A study of indoor particle concentrations of less than 10μm in Wellington office buildings.

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ABSTRACT

Indoor air pollution can have significant effects on the health of people. Indoor pollutants can exceed outdoor concentrations by 2-5 times, and occasionally more than 100 times. This is significant not only because of occupational indoor exposures, but because in general people spend over 90% of time indoors. Particles are one indoor pollutant that has been linked as a causal factor of the Sick Building Syndrome. Particles can be noxious substances or have noxious substances adsorbed on to them. Of most concern are particles that penetrate to the gas exchange region of the human body as clearance times are often in excess of months. This study explores the relationship between particle concentrations measured indoors and outdoors and the affect of occupant activity on indoor particle concentrations.

Particle concentrations were measured indoors and outdoors of four office buildings in Wellington. Indoor particle concentrations as a function of occupancy were assessed and the presence of occupants was shown to increase particle concentrations indoors for the size bands of 5μm and 3μm on a working day. Particles below 1μm were shown to generally behave independent of occupant activity. The concentrations of particles generated during a working day decreased over a period of no occupancy due to deposition and the air exchange rate of the building for the larger size bands of 5μm and 3μm. However below 1μm the pattern of a reduction in particles was not apparent. Overall there was no statistically significant vertical gradient of particles between 1.2m and 1.8m for the particle sizes of 5μm, 3μm, 1μm, 0.5μm, and 0.3μm.

Standard filter media were shown to be effective at reducing particle sizes of 5μm and 3μm and less effective with particles below the 1μm range. The operation of the air handling unit over a weekend period resulted in a reduction of the number of fine particles (1μm, 0.5μm, 0.3μm) in the indoor space. The stack effect and its influence on particle transportation throughout the four buildings studied was inconclusive with several factors capable of confounding the collected data.

Overall, the results of the study were consistent with other researchers' findings in relation to occupant influence on particle concentrations and filtering efficiency of standard media. Factors that may confound the assessment of the influence of the stack effect on particle concentrations need to be carefully monitored in future studies.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

Indoor air pollution can have significant effects on the health of people. United States Environmental Protection Agency (US EPA) studies of human exposure to air pollutants indicate that indoor air levels of many pollutants may be 2-5 times, and occasionally more than 100 times, higher than outdoor levels (United States Environmental Protection Agency, 2001). High levels of indoor air pollutants are of particular concern, not only because of occupational indoor exposures (Statistics New Zealand, 2000) but because in general people spend over 90% of time indoors.

A 1984 World Health Organisation (WHO) Committee report suggests that up to 30 percent of new and remodelled buildings world-wide may be the subject of excessive complaints related to indoor air quality (IAQ) (United States Environmental Protection Agency, 2000). The term 'building related illness' (BRI) is used where symptom complaints can be clinically defined and linked to identifiable airborne building contaminants. However, there are situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified. This is described as the "Sick Building Syndrome" (SBS) (World Health Organisation, 1982).

SBS symptom complaints may be localised in a particular room or zone, or may be widespread throughout a building. Occupants will experience relief of SBS symptoms soon after leaving a building. SBS problems can result when a building is operated or maintained in a manner that is inconsistent with its original design or prescribed operating procedures.

Elevated levels of indoor particles are identified as a causal factor of the SBS (Raw, 1993; Gyntelberg et al., 1994; Kemp et al., 1998). The main symptoms associated with high particle levels indoors include irritation of the nose, eyes, and throat; dry unproductive cough; fatigue; headache; and respiratory difficulties. These symptoms can occur either singularly or in combinations.

The chemical and/or biological composition of each inhaled particle in conjunction with their deposition on the human respiratory tract will determine the affect on the health of the occupant. Particles of a size less than 1 micron (μm) are part of the respirable mass fraction and easily penetrate to the gas exchange region. Penetration of particles beyond the terminal bronchioles is of concern as this region is non-ciliated and insoluble particles deposited by sedimentation and diffusion have clearance averages of a month or more.

The size, shape, density and velocity of the particle will affect the suspension time of the particle in the environment and thus occupant exposure to the particle. Particles with an aerodynamic diameter (the diameter of a unit density sphere of the same mass) greater than 1μm on average settle within hours while particles below 1μm can remain suspended for days.

Indoor particle concentrations are a mixture originated from outdoor sources and indoor sources. Particles are transported from the outdoors through unintentional pathways such as small penetrations in the building envelope, and through intentional pathways such as the heating, ventilating and air conditioning route. Occupants and visitors also introduce particles from outside as they enter the work place. Occupants then generate further particles by their daily activities and re-suspend settled indoor particles.

The measurement of particle concentrations inside and directly outside office buildings will provide an understanding of particle sources and behaviour indoors, the influence of the outdoor environment on particle concentrations indoors, and the influence of occupants on particle concentrations through generation and re-suspension of particles.

This study will develop an understanding of the influence of the activity and presence of people in the built environment on particle concentrations. The effect of intentional pathways such as the heating, ventilating, and air conditioning system and unintentional pathways such as the thermal stack effect on the transport of particles into, within and from the building will also be explored. In conjunction with above two aims a standardised procedure to ensure comparable data collection by the research will be piloted.

2 LITERATURE REVIEW

2.1 Introduction

Short-term and long-term exposure to concentrations of particulate air pollution (particles below 10 microns, PM_{10}) is associated with morbidity and mortality in human populations. Studies have shown exposure to ambient particulate air pollution can cause and exacerbate respiratory disease; and cardiovascular disease due to the increase of blood coagulability (Pope, Schwartz, & Ransom, 1992; Schwartz, 1994; Seaton, MacNee, Donaldson, & Godden, 1995).

PM_{10} has been identified in international studies as contributing to sick building syndrome symptoms in the built environment (Armstrong, Sherertz, & Llewellyn, 1989; Gyntelberg et al., 1994; Ohman & Eberly L. E., 1998). Hagan (1998) and Raw et al. (1993) reported symptoms associated with PM_{10} concentrations include irritation of the nose, eyes, and throat; dry unproductive cough; fatigue; headache; and respiratory difficulties.

Subgroups of the population with greater susceptibility to PM_{10} concentrations include asthmatic individuals who may have asthmatic episodes triggered by high PM_{10} concentrations (Dockery et al., 1989; Pope et al., 1991; Schwartz et al., 1993); people with existing respiratory disease (emphysema and chronic obstructive pulmonary disease); the elderly (Pope et al., 1991); smokers (Pope & Kanner, 1993); and children who breathe a greater volume of air than adults relative to their body weight (Roemer et al., 1993).

2.2 Penetration and Deposition of Particles in the Respiratory Tract

The aerodynamic diameter of the particle and its chemical, and/or biological properties will affect the degree of the potential health hazard resulting from the inhalation of PM_{10}. A particle's size determines regional lung deposition of the particle, and a particle's chemical and/or biological properties determine contaminant concentration to the human. Particles classified as PM_{10} are less than a third of the width of a human hair

(Hagan, 1998). Particles <2.5μm are defined as fine particles and particles of a size >2.5μm are defined as coarse particles.

The penetration and deposition location in the respiratory tract, in conjunction with the chemical composition, determines the health risk of inhaled particles to the individual. The risks of adverse health effects associated with the deposition of ambient fine and coarse particles in the thoracic (tracheobronchial and pulmonary) region are markedly greater than those associated with deposition in the extrathoracic region. Maximum particle penetration to the thoracic region occurs during oronasal or mouth breathing. Figure 1 illustrates the penetration and deposition of particles in the respiratory tract.

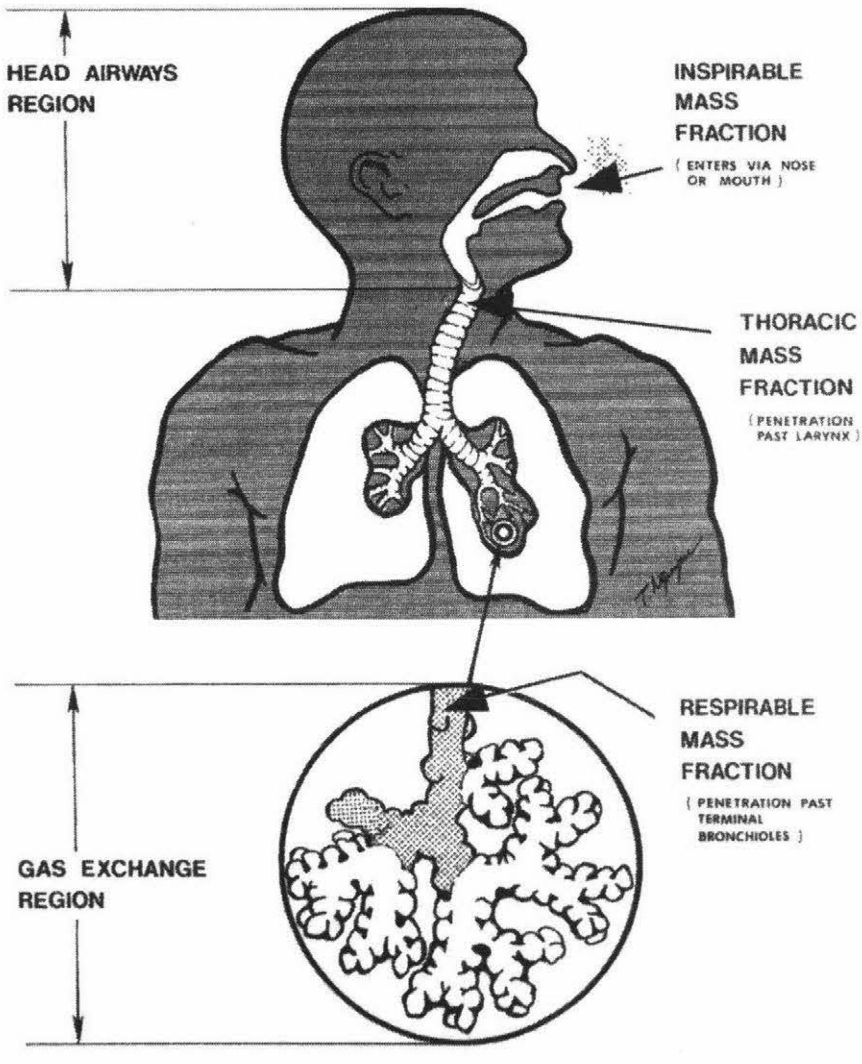


Figure 1. A schematic representation of the major respiratory tract regions of the American Conference of Governmental Industrial Hygienists. Note. From Air sampling instruments (p.99) by M. Lippman, 1995, Ohio: American Conference of Governmental Industrial Hygienists.

2.2.1 Head Airways Region

Particulate matter (PM) deposited in the head airways region range in size from 5-10μm in diameter (Owen et al., 1992). Particles enter through the nostrils, pass through a web of nasal hairs, and flow towards the nasopharynx. Except for the anterior nares, the surfaces are covered by a mucous membrane composed of ciliated and goblet cells. The mucus produced by the goblet cells is propelled toward the pharynx by the beating of the cilia, carrying deposited particles along with it. Particles deposited on the anterior unciliated portion of the nares and at least some of the particles deposited on the nasal hairs are not usually swallowed, but rather are removed mechanically by nose wiping, blowing, and sneezing.

2.2.2 Tracheobronchial Region

PM of the size range 1 to 5μm is typically deposited in the tracheobronchial region (Owen et al., 1992). In the larger airways of the tracheobronchial tree, particles too large to follow the bends in the air path are deposited by impaction. At the low velocities in the smaller airways, particles deposit by sedimentation and, if small enough, by diffusion. Ciliated and mucus-secreting cells found at all levels of the tracheobronchial tree carry non-soluble particles (within hours) toward the larynx on the moving mucous sheath that is propelled proximally by the beating of the cilia. Beyond the larynx, the particles enter the oesophagus and pass through the gastrointestinal tract.

Particles deposited in the head airways and tracheobronchial regions can also contribute to the development of diseases such as bronchitis and cancers of the nasal and bronchial airways. Often these larger particles can be noxious substances or have noxious substances adsorbed on to them which may be corrosive to tissues or systemic poisons, for example lead. Also these larger particles if breathed through the mouth may be swallowed (Owen et al., 1992; Lippmann, 1995; Seaton et al., 1995).

2.2.3 Gas Exchange Region

Particles smaller than 1μm deposit readily on the alveolar walls mostly by diffusion. This is where the gas exchange process takes place and poses the largest health risk to the human. The gas exchange region is nonciliated and any deposited insoluble particles are removed at a very slow rate, with clearance times often in excess of a month. This results in long exposure times to potentially noxious substances.

2.3 Standards and Guidelines for PM

In 1987, under the United States of America (USA) Clean Air Act, the US EPA developed two ambient air quality standards that state acceptable concentrations of PM. Since that time, many important new studies were published showing that breathing particulate matter at concentrations allowed by the existing primary standard could still cause significant health effects including premature death and an increase in respiratory illness. As a result the US EPA published final revisions to the existing particulate matter standards in July 1997 strengthening the particulate matter standards by changing the form of the existing coarse mode PM_{10} standard by using the 99th percentile concentration approach and adding two new fine mode $PM_{2.5}$ standards. EPA standards focus on actual monitored concentrations rather than the number of days on which the standard is exceeded (regardless of the magnitude of the exceedance) which better accounts for the effects on public health.

Table 1 provides a summary of standards and guidelines established by various governing bodies to regulate air pollution. Guidelines and/or standards relating to the indoor office environment are limited.

Table 1. Air quality guidelines/standards for particulate matter that have been established by various governing bodies to regulate air pollution.

Organisation	Standard/Guideline	
Japanese Government	150μg/m^3	Indoor air standard for office buildings ($PM_{3.5}$)
California	50μg/m^3	24-hour average (PM_{10})
	30μg/m^3	Annual geometric mean (PM_{10})
WHO	120μg/m^3	European ambient air quality guideline, 24-hour total suspended particles
	70μg/m^3	European ambient air quality guideline, 24-hour thoracic particles
German government	480μg/m^3	Outdoor standard, 1-hour total particulate concentration

Canadian Government	$40\mu g/m^3$	Long-term indoor air exposure guideline ($PM_{2.5}$)
	$150\mu g/m^3$	One- hour indoor exposure guideline ($PM_{2.5}$)
ACGIH	$10,000\mu g/m^3$	Eight-hour (PM_{10}) occupational exposure guideline
OSHA	$15,000\mu g/m^3$	Occupational exposure guideline for total dust not otherwise classified
	$5,000\mu g/m^3$	Occupational exposure guideline for respirable fraction, not otherwise classified
ASHRAE	$50\mu g/m^3$	Indoor air exposure guideline, average annual (PM_{10})
ASHRAE	$50\mu g/m^3$	Indoor air exposure guideline, 24 hour average (PM_{10})
US EPA	$150\mu g/m^3$	Outdoor National ambient standard, 24 hour average (PM_{10}) [1]
	$50\mu g/m^3$	Average annual ambient standard (PM_{10}) [2]
	$65\mu g/m^3$	Average, 24 hour ($PM_{2.5}$) [3]
	$15\mu g/m^3$	Average, annual ($PM_{2.5}$) [4]

Note. From Particles in our air: concentrations and health effects (p. 215), by J. Spengler and R. Wilson, 1996, Harvard: Harvard University Press.

2.4 Sources of Particles in Indoor Air, and Particle Sizes

Particles (PM_{10}) are a significant indoor pollutant (Colome et al., 1990; Ozkaynak & Spengler, 1996; Wallace, 1996). Particles in the indoor air may be generated indoors or outdoors. Particles can enter through windows, cracks and fissures of the building envelope, the HVAC system, or brought indoors on the occupant's body, clothing and shoes. Several studies show that fine particles will infiltrate through the building envelope as well as entering by bulk flow via openings. PM_{10} loading indoors can be exacerbated when temperature inversions trap pollution close to the ground raising

[1] To attain this standard, the 99th percentile of the distribution of the 24-hour concentrations for a period of 1 year, averaged over 3 years, must not exceed 150 µg/m3 at each monitor within an area.
[2] To attain this standard, the arithmetic average of the 24-hour samples for a period of 1 year, averaged over 3 consecutive years, must not exceed 50 µg/m3.
[3] To attain this standard, the 98th percentile of the distribution of the 24-hour concentrations for a period of 1 year, averaged over 3 years, must not exceed 65 µg/m3 at each monitor within an area.
[4] To attain this standard, the 3-year average of the annual arithmetic mean of the 24-hour concentrations from single or multiple population oriented monitors must not exceed 15.0 µg/m3.

outdoor levels. This effect is most marked in valleys and coastal regions (Pope et al., 1992).

Indoor PM is a mixture of many subgroups of pollutants of natural or anthropogenic origin. Major components of fine-mode $PM_{2.5}$ (<2.5μm) atmospheric particles include sulphate, strong acids, ammonium, nitrate, organic compounds, elemental carbon, trace elements (including metals), and water. Crushing, grinding, and the abrasion of surfaces form coarse-mode PM_{10} (>2.5μm).

2.4.1 Combustion Products

Combustion generated particles are a major source of fine-mode $PM_{2.5}$. Combustion sources that result in the release of particles into the atmosphere include wood, refuse burning and forest fires and the combustion of fossil fuels, such as coal and oil for industrial fuel use in boilers, kilns, pulp mills, refineries, and power generating stations. Xu & Wang (1983) showed that fine-mode particle concentrations were highest in an industrial area and lowest in a suburban area.

Diesel and gasoline fuelled vehicles are also sources of PM. $PM_{2.5}$ from motor vehicles originates from tail pipe exhausts and from friction acting on individual components such as tires and brakes. A road system spread throughout a relatively densely populated urban area may increase the exposure of the community that work or live in nearby areas. Several studies conducted in office buildings and in hospitals located near busy arterial roads show that outdoor sources (both fine and larger) are an important source of indoor particles (Jamriska & Morawska, 2000).

Jamriska et al. (1999) investigated the outdoor exposure to sub-micrometer particles and their relationship with indoor exposure in a hypothetical office building located in the vicinity of a busy arterial road. The results of the study indicated that exposure to $PM_{0.7}$ particles in ambient air close to a busy road often exceeded the levels of the annual and 24-hour US EPA National Ambient Air Quality $PM_{2.5}$ Standard.

Another important source of PM in the indoor environment is tobacco smoke particles that contain a wide range of toxic and carcinogenic substances. These particles are released from exhaled puffs and as sidestream smoke (Chao et al., 1998; Turk et al., 1989; Wallace, 1996). A one-pack-a-day smoker will raise mean indoor respirable particle concentrations by 17.6ug/m^3 and indoor mean respirable particle concentrations increase by 0.88ug/m^3 for every cigarette smoked in the house (Dockery & Spengler, 1981). Smoke free laws in New Zealand prohibit smoking in the majority of office buildings however tobacco smoke may be entrained into the office space by wind currents and air inlets.

Heating fuels such as gas and other combustion space heating and cooking also contribute to PM levels in the indoor environment (Chao et al., 1998). Xu & Wang (1983) found that households with coal stoves for cooking and heating had substantially higher indoor particulate concentrations than those with gas stoves, and households that used coal or gas for cooking and heating had higher particle concentrations than those households that used neither.

2.4.2 Mineral Particles

Mineral aerosols are produced when mechanical processes, such as wear and tear and grinding break down non-organic matter. Asbestos and many types of man made mineral fibres (MMMF) are present in building materials, manufactured products and textiles.

Fibreglass is a MMMF used for thermal and acoustic insulation in construction materials and as insulation lining in the Heating, Ventilating, and Air Conditioning (HVAC) system. The degradation of the fibreglass seal due to high air velocities or mechanical damage due to maintenance repair or impact can fracture and liberate particles. Particles aerosolised from insulation lining ductwork are within the respirable range and are often coated with phenol formaldehyde (resin binders and latex), which is a potent irritant (Garnys, 1995). Fibreglass from domestic duct lining has been found to cause many respiratory symptoms, although only low concentrations were measured in the occupants' breathing zone (Newball & Brahim, 1976). Hedge et al. (1993) observed a significant correlation between settled MMMF levels and SBS symptoms.

Asbestos is a carcinogenic fibre, released into the indoor environment due to material degradation or during removal procedures. Household members of former asbestos workers are at a higher risk of dying from mesothelioma due to asbestos exposure when cleaning asbestos-contaminated working clothes of their relatives (Schneider & Woitowitz, 1996).

Particles liberated from ceiling tiles are of concern as they can be composed of fibrous glass, mineral wool or cellulose and frequently contain fire-inhibiting compounds (Godish, 1995).

2.4.3 Bioaerosols

Plant particles such as pollens and moulds have a wide size range from fine up to 250μm and are potential allergens. Pollen particles are often too large to remain in the air for prolonged periods and settle within hours (Fisk et al., 1999). However sweeping, dry dusting and vacuuming can re-suspend these particles.

Fungi and bacteria can grow in damp conditions. Potential contaminant areas include bacteria and fungi growing in stagnant water left in the humidifier only to be aerosolised when the unit is re-activated. Fungi may also grow on HVAC filters, in the lining of ductwork if sufficient condensation, and terminal boxes, thus the air cleaning system may exacerbate the contamination problem (Pejtersen, 1997).

Bacteria can grow on lifeless media and do not need to feed on other organisms. This viability factor distinctly sets apart a typical dust aerosol from a microbial aerosol. In addition bacteria have the ability to change to a dormant form (spore) that resists typical control methods such as heat and desiccation, to then regenerate under appropriate conditions of temperature and humidity if nutrients are present (Kuehn et al., 1992).

Lifeless media such as filters need to be kept dry to prevent them becoming a host breeding ground for mould and bacteria. Biocides are not recommended for filters. These have limited effectiveness as they will cull only bacteria and not fungi, and a layer of dust can block the bacteria's contact with the biocide. Viruses are much smaller than bacteria and will stay airborne longer and are less likely to be caught by filters. Also some disinfecting methods that would be effective against many bacteria will not kill viruses provided the virus has a water droplet to remain viable. Biological contaminants will also be present and amplify if condensate trays are not drained.

There are no standards for the method of replacing filters and many installations require considerable physical aggravation of the material to remove the old filters. This action releases undesirable respirable particulate matter directly into the air supply to the building and it is hypothesised that this can pose a risk to building occupants and maintenance personnel.

Animal particles include pathogens such as bacteria and viruses, hair, insect parts, and skin cells. Humans and animals shed hairs, which generally settle within hours however they are important from an allergy perspective. Skin cells also flake off humans and animals.

Insects and arachnids also produce particles such as insect parts and by-products that can become aerosolised. House dust mite faecal matter that disintegrates to form particles in the respirable range is associated with allergic reaction in people especially those susceptible to asthma (Godish, 1989).

2.4.4 Personal Care Products

Personal care products such as deodorant and hair spray are dispensed as particles. Although these products produce a relatively small amount of mass they do so in a short period of time so that the initial concentration is quite high. Since most of the use of these products is in the breathing zone, the dose delivered to the occupant is highly concentrated.

Talcum powder is another source of mineral-based particles that is often indoors in origin and introduced into the air by the occupants episodically. While many of these particles settle out of the air rapidly, others are inhaled especially since the powders are usually used close to or within the breathing zone.

2.4.5 Natural Sources

Other natural or non-industrial sources include sea salt, windblown soil dust, dust from volcanoes, and sand from roads (especially when pulverized by traffic). The production of sea-salt aerosols is produced by wind agitation of the sea surface. Windblown dust constitutes a major component of the total atmospheric PM, especially in arid and semi-arid areas of the world. Unpaved roads and other unpaved areas with vehicular activity are essentially unlimited reservoirs of dust loading when vehicles are moving. Dust loading on a paved road surface builds up by being tracked out from unpaved areas and by wear of the pavement surface. Most of the natural sources of particles mentioned above are in the coarse size mode.

2.4.6 Cleaning

Routine cleaning in an office building can reduce particle concentrations or increase particle concentrations dependent on methods employed and time performed. Carrer et al. (1999) in a study of 100 office personnel in Milan found that complaints rates of mucous membrane symptoms related to the office environment (range 11-50%) were higher than complaint rates related to home (range 10-16%). A dirty dusty environment (50%) and nasal symptoms (25%) were the complaint and symptom most frequently reported by office occupants.

Cleaning can generate pollution through the re-suspension of settled PM (Ragsdale et al., 1995; Chao et al., 1998). Dry methods tend to stir more dust than wet methods. On furniture, the traditional damp cloth method is more effective than dry cloth at medium and high contamination levels (Schneider et al., 1993).

A high "fleece factor" (ratio of fleecy surfaces, to smooth, non-porous surfaces, which includes carpets and upholstery), and a high "shelf factor" (ratio of open storage to other room surfaces) can exacerbate and contribute to particle concentrations indoors (Skov et al., 1987). The risks associated with these two factors are partly linked with the ease of cleaning as well contributing to the sources and sinks for dust. Skov et al. (1987) showed that large areas of textiles and the open storage of paper were strongly correlated with SBS symptoms. This theory was strengthened in an interventional study by Raw (1993) which showed symptoms could be reduced by thorough cleaning of paperwork stored on open shelving.

