Measures to conserve cooling and heating load using a pulse ventilation system and adsorbent materials

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ABSTRACT
Compatibility between energy saving and indoor air quality is a key issue facing the modern society today. We propose a novel energy-saving ventilation system using a pulse ventilation system and an adsorbent material. The adsorbent material can reduce the fluctuation of concentration during the off-ventilation period and increase the ventilation efficiency because it releases chemicals during the on-ventilation period. We evaluated the effect of energy consumption by this system. Based on the assumption that daily average high and low temperatures in August in Japan are 31 and 24°C, respectively, and room temperature under air conditioning is 25°C, we calculated the energy consumption to pump up the heat led into the room during ventilation. As a result, in this ventilation system, we estimated that 150 kW per room per month (3500 Japanese Yen in expenses) is saved as compared to the case of continuous ventilation.

INDEX TERMS
Ventilation; Adsorbent; VOCs; Indoor air quality

INTRODUCTION
Recently, the indoor air pollution caused by chemical substances emitted from building materials, furniture and so on has attracted much attention. Ventilation is an effective countermeasure to reduce the indoor level of chemical substances such as VOCs and SVOCs. At the same time, energy saving in an office or a residence is an urgent subject in relation to the global warming issue. Excess ventilation will lead to increase of air conditioning load in a summer or winter. On demand ventilation is an approach to cope with cleaning of indoor air and energy saving (Raymer, 2002; Sowa, 2002). However, it needs continuous monitoring of the level of indoor air and as a result it will become an expensive method. Besides, it may be insufficient to identify the chemicals out of the measurements. In this paper, we propose a novel energy-saving ventilation system consisting of a pulse ventilation system (i.e. on-and-off cyclic ventilation) and adsorbent materials. The pulse ventilation is a very cheap countermeasure and needs only the installation of an on–off timer into an existing ventilator.

PULSE VENTILATION AND ADSORBENT
If the total amount of ventilated air is equal, occasional ventilation with a high flow rate is more effective for the reduction of indoor air pollutant than continuous ventilation with a low flow rate. This is because, in case of high flow rate ventilation, air exchange between indoor

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air and outdoor air becomes a plug flow, while in case of low flow rate ventilation the air exchange becomes a perfect mixed flow. The difference in both ventilation efficiencies (i.e. the volume of ventilation required in order to maintain indoor time-average concentration at a certain level) is twice at the maximum. Disadvantages of the pulse ventilation are, when the flow rate of the ventilator is small in comparison with the volume of a room, the difference of efficiency becomes small and indoor concentration becomes high during the shut-down period. These faults are cancelled by the combination of the pulse ventilation system and the adsorbent material. The adsorbent will capture chemicals during the off-ventilation period during which the indoor level is high and will release chemicals during the on-ventilation period during which the indoor level is low. Since the timing of the release of chemicals into indoor air is concentrated during the on-ventilation period, the coupled system of pulse ventilation and adsorbent material can exhaust a pollutant efficiently and restrain the fluctuation of concentration.

MODEL DESCRIPTION

Outline

We have developed a simple model to evaluate the effect of a coupled system of pulse ventilation and adsorbent material. Toluene was selected as a typical indoor pollutant. A room with a volume 40 m^3 was assumed (Figure 1). The concentration was calculated simply assuming a perfect mixing in the room. The room has a ventilation fan (ventilation rate is 600 m^3 h^{-1}), source of toluene and adsorbent material. A model toluene source is plywood with an area of 10 m^2 where the emission rate of toluene is 0.7 mg m^{-2} h^{-1}. The adsorption rate of toluene to the adsorbent was set as 9×10^{-4} m s^{-1} assuming that the mass transfer coefficient in the boundary layer (1 cm) on the adsorbent surface determines the apparent adsorption rate. Langmuir model was applied to calculate the adsorption–desorption equilibrium. Two types of adsorbents were considered in this paper. One is an activated carbon fabric cloth and another is a contrasting adsorbent of less adsorption capacity. The adsorption capacity of the activated carbon fabric cloth was set based on Singh *et al*. (2002). The calculation conditions about

