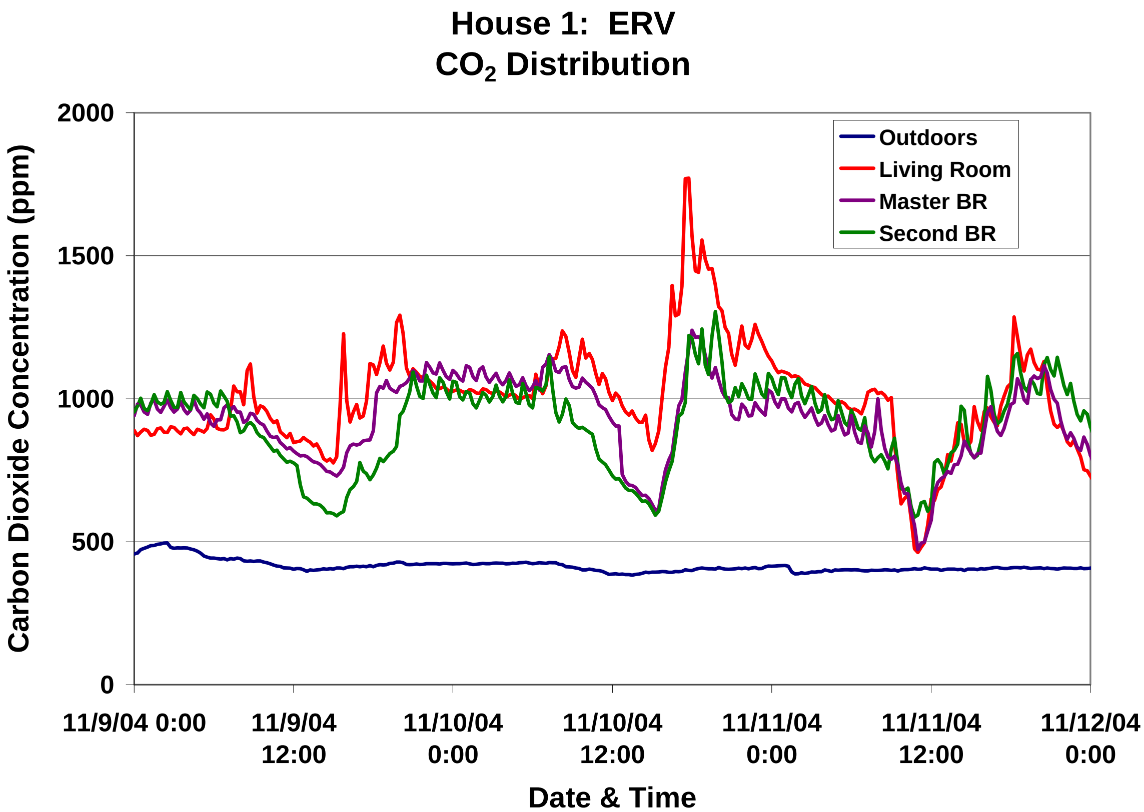
The higher flow rates in the ERV system cannot be explained in the same way. It is interesting to note a decrease (from 80 CFM to 70 CFM) in ERV flows during February. This decline was likely caused by homeowners adjusting the controls of the ERV. Recorded ERV operating time was reduced from 70% to 60% during February; it is likely this was due to homeowner behavior. No such duty cycle change occurred in the Air Cycler™ system.

Carbon Dioxide and Fresh Air Distribution

To evaluate the quality of fresh air distribution, SWA has relied primarily upon carbon dioxide concentration measurements. Three CO_2 sensors are installed in each home:

