Optimization of Occupancy Based Demand Controlled Ventilation in Residences

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Abstract

Although it has been used for many years in commercial buildings, the application of demand controlled ventilation in residences is limited. In this study we used occupant exposure to pollutants integrated over time (referred to as "dose") as the metric to evaluate the effectiveness and air quality implications of demand controlled ventilation in residences. We looked at air quality for two situations. The first is that typically used in ventilation standards: the exposure over a long term. The second is to look at peak exposures that are associated with time variations in ventilation rates and pollutant generation. The pollutant generation had two components: a background rate associated with the building materials and furnishings and a second component related to occupants. The demand controlled ventilation system operated at a low airflow rate when the residence was unoccupied and at a high airflow rate when occupied. We used analytical solutions to the continuity equation to determine the ventilation effectiveness and the long-term chronic dose and peak acute exposure for a representative range of occupancy periods, pollutant generation rates and airflow rates. The results of the study showed that we can optimize the demand controlled airflow rates to reduce the quantity of air used for ventilation without introducing problematic acute conditions.

Key words: demand controlled ventilation, airflow rates, equivalent dose, acute to chronic exposure, effectiveness.

1. Introduction

Ventilation is used to provide an acceptable air quality by controlling the concentration of pollutants in a space. The quantity of whole-house ventilation required to provide acceptable indoor air quality depends on the emission rates of pollutants in a space. In most buildings pollutant emission rates depend on occupancy, and are higher when occupants are present due to biological processes and occupant activities. These emissions are in addition to the emissions from materials within the building that occur independent of occupancy. Some pollutants with short emission profiles such as moisture emitted during cooking or showering are often dealt with by source control methods, although they may be considered to be a part of the background emission over the long term. Other short term emission and exposure related issues include chemical reactions and household cleaning products (Singer et al. 2006), particulate generation by cooking, particulate resuspension from vacuuming (Corsi et al. 2008), and differences in concentrations between breathing zone air and spatial averages (Novoselac et al. 2003). Codes and standards for indoor air quality in residences treat short-term high polluting localized events separately from whole house ventilation. Typically this is achieved from a standards and house design perspective by exhausting air from kitchens and bathrooms when these rooms are in use. Other events in other rooms of a house are not explicitly addressed, as there is no practical way to do so. Instead, they are dealt with indirectly through the whole house ventilation system that implicitly assumes that pollutants are well mixed in the space. This is a reasonable assumption for the long-term chronic exposures that whole house ventilation typically is recognized to address. From a practical point of view, it is also the only reasonable approach for codes, standards and system design in which spatial and temporal distribution of pollutants and the magnitude of mixing within and between zones is effectively unknowable. Disregarding these localized effects does not change the results or conclusions of this study because we are comparing the performance of whole house ventilation systems and these complications would be the same for all

whole house systems. For simplicity and to ensure relevance to potential users of the equivalent dose approach, this study follows existing codes and standards for residential ventilation requirements that focus on pollutant removal by ventilation and not by other mechanisms such as filtration or sorption on surfaces. Furthermore it does not include dilution due to natural infiltration, which is highly variable from building to building, and with external weather conditions. Instead we focus on intentional ventilation for pollutant control.

The intent of this study is to provide results that can provide more flexible approaches to ventilation design for residences that allow Demand Controlled Ventilation (DCV) approaches to comply with codes and standards that are currently based on continuous ventilation rates. This study will also show that reductions in the quantity of air used for ventilation (and the energy used to condition this air) can be achieved without impacting health – either in terms of long-term exposure (that is addressed by current ventilation standards) or short-term acute impacts.

The ventilation required in buildings today by standards and building codes is often given by a constant airflow rate (Constant Air Volume or CAV). It is typically recognized that the rates are set to keep long-term exposures at an acceptable level. A constant ventilation rate is an appropriate solution when pollutants are emitted at a fixed rate. However, any variation in emission of pollutants means that the constant ventilation rate may lead to periods with poor short-term indoor air quality when the ventilation rate is too low and/or unnecessary energy consumption when the ventilation rate is too high. In this study appropriate ventilation rates based on demand are not set from a health perspective because thorough knowledge of all pollutants health effects on people are needed to do this. Instead we make use of the fact that the requirements for long-term acceptable air quality indirectly are set by the codes and standards. We examine the effects of varying ventilation rates as occupancy changes and look for optimum air flows that minimize the quantity of air used for ventilation that gives long-term chronic exposures equivalent to that provided by existing codes and standards. Although we do not directly calculate the energy impacts it can be assumed that reducing the quantity of air implies a reduction in energy use.

