The carbon dioxide leakage from chambers measured using sulfur hexafluoride

David T. Tingey *, Ronald S. Waschmann, Donald L. Phillips, David M. Olszyk

US Environmental Protection Agency, Western Ecology Division, 200 SW 35th Street, Corvallis, OR 97333, USA

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Abstract

In plant chamber studies, if CO₂ leaking from a chamber is not quantified, it can lead to an overestimate of assimilation rates and an underestimate of respiration rates; consequently, it is critical that CO₂ leakage be determined. Sulfur hexafluoride (SF₆) was introduced into the chambers as a tracer gas to estimate leakage rates. Chamber leakage constants were determined by measuring the rate of decline in SF₆ concentration in the chambers. The leakage in the chambers occurs via pressure differences within the air handler rather than via diffusion through the Teflon film covering the chamber. Consequently, the leakage constant for CO₂ is the same as for SF₆, i.e. no adjustment for differences in molecular weight is required. The leakage rate for CO₂ averaged 0.26 μmol m⁻² s⁻¹ at ambient CO₂ and averaged ~2.7 μmol m⁻² s⁻¹ at elevated CO₂. The CO₂ leak rate is essentially constant in the chambers despite a diurnally varying ambient concentration; chamber leakage was not correlated with changes in temperature, wind speed, dew point or atmospheric pressure. The results of this study show that SF₆ can be used to estimate chamber leakage with precision and reproducibility and it can be used to estimate the leakage of CO₂, H₂O vapor and other gases of interest. The use of SF₆ has the advantage of using a gas for measuring chamber leakage that is not involved in physiological processes. © 2000 Published by Elsevier Science B.V.

Keywords: Assimilation; Carbon flux; Respiration; SF₆; CO₂ enrichment; Controlled environment chamber

1. Introduction

In plant ecophysiological studies, CO₂ assimilation and respiration rates of plants and plant/soil systems are frequently determined and a number of techniques have been developed to measure the processes (Field et al., 1991). When closed or semi-closed chambers are used, it is necessary to measure several system parameters; (i) CO₂ injection rate; (ii) change in CO₂ concentration (storage); and (iii) chamber leakage, i.e. the loss (or gain) of CO₂ from the chamber to the surrounding environment. The CO₂ injection rate is easily determined with mass-flow meters and change in system storage is measured with an infrared gas analyzer. The determination of chamber leakage

* Corresponding author. Tel.: +1-541-754-4621; fax: +1-541-754-4799.
E-mail address: dtingey@mail.cor.epa.gov (D.T. Tingey)
is more difficult, yet essential so that unmeasured chamber leakage does not lead to an overestimate of the assimilation rate or an underestimate of the respiration rate in the chamber.

Leakage from semi-closed chambers is the consequence of either pressure differences and/or diffusional processes (Acock and Acock, 1989). It can vary among different chamber types and construction materials (Acock and Acock, 1989). Leakage can vary over time due to deterioration of gaskets and seals or doors/sampling ports not being sealed the same each time they are used. Depending on the weather conditions and CO₂ concentration in the chamber, Acock and Acock (1989) found that leakage can account for a significant portion of the CO₂ lost from chambers during CO₂-enrichment studies.

Several approaches are used to account for chamber leakage. In some chambers, it is assumed that leakage does not occur or it is relatively small compared to the CO₂ assimilation rate (Jones et al., 1984). Leakage can be determined by measuring the CO₂ loss from chambers before plants are placed in the chambers and/or after they are removed (Acock et al., 1977). With this method, one assumes that leakage is constant over the experiment or that it will vary linearly with time, assumptions which can be problematic. Acock and Acock (1989) developed a method and equations to use CO₂ as a tracer gas to determine chamber leakage during the course of an experiment while plants were in the chamber. They sealed the soil surface to prevent CO₂ effluxing from the soil from entering the shoot enclosure; a single measurement was made, each day, when plant respiration was low and stable. Using a similar approach to Acock and Acock (1989), Kimball (1990) derived ‘theoretically exact’ equations for determining chamber leakage when the ambient CO₂ concentration was variable. At night, when CO₂ addition and scrubbing were suspended, Prudhomme et al. (1984) measured the loss of CO₂ from small greenhouses over a 5-min time period to minimize the influence of respiration on the leakage estimate. The measured CO₂ leakage varied less than 10% over 4 successive days; thus, this value was used for the experiment.

