USER "FRIENDLY", RESIDENTIAL VENTILATION SYSTEM CONTROL STRATEGIES AND EFFECTIVENESS

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ABSTRACT
The most efficient ventilation system would only operate on demand, when ventilation was "needed". Running the ventilation system all the time at a low flow rate, a rate sufficient to match the ASHRAE recommended .35 ACH is a crude control approach to an optimum system. Conditions in a house are not constant. On average, a constant flow rate ventilation system will work reasonably well and certainly is simple, but there are more energy efficient approaches, and users tend to shut down systems that run constantly. Optimizing the ventilation control system is a way to meet the airflow requirements while minimizing the operating cost. Optimization must include consideration of the installer "setup" and user interface. The most perfect ventilation system is useless if it does not run. This paper considers the previous research that has been performed regarding ventilation system control approaches and user interface with the system, and then relates the results of a test of six different ventilation control approaches in an attempt to determine the optimum, most "user friendly", most energy efficient systems.

INTRODUCTION
A lot of different control strategies for residential ventilation systems have been tried including cycle timers, humidity controls, motion sensing controls, mixed gas, and CO_2 controls. Determining when one system is more applicable than another and if there is a "best" general strategy for residential ventilation control is a difficult question to answer. Since it is not feasible to remove all indoor pollutants directly at their source, a general mechanical ventilation system that reduces the concentration levels through dilution and removes some of the pollutants is key to improving indoor air quality. And if the pollutant source were constant, the airflow rate could be constant and no control would be needed. The Effective ACH is equivalent to the pollutant source strength divided by the average concentration. If the rate of air change is not constant and the pollutant source is constant, then the Effective ACH will be reduced.

Pollutant levels in a house are rarely constant such as a piece of Limburger cheese sitting on the kitchen table. Although it is simpler to set a standard ACH rate, it is not the most economical or effective approach. The right control strategy optimizes the ventilation system.

Because of the complexity of the problem, to date the only manageable way to build comfortable environments has been to generalize the parameters within which comfort and safety can be achieved. From a comfort maintenance standpoint, people would live in "moon suits"; each body contained within a limited space within which all the parameters of that particular body would be optimized. Moving away from such an impractical ideal toward a more manageable condition requires generalizations. Temperature, for example, is a relatively easy component to both measure and control and thermostats are the most common and familiar of residential controls. People have gradually come to accept the fact that the temperature in the house need not be the same at all times, and time of day or programmable thermostats have become much more common.

The ideal ventilation system would be controlled in a similar way. The difficulty is that there is no obvious condition parameter such as temperature for a ventilation control to sense. A wide range of approaches have been tried with mixed results.

INSTALLED SYSTEMS

Although a great deal of work has been done on ventilation strategies and the means to determining ventilation rates, most of the work has considered that a residential ventilation system will supplement a natural ventilation rate. The work with ASHRAE 62-2 has been to struggle to establish an annual average ventilation rate, and there was extensive discussion about how much credit to give for “natural ventilation” due to building infiltration, stack and wind effects. If the ventilation system is going to run 24/7, there is no question of how it is controlled. But just as a passive ventilation system can under-ventilate when indoor and outdoor temperatures are similar and there is no wind and no driving force and over-ventilate under the opposite conditions, a ventilation system that runs all the time will also over or under ventilate the space. The mathematical “average” ventilation rate may be achieved either way, but the instantaneous conditions may not be satisfied.

The most common mechanical ventilation system for American residential applications is a fan in the bathroom. There are certainly other mechanical devices that move air through homes such as range hoods, clothes dryers, and central vacuums and passive systems such as fireplaces, combustion appliances, and windows. A variety of state and local energy and weatherization programs, however, require that the home have at least one bathroom fan to provide a flow of air through the home and this becomes the “ventilation system”.

The most common residential ventilation “control” is a manual switch. The fan is activated when the occupant wants it to. Exhaust fans controlled this way operate only a few minutes to 1.5 hours per day (Parent, Fugler, 1994), kitchen fans 15 to 45 minutes, and clothes dryers 45 minutes to 2.75 hours. Occupant controlled fans are minimally used. More than 81% of the tenants in one study reported using the fan for less than one hour per day. The rest didn’t use them at all. (Hayes, Shapiro-Baruch, 1994) The driving forces to activate the bathroom fan are condensation on the mirror or odors in the air. A typical bathroom fan moving less than 9.5 L/s (20 cfm) for this length of time will have little effect on the humidity level in the bathroom far less the house. Coupling the fan to the light switch guarantees that as long as the bathroom is occupied the fan will be running, but this does not significantly increase the length of operating time. Although not common in the U.S., a delayed “off” switch will increase the length of time the fan stays on. Controlling the fan with a motion detector is quite similar to the switch connected to the room light.

Running the ventilation fan constantly assures that an average ventilation rate can be achieved. In small houses (under 140 m^2 (1500 ft^2)), running the fan continuously has been shown to be the most effective means for removing moisture (Kelley, 1996). The cost for constant fan operation has been shown to be more complex than simply adding the fan induced flow rate to the natural airflow. Evidence suggests that the fan-induced flow will dominate the air change rate, offsetting some of the natural forces. Theoretical work done at LBL in 1990 (Sherman, 1990) and field studies done by ECOTOPE for EPRI (Palmiter, Bond, 1991) support this. But calculating just the cost of the total energy exhausted at 9.5 L/s over the course of a heating season results in 1200 kWh for a tight house. Added to that must be the cost of motor operation.

