Balancing Reductions in Exposure to VOCs and their Secondary Products Indoors vs. the Infiltration of Outdoor Pollutants

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ABSTRACT

Ventilation and source control (e.g. using low volatile organic compound (VOC) emitting materials) are two recommended approaches to control indoor air pollution and VOC's in particular. Decisions on how to minimize exposure can be supported by indoor air chemistry modeling, since the relationships between VOC's, their precursors, and building ventilation is so complex. For example, modeling could be used to examine the impact of altering building ventilation. Increasing ventilation could remove some VOC's while bringing in more oxidants such as hydroxyl radicals, ozone and nitrogen oxides, that could react indoors.

In this analysis, we used the Simplified Indoor Air Chemistry Simulator (SIACS), currently under development at EPA, to investigate the relative benefits of reducing all indoor VOC emissions (by using source control) vs. reducing infiltration of ambient oxidants (by making buildings tighter), focusing on a few selected gas-phase compounds with known adverse human health impacts. The modeled scenario used CMAQ ambient air and weather data for Atlanta, Phoenix, New York City and Minneapolis during July, and indoor VOC emissions from the literature. Infiltration was the only source of ventilation.

The results for this scenario showed that while secondary species such as PAN-like compounds, acrolein, and glyoxal were reduced by both strategies, the reduction was greater (2-25 times, 1.5 times and 3 times greater, respectively) by decreasing infiltration than by reducing all indoor emissions. Conversely, the reduction of formaldehyde and acetaldehyde, which have important indoor sources, was greater (20 times and 4 times greater, respectively) when indoor emissions were reduced for all VOCs than by increasing infiltration. Indoor ozone and nitric acid concentrations rose somewhat in response to lower indoor VOC emissions, but could be controlled by reducing infiltration. These preliminary results show that, in the modeled scenario, different and sometimes conflicting strategies are needed to control various indoor pollutants, which could be balanced by considering relative risks.

INTRODUCTION

Ventilation and source control (e.g. using low VOC emitting materials) are two recommended approaches to control indoor air pollution. Some harmful gas-phase pollutants result from oxidation of VOC's emitted by indoor sources, a process also controlled by oxidants (such as hydroxyl radical, ozone, nitrogen oxides) introduced largely by building ventilation, including passive infiltration. Decisions on how to minimize exposure can be supported by indoor air chemistry modeling, since the relationships between VOC's, their precursors, and building ventilation is so complex. The Simplified Indoor Air Chemistry Simulator (SIACS) is a deterministic, dynamic model of gas and particle concentrations in indoor air that assumes a single well mixed zone. SIACS is based on the condensed version of SAPRC-99 (1,2). The five processes included in the model are: 1) infiltration from the outdoors, 2) exfiltration to the outdoors,

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3) indoor photochemical reactions, 4) indoor emissions, and 5) indoor deposition on surfaces. In this analysis, we used the Simplified Indoor Air Chemistry Simulator (SIACS), currently under development at EPA, to investigate the relative benefits of reducing all indoor VOC emissions vs. reducing infiltration of ambient oxidants (by making buildings tighter), focusing on a few selected gas-phase compounds with known adverse human health impacts.

METHODS

The analysis using SIACS focused on the cities of Atlanta, Minneapolis, New York City and Phoenix which were selected to represent distinct climate zones within the United States. The ambient air concentrations, temperature and wind speed were sourced from the Community Muiltscale Air Quality model (CMAQ) which simulated conditions in each of the cities for the month of July. SIACS was run 72 hours with a simulated home size of 140 m^2. The indoor temperature was 295° K and the relative humidity indoors was 50%. Infiltration was calculated using the LBLX mechanism (4). The baseline effective leakage area was set at 0.1 m^2 while indoor VOC emissions were taken from the literature (1). Three indoor emissions scenarios for each city were calculated by varying indoor source emissions from baseline, while holding infiltration steady; three ventilation scenarios were also calculated, varying ventilation from baseline while holding emissions steady (Table 1). Eleven gas-phase secondary compounds of public health consequence were selected for comparison: peroxy acetyl nitrate (PAN), and various analogues, including higher alkyl PAN analogues (PAN2) and those formed from aromatic aldehydes (PBZN), analogues formed from methacrolein (MAPAN); formaldehyde (HCHO); acetaldehyde (CCHO); methacrolein (METHACRO); glyoxal (GLY); organic nitrates (RNO3); nitric acid (HNO3); and peroxynitric acid (HNO4) (3). The rate of change in concentration of each compound as infiltration varied was then compared to the rate of change as indoor emissions varied (Figure 1 shows the rates).