Kemp et al. (1998) performed an interventional study (blinded to the occupants) targeted at reducing deposits of surface dust on carpet and hard surfaces and respirable suspended particulate matter, by replacing normal carpet cleaning practices with higher performance vacuum cleaner and improved cleaning practices. The interventions reduced indoor surface levels and significantly lowered respirable suspended PM concentrations by approximately 80% from initial values and against control floors. A follow-up SBS questionnaire revealed significant reductions in eye irritation, throat irritation, dry unproductive cough, and nose irritation.

Franke et al. (1997) also showed dust concentrations were 43-56% lower on each floor in the period following deep cleaning than before cleaning. Kildeso et al. (1998) found that improved cleaning techniques including the use of high efficiency filters on vacuum cleaners caused the reduction of airborne dust mass

2.5 Particle Deposition

Dry deposition of fine-mode particles (<2.5μm) is slow thus fine particles have long lifetimes in the atmosphere (days to weeks) and travel long distances (hundreds to thousands of kilometres). Coarse particles (>2.5μm) generally have shorter lifetimes in the atmosphere (minutes to hours) and only travel short distances (<10's of km) (Wilson et al., 1995, in (Wilson & Spengler, 1996). Fine particles are removed from the atmosphere primarily by forming cloud droplets and falling out in raindrops. Nieto et al. (1994) showed that 37% of urban respirable dust may be removed from the atmosphere during short periods of heavy rain. Coarse particles are generally removed mainly by gravitational settling and inertial impaction.

Once indoors, PM of ambient origin decreases due to deposition on surfaces through gravitational settling and electrostatic attraction. Coarse PM has a much higher deposition rate requiring turbulence greater than their settling velocity to allow them to remain suspended in the air, than fine PM thus particle number concentrations are dominated by fine particles (Fisk et al., 1999).

Dockery & Spengler (1981) determined that for respirable particles the removal rate constant by sedimentation in a well-mixed room is less than $0.5h^{-1}$ and for particles with aerodynamic diameter less than 1um the removal rate is less than $0.05h^{-1}$.

Human indoor activity such as walking on carpets will re-suspend previously deposited PM and suspend other material such as tracked-in soil and a variety of biological material such as mould spores and insect debris. This activity most markedly increases indoor PM_{10} rather than indoor $PM_{2.5}$.

Micallef et al. (1998) explored the influence of human activity on the vertical distribution of airborne particle concentration in confined environments. They found that human movement tends to re-suspend deposited particles from indoor surfaces and clothing, giving rise to an increased airborne concentration. Human activity induced higher particle concentrations with peaks appearing over the height range 1.29 – 1.77m with the highest concentration measured at approximately 1.3 metres (m). This study confirmed that the extent to which human movement and activity influence the level and spatial distribution of airborne particles is not negligible and also suggest that different height groups of the population may be exposed to different concentrations.

Jansson et al. (1999) showed a fifty to a hundred fold increase in particles >5μm caused by occupant activity which took three to four hours to resume background levels after the activity ceased. It was also found that the occurrence of small particles was not as affected by occupant activity but above a size of 1μm the increase in particle concentrations from occupant activity was clearly noticeable.

The above studies suggest that an integrated measurement of air quality in an enclosed space that includes time when it is unoccupied may not be a valid measure. If this measure includes periods of time when the space is unoccupied, it can make exposure during periods of occupancy biased low.

2.6 Pathways

Particles enter into the building either by bulk flow, for example through an open window or by pressure differences through the building envelope. In the latter mode of entry, velocities are relatively lower, causing the settling of large coarse particles >25μm in the passage through the barriers (Thatcher & Layton, 1995).

Many building investigations have identified the stack effect as being responsible for the transport of air contaminants in many building investigations. The thermal stack effect refers to the movement of warm air to the top of the building that is then replaced by colder outdoor air near the base of the building due to pressure differentials.

The operation of the HVAC can either aggravate the conditions created by the thermal stack effect or it can work to reduce their effects. If the lower levels of a building are being maintained at a positive pressure with respect to the outdoors this will prevent or minimise the infiltration of particles without filtration into the occupied areas of the building. The pressurisation of the occupied spaces with respect to the outdoors is typically achieved by operating the supply fan to introduce a larger volume of air into the building than the return air fans and exhaust fans can remove from the building. Since the quantity of air that can be introduced into the building must equal the quantity leaving, a net overpressure is achieved in the occupied areas of the building. Difficulties frequently arise when the relative internal air pressure drops due to ventilation fans being switched off and this can lead to entrainment of PM (Billings & Vanderslice, 1982).

Chao et al. (1998) observed that heavy rain cooled down the temperature outside, thus raising the pressure differential between the indoor and outdoor environment causing the outdoor ambient air to purge a sampling room due to a strong convection effect.

Localised low-pressure zones can occur in the wake of a lift car, drawing in PM from adjacent zones. This is a major conduit for entrainment especially when the adjacent zones are a source of contamination, such as a carpark, truck dock, rubbish collection space or laundry (Tamura & Wilson, 1967).

2.7 Indoor/Outdoor Concentrations

Several studies have found indoor particle concentrations to be lower than outdoor concentrations. Jamriska & Morawska (1996) in a study of a fifth floor of a six storey office building found that the concentration of particles in an office building to be 40% less than outdoor concentrations. Brightman et al. (1996) found that baseline information collected on indoor air quality in 29 large office buildings during 1994 and 1995 showed PM_{10} concentrations were generally lower indoors than outdoors. In addition the difference between indoor and outdoor concentrations was more pronounced when outdoor concentrations were elevated as buildings seem to attenuate the outdoor concentrations. Fisk et al. (1999) found that even with standard filters indoor concentrations of submicron particles are lower than outdoor concentrations by a factor of three to six in commercial buildings without smoking. Turk et al. (1989) in a study of 38 commercial buildings found that average concentrations of PM in non-smoking areas are lower than outdoor levels.

2.8 Indoor Particle Monitoring

The principal problem in an epidemiological study of air pollution is the estimation of pollution exposure. Total personal exposure to PM consists of the regulated outdoor concentration that has penetrated the indoor air environment and non-regulated indoor exposures. Indoor particle concentrations vary with time. Fisk et al. (1999) found large week-to-week and within-day variation in particle concentrations in building without smoking. Jamriska & Morawska (1996) also reported large temporal variation in particle concentrations within commercial buildings. It is possible that short term instantaneous monitoring is not representative of the average concentration in the building over a period of time. Fixed air monitoring stations that observe air quality levels may be different to levels encountered by the individual.

2.9 Human PM Exposure

Measurements of urban air pollution at outdoor monitoring sites do not provide an accurate estimate of personal exposure, since most people spend up to 90% of their time indoors (United States Environmental Protection Agency, 2001). Actual exposure of each individual is determined by their activities, coupled with the emission rate of the pollutant.

Several authors (Raw et al., 1991; Hedge et al., 1993; Ozkaynak et al., 1996; Raw et al., 1993) have reported that in addition to indoor background levels, occupants are exposed to a cloud of particles re-suspended by activities such as disturbing papers, and consequently human exposure can be 3-5 greater than PM exposures from area sampling would indicate. Mamane et al (1993) also showed that personal exposure to indoor and outdoor particles could be 50% higher than parallel airborne exposure counts due to personal clouds.

This is because people create their own PM cloud in the course of their work by generating fine particles (<2.5 μm) and coarser particles (>2.5 μm) and re-suspending coarse particles that have previously settled out (Micallef et al., 1998). For example, a kitchen with a wood stove in operation would have a significant vertical PM concentration gradient however a child on the floor in the far corner could be exposed to significantly different PM concentrations than an adult standing at the stove.

Personal monitors carried by individuals close to the breathing level may provide a more realistic concentration measurement than fixed monitoring. However personal monitors can only give the average concentration over a time period long enough to have a measurable mass of collected particles and thus have poor temporal resolution.

2.10 Particle Measurement Instrumentation

PM represents a generic class of pollutants, which requires a different interpretation of exposure in contrast to that for other specific criteria gaseous pollutants, such as CO. Whereas molecules of CO emitted from a motor vehicle and a fireplace are indistinguishable, 1μm aerodynamic diameter (AD) particles emitted from a motor vehicle and a 1μm particle emitted from a fireplace can have a different shape, mass, chemical composition, and/or toxicity. Furthermore a particle can be a single entity, or an agglomeration of smaller particles, such as a small lead particle bound to a larger crustal particle.

Size selective sampling which allows a sample to be described by the **quantity, amount**, or **number** of particles in each defined size class provides more useful information on particle distribution and concentrations (count per unit volume) than weight measurements. Weight makes it impossible to distinguish the distribution of particles in each of the major respiratory tract subdivisions (inhalable, thoracic, and respirable). This can make exposure estimates difficult. **Weight** measurements also can mask highly elevated numbers of respirable particulate matter due to the relatively small amount respirable particles weigh in comparison to coarse particles (Nathanson, 1995). More than 99% of the particles present in the atmosphere have diameter below the 1 μm size (Fracastoro & Tronville, 1999). Ideally it would be useful to measure PM exposure in terms of mass and chemical composition as a function of size distribution.

2.11 Filtration Of Particles

Better filtration of office air can contribute to the reduction of SBS complaints (Armstrong et al., 1989). In a double-blind crossover study of an office building enhanced particle filtration greatly reduced concentrations of submicron airborne particle and was associated with slight improvements in most symptoms in the questionnaire (Mendell et al., 1999). Dockery & Spengler (1981) showed the direct infiltration of the respirable particles outdoors to be approximately 70%. The effect of full air conditioning was to reduce this penetration by 0.39, which implies net infiltration of only 31%.

It should be stressed that in urban areas, the dilution of the pollutants present in indoor environments with outdoor air, as far as particle concentrations are concerned, may not work properly. In fact, the 'threat' often comes from outdoor air in which the smallest particles, usually generated by combustion processes, are suspended (Fracastoro & Tronville, 1999).

In a study conducted by Fisk et al. (1999) it was found that the number concentration of submicron particles was much lower with high efficiency filtration as compared with standard filtration. The benefits gained from the high efficiency filtration decreased with an increase in particle size due presumably because the efficiency of the normal filters increases with particle size. United States Environmental Protection Agency

(2000) showed the installation of a HEPA filters resulted in substantial decreases of approximately 60% in PM_{10} and $PM_{2.5}$ concentrations in an undisturbed indoor environment. However as Bowser et al. (1999) showed a high efficiency filter will significantly reduce the PM concentrations during non-movement periods, for most occupants their activity will create a dust cloud that will overwhelm background concentrations and will determine the bulk of respiratory exposure.

Particles with an aerodynamic diameter of 5μm are difficult to eliminate by conventional ventilation methods because of their settling characteristics. Settling particles have difficulties leaving the room via conventional exhaust outlets located above the breathing zone. Furthermore settling respirable particles, which are often generated below the breathing zone, entrain into the buoyant convective air streams around the humans and thus increase the particle concentration levels in the breathing zone (Holmberg et al., 1999).

2.12 Conclusions

Respirable particles, of which more than 99% present in the atmosphere are below 1μm, are a significant health risk and a cause of sick building syndrome in office environments. The size, shape, density and velocity of particles will determine deposition on the human respiratory tract and suspension time in the indoor environment. Occupants transport particles indoors and create particles by activity throughout the day. Standard filters effectively filter particles from the outdoor air in the larger size bands however this effectiveness decreases as the particle size decreases. Often the cloud of particles that an individual occupant is exposed to can be 3-5 times greater in concentration than background levels. The level of particles generated during a working day is likely to decrease over a period of no occupancy due to deposition and flushing of the building.

3 STUDY OBJECTIVES

The objectives of the study are to:

- develop an understanding of the influence of people on particle concentrations in the built environment,
- determine if there is a vertical gradient of particles between the heights of 1.2 metres and 1.8 metres when people are present in the built environment,
- develop an understanding of the influence of the thermal stack effect on the concentration of particles between lower, middle, and upper floor levels,
- develop an understanding of whether the positioning of the outdoor air intake and the type of filter material used affects the concentration of particles introduced to the indoor environment,
- develop and pilot a procedure to collect particle concentrations in multi-storey office buildings for use by indoor air quality researchers.

4 METHODOLOGY

4.1 Introduction

Particle concentrations were measured in four office buildings in Wellington over four consecutive Friday and Sunday periods. Measurements were made on Friday and on Sunday indoors to assess the difference in particle concentrations due to occupancy rates. The stack effect pathway was also profiled on Friday and Sunday. Measurements of ambient air were taken directly outside the building air intakes and at footpath level. Particle concentrations at specific locations in the components of the heating and ventilation system were measured.

4.2 Building Selection

A letter (including a tear-off response slip and freepost envelope) was sent to 95 building owners and managers located in the Wellington central business district (CBD). The letter briefly described the purpose of the study, the degree of involvement that would be required by participant building owners/managers and tenants, and access requirements to the building on Friday and Sunday. Twenty responses were received indicating a desire to participate. A site inspection was undertaken of all willing potential participant buildings to confirm suitability for study and four buildings with mechanical ventilation were chosen from this set.

The four buildings selected from the set of 20 potential participants were chosen based on their similarity in location in relation to arterial routes, activity of occupants, floor size and occupancy level to ensure collection of comparable data. The buildings included in the study were not specifically chosen on the basis of indoor air quality (IAQ) complaints.

An information sheet was provided to participants (building owners/managers, and tenants) and a consent form and a confidentiality agreement were signed by the building representative(s) prior to the commencement of sampling. Access arrangements during occupied work hours and after work hours to tenant floors and mechanical plant areas were negotiated. A schematic plan of the heating, ventilating, and air conditioning (HVAC) system and floor plans of occupied levels were used to identify suitable sampling points prior to physical sampling being conducted.

4.3 Sampling Schedule

Each of the four selected buildings was visited on a Friday and Sunday consecutively over a four week period (see Table 2). Friday measurements allowed a profile to be gained of particle concentrations during a typical working day and Sunday profiles provided background particle concentrations for comparison purposes.

Table 2. Summary of visit dates to the four participant buildings to sample particle concentrations.

Building	Visit 1	Visit 2
Building One	Friday, 30th June 2000	Sunday, 2nd July 2000
Building Two	Friday, 7th July 2000	Sunday, 9th July 2000
Building Three	Friday, 14th July 2000	Sunday, 16th July 2000
Building Four	Friday, 28th July 2000	Sunday, 30th July 2000

4.4 Instrumentation

Particle concentrations were measured with a factory calibrated MetOne 3113 laser particulate analyser with computerised data recording. The duration of each particle sample was one minute. The flow rate was 0.0283164 cubic metres/min and the number of particles were counted within the size bands of 0.3μm, 0.5μm, 1.0μm, 3.0μm, 5μm, and 10μm. Continuous monitoring at all locations was not possible due to equipment constraints. Outdoor control measurements were taken in the morning, at noon, and in the afternoon. Invasive sampling, for example drilling holes in ductwork, was not performed to avoid damage or the alteration of existing building coverings.

A collapsible tripod was designed with two height settings to ensure particle concentrations were consistently measured at 1.2m and 1.8m across all participant buildings. The particle counter was securely attached to a trolley (with rubber wheels, for impact and noise attenuation) to minimise time lapses between samples taken in each zone in the participant building. A 2.5m plastic hose was used to connect the particle sensor inlet to the isokinetic probe, which was attached to the collapsible tripod (see Figure 2).

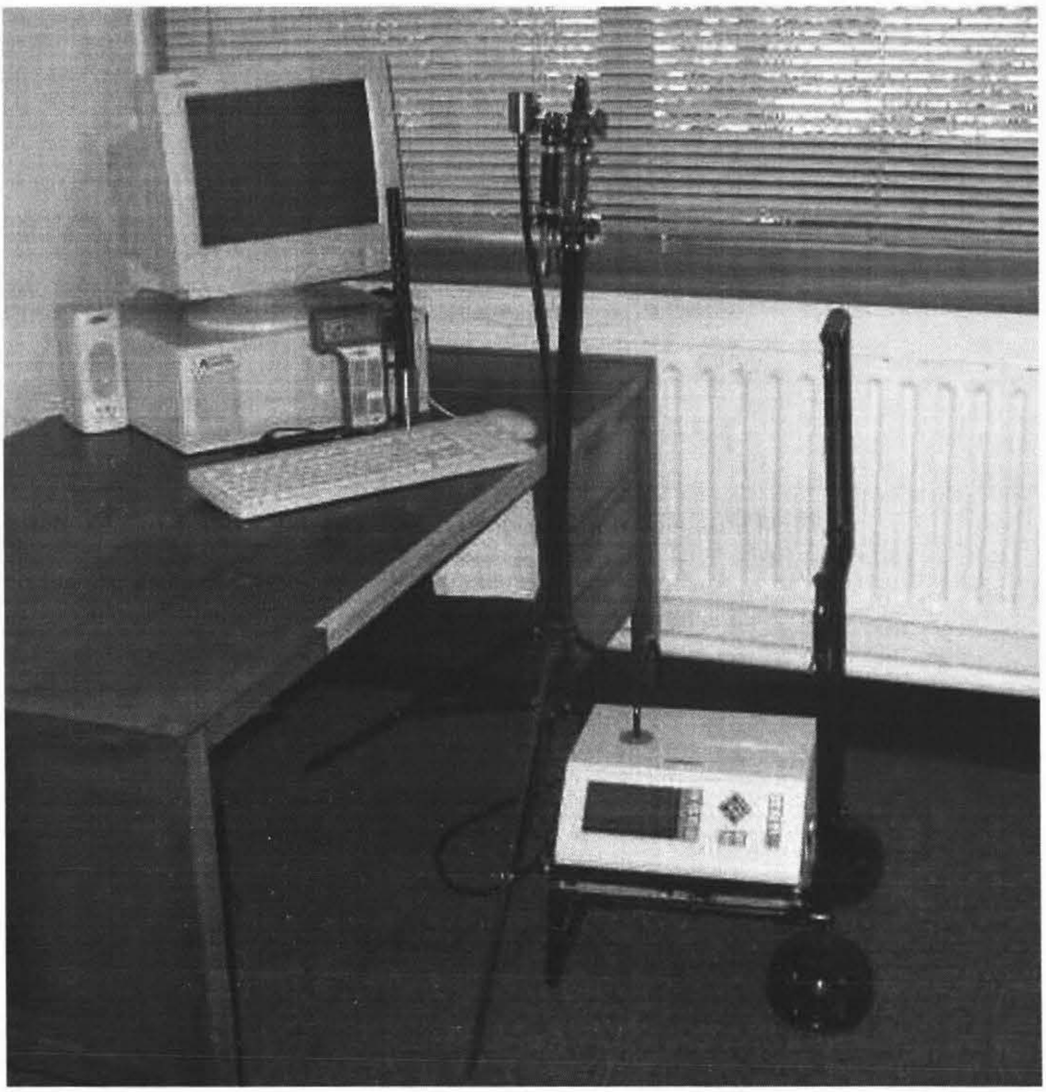


Figure 2. Representation of Metone 3113 particle counter on trolley with isokinetic probe attached to tripod during sampling of particle concentrations in a participant building.

4.5 Sampling Strategy

Occupants of the four participant buildings worked a five-day week from Monday to Friday with the two days of Saturday and Sunday assigned as a weekend. Measurements were taken on the working day of Friday and the non-working day of Sunday. On Friday the floor levels were occupied and the HVAC system operational. Measurements were taken on Sunday to assess background particle concentrations when occupancy numbers were at a minimum (if any) and provide comparison for the particle concentrations measured on Friday.

4.6 Occupied Space

Measurements were taken on three floor levels from each building. Where possible approximately the bottom, middle and top levels of each building were selected to gain a stack effect profile in addition to gaining a representative particle sample of the overall levels of the building (see Table 3). It was also necessary to space out floor levels due to the positioning of air handling unit(s). For one subject building the bottom half of the building was served by one set of air handling plant and the top half of the building was served by another set of air handling plant. The selection process of each floor level was influenced to a degree by lessee co-operation.

Table 3. Guidelines used for the selection of floor levels for study in participant buildings.

Building Height	Floor Levels for Study
20 storeys	1, 10, 20
15 storeys	1, 5, 15
10 storeys	1,5,10
5 storeys	1, 3, 5

The particle concentrations of each floor level were profiled on Friday during occupation and on Sunday when the building was unoccupied. This allowed comparisons to be made between particle levels to determine if the presence and activities of occupants were responsible for the generation of particles and the extent of that contribution.

4.6.1 Selection of sampling points on each floor level for participant buildings.

Each floor level was arbitrarily separated into four sampling zones. Two zones were near the core of the building, and two zones were near the perimeter of the building. This was to ensure a representative data set of each floor level's particle concentrations was obtained. The exact sampling location of each sample within each of the four zones required subjective assessment by the researcher (see figures 3,4,5, and 6).

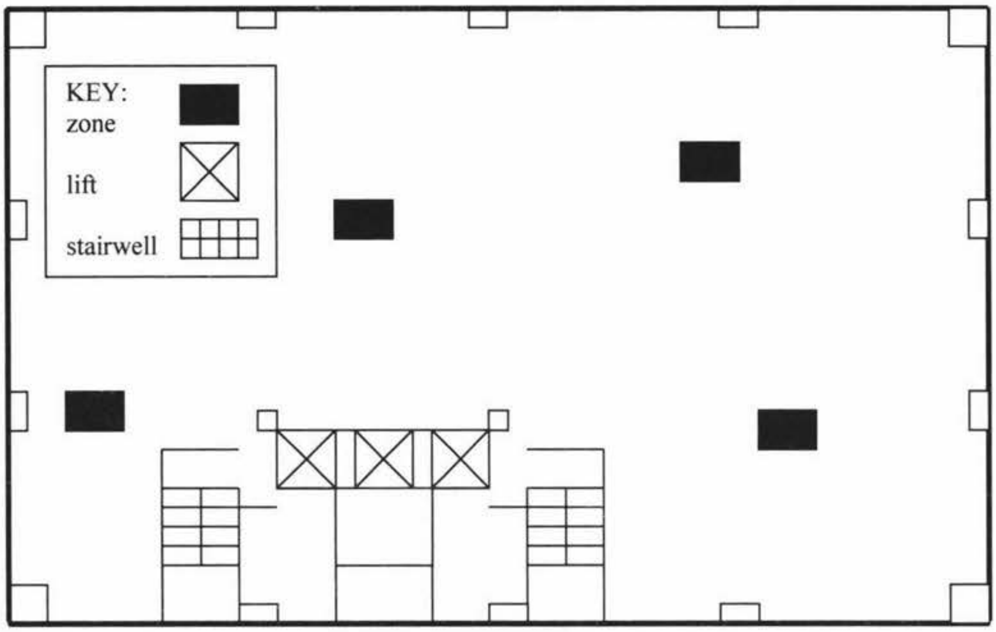


Figure 3. Floor plan of building one outlining the sampling zones selected on all three levels (not to scale).

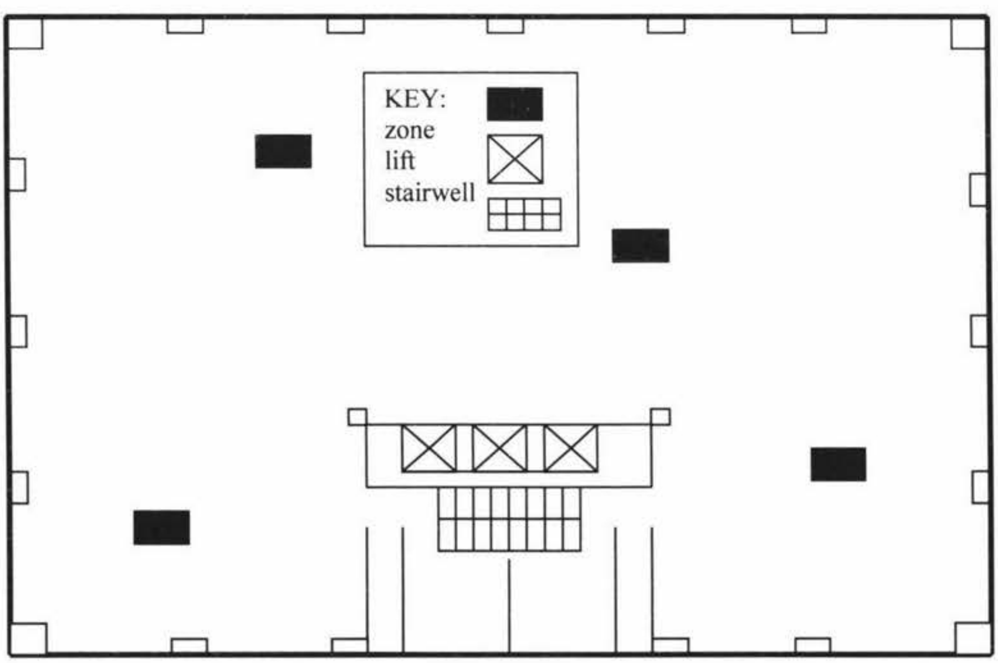


Figure 4. Floor plan of building two outlining the sampling zones selected on all three levels (not to scale).