Fans use less power than their motor ratings. The actual power consumed depends on break horsepower, which is governed by the work done in the actual installation. The power consumed by the motor may far exceed the energy saved by a heat recovery system. A bathroom fan running at less than 20 watts continuously would consume 175 kWh whereas an HRV system running at 147 watts would consume nearly 1700 kWh. If the 20 watt fan exhausted 1200 kWh, it would have a total energy cost of 1,375 kWh, whereas an 80% efficient HRV would have a total energy cost of 1,940 kWh.

(watts x hours/year)/1000 + energy exhausted by the air flow = fan energy cost

Beyond the basic cost of operating the system all the time, the occupant of the house often feels that he or she should have some control of the system. In the summer, the windows in the house may be open, and running the fan even for a low operating cost, may seem unnecessary or even foolish. And although it may be unlikely at the low flow rates, there may be times when running the system may seem to create uncomfortable conditions. These may seem like small concerns to the building scientist, but many systems have been shut down or defeated, creating a condition where there is no mechanical ventilation in a tight house (Tsongas, 1995).

A modicum of control can be provided to the homeowner by providing them with a control that allows them to boost the flow rate of the system on demand. (Raymer, Kelley, 2000) If the background flow rate is low and the system is very quiet, the homeowner may barely notice the constant operation as long as they are able to use the system for what they believe it is there for – removing odors or defogging the mirror.

Since poor indoor air quality can only affect people when they are in the house, the operating time and cost can be limited to periods of occupancy by using a cycle timer. (Shapiro, Cawley, King, 1999) Occupation is commonly during the night, but will change on weekends and can be quite unpredictable. If the timing mechanism is electro-mechanical, it will be shifted by power failures. An electronic timing control can avoid the power failure problem with battery back-up or other memory storage capability, but the periods of occupancy can only be guessed at in advance. And the problem of user interference arises again if the occupant cannot shut the system off when they don't feel it is necessary for it to be running.

If the system operates under positive pressure, drawing fresh air into the return side of the air handler and using the existing system blower to circulate it around the house, control can be provided by the thermostat. By adding a timer to the system, the optimum run-time for ventilation can be preprogrammed and the total required run-time of the air handler can be limited. (Fugler, 2000). This approach does an effective job of circulating fresh air throughout the house, but it does require the use of the system's air handler blower, a generally inefficient device.

Controlling the ventilation system by "demand" is an ideal approach since the system will only be running when there is a "need" for ventilation. The difficulty is in selecting the correct, measurable "marker". In commercial and school applications this is CO_2 (Bearg, 1995) (Turpin, 2000) where the level of CO_2 can accurately reflect the number of people in the space. CO_2 sensors, however, have been expensive and susceptible to drift and the need for regular recalibration. (Barley, 2001)

Since humidity can often be the cause of a high number of IAQ problems, it can also be used as an effective marker (Liddament, 2000). A ventilation system, however, can only push air out or bring air in and effect a change in humidity level by diluting the indoor air. If the humidity level of the diluting air is higher than the humidity of level of the air to be diluted, it will obviously incur a negative effect, actually causing the system to continue to run, steadily increasing the RH level. (Tsongas, 1995) Several sophisticated electronic controls have been developed to avoid this situation. One of these utilizes a differential humidity approach, measuring both the fresh air source and sink and preventing the system from operating if the source level exceeds the sink level. Another approach is to activate the fan system on a rapid change in humidity conditions. The operation of a shower will generate an "unnatural" humidity change, indicating that the ventilation system should be running to remove the humidity. Another approach is to simply measure the outside humidity and prevent the fan from running when the external RH is above a certain level. (Parent, Fugler, 1994)

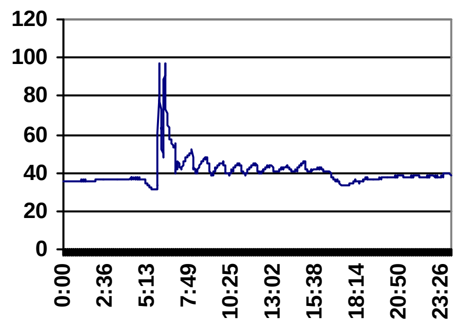
An interesting new approach is to combine a "mixed gas" sensor and a "sudden" humidity sensor to control the ventilation system. Stable, reliable and low cost sensors are available that can detect H_2, CO, NH_3, H_2S, $C_6H_5CH_3$, HCHO, and other gases that are likely to be contained in cigarette smoke. Looking for a rapid change in any of these conditions can offer a reasonable means for monitoring occupancy of a space. Preliminary tests in the author's home with such a control have shown that the system not only responds to obvious pollutants such as humidity and flatulence, but also activates the system when no user noticeable conditions would warrant it.