We use the concept of dose, which is the integrated exposure to a pollutant over time, as the metric for equivalent long-term chronic exposures. We assume exposure and thus dose is linearly proportional to the pollutant concentration. Dose is used because the vast majority of indoor air quality issues examined for ventilation standards are limited to chronic, long-term exposure and do not address short-term acute exposures or highly toxic substances with non-linear dose response for human health. However acute exposure can become a concern for some pollutants so we also examine the ratio of acute to chronic exposures and compare these with literature. Other criteria to assess the performance of residential ventilation systems concerning hygiene and indoor air quality are given in the standard EN15665 (CEN 2009). To provide acceptable ventilation with variable ventilation rates we require that the dose be the same or lower than that provided by a constant ventilation rate.

Occupants are not exposed to pollutants when they are absent and a key concept in this study is therefore to limit dose calculations to times when occupants are present. Our task is to identify the airflow rates that provide the same dose. Because concentration and ventilation are dynamically and inversely related through the continuity equation the dose cannot be calculated in a straightforward manner. Instead, we develop analytical solutions that specify how much air is needed in one ventilation system compared to another to obtain the same dose. We define the ratio of air requirements between systems as the ventilation effectiveness.

2. Background

The principle of air quality equivalency in terms of dose was studied for intermittent ventilation systems by Sherman (2006) The results of the study have been included in ASHRAE Standard 62.2 (ASHRAE, 2010) by allowing intermittent ventilation provided that the ventilation rate is raised when the ventilation system is operating. Sherman's study was limited to on/off operation of the ventilation system, constant emission of pollutants, and dose was evaluated on a 24 hour basis.

Sherman expanded the study of equivalent air quality in terms of dose so that the three parameters: ventilation rates, emission rates and the evaluation period of dose could vary (Sherman et al., 2011). Because roughly the same things occur in a building on a daily basis the pollutant emission and ventilation patterns are repeated resulting in a cyclic pollutant concentration and a general expression for

dilution of an unsteadily generated pollutant by a variable ventilation rate, under cyclic temporal boundary conditions was derived.

The general equation for the time-varying concentration under cyclic boundary conditions is:

$$C(t) = \frac{\int_{t-T}^{t} S(t')\xi(t,t')dt'}{(1-\xi(T,0))} \quad (1)$$

where

$$\xi(t,t') \equiv e^{-\int_{t'}^{t} A(u)du} \quad (2)$$

C is pollutant concentration, A is ventilation rate, S is pollutant source strength, T is the duration of the cyclic period and t is time. The time-varying concentration was integrated over the cyclic period T to calculate the dose d (Equation 3). To omit or emphasize parts of the cyclic period differently than others a weighting function W was added. The weighting function can account for occupancy, i.e., when occupants are absent W=0 and the pollutant concentration during that period does not contribute to the dose.

$$d = \frac{\oint W(t) \int_{t-T}^{t} S(t')\xi(t,t')dt'dt}{(1-\xi(T,0))} \quad (3)$$

3. Method

These equations were used in this study to calculate the ventilation effectiveness of a DCV system together with the system's effect on indoor air quality. The effectiveness only considers time variation of the airflow rate and not local inefficiencies associated with imperfect mixing within and between zones or the spatial distribution of pollutants in the home. Pollutants were assumed to be removed by ventilation and not by other mechanisms such as filtration or sorption on surfaces. The performance was evaluated using a CAV system as a reference case and this system set the target for equivalent dose. The performance of the DCV system was evaluated assuming a repeated 24 hour cycle during which there is one step change in pollutant emission rates from high to low corresponding to a change from the residence being occupied to unoccupied. There is a corresponding step up at the end of the unoccupied period. There is only one occupied period in each 24 hour cycle. During both occupied and unoccupied times the pollutant emission and ventilation rates are constant. Because the ventilation and emission profiles were step-wise constant we could set up an analytical expression for equivalent dose for the CAV and DCV systems using Equation 3. The equivalency equation was solved to find the airflow rates in the DCV system that provided equivalent dose to the CAV system.

