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DYNAMIC BEHAVIOR OF POLLUTANTS GENERATED BY INDOOR COMBUSTION

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Abstract

When indoor air concentrations from indoor combustion processes are estimated source strengths and ventilation rates are usually considered. Recent studies, conducted in the Energy Research House at Iowa State University, indicate that several other factors also have a significant effect on indoor air concentrations. In one of these studies, a ventless kerosene heater served as the source of pollutants. Resultant concentrations of NO_x, CO_2, H_2O and air temperatures were monitored throughout the house. A tracer gas, SF_6, was released in the house and at the same points as the pollutant concentrations. It is concluded that, in non-steady conditions, it is invalid to assume that pollutants from a local source disperse uniformly throughout a house. To the contrary, various pollutants are dispersed at various rates, and additional research should be directed to these dynamic behavioral characteristics.

Introduction

Indoor air pollutant concentrations from indoor combustion processes depend on pollutant source strengths and locations, ventilation rates, ventilation effectiveness and pollutant removal rates. Most of the current indoor air quality calculation methods, ventilation design guidelines and ventilation standards consider only the ventilation rates and pollutants source strengths when indoor air concentrations of combustion products are estimated. Moreover, often it is assumed that indoor air pollutants are uniformly mixed throughout the enclosure and that pollutant emission rates and ventilation (dilution) rates are constant. These assumptions naturally simplify the calculations, but they can also lead to significant errors in estimating the human exposures.

In this paper dynamic characteristics of the most important indoor air quality factors are addressed. To describe the complexity of these factors, the NO_x has been chosen as an example gas due to its high reactivity, harmfulness, and common existence in conjunction with indoor combustion processes.

Dynamic factors affecting pollutant exposure

Pollutant sources

Indoor combustion processes are diverse. Gas stoves, unvented gas and kerosene heaters and fireplaces emit significant amounts of gases, like CO, CO_2, NO_x, hydrocarbons and water vapor. The most common indoor combustion process, smoking, produces small amounts of over 3000 identified pollutant components (2).

The emission rates of various pollutants depend on the fuel and the characteristics and the speed of the combustion. For example, SO_2 is generated from the sulfur in the fuel, whereas NO_x results mainly from the reaction of nitrogen and oxygen in the air. The rate of production of NO_2 by oxidation of NO is inversely proportional to the cooling ratio of the combustion products (10). Hence, relatively small changes in the combustion process can change the emission characteristics significantly. For example, Leaderer (5) reported over 100% increase in NO_2 output per mass unit of fuel consumed when the flame setting of a convective ventless kerosene heater was changed from high to low.

Due to variable and mostly intermittent properties of combustion processes, the characterization of these pollutant sources is a difficult but incumbent task when human exposures to pollutants are estimated.

Ventilation rates and effectiveness

The ventilation air flow rate introduced into the microclimate of a person reduces his/her exposure to indoor air pollutants. This air flow rate depends on the total ventilation rate of the space and on the ventilation effectiveness (ventilation effectiveness is the measure of the ventilation air distribution in a space, also called ventilation efficiency (9)).

Among other factors, such as infiltration and the location and function of the supply and return air devices, the ventilation effectiveness is affected to a great extent by indoor combustion processes. A recent study in the Energy Research House (ERH) at Iowa State University showed that a heat source, in this study a ventless

space heater, can create strong convective room air flows which transport combustion products and cause pollutant concentrations to vary in different parts of the house (6).

In this study the space heater was placed in the living room on the middle level of the three story ERH. The concentrations of NO_x, CO_2, H_2O and dry bulb temperatures were monitored in 11 points throughout the house and outdoors. A tracer gas, SF_6, was released as a pulse in the living room above the heater and its concentrations were monitored at the same 12 points.

The results show that due to convective air flows the combustion products dispersed rapidly from the living room to the adjoining kitchen and upper staircase which were open to the living room. Dispersion was much slower to the open basement, due to stratification, and to the bedroom in the upper level which had a closed door. However, the relative exposure index of CO_2 (see table 1) was the same magnitude in the bedroom as in the rooms which were open to the living room. This was due to slower decay rates of the pollutants in the bedroom after the heater was turned off. The relative exposure index of NO_x in the bedroom was lower than that of CO_2 because of NO_x removal by means other than dilution.