As a tracer for estimating chamber leakage, CO₂ is easily measured with the same equipment used to monitor assimilation and respiration. However, leakage can only be estimated when plant and soil respiration are stable which limits the time period during an experiment when measurements can be made. Also the use of a seal at the soil surface (Acock and Acock, 1989) to prevent soil respired CO₂ from entering the chamber is a significant limitation for many experiments.

To eliminate the assumptions about respiration rate and problems arising from using changes in CO₂ concentration to estimate chamber leakage, assimilation and respiration, N₂O has been used. Lake (1966) recommended the use N₂O to measure leakage from greenhouses and presented equations to account for CO₂ leakage when determining CO₂ assimilation in greenhouses. To determine chamber leakage in null-balance field chambers, Oechel et al. (1992) added N₂O at a constant known low flow rate into each chamber. The equilibrium concentration of N₂O was inversely proportional to the chamber leakage rate. Baker et al. (1992, 1997) also used N₂O to estimate leakage. They injected N₂O twice daily into each chamber and calculated chamber leakage from the resultant decrease in the N₂O concentration in the chamber. Both research groups have used this method for several years and are pleased with the results (Baker, J.T., Hastings, S.J., personal communications).

However, N₂O is highly soluble in water and would readily dissolve in water condensed in the chamber/air handler system. Also N₂O is produced microbially during the N transformations associated with nitrification and denitrification (Fenchel and Blackburn, 1979; Parton et al., 1996; Butterbach-Bahl et al., 1997). As we are interested in studying nitrogen transformation in a forest-soil ‘ecosystem’, it was not possible to use N₂O for determining leakage in this study because it would prevent the measurement of nitrification and denitrification. In addition, there was concern that the soil microorganisms might be a sink for N₂O (Fenchel and Blackburn, 1979).

Sulfur hexafluoride (SF₆) has no known biologic source and has been used to study a variety of processes such as ocean mixing and circulation.
isoprene emissions from vegetation (Lamb et al., 1986), methane emissions from natural gas facilities (Lamb et al., 1995) and ruminant livestock (Johnson et al., 1994). As a tracer, SF₆ has number of advantages over CO₂ and N₂O as it is a physiologically inert gas (Lester and Greenberg, 1950) and has among the lowest water solubilities for any gas (Friedman, 1954). Air incursion rates into open-top field exposure chambers have been determined using SF₆ (Unsworth et al., 1984) and it has been used to determine the leakage rates of homes (Costello et al., 1984; Lamb et al., 1985). Costello et al. (1984) concluded that leakage rates for homes were the same using SF₆ or CO₂, i.e., SF₆ is a suitable tracer for estimating the leakage of CO₂ from a structure. Although SF₆ has a long atmospheric lifetime and a significant global warming potential, its impact on atmospheric warming is minimal because of its small atmospheric concentration (Ko et al., 1993) and the trace amounts required to assess leakage.

After reviewing the various techniques for estimating chamber leakage SF₆ was selected as it was a better fit to the experimental objectives than either CO₂ or N₂O. The objective of this paper is to describe the implementation of the SF₆ technique to measure chamber leakage and evaluate factors that may influence leakage rate estimates.

