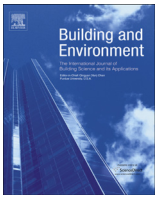
Building and Environment 93 (2015) 112–118

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv



# Study of outdoor ozone penetration into buildings through ventilation and infiltration

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## ARTICLE INFO

*Article history:*
Received 1 April 2015
Received in revised form
7 June 2015
Accepted 15 June 2015
Available online 20 June 2015

*Keywords:*
Ozone
Infiltration
Natural ventilation
Mechanical ventilation
Air exchange rate
Surface removal rate

## ABSTRACT

Ozone is known to cause adverse health effects such as decreased lung function and respiratory symptoms. Indoor ozone originates mainly from the outdoor environment and enters a building through three different ventilation mechanism: infiltration, natural ventilation, and mechanical ventilation. This study investigated the relationship between ventilation and indoor/outdoor ozone concentration by measuring the concentration and the ventilation rate in two chambers and in an actual office space with different ventilation systems. The ventilation rate was determined by using the decay method with sulfur hexafluoride ($SF_6$) as a tracer gas. The surface removal rates were estimated from the information provided in the previous literature. The results show that within the range of our investigation, the indoor/outdoor ozone concentration ratio can be predicted by a simple steady-state model within 80% accuracy. By using the model and according to the ventilation rate and surface removal rate data collected from literature, the most common indoor-to-outdoor ozone ratios were found to be 0.09, 0.19, and 0.47 for infiltration, mechanical ventilation, and natural ventilation, respectively.

## 1. Introduction

Ozone in air can cause adverse health effects, such as decreased lung function and respiratory symptoms [1]. A number of large-scale analyses have found a positive relationship between the outdoor ozone concentration and mortality. For example, Chen et al. [2] discovered a strong association between mortality and ozone exposure. Bell et al. [3] also found a significant correlation between short-term changes in ozone and mortality in 95 large communities in the United States. People are exposed not only to outdoor ozone but also to ozone that penetrates from outdoor to indoor spaces. Since people spend about 90% of their time indoors [4], their exposure to indoor ozone could be greater than that to outdoor ozone [5]. The indoor-to-outdoor ozone concentration (I/O) ratio is an essential parameter in assessing the overall exposure.

In the absence of indoor ozone sources, the I/O ratio can be described by a relatively simple equation [6] and the use of this equation under mechanical ventilation has been verified by Weschler [5]. Outdoor ozone is also brought into indoor environments by infiltration and natural ventilation [7,8]. Infiltration is the flow of outdoor air into a building through cracks and other unintentional openings. It is suspected that because of the narrow path of the cracks and openings, a portion of the ozone is deposited and reacts with the path surfaces before it can enter the indoor space [9]. This effect is described by the ozone penetration factor. Liu and Nazaroff [10] developed a model to predict this factor on the basis of crack geometry and reaction probability. Stephens et al. [11] measured the mean ozone penetration factor to be 0.79 ± 0.13 in eight homes. For natural and mechanical ventilation, the penetration factor is considered to be equal to unity because of the large opening used for natural ventilation. In the mechanical ventilation process, there may be additional reactions between ozone and HVAC components such as filters [12,13] and ducts [14].

Because of the three ventilation mechanisms have different air exchange rates and paths, they will also have different I/O ratios. Walker and Sherman [15] simulated the indoor ozone level of outdoor origins with the consideration of the above three ventilation mechanisms. Our literature search did not reveal any rigorous experiment studies of I/O ratios for natural ventilation and

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http://dx.doi.org/10.1016/j.buildenv.2015.06.015

infiltration. There have been several large-scale studies of indoor and outdoor ozone concentrations [16–19]. However, these studies did not identify the mechanisms by which ozone penetrated the buildings.

This paper examined the I/O ratios under three different ventilation routes. Our investigation measured the indoor/outdoor ozone concentration and air exchange rate in two chambers and an office space with different ventilation systems. The data were also used to validate the I/O model from Weschler [6] under the three mechanisms.