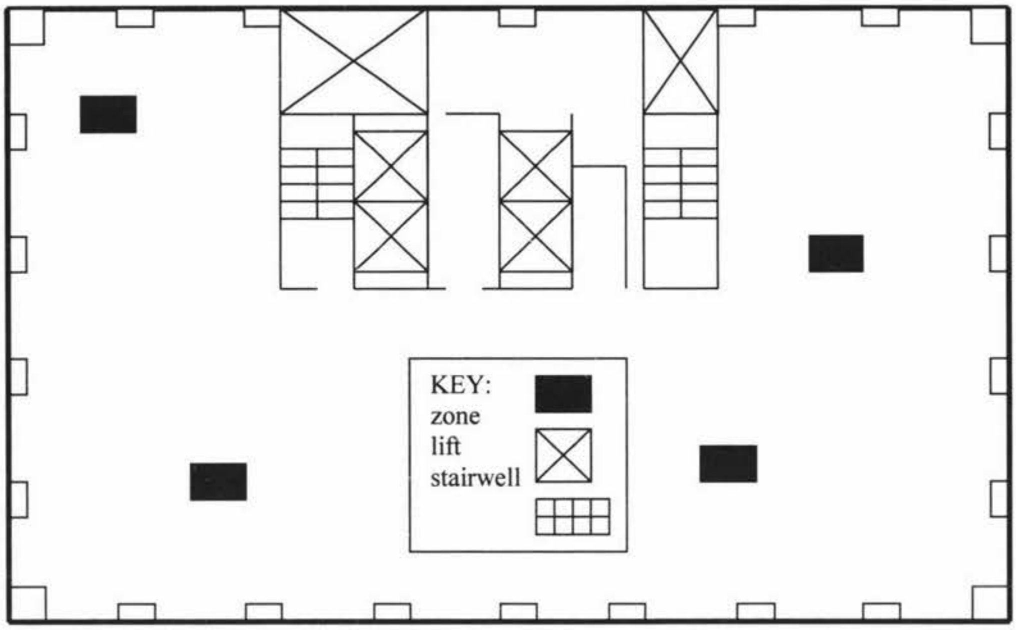


Figure 5. Floor plan of building three outlining the sampling zones selected on all three levels (not to scale).

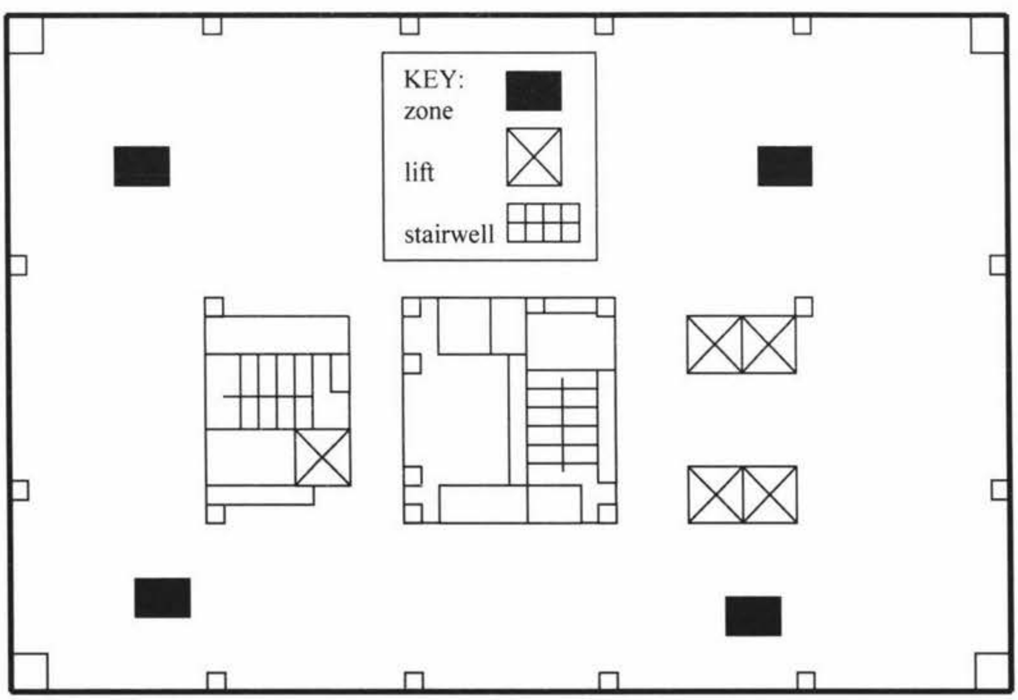


Figure 6. Floor plan of building four outlining the sampling zones selected on all three levels (not to scale).

Three particle concentration measurements were taken in each zone at the same location on Friday and Sunday (see figure 7). Samples were taken in each zone:

1. at an occupied desk space (height of 1.2 metres) to represent the approximate breathing zone of a seated occupant.
2. under a diffuser at a height of 1.2 metres (approximate breathing height)
3. under a diffuser at a height of 1.8 metres (approximate breathing zone of a standing occupant).

Particle concentrations were also measured at lift lobbies and stairwells of all floor levels selected for study in each building.

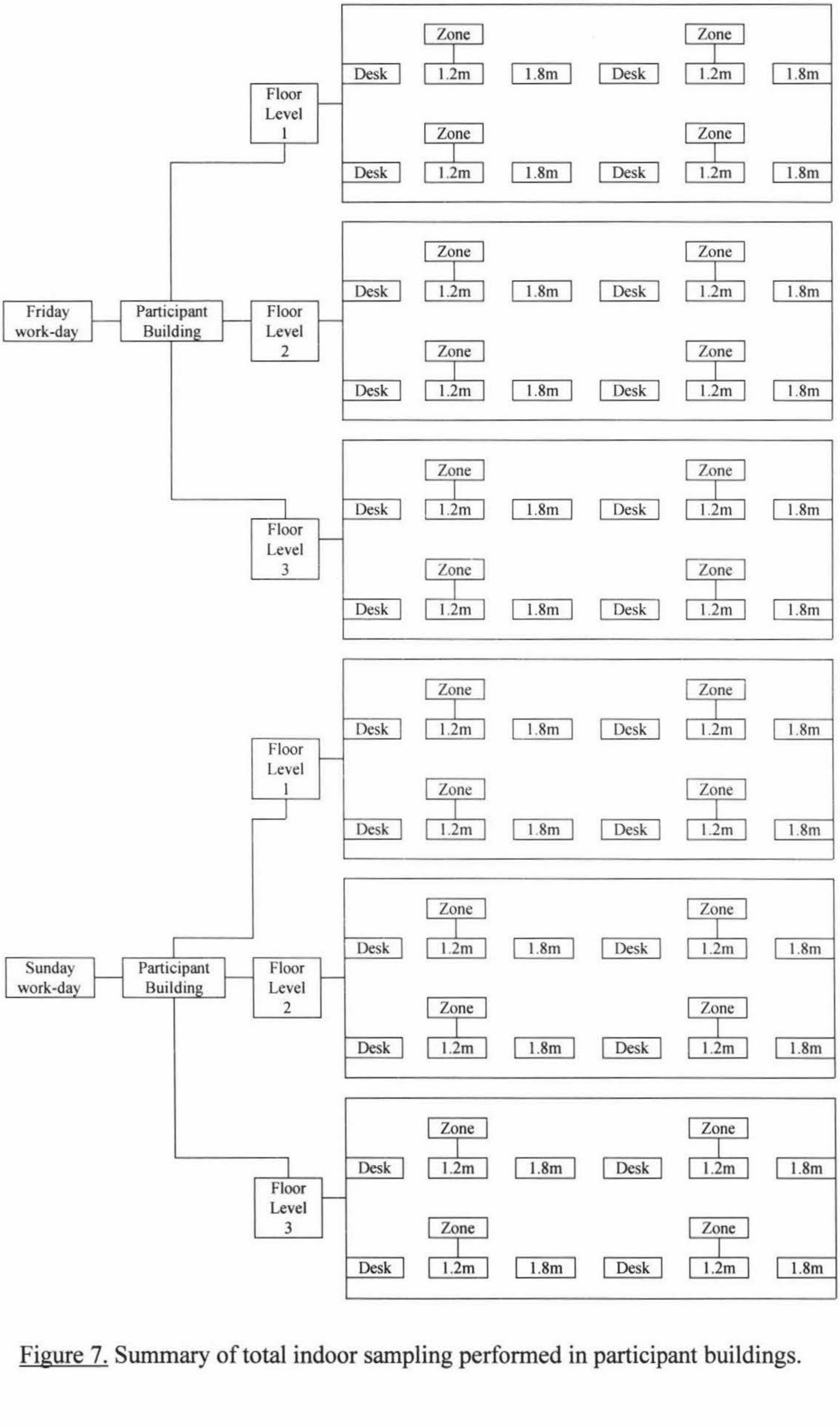


Figure 7. Summary of total indoor sampling performed in participant buildings.

4.7 Pathways

4.7.1 Stack Effect Pathway

Particle concentration measurements were taken at the following locations:

- primary entrance
- secondary entrance
- lift lobby on ground floor (including service lift lobby where applicable)
- lift lobby on floor levels sampled
- stairwells on floor levels sampled (including service stairwells where applicable)

4.7.2 Heating, Ventilating and Air Conditioning System Pathway

Particle concentrations were measured (where feasible) directly beside and in the air handling unit. The specific sampling locations were:

- before the outdoor air intake to assess ambient particle concentrations drawn into the air supply.
- between the outdoor air intake and before the outdoor air supply dampers to assess the degree to which the air drawn through the outdoor air intake differs to outdoor ambient air
- up and downstream of the filters to provide a comparison between the particle concentrations in the mixing plenum and those that remain after being passed through the filter media.

4.8 Data Recording

Checklists were designed and used to ensure comparable information was collected between the building by the indoor air researcher involved in the study (see appendix E). These checklists were based on the standardised US EPA protocol for characterising indoor air quality in large office buildings. The checklists characterised each participant building in terms of location, physical structure, furnishings, ventilation, occupant activities and density, and potential indoor pollutant sources.

4.9 Environmental Parameters

Temperature levels, relative humidity levels, and carbon dioxide levels were also measured at each sampling location.

4.10 Research Procedure

4.10.1 Documentation

The following standard forms were developed for use by the IAQ researcher to identify and recruit participant buildings for the study, and record particle concentrations during field work:

- recruitment letter (see appendix A),
- response letter to participants willing to be involved (see appendix B),
- information sheet for building managers and tenants (see appendix C),
- consent form for building managers (see appendix D),
- checklist for collection of data during fieldwork (appendix E).

The four buildings selected from the set of 20 possible buildings provided sufficient data to pilot the feasibility of the procedure developed for future studies.

5 RESULTS

5.1 Introduction

The results section is separated into five main parts. Part one summarises the physical characteristics of the four participant buildings and reports weather conditions on the eight days of sampling. Part two summarises the results of the Analysis of Variance conducted on each of the size bands and identifies significant differences between particle concentrations of key variables such as sampling days, building and floor level. Actual particle concentrations measured during occupancy on Friday and during minimal occupancy (if any) on Sunday are also analysed.

In part three the particle concentrations at the exterior sampling points (footpath, entrances etc), the outdoor air intake, and before and after filters are graphed to evaluate the effectiveness of the filters at removing the five particle size bands of 5μm, 3μm, 1μm, 0.5μm and 0.3μm size bands. The particle concentrations measured at the lower, middle and upper floor levels to assess the presence of the stack effect are reported in part four. Finally in part five the documentation developed for use by the IAQ researcher to measure particle concentrations in office buildings is presented.

Table 4 summarises abbreviations used in the presentation of results.

Table 4. Key to abbreviations used in the presentation of results.

Abbreviation	Description
Bx	building
Lx	floor level of participant buildings
Zx	zone
H	sampling measurement height
m	metres
F	Friday
S	Sunday

5.2 Part One: Sample Description

The physical characteristics of each participant building are summarised in Table 5.

Table 5. Physical characteristics of participant building construction features and building services.

	Building 1	Building 2	Building 3	Building 4
General				
Built	1986	1980's	1980's	1972
Renovated	-	1991, 1992	1992	1992, 1993
Exterior Cladding	Pre-cast concrete	Pre-cast concrete	Pre-cast concrete	Pre-cast concrete
Roof Cladding	Mild Steel	Concrete	Concrete	Mild Steel
Interior				
Floor to ceiling height	2.64m	2.54m	2.5m	2.67m
Partition height	1.5m	1.5m	1.5m	1.5m
Wall finish	Plasterboard	Plasterboard	Plasterboard	Plasterboard
Partition	Fabric covered	Fabric covered	Fabric covered	Fabric covered
Approx. partitioned workspaces	30	40	30	35
Suspended ceiling	Tiled plaster	Tiled plaster	Tiled rock fibre	Tiled plaster
Floor finish	Carpet	Carpet	Carpet	Carpet
Desk finish	Wood veneer	Wood veneer	Wood veneer	Wood veneer
Chair finish	Fabric covered	Fabric covered	Fabric covered	Fabric covered
Smoking permitted	No	No	No	No
HVAC				
Supply vent type	Ceiling diffusers	Ceiling diffusers	Ceiling diffusers	Ceiling diffusers
Return vent type	Ceiling grilles	Ceiling grilles	Ceiling grilles	Ceiling grilles
Additional space conditioning	Radiators	-	-	Induction units
Windows	Openable[a]	Sealed	Sealed	Sealed
Podium storeys	9	13	17	14
Retail storeys	1	2	1	0
Number of lifts	3	4	4	4
Land area (m^2)	3,151	2,103	1,419	2,890
Gross floor area (m^2)	5,700	46,920	13,420	23,470
Car parking	53[b]	24[c]	-	50[d]

Note. [a]Occupants are requested to keep windows closed at all times. [b]Uncovered. [c]Covered on level 5. [d]Underground.

5.2.1 Climate Description

Table 6 details rainfall, maximum and minimum temperature, and wind speeds measured outside at the Wellington airport on each of the eight sampling days. Sampling days were fine except for heavy rain of 8.2mm on the Friday and 1.8mm of the Sunday of the visit to B4. Minimal rain was also measured of 2.2mm on the Sunday of the visit to B1 and 0.2mm on the Sunday of the visit to B2. The difference in maximum temperature between the sampling days for all buildings ranged from 12.7°C to 16.8°C. The range for the minimum temperatures was wider from 2.0°C to 11.7°C. The highest wind run of 769km/hour and the highest average wind speed of 32km/hour were recorded on the Sunday of the visit to B1. A high wind run of 681km/hour and an average wind speed of 28.4km/hours were also recorded on the Friday of the visit to B4.

Table 6. Summary of rainfall, temperature and wind speeds measured in Wellington on each of the eight sampling days.

	Building 1		**Building 2**		**Building 3**		**Building 4**	
	30 June	**2 July**	**7 July**	**9 July**	**14 July**	**16 July**	**21 July**	**23 July**
Rain (millimetres)	0.0	2.2	0.0	0.2	0.0	0.0	8.2	1.8
Max Temperature °C	15.9	13.6	14.5	12.7	15.2	16.4	16.8	13
Min Temperature °C	10.9	2.9	6.7	2.6	7.0	2.0	11.7	11.4
Wind run (km)	470	769	158	158	222	230	681	327
Average wind speed (km/hour)	19.6	32.0	6.6	6.6	9.25	9.6	28.4	13.6

Note. From National Institute of Water and Atmospheric Research Ltd, 2000.

5.2.2 Missing Data

There were no particles in the 10μm band measured in any of the four study buildings on either the Friday or Sunday visit. In addition it was not possible to gain access to the following areas:

- Z4, L5, B1 on Friday and Sunday
- Z4, L3, B1 on Sunday
- roof level of B3 on Sunday,
- Z1 and Z2 of L11, B4 on Sunday

5.3 Part Two: Occupancy and Analysis of Variance (ANOVA)

5.3.1 Percentage Distribution of Particles

Table 7 shows that the percentage proportions of each size band were similar relative to the total for the four participant buildings although there were large variations in actual particle concentrations measured in each building.

Table 7. Distribution of particles in the five size bands measured indoors on Friday and Sunday.

	Total Particles	5μm	3μm	1μm	0.5μm	0.3μm
B1, F	4.52×10^7	0.15%	0.53%	6%	15%	79%
B2, F	4.02×10^7	0.16%	0.62%	6%	16%	78%
B3, F	6.78×10^7	0.05%	0.18%	2%	9%	89%
B4, F	2.86×10^7	0.45%	1.63%	9%	16%	73%
B1, S	7.31×10^7	0.01%	0.07%	1%	12%	87%
B2, S	2.84×10^7	0.10%	0.38%	4%	12%	84%
B3, S	7.38×10^7	0.04%	0.14%	2%	11%	87%
B4, S	3.29×10^7	0.16%	0.58%	7%	21%	72%

5.3.2 Summary of ANOVA Method

An analysis of variance (ANOVA) was conducted on each of the five size bands 5μm, 3μm, 1μm, 0.5μm, and 0.3μm to identify significant patterns with relation to the:

- measurement days of Friday and Sunday
- buildings,
- floor levels, and
- measurement height levels of desk, 1.2m and 1.8m.

The particle concentrations measured in each building, while occupied on Friday and while unoccupied on Sunday were treated as repeated measures. The between subjects factors were:

- the four buildings,
- the three floors in each of the four buildings, and
- the three height measurements on the desk (approximately 1.2m), 1.2m, and 1.8m in the four zones on each of the three floor levels in each of the four buildings.

5.3.3 ANOVA Assumptions

The assumptions underlying a repeated measures analysis of variance are:

1. the dependent variable is normally distributed in the population for each level of the within subjects factor,
2. the population variance of the difference scores computed between any two levels of a within-subjects factor are the same value regardless of which two levels are chosen, and
3. the cases represent a random sample from the population and there is no dependency in the scores between the participants.

5.3.4 Residual Plots of the Raw Data

Standardised residual by predicted value plots were used to indicate outliers or erroneous observations and also identify possible violations of the assumptions underlying the ANOVA for all size bands.

The Friday and Sunday raw data scatterplots of standardised residuals by predicted values of the particle concentration graphs showed that high values were more variable than low values for all size bands on both Friday and Sunday. This is a violation of assumption 2 (above). In order to overcome this problem the logarithms ($\log_{10}$) of particle concentrations were taken and these figures analysed. The logarithms of the standardised residual data set were then examined for extreme data points. Where outlying points were identified an ANOVA was performed with the entire data set and then with the outlying points excluded.

5.4 Analysis of Variance Occupancy Summary of Results

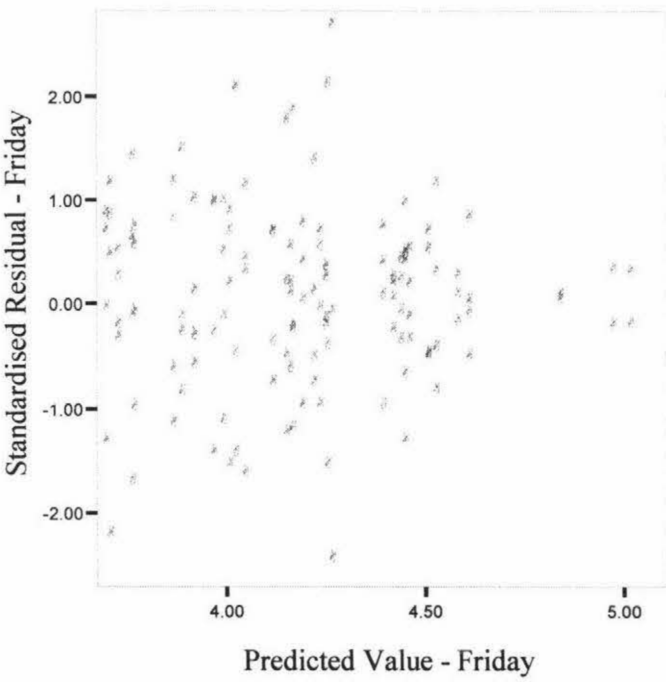
The results of the analysis of variance for each size band showed <u>significant</u> particle concentration differences ($p=0.05$) between:

- buildings,
- levels within buildings,
- Friday and Sunday. In addition the size of the difference between days varied between buildings and levels within buildings.

The results of the ANOVA for each size band also showed no significant particle concentration differences (p=0.05) between measurement heights and any interactions involving height.

5.4.1 Results of Repeated Measures Analysis of Variance 5μm

Figures 8 and 9 showed a group of outlying points on the right hand side of the plot, with predicted values between 4.8 and 5.1 on Friday and between 4.6 and 4.8 on Sunday. These points were from B4. Examination of the raw data showed these data points were correctly entered, therefore were valid entries. However exclusion of these points did result in improved scatter (Figures 10 and 11) but did not affect the outcome of the ANOVA results (see table 8).

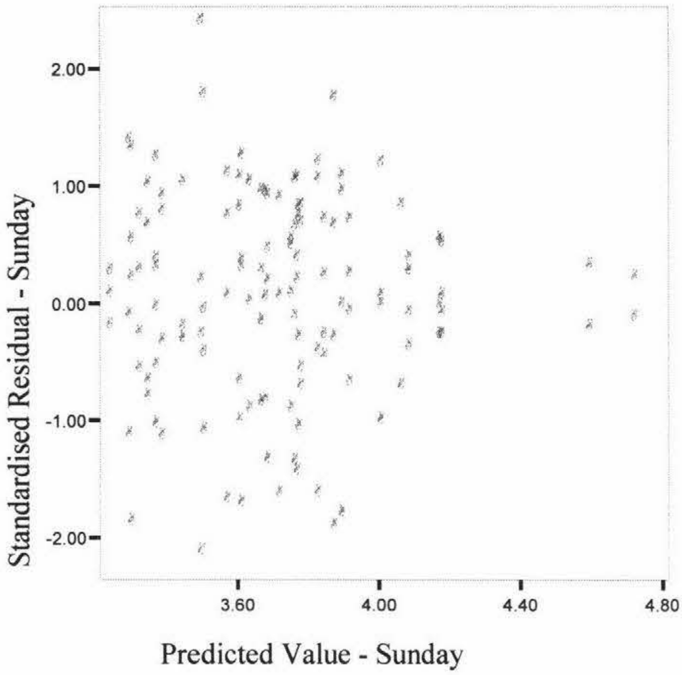


Outlying Points: Building 4, Level 11

Z	H	F	FLog	P
3	1	74196	4.87	4.87
4	1	75573	4.88	4.87
3	2	116644	5.07	5.01
4	2	87757	4.94	5.01
3	3	99022	5.00	5.05
4	3	128439	5.11	5.05

Note.
1 = Desk P = Predicted Value
2 = 1.2m
3 = 1.8m

Figure 8. Residual plot of log particle concentrations on Friday in four participant buildings.



Outlying Points: Building 4, Level 11				
Z	H	F	FLog	P
3	1	49405	4.69	4.76
4	1	65579	4.82	4.76
3	2	6498	3.81	4.09[a]
4	2	23590	4.37	4.09[a]
3	3	33973	4.53	4.63
4	3	52442	4.72	4.63

Note.
1 = Desk P = Predicted Value
2 = 1.2m
3 = 1.8m
[a]The logarithm of zone 3 and 4 height 1.2m were not outliers but were removed as they form part of B4, L11 measurements.

Figure 9. Residual plot of log particle concentrations on Sunday in four participant buildings.

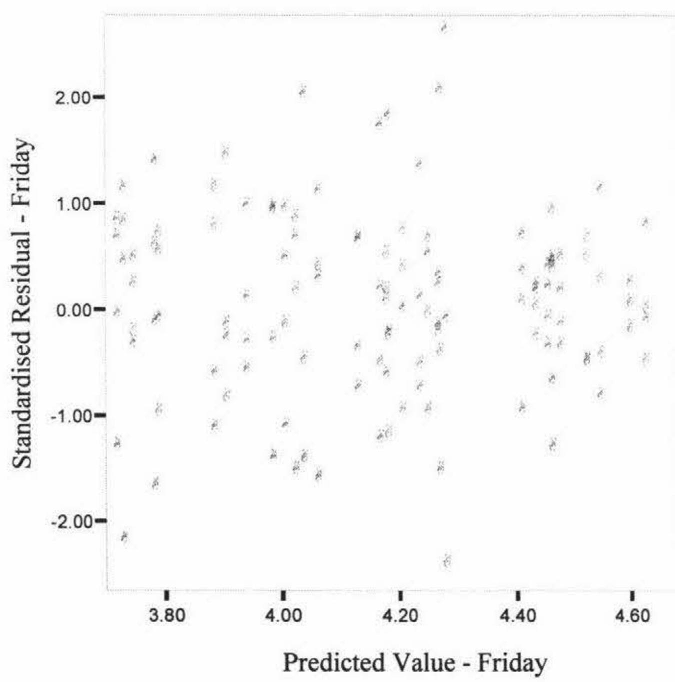


Figure 10. Residual plot of log particle concentrations on Friday with B4, L11, Z1 and Z2 excluded.