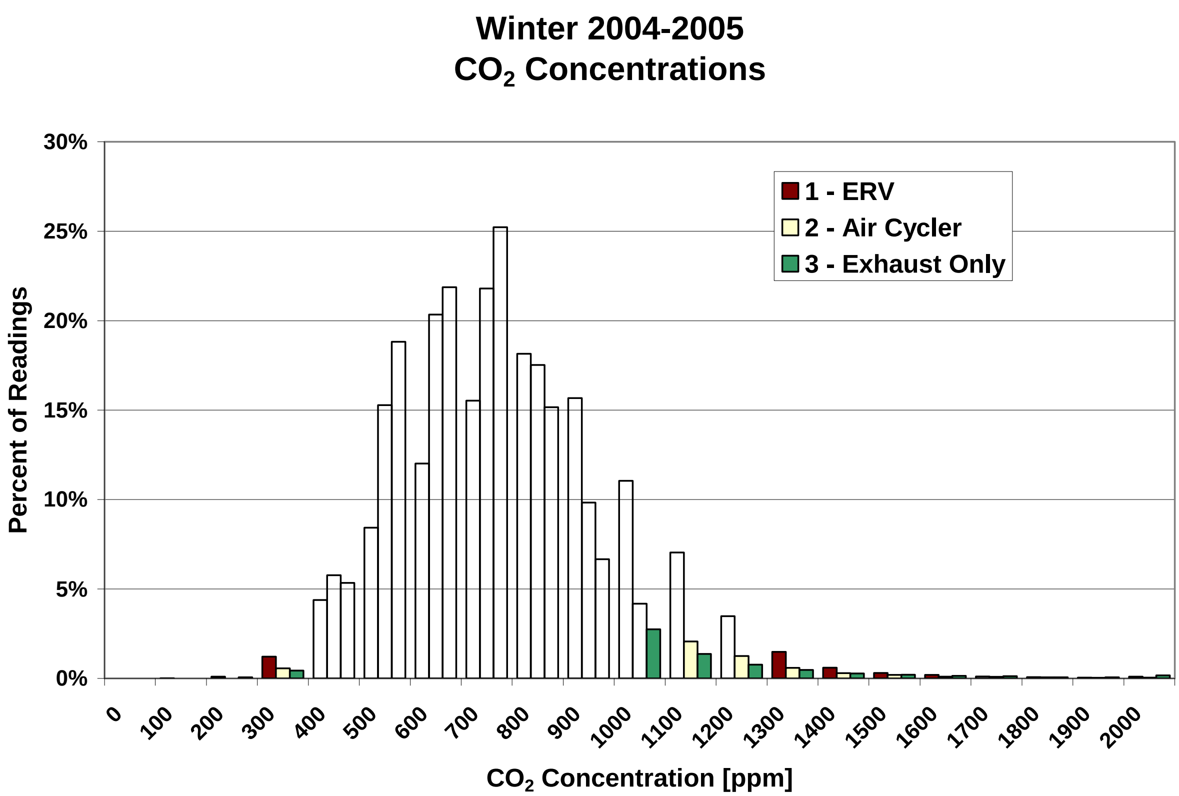
- Living Room (central, first floor)
- Master Bedroom (second floor)
- Secondary Bedroom (second floor)

An example CO_2 profile is shown below.

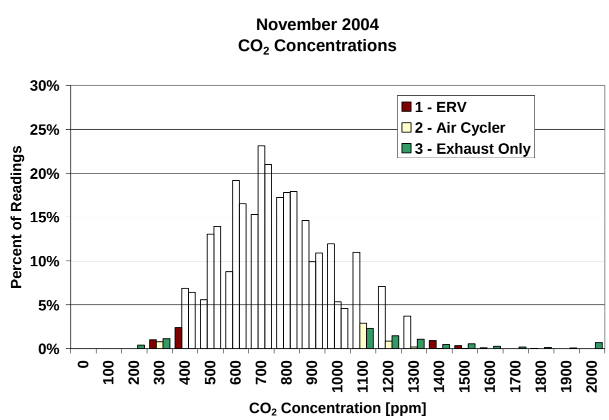


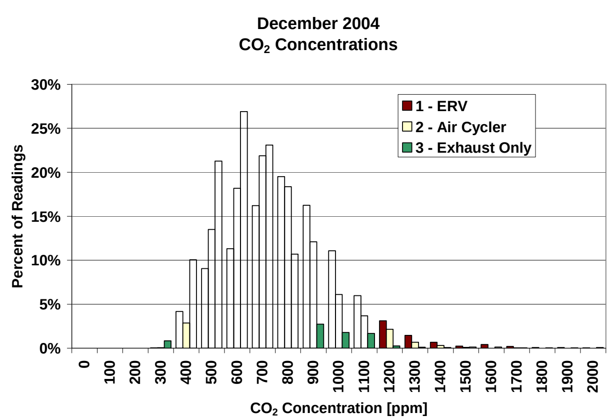
Example CO_2 distribution in the ERV home during three days in November.

