Performance evaluation of an air cleaner using sorption effect and its life cycle inventory analysis

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ABSTRACT

This study addresses the development of an indoor air cleaner using the adsorption/desorption effect by experiment and impact assessment on the global environment by the life cycle inventory (LCI) analysis. The fundamental performance of contaminant removal for an air cleaner is presented. A porous ceramic tile and cultivated carbon were used to adsorb chemical contaminants in the prototype system with a single adsorption unit. As a result of the experiment, a significant effect of contaminant removal was observed in the system with a honeycomb-type cultivated carbon. Moreover, an evaluation method to estimate life cycle energy (LCE) consumption and life cycle CO_2 ($LCCO_2$) emission was investigated. Energy consumption and CO_2 emission on the usage stage for the mechanical ventilation systems was quite large in all the stages.The LCI of the present air cleaner with removal efficiency 50% was equivalent to the conventional mechanical ventilation system with the heat exchange efficiency 70%.

INDEX TERMS

Life cycle inventory analysis; Indoor air cleaner; Adsorption/desorption effect

INTRODUCTION

The air cleaner has been recognized as one of the effective strategies to remove air contaminants and reduce the ventilation load for energy saving in buildings. All filters can definitely remove particulates from the indoor air, but they are not always effective, except for the special filters with chemical additives, for gaseous contaminants such as VOC. The authors have been investigating the sink effect of building materials and the application of air cleaners to remove chemical contaminants from indoor air (Matsumoto and Hayashi, 1999; Matsumoto *et al.*, 2001).

On the other hand, life cycle inventory (LCI) analysis has been generally used to investigate the impact assessment on the global environment in many industrial fields. Especially for the environment objected products such as household appliances, i.e. refrigerator, washing machine, television and so on, LCI is recognized as one of the important evaluation indices. As is well known, the building related industries including

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building material production, manufacturing, building management, material demolition fields, have the greatest influence on the global environment. Therefore, several projects on the building related LCI have been carried out in the last decade (CIB, 1999; Matsumoto, 1999).

The object of this study is to investigate the fundamental performance of a novel air cleaner using the adsorption/desorption effect by a model experiment, and present the impact assessment on the global environment by the LCI analysis. The basic system consists of adsorption/desorption units, fans, ducts and control valves. A porous ceramic tile and cultivated carbon were used to adsorb chemical contaminants in the prototype system with a single adsorption unit. Moreover, the life cycle energy (LCE) and life cycle CO_2 ($LCCO_2$) emission for the indoor air quality control systems were predicted to investigate the impact on the global environment.

BASIC CONCEPT OF THE PRESENT AIR CLEANER

The aim of the present air cleaner is not only to remove chemical contaminants from indoor air, but also to reduce the operation energy and the maintenance costs. The system consists of sorption units, fans and dampers to control airflow. It operates at two modes, the adsorption mode to circulate indoor air and adsorb chemical contaminants on the surface of the sorption unit and the desorption mode to emit the contaminants from the unit surface to outdoor (Figure 1).

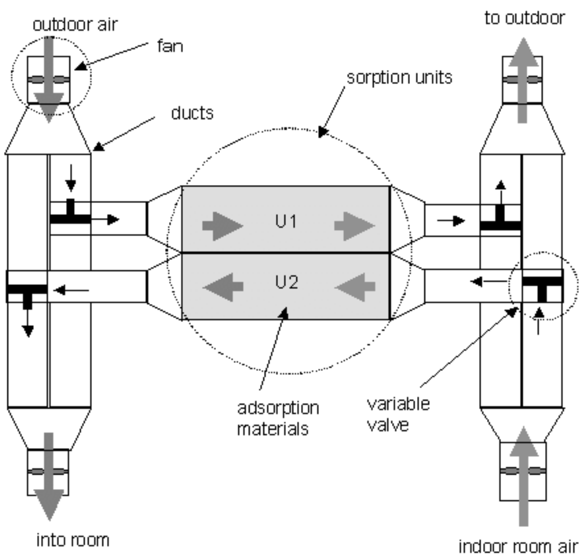

Figure 1 Overview of the present air cleaner.