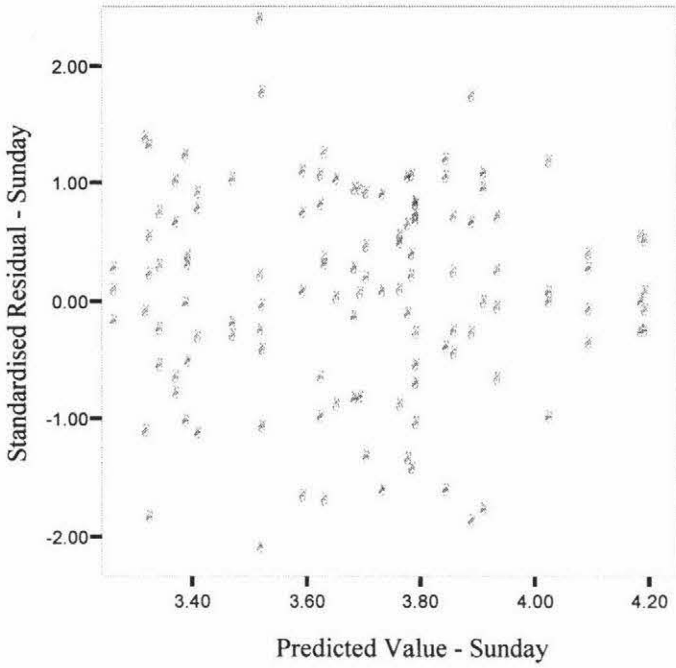


Figure 11. Residual plot of log particle concentrations on Sunday with B4, L11, Z1 and Z2 excluded.

Table 8. ANOVA results of the subject effect tests for the 5μm band.

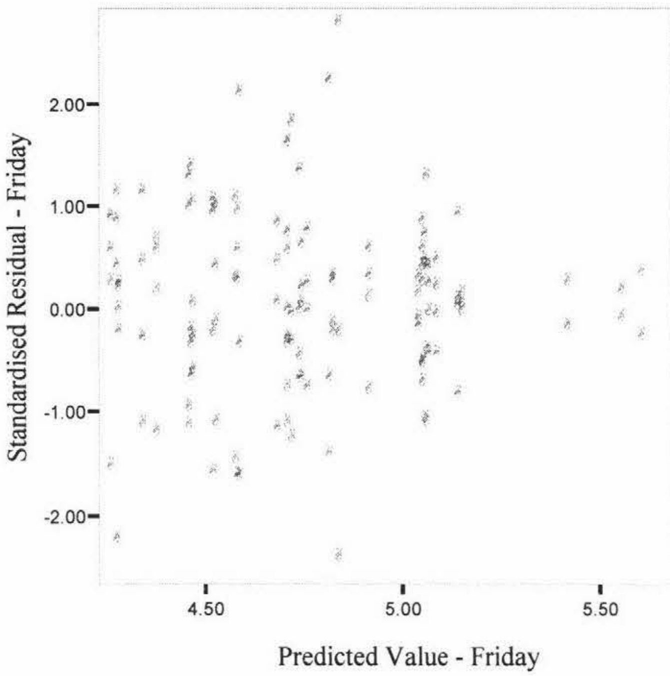
	entire data set			B4, L3, Z3 and Z4 excl[a]		
Between sites	**Degrees of freedom**	**F**	**P Value**	**DF**	**F**	**P Value**
Building	3	24.035	<.001*	3	8.829	<.001*
Height	2	.066	.936	2	.319	.727
Building*Level	8	12.601	<.001*	7	6.965	<.001*
Building*Height	6	.394	.881	6	.491	.813
Building*Level*Height	16	.727	.760	14	.608	.852
Error	96			93		

	entire data set			B4, L3, Z3 and Z4 excl[a]		
Within sites, between days	**Degrees of freedom**	**F**	**P Value**	**DF**	**F**	**P Value**
Day	1	172.086	<.001*	1	171.273	<.001*
Day*Building	3	11.33	<.001*	3	11.686	<.001*
Day*Height	2	.254	.776	2	.416	.661
Day*Building*Level	8	4.803	<.001*	7	5.306	<.001*
Day*Building*Height	6	2.096	.061	6	1.977	.077
Day*Building*Level*Height	16	.686	.802	14	.483	.937
Error	102			93		

Note. Results from multivariate and univariate tests were the same for within subject tests. The exclusion of outlying data measurements did not markedly affect the F and p values.
*p < .05.

5.4.2 Results of Repeated Measures Analysis of Variance 3µm

Residual plots for the 3µm size band were similar to 5µm, with a group of unusually high concentration points between 5.4 and 5.7 for Friday and 5.2 and 5.4 for Sunday from B4, however examination of the raw data showed these data points were correctly entered (Figures 12 and 13). Exclusion of these points resulted in improved scatter (Figures 14 and 15) but did not affect the outcome of the ANOVA results (see table 9).



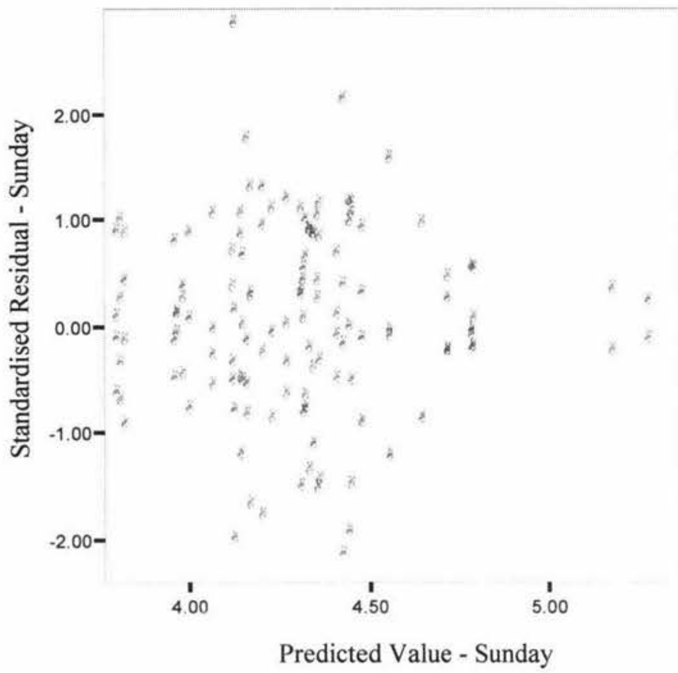
Outlying Points: Building 4, Level 11

Z	H	F	FLog	P
3	1	250805	5.4	5.45
4	1	311617	5.49	5.45
3	2	408414	5.61	5.58
4	2	357173	5.55	5.58
3	3	364341	5.56	5.63
4	3	505035	5.70	5.63

Note.
1 = Desk
2 = 1.2m
3 = 1.8m

P = Predicted Value

Figure 12. Residual plot of log particle concentrations on Friday in four participant buildings.



Building 4, Level 11				
Z	H	F	FLog	P
3	1	178163	5.25	5.31
4	1	229899	5.36	5.31
3	2	24367	4.39	4.67[a]
4	2	89911	4.95	4.67[a]
3	3	130488	5.12	5.21
4	3	197162	5.29	5.21

Note.
1 = Desk P = Predicted Value
2 = 1.2m
3 = 1.8m
[a]The logarithm of zone 3 and 4 height 1.2m were not outliers but were removed as they form part of B4, L11 measurements.

Figure 13. Residual plot of log particle concentrations on Sunday in four participant buildings.

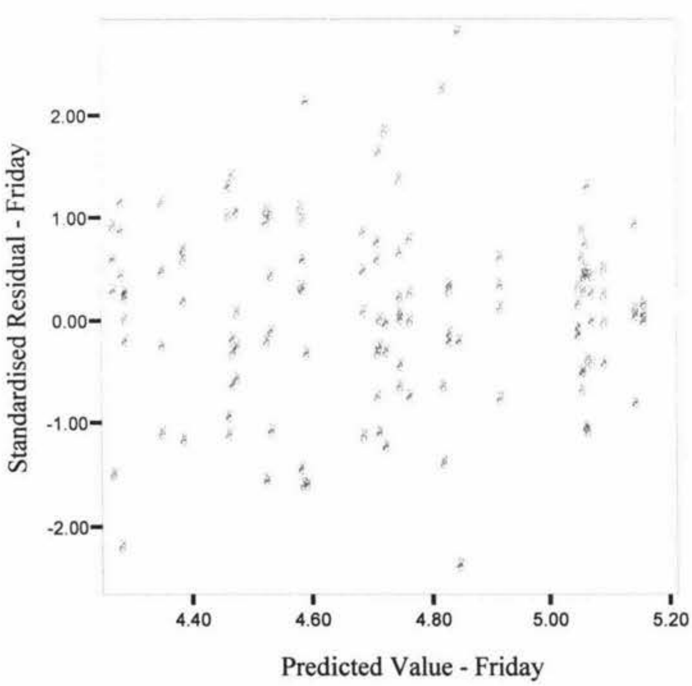


Figure 14. Residual plot of log data while participant buildings were occupied with B4, L11, Z1, and Z2 excluded.

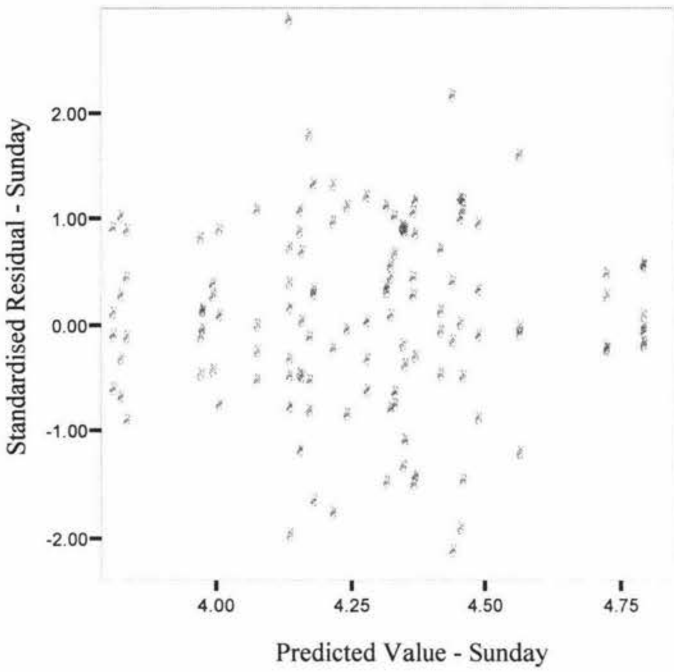


Figure 15. Residual plot of log data while participant buildings were Sunday with B4, L11, Z1, and Z2 excluded.

Table 9. ANOVA results of the subject effect tests for the 3μm band.

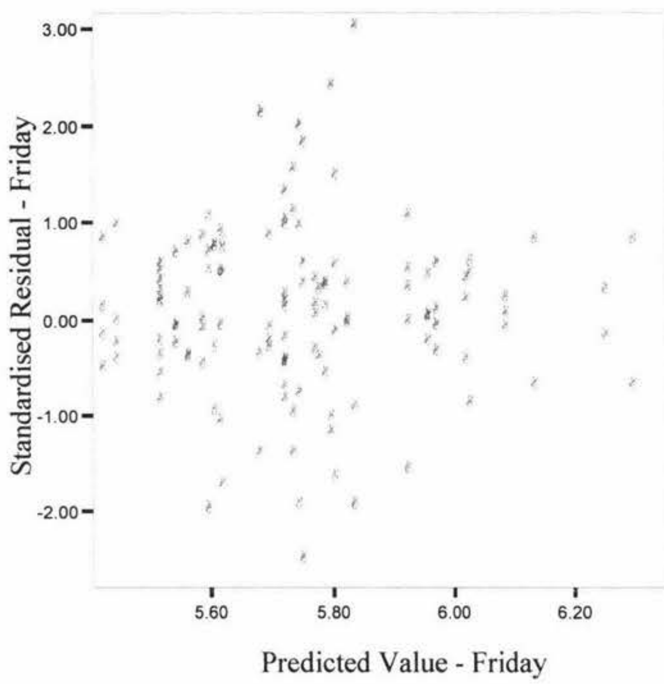
	entire data set			B4, L3, Z3 and Z4 excl[a]		
Within subjects	**Degrees of freedom**	**F**	**P Value**	**DF**	**F**	**P Value**
Day	1	197.359	<.001*	1	192.072	<.001*
Day*Building	3	16.744	<.001*	3	16.660	<.001*
Day*Height	2	.576	.564	2	.734	.483
Day*Building*Level	8	6.434	<.001*	7	7.208	<.001*
Day*Building*Height	6	1.830	.101	6	1.550	.171
Day*Building*Level*Height	16	.652	.833	14	.427	.962
Error	96			93		

	entire data set			B4, L3, Z3 and Z4 excl[a]		
Between subjects	**Degrees of freedom**	**F**	**P Value**	**DF**	**F**	**P Value**
Building	3	30.558	<.001*	3	12.618	<.001*
Height	2	.004	.996	2	.153	.858
Building*Level	8	16.404	<.001*	7	9.191	<.001*
Building*Height	6	.493	.812	6	.316	.927
Building*Level*Height	16	.577	.894	14	.481	.938
Error	96			93		

Note. Results from multivariate and univariate tests were the same for within subject tests. [a]The exclusion of outlying data measurements did not markedly affect the F and p values.
* $p < .05$

5.4.3 Results of Repeated Measures Analysis of Variance 1um

Residual plots for 1μm showed a high concentration of points from B4 between 6.1 and 6.4 on Friday and 6.1 and 6.2 on Sunday (Figures 16 and 17). These points were however correctly entered. Exclusion of these points did result in improved scatter (Figures 18 and 19) but did not affect the outcome of the ANOVA results (see table 10).

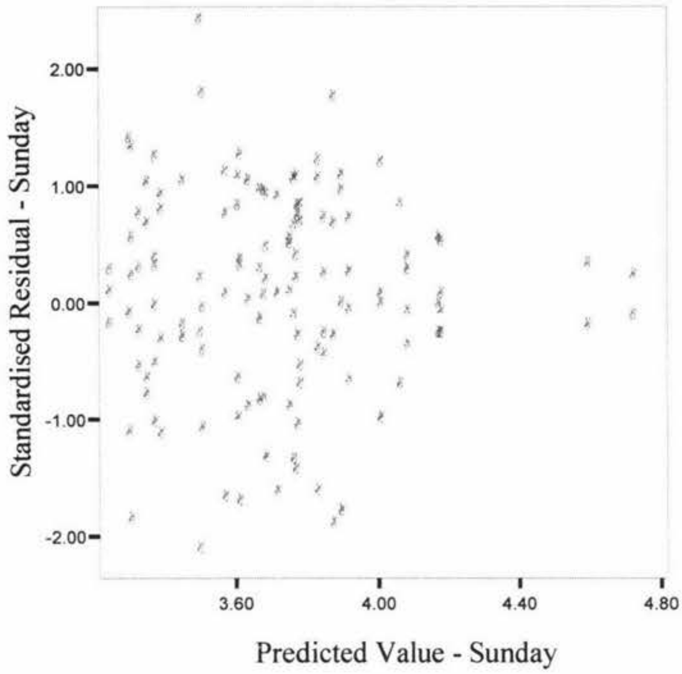


Outlying Points: Building 4, Level 11

Z	H	F	FLog	P
3	1	1122441	6.05	6.15
4	1	1818458	6.26	6.15
3	2	1718553	6.24	6.27
4	2	2005697	6.30	6.27
3	3	1623733	6.21	6.32
4	3	2631720	6.42	6.32

Note.
1 = Desk P = Predicted Value
2 = 1.2m
3 = 1.8m

Figure 16. Residual plot of log particle concentrations on Friday in four participant buildings.



Building 4, Level 11				
Z	H	F	FLog	P
3	1	1304312	6.12	6.15
4	1	1507018	6.18	6.15
3	2	674934	5.83	5.90[a]
4	2	927187	5.97	5.90[a]
3	3	1180181	6.07	6.11
4	3	1429644	6.16	6.11

Note.
1 = Desk P = Predicted Value
2 = 1.2m
3 = 1.8m
[a]The logarithms of zones 3 and 4 height 1.2m were not outliers but were removed as they form part of level 11 measurements.

Figure 17. Residual plot of log particle concentrations on Sunday in four participant buildings.

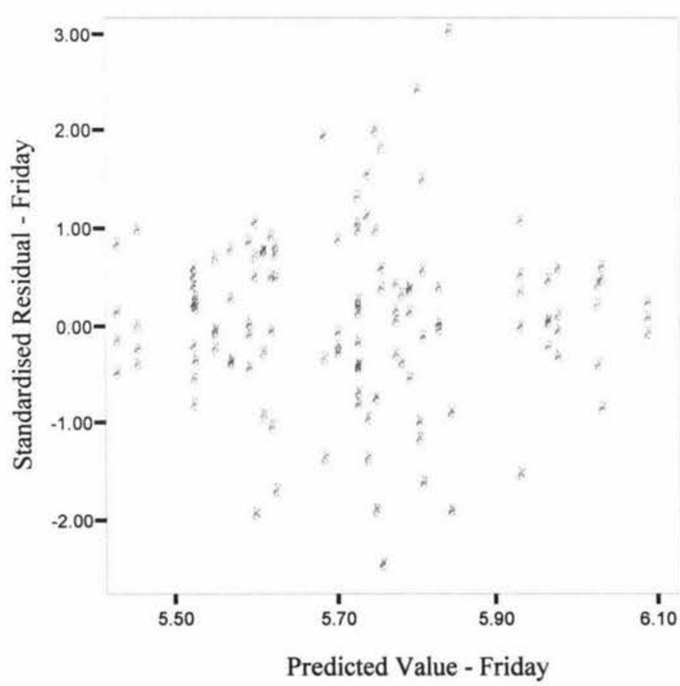


Figure 18. Residual plot of log particle concentrations on Friday with B4, L11, Z3 and Z4 excluded.

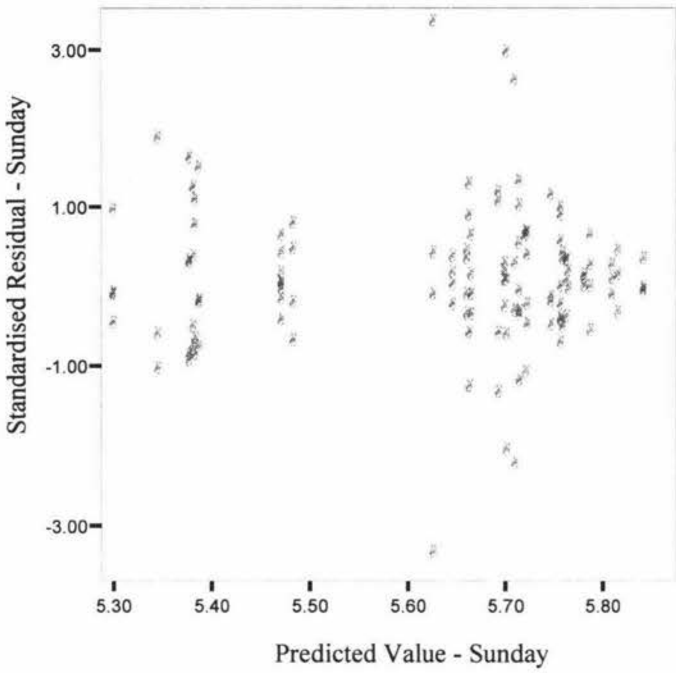


Figure 19. Residual plot of log particle concentrations on Sunday with B4, L11, Z3 and Z4 excluded.

Table 10. ANOVA results of the subject effect tests for the 1μm band.

	entire data set			B4, L3, Z3 and Z4 excl[a]		
Within subjects	**Degrees of freedom**	**F**	**P Value**	**DF**	**F**	**P Value**
Day	1	39.315	<.001*	1	24.714	<.001*
Day*Building	3	36.562	<.001*	3	41.892	<.001*
Day*Height	2	.198	.820	2	.329	.720
Day*Building*Level	8	13.343	<.001*	7	13.197	<.001*
Day*Building*Height	6	1.090	.374	6	1.008	.425
Day*Building*Level*Height	16	.563	.904	14	.301	.993
Error	96			93		

	entire data set			B4, L3, Z3 and Z4 excl[a]		
Between subjects	**Degrees of freedom**	**F**	**P Value**	**DF**	**F**	**P Value**
Building	3	23.991	<.001*	3	8.489	<.001*
Height	2	.042	.959	2	.116	.891
Building*Level	8	31.698	<.001*	7	18.485	<.001*
Building*Height	6	.475	.825	6	.455	.840
Building*Level*Height	16	.317	.994	14	.204	.999
Error	96			93		

Note. Results from multivariate and univariate tests were the same for within subject tests. [a]The exclusion of outlying data measurements did not markedly affect the F and p values.
* $p < .05$.

5.4.4 Results of Repeated Measures Analysis of Variance 0.5μm

The residual plot of particle concentrations of Friday's data showed good scatter (Figure 20), however there were some outlying points on Sunday with standard residuals below –3 (Figure 21). These points were random, valid entries with no pattern and did not show any reason for exclusion.

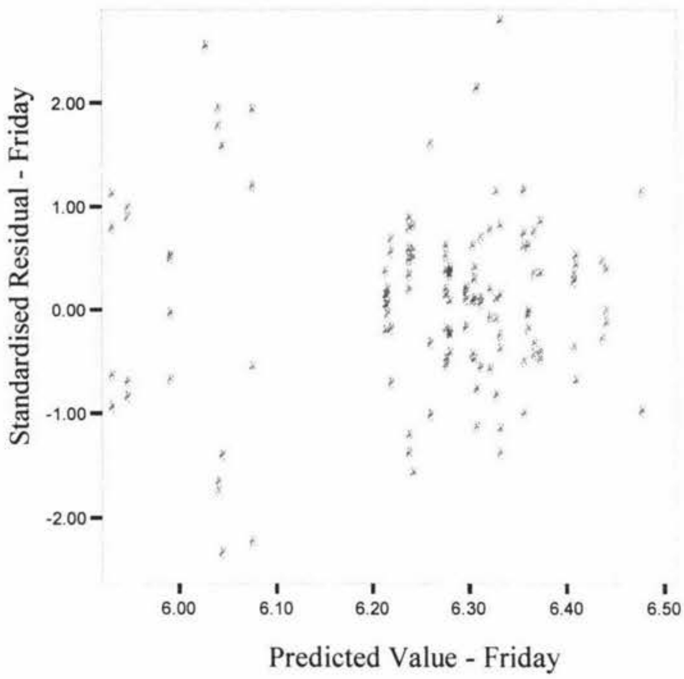


Figure 20. Residual plot of log particle concentrations on Friday in four participant buildings.

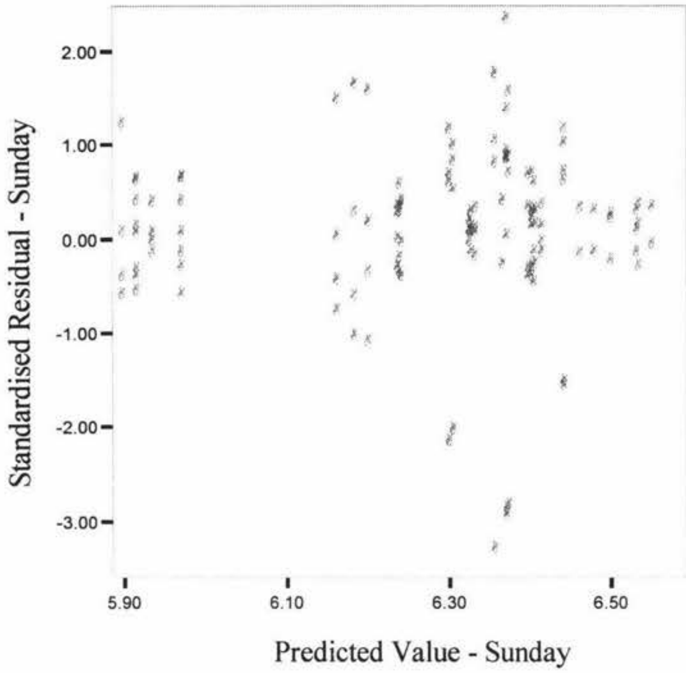


Figure 21. Residual plot of log particle concentrations on Sunday in four participant buildings.

Table 11. ANOVA results of the subject effect tests for the 0.5μm band.

	entire data set		
Within subjects	**Degrees of freedom**	**F**	**P Value**
Day	1	11.697	.001*
Day*Building	3	140.980	<.001*
Day*Height	2	.447	.641
Day*Building*Level	8	15.374	<.001*
Day*Building*Height	6	.306	.932
Day*Building*Level*Height	16	.476	.953
Error	96		

Between subjects	**Degrees of freedom**	**F**	**P Value**
Building	3	113.447	<.001*
Height	2	.084	.920
Building*Level	8	31.072	<.001*
Building*Height	6	.168	.985
Building*Level*Height	16	.267	.998
Error	96		

Note. Results from multivariate and univariate tests were the same.
* $p < .05$.

5.4.5 Results of Repeated Measures Analysis of Variance 0.3μm

The residual plots for the 0.3μm size band showed good scatter (Figures 22 and 23). There was some grouping of data according to buildings however it is possible if more buildings had been studied thus providing a larger data set, then these gaps may have been filled.

