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Indoor Air Quality and Ventilation Strategies in the Use of Combustion Space Heating Appliances in Housing

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ABSTRACT

Indoor air quality (IAQ) in the use of combustion appliances is important for adequate evaluation of air pollution health risks. Since people spend most of their time inside buildings, especially the elderly and children, their exposure to indoor air contaminants can increase health problems in the community. Combustion materials emitted from combustion space heating appliances in housing during the winter may become a serious problem to health, since sources of ventilation are usually left closed to obtain a comfortable temperature level. To evaluate the IAQ and factors that may decrease combustion materials emitted from heaters, a study was done by using a house exposure model. The study found that IAQ in an unventilated house during combustion heater use was poor due to lack of fresh air. When using a heater, natural ventilation should be used to dilute air contaminants emitted from the heater. A concentration of carbon dioxide at about 1000 ppm and a comfortable temperature of 20°C could be maintained by applying natural ventilation of about 0.12 m^2 during the use of an unvented kerosene space heater. However, ventilation also depends on the number of the occupants and the wind velocity. The use of a steamer is also important to provide optimum humidity levels without elevating the respirable dust concentration above the acceptable limit.

Key words: *Indoor air quality (IAQ), Combustion materials, Natural ventilation, Humidification*

IAQ is receiving increased attention from researchers and public health officials as a critical component of human exposure to a variety of air pollutants. An increasing number of health and comfort problems in relation to IAQ have been reported during the winter. Indoor air contaminants are thought to cause adverse effects spanning a range of chemical, physical and biological substances, in which the concentrations are often higher than those found outdoors[6,12]. To evaluate the IAQ and determine the effects from exposure to emissions from pollutant sources, a study was done by using a house exposure model. There are many reasons why investigations of IAQ are essential for the adequate evaluation of air pollution health risks. Since people spend 80–90% of their time inside buildings, indoor air contaminants at any significant level is bound to lead to increased levels of complaint and possibly to health problems[2,4]. Especially for the elderly and infants, the exposure to indoor air contaminants is still higher. IAQ may be adversely related to trends toward reduced ventilation in buildings, increased use of synthetic materials, and increased reliance on unvented combustion appliances for space heating.

In modern buildings and apartments, the reduced air exchange rate between conditioned indoor air and unconditioned outdoor air can increase the indoor concentration of pollutants[5,14]. One type of indoor air pollution source is unvented combustion used for space heating, including unvented kerosene space heaters, unvented gas appliances, wood stoves and fireplaces[6,13,14]. Combustion sources in homes can emit carbon monoxide and carbon dioxide, oxides of nitrogen, formaldehyde, organic compounds, nitrous and other acids and particulate matter that may affect IAQ. High temperatures from space heating appliances may also influence the air humidity and affect the concentration of respirable dust[8].

The aim of this study was to identify indoor air quality in the use of combustion space heating appliances in housing and the factors that may reduce indoor air contaminants.

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METHODS

IAQ during the use of combustion space heating appliances in housing was measured by using a house exposure model. One Japanese style apartment with 2 rooms (floor areas of 32 m^2 and volumes of 80 m^3) located in Hiroshima, Japan was used for this study. The study was done in February, 1994. IAQ measurements, including the temperature, relative humidity, concentration of carbon dioxide, carbon monoxide and respirable dust were taken during the use of kerosene space heating appliances. Two types of unvented kerosene space heater were used in this study. Type I was an unvented kerosene space heater that was equipped with a fan, steamer and automatic temperature control (Toyostove, LCB30D). The other was an ordinary unvented kerosene space heater. Each experiment was conducted by using the two kinds of heater for four days. Measurements were taken 5 hours each day until a nearly saturated concentration of carbon dioxide was achieved. To study the role of fresh air in diluting the combustion materials emitted from the heater, natural ventilation was introduced for about one minute during heater using time. This was intended to stimulate the effect of people going out and opening the door for one or two minutes. Air quality sampling was taken randomly five times each hour in a space at the height between 0.6 and 1.5 m. The differences between carbon dioxide and carbon monoxide concentration before and after using natural ventilation were also measured. Before carrying out the experiment, the air quality outside and inside the house was also adjusted by opening all the doors and the windows for about one hour. The effect of humidification when using the heater was also studied. Air temperature and relative humidity were recorded with a battery-operated psychrometer. Indoor carbon monoxide and carbon dioxide concentrations were measured by colorimetric detector tubes (Kitagawa , 106G and 126 B). Concentrations of respirable dust were measured by a Sibata P-5H2 digital dust monitor, a direct reading instrument based on light scattering calibrated by the manufacturer to 0,3 μm particles of stearic acid.

RESULTS

Figure 1 shows that the concentration of carbon dioxide increased quickly in the first three hours and then the increase slowed until it approached saturation after five hours. However, the carbon monoxide concentration will continue to increase as the heater using time is prolonged. There was a slight difference between the concentration of carbon monoxide and carbon dioxide in the use of two types of heaters. It was also found that the average concentration of carbon monoxide was higher with the use of type II heater.