The generation of pollutants comprised of a constant part ($S_{constant}$) associated with the building and an intermittent part ($S_{intermittent}$) associated with the occupants. The pollutants were assumed to be additive resulting in a step-wise constant emission profile. The pollutant profile was described by the emission ratio (ER) relating the emission during occupied hours to unoccupied hours.

$$\mathrm{ER} = \frac{\mathrm{S_{constant}} + \mathrm{S_{intermittent}}}{\mathrm{S_{constant}}} \quad (4)$$

The DCV system was controlled by occupancy with a high airflow rate during occupied hours and a low airflow rate during unoccupied hours. There exist many combinations of high and low flow rates that provide a dose equivalent to that in the CAV system. However, the range of possible DCV systems is restricted by the low rate ($A_{DCV,low}$) that never can be less than zero. We further limited our investigations to DCV systems where the upper bound for the low rate is the ventilation rate of the CAV system. The low rate was therefore used to categorize the range of DCV systems by introducing the Low-Ventilation Factor (LVF) that expressed the low ventilation rate as a percentage of the CAV rate, A_{CAV}. At a low-ventilation factor of 1 the low and high airflow rates are identical.

$$\mathrm{LVF} = \frac{\mathrm{A_{DCV,low}}}{\mathrm{A_{CAV}}} \quad (5)$$

The low and high ($A_{DCV,high}$) airflow rates that provided equivalent dose were used to express the effectiveness (ε) of the system. The effectiveness is a measure of how good the DCV system is at providing an air quality relative to the CAV case. The effectiveness is defined by the volume of air one would need in the reference system to that needed in the DCV system throughout the cyclic period. For the occupancy controlled DCV system the effectiveness is calculated by:

$$\varepsilon = \frac{A_{CAV}}{A_{DCV,low} \cdot (1 - f_{occ}) + A_{DCV,high} \cdot f_{occ}} \quad (6)$$

Where f_{occ} is the fractional occupied time during the cyclic period *T*. Systems can have equivalent dose but different cyclic concentration profiles resulting in different peak concentrations. To evaluate the overall air quality performance of the systems we calculated acute to chronic exposures represented by peak to average dose exposures using Equations 1 and 3. Furthermore, an analysis determining how uncertainties in the high and low ventilation rates influence the effectiveness and dose during occupied hours was made.

3.1 Example Calculations

To determine optimum airflow rates for occupancy controlled DCV systems the total airflow reductions over 24 hours were calculated for three scenarios using representative values for CAV airflow rate, occupied hours and emission ratios.

In the first scenario we evaluated the effect of increasing the ventilation rate when people are present. The generation of pollutants was constant (ER=1) and we used a reference CAV rate of 0.5 h^{-1}. The number of occupied hours was based on studies of occupancy in buildings (Brasche et al. 2005; Leech et al. 2002) that showed that people in general spend 16 hours a day in their home. To cover upper and lower limits of people's presence in their home occupancies of 8 and 20 hours were also analyzed.

The second scenario evaluated the effect of increasing the ventilation rate when people are present and more pollutants are emitted during these hours. We used a reference CAV rate of 0.5 h^{-1} and assumed people were present in the home 16 hours a day. Emission ratios were deduced from ASHRAE Standard 62.2 (ASHRAE 2010) and EN15251 (CEN 2007) that both use floor area and number of occupants to specify continuous ventilation requirements. The floor area is related to the emission of pollutants from the building and the number of occupants is related to the additional emission of pollutants due to occupants. In this study we assumed that pollutant emission rates are proportional to the airflow rates in the standards. The emission ratios for a home of 120 m^2 and varying number of occupants are given in Figure 1(a). A common occupancy for the home is estimated to be 2-3 people, which means that ER equals approximately 1.5. In Figure 1(b) minimum, maximum and mean emission ratios for homes of 60, 120 and 180 m^2 and expected occupancies have been calculated from the two standards. The average value for all three homes is approximately 1.5 and we evaluate the effectiveness using this value.

Furthermore we analyzed cases with upper and lower limits of ER equal to 1 and 4. The emission ratio of 1 corresponds to occupants emitting no pollutants. The emission ratio of 4 corresponds to people being the main pollutant source. This high ER case is of increasing interest as occupant generated pollutants becomes more important due to the development, regulation and labelling (e.g., California Environmental Protection Agency

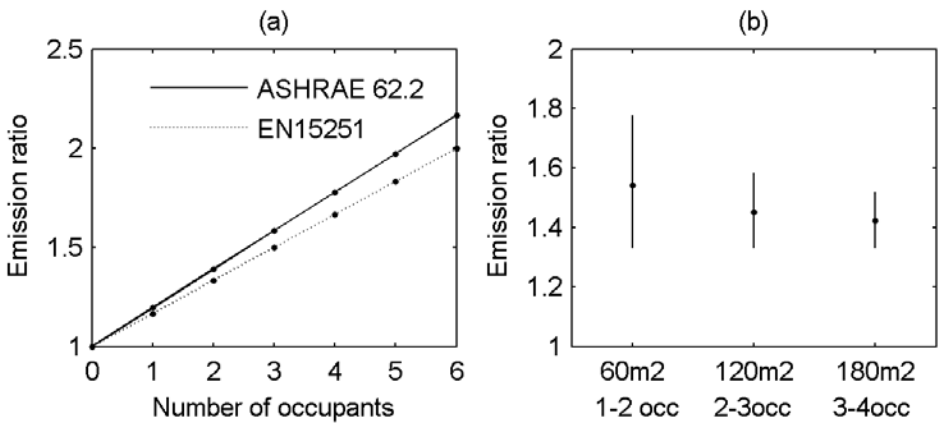

Figure 1. (a) Emission ratios for a 120 m^2 home with various number of occupants. (b) Emission ratio for typical matching home sizes and occupants.

composite wood product Airborne Toxic Control Measure (CEPA, 2011) and Danish Indoor Climate Labelling (DICL, 2011)) of low emitting buildings materials and furniture.