2. Materials and methods

The chambers are located at the USEPA research laboratory in Corvallis, OR; their design and performance have been described in detail (Tingey et al., 1996). The chambers track and control CO₂, air temperature and vapor pressure deficit (VPD), and have operated continuously for several years. Chamber wind velocity averages 0.27 m s⁻¹ (CV 0.91) within and 0.35 m s⁻¹ (CV 0.61) above the canopy which is sufficient to cause some needle flutter. The aboveground portion of a chamber is enclosed with an aluminum frame covered with 3 mil clear Teflon film (Du Pont Electronics, Wilmington, DE) except the back wall, which is Plexiglas (0.65 cm thick). An aluminum air handler, is attached to the north side of each chamber. The air handler contains a squirrel case blower, which draws air from the chamber, on the low pressure side, and on the high pressure side forces air over cooling and heat fins and into the chamber. To minimize leaks, the joints of the air handler and aluminum frame are welded except at access ports. At these joints the surfaces are covered with closed-cell neoprene gaskets and held together via compression fittings. The surfaces where the aboveground enclosure is joined to the water-tight aluminum soil lysimeter are also covered with closed-cell neoprene gaskets and held together via compression fittings.

Lysimeters are filled with a coarse textured sandy loam that was collected, by horizon, from the perimeter of a 500–600-year-old Douglas fir stand in the Oregon Cascade Mountains (Tingey et al., 1996). Two-year old Pseudotsuga menziesii (Mirb.) Franco seedlings were planted into the soil during June 1993 and shortly after planting, 6 cm of forest floor litter was placed on the soil surface (Tingey et al., 1996). The trees had been in the chambers almost 4 years when the carbon exchange rate (CER) (Fig. 1) was determined.

To prevent instrument or mechanical failures from jeopardizing the experiment, two pneumatically-controlled dump valves, located at each air handler inlet and outlet, are opened when the CO₂ concentration or air temperature exceeds (for more than 30 s) its target value by more than 150 µmol mol⁻¹ or 6°C, respectively. Opening these valves brings chamber environmental conditions to ambient conditions within 15 min. An analysis of the change in CO₂ concentrations in the chambers, when the dump valves are opened, showed that the chambers are well mixed, i.e. the CO₂ concentration is the same throughout the chamber-air handler system. Consequently, a leak has the same influence anywhere in the system.

The chamber leak detection system uses a centralized, time-shared configuration. All sample locations (12 chambers and two ambient monitoring stations) are connected in series using stainless steel tubing (1/8 in. outer diameter) connected to Teflon®-bodied 3-way solenoids (Furon, Anaheim, CA) located at each sample location. A metal bellows vacuum pump (Senior Flexonics, Sharon, MA) draws air from a given sample
location at 350–750 ml min$^{-1}$, resulting in 0.01–0.02% of the total chamber air volume being removed by the leak detection system each minute of sampling. Sample air passes through a stainless steel purge valve (Swagelock, Highland Heights, OH), to bleed off excess sample flow, before entering the continuous flow Electron-Capture Detector (ECD) using tritium as the electron source (Scientech, Pullman, WA) at a flow rate of approximately 120 ml min$^{-1}$. A sample pump inside the ECD draws approximately 60 ml min$^{-1}$ of air into the instrument for analysis of the SF$_6$ concentration, with the instrument exhaust being vented to the atmosphere approximately 15 m downwind from the chambers. The excess air not removed from the sample tee by the ECD pump was vented to the atmosphere, thereby reducing overpressurization of the sample entering the ECD.

The ECD was cleaned with 25–30 ml of methanol every 1–2 months to maximize the detector sensitivity. The instrument was calibrated each time the detector was cleaned by diluting known concentrations of SF$_6$ with ambient air through mass flow meters to produce the desired range of concentrations (0–2000 nmol mol$^{-1}$). Repeated calibrations demonstrated that the detector response was similar among calibrations, consequently, data from all calibrations were used to develop a single calibration equation. The detector response to a range of known SF$_6$ concentrations was best fit with a quadratic equation.