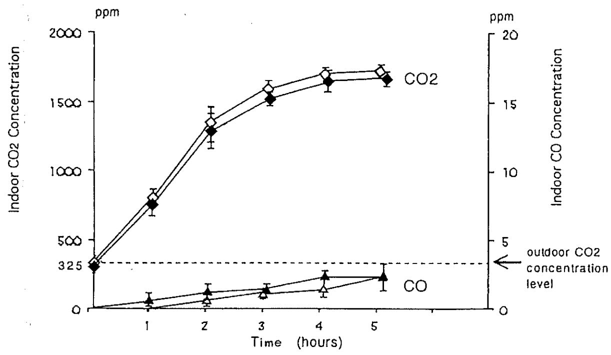

Fig. 1. Indoor CO_2 and CO concentration during the use of unvented combustion space heater appliances.
◇;△ Type I heater (with fan and steamer)
◆;▲ Type II heater (without fan and steamer)

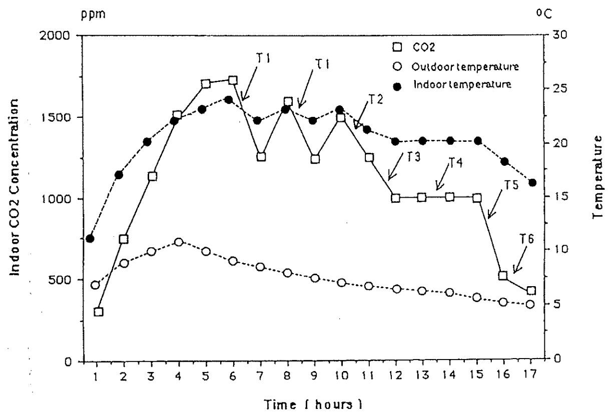

Fig. 2. Average CO_2 concentration and temperature level during the use of kerosene space heater appliance with treatment by several forms of natural ventilation (starting time 10.00 a.m.)
T1: window open for 2 min
T2: door open for 1 min
T3: window open for 30 min
T4: by applying 0.24 square meters of natural ventilation during the course of the study (bathroom window)
T5: by applying 0.12 square meters of natural ventilation during the course of the study (living-room window)
T6: by applying 0.24 square meters of natural ventilation during the course of the study (cross ventilation)

Figure 2 shows the concentration of carbon dioxide, carbon monoxide and the indoor temperature with treatment by employing several sources of natural ventilation, and different opening durations. The results showed that a decrease of carbon dioxide and carbon monoxide concentration was appropriate to the width of the window and the length of time the window was open. A

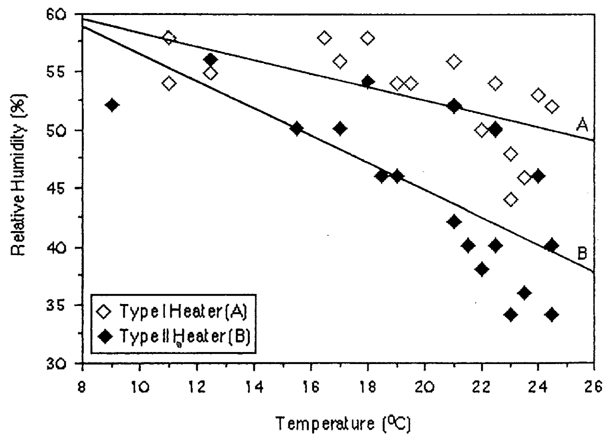

Fig. 3. Linear regression values of the relative humidity as a function of the indoor temperature in the use of type I and II heater.
Type I heater (A): HUMIDITY = –0.58 TEMP + 64.16; R = 0.63, n = 18, p<0.01
Type II heater (B): HUMIDITY = –1.18 TEMP + 68.29; R = 0.72, n = 18, p<0.001;
where HUMIDITY is the relative air humidity, TEMP is the indoor temperature, R is the correlation coefficient, n is the number of measurements and p is the two tailed p value of the slope.

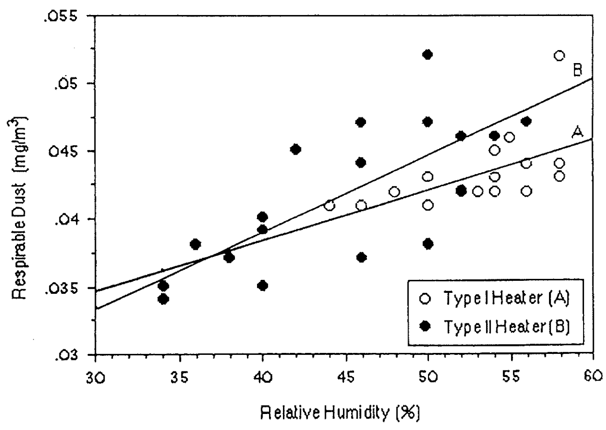

Fig. 4. Linear regression values of the respirable dust concentration as a function of the relative air humidity in the use of the type I and type II heater.
Type I heater (A): DUST = 0.00037 HUMIDITY + 0.24; R = 0.58, n = 18, p<0.01
Type II heater (B): DUST = 0.001 HUMIDITY + 0.017; R = 0.73, n = 18, p<0.001;
where DUST is the respirable dust concentration, HUMIDITY is the relative air humidity, R is the correlation coefficient, n is the number of measurements and p is the two tailed p value of the slope.

lower concentration of carbon dioxide during the use of the kerosene heater was achieved when using cross ventilation or when both sides of the window were opened at the same time.