The last scenario evaluated different reference CAV rates. We did this for a case with 16 occupied hours and an emission ratio of 1.5. The CAV airflow rates were selected based on residential ventilation requirements. The ventilation required in residential buildings in Denmark (BR10, 2010) corresponds to 0.5 h^{-1}. The ventilation required by ASHRAE 62.2 is approximately 0.35 h^{-1} including a credit for infiltration and we use this as a lower boundary for the CAV rate. Furthermore we analyzed at an upper limit for the CAV rate of 1.0 h^{-1}.

4. Results

4.1 Cyclic Concentration Profiles

To enhance the explanation of the results of dose based design of DCV systems, the 24 hour cyclic concentrations for low-ventilation factors of 1, 0.75, 0.5, 0.25 and 0 and emission ratios of 1 and 4 are shown in Figures 2 and 3, respectively. Both figures have a reference CAV rate of 0.5 h^{-1} and 16 occupied hours (hour 0 to 16). The cyclic concentration is normalized to the maximum concentration for the CAV system. Integration of the cyclic concentration from hour 0 to 16 gives us the occupant dose. The occupant dose is equivalent for the five low-ventilation factors when the emission ratio does not

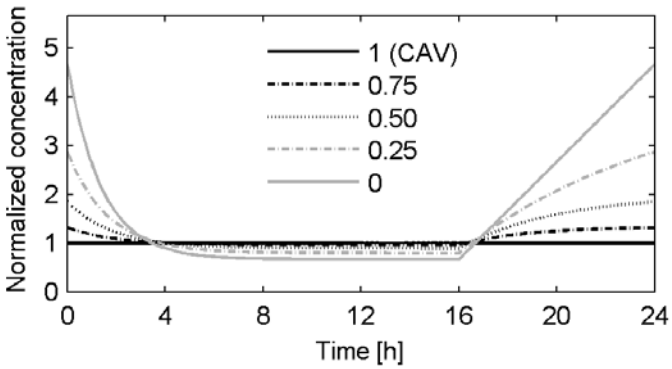

Figure 2. Cyclic concentration profiles for five low-ventilation factors normalized to the maximum concentration in the reference CAV system. All systems have an emission ratio of 1, 16 occupied hours and the reference CAV rate is 0.5 h^{-1}.

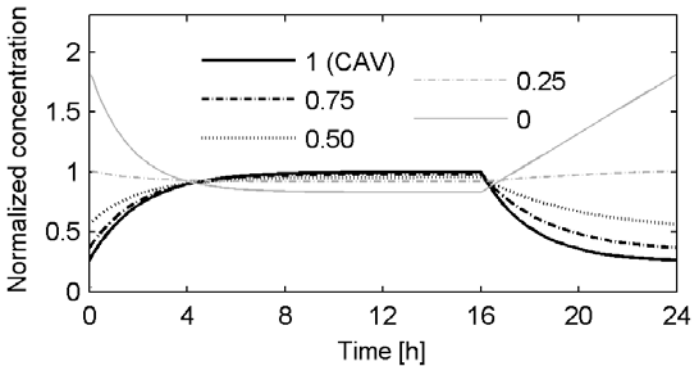

Figure 3. Cyclic concentration profiles for five low-ventilation factors normalized to the maximum concentration in the reference CAV system. All systems have an emission ratio of 4, 16 occupied hours and the reference CAV rate is 0.5 h^{-1}.

change. However, the dose changes when the emission ratio, reference CAV rate or the number of occupied hours change. At an emission ratio of 1 the CAV rate holds the concentration constant at a steady state value shown in Figure 2. Lowering the ventilation rate during unoccupied hours results in increased concentration at the beginning of the occupied period and the peak concentration in the DCV systems is therefore always higher than the peak concentration in the CAV system.

Changing the emission ratio from 1 to 4 strengthens the incentive to ventilate less during unoccupied periods. When the high to low airflow ratio equals the emission ratio the concentration is held at a constant steady state value and for ER=4 this occurs when LVF is between 0.25 and 0.5, as shown in Figure 3. At high to low airflow ratios above ER the peak concentration occurs at the beginning of the occupied period but shifts to the end of the occupied period when the high to low airflow ratio is below the ER.