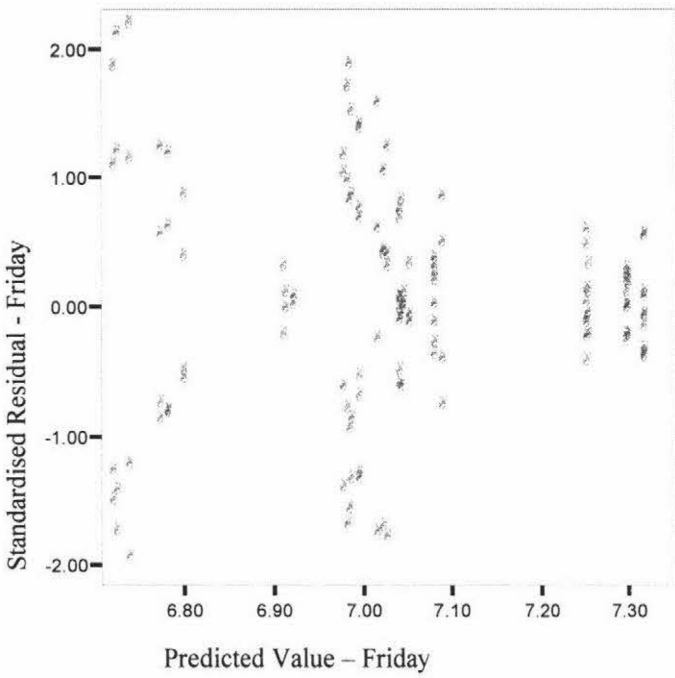


Figure 22. Residual plot of log particle concentrations on Friday in four participant buildings.

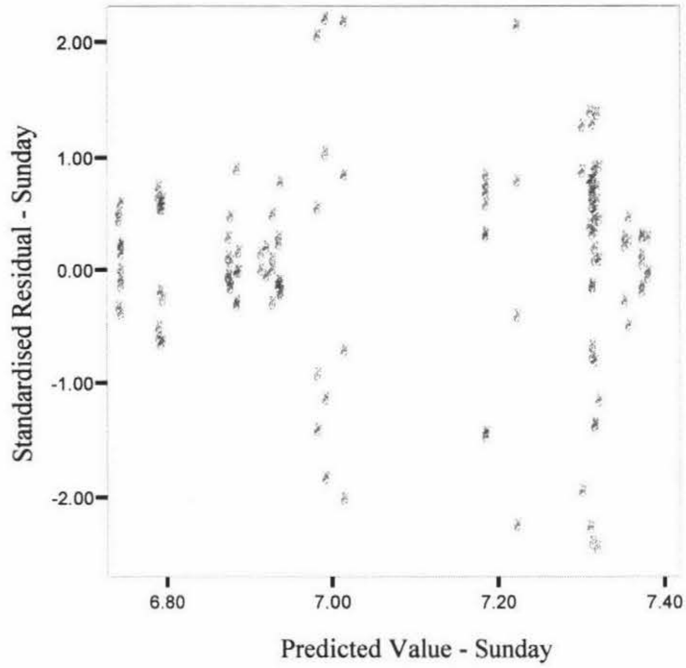


Figure 23. Residual plot of log particle concentrations on Sunday in four participant buildings.

Table 12. ANOVA results of the subject effect tests for the 0.3μm band.

	entire data set		
Within subjects	**Degrees of freedom**	**F**	**P Value**
Day	1	60.424	<.001*
Day*Building	3	119.522	<.001*
Day*Height	2	.023	.977
Day*Building*Level	8	22.419	<.001*
Day*Building*Height	6	.011	1.000
Day*Building*Level*Height	16	.154	1.000
Error	102		

	entire data set		
Between subjects	**Degrees of freedom**	**F**	**P Value**
Building	3	663.891	<.001*
Height	2	.024	.976
Building*Level	8	9.264	<.001*
Building*Height	6	.074	.998
Building*Level*Height	16	.103	1.000
Error	96		

Note. Results from multivariate and univariate tests were the same.
* $p < .05$.

5.5 GRAPH ANALYSIS

5.5.1 Line graphs

Due to the lack of a significant vertical gradient in particle concentrations between the height levels of desk, 1.2m and 1.8m, particle concentrations were averaged for each **zone.** These zone averages were then graphed to compare the difference in particle concentrations measured on the Fridays and Sundays for the four participant buildings.

5.5.2 Means and Confidence Intervals

Means tables of the entire data set were used to identify any overlapping of confidence intervals and thus identify where there was not a marked difference between the particle concentrations measured on the Fridays and Sundays.

5.5.3 Sunday concentrations as a percentage of Friday concentrations

Floor level particle concentration averages were calculated for each building and these concentrations on the Sundays were reported as a percentage of Friday concentrations. This provided quantitative data of the influence of occupants on particle concentrations when present and absent from the indoor space.

5.6 5μm

5.6.1 Graphs Analysis 5μm

Figure 24 shows particle concentrations were varied on Fridays and Sundays between zones, floor levels and buildings. The lowest particle concentrations of 10,000 particles and below were measured on Friday in L1 of B1. Particle concentrations recorded in L11 of B4 on both the Friday and Sunday were higher than all other participant buildings. L3 of B1 also showed high concentrations with a peak in one zone on the sampling day of Friday.

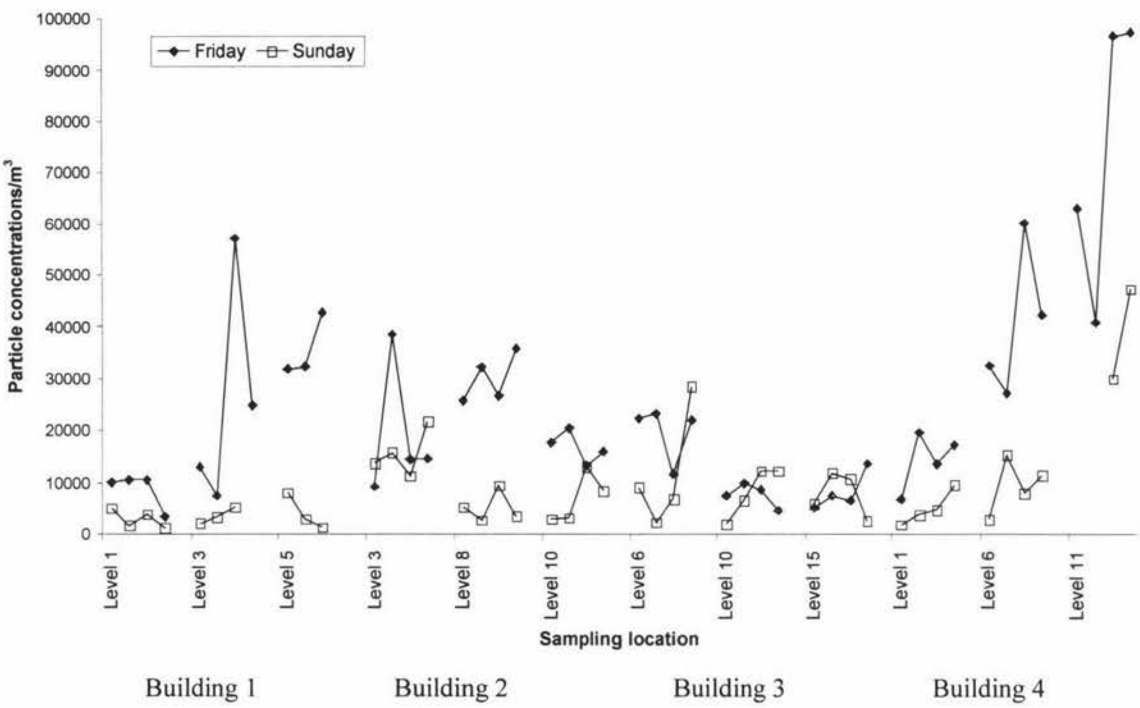


Figure 24. Particle concentrations of 5μm in participant buildings on Fridays and Sundays.

5.6.2 Means and Confidence Intervals 5μm

Table 13 summarises the log and non-log particle concentrations of the entire data set for each building's floor level on the two sampling days. The means table shows the means for all floor levels decrease from each Friday period to Sunday period. There is a clear separation between confidence intervals showing a large decrease in particle concentrations between Fridays and Sundays (see figure 25). B2, L3, and B3, L10 and L15 were exceptions to this due to minimal occupancy on Friday in B3 and high occupancy on Sunday in B2.

Table 13. Means and confidence intervals of particle concentrations on Fridays and Sundays for the size band of 5μm.

B	L	Day	Log scale				Original scale		
				Std.	95% CI			95% CI	
			Mean	Error	Lower	Upper	Mean	Lower	Upper
1	1	Friday	3.864	.067	3.732	3.997	7311	5395	9931
		Sunday	3.391	.104	3.184	3.598	2460	1528	3963
	3	Friday	4.215	.077	4.062	4.367	16406	11535	23281
		Sunday	3.466	.120	3.227	3.705	2924	1387	5070
	5	Friday	4.526	.077	4.373	4.678	33574	23605	47643
		Sunday	3.470	.120	3.231	3.709	2951	1702	5117
2	3[a]	Friday	4.212	.067	**4.080**	**4.345**	16293	12023	22131
		Sunday	4.177	.104	**3.970**	**4.384**	15031	9333	24210
	8	Friday	4.473	.067	4.340	4.605	29717	21878	40272
		Sunday	3.636	.104	3.429	3.843	4325	2685	6966
	10	Friday	4.209	.067	4.077	4.342	16181	11940	21979
		Sunday	3.720	.104	3.513	3.927	5248	3258	8453
3	6	Friday	4.233	.067	4.101	4.365	17100	12618	23174
		Sunday	3.829	.104	3.622	4.036	6745	4188	10864
	10[a]	Friday	3.838	.067	**3.706**	**3.970**	6887	5082	9333
		Sunday	3.798	.104	**3.591**	**4.005**	6281	3899	10116
	15[a]	Friday	3.853	.067	**3.720**	**3.985**	7129	5248	9661
		Sunday	3.785	.104	**3.578**	**3.992**	6095	3784	9817
4	1	Friday	4.109	.067	3.977	4.242	12853	9484	17458
		Sunday	3.544	.104	3.337	3.751	3499	2173	5636
	6	Friday	4.582	.067	4.450	4.714	38194	28184	51761
		Sunday	3.869	.104	3.662	4.076	7396	4592	11912
	11	Friday	4.977	.094	4.790	5.164	94842	61660	145881
		Sunday	4.491	.148	4.198	4.784	30947	15776	60814

Note. CI = confidence interval. [a]Confidence intervals overlap.

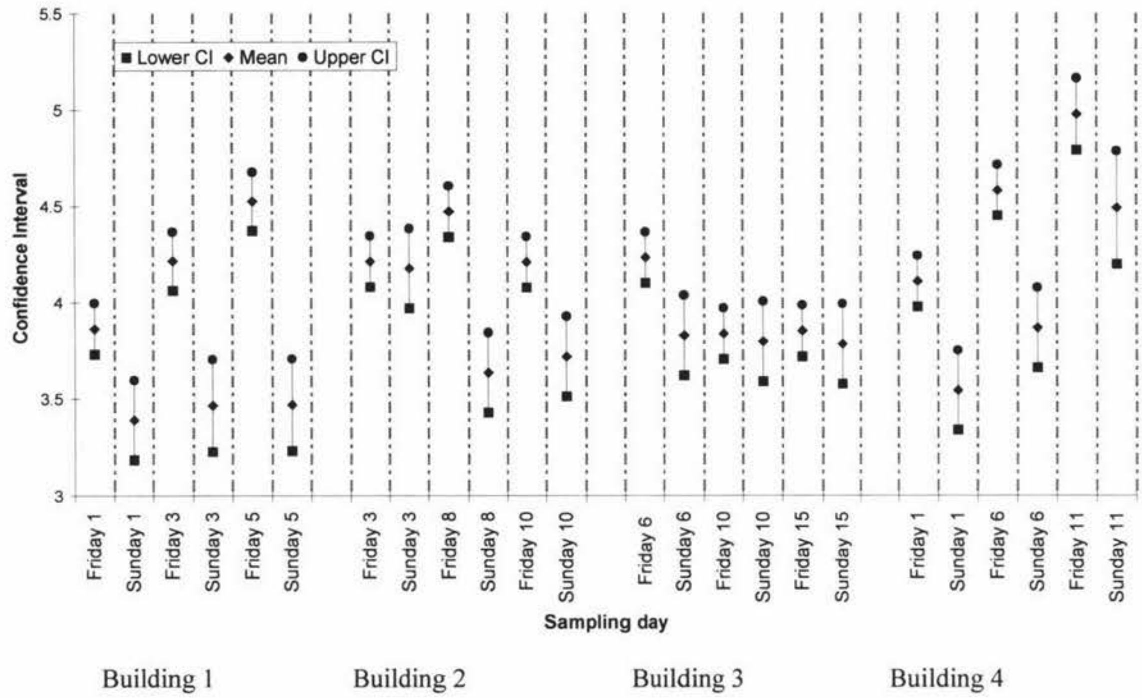


Figure 25. Confidence intervals for Friday and Sunday for the particle size 5μm.

5.6.3 Sunday concentrations as a percentage of Friday concentrations 5μm

Table 14 shows Sunday particle concentrations as a percentage of Friday particle concentrations for all four participant buildings. B3, L10 and L15 showed small reductions in comparison to other buildings. However two of the four zones on L15 were meeting rooms not in use and two of the four zones on L10 were unoccupied on the Friday. The calculation of the average for floor levels 10 and 15 excluding unoccupied areas on Friday resulted in percentage concentrations aligned with the other participant building results. B2, L3 had 60% occupancy on Sunday and the ventilation fans were operational from 8am to 2pm which explains the small % decrease in particle concentrations.

Table 14. Sunday particle concentrations as a percentage of Friday particle concentrations 5μm for all four participant buildings.

Building One	**Level 1**	**Level 3**	**Level 5**
Friday floor level average	8596	25839	35609
Sunday floor level average	2937	3579	4081
%	**34%**	**14%**	**11%**
Building Two	**Level 3**	**Level 8**	**Level 10**
Friday floor level average	19149	30056	16774
Sunday floor level average	15594	5218	6889
%	**81%**	**17%**	**41%**
Building Three	**Level 6**	**Level 10**	**Level 15**
Friday Average	19735	7593	8125
Sunday Average	11613	8225	7710
%	**59%**	**108%**	**95%**
%		**59%**[a]	**45%**[a]
Building Four	**Level 1**	**Level 6**	**Level 11**
Friday Average	14249	40474	74405
Sunday Average	4958	9347	38581
%	**35%**	**23%**	**52%**

Note. [a]% with levels 10 and 15 unoccupied zones on the Friday removed.

5.7 3μm

5.7.1 Graph Analysis

Figure 26 shows particle concentrations were varied on Fridays and Sundays between zones, floor levels and buildings. The lowest particle concentrations of below 50,000 on Friday were recorded on L1, B1 and L10, and 15 of B3. High particle concentrations were recorded on L11 of B4 on both the Friday and Sunday than all other participant buildings. L3 of B1 also showed high concentrations with a peak in one zone on the sampling day of Friday.

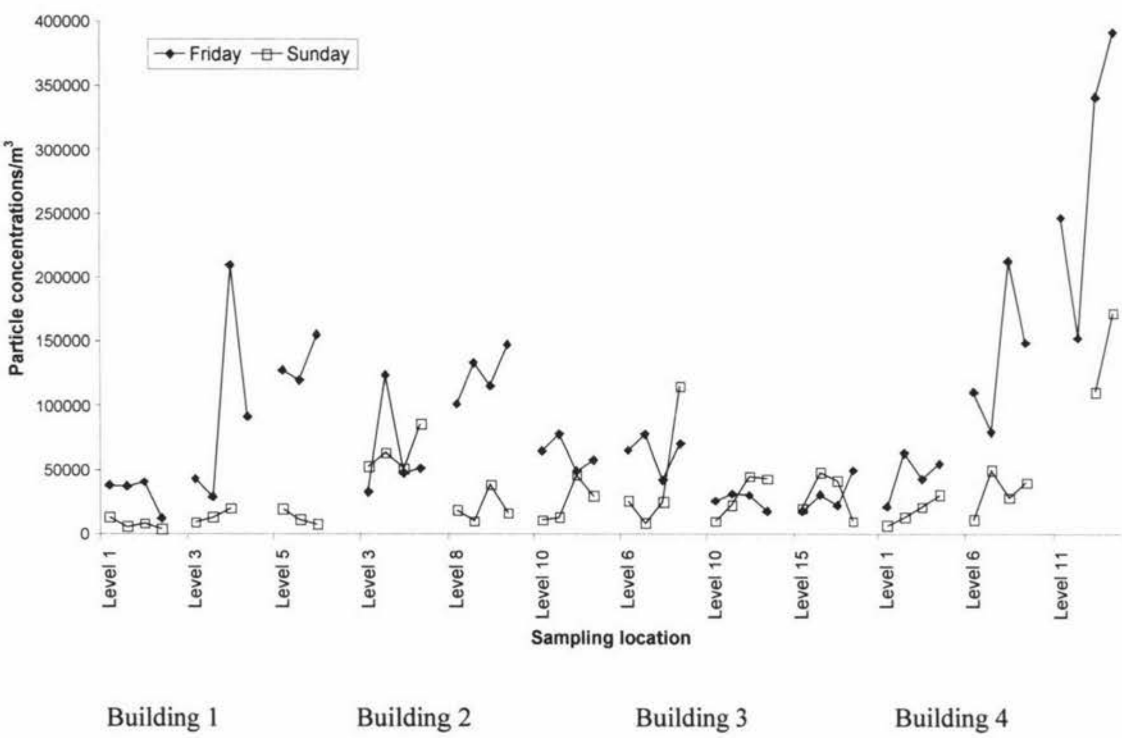


Figure 26. Particle concentrations of 3μm in participant buildings on Friday and Sunday.

5.7.2 Means and Confidence Intervals 3μm

The means and confidence intervals followed the same pattern as the 5μm range. The pattern of the means for all floor levels decreased from Friday to Sunday. As with the 5μm band there was a clear separation between confidence intervals except for B2, L3 and B3, L10 and L15 (see table 15 and figure 27).

Table 15. Means and confidence intervals of particle concentrations on Friday and Sunday for the size band of 3μm.

			Log scale				Original scale		
B	L	Day	Mean	Std. Error	95% CI Lower	95% CI Upper	Mean	95% CI Lower	95% CI Upper
1	1	Friday	4.435	.065	4.306	4.563	2943031	2192857	3916757
		Sunday	3.840	.089	3.663	4.018	697899	434737	1096645
	3	Friday	4.771	.075	4.623	4.920	6114702	4457361	8307397
		Sunday	4.090	.103	3.885	4.295	1309966	783296	2136331
	5	Friday	5.111	.075	4.962	5.259	12159626	9054816	16191746
		Sunday	4.065	.103	3.860	4.270	1232183	734402	2015377
2	3[a]	Friday	4.746	.065	**4.617**	**4.874**	5793482	4401893	7569203
		Sunday	4.790	.089	**4.612**	**4.967**	6354759	4355677	9144733
	8	Friday	5.089	.065	4.960	5.218	11650952	9020188	14953182
		Sunday	4.244	.089	4.066	4.422	1895643	1236411	2855900
	10	Friday	4.780	.065	4.651	4.909	6227144	4740876	8120360
		Sunday	4.305	.089	4.127	4.482	2184572	1433649	3272621
3	6	Friday	4.753	.065	4.625	4.882	5885418	4473705	7686127
		Sunday	4.398	.089	4.221	4.576	2709032	1794179	4024203
	10[a]	Friday	4.388	.065	**4.260**	**4.517**	2648592	1967235	3535440
		Sunday	4.394	.089	**4.217**	**4.572**	2685126	1777683	3990063
	15[a]	Friday	4.417	.065	**4.288**	**4.546**	2826533	2103511	3766006
		Sunday	4.377	.089	**4.199**	**4.554**	2578492	1704170	3837652
4	1	Friday	4.618	.065	4.490	4.747	4412476	3326917	5807033
		Sunday	4.175	.089	3.997	4.353	1609150	1042004	2440411
	6	Friday	5.108	.065	4.979	5.236	12082728	9363281	15493460
		Sunday	4.431	.089	4.253	4.608	2915924	1937168	4319228
	11	Friday	5.554	.092	5.372	5.735	27910495	20006899	38520888
		Sunday	5.061	.126	4.809	5.312	11015042	6621798	17876885

Note. CI = confidence interval. [a]Confidence intervals overlap.

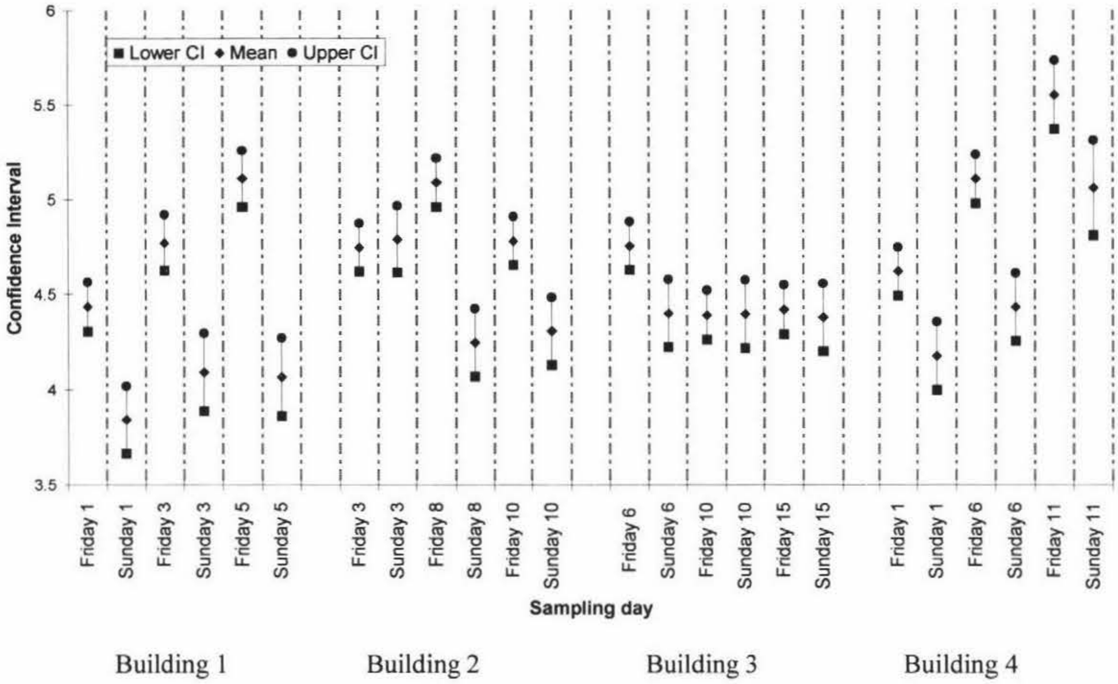


Figure 27. Confidence intervals for Friday and Sunday for the particle size 3μm.

5.7.3 Sunday concentrations as a percentage of Friday concentrations 3μm

The pattern of concentrations was the same for 3μm for the 5μm band with small reductions in B3, L10 and L15 due to minimal occupancy on Friday and with small reductions in B2, L3 due to 60% occupancy on Sunday and the operation of the ventilation fans (see table 16).

Table 16. Sunday particle concentrations as a percentage of Friday concentrations 3μm for the four participant buildings.

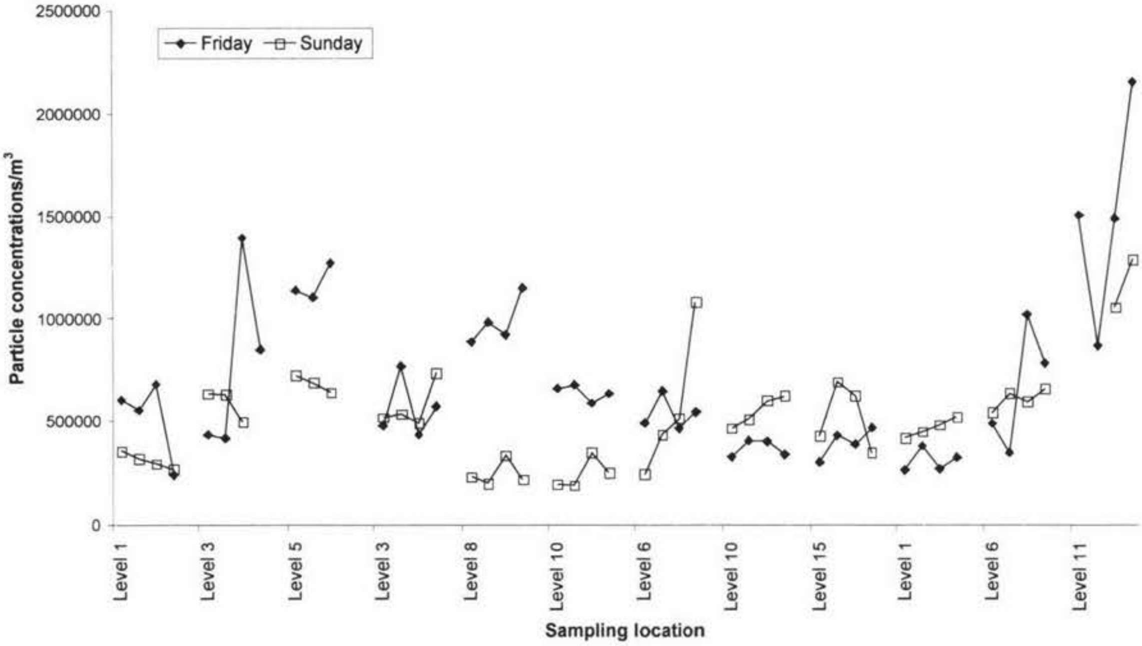
Building One	Level 1	Level 3	Level 5
Friday floor level average	31827	93210	133901
Sunday floor level average	7643	14106	12800
%	**24%**	**15%**	**10%**
Building Two	**Level 3**	**Level 8**	**Level 10**
Friday floor level average	63778	124281	62342
Sunday floor level average	63269	20962	24938
%	**99%**	**17%**	**40%**
Building Three	**Level 6**	**Level 10**	**Level 15**
Friday Average	63943	26180	30062
Sunday Average	43625	30188	29914
%	**68%**	**115%**	**99.5%**
%		**67%**[a]	**45%**[a]
Building Four	**Level 1**	**Level 6**	**Level 11**
Friday Average	45553	138230	283082
Sunday Average	17840	32481	141665
%	**39%**	**23%**	**50%**

Note. [a]% with levels 10 and 15 unoccupied zones on the Friday removed.