Fig. 1. Comparison of CO$_2$ leakage and carbon exchange rates (CER) for selected chambers on 1 May 1997. The data are expressed on a unit ground area, not leaf area. The data are shown for 30-min intervals; gaps in the data are periods when there were insufficient data to perform the calculations. The diurnal temperature range was 4–16 and 8–18°C in the ambient and elevated temperature treatments, respectively, while the diurnal vapor pressure deficit (VPD) ranged from 0.80 to 0.05 kPa. The treatment abbreviations are: ACAT, ambient CO$_2$, ambient temperature; ACET, ambient CO$_2$, elevated (+4°C) temperature; ECAT, elevated (+200 μmol mol$^{-1}$) CO$_2$, ambient temperature; ECET, elevated (+200 μmol mol$^{-1}$) CO$_2$, elevated (+4°C) temperature.
The temperature and dew point of the air were continuously controlled and the dump valves were not allowed to open while chamber leakage was determined. The chambers were designed to continuously monitor ambient CO₂ concentrations and control the concentrations in the ambient and elevated CO₂ chambers at the ambient or ambient + 200 μmol mol⁻¹ CO₂ concentrations, respectively (Tingey et al., 1996). This control approach maintained essentially a constant CO₂ gradient between the chamber and the ambient air. Leakage (using SF₆) was estimated every 8 h for each chamber with measurements spread among all chambers each day. Ambient SF₆ concentrations (below detection levels) were measured at one of two separate locations for a 30-min period every 2 h. Thirty minutes prior to estimating chamber leakage, SF₆ was metered into a chamber for 1-min to establish a stable SF₆ concentration; then just before estimating leakage, air was sampled for 5 min (empirically determined to allow at least seven complete volume changes of the sample tubing to occur). After this equilibration time ($t_0$), the initial SF₆ concentration ($C_0$) was ~1500 nmol mol⁻¹ and was continuously monitored until it had decreased by ~5% ($C_1$) and the time ($t = t_1 - t_0$) for this decrease (typically 5–6 min) was noted. The rate of change in the SF₆ concentration is the SF₆ leakage rate which can be represented mathematically as:

$$\frac{dC}{dt} = -L(C - C_a) \quad (1)$$

where $C = [SF₆]$, $t =$ time, $L =$ leakage decay constant, and $C_a =$ ambient $[SF₆]$ (Acock and Acock, 1989, Eq. (1)). Integrating Eq. (1) over time and solving for $L$ gives:

$$L = \frac{\ln[(C_0 - C_a)/(C_1 - C_a)]}{t} \quad (2)$$

where $t = t_1 - t_0$ (Acock and Acock, 1989, Eq. (2)). This equation can be rearranged as:

$$C_1 - C_a = (C_0 - C_a)e^{-Lt} \quad (3)$$

which shows that $L$ is an exponential decay constant (in units of time⁻¹), which defines how quickly the original concentration gradient $(C_0 - C_a)$ declines to $(C_1 - C_a)$ over time.

Because chamber leakage occurs by mass flow via pressure differences, created by the squirrel cage blower, within the air handler, the leakage decay constant for CO₂ is the same as for SF₆, i.e. no adjustment for differences in molecular weight is required (Jones, 1992). The leakage rate for CO₂ can be represented mathematically as:

CO₂ leakage ($\mu$mol m⁻² s⁻¹)

$$= L \times V \times D \times T_{cor} \times P_{cor} \times (C - C_a)/A \quad (4)$$

where $L$ is leakage decay constant (time⁻¹); $V$ is chamber volume (m³); $D$ is density of CO₂ at STP (mol m⁻³); $T_{cor}$ is temperature corrections (K K⁻¹); $P_{cor}$ is pressure correction (Pa Pa⁻¹); $C - C_a$ is CO₂ concentration gradient ($\mu$mol mol⁻¹); $A$ is ground area (m²).

This leakage term reflects both mass flow of air into the chambers from outside (at concentration $C_a$) and vice versa (at concentration $C$). The net leakage may be in either direction depending on the concentration gradient.

Approximately 300 separate determinations of $L$ were made in each chamber over a 6 month period (January 1997 through June 1997); the median $L_{SF₆}$ value was calculated to represent the CO₂ leakage decay constant for each chamber. To determine whether the variation in the ~300 $L_{SF₆}$ values for a given chamber were related to environmental differences at the times when they were determined, for each chamber the correlation of $L_{SF₆}$ with chamber temperature, dew point, light, wind velocity around the chamber, barometric pressure and initial SF₆ concentration were examined. In addition, partial correlations with temperature after accounting for wind velocity, and with wind velocity after accounting for temperature were examined.