PROTOTYPE CLEANER

The fundamental performance of contaminant removal for the prototype air cleaner with one sorption unit, two duct fans and four dampers was investigated as shown in Figure 2 (Okamura and Matsumoto, 2002). The numbers 1–5 show the sampling points for measuring contaminant concentration. Number 1 is the outside of the air cleaner, Number 2 is inside the chamber with the contaminant source, Number 3 is the inlet of the sorption unit, Number 4 is the outlet of the unit and Number 5 is the outdoor. In this experiment, two materials, a ceramic tile with a fine porous surface to adsorb chemical compounds and cultivated carbon with many small honeycomb holes were measured. The measurement conditions are shown in Table 1. Toluene was used as a chemical contaminant source, and put in a small flask in the room model (0.9 × 0.5 × 0.45 m). Both step-up and step-down tracer gas methods were used to identify the removal performance for the adsorption materials by B&K Multi Gas Monitor. The circulation flow rate was measured by an orifice flow meter.

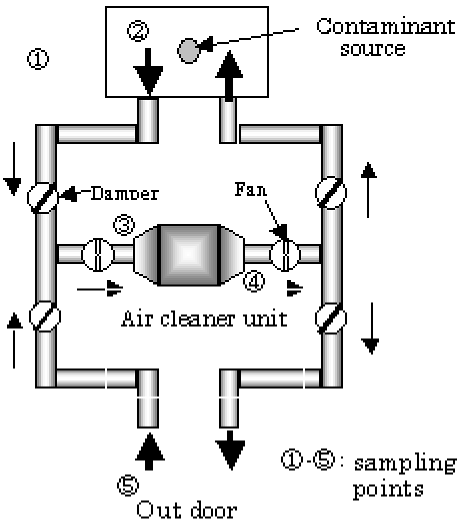

Figure 2 Prototype air cleaner.

Table 1 Measurement conditions

Case	Adsorption material	Operation time per mode (h)	Circulation flow rate (l/s)
1	No	3	Low (12.1)
2	No	3	High (17.2)
3	Yes	3	Low (12.1)
4	Yes	3	High (17.2)
5	Yes	6	Low (12.1)
6	Yes	6	High (17.2)

MEASUREMENT RESULTS

Figures 3 and 4 show the concentration changes of sampling point Nos. 2, 3 and 4 for Case 1 with no adsorption material and Case 5 with adsorption material, respectively. The air cleaner was operated under the adsorption and desorption modes for 3 or 6 h. As shown in Figure 4, a slow increase of concentration for a couple of hours just after the start of the measurement shows the contaminant removal effect. The total adsorption rate was approximately 14.6 mg for first 6 h at the adsorption mode.

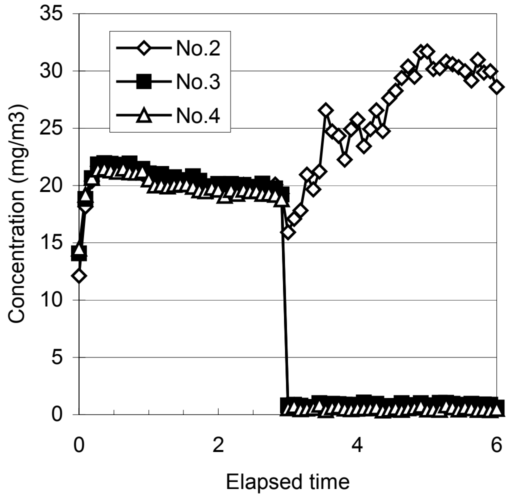

Figure 3 Concentration vs. elapsed time (no adsorption material).

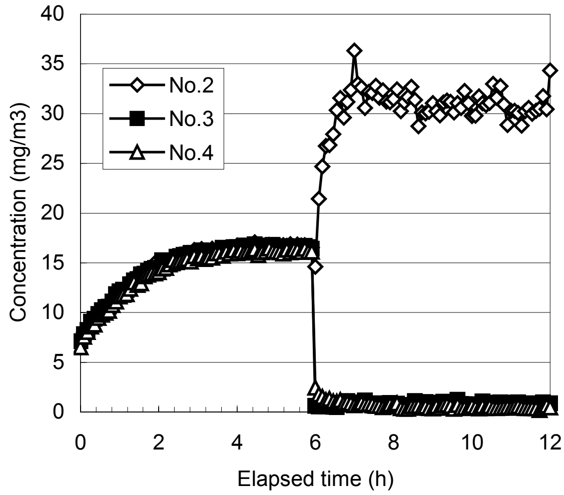

Figure 4 Concentration vs. elapsed time (adsortion material inside).