## 2. Method

To investigate the I/O ratio under different ventilation mechanisms, we first introduced a simplified ozone I/O model expressed as a function of air exchange rate and surface removal rate. Then we perform measurements of indoor/outdoor ozone concentrations. This investigation also measured the air exchange rate by the decay method, using sulfur hexafluoride ($SF_6$) as a tracer gas and estimated the surface removal rate on the basis of data in the literature. Then the predicted I/O ratio was compared with experimental data.

### 2.1. Ozone penetration model

The indoor to outdoor ozone concentration ratio can be expressed by the continuity equation if the reaction between ozone and other indoor chemicals are ignored [6]:

$$dC_{in}/dt = aPC_{out} - (a+K)C_{in} + \dot{S} \tag{1}$$

where $C_{in}$ is the indoor ozone concentration (ppb), $t$ is time (hours), $a$ is the air exchange rate ($h^{-1}$), $C_{out}$ is the outdoor ozone concentration (ppb), $P$ is the penetration factor which represents the fraction of outdoor ozone passes through the building envelope. $K$ is the surface removal rate ($h^{-1}$), and $\dot{S}$ is the indoor ozone generation rate (ppb $h^{-1}$). Assuming that there are no source of ozone in the indoor space, a negligible penetration loss and a negligible rate of change of the indoor ozone concentration, the ratio of indoor to outdoor ozone concentration, I/O, can be written as:

$$I/O = a/(a+K) \tag{2}$$

This equation shows that I/O can be approximated as a function of the air exchange rate and the surface removal rate.

### 2.2. Measurements of ozone concentration and air change rate

In order to investigate the I/O ratio under different ventilation routes and to validate the above model, we measured the indoor and outdoor ozone concentrations and the air exchange rates in three different indoor spaces (Fig. 1). These spaces were equipped with different ventilation systems. The first indoor space was a chamber that allowed natural ventilation driven by wind and buoyancy through operable windows. The second indoor space was a similar chamber that included a simple mechanical ventilation system in addition to the operable windows. The mechanical system was able to exhaust air from the ceiling and take air in through an open window. The third indoor space was a student office with 20 workstations that serves as a "living lab" at Purdue University. Although the windows in the living lab were not operable, natural ventilation could be achieved by the use of the lab's double façade system. Mechanical ventilation in the living lab was provided by a standard HVAC system that consisted of fans, a cooling coil, a heating coil, a filter, etc. For all three rooms, infiltration was achieved by closing all windows and doors. The experimental measurements were performed under different scenarios as shown in Table 1.

**Table 1**
Summary of the experimental measurements.

| Ventilation mechanism | Location | Case name |
|---|---|---|
| Infiltration | Chamber 2 | Infil_1 |
| | Living Lab | Infil_2 |
| | Living Lab | Infil_3 |
| Mechanical ventilation through simple exhaust | Chamber 2 | Simple_MV_1 |
| | Chamber 2 | Simple_MV_2 |
| Mechanical ventilation with HVAC system | Living Lab | HVAC_MV_1 |
| | Living Lab | HVAC_MV_2 |
| Natural ventilation with open windows | Chamber 1 | Window_NV_1 |
| | Chamber 1 | Window_NV_2 |
| | Chamber 1 | Window_NV_3 |
| | Chamber 1 | Window_NV_4 |
| | Chamber 2 | Window_NV_5 |
| | Chamber 2 | Window_NV_6 |
| Natural ventilation with double façade system | Living Lab | Facade_NV_1 |
| | Living Lab | Facade_NV_2 |

Fig. 2 is a schematic of the instrumentation setup. Two photometric ozone analyzers (2B Technology Model 202), with a measuring range of 1.5 ppb–250 ppm and a resolution of 0.1 ppb, were used to measure the indoor and outdoor ozone concentrations simultaneously. The accuracy of the measurements was the greater of 1.5 ppb or 2% of the reading. The measurements were conducted between 12:00 and 17:00 when the outdoor ozone concentration was relatively high. The air exchange rate was measured by the decay regression method [20] using sulfurhexafluoride ($SF_6$) as the tracer gas. The air was sampled by a multipoint sampler (INNOVA Model 1309), and the $SF_6$ concentration was analyzed by a photo-acoustic gas monitor (INNOVA Model 1412). Two mixing fans were used to ensure the uniformity of the $SF_6$ distribution and the $SF_6$ concentration was sampled at two locations to verify uniformity, as shown in Fig. 2.