Table 1 Comparison scenarios varying infiltration and indoor emissions of all VOC's

Infiltration	Indoor VOC Emissions
Baseline	Baseline
25%	Baseline
50%	Baseline
75%	Baseline
Baseline	25%
Baseline	50%
Baseline	75%

RESULTS AND DISCUSSION

The results of this analysis emphasize the importance of the connection between outdoor and indoor environments, local ambient air differences and building design. Building tightness, as well as source emissions can impact indoor air. The illustration below (Figure 1) shows the varying responses modelled in each city and what strategies may follow from those responses. The farther above 1 any compound is in Figure 1 the more affected by reductions in infiltration the compound is. In this analysis, concentrations of compounds such as PAN, PAN2, MAPAN, METHACRO, GLY, RNO3 and HNO3 are more impacted by infiltration whereas compounds such as HCHO, and CCHO are more impacted by reductions in indoor emissions. For compounds that are close to the 1, in the light-green shaded area, both strategies of infiltration and emission strength reduction matter. It is interesting to note the inter-city variation in the magnitude and in some cases the direction of the response for certain compounds. In the case of PAN in NYC vs. Phoenix, while the results show PAN overall responds more to reductions in infiltration in both cities, in NYC, PAN is about ten times higher than Phoenix. This response is similar for other PAN analogues (PAN2 and MAPAN). Possible reasons for the heterogenous response of the same compounds in different cities include temperature variations, which impact infiltration, and local ambient air compositions. In

Phoenix for example which had less PAN in ambient air, reducing infiltration is less important than in NYC and Atlanta where PAN levels in ambient air are higher. This relationship holds true for compounds that respond more to source control as well. In Atlanta, with higher ambient levels of formaldehyde, increasing ventilation is less effective than emissions reduction than in cities like Phoenix and Minneapolis.

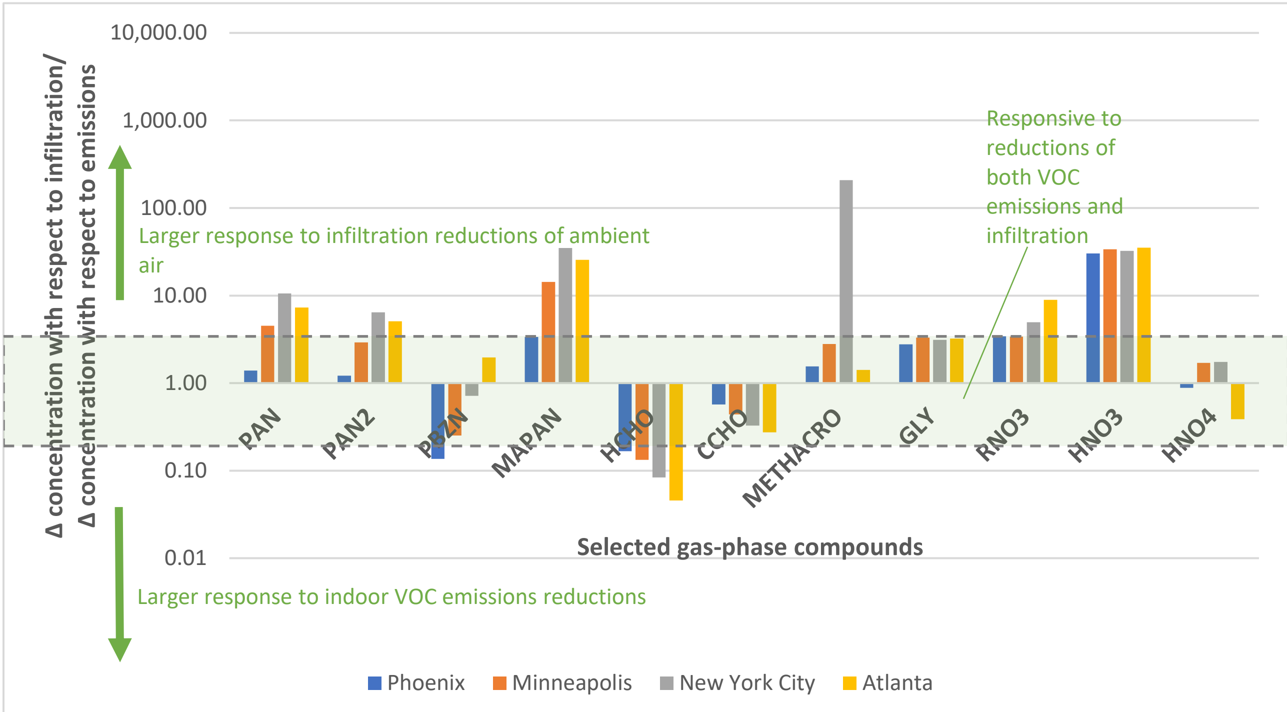

Figure 1 Ratios of the concentration change with respect to infiltration to the concentration change with respect to indoor emissions. High ratios indicate indoor concentrations are more easily controlled by reducing infiltration, while low ratios identify compounds better controlled by reducing indoor sources.

CONCLUSIONS

The complexity of managing source control and ventilation to reduce exposure to indoor contaminants is well illustrated in this four city comparsion. Based on this limited analysis some compounds are more responsive to source control (formaldehyde and acetaldhyde) others are more responsive to ventilation (PAN and HNO3) and both strategies were important for many. It was also clear that the response of compounds to these strategies varies by city. This indicates it could be important to take a locally tailored approach to building design and operation to minimize indoor pollutant exposure. The use of indoor air chemistry models such as SIACS may be helpful in unraveling this complexity and in determining locally effective control strategies for indoor contaminants.

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