A honeycomb-type cultivated carbon filter (0.15 × 0.15 × 0.03 m, 45 cell/cm^2, 3.6 kPa/m pressure drop) was used under the adsorption mode during about 2 h as shown in Figure 5. The average concentration difference between inlet air and outlet air was 0.59 mg/m^3. The relationship between inlet air and outlet concentration is shown in Figure 6. The correlation coefficient of the outlet concentration to inlet one was approximately 0.7.

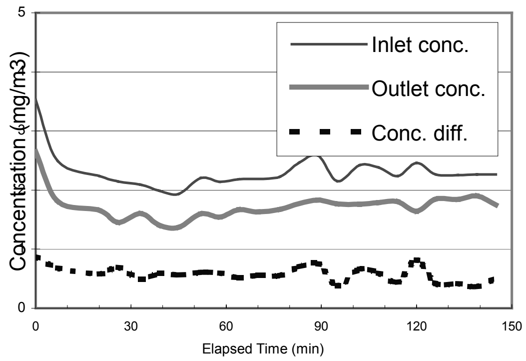

Figure 5 Concentration vs. elapsed time.

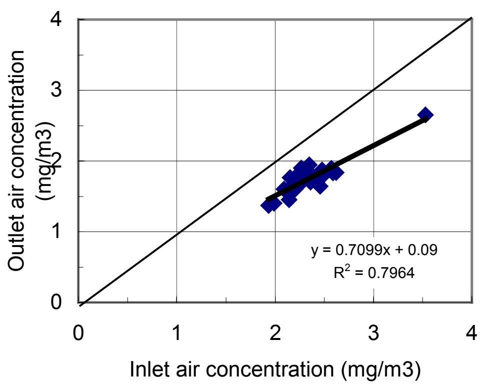

Figure 6.Inlet vs. outlet concentration.

LIFE CYCLE INVENTORY ANALYSIS

The following approach was employed in evaluating indoor air quality control strategies by the LCI analysis. The life cycle inventory *LCI* on four life cycle stages, production, usage, maintenance and demolition, can be expressed as Eqn (1):

$$LCI = I_{\mathrm{p}} + I_{\mathrm{u}} + I_{\mathrm{m}} + I_{\mathrm{d}} \qquad (1)$$

where I_{p}, I_{u}, I_{m} and I_{d} are production, usage inventory, maintenance and demolition inventory, respectively, and each term can be assumed as follows:

$$I_{\mathrm{p}} = E_{\mathrm{embodied}} \cdot W_{\mathrm{f}} \quad (2)$$

$$I_{\mathrm{u}} = I_{\mathrm{u,op}} + I_{\mathrm{u,vent}} \quad (3)$$

$$I_{\mathrm{m}} = I_{\mathrm{p}} \cdot C_{\mathrm{m}} \cdot T_{\mathrm{period}} \quad (4)$$

$$I_{\mathrm{d}} = I_{\mathrm{p}} \cdot C_{\mathrm{d}} \quad (5)$$

where E_{embodied} is the embodied energy consumption or CO_2 emission of the equipment, W_{f} is the equipment weight, $I_{\mathrm{u,op}}$ is the inventory, energy consumption or CO_2 emission per hour during the service life, $I_{\mathrm{u,vent}}$ is the equivalent inventory by ventilation load, C_{m} and C_{d} are the ratio of maintenance and demolition inventory to I_{p}, respectively, and T_{period} is the period for the regular maintenance.

Table 2 shows the parameters for a simulation example. Service life evaluated is 20 years, and a part of the equipment is changed or maintained every year. Figures 7 and 8 show energy consumption and CO_2 emission on each stage, respectively. Both inventories on the usage stage were quite large in all the stages.

Figures 9 and 10 show LCE and $LCCO_2$ of IAQ control strategies, respectively. The LCIs for the present air cleaner with removal efficiency 50% was equivalent to the conventional mechanical ventilation system with the heat exchange efficiency 70%. If the present system has the removal efficiency 90%, the reduction of LCI can be expected to be about 60%.

Table 2 Calculation conditions

Service life (years)	20
Equipment weight (kg)	10
Embodied energy consumption (MJ/kg)	55.945
Embodied CO_2 emission (kg-C/kg)	3.565
Equivalent ventilation rate (m^3/h)	30
Total operation hours (h)	720
Equipment power (W)	30
Ratio of maintenance energy/CO_2 to I_{p}	0.05
Ratio of demolition energy/CO_2 to I_{p}	0.1
Period for maintenance	1

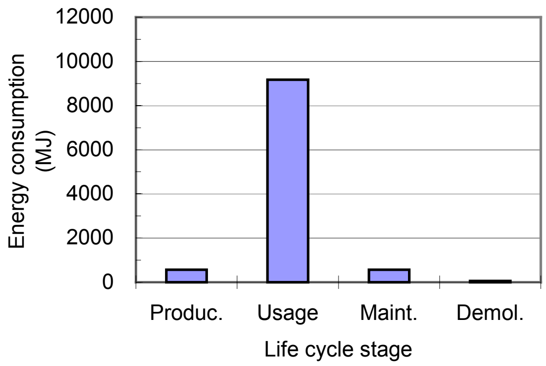

Figure 7 Energy consumption on each life cycle stage.