To place the CO₂ leakage term in perspective, we used a mass balance approach to calculate the total CO₂ exchange rate (CER) for each terracosm.

CER ($\mu$mol m⁻² s⁻¹)
Table 1
Leakage decay constants* for sulfur hexafluoride ($\text{SF}_6$) from sun-lit controlled environment chambers

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Chamber</th>
<th>$\text{SF}_6$ leakage decay constant (min$^{-1}$)</th>
<th>Half-life $\text{SF}_6$ leakage (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5th</td>
<td>50th</td>
</tr>
<tr>
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<td>0.0134</td>
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<td>0.0190</td>
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<td>ACET</td>
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</tr>
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<td>0.0095</td>
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<td>4</td>
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<td>ECET</td>
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<td>0.0050</td>
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<td>ECET</td>
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<td>0.0062</td>
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<tr>
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<td>0.0064</td>
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<tr>
<td>Minimum</td>
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<td>0.0038</td>
<td>0.0062</td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td>0.0139</td>
<td>0.0212</td>
</tr>
</tbody>
</table>

* Leakage decay constants for $\text{SF}_6$ was calculated using Eq. (2). As chamber leakage occurs via pressure differences within the air handler, the leakage decay constant for CO$_2$ is the same as for $\text{SF}_6$, i.e. no adjustment for differences in molecular weight is required (Jones, 1992).

b The leakage data are expressed as the median (50th percentile) and 90% confidence limits (5th and 95th percentiles) to show variability in the measurements. The leakage decay constant and half-life data are expressed for conditions of standard temperature and pressure. Leakage was determined between January and June 1997.

c The chambers were maintained at one of the following treatments when the leakage decay constant for $\text{SF}_6$ was determined: ACAT, ambient CO$_2$, ambient temperature; ACET, ambient CO$_2$, elevated (+4°C) temperature; ECAT, elevated (+200 μmol mol$^{-1}$) CO$_2$, ambient temperature; ECET, elevated (+200 μmol mol$^{-1}$) CO$_2$, elevated (+4°C) temperature.

\[ D = C - (I + D + \text{CO}_2 \text{ leak} + E + S) \]  

where $D$ is $\Delta$CO$_2$ storage (μmol m$^{-2}$ s$^{-1}$); $I$ is CO$_2$ injection (μmol m$^{-2}$ s$^{-1}$); $D$ is dump valve intake (μmol m$^{-2}$ s$^{-1}$); $E$ is dump valve exhaust (μmol m$^{-2}$ s$^{-1}$). $S$ is CO$_2$ removed by scrubber (μmol m$^{-2}$ s$^{-1}$).

This term incorporates CO$_2$ fluxes which add CO$_2$ to the chamber (respiration, CO$_2$ injection, dump valve intake, CO$_2$ leakage in), which are assigned negative values by convention and fluxes which remove CO$_2$ (assimilation, scrubbing, dump valve exhaust, CO$_2$ leakage out) which are assigned positive values by convention. Net CO$_2$ leakage may be in either direction, depending on the concentration gradient. One chamber was selected, at random, from each of the four treatments (ambient and elevated temperature × ambient and elevated CO$_2$) for this analysis.

3. Results

The median $\text{SF}_6$ leakage decay constants (i.e. Eq. (2)) varied both among chambers and over the measurement period (Table 1). The median leakage decay constants for all chambers averaged 0.0111 min$^{-1}$ and ranged from a low of 0.0062 min$^{-1}$ in chamber 12 to high of 0.0212 min$^{-1}$ in chamber 4 (Table 1). The 5th and 95th percentiles (i.e. 90% confidence limits) show the variation in leakage decay constants about the median; typically the 5th percentile is approximately half the median and the 95th percentile is approximately twice the median. To help illustrate the differences in leakage decay constants among chambers, the half-life for $\text{SF}_6$ leakage (i.e. the time for the concentration of $\text{SF}_6$ to decrease by 50% due to leakage) is shown (Table 1). The half-lives ranges
from 33 to 112 min with the mean half life being 71 min. Leakage decay constants were not different between the ambient temperature chambers and the elevated temperature chambers or between the ambient and elevated CO₂ chambers.