4.2 Scenario 1

Effectiveness curves for 8, 16 and 20 occupied hours are given in Figure 4. Each occupancy time has one combination of low and high flow rates where the effectiveness peaks. This peak corresponds to the minimum amount of air required to provide equivalent dose. The effectiveness is 1 at the LVF boundaries of 0 and 1. The upper LVF boundary is identical to the CAV that is our reference case. At the lower boundary where there is no ventilation during unoccupied hours we observe that ventilation is linearly related to concentration for ER=1. The maximum effectiveness increases with fewer occupied hours from 1.03 to 1.36 within a narrow range of LVF from 0.33 to 0.44. For the case of 16 occupied hours and a CAV rate of 0.5 h^{-1} the amount of air can be reduced by 9% (maximum effectiveness=1.10) when the LVF is 0.4.

Table 1 show the high and low airflow rates necessary to achieve maximum effectiveness expressed as a percentage of the CAV rate (in the same way as the low-ventilation factor expresses the low airflow rate as a percentage of the CAV rate). Furthermore the high to low airflow ratios are calculated. Shorter occupied times require higher airflow rates during occupied hours to provide equivalent dose but also lower airflow rates during unoccupied hours. This result in increased high-to-low airflow ratios with fewer occupied hours.

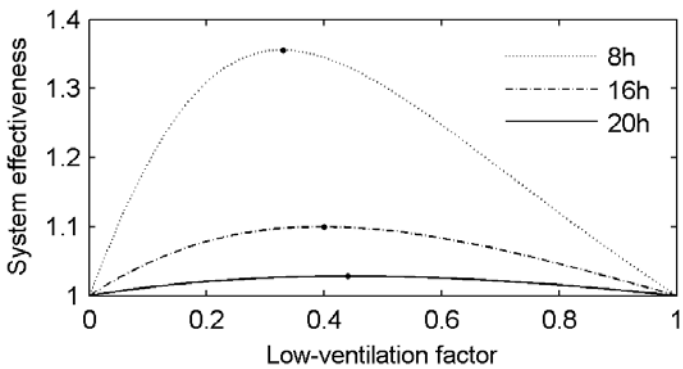

Figure 4. Changes in effectiveness for three periods of occupancy as a function of the low-ventilation factor. Reference CAV rate is 0.5 h^{-1} and emission ratio is 1. Peak effectiveness' are marked by a dot.

Table 1. High and low airflow factors at peak effectiveness.

	8h	16h	20h
LVF ($A_{DCV,low}$/ A_{CAV})	0.33	0.40	0.44
$A_{DCV,high}$/ A_{CAV}	1.55	1.16	1.08
High-to-low airflow ratio	4.7	2.9	2.5

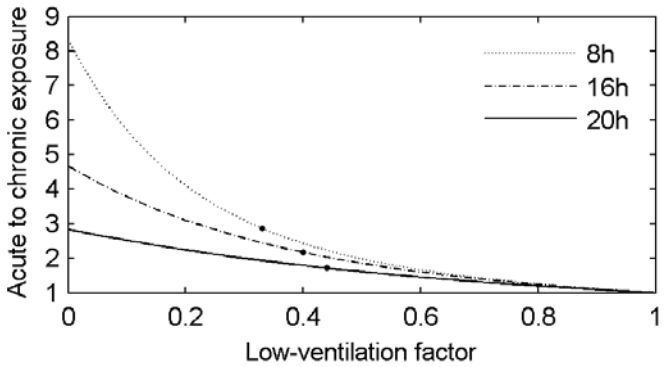

Figure 5. Acute to chronic exposure for 8, 16 and 20 occupied hours. Peak effectiveness' are marked by a dot on the curves.

Figure 5 shows the variability in acute to chronic exposure. Because the CAV rate holds the concentration constant at a steady state level the acute to chronic exposure is 1 at LVF=1 and above 1 for all other LVF and the peak concentration always occurs at the beginning of the occupied period (see cyclic concentration profiles for ER=1 in Figure 2). For the case of 16 occupied hours the acute to chronic exposure at maximum effectiveness (LVF=0.40) is approximately 2.2 times that in the CAV system. The acute to chronic exposure is 1.7 to 2.9 at maximum effectiveness for occupancies of 20 and 8 hours respectively.