The control's microprocessor constantly calculates and maintains a baseline value for its inputs. The microprocessor samples the signal from each sensor once a second. The reading at two minutes is considered the Baseline value. If the current one-second reading exceeds the Baseline value plus the Delta or Spike value (set at 5%), the fan will turn on. While the fan is running, the Baseline value is not updated. When the instantaneous value drops below the Baseline value, the fan shuts off. If the Spike value does not return to the Baseline value within three hours, the fan is shut off and the Baseline value is recalculated.

CONTROL SYSTEM TESTING

A variety of control systems were tested in a small bathroom in an occupied home. A sampling device was used that recorded the levels of temperature, relative humidity, CO_2, CO, small particles, large particles, TVOC's, and radon. The controls were connected to a 23 l/s (49 cfm) in-line exhaust system. (This was the flow rate with the room door open. The flow dropped to 20 l/s or 43 cfm with the room door closed.) The bathroom has a volume of 8.5 m^3 (300 ft^3) and is heated by a steam radiator connected to a central thermostat. The system was tested with no control (fan off), fan on constantly, fan on manually during occupancy, fan on with humidity set point at 30%RH, fan controlled by time set at 20 minutes per hour, and the fan controlled by the mixed gas/sudden humidity change control. The bathroom was typically used for two showers in succession each morning with the heat turning on to warm the building at 5AM.

The temperature trace was fairly consistent for all the control systems, varying from a low of 4.5°C (66°F) at 5AM and a high of 15°C (85°F) at 7AM. The twenty minute on-time control created a 1.1°C (2°F) fluctuation in the curve as the temperature dropped back down to 4.5°C (66°F) at 4PM and the room heat came back on. The Constant-On fan control dropped the temperature to 3°C (63°F). Since the house temperature did not drop below 4°C (65°F) at the same time, it is likely that the system was drawing air in from the outside. The fan's 15% decrease in flow with the door closed, indicates the increase in negative pressure in the room.



RH Level Using Timed Control

The airflow from the system was not enough to overcome the massive surge in humidity when the shower was turned on. After the spike, the humidity settled back to 46% RH in the No-Fan configuration. The On-Occupancy configuration dropped the humidity to 45%, Timed-On to 38%, Humidity-On to 38%, Mixed-Gas to 35% and Constant-On to 30%. The "saw tooth" pattern that was apparent in the Timed-On temperature curve was exaggerated in the humidity curve, swinging between 40 and 46% RH over each 20 minute period between 7AM and 3PM.

Control of the CO_2 level is complex to summarize. The Fan-On control had the lowest average CO_2 level; the Humidity-On control the highest. The general curves of the Fan-On and Humidity-On controls were quite similar spiking during morning occupancy and then curving down to below 470 ppm for the rest of the day. There was little apparent impact on the small and large particle counts, the CO or Radon levels from any of the fan systems.

The TVOC index readings were similar in the No-Fan, Fan-On, Humidity-On, and Mixed-Gas - all averaging below 1. The On-Occupancy controlled system averaged 1.75 and the Timed-On system 5. But there is no clear indicated relationship in the data that any of the fan systems had any effect on the TVOC level.

Operating the system with No-Fan set the baseline, establishing the worst operating conditions. Operating the system with the Occupancy-On control had remarkably similar results to having no fan at all. Since this is the most common installation, this lack of effect is perhaps the most dramatic result of these tests. The Fan-On control reduced the temperature more quickly in the room, indicating an excess of heat being removed. The Time-On control set to 20 minutes performed reasonably well, although a somewhat longer run time or greater flow rate is suggested from the oscillating results.

Configuration	**Average RH**	**Temp Drop 4 Hrs (ºC)**	**Max TVOC (index)**	**Average CO_2 (ppm)**	**Small Part Decay Time (hrs)**
No-Fan	41	6.8	1.99	943	6:05
Fan-On	34	9.02	4.16	667	1:53
On-Occupancy	40	7.73	4.6	985	4:39
Humidity-OnCntr	37	7.26	10.9	1019	1:05
Mixed-Gas On	36	8.41	2.46	933	4:38
Timed-On	37	4.39	32.16*	806	3:24

*This reflects a burst of cleanser.

The differences between the various strategies are subtle, and no definitive "winner" resulted from these tests. Elements such as the max TVOC level appear to be indicative of events in the room rather than the fan operation. The large particles recorded by the system reflect the water droplets from the shower operation. The effect of the small particle decay time, i.e. the length of time for the small particle level to return to a low level after a shower is potentially a good indicator of the ventilation effect if the particle source emission and timing can be controlled, which it was not in this test.

It is clear that a residential ventilation system needs to be controlled over a longer period of time than just during occupancy. These tests were not long enough to clearly answer the question of what the most effective control system would be. Indicators such as humidity and CO_2 are not concurrent so that control by either of these factors may miss conditions indicated by the other. A more definitive research project would have to be done under "real world" conditions, conditions that are difficult to control. There remains the question of what exactly would the "ideal" ventilation control be able to do? The entire debate about the correct volume of airflow for a residential ventilation system is moot if the system is not allowed to run long enough. Selecting the right control is as important as selecting the right fan and detailing the installation.

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