The regression of leakage decay constants on time for each chamber found no significant relationships over the 6 month measurement period, establishing that there was not a consistent change in leakage rate over the measurement period. Similarly, a regression of SF₆ leakage decay constants on time of day also found no relationship establishing the lack of a diurnal pattern in leakage rates. A correlogram of leakage decay constants for each chamber showed no significant temporal correlation among different measurement periods. These various analyses showed that there were no consistent temporal trends in the constants, consequently the median value will be applied for the course of the experiment.

To determine if leakage decay constant varied as a function of wind speed (around the chambers), climate conditions (within the chambers) or initial SF₆ concentration, Pearson correlation coefficients were calculated (Table 2). There were no consistent correlation patterns between leakage constants and air temperature, dew point, light intensity, wind speed, barometric pressure, or initial SF₆ concentration. Even the highest correlation, 0.284 for barometric pressure, only explained about 8% of the variation. The partial correlation of leakage decay constants with air temperature when wind speed was held fixed, and also with wind speed when air temperature was fixed were also computed. Neither of these partial correlations showed any clear association with leakage constants. As a result of these analyses it was concluded that chamber leakage was not significantly influenced by a number of climate factors.

To observe the daily pattern of CO₂ leakage and to compare the amount of CO₂ lost among treatments we computed CO₂ leakage rates for one chamber in each of the four treatments for 1 May 1997 (Fig. 1). CO₂ leakage rates were computed for 1 min increments (using Eq. (4)) and averaged over 30 min intervals. In the ambient CO₂ treatments, CO₂ leakage averaged ~0.25 μmol m⁻² s⁻¹, while as a consequence of the larger CO₂ gradient in the elevated CO₂ treatments, it averaged between 2.3 and 3.1 μmol m⁻² s⁻¹, depending on the chamber. In all treatments, CO₂ leakage was essentially constant over the 24 h period, even though the diurnal temperature range was 4–16 and 8–18°C in the ambient and elevated temperature treatments, respectively. For one chamber in each of the four treatments (Fig. 1), CER was calculated for the same time intervals to compare CER with the amount of CO₂ lost via leakage. During the night, the CER ranged between −7 and −8 μmol m⁻² s⁻¹, while the CO₂ leakage rate was approximately 0.5 μmol m⁻² s⁻¹ in the ambient CO₂ treatments and approximately 2.5–3.3 μmol m⁻² s⁻¹ in the elevated CO₂ treatments. During the mid—part of the day, CER ranged between 13 and 17 μmol m⁻² s⁻¹, while CO₂ leakage ranged between 0 and 0.2 μmol m⁻² s⁻¹ in the ambient CO₂ treatments and 2.2–3.0 μmol m⁻² s⁻¹ in the elevated CO₂ treatments. As anticipated, the CER showed a strong dependency on photosynthetically active radiation (PAR). The comparison of leakage and CER shows that on a daily basis, cumulative (absolute value) CO₂ leakage can range from less than 5–40% of the CER, depending on the CO₂ treatment.

4. Discussion

It was concluded that leakage from the chambers occurs via pressure differences within the air handler because we have been unable to detect any pressure differences between the plant chamber and the outside air. Also chamber leakage was not correlated with changes in air temperature, wind speed, dew point or atmospheric pressure, in contrast to other reports (Acock and Acock, 1989). The lack of influence of these factors in this study could indicate that the range of these conditions was smaller than those experienced in other studies, or that the pressure differential was constant across the air handler. The latter is more likely as the fans were operated at a constant speed. Also the conductance of the Teflon film to CO₂ is very low (approximately 0.00001 cm s⁻¹, Du Pont Electronics, Wilmington, DE).
Table 2
The correlation of sulfur hexafluoride (SF₆) leakage decay constants with air temperature, dew point, light and initial SF₆ concentration in each chamber and ambient wind speed