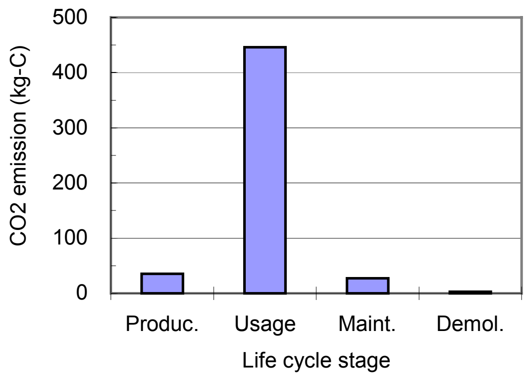

Figure 8 CO_2 emission on each life cycle stage.

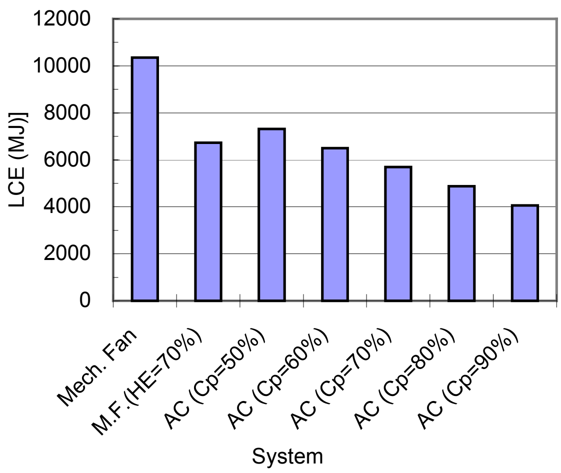

Figure 9 LCE..

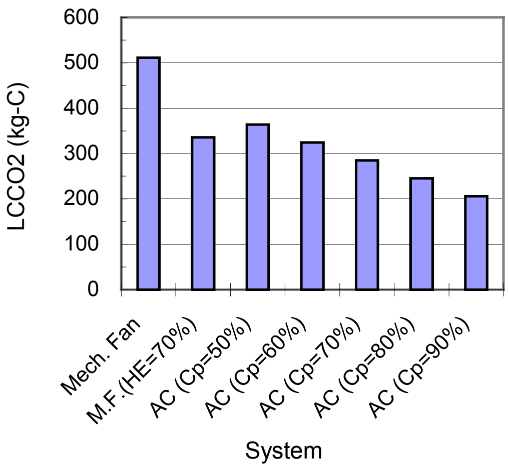

Figure 10 LCCO2.

CONCLUSIONS

An indoor air cleaner using the adsorption/desorption effect by experiment was developed and its impact assessment on the global environment by the LCI analysis was presented. As a result of the model experiments, a significant effect of contaminant removal was observed in the system with the honeycomb-type cultivated carbon. Moreover, LCE and $LCCO_2$ emission for the indoor air quality control systems were predicted to investigate the impact on the global environment. The present air cleaner showed an efficient performance and low impact on the global environment.

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REFERENCES

CIB (1999). Agenda21 on sustainable construction. CIB Report Publication 237.

Matsumoto, H. (1999). System dynamics model for life cycle assessment (LCA) of residential buildings. *Proceedings of the Sixth International Conference on Building Simulation*, pp. 1013–1018.

Matsumoto, H. and Hayashi, S. (1999). Removal and control of pollutants from building materials by ventilation. *Proceedings of the 8th International Conference on Indoor Air Quality and Climate*, Vol. 1, pp. 436–441.

Matsumoto, H., Kato, M. and Yoshino, H. (2001). IAQ control by hybrid ventilation and material sorption in houses. *Proceedings of the 4th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings*, pp. 125–132.

Okamura, G. and Matsumoto, H. (2002). Experimental study on IAQ control by adsorption/desorption effect. Part 1: experiments of sorption effect for a sorption unit type. *AIJ Annual Meeting*, pp. 987–988.