### 2.3. Estimation of surface removal rate

The I/O ratio can be estimated by Eq. (2) if the air exchange rate and surface removal rate are known. The surface removal rate is the

**Fig. 1.** Indoor spaces in which measurements were taken, from left to right: chamber 1, another chamber 2, and a student office as a living lab.

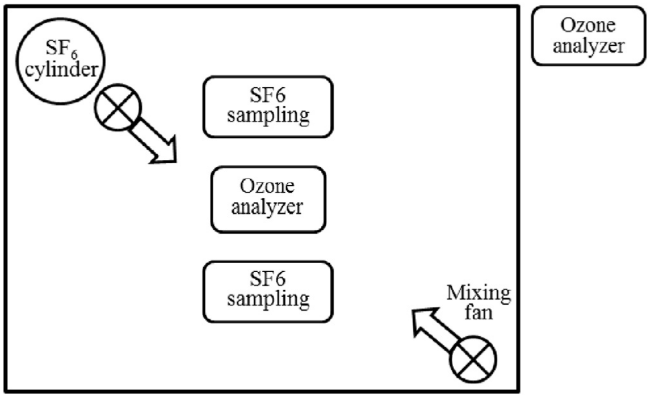

**Fig. 2.** Setup of the instruments.

product of the deposition velocity $v_d$ (m/s) and surface-to-volume ratio A/V [6]:

$$K = \sum v_d(A/V) \tag{3}$$

The ozone deposition velocity is defined as the net flux of ozone to a unit area of surface (μg/m$^2$/s) normalized by the ozone concentration (μg/m$^3$) [21]. The determination of $v_d$ should involve careful chamber measurements. Several studies have measured the deposition velocities for different building materials [22–26] and they were used in this investigation. Table 2 determined the deposition velocities for the materials in this study by the averaged values from previous literature. Although the surface materials in this study were not exactly the same as those in the literature, the data can still provide good estimations when we did not measure the K. Table 3 shows the surface removal rates that were estimated for the three spaces by using the averaged deposition velocities data. The estimated rates were 5.47 h$^{-1}$ for Chamber 1, 5.96 h$^{-1}$ for Chamber 2, and 4.78 h$^{-1}$ for the living lab.

## 3. Results

This section first presents the measured air exchange rates and indoor and outdoor ozone concentrations. The data are then used to test the simplified model. Finally, the use of the tested model to predict I/O ratios for different ventilation mechanisms under various conditions is discussed.

**Table 2**
Determination of deposition velocities of materials used in this study.

| Material | $v_d$ (cm/s) | Refs. | Mean $v_d$ (cm/s) |
|---|---|---|---|
| Grey tile | 0.32 | [23] | 0.32 |
| Concrete | 0.32 | [23] | 0.32 |
| Polystyrene tile | 0.008 | [26] | 0.008 |
| Paint | 0.003 | [26] | 0.003 |
| Gypsum board | 0.07 | [26] | 0.055 |
| | 0.04 | [24] | |
| Wood | 0.07 | [24] | 0.15 |
| | 0.06 | [26] | |
| | 0.55 | [26] | |
| | 0.20 | [26] | |
| | 0.14 | [26] | |
| | 0.14 | [26] | |
| | 0.03 | [22] | |
| | 0.005 | [22] | |
| Glass | 0.00016 | [26] | 0.005 |
| | 0.00007 | [26] | |
| | 0.00015 | [25] | |
| | 0.002 | [22] | |
| | 0.001 | [22] | |
| | 0.026 | [23] | |

### 3.1. Test of the ozone I/O prediction model

Table 4 shows the measured air exchange rates together with the corresponding indoor and outdoor ozone concentrations. The air exchange rates were the lowest for infiltration with a range of 0.23–0.32 h$^{-1}$. The highest air exchange rates, 8.76 and 9.07 h$^{-1}$, were observed under mechanical ventilation with the simple exhaust system in Chamber 2 while the air exchange rates under mechanical ventilation in the living lab were 1.03 and 4.68 h$^{-1}$. The reason for the difference was that, during the second measurement, the temperature of the outside air was favorable for free cooling, and therefore a large amount of outdoor air was needed to cool down the indoor space. During the first measurement, outdoor air was just for meeting the minimum requirement for ventilation. The air exchange rates under natural ventilation ranged from 1.08 to 3.76 h$^{-1}$.

