Building and Environment 45 (2010) 2644–2651

Contents lists available at ScienceDirect

Building and Environment

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

Effect of green roof on ambient CO_2 concentration

Jian-feng Li [a], Onyx W.H. Wai [b,*], Y.S. Li [b], Jie-min Zhan [a], Y. Alexander Ho [c], James Li [d], Eddie Lam [b]

[a] Department of Applied Mechanics and Engineering, Sun Yat-sen University, Guangzhou, China
[b] Department of Civil & Structural Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
[c] Hong Kong Housing Society, World Trade Centre, Causeway Bay, Hong Kong
[d] Department of Civil Engineering, Ryerson University, Toronto, Ontario, Canada

ARTICLE INFO

Article history:
Received 26 January 2010
Received in revised form
24 May 2010
Accepted 24 May 2010

Keywords:
Green roof
Air quality
CO_2 absorption velocity
Numerical simulation
Field measurement
Chamber experiment

ABSTRACT

Plants can improve air quality by removing pollutants. The air purification capability of plants has been receiving increasing attention because of the rapid deterioration of the environment. However, research on evaluating quantitatively the effect of plants on the environmental pollutant concentrations is still scarce. This paper studies the effect of a green roof on the ambient CO_2 concentration as an example to assess the benefit of urban greening. The study comprises three parts: (1) Field measurement of the difference of CO_2 concentration at a location in the middle of the plants in a small plot of green roof and one in the surrounding area, (2) Experiments to measure the plant's CO_2 absorption velocity and emission rate using a sealed glass chamber; and (3) Computer simulation of the CO_2 concentration distribution around a green roof using the measured CO_2 absorption velocity and emission rate to quantify the effects of the green roof on the ambient CO_2 concentration.

1. Introduction

Vegetation can be in the forms of trees, shrubs and grasses and it takes up a certain proportion of land areas in cities and is an important part of the cities. It has been increasingly popular to use roofs of buildings for growing plants, not only because of aesthetic reasons, but also for improving the environment. Plants can reduce the heat reaching on buildings by increasing the reflection of radiation and shading. They also take the heat away through the process of transpiration. This results in a reduction of indoor and outdoor temperatures[1,12–14]. Plants can improve urban air quality by removing air pollutants and trapping of particulates in their leaves [1–11]. As air pollution is now a major environmental problem in many cities, the air purification capability of urban vegetation has been receiving increasing attention.

A lot of studies have been carried out to evaluate the air purification capability of urban vegetation and it is found that urban plants can improve air quality noticeably. Nowak et al. [4] estimated the total annual air pollutant (O_3, PM_{10}, NO_2, SO_2, CO) removal by US urban trees at 711,000 metric tons ($3.8 billion value). Yang et al. [3] quantified the level of air pollution removal by green roofs in Chicago using a dry deposition model. Their result, based on the local weather and plants conditions and air pollutants concentrations, showed that a total of 1675 kg of air pollutants was removed by 19.8 ha of green roofs in oneyear. Gratani et al. [2] compared the difference between the CO_2 concentrations on the road side and inside a park in Rome and calculated the amount of CO_2 absorbed by the trees at the two sites. They concluded that trees had an important effect on the difference of CO_2 concentrations between the two sites.

However, most investigations focused on estimating the amount of air pollutants removed by urban plants [3–8] and studies on the quantification of the effects of pollutant removal on ambient air pollutants concentration are still scarce. This paper uses a green roof as an example to quantify its effect on the ambient CO_2 concentration. The study comprises three parts: (1) Field measurement of CO_2 concentration at a location in the middle of the plants and 2 m away from vegetation, (2) Experiments of measuring plant's CO_2 absorption velocity and emission rate using a sealed glass chamber, and (3) Computer simulation of CO_2 concentration distribution around a green roof using the measured CO_2 absorption velocity and emission rate to quantify the effects of green roof on the ambient CO_2 concentration.

2. Field measurement

The field measurement was carried out to evaluate the difference of CO_2 concentrations at two locations: one was at the middle

* Corresponding author. Tel.: +852 2766 6025.
E-mail addresses: ceonyx@inet.polyu.edu.hk, ceonyx@polyu.edu.hk (O.W.H. Wai).