4.3 Scenario 2

The second scenario evaluated the effect of increasing the ventilation and pollutant emission rate when occupants are present for the case where occupants are present 16 hours a day and the reference CAV rate is 0.5 h^{-1}. Figure 6 shows effectiveness curves for emission ratios of 1, 1.5 and 4 where the peak effectiveness is 1.10 to 1.22. These maximum values occur when the LVF is in the range of 0.13 to 0.4. The greatest reduction in total volume of air is 18% (maximum effectiveness = 1.22) when the ER is 4.

The high and low airflow factors necessary to achieve maximum effectiveness expressed as a percentage of the CAV rate are given in Table 2 together with the high-to-low airflow ratios. The high airflow rate at peak effectiveness is almost independent of the emission ratio. However the low-ventilation factor is reduced with higher emission rates resulting in increased high-to-low airflow ratios at higher emission ratios.

Figure 7 shows how the acute to chronic exposure changes with emission ratio. At LVF=1 the acute to

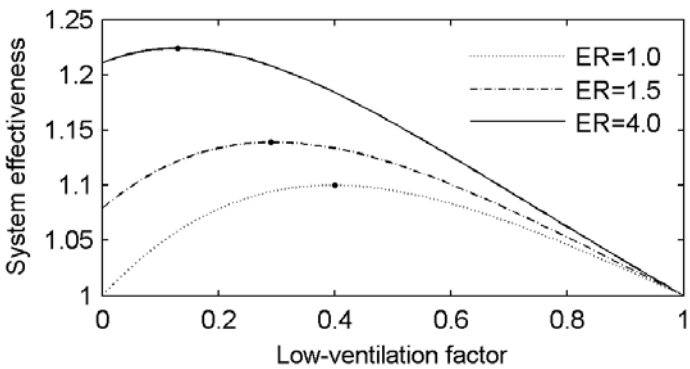

Figure 6. Changes in effectiveness for three emission ratios as a function of the low-ventilation factor. Peak effectiveness' are marked by a dot.

Table 2. High and low airflow factors at peak effectiveness.

	ER=1	ER=1.5	ER=4.0
LVF ($A_{DCV,low}$/ A_{CAV})	0.4	0.29	0.13
$A_{DCV,high}$/ A_{CAV}	1.16	1.17	1.16
High-to-low airflow ratio	2.9	4.0	8.9

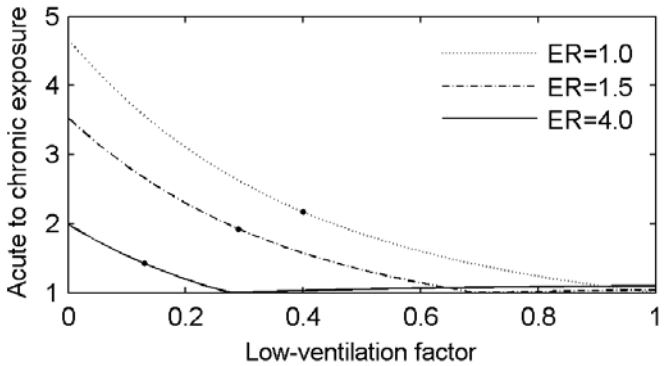

Figure 7. Acute to chronic ratio as a function of low-ventilation factor. Peak effectiveness' are marked by a dot on the curves.

chronic exposure is above 1 when ER>1 (1.04 when ER=1.5 and 1.10 when ER=4) because the cyclic concentration is not steady, whereas it is 1 when ER=1. For ER=1.5 the acute to chronic ratio is 1 when LVF is 0.70 because the high to low ventilation ratio is 1.5 (high-ventilation factor=1.04) and the concentration is thereby held at constant steady state value. In this system the effectiveness is 1.08 resulting in a 7% reduction in total volume of air. When ER=4 the acute to chronic exposure is 1 when LVF=0.28 and the high-ventilation factor is approximately 1.10. The effectiveness is 1.21 resulting in a reduction in total volume of air of 17%. This means that if ER>1 we can reduce the total volume of air and at the same time improve the air quality compared to CAV operation. The acute to chronic ratio is between 1.3 and 2.2 at maximum effectiveness. The highest ratio and thereby the worst case occurs when the emission ratio is 1.

4.4 Scenario 3

Finally we evaluate the reference CAV rates effect on system effectiveness. We do this for the case where people are home 16 hours a day and the emission ratio is 1.5. Figure 8 shows the effectiveness for CAV rates of 0.35, 0.5 and 1.0 h^{-1} and it is seen that the maximum effectiveness increases with increasing CAV rate. The maximum effectiveness ranges from 1.10 to 1.21 and at these peak values the low-ventilation factor is 0.32 and 0.24 respectively. At a CAV rate of 0.5 h^{-1} the maximum expected reduction in total volume of air is about 12% (maximum effectiveness=1.10 at LVF=0.29).