Table 4 also shows the measured outdoor and indoor ozone concentrations. The outdoor ozone concentration ranges from 20.11 to 53.50 ppb. The lowest indoor ozone concentrations were measured in the infiltration cases. The two highest indoor ozone concentrations occurred in the mechanical ventilation cases in Chamber 2 with the highest air exchange rates. With the exception of these cases, the indoor ozone concentrations were less than 20 ppb. It can be seen in the table that a higher air exchange rate will lead to a higher I/O ratio.

Fig. 3 shows the difference between measured and predicted I/O ratio against the air exchange rate. The predicted I/O ratios by Eq. (2) generally have an error of less than 20% compared with the measured I/O ratios, with the exception of the two infiltration cases. The errors tend to be higher at lower ventilation rates, since reducing ventilation rate will increase the time available for chemical reaction and thus violate the assumptions of negligible indoor chemical reaction between ozone and pollutants.

In the simplified model, two parameters, the air exchange rate, a, and the surface removal rate, K, compete with each other to determine the I/O ratio. Higher ventilation brings in more outdoor ozone to indoors while higher surface removal rate leads to a higher consumption of indoor ozone. Thus, their ratio (a/K) is a good indication of I/O ratio. Fig. 4 shows the I/O ratio against the a/K ratio for the measurement and prediction. Beside the good performance of the simplified model, the I/O ratio varied almost linearly with the a/K ratio at the region of the measurement where a/K ratio is less than 1.5. However, the slope becomes much flatter outside that region.

### 3.2. Prediction of ozone I/O ratios for different ventilation routes

The ozone I/O model (Eq. (2)) shows that the ratio depends on the air exchange rate and the surface removal rate. The air exchange rate depends on ventilation mechanisms: infiltration, mechanical ventilation, or natural ventilation. It is useful to know the typical air exchange rates for the different mechanisms.

Table 5 summarizes the 10th percentile, median, and 90th percentile air exchange rates for infiltration, natural ventilation, and mechanical ventilation from previous studies in the literature. The infiltration rates were obtained from the frequency distribution for 209 houses in 19 U.S. cities [27]. The mechanical ventilation rates were taken from a survey of 100 US office buildings by the Environmental Protection Agency (EPA) Building Assessment Survey and Evaluation (BASE) study [28]. The natural ventilation rates were gathered from 76 measurements in four different studies [29–32] as well as from the present study. As expected, the

**Table 3**
Estimation of surface removal rates.

| Location | Dimension $L$(m) × $W$(m) × $H$(m) | Volume (m$^3$) | Com-ponent | Material | Area (m$^2$) | $A/V$ (m$^{-1}$) | $v_d$ (cm/s) | $K$ (h$^{-1}$) | Total $K$ (h$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| Chamber 1 | 4.57 × 4.83 × 3.66 | 80.79 | Wall | Gyp. board | 57.13 | 0.71 | 0.055 | 1.41 | 5.47 |
| | | | window | Glass | 11.68 | 0.14 | 0.005 | 0.03 | |
| | | | Ceiling | Poly. tile | 22.07 | 0.27 | 0.01 | 0.08 | |
| | | | Floor | Concrete | 22.07 | 0.27 | 0.32 | 3.15 | |
| | | | Desk | Wood | 12.00 | 0.15 | 0.15 | 0.80 | |
| Chamber 2 | 4.57 × 3.30 × 3.66 | 55.20 | Wall | Gyp. board | 59.29 | 1.07 | 0.055 | 2.15 | 5.96 |
| | | | window | Glass | 1.69 | 0.03 | 0.005 | 0.01 | |
| | | | Ceiling | Poly. tile | 15.08 | 0.27 | 0.01 | 0.08 | |
| | | | Floor | Concrete | 15.08 | 0.27 | 0.32 | 3.15 | |
| | | | Desk | Wood | 6.00 | 0.11 | 0.15 | 0.59 | |
| Living lab | 10.50 × 9.88 × 4.60 | 477.20 | Floor | Grey tile | 103.74 | 0.22 | 0.32 | 2.50 | 4.78 |
| | | | Ceiling | Gyp. board | 207.48 | 0.43 | 0.055 | 0.87 | |
| | | | Wall | Gyp. board | 142.05 | 0.30 | 0.055 | 0.59 | |
| | | | Window | Glass | 45.45 | 0.10 | 0.005 | 0.02 | |
| | | | Desk | Wood | 69.33 | 0.15 | 0.15 | 0.78 | |
| | | | Cabinet | Paint | 58.23 | 0.15 | 0.003 | 0.02 | |