5.8 1μm

5.8.1 Graph Analysis 1μm

Figure 28 shows particle concentrations were varied on Fridays and Sundays between zones, floor levels and buildings. Particle concentrations recorded on Sunday were higher than on Friday for B3, L10 and L15 and L1 of B4. Again, as with the 5μm and 3μm range higher particle concentrations were recorded on L11 of B4 on both the Friday and Sunday than all other participant buildings. L3 of B1 also showed high concentrations with a peak in one zone on the sampling day of Friday.



Building 1 Building 2 Building 3 Building 4

Figure 28. Particle concentrations of 1μm in participant buildings on Friday and Sunday.

5.8.2 Means and Confidence Intervals 1μm

The means for the majority of floor levels decreased from Friday to Sunday. There is a clear separation between confidence intervals except for B1, L3; B2, L3; and B3, L6 and L15; and B4, L6 and L11 (see Table 17).

Table 17. Means and confidence intervals of particle concentrations on Friday and Sunday for the size band of 1μm.

B	L	Day	Log scale Mean	Std. Error	95% CI Lower	95% CI Upper	Original scale Mean	95% CI Lower	95% CI Upper
1	1	Friday	5.674	.041	5.594	5.755	472245	392403	568333
		Sunday	5.485	.034	5.417	5.553	305695	261390	357510
	3[a]	Friday	5.790	.047	**5.697**	**5.883**	616616	497893	763650
		Sunday	5.763	.040	**5.685**	**5.842**	579750	483862	694639
	5	Friday	6.063	.047	5.970	6.156	1156215	933597	1431917
		Sunday	5.832	.040	5.754	5.911	680238	567730	815041
2	3[a]	Friday	5.740	.041	**5.660**	**5.820**	549111	456273	660839
		Sunday	5.749	.034	**5.681**	**5.817**	561510	480129	656684
	8	Friday	5.971	.039	5.893	6.049	935324	782085	1118589
		Sunday	5.365	.033	5.299	5.431	231789	199250	269641
	10	Friday	5.809	.043	5.724	5.893	643560	529422	782304
		Sunday	5.380	.036	5.309	5.452	240053	203531	283130
3	6[a]	Friday	5.718	.041	**5.637**	**5.798**	522090	433820	628321
		Sunday	5.688	.034	**5.620**	**5.756**	488069	417332	570795
	10	Friday	5.561	.041	5.481	5.642	364143	302578	438236
		Sunday	5.736	.034	5.668	5.804	543940	465106	636136
	15[a]	Friday	5.589	.041	**5.509**	**5.670**	388404	322736	467433
		Sunday	5.700	.034	**5.632**	**5.768**	501063	428443	585992
4	1[a]	Friday	5.481	.041	5.401	5.562	302856	251652	364479
		Sunday	5.668	.034	5.600	5.736	465319	397880	544190
	6[a]	Friday	5.780	.041	**5.699**	**5.860**	601958	500185	724439
		Sunday	5.782	.034	**5.714**	**5.850**	605185	517474	707762
	11[a]	Friday	6.246	.057	**6.133**	**6.360**	1763362	1357027	2291368
		Sunday	6.053	.048	**5.957**	**6.149**	1129408	905077	1409342

Note. CI = confidence interval. [a]Confidence intervals overlap.

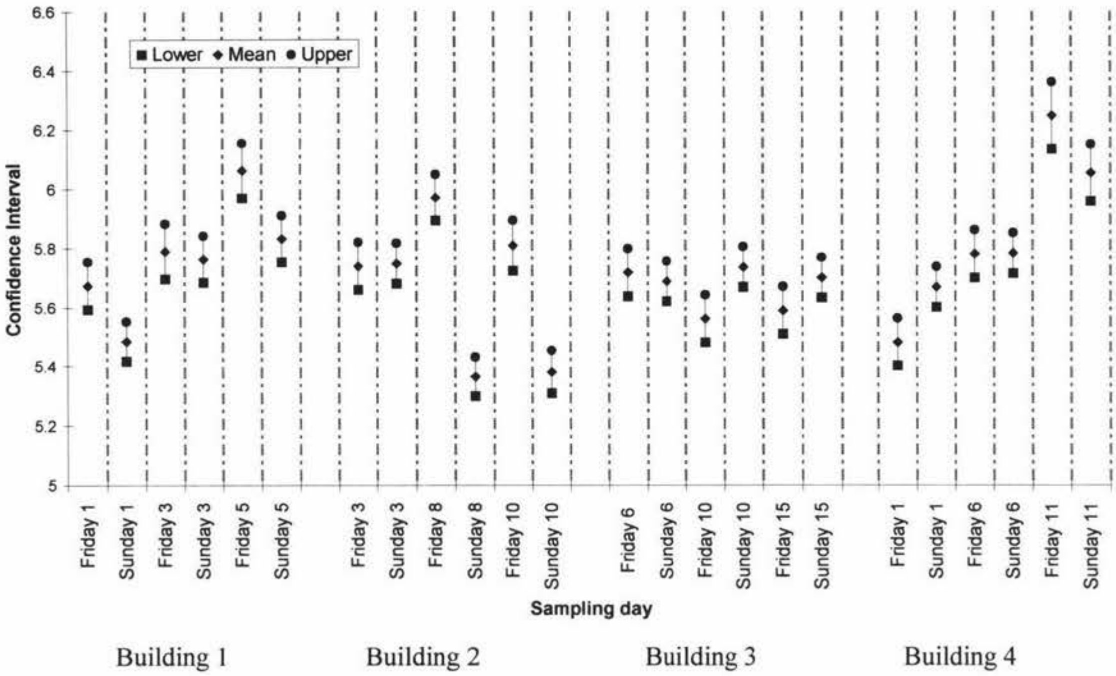


Figure 29. Confidence intervals for Friday and Sunday for the particle size 1μm.

5.8.3 Sunday concentrations as a percentage of Friday concentrations 1μm

Particle concentrations on Sunday were less than Friday for all floor levels in B1 and on L8 and L10 of B2, and L6 and L11 of B4. Particle concentrations increased on all floor levels of B3 and on L1 of B4 (see table 18).

Table 18. Sunday concentrations as a percentage of Friday particle concentrations 1μm.

Building One	**Level 1**	**Level 3**	**Level 5**
Friday floor level average	517943	772302	1169665
Sunday floor level average	307770	586404	68192
%	**59%**	**76%**	**58%**
Building Two	**Level 3**	**Level 8**	**Level 10**
Friday floor level average	563075	982840	637954
Sunday floor level average	569555	244531	244948
%	**101%**	**25%**	**38%**
Building Three	**Level 6**	**Level 10**	**Level 15**
Friday Average	536462	367352	398866
Sunday Average	567583	549758	521598
%	**106%**	**150%**	**131%**
%[a]		**132%**	**101%**
Building Four	**Level 1**	**Level 6**	**Level 11**
Friday Average	308294	658471	1502283
Sunday Average	467122	607586	1170546
%	**152%**	**92%**	**78%**

Note. [a]% with levels 10 and 15 unoccupied zones on the Friday removed.

5.9 0.5μm

5.9.1 Graph Analysis

Figure 30 shows particle concentrations were varied on Fridays and Sundays between zones, floor levels and buildings. Particle concentrations recorded on Sunday were higher than on Friday for all buildings except B2. B1 and B3 recorded the highest concentrations on Sunday of all four participant buildings. L11 of B4 was higher on both the Friday and Sunday than L1 and L6 of B4.

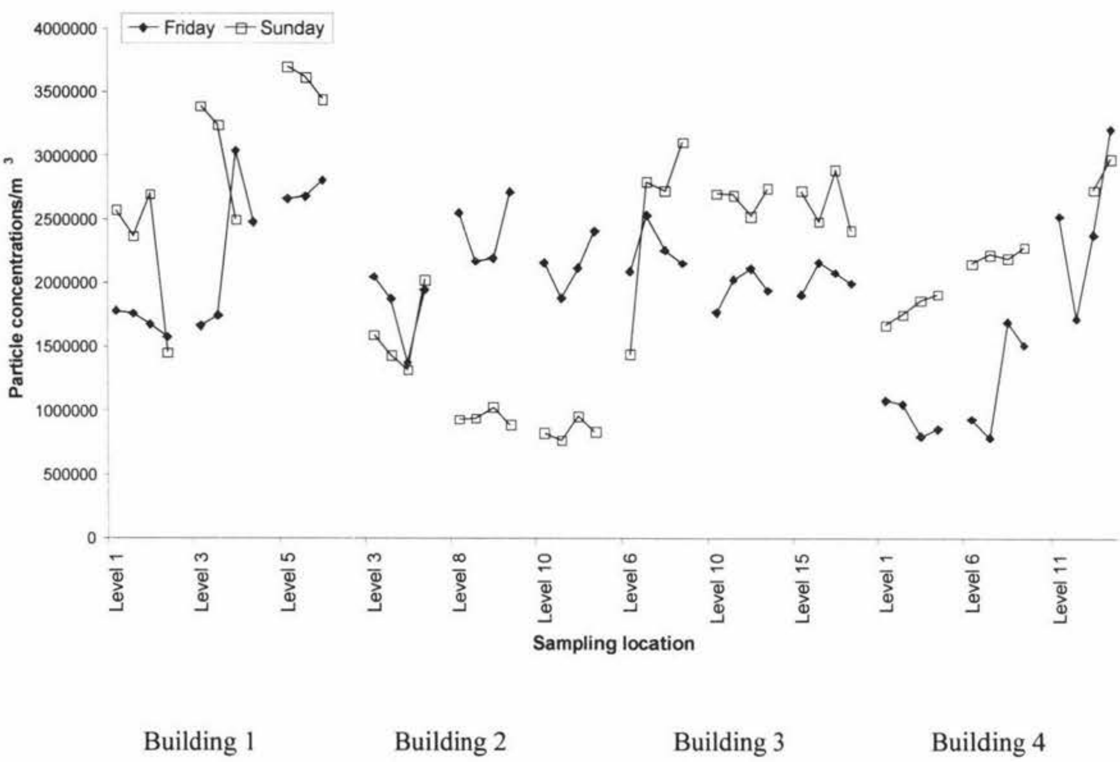


Figure 30. Particle concentrations of 0.5μm measured in four participant buildings while occupied on a Friday.

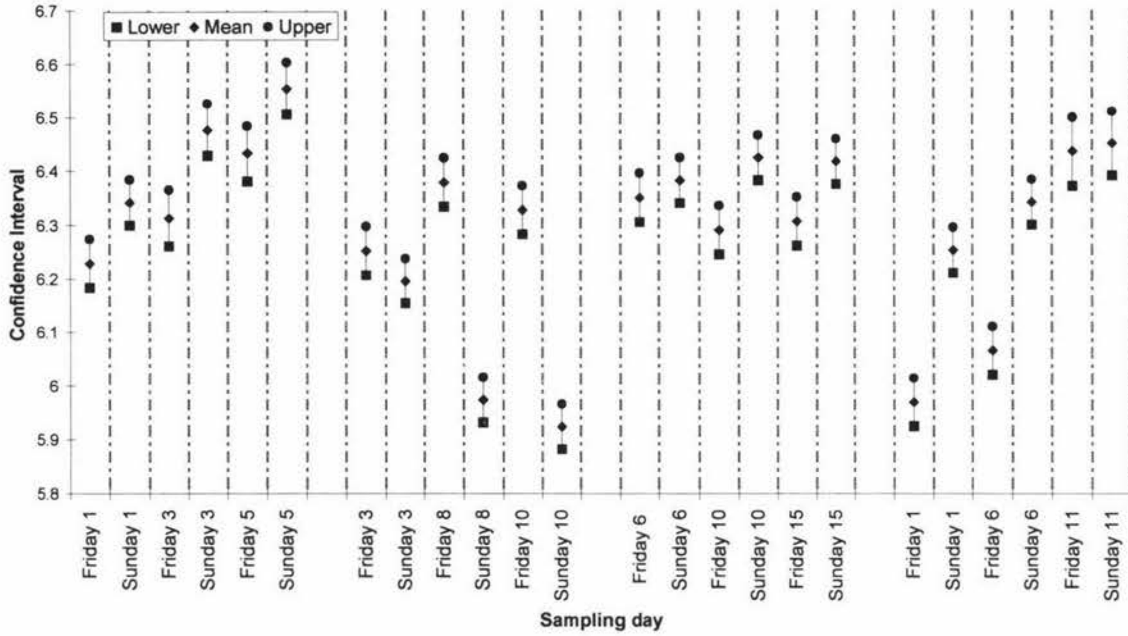
5.9.2 Means and Confidence Intervals 0.5μm

Confidence intervals overlapped on L3 of B2; L6, B3; and L11, BB (see table 19). An overlap of confidence intervals provides an indication that there is no statistical difference between particle concentrations on Friday and Sunday.

Table 19. Means and confidence intervals of particle concentrations on Friday and Sunday for the size band of 0.5μm.

B	L	Day	Log scale Mean	Log scale Std. Error	Log scale 95% CI Lower	Log scale 95% CI Upper	Original scale Mean	Original scale 95% CI Lower	Original scale 95% CI Upper
1	1	Friday	6.229	.023	6.184	6.274	87920704	81778197	94475374
		Sunday	6.342	.021	6.300	6.384	105227294	98472679	112396078
	3	Friday	6.313	.026	6.261	6.365	100568182	92599325	109149016
		Sunday	6.477	.024	6.429	6.526	129995297	120597799	140046800
	5	Friday	6.433	.026	6.381	6.484	121285322	111846778	131434765
		Sunday	6.554	.024	6.506	6.603	146304036	135847722	157479205
2	3[a]	Friday	6.252	.023	**6.207**	**6.297**	91247695	84895624	98024358
		Sunday	6.196	.021	**6.154**	**6.238**	83360251	77887001	89177253
	8	Friday	6.379	.023	6.334	6.424	111516827	103903064	119629087
		Sunday	5.974	.021	5.932	6.016	57938328	53997710	62135902
	10	Friday	6.328	.023	6.283	6.373	102906818	95826019	110455081
		Sunday	5.924	.021	5.882	5.966	53216269	49566894	57105706
3	6[a]	Friday	6.351	.023	**6.306**	**6.396**	106732928	99414776	114532396
		Sunday	6.383	.021	**6.341**	**6.425**	112218288	105059744	119812870
	10	Friday	6.291	.023	6.246	6.336	97027042	90312682	104187374
		Sunday	6.425	.021	6.383	6.467	119841138	112244938	127896914
	15	Friday	6.307	.023	6.262	6.352	99522397	92652265	106847653
		Sunday	6.418	.021	6.376	6.460	118544724	111022760	126522283
4	1	Friday	5.970	.023	5.925	6.015	57467987	53284502	61944795
		Sunday	6.254	.021	6.212	6.296	91482893	85530250	97805832
	6	Friday	6.066	.023	6.021	6.111	67501634	62663576	72673314
		Sunday	6.343	.021	6.301	6.385	105487861	98718145	112672566
	11[a]	Friday	6.437	.032	**6.373**	**6.500**	122053741	110521485	134657908
		Sunday	6.452	.030	**6.392**	**6.511**	124940619	113919507	136912227

Note. CI = confidence interval. [a]confidence intervals overlap.



Building 1 Building 2 Building 3 Building 4

Figure 31. Confidence intervals for Friday and Sunday for the particle size 0.5μm.

5.9.3 Sunday concentrations as a percentage of Friday concentrations 0.5μm

Particle concentrations decreased from Friday to Sunday in B2 only. L3 of B2 had the lowest decrease of the three levels in B2. All other participant building's particle concentrations increased (see table 20).

Table 20. Sunday particle concentrations as a percentage of Friday concentrations 0.5μm.

Building One	**Level 1**	**Level 3**	**Level 5**
Friday floor level average	1697302	2230684	2715231
Sunday floor level average	2273653	3042598	3586530
%	**134%**	**136%**	**132%**
Building Two	**Level 3**	**Level 8**	**Level 10**
Friday floor level average	1807949	2403607	2136367
Sunday floor level average	1591953	945362	842826
%	**88%**	**39%**	**39%**
Building Three	**Level 6**	**Level 10**	**Level 15**
Friday Average	2251346	1956951	2028928
Sunday Average	2515320	2661514	2624263
%	**112%**	**136%**	**129%**
%[a]		**137%**	**132%**
Building Four	Level 1	Level 6	Level 11
Friday Average	942625	1228171	2451285
Sunday Average	1795925	2205501	2849706
%	**191%**	**180%**	**116%**

Note. [a]% with levels 10 and 15 unoccupied zones on the Friday removed.

5.10 0.3μm

5.10.1 Graph Analysis

Figure 32 shows particle concentrations were variable on Fridays and Sundays in all four participant buildings. Particle concentrations recorded on Sunday were higher than Friday in B1. Particle concentrations in B2, B3 and B4 overlapped with particle concentrations clearly higher on Sunday than Friday on L6 of B4 only.

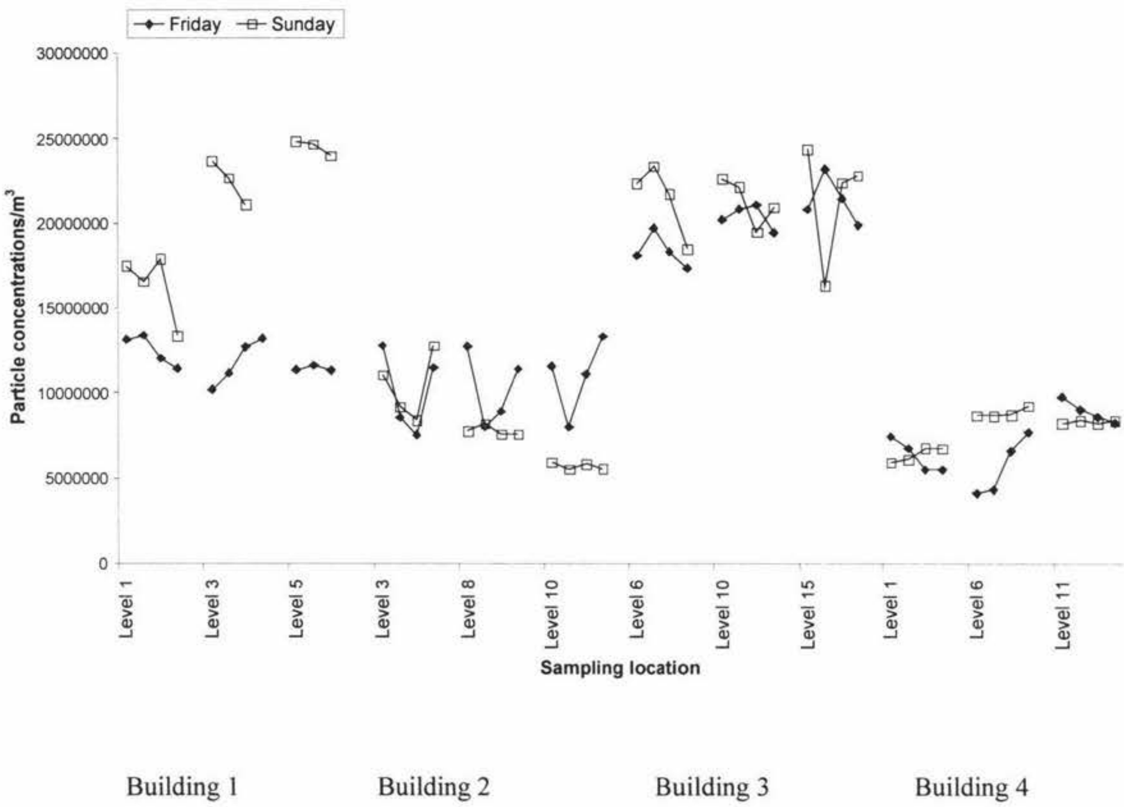


Figure 32. Particle concentrations of 0.3μm in participant buildings on Friday and Sunday.

5.10.2 Means and Confidence Intervals 0.3μm

Confidence intervals overlapped on L3, B2; all floor levels on B3; and L1 and L11 on B4 (see table 21).

Table 21. Means and confidence intervals of particle concentrations on Friday and Sunday for the size band of 0.3μm.

			Log scale				Original scale		
B	L	Day		Std.	95% CI			95% CI	
			Mean	Error	Lower	Upper	Mean	Lower	Upper
1	1	Friday	7.096	0.021	7.054	7.138	323551904	304964830	343152400
		Sunday	7.210	0.013	7.183	7.236	379369238	365524187	393684486
	3	Friday	7.053	0.024	7.004	7.101	304461208	284228454	325981098
		Sunday	7.349	0.016	7.318	7.380	459598393	440640542	479287179
	5	Friday	7.058	0.024	7.009	7.106	306580343	286220457	328234526
		Sunday	7.389	0.016	7.358	7.420	485013550	465112734	505677461
2	3[a]	Friday	6.994	0.021	**6.952**	**7.036**	279996103	263683202	297211736
		Sunday	7.009	0.013	**6.982**	**7.036**	286133935	275397890	297245200
	8	Friday	7.004	0.021	6.962	7.046	284181336	267648488	301627694
		Sunday	6.891	0.013	6.865	6.918	241573154	232357021	251116983
	10	Friday	7.034	0.021	6.992	7.076	296431249	279256429	314550946
		Sunday	6.757	0.013	6.730	6.783	198268204	190555942	206260259
3	6[a]	Friday	7.264	0.021	**7.222**	**7.306**	408927968	385966000	433112156
		Sunday	7.330	0.013	**7.304**	**7.357**	447964799	431881418	464585241
	10[a]	Friday	7.309	0.021	**7.267**	**7.351**	435169710	410881850	460742141
		Sunday	7.328	0.013	**7.301**	**7.354**	446237398	430209947	462800253
	15[a]	Friday	7.328	0.021	**7.286**	**7.370**	446656080	421790341	472833443
		Sunday	7.327	0.013	**7.300**	**7.354**	445789497	429776551	462337416
4	1[a]	Friday	6.796	0.021	**6.754**	**6.837**	210032853	197449004	223333954
		Sunday	6.805	0.013	**6.779**	**6.832**	213046983	204818171	221572151
	6	Friday	6.739	0.021	6.697	6.781	193226115	181554957	205568232
		Sunday	6.946	0.013	6.920	6.973	261563572	251662452	271813908
	11[a]	Friday	6.926	0.030	**6.867**	**6.985**	254040249	233145072	276605997
		Sunday	6.919	0.019	**6.882**	**6.957**	251600564	238176826	265701416

Note. CI = confidence interval. [a]Confidence intervals overlap.