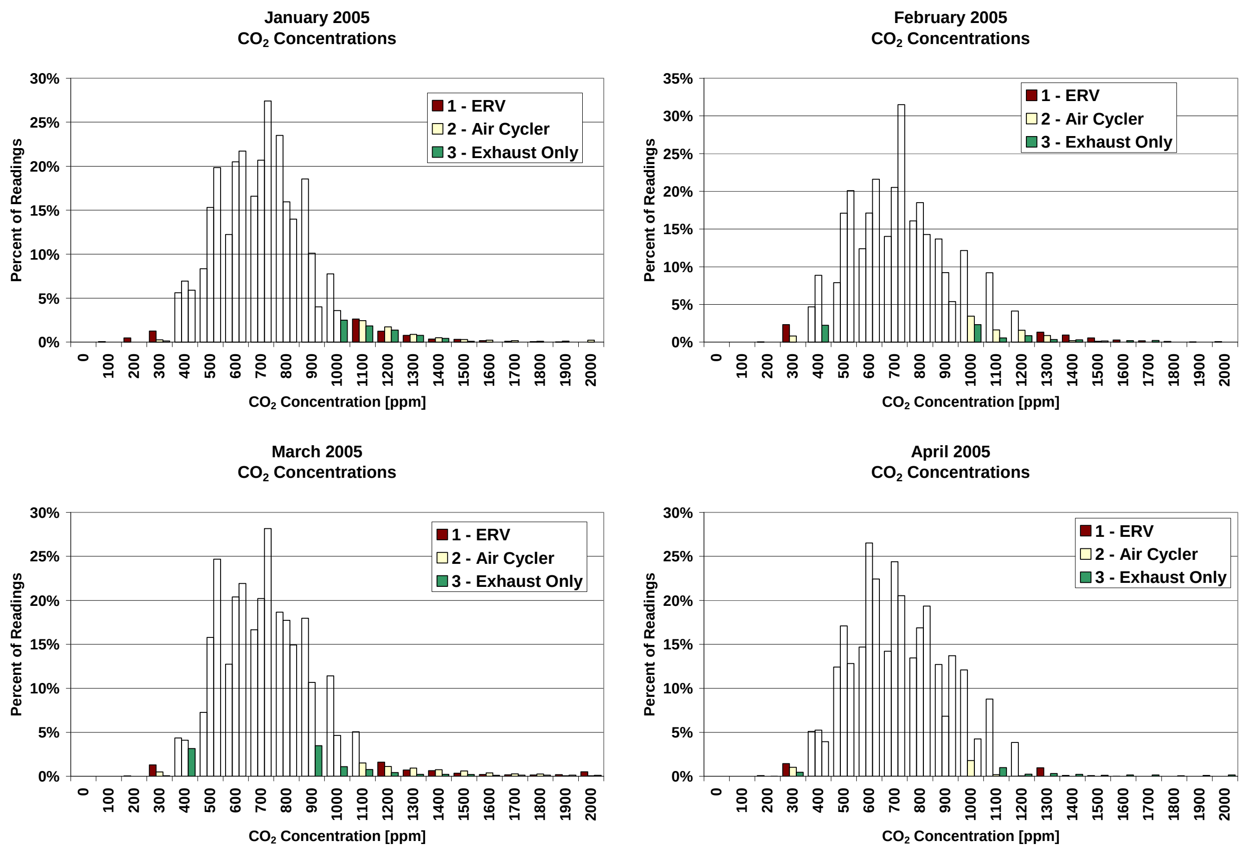
To evaluate the effectiveness of the distribution, SWA generated histograms of CO_2 concentrations for each month for each ventilation system. The histogram of the best performing system should have the smallest (tightest) distribution as well as low CO_2 values. The occupancy of these homes is very similar: the first home (ERV) houses two adults, three children, and one dog; the second and third homes house two adults, three children, and one dog. Because the homes are occupied by different people with different living patterns an entirely straight-forward comparison is not possible. Still, the tightest, lowest CO_2 concentration distribution indicates better fresh air distribution. The histogram for the entire six-month period is shown below and is followed by each month shown separately.