0360-1323/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2010.05.025

of the plants in a small plot of green roof and the other was in the surrounding area 2 m away from the plants. The purpose was to investigate the effect of green roof on the surrounding CO_2 concentration.

2.1. Measurement site and methods

Hong Kong is under subtropical monsoon climate with a mean air temperature of 27.5 °C in summer. The measurements were carried out on the rooftop of a six-storey building in Hong Kong (Fig. 1). There are four small plots, each with an area of 4 m × 4 m for growing plants. Besides the plants there are no other sinks or sources of CO_2 on and around the roof. The background of Fig. 1 is facing south. Sunshine can irradiate on the plants directly from about 7:30 to 16:00. And after 16:00 sunshine could not directly reach the plants because of the shading of nearby buildings. The CO_2 concentrations at the two locations P1 and P2 indicated in Fig. 1 were measured by a CO_2/H_2O analyzer LI-7500 in the sunny days of July and August 2009. The LI-7500 measures the concentrations of CO_2 and vapor. The analyzer consists of a control box and a sensor head. The control box is connected to a computer for real-time measurement. The accuracy of the LI7500 can reach 1 mg/m^3 for CO_2 concentration measurement. P1 was located in the middle of the plants in one of the plots and P2 was 2 m away from the plot[3]. The sequence of measurement with the same sensor is as follows. First the CO_2 concentration at P1 was measured for about five to ten minutes and followed immediately by the measurement at P2. The measurement sequence was repeated throughout the day. The sampling rate of CO_2 concentration was 1 Hz.

2.2. Measurement results

The CO_2 concentration fluctuates throughout a day, with an average value of about 700 mg/m^3. Fig. 2 shows the CO_2 concentration variations at P1 and P2 in a representative sunny day with some clouds and atmospheric wind of wind force 2 (wind speed of 1.6–3.3 m/s). Every point on the curves is the 10-min average value.

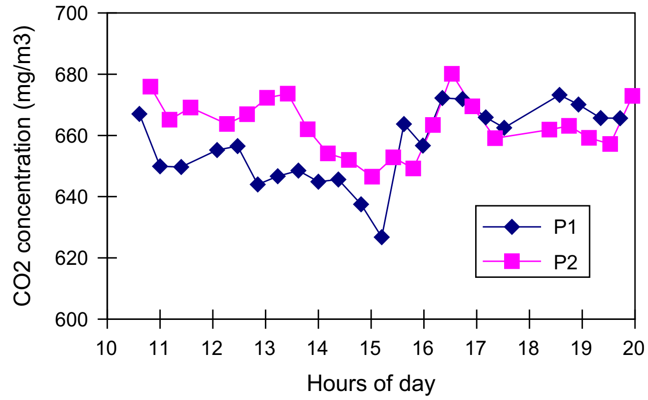

Fig. 2. CO_2 concentration curves at P1 and P2 obtained between 10:30 and 20:00 on 22 July 2009.

The differences in CO_2 between the two curves are obvious. The average CO_2 concentration at P1 was 12.9 mg/m^3 lower than that at P2 before 16:00, while the average CO_2 concentration at P1 was 4.9 mg/m^3 higher than that at P2 after 17:00. Fig. 3 shows the curves of CO_2 concentrations at P1 and P2 in a sunny day with modest strong wind of wind force 4 (wind speed of 5.5–7.9 m/s) in the daytime. The wind became weak in the evening. Every point on the curves is a 5-min average value. The average CO_2 concentration at P1 was only 4.3 mg/m^3 which was lower than that at P2 before 16:00.

Fig. 2 shows a representative situation in a sunny day with light wind. When sunshine reaches the plants directly in the daytime, the CO_2 concentration at P1 is lower than that at P2. On the contrary, CO_2 concentration at P1 is slightly higher than that at P2 during the night time. Plants absorb CO_2 from the atmosphere for photosynthesis and release CO_2 to the atmosphere during respiration. The rate of photosynthesis is greatly dependent on the intensity of light. In the daytime with abundant of sunlight, photosynthesis is very active and plants act as a sink of CO_2,

Fig. 1. Setup of field measurement.