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Temporal variations in particulate exposure to wood smoke in a residential school environment

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Abstract

Much research has examined associations between particulate pollution and health. The majority of this research has focused on outdoor air. Yet it is known that people spend most of their time indoors. This research has examined concentrations of PM_{10}, $PM_{2.5}$ and PM_1 inside and outside of a boarding school in Christchurch, New Zealand. Christchurch is a city with a known wintertime particulate pollution problem as a result of burning wood for domestic heating. Data were collected over the winter of 2004 (May–September) using TEOM and GRIMM dust analysers. Results show that there is a close relationship between the fine fraction ($PM_{2.5}$ and PM_1) of indoor and outdoor particles. However, the activities of the building occupants resulted in the resuspension of coarse particulate fractions resulting in weaker indoor–outdoor relationships for PM_{10}.

Keywords: Indoor air pollution; PM_{10}; $PM_{2.5}$; PM_1; Boarding school; Wintertime; Wood smoke

1. Introduction

Ambient air pollution has long been recognised as a causal factor in mortality and morbidity, especially when concentrations of particulate matter, sulphur dioxide, ozone or other pollutants are high during the urban air pollution 'events' that have occurred since the industrial revolution (Brimblecombe, 1986). Whilst acute air pollution exposure is clearly harmful, it is now increasingly accepted that chronic exposure to particulate matter and other pollutants plays an additional and significant role in population health (Jones, 1999; Samet et al., 1987; Spengler and Sexton, 1983).

However, while the focus is often on ambient air quality, people in the developed world on average spend the greater part of their time indoors (Jenkins et al., 1992; Robinson and Nelson, 1995), yet relatively little is known about indoor exposures and their health effects. An improved understanding of the effects of indoor air pollution is crucial, as Jones (1999) has implicitly argued "given that the total exposure to particles is greater indoors than

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outside by virtue of the time spent indoors, a good deal of the apparent effects of outdoor particles probably occurs due to exposure indoors'' (Jones, 1999, p. 4545).

Much of the recent work (Chaloulakou and Mavroidis, 2002; Fischer et al., 2000; Hussein et al., 2002; Jones, 1999; Kingham et al., 2000; Koponen et al., 2001; Kukadia and Palmer, 1998; Kulmala et al., 1999; Matson, 2005; Morawska et al., 2001) on indoor air pollutants has shown, in the absence of strong indoor sources, indoor concentrations are strongly related to those outdoors, and that concentrations of some air pollutants indoors, and inside vehicles, commonly match or exceed those found outside. However, all the variations in indoor PM concentrations cannot be explained as functions of outdoor PM concentrations. Particle resuspension by the normal activities of building occupants is an important factor in indoor particle concentrations. Thatcher and Layton (1995) found that 'light' activities by four people, or continuous walking and sitting by a single occupant, caused a 2–4 times increase in the concentrations of $PM_{>5<10}$. Janssen et al. (1999) identified resuspension, arising from classroom activity as the most likely cause of elevated PM_{10} concentrations, and found that most of the particles were dust brought in by shoes and not combustion products. They concluded that indoor PM_{10} measurements in environments with a lot of activity would not provide a good measure of the indoor exposure to combustion particles, a finding supported elsewhere (Branis et al., 2005). In particular, indoor activities appear to primarily result in the resuspension of coarse, but not fine, particles (Thatcher and Layton, 1995). This resuspension of coarse particles has resulted in higher personal exposures to PM_{10} than those measured at fixed monitors outdoors (Clayton et al., 1993; Janssen et al., 1999; Jarup, 2004; Özkaynak et al., 1996). In classroom PM_{10} during school hours has been shown to be 2–5 times higher than outdoor concentrations and twice as high as the average 24 h classroom (Janssen et al., 1999; Roorda-Knape et al., 1998). Janssen et al. (1999), based on comparison of measurements from personal samplers and fixed-site monitors suggested that long-term childhood exposure to PM_{10} was on average three times higher than that indicated by outdoor measurements alone. However, their research suggests that levels of fine particles ($PM_{2.5}$ and smaller) operate differently and fixed-site measurements of them can be good indicators of exposure.

Ideally to better understand the relationships between exposure to air pollutants and health effects, exposure data unique to the individuals being studied would be used, but this is not often possible for reasons of practicality and expense (Janssen et al., 1998a, b). Arguably, a compromise may be the measurement of indoor air quality in addition to outdoor air quality. However, since most individuals are exposed to air pollutants at home, at work, in transit and elsewhere, the question remains over which indoor site is most representative of exposure, and therefore the value added by a single additional indoor monitor may be limited. A unique situation where analysis of indoor and outdoor air pollution can provide useful information is where a population lives and works in the same location. This reduces the number of relevant exposure situations and allows investigators to estimate exposures using a relatively small number of fixed monitors. Schools, and in particular boarding schools, are places where young people spend a significant proportion of their time (Silvers et al., 1994). At boarding schools boarders spend the majority of their week-day time on site. The time-tabled structure of the week can also be used to estimate the time spent exposed to air pollutants both indoors and outdoors.

This paper discusses indoor and outdoor particulate air pollution measured during winter (May–September 2004) at a boarding school in Christchurch, New Zealand. Fluctuations in the concentrations of PM_{10}, $PM_{2.5}$ and PM_1, and the proportions of $PM_{2.5}$ and PM_1 within PM_{10} are investigated and discussed in relation to temporal variations in emissions and resuspension.

2. Methods

2.1. Study site

The study was undertaken at Christ's College, a boys boarding school lying immediately adjacent to the Christchurch central business district (CBD) but inset into the grounds of Hagley Park, a $\sim 5\,km^2$ area of grassland and trees to the immediate west of the CBD but surrounded by the urban area on all sides.

Winter air pollution in Christchurch is characterised by high concentrations of PM_{10} (~90% of which is $PM_{2.5}$) that is generated largely by ~16,000