infiltration rate was the lowest, with a median value of 0.40 h$^{-1}$. The natural ventilation rate had the highest median value at 3.67 h$^{-1}$, and the largest variance.

The surface removal rate is another important factor in determining the I/O ratio. The measured surface removal rates from previous studies and this study were combined, and the resulting surface removal rates are summarized in Table 6. The 10th percentile value, median value, and 90th percentile value of the averaged surface removal rate from these studies were 2.80, 4.13, and 5.40 h$^{-1}$, respectively.

Using the air exchange rates from Table 5 and the surface removal rates from Table 6, Fig. 5 shows the I/O ratios that were due to infiltration, mechanical ventilation, and natural ventilation. The 10th percentile, median, and 90th percentile of the air exchange rates in Table 5 and the surface removal rates in Table 6 were used to calculate the corresponding ozone I/O ratios. The I/O ratios at the median air change rate and median surface deposition rate can be described as the most common ones, i.e. 0.09, 0.19, and 0.47 for infiltration, mechanical ventilation, and natural ventilation, respectively. The highest I/O ratio was 0.73, corresponding to the 90th percentile of the air exchange rate and 10th percentile of the surface removal rate for natural ventilation. The lowest I/O ratio was 0.03, corresponding to the 10th percentile of the air exchange rate and 90th percentile of the surface removal rate for infiltration. It can be seen that natural ventilation generally had a much higher I/O ratio because of the higher air exchange rate.

**Table 4**
Summary of measured indoor/outdoor ozone concentrations and air exchange rate.

| Cases | $C_{out}$ (ppb) | $C_{in}$ (ppb) | Air exchange rate (h$^{-1}$) |
|---|---|---|---|
| Infil_1 | 53.50 ± 2.17 | 5.28 ± 1.98 | 0.32 |
| Infil_2 | 24.02 ± 1.61 | 1.20 ± 0.91 | 0.23 |
| Infil_3 | 29.71 ± 2.62 | 2.02 ± 1.35 | 0.27 |
| Simple_MV_1 | 38.96 ± 3.13 | 22.39 ± 2.85 | 8.76 |
| Simple_MV_2 | 39.69 ± 1.42 | 24.91 ± 3.57 | 9.07 |
| HVAC_MV_1 | 34.49 ± 2.72 | 5.07 ± 1.85 | 1.03 |
| HVAC_MV_2 | 20.11 ± 1.64 | 8.66 ± 2.69 | 4.68 |
| Window_NV_1 | 34.87 ± 3.85 | 10.03 ± 1.73 | 2.77 |
| Window_NV_2 | 40.64 ± 2.65 | 17.11 ± 3.84 | 3.76 |
| Window_NV_3 | 30.85 ± 1.65 | 10.66 ± 2.40 | 2.19 |
| Window_NV_4 | 51.02 ± 2.61 | 11.66 ± 2.68 | 1.24 |
| Window_NV_5 | 36.65 ± 2.90 | 8.41 ± 1.96 | 2.21 |
| Window_NV_6 | 35.64 ± 3.13 | 10.68 ± 2.39 | 2.66 |
| Facade_NV_1 | 27.68 ± 1.64 | 9.04 ± 2.14 | 2.33 |
| Facade_NV_2 | 22.09 ± 1.93 | 4.07 ± 1.87 | 1.08 |