The high and low airflow rates necessary to achieve maximum effectiveness expressed as a percentage of the CAV rate are given in Table 3 together with high-to-low flow ratios. Higher reference CAV rates are more effective in removing pollutants; hence the airflow factor is lower at both occupied and unoccupied times than systems with low reference CAV rates. However the high-to-low ratio increases with higher reference CAV rate.

The acute to chronic ratios for CAV rates of 0.35, 0.5 and 1.0 are given in Figure 9. The ratio equals 1 when the high to low ventilation ratio is 1.5 but because the reference CAV rate affects the pollutant accumulation rate the low-ventilation factor at the steady state concentration will not be the same. LVF is approximately 0.69 to 0.71 for the three CAV rates. At maximum effectiveness the acute to chronic ratio is 1.7 to 2.6 with highest values at high CAV rates.

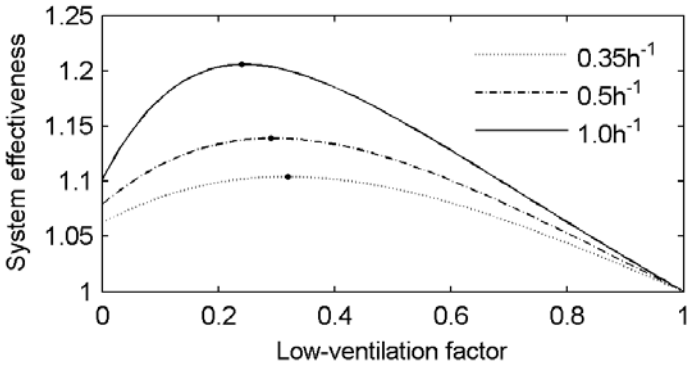

Figure 8. Changes in effectiveness for CAV rates of 0.35, 0.5 and 1.0 h^{-1}. Peak effectiveness' are marked by a dot on the curves.

Table 3. High and low airflow factors at peak effectiveness.

	$0.35h^{-1}$	$0.5h^{-1}$	$1.0h^{-1}$
LVF ($A_{DCV,low}$/ A_{CAV})	0.32	0.29	0.24
$A_{DCV,high}$/ A_{CAV}	1.20	1.17	1.12
High-to-low airflow ratio	3.7	4.0	4.7

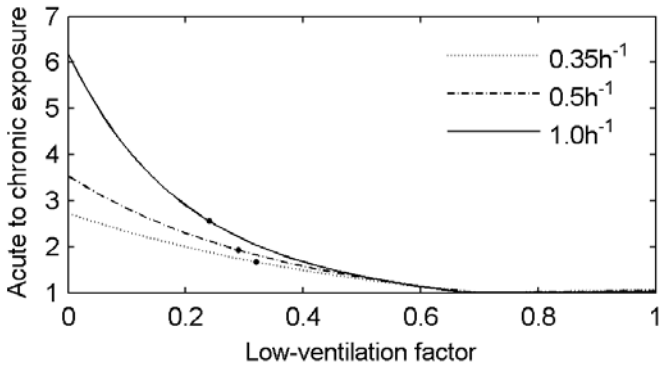

Figure 9. Acute to chronic exposure as a function of the low-ventilation factor. Peak effectiveness' are marked by a dot on the curves.

4.5 Implications of Uncertainty in Ventilation Rates

Figure 10 shows ventilation effectiveness and dose during occupied hours relative to their values at peak effectiveness for uncertainties in high and low ventilation rates of ±5%. Changes in dose during occupied hours are calculated by Equation 3 for the cases included in the three scenarios. Changes in effectiveness are calculated by Equation 6.

The relative effectiveness and dose are both approximately inversely proportional to the uncertainty in ventilation rates. Uncertainties of ±5% in high and low ventilation rates result in

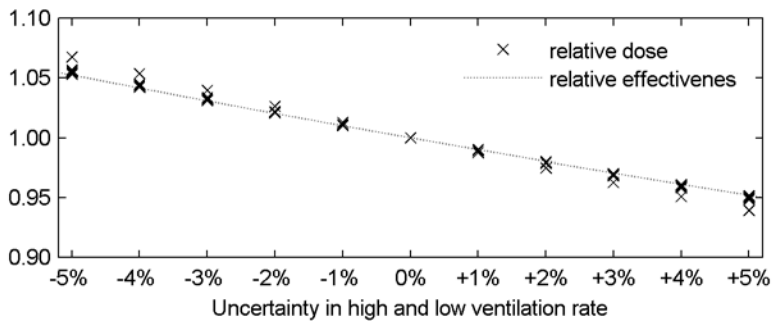

Figure 10. Effectiveness and dose during occupied hours relative to their values at peak effectiveness for ±5% changes in ventilation rates.

uncertainties of ±5% in effectiveness and dose relative to their values at peak effectiveness.