CO_2 distribution from November 2004 through April 2005.







Monthly histograms of carbon dioxide distribution in the three South Chicago homes.

The histograms present all data points from all rooms at all times. Another indicator of fresh air distribution effectiveness is the range in CO_2 concentrations throughout each house at the same points in time. To clarify, the "range" in CO_2 concentrations discussed here is the maximum concentration in one home minus the minimum concentration at the same time in the same home. In homes with the best distribution, this CO_2 "range" will be small. Table 2 shows the average ranges during each month of the analysis.

Ranges in CO_2 Concentrations [ppm]

	1 - ERV		2 - Air Cycler		3 - Bath Exhst	
Month	Avg. Range	Median Conc.	Avg. Range	Median Conc.	Avg. Range	Median Conc.
Nov	124	798	80	646	160	659
Dec	120	748	85	674	83	565
Jan	132	724	102	633	79	609
Feb	128	753	85	631	88	615
Mar	150	743	93	645	88	601
Apr	185	713	77	601	164	648
Avg.	140	747	87	638	110	616

Table 2: Summary of CO_2 "ranges" (the differences between the minimum and maximum concentrations in each house at the same points in time) for the South Chicago homes.

According to the histograms, it is the Air Cycler™ and Exhaust systems that have the tightest distributions with the lowest CO_2 concentration peaks. Table 2 confirms this, showing the Air Cycler™ system has the least variability in CO_2 range followed by the Exhaust system; the ERV system has the highest variability. Because of the variability in occupant habits, however, SWA cannot definitively label a system as "better" or "best." SWA can say qualitatively, however, that no system performed poorly in these homes in distributing fresh air.

It is interesting that in data from the Exhaust Only house shown in Table 2, CO_2 ranges are higher in November and in April. During these months the furnace operation is lowest (20% and 8% run fractions, respectively). While some of this may be coincidental, it certainly suggests that the air handler operation does indeed improve fresh air distribution.

Ventilation Energy: Electricity

Knowing the actual power consumption and operation times of the ventilation equipment, it is fairly easy to assess how much electricity each ventilation system consumed in the six-month period. The ventilation electricity shown in Table is the sum of the electrical energy consumed by the ventilation fans themselves and, where applicable, the electricity for the additional operation of the air handler.

Even though the furnaces in these homes have high combustion efficiencies (92.5%), they have very poor electrical efficiencies (fan power consumption of 712 Watts). This results in very high ventilation-related electric loads for the first two homes. This problem is exacerbated by the oversized furnaces; smaller furnaces would run much more frequently during the winter and much less operation would be required for ventilation alone.

Ventilation Energy: Natural Gas

Clearly, bringing outdoor air into the home during the winter increases the space heating load. The ERV recovers 70-75% of the energy in exhaust air, but the other two systems must rely on the furnace for reheating. Increased gas consumption caused by ventilation is shown in Table 3. A slight silver lining to the enormous electricity consumption of the furnace fans is that this electric energy contributes to space heating. Because of this, gas consumption for the first two homes is actually less than for a home with no ventilation at all. This reduction in gas consumption is evident in the homes' gas bills.

Ventilation Energy: Costs

The final column of Table 3 shows energy costs associated with ventilation. Cost for natural gas in South Chicago were $0.65 per therm; electricity costs $0.10 per kWh.

Ventilation System	Electricity kWh/yr	Gas Therms/yr	Total Ventilation Cost
ERV + AHU	1834	-33	$162
Air Cycler™	1806	-14	$171
Exhaust Only	114	97	$75

Table 3. Increased energy consumption and associated costs (compared to a home with no ventilation) for each South Chicago home for the six-month period monitored (November 2004 through April 2005).