Relative Exposure Index is a measure of the pollutant distribution and it was calculated from the equation (7):

$$E_i = \frac{\int_0^\infty C_i(t)\, dt}{\int_0^\infty C_1(t)\, dt}$$

E_i = Relative Exposure Index in the room i
C_i = Concentration of the pollutant in the room i
C_1 = Concentration of the pollutant in the living room

Comparing the tracer gas data of the study with the space (6) heater to the data of an earlier study in the same house without a heater (7) showed that the tracer gas, and hence the pollutants, spread out faster when the space heater was operated. The tracer gas concentration in the bedroom achieved a maximum value in less than three hours after the gas release in the living room when the heater was operated. Without a heater, this took about 4.5 hours. The use of the heater also made the flow patterns more stable. However, the relative exposure indices around the house were about the same in both studies.

These results indicate the invalidity of the assumption of uniform distribution of the pollutants in a house, if the pollutant source is intermittent, even in cycles of several hours. For example, in the above described situation, if a person would move from the living room

to the bedroom after shutting off the space heater, his/her exposure to the pollutants would be higher than calculations based on a dynamic model with uniform mixing would predict.

Pollutant removal by other means than dilution

In addition to dilution (ventilation), pollutants can be removed from the indoor air by sorption in building materials and furniture, by reactions with other pollutants, building materials and dust, by photodissociation and by catalytic reactions. These reactions can deteriorate building materials and they can result in new pollutants.

Behavior of air pollutants in the atmosphere has been amply studied. For example, the chemical transformation of atmospheric NO_x is known in the main features (1). However, few studies have been made on the reactive chemistry of indoor pollutants. Even though many of the same reactions take place both outdoors and indoors, their importance is different. For example, photodissociation of NO_2 to NO and O_2 is slow indoors, while the photolytic half life of NO_2 is only about 2 min in sunlight (3). On the other hand, the oxidation of NO to NO_2 can be relevant indoors if the space has O_3 sources. If NO and O_3 concentrations are of the same magnitude, NO has a life time of only about 1 min due to oxidation (1). However, without O_3 sources, the background ozone in a room is consumed fast and the reaction is limited.

Ozkaynak et al. (8) have developed a simplified indoor air quality model which accounts for the photodissociation of NO_2 and oxidation of NO. They derived the model parameters from the experimental studies made in the atmosphere and found quite good correspondence between the measured and predicted concentrations.

In indoor environments sorption in building materials and surface catalyzed reactions can be of great importance due to the high surface-area/room-volume ratio and the large number of different building materials. Judeikis et al. (4) have studied NO and NO_2 deposition onto cement (and soil) surfaces. They found deposition velocities 0.21 cm/s for NO and 0.32 cm/s for NO_2 onto "fresh" cement surface. However, deposition decreased to practically nonexistence during prolonged exposure and was irreversible. Surface treatment by gaseous ammonia restored the NO_2 deposition but had no effect on the NO deposition. These results indicate that in a house in which a gas stove, a ventless heater, or other NO_x source is operated regularly the NO_x deposition is reduced in the course of time.

In the study made in ERH the removal of NO_x by other means than dilution was noticed by comparing the decay curves of NO_x to those of CO_2 and SF_6 after the space heater was turned off. The NO_x decay rate in the living room was 0.51 h^{-1} while the CO_2 and SF_6 decay rates were 0.21 h^{-1}. Hence the NO_x removal by reactions and sorption was 48%

higher than the NO_x removal by dilution. The NO_x removal was seen also from the relative exposure indices, table 1. The NO_x indices compared to the CO_2 and SF_6 indices are relatively lower in the bedroom and in the basement than in the living room, kitchen and upper staircase. Thus, NO_x had decayed as it was transported from the living room to those farthest parts of the house. The NO_x removal has also been reported in other papers. Wade et al (12) reported NO half-life of 1.8 h and NO_2 half-life of 0.6 h in a house with a gas stove. They correspond to decay rates of 0.39 h^{-1} and 1.16 h^{-1} respectively. Traynor et al (11) found a decay rate of 0.18 h^{-1} for NO_2 due to other means than dilution in a house in which a ventless kerosene heater was operated.

3 Recommendations

The dynamic behavior of indoor combustion products has been addressed in this paper. However, the subject can be expanded to concern all reactive pollutants regardless of the source. Since the use of various chemical products is increasing, the problem is becoming more complicated. More research is needed on all dynamic indoor air quality factors, especially those on the ventilation effectiveness and on the reactiveness of pollutants.

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Table 1. Relative Exposure Indices in different rooms of the Energy Research House. The CO and NO were emitted by a ventless space heater, which was operated for 6.2 hours in the living room. The SF was released as a pulse above the heater at the time when the heater was ignited.

Room	Relative Exposure Index (dimensionless) CO_2	NO_x	SF_6
living room, middle level	1.00	1.00	1.00
kitchen, middle level	1.12	1.18	1.06
basement, lower level	0.86	0.56	0.74
upper staircase, upper level	1.13	1.15	1.07
bedroom, upper level	1.00	0.72	0.85