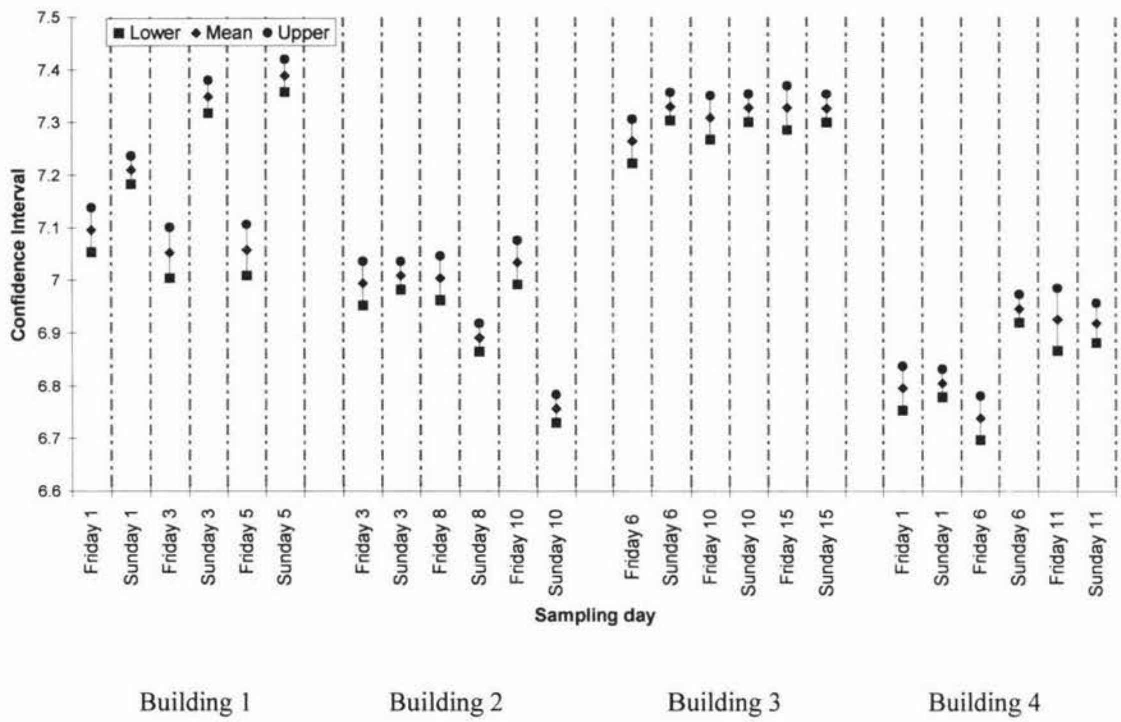


Figure 33. Confidence intervals for Friday and Sunday for the particle size 0.3μm.

5.10.3 Sunday concentrations as a percentage of Friday concentrations 0.3μm .

Particle concentrations on Sunday as a percentage of Friday's particle concentrations increased for B1; B3; and L1 and L6 of B4. In B2, there was a decrease in particle concentrations on L8 and L10 and concentrations on Level 3 were relatively stable between Friday and Sunday (see table 22).

Table 22. Sunday particle concentrations as a percentage of Friday concentrations 0.3μm.

Building One	Level 1	Level 3	Level 5
Friday floor level average	12498851	11805267	11420007
Sunday floor level average	16346587	22468021	24486145
%	**131%**	**190%**	**214%**
Building Two	Level 3	Level 8	Level 10
Friday floor level average	10088234	10272789	10998624
Sunday floor level average	10353306	7791935	5712351
%	**103%**	**86%**	**22%**
Building Three	Level 6	Level 10	Level 15
Friday Average	18379361	20386900	21324831
Sunday Average	21479280	21294346	21465395
%	**117%**	**104%**	**101%**
%[a]		**111%**	**116%**
Building Four	Level 1	Level 6	Level 11
Friday Average	6305349	5689102	8916919
Sunday Average	6398633	8843532	8312396
%	**101%**	**155%**	**93%**

Note: [a]% decrease with levels 10 and 15 unoccupied zones on the Friday removed.

5.11 Environmental parameters

5.11.1 Carbon Dioxide

Carbon dioxide measurements were taken at midday. ASHRAE Standard 62-1989 Ventilation for Acceptable Indoor Air Quality states that CO_2 concentrations should be below 1000 parts per million (ppm). B2, B3, and B4 had concentrations from 500-800ppm. These are typical levels expected in office buildings. CO_2 concentrations in B1, L5 were the highest recorded for the Friday with all zones exceeding the highest guideline levels for office buildings of 800ppm (see table 23).

Table 23. Carbon dioxide concentrations measured in participant buildings

Building		1			2	
Floor Level	**1**	**3**	**5**	**3**	**8**	**10**
Friday						
Zone 1	730	600	843	802	783	737
Zone 2	800	586	1055	782	738	725
Zone 3	832	556	1055	664	687	757
Zone 4	794	585	921	678	730	708
Average	**789**	**582**	**969**	**732**	**735**	**732**
Sunday						
Zone 1	511	-	493	599	547	479
Zone 2	540	-	520	611	500	510
Zone 3	519	-	499	614	507	531
Zone 4	563	-	564	683	523	497
Average	**533**	-	**519**	**627**	**519**	**504**
Average Reduction	**256**	-	**450**	**105**	**216**	**228**

Building		3			4	
Floor Level	**6**	**10**	**15**	**1**	**6**	**11**
Friday						
Zone 1	516	538	480	525	510	564
Zone 2	538	564	515	608	560	618
Zone 3	502	555	523	598	619	688
Zone 4	593	525	486	522	687	622
Average	**537**	**546**	**501**	**563**	**594**	**623**
Sunday						
Zone 1	466	459	448	521	402	-
Zone 2	437	472	456	465	427	-
Zone 3	507	492	485	487	426	402
Zone 4	472	475	478	479	433	417
Average	**471**	**475**	**467**	**488**	**422**	**410**
Average Reduction	66	71	34	75	172	213

5.11.2 Temperature and Relative Humidity

All buildings met the ASHRAE Standard 55-1992 Thermal Environmental Conditions for Human Occupancy of 20-60% RH. However not all buildings met the ASHRAE standard for temperature between 23^{o} to 25^{o} on the days of sampling (see table 24). Compliance with the standards ensures that thermal conditions are comfortable for 80% of the occupants in the office environment.

Table 24. Temperature and relative humidity levels measured in participant buildings.

Building			**1**			
Level	**1**		**3**		**5**	
	T	**RH**	**T**	**RH**	**T**	**RH**
Friday						
Zone 1	23.9	48.1	23.3	49.0	22.3	47.6
Zone 2	19.8	59.7	22.9	49.1	23.4	48.9
Zone 3	22.6	51.8	22.6	48.9	22.9	49.7
Zone 4	22.8	49.9	23.6	46.6	22.4	48.9
Average	**22.3**	**52.4**	**23.1**	**48.4**	**22.8**	**48.8**
Sunday						
Zone 1	18.4	48.2	-	-	19.7	48.5
Zone 2	18.3	47.9	-	-	21.0	43.1
Zone 3	18.0	48.8	-	-	21.0	42.9
Zone 4	18.5	47.7	-	-	20.4	44.8
Average	**18.3**	**48.2**	**-**	**-**	**20.5**	**44.8**
Average Reduction	**4**	**4.2**				

Building			**2**			
Level	**3**		**8**		**10**	
	T	**RH**	**T**	**RH**	**T**	**RH**
Friday						
Zone 1	22.3	40.0	23.1	38.4	22.2	39.0
Zone 2	22.6	40.3	22.7	38.6	22.3	39.4
Zone 3	22.7	39.7	22.3	38.5	22.7	38.2
Zone 4	22.7	38.6	22.1	39.6	22.8	38.4
Average	**22.6**	**39.7**	**22.6**	**38.8**	**22.5**	**38.8**
Sunday						
Zone 1	19.2	48.9	21.8	37.1	18.7	48.0
Zone 2	19.8	42.3	21.6	37.3	20.3	41.4
Zone 3	20.6	40.2	21.4	37.6	20.9	40.2
Zone 4	21.0	39.3	21.3	38.0	21.8	38.4
Average	**20.2**	**42.7**	**21.5**	**37.5**	**20.4**	**42.0**

Building			**3**			
Level	**6**		**10**		**15**	
	T	**RH**	**T**	**RH**	**T**	**RH**
Friday						
Zone 1	21.2	37.9	22.3	34.6	22.1	35.7
Zone 2	22.1	35.8	21.9	35.6	22.7	35.4
Zone 3	23.0	33.8	22.1	35.2	22.7	34.2
Zone 4	22.7	33.7	22.4	34.5	22.3	36.0
Average	**22.3**	**35.3**	**22.2**	**35.0**	**22.5**	**35.3**
Sunday						
Zone 1	22.8	34.8	21.6	37.3	18.7	43.5
Zone 2	23.7	33.5	22.1	36.7	18.9	42.5
Zone 3	22.1	37.1	22.7	35.3	19.8	41.9
Zone 4	20.8	35.6	21.3	38.1	21.5	38.8
Average	**22.4**	**35.3**	**21.9**	**36.9**	**19.7**	**41.7**

Building			**4**			
Level	**1**		**6**		**11**	
	T	**RH**	**T**	**RH**	**T**	**RH**
Friday						
Zone 1	22.4	48.8	21.8	49.5	21.3	52.4
Zone 2	22.8	48.5	22.2	48.8	21.9	49.9
Zone 3	23.1	46.6	22.2	49.3	22.1	49.5
Zone 4	22.9	47.0	22.3	49.0	21.8	49.4
Average	**22.8**	**47.7**	**22.1**	**49.2**	**21.8**	**50.3**
Sunday						
Zone 1	-	-	17.6	53.5	19.7	46.6
Zone 2	-	-	19.7	48.8	19.1	48.6
Zone 3	20.4	42.9	20.7	44.9	18.8	49.2
Zone 4	21.2	41.7	20.7	44.2	19.1	49.2
Average	**20.8**	**42.3**	**19.7**	**47.9**	**19.2**	**48.4**

5.12 Part 3 – Heating, Ventilating, and Air Conditioning Pathway

5.12.1 Introduction

The concentrations of particles are measured as they travel from exterior source locations such as roads and footpaths to the outdoor air intakes on each participant building through the filters and to the indoor space via the ductwork.

5.12.2 Exterior Source Locations: Vehicle and Pedestrian Traffic

To ascertain the contribution of outdoor sources to indoor particle concentrations measurements were made of vehicle and pedestrian foot traffic. Figure 34 shows the proximity of buildings to various intersections and summarises the five-day average traffic counts of vehicles passing through these intersections. The scats count system for assessing traffic numbers positively discriminates against bicycles however is unable to distinguish heavy vehicles from cars. All four participant buildings are located within close proximity to several major intersections in the central business district. Traffic concentrations ranged from a relatively low average of 7,304 vehicles on a week day at a minor intersection to 22,456 vehicles at a major intersection.

Table 25 summarises pedestrian traffic concentrations and shows that B3 has the highest number of pedestrian traffic of all four participant buildings. B1 has the sixth highest ranking for pedestrian traffic for those sites monitored. B2 and B4 had pedestrian counts below 500.

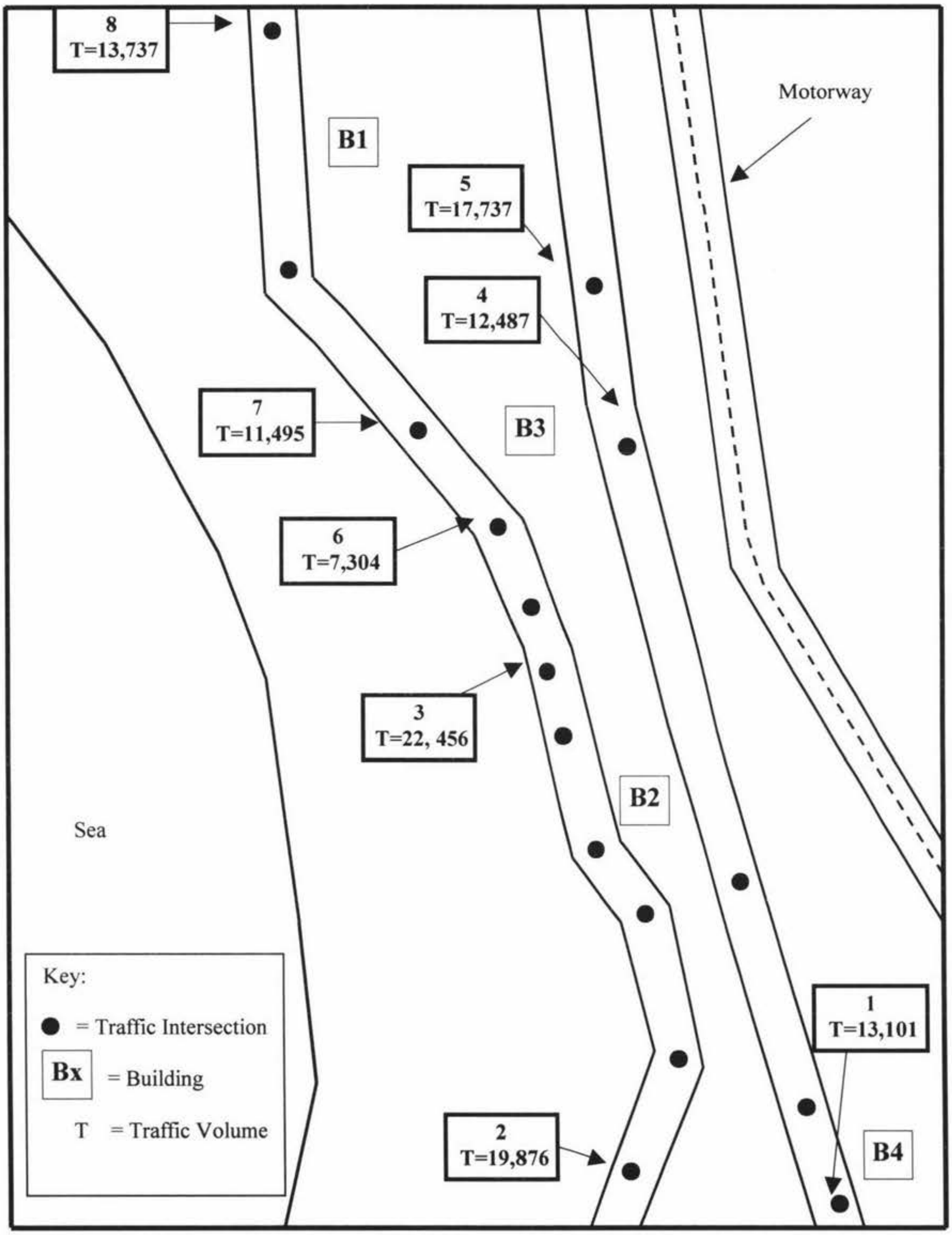


Figure 34. Proximity of participant buildings to the motorway, the sea, and major intersections including a summary of the average daily traffic volumes at these intersections August 1999 (not to scale).

Table 25. Summary of pedestrian traffic outside participant buildings October 1999

	am	midday	pm	total	rank/61
Building 1	339	1029	515	**1883**	**7**
Building 2	43	360	54	**457**	**42**
Building 3	471	1508	611	**2590**	**1**
Building 4	26	240	63	**329**	**54**

5.12.3 Comparison of Exterior Location Sampling Points between Friday and Sunday

In general, particle concentrations measured outside at locations such as the footpath, loading docks and entrances, were higher on Friday than Sunday due to activity levels in the CBD.

For the **5μm** size range all exterior sampling points recorded higher concentrations on Friday than Sunday except for the back entrance areas of B1 and the primary and minor footpath and car park of B4 (see figures 35 and 36).

For the **3μm** range all exterior sampling points recorded higher concentrations on Friday than Sunday except for the back entrance, footpath and loading dock, the primary footpath for B3, and the primary and minor footpath and car park of B4 (see figures 37 and 38).

For the **1μm** range all exterior sampling points recorded higher concentrations on Friday than Sunday for B1 and B2 except at the secondary entrance of B1. However for B3 and B4 all exterior sampling points recorded higher concentrations on Sunday than Friday (see figures 39 and 40).

For the **0.5μm** range all exterior sampling points recorded higher concentrations on Friday than Sunday for B1 and B2 except for the secondary footpath and carpark of B1. For B3 exceptions were the primary footpath, and secondary footpath and alleyway, and for B4 the only exception was the loading dock (see figures 41 and 42).

For the **0.3μm** range all exterior sampling points recorded higher concentrations on Sunday than Friday for B1 except for the lifts. For the remaining building all concentrations were higher on Friday than Sunday except at the alleyway of B3 and the primary entrance of B4 (see figures 43 and 44).

5.12.4 Outdoor Air Intake Sampling Point

The outdoor air intake and filtration component of the HVAC system was positioned on the top level of the building for B1, B3, and B4, and halfway up the building structure for B2.

Figures 35 and 37 show particle concentrations were lower for the 5μm and 3μm size band at the outdoor air intake when compared with particle concentrations measured at street level and at the major and minor entrance points of all four participant buildings on Friday. At the outdoor air intake B3 recorded a higher concentration than the other two buildings but particle concentrations all were below 20,000 once they had passed through the filter media (after filters sampling location). When comparing the after filters concentrations with the concentrations at 1.8m under the diffuser on the floor levels there is a large increase in particle concentrations possibly due to occupant activity in addition to the possibility of the ductwork contributing to concentrations.

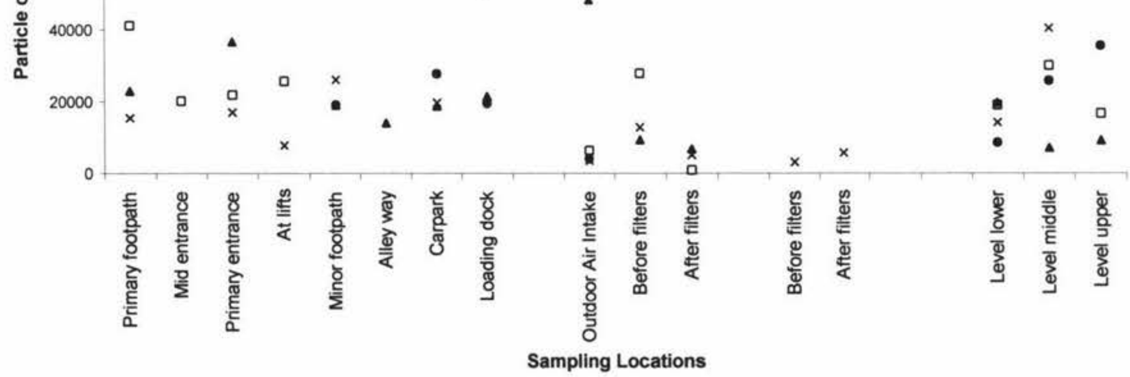
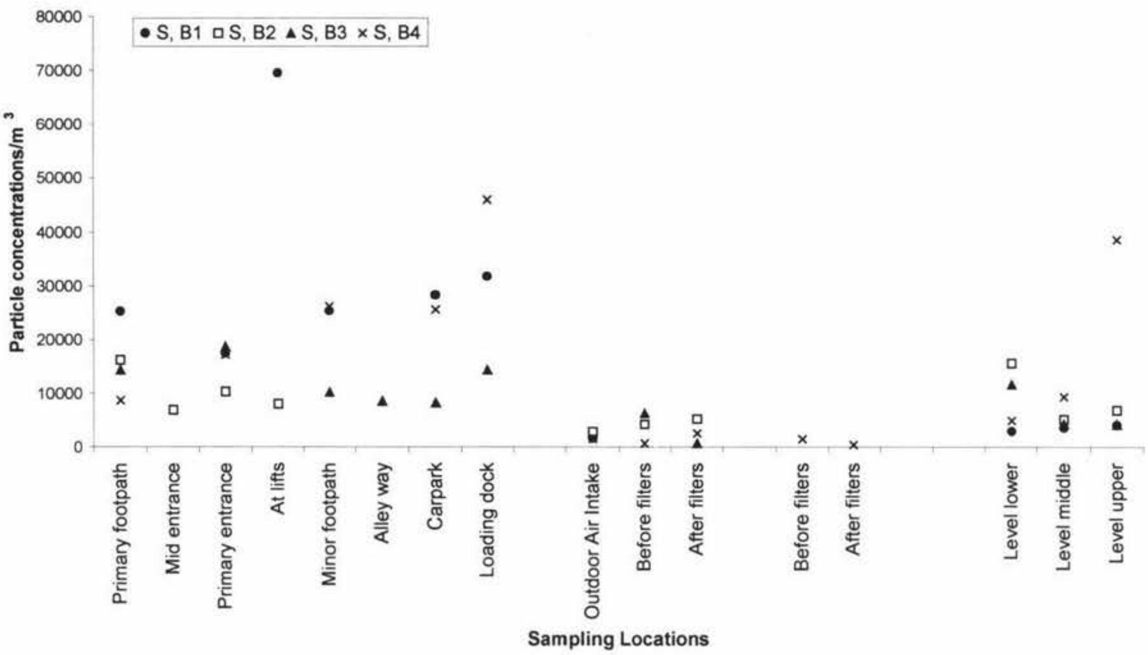


Figure 35. Particle concentrations of 5μm on Friday for all participant buildings.



<u>Figure 36.</u> Particle concentrations of 5μm on Sunday for all participant buildings.

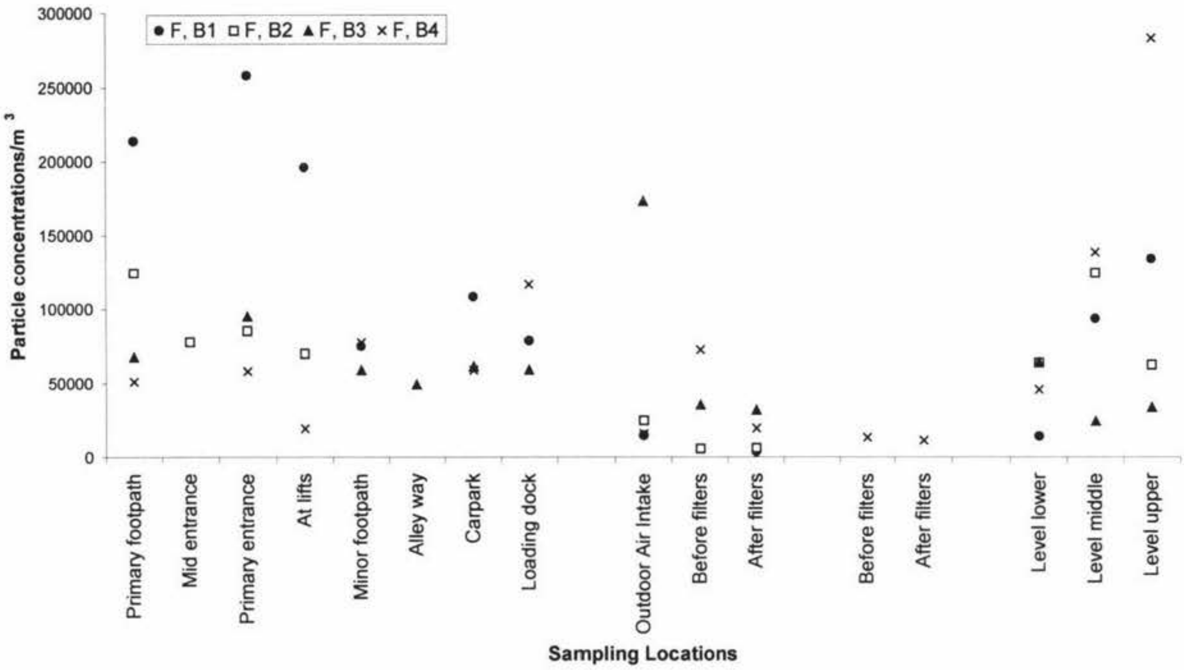


Figure 37. Particle concentrations of 3μm on Friday for all participant buildings.

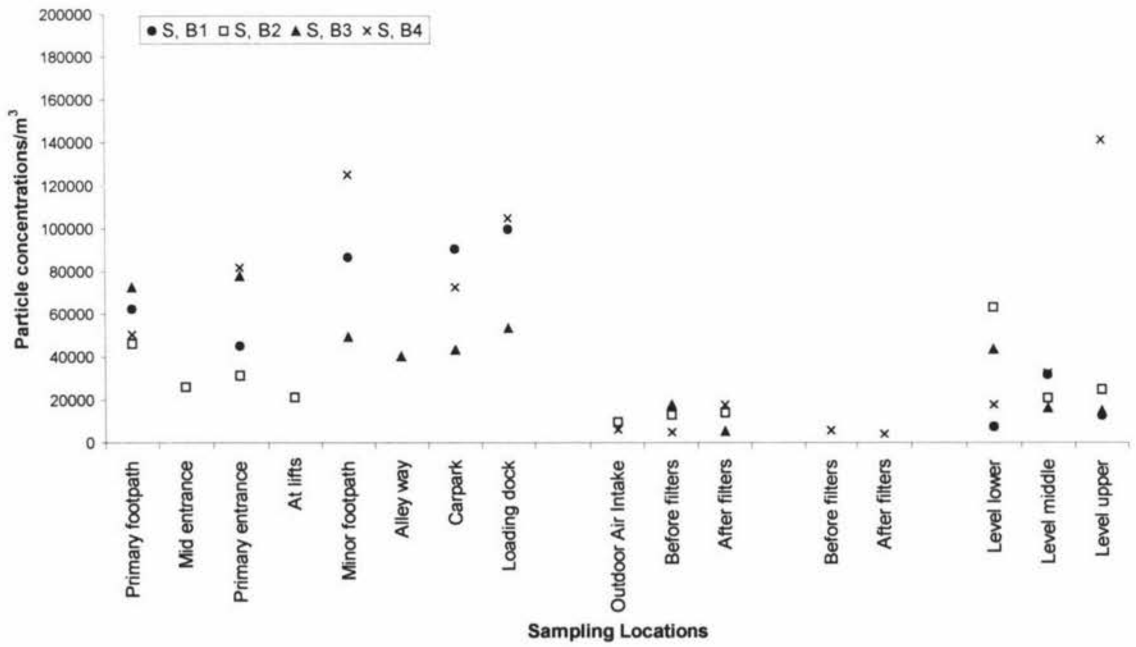


Figure 38. Particle concentrations of 3μm on Sunday for all participant buildings.