5. Discussion

The results show that the performance of a DCV system can be optimized given occupancy time and emission ratio. Despite the variation of the parameters the three scenarios have many common characteristics. Firstly, all values of peak effectiveness lie within a limited range from 1.03 to 1.36. Furthermore none of the investigated cases had an effectiveness below 1. This means that we can expect reductions in total volume of air up to 26% by redistributing the air to times of occupancy and never use more air than in our reference CAV case. We have thereby demonstrated an upper limit to the theoretically expected reductions. A reasonable estimate of the expected reduction in total volume of air is 12% representing the case of 16 occupied hours, a reference CAV rate of 0.5 h^{-1} and an emission ratio of 1.5.

Another common characteristic is that the low-ventilation factor was 0.13 to 0.4 at peak effectiveness. This means that peak effectiveness occurred when the low airflow rate was 13% to 40% of the reference CAV rate independent of occupancy, emission ratio and reference CAV rate. At peak effectiveness the high airflow rate ranged from 108% to 154% of the reference CAV rate. By pairing the flow rates that provide equivalent dose, the high to low airflow ratio ranged from 2.5 to almost 9. This ratio is of interest when sizing ducts and selecting fans. The largest differences in high to low airflow ratio occurred in the system with 16 occupied hours, a reference CAV rate of 0.5 h^{-1} and ER=4. This change in flow ratio was primarily due to a reduced low airflow rate. All other systems had a high to low airflow ratio of 2.5 to approximately 5 at peak effectiveness.

The relative uncertainty in effectiveness and dose during occupied hours compared to their values at peak effectiveness were approximately inversely proportional to the uncertainty in ventilation rates. An uncertainty of ±5% in high and low ventilation rates translate to a similar uncertainty in the predicted relative dose and relative effectiveness. Specific pollutants must be addressed to determine if such changes in dose are acceptable in relation to meeting relevant standards and codes relating to ventilation. Similar uncertainty analysis could be made for the emission ratio, reference CAV rate and the number of occupied hours.

A significant consequence associated with dose based design of a DCV system is that the peak concentration changes. The metric, acute to chronic exposure was used to evaluate this effect. At maximum effectiveness the highest acute to chronic ratio was below 3. To determine if peak concentrations are an issue of concern we need to look at the differences between chronic long-term and acute short-term health effects. A literature review of reported chemical pollutants in residences identified 23 pollutants of concern as chronic hazards (Logue et al, 2010) The acute to chronic ratio for these pollutants was determined based on published health standards (Sherman et al, 2010). The health standards based short-term exposures on 1, 8 or 24 hour averaged values whereas our peak concentration was an instantaneous value. Averaging of our peak concentration over 1 or more hours will therefore lead to lower acute to chronic ratios. The pollutants with the lowest acute to chronic ratios were PM2.5,

NO_2 and formaldehyde with ratios of 2.5 (24h average), 5.4 (8h average) and 4.7 (1h average) respectively. Because outdoor air can be a significant source of particulates we used formaldehyde as the limiting case. Therefore, if the ratio of the acute to chronic exposure in our DCV systems is below 4.7 then the peak concentrations are acceptable. As our results showed, the ratio is always less than 3, meaning that the peak concentrations are acceptable and not a barrier to adoption of the DCV technique in residential applications. The results also showed that if occupants contribute to the majority of emissions then acute to chronic ratios may be lower for the DCV system than for a CAV system. In the limit we only need to ventilate when the home is occupied.

6. Conclusions

Theoretical evaluations of effectiveness of occupancy controlled ventilation compared to CAV operation were carried out. The evaluations were based on a range of assumptions e.g. the ventilated space was perfectly mixed, different pollutants' load could be added, and the hours of occupancy were fixed and consecutive. The results provide an estimate of the expected impact of DCV in residential buildings but because of the assumptions the results are not necessarily applicable outside that range and not definitive in the real world. However it was evident that if you know when occupants are present a DCV system can reduce the air necessary to achieve acceptable indoor air quality. For a home occupied 16 hours a day reductions in total volume of exchanged air is about 12%. For a limiting case of no occupant contribution to pollutants, the reduction is about 9%. At the other extreme of occupant dominated pollutant emissions the reductions are 18% or more. The trade off is an increased peak concentration. However, the increase in acute to chronic exposure is well below the acute to chronic exposures of concern derived from health standards.

Acknowledgement

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the U.S. Department of Energy under contract No. DE-AC02-05CH11231.

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