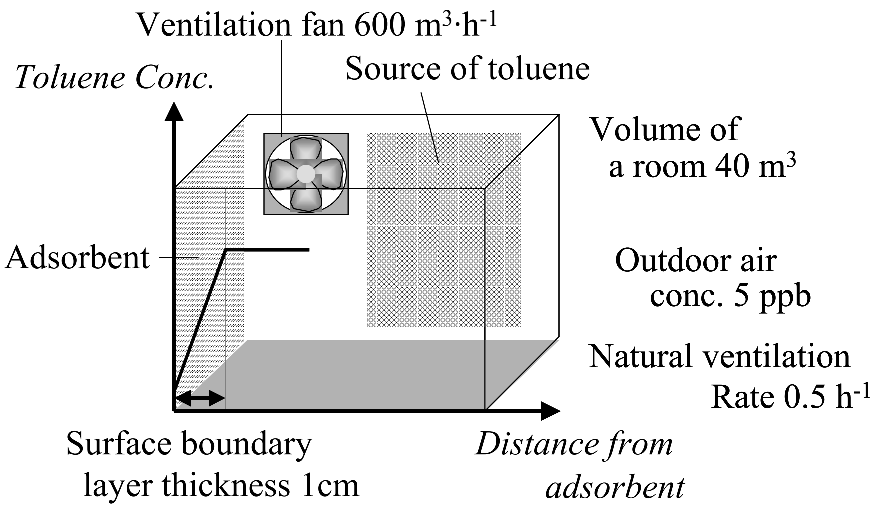

Figure 1 Schematic diagram of the model for calculating indoor air concentration in the coupled system of pulse ventilation and adsorbent material.

adsorbents are summarized in Table 1.

Table 1 Calculation conditions about adsorbent

Adsorbent	Activated carbon fabric cloth	Low-capacity adsorbent
Adsorption equilibrium constant $m^3 \cdot g^{-1}$	3×10^4	1×10^3
Monolayer adsorption capacity $g \cdot g^{-1}$	2×10^{-1}	2×10^{-4}
Area m^2	20	20
Density of adsorbent $g \cdot m^{-2}$	3×10^3	3×10^3

Temperature Dependence of Adsorption

Based on the kinetic theory of gases, the temperature dependence of the adsorption rate constant and desorption rate constant are proportional to $T^{-0.5}$ and $\exp(-RQT^{-1})$, respectively, where T is absolute temperature (K), R is the gas constant ($J\ K^{-1}\ mol^{-1}$) and Q is the heat of adsorption ($J\ mol^{-1}$) (Adamson, 1982). Such temperature dependence was considered to calculate the adsorption equilibrium. Generally, the heat of adsorption of activated carbon will exceed 42 kJ mol^{-1} (Takeuchi, 1995). For the value of Q, each case of 50 kJ mol^{-1} was assumed.

Estimation of the Energy Saving

The change of outdoor air temperature was set by interpolating monthly average maximum temperature (31°C) and minimum temperature (24°C) in August in Japan with a sine curve. Electric power consumption to exhaust equivalent heat flow into the room by ventilation was calculated under the following conditions: setting temperature of air conditioning is 25°C; the performance coefficient of an air conditioner is 3.0; ventilation schedule is continuous ventilation at night (8 h) and 1-min-on and 9-min-off ventilation cycles during the day (16 h).

RESULTS AND DISCUSSION

The calculation was repeated in 20-day cycles in every case. Figure 2 shows the changes of indoor concentration with time under the pulse ventilation operation with and without the activated carbon fabric cloth. Since the activated carbon fabric cloth has large adsorption capacity, it always absorbs toluene irrespective of the ventilation mode. Figure 3 shows the changes of indoor concentration with time in the case of low capacity adsorbent. In this case, the low capacity adsorbent reaches steady state and does not work as a net sink of toluene (i.e. adsorption amount is equal to desorption amount during a 1-day cycle). In spite of the balance of adsorption and desorption, the indoor daily mean concentration can decrease in comparison with the case without adsorbent. The effectiveness of pulse ventilation was evaluated and it was found that 150 kW per room per month (3500 Japanese Yen in expenses) will be saved in comparison with continuous ventilation. Figure 4 shows the changes of indoor concentration with time when the room temperature becomes 40°C at the maximum (high temperature case in Figure 5). There may be a danger of being exposed to high-levels toluene at the time of reaching home.

CONCLUSION

We proposed a novel energy-saving ventilation system using a pulse ventilation system and an adsorbent material. The effectiveness of this system was evaluated by model calculation. It was projected that the current system can maintain the concentration at low level with less total ventilation amount.