Figure 3 shows the relationship between relative air humidity and indoor temperature during the use of a combustion space heating appliance. The linear regression values of the respirable dust concentration as a function of the relative air humidity is also shown in Fig. 4.

DISCUSSION

In housing using a kerosene space heater, IAQ is poor due to the high concentration of combustion materials emitted by the heater. It was found that the concentration of carbon monoxide in the use of type I heater was lower, although the concentration of carbon dioxide was almost the same. However, the concentration of carbon dioxide was still high when using either type I or type II heaters, although a small ventilation above the stove was kept opened. This showed that the air exchange is insufficient to dilute the air contaminants from combustion sources.

Carbon dioxide concentrations are properly used in indoor air quality studies as a crude indication of whether or not an acceptable outdoor air ventilation rate is being provided to dilute air contaminants. If the carbon dioxide level exceeds 1000 ppm and gaseous and particulate air contaminants are not otherwise removed, there is a strong likelihood that the amount of outdoor air being provided to the occupied space is inadequate to dilute air contaminants. As was recommended by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standard 62–1989, indoor carbon dioxide concentration should not exceeds 1000 ppm to satisfy the occupant's comfort needs[7].

When using combustion appliances in housing natural ventilation is required to dilute air contaminants from combustion sources. The level of combustion emissions within a building can also be lowered by controlling the sources or improving ventilation[3]. By using cross ventilation and mechanical ventilation the concentration of air contaminants can be diluted almost perfectly with fresh outdoor air. It was found that the concentration of carbon dioxide did not exceed 500 ppm, although the heater was still being used, but the temperature fell as a consequence of too much ventilation. By opening the window of about 0.12 m^2, the concentration of carbon dioxide could be maintained at about 1000 ppm without decreasing the temperature too much. The average temperature using this natural ventilation could be maintained at about 20°C, a comfortable indoor temperature during the winter.

By opening the door or the window for one or two minutes as a simulation of people entering or leaving the house, the concentration of air contaminants was found to decrease, but the concentration would become higher shortly after the sources of ventilation were closed again. Based on a preliminary observation in the community that doors and windows are usually left closed in winter, the resulting high concentration of indoor air contaminants could threaten the health of occupants. Opening the window for a few minutes each hour as suggested on heater appliances is not always practical. A better way to dilute air contaminants in housing is by natural ventilation when using combustion appliances, unless heating, ventilation, and air conditioning (HVAC) systems are provided. It was found that a carbon dioxide concentration below 1000 ppm could be achieved by using natural ventilation of about 0.12 m^2 or about 0.4 % of the floor area, and a better dilution rate could be reached by using natural ventilation of about 1.1% of the floor area. However, the use of a high ventilation rate in winter is not appropriate for energy conservation. The use of a heater also had an influence to humidity and the respirable dust concentration. As the temperature increases, relative humidity and the respirable dust concentration decrease. Although a humidity decrease was still acceptable in the first five hours, a prolonged duration of heater use might decrease the humidity still further and problems related to humidification would increase[1)]. By using a steamer that functions as a humidifier, the acceptable humidity can be achieved during heater use. Most people are comfortable when the humidity at 20°C is between 40% and 60 %. Very high indoor humidity levels, e.g., more than 70%, encourage the growth of mold and other microbiological contaminants, whereas levels below 30% can cause drying of the mucous membrane[10)].

However, the use of a steamer has only a minor effect on the concentration of respirable dust and does not elevate the respirable dust concentration above an acceptable limit. Consequently, the use of a steamer when using a space heating appliance is better for maintaining optimum humidity levels. If it is felt that the air has to be humidified, this is best done with steam[11)].

In conclusion, this study shows that indoor air quality in a closed house during the use of combustion space heater appliances is poor due to the lack of fresh air. The concentration of air contaminants in housing can be minimized by using ventilation during heater use. An adequate intake of outdoor air is needed to dilute air contaminants emitted from the heater. For ventilation strategies, at least about 0.12 m^2 of natural ventilation is needed when using a kerosene space heater appliance. However, ventilation also depends on the number of the occupants and wind velocity. With such natural ventilation, carbon dioxide concentration in housing can be maintained at about 1000 ppm, assuming that the air exchange is adequate to dilute air contaminants without decreasing the temperature too low and does not threaten the occupant with health hazards. Without using a steamer, the relative humidity is still acceptable as long as the heater is not used for more than five hours.

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