## 4. Discussion

### 4.1. Uncertainty analysis

It was shown in Section 3.1 that the difference between the measured and predicted I/O ratio was generally smaller than 20%. This investigation has also calculated the errors of the measured and modeled I/O ratio. The errors in the measured I/O ratios were from the instrumentation (1.5 ppb) for ozone concentration

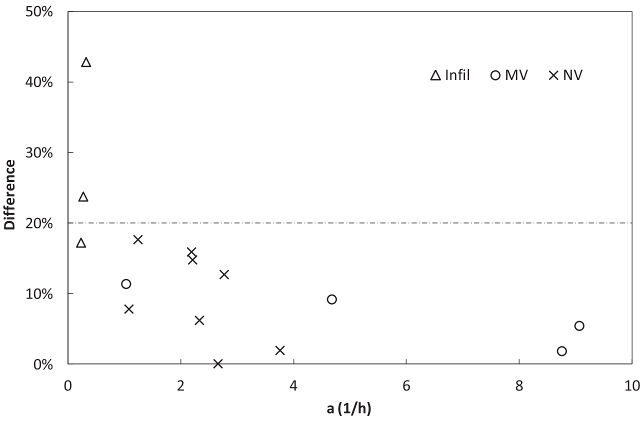

**Fig. 3.** Difference between measured and predicted I/O ratio.

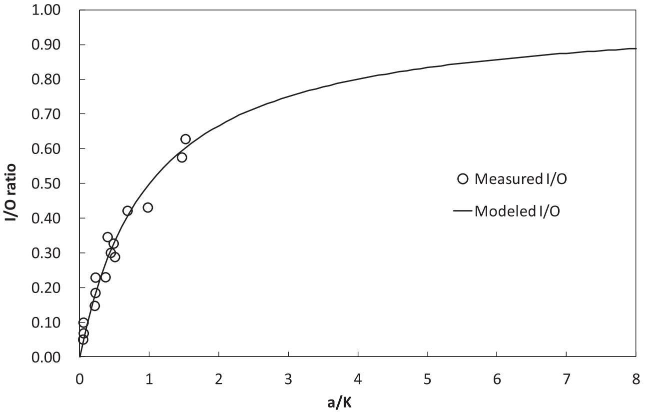

**Fig. 4.** I/O ratio vs. a/K ratio for measurement and prediction.

**Table 5**
Summary of air exchange rates for infiltration, natural ventilation and mechanical ventilation from different studies in literature.

| Ventilation mechanism | Case | Air exchange rate ($h^{-1}$) | Source |
|---|---|---|---|
| Infiltration | 10th percentile | 0.15 | [27] |
| | Median | 0.40 | |
| | 90th percentile | 0.85 | |
| Mechanical ventilation | 10th percentile | 0.22 | [28] |
| | Median | 0.98 | |
| | 90th percentile | 4.84 | |
| Natural ventilation | 10th percentile | 0.74 | [29–32] and present study |
| | Median | 3.67 | |
| | 90th percentile | 7.70 | |

measurements and the variation of time series data. The errors in the predicted I/O ratios came from the uncertainties in the measured air exchange rate and the estimated surface removal rate. The uncertainty of air exchange rate was from the $R^2$ when using regression analysis to determine the slope of the decaying curve. The uncertainty of surface removal rate was from the standard deviation of the deposition velocities obtained from different literature. Fig. 6 shows the results of the uncertainty analysis with error bars. With the present of uncertainties, the largest difference between the measured and predicted I/O ratio increased from 20% to about 40%. This was due to the errors from experiment and the variation of the deposition velocities from the literature.