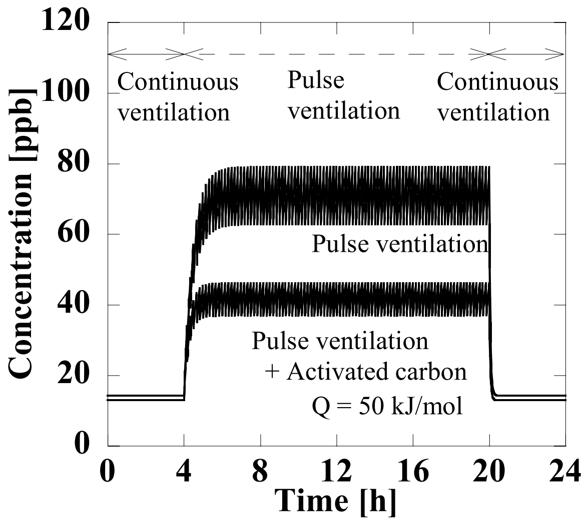

Figure 2 Result of model calculation (pulse ventilation + activated carbon).

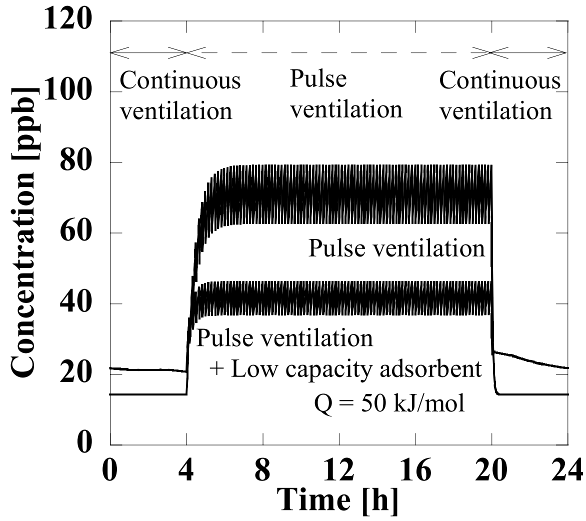

Figure 3 Result of model calculation (pulse ventilation + low capacity adsorbent).

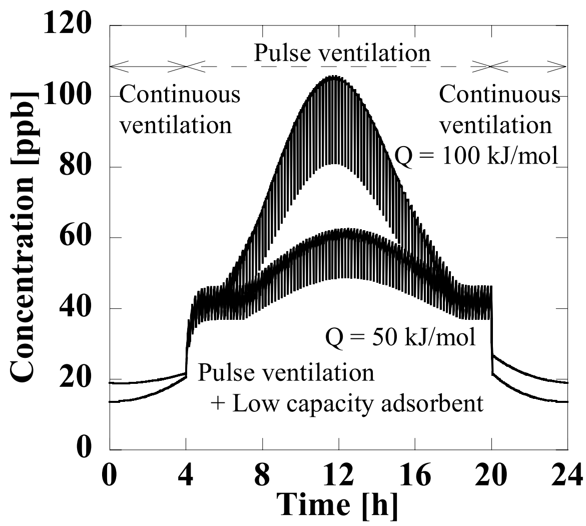

Figure 4 Result of model calculation (pulse ventilation + low capacity adsorbent).

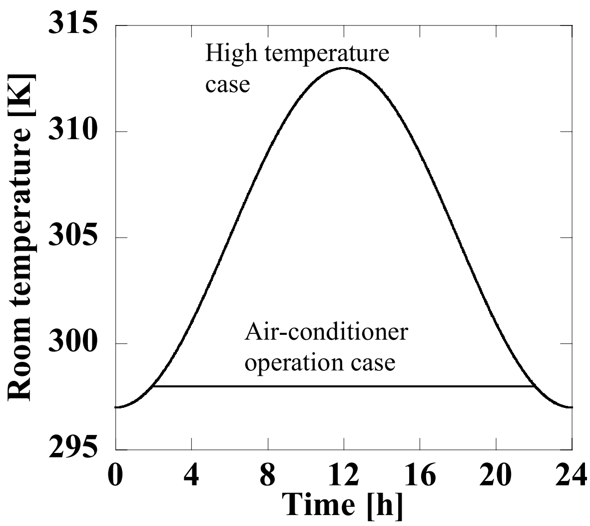

Figure 5 Setting of the room temperature.

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