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Chamber</th>
<th>No. observations</th>
<th>Air temperature</th>
<th>Dew point</th>
<th>Light</th>
<th>Barometric pressure</th>
<th>Initial SF₆ level</th>
<th>Wind speed</th>
<th>Partial corr temperature wind fixed</th>
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<td>264</td>
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<td><strong>−0.032</strong></td>
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<td>0.038</td>
<td>0.055</td>
<td>0.090</td>
<td>0.021</td>
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<td><strong>0.117</strong></td>
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*The correlations highlighted in bold were statistically significant at $P \leq 0.05$.

b The treatment abbreviations are: ACAT, ambient CO₂, ambient temperature; ACET, ambient CO₂, elevated (+4°C) temperature; ECAT, elevated (+200 μmol mol⁻¹) CO₂, ambient temperature; ECET, elevated (+200 μmol mol⁻¹) CO₂, elevated (+4°C) temperature.

c A few leakage values were excluded from the analyses as the values were negative or too large to be realistic.
If CO₂ leaking from the chamber is not quantified, it can lead to an overestimate of assimilation rates and an underestimate of respiration rates; consequently, it is critical that CO₂ leakage be estimated. In chambers similar to here (Baker et al., 1997), CO₂ leakage rate at ambient [CO₂] averaged 0.14 μmol m⁻² s⁻¹ (J.T. Baker personal communications) while these averaged 0.26 μmol m⁻² s⁻¹. At elevated CO₂ (700 μmol mol⁻¹), CO₂ leakage averaged 1.4 μmol m⁻² s⁻¹ (J.T. Baker personal communications) while leakage in the chambers at ambient + 200 μmol mol⁻¹ averaged ~2.7 μmol m⁻² s⁻¹. These data indicate that the chambers tend to have higher leakage rates (by a factor of ~2) than those described by Baker et al. (1997). The reason for this difference is not clear but is likely related to differences in construction and sealing of the air handler. To compare the chambers to those described by Acock and Acock (1989), their chamber leakage constants were converted to half-lives. The CO₂ half-lives in their chambers ranged from 35 to 40 min while those here ranged from 33 to 112 min with a median of 71 min, suggesting that our chambers were less leaky. These data show that SF₆ can be used to estimate chamber leakage with precision and are in agreement with the observation (Costello et al., 1984) that SF₆ was a good analog for estimating CO₂ infiltration into houses.

The CO₂ concentration is an important factor controlling the magnitude of leak rate. In the ambient CO₂ chambers, the ability to control the chamber CO₂ concentration to near the ambient concentration is a key factor in the magnitude of the leakage. If one was perfectly able to control the CO₂ concentration in the chambers to match the ambient CO₂ concentration there would be no net change in CO₂, i.e. there would be no net leakage. When the CO₂ concentration was maintained at +200 μmol mol⁻¹ above ambient in the chambers, CO₂ leakage increased by a factor ~10; while in the chambers described by Baker et al. (1997) the leakage rate increased by a factor of 7 when a gradient of ~300 μmol mol⁻¹ above the ambient CO₂ concentration was maintained. Within a CO₂ treatment, the CO₂ leak rate is essentially constant in our chambers despite a diurnally varying ambient concentration because our CO₂ control strategy is to maintain a constant CO₂ gradient between the chambers and the ambient air (Tingey et al., 1996).

Compared to other trace gases, the use of SF₆ has the advantage of measuring chamber leakage using a gas that is not involved in any physiological process. The results of this study show that SF₆ can be used to estimate chamber leakage with precision and reproducibility and it can be used to estimate the leakage of CO₂, H₂O vapor and other gases of interest. To estimate leakage of other gases in the same chambers, the concentration gradient of the gas of interest must be determined and then Eq. (4) can be used to calculate the leakage. This method can be applied to different chamber designs and used without making assumptions about respiration rates. To estimate the leakage rate of a gas from a different set of chambers, the loss of SF₆ from the chambers needs to be measured and then the leakage can be determined using equations. To illustrate the applicability of the method to other types of systems, Costello et al. (1984) used SF₆ to estimate the leakage of CO₂ from a building.

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References


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