Efficient Air Handlers

The most striking component of ventilation energy consumption is the electricity used by the air handlers in the homes. It is unfortunate that efficient Electrically Commutated Motor (ECM) furnaces were not installed. While SWA has strongly recommended that more efficient furnaces be installed, additional cost for this equipment in each home would have been near $1000; the budget did not allow for this. SWA feels it is important, however, to investigate the energy consumption of these ventilation systems with efficient air handlers. To do this, SWA repeated the energy calculations above using an air handler power consumption value of 250 Watts in lieu of the measured 712 Watts. Results of this analysis for the six-month monitoring period are shown in Table 4.

Ventilation System	Electricity kWh/yr	Gas Therms/yr	Total Ventilation Cost
ERV + AHU	829	3	$85
Air Cycler™	634	28	$81
Exhaust Only	114	97	$75

Table 4. Calculated ventilation energy consumption and associated costs for the monitored six-month period assuming installation of an efficient, 250-Watt furnace fan.

Modeling Annual Performance

As described above, SWA was able to obtain only six months of data for these homes (most of the 2004-2005 heating season). To asses the operating costs for each ventilation system over an entire year, SWA calculated energy use of each system based on recorded 15-minute weather data from 2004. To more accurately compare the systems' relative performances, SWA also normalized the operating times and air flow rates in the modeling.

For the annual simulations, each ventilation system was modeled to deliver 90 CFM and to operate 67% of the time to meet the 60 CFM continuous equivalent required by ASHRAE 62.2.

TableTable 5 shows results of this annual modeling using measured power consumption of the furnaces installed (712 Watts); Table 6 shows the simulation results using an efficient air handler (250 Watts). During the winter, the internal gains from additional furnace fan operation required by the ERV and the Air Cycler™ largely offset additional gas loads for heating outdoor air. The negative numbers represent a *reduction* in net gas use caused by the ventilation system. There is no air conditioning in these modeled systems. If cooling were installed, internal gains from air handlers (when used for ventilation) would result in higher incremental ventilation costs.

Ventilation System	Electricity kWh/yr	Gas Therms/yr	Total Ventilation Cost
ERV + AHU	4309	-51	$398
Air Cycler™	3714	12	$379
Exhaust Only	263	76	$76

Table 5. Annual modeling results showing increased energy use and cost for operating each ventilation system (compared to a home with no ventilation). Furnace fan power consumption is 712 Watts as in the South Chicago homes.

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Ventilation System	Electricity kWh/yr	Gas Therms/yr	Total Ventilation Cost
ERV + AHU	1899	-9	$184
Air Cycler™	1304	54	$165
Exhaust Only	263	76	$76
ERV w/o AHU	595	13	$68

Table 6. Annual modeling results showing increased energy use and cost for each ventilation system (compared to a home with no ventilation). Furnace fan power consumption is 250 Watts.

The last line of Table 6 shows results of modeling an ERV system that does not use the central air handler to distribute air. Such a system requires separate ductwork for delivering ventilation air. As described above, the ERV in the first South Chicago home was originally ducted into the heating ducts in the basement without controls to operate the furnace fan. This proved entirely unacceptable as CO_2 concentrations were often above 2000 ppm in the living spaces before SWA installed controls to distribute fresh air with the air handler. Running dedicated ventilation ducts certainly carries extra costs but, as shown above, there are considerable energy and cost savings.

Summary and Conclusions

Among the systems monitored, it is clear that the exhaust only system is the least costly to operate; costs were less than 50% of those of the other systems. Looking at carbon dioxide concentrations and air distribution, SWA believes that data show that the exhaust system does provide adequate distribution and is the most appropriate system for these homes.

It is worth reiterating that the exorbitant energy costs for the Air Cycler™ and ERV systems would be significantly reduced with electrically efficient, well-sized furnaces or especially (in the case of the ERV) with a dedicated duct system for ventilation.

This study certainly does not suggest that exhaust-only systems are appropriate for all applications. These small homes had an efficient exhaust fan in the center of both floors (each approximately 850 ft^2). The effectiveness of exhaust strategies in larger homes requires more investigation, and the need for active air distribution may grow as house size increases. Nevertheless, this study shows that exhaust-only ventilation certainly can be a very effective, low-cost ventilation option.

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