**Table 6**
Summary of surface removal rates in literature.

| Literature | Averaged surface removal rate ($h^{-1}$) | Number of samples |
|---|---|---|
| [33] | 3.95 | 4 |
| [22] | 4.15 | 2 |
| [34] | 4.30 | 1 |
| [35] | 4.15 | 2 |
| [36] | 3.70 | 3 |
| [37] | 3.60 | 1 |
| [38] | 4.30 | 2 |
| [5] | 3.96 | 5 |
| [39] | 0.90 | 1 |
| [40] | 2.80 | 28 |
| [11] | 8.19 | 10 |
| Present study | 5.40 | 3 |
| 10th percentile | 2.80 | 12 studies |
| Median | 4.13 | |
| 90th percentile | 5.40 | |

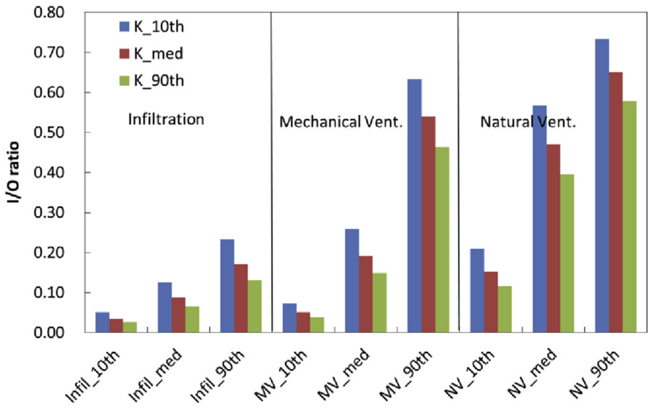

**Fig. 5.** Ozone I/O ratios at the 10th percentile, median, and 90th percentile of the air exchange rate and surface removal rate, for infiltration, mechanical ventilation, and natural ventilation, respectively.

### 4.2. Penetration factor of ozone by means of infiltration

As discussed in the introduction section of this paper, a portion of the outdoor ozone can be consumed as air penetrates through the cracks by means of infiltration. The simplified model (Eq. (2)) can be modified by adding a penetration factor as follows:

$$I/O = aP(a + K) \tag{4}$$

where P is the penetration factor with a value between zero and unity. Since the I/O ratio for infiltration is already small in comparison to the ratio for mechanical and natural ventilation, multiplication by the penetration factor will make it even smaller. For example, if we apply the average penetration factor of 0.79 obtained by Stephens et al. [11] to the most common I/O ratio for infiltration, the ratio will decreases from 0.09 to 0.07. Neglecting the penetration factor would lead to a small overestimation, which is tolerable.

### 4.3. Ozone initiated byproducts in indoor spaces

Although the surface ozone reaction decreases the indoor ozone concentration, it can generate secondary byproducts such as volatile organic compounds (VOCs) and ultrafine particles that can be even more harmful than ozone itself [6,41,42]. According to Eq. (2), it seems possible to decrease the ventilation rate in order to reduce the indoor ozone concentration. However, a recent review [43] showed that decreasing the ventilation rate increases inflammation, respiratory infections, asthma symptoms, and the amount of

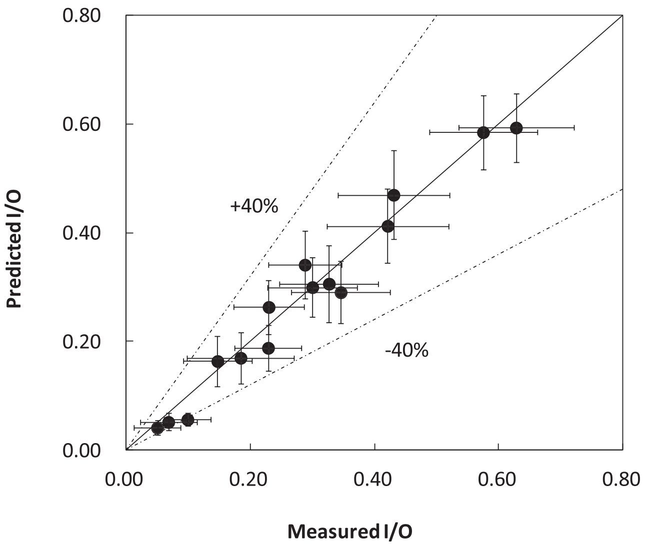

**Fig. 6.** Uncertainty analysis of the measured and predicted ozone I/O ratios.

short-term sick leave. This finding indicates that although ozone is an important pollutant, there are also other pollutants in indoor spaces. Ventilation standards such as ASHRAE 62 [44] have set minimum ventilation requirements for maintaining acceptable indoor air quality. While reduction of outdoor air ventilation rate can be examined as an indoor ozone management strategy, to control other indoor pollutants, the ventilation rate should not be lower than the minimum levels required by ventilation standards.

### 4.4. Limitation of this study

Several assumptions were made to derive the simplified model (2), such as no indoor ozone source, negligible penetration loss, negligible reactions between indoor ozone and other chemicals, and negligible change rate of indoor ozone concentration. The first assumption was justified because there were no indoor ozone sources like photocopiers and laser printers [6] in the tested spaces. Other assumptions may not be always true and may contribute to the errors between the measured and modeled ratios. For the infiltration cases, the time available for chemical reaction (with the indoor pollutant and the penetration path) would increase due to the smaller air exchange rate. Thus, the errors in those cases were even higher.

The surface removal rates in this study were determined from the averaged deposition velocity from previous studies. The rates provide good estimates when detailed experiment is not available. Fig. 7 compares the estimated surface removal rates in this study with the calculated ones by Eq. (2). Since the calculated and the estimated rates were similar, the estimated method seems reasonable. However, the deposition velocity and the corresponding surface ozone removal rate depend on many factors such as the age of the material [25], the surface flow conditions [21], and the relative humidity [6]. Unfortunately, those factors are difficult to quantify without detailed measurements in chambers.

The prediction of ozone I/O ratio for three ventilation routes were performed by using complied data of ventilation rate and surface removal rate from the literature. While it may be acceptable to use these data for this study, the data determines the accuracy of the prediction. Due to many unknown factors in the data sources, those data may contribute to the errors in the predicted results.

Unlike the relatively simple conditions of the three rooms in this study, the real living environment is more complicated. Occupants might be a significant part of ozone sink [41,42], and thus different density of occupants will pose uncertainties to the ozone surface removal rate and make the prediction of I/O ratio less accurate.

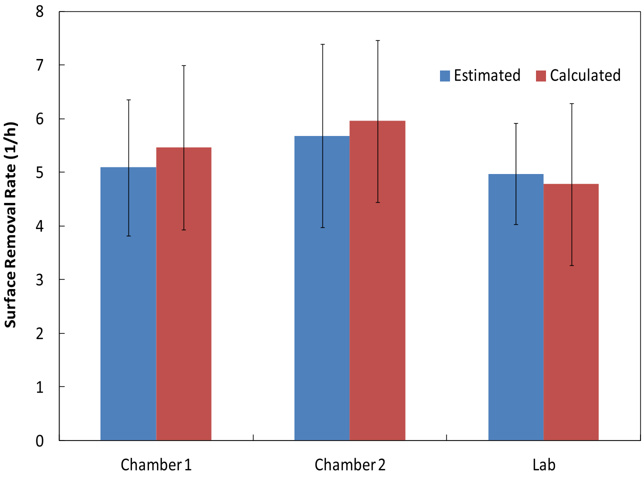

**Fig. 7.** Comparison between the estimated and calculated surface removal rate.

## 5. Conclusion

This study investigated indoor/outdoor ozone concentration ratio for infiltration, mechanical ventilation and natural ventilation. The following conclusions can be obtained from the study:

The simple model for estimating ozone I/O ratio was tested by measuring indoor/outdoor ozone concentrations and air exchange rates at two test chambers and an office space and by using the surface ozone removal rates obtained from the literature. Within the range of our study, the model can predict the ozone I/O ratio within 20% of error.

The model was then used to estimate quantitatively the ozone I/O ratios for different ventilation routes. Based on the ventilation rate and surface removal rate data collected from the literature, the most common ozone I/O ratio was 0.09, 0.19, and 0.47 for infiltration, mechanical ventilation, and natural ventilation, respectively.

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