Figure 39 shows particle concentrations for B3 at the outdoor air intake are higher than at all exterior location points for 1μm particles. Particle concentrations at the outdoor air intake are much lower than at the exterior sampling points for B1, B2, and B4. Particle concentrations after filters were all lower than at the outdoor air intake. There is a rise in particle concentrations when comparing the after filters concentrations with the concentrations at 1.8m under the diffuser on the floor levels.

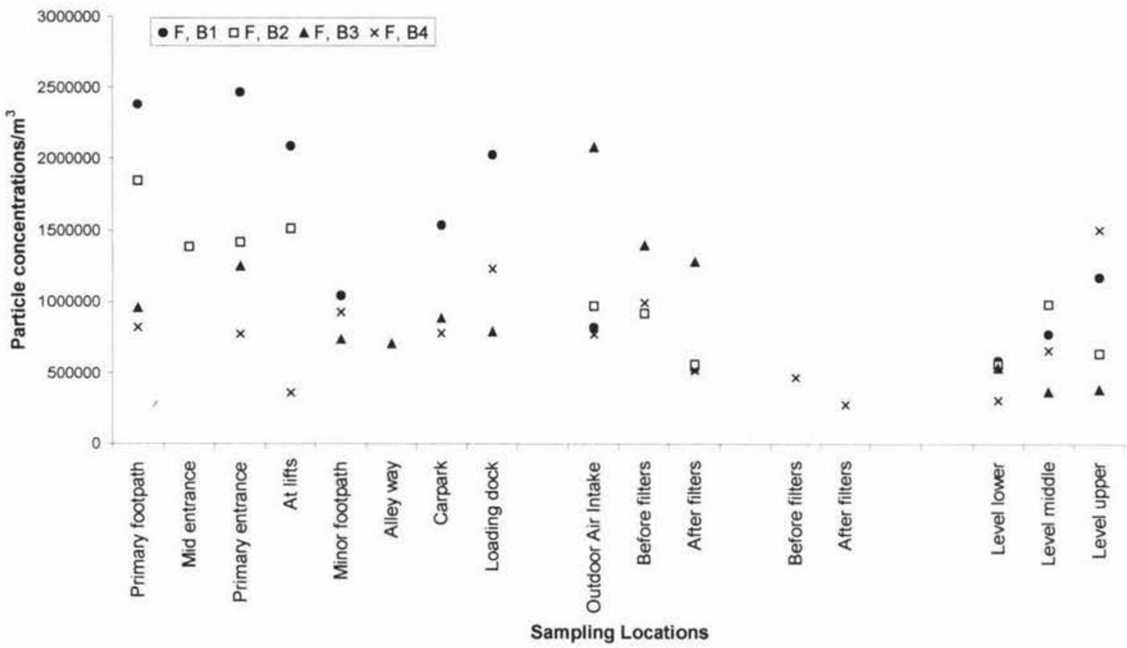


Figure 39. Particle concentrations of 1μm on Friday for all participant buildings.

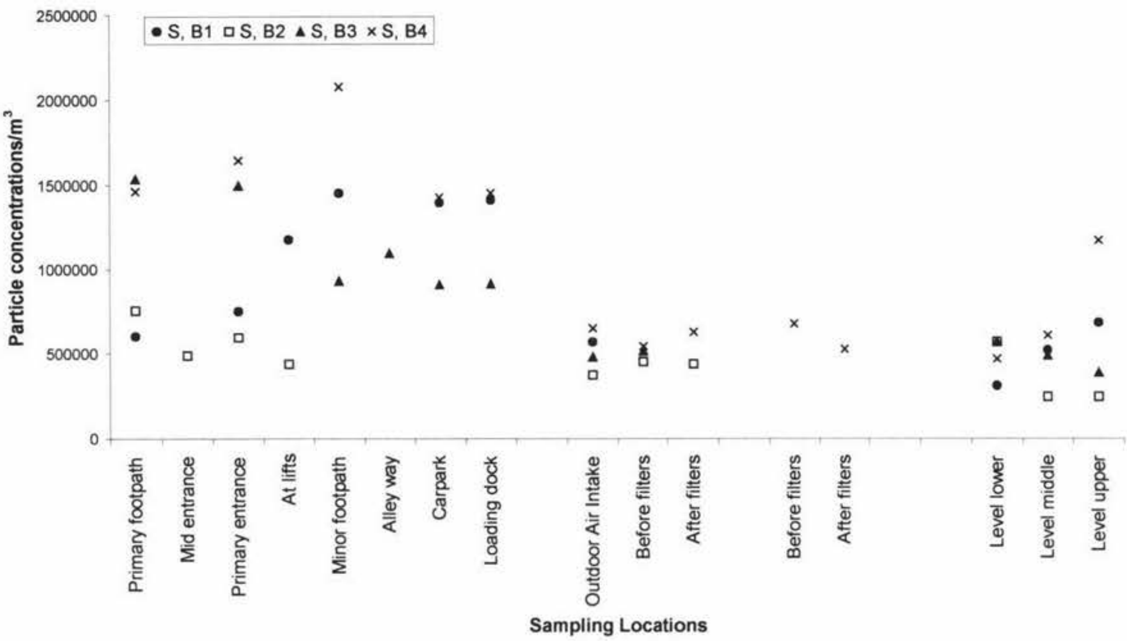


Figure 40. Particle concentrations of 1μm on Sunday for all participant buildings.

Figure 41 shows particle concentrations for B3 at the outdoor air intake are higher than at all exterior location points for 0.5μm particles. Particle concentrations at the outdoor air intake are much lower than at the exterior sampling points for B1, and B2. Particle concentrations are in the majority at similar concentrations at the exterior sampling points and at the outdoor air intake for B4. Particle concentrations after filters were all lower than at the outdoor air intake. Particle concentrations when comparing the after filters concentrations with the concentrations at 1.8m under the diffuser on the floor levels were all lower except for B3.

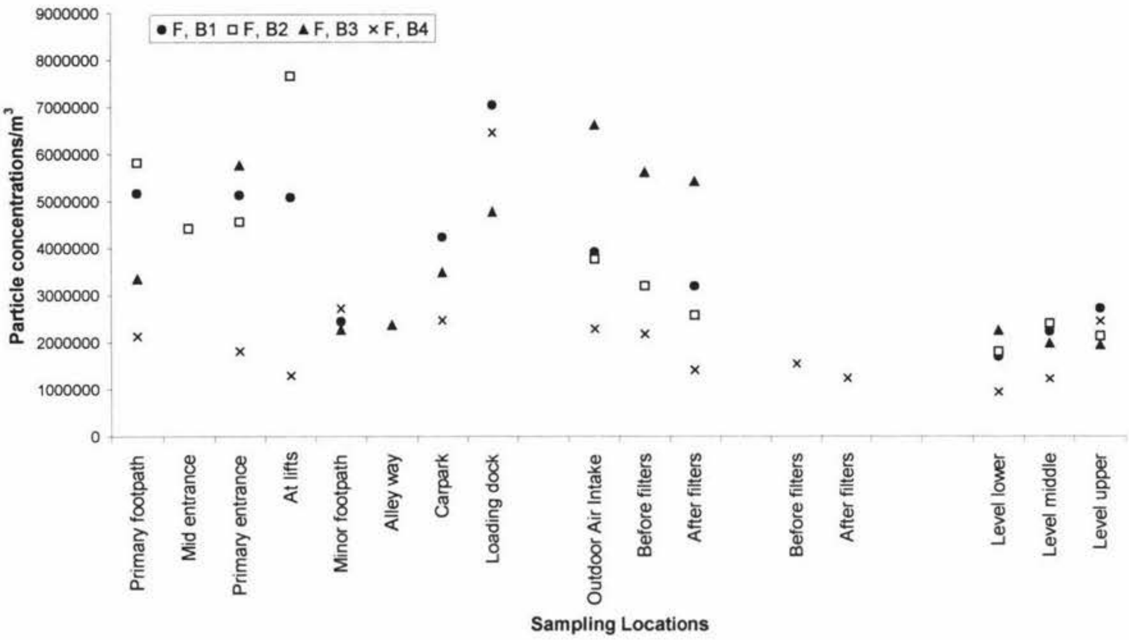


Figure 41. Particle concentrations of 0.5μm on Friday for all participant buildings.

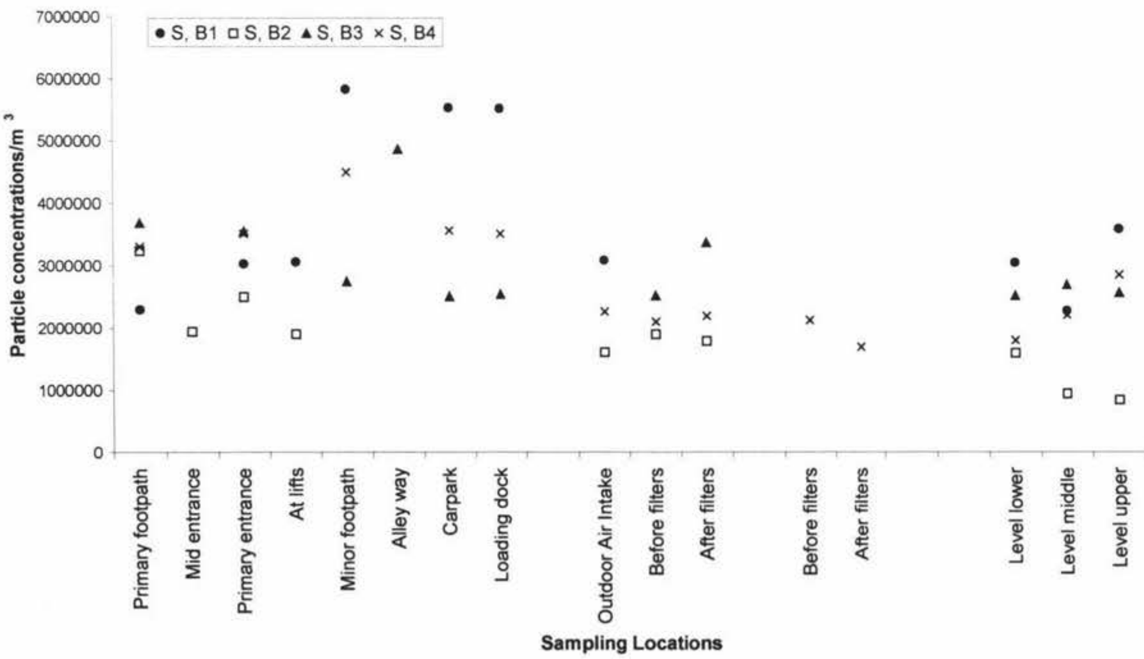


Figure 42. Particle concentrations of 0.5μm on Sunday for all participant buildings.

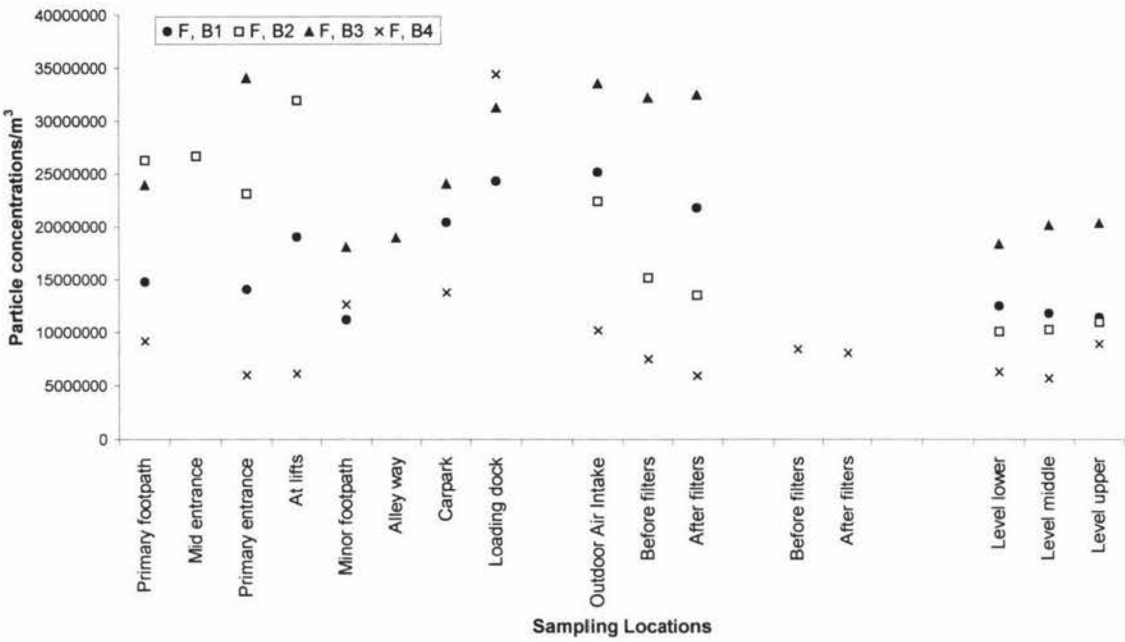


Figure 43. Particle concentrations of 0.3μm on Friday for all participant buildings.

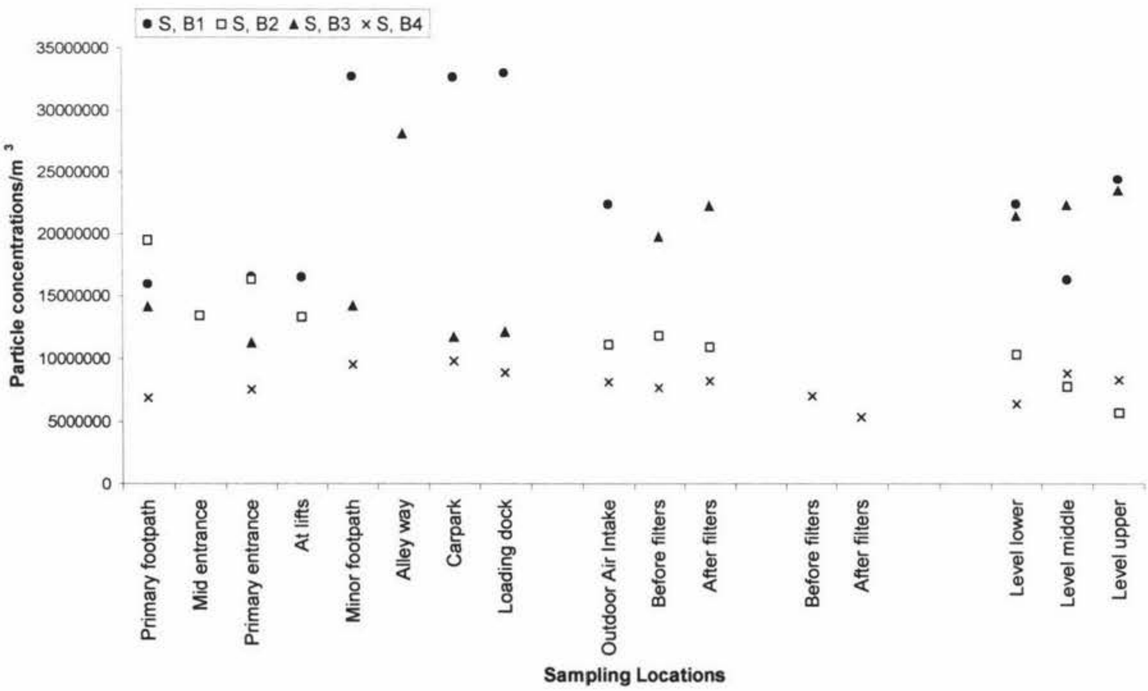


Figure 44. Particle concentrations of 0.3μm on Sunday for all participant buildings.

5.12.5 Building One - Filters

Information regarding filters for building one was limited. Building one has a stainless steel framed washable panel filter, with a medium filtration class. Access to before the filter was not possible as this required removal of a screwed panel. The filters removed a portion of the particles at the outdoor air intake.

Table 26. Particle concentrations measured in the Heating Ventilating and Air Conditioning Pathway on Friday and Sunday in B1.

	Outdoor Air Intake	Before filters	After filters	Level 1 average	Level 3 average	Level 5 average
5μm						
Friday	4061	inaccessible	777	8596	25839	35609
Sunday	16245	-	-	2937	3579	4081
3μm						
Friday	14938	inaccessible	3779	14016	93210	133901
Sunday	9358			7643	31827	12800
1μm						
Friday	820113	inaccessible	533004	586404	772302	1169665
Sunday	567542			307770	517943	681942
0.5μm						
Friday	3917562	inaccessible	3191493	1697302	2230684	2715231
Sunday	3085407			3042598	2273653	3586530
0.3μm						
Friday	25137582	inaccessible	21779405	12498851	11805267	11420007
Sunday	22423156			22468021	16346587	24486145

5.12.6 Building Two - Filters

The filter type is a stainless steel framed panel filter with synthetic media P15/500. The filtration class is medium and the filter is washable, cleaned every three months, with replacement due December 2001. The filters were last washed on the 18th June. The filters measure 400x625x50.

Table 27. Particle concentrations measured in the Heating Ventilating and Air Conditioning Pathway on Friday and Sunday in B2.

	Outdoor Air Intake	Before filters	After filters	Level 1 average	Level 3 average	Level 5 average
5μm						
Friday	6498	27934	954	19149	30056	16774
Sunday	2896	4238	5262	15594	5218	6889
3μm						
Friday	25003	5923	6321	63778	124281	62342
Sunday	9923	13152	14232	63269	20962	24938
1μm						
Friday	971083	918994	560974	563075	982840	637954
Sunday	371404	452063	437761	569555	244531	244948
0.5μm						
Friday	3769876	3199968	2576170	1807949	2403607	2136367
Sunday	1607630	1895868	1788229	1591953	945362	842826
0.3μm						
Friday	22422096	15150453	13517255	10088234	10272789	10998624
Sunday	11133691	11838572	10937624	10353306	7791935	5712351

5.12.7 Building Three - Filters

The filtration type is a stainless steel framed four pocket filter with media SCF Eu3 Synthetic and a filtration class of medium. The filter media is washable with a measurement of 592x592x635.

Table 28. Particle concentrations measured in the Heating Ventilating and Air Conditioning Pathway on Friday and Sunday in B3.

	Outdoor Air Intake	Before filters	After filters	Level 1 average	Level 3 average	Level 5 average
5μm						
Friday	48452	9429	6922	19735	7198	9306
Sunday	-	6286	706	11613	4273	4220
3μm						
Friday	173183	35421	32030	63943	24397	33696
Sunday	-	17799	5509	43625	16374	15009
1μm						
Friday	2076891	1395071	1280298	536462	371022	384565
Sunday	-	479326	514146	567583	487884	386543
0.5μm						
Friday	6610730	5600483	5408760	2251346	1978822	1944326
Sunday	-	2518501	3367889	2515320	2692914	2564516
0.3μm						
Friday	33536329	32203094	32467813	18379361	20137573	20338772
Sunday	-	19781724	22264473	21479280	22384651	23583254

5.12.8 Building Four - Filters

Building four employs the use of a pre-filter and a final filter. The pre-filter measures 500x500x450 and has a medium filtration class. This filter is washable and the media type is PSB/290. The final filter is a stainless steel framed four pocket filter with a high filtration class. The filter is disposable and the media type PA/300. The measurement is 600x600x450.

Table 29. Particle concentrations measured in the Heating Ventilating and Air Conditioning Pathway on Friday and Sunday in B4.

	Outdoor Air Intake	Before filters	After filters	Level 1 average	Level 3 average	Level 5 average
5μm						
Friday	3496	12890	5085	14249	40474	74405
Friday		3108	5756			
Sunday	1554	671	2543	4958	9347	38581
Sunday		1483	424			
3μm						
Friday	16103	72324	19635	45553	138230	283082
Friday		13455	11548			
Sunday	6392	5050	17799	17840	32481	141665
Sunday		5933	4273			
1μm						
Friday	772261	993649	518172	308294	658471	1502283
Friday		467919	277361			
Sunday	649154	542045	627294	467122	607586	1170546
Sunday		676558	525941			
0.5μm						
Friday	2287826	2180575	1416295	942625	1228171	2451285
Friday		1546218	1242299			
Sunday	2262929	2097833	2190569	1795925	2205501	2849706
Sunday		2122235	1691996			
0.3μm						
Friday	10192661	7482225	5932158	6305349	5689102	8916919
Friday		8422867	8079537			
Sunday	8153910.1	7677621	8221856	6398633	8843532	8312396
Sunday		7025889	5360979			

Comparison of particle levels before and after the filters was graphed to show filter effectiveness at removing particles within each size band. Table 30 shows that particle concentrations reduced for all size bands in all buildings except for B4, 5μm, B2, 3μm, and B5, 0.3μm. This may be due to the physical disturbance caused by the researcher when opening the access door and placing the probe inside.

Table 30. After filter particle concentrations as a percentage of before filter particle concentrations for all four participant buildings.

Building	After filter particle concentration as a % of before filter concentration				
	5μm	3μm	1μm	0.5μm	0.3μm
1	19%	25%	65%	81%	87%
2	3%	107%	61%	81%	89%
3	73%	90%	92%	97%	101%
4a	39%	27%	52%	65%	79%
4b	185%	86%	59%	80%	96%

The overall trend of particle concentrations shows that standard filters installed in all four participant buildings filter a higher proportion of the large particle of 5μm and 3μm and this proportion decreases as the size particle decreases from 1μm and below (see figure 45).

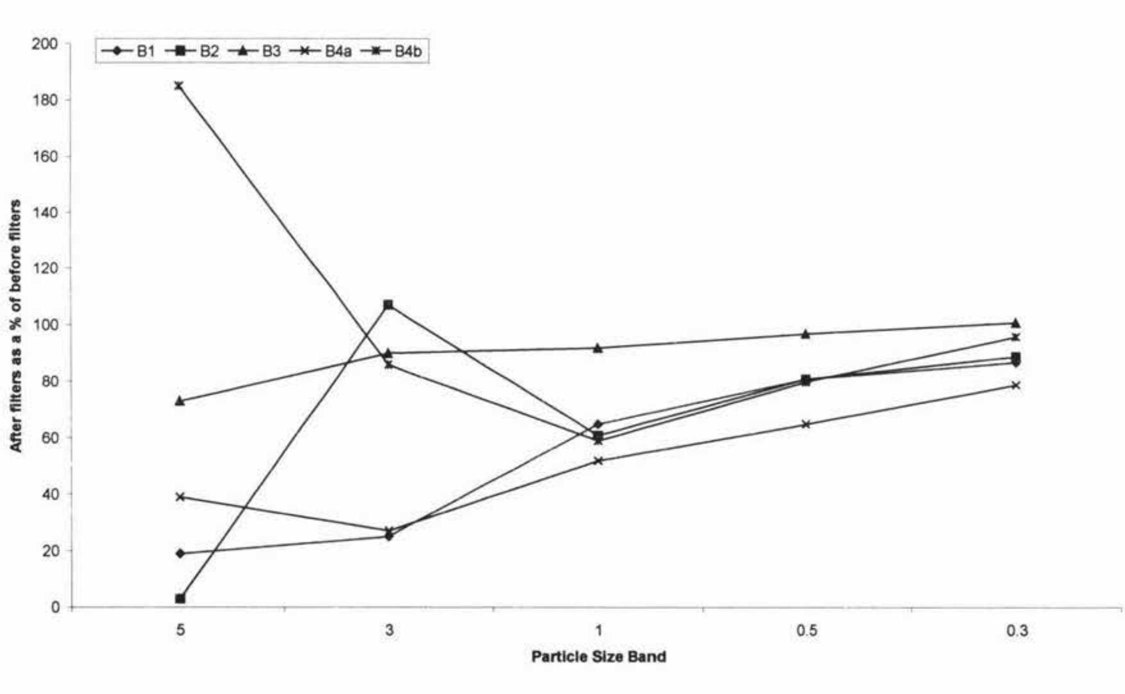


Figure 45. After filter concentrations as a percentage of before filter concentrations.

5.13 Part 4: Stack Effect

5.13.1 Floor Levels, lobbies and stairwells

The stack effect pathway for all four participant buildings is graphed to assess if the presence of pressure differentials between the lowest floor, middle floor and highest upper floor sampled affect particle concentrations on the floor levels, at the lobbies and in the stairwells.

For the **5μm** size range, particle concentrations in B1 and B4 all increased in accordance with an increase in floor level, lobby, and decreased by stairwell. For B2 concentrations decreased in the lobbies, and were lower at the lower and higher levels and stairs than in the middle. For B2 concentrations increased in the stairwells, and were higher at the lower and higher levels and lobbies than in the middle (see figures 46 and 47).

For the **3μm** size range particle concentrations for B1, B2, and B3 followed the same pattern as reported in the 5μm range. In B4 there was an increase in floor levels, increase the lower and middle lobbies then slight decrease on the higher lobby, and a higher low high for stairwells (see figures 48 and 49).

For the 1**μm** size range particle concentrations in B4 increased by floor level, lobby, and stairwell. In B1 particle concentrations increased by floor levels and lobby, but decreased by stairwell. In B2 and B3 particle concentrations were variable by floor level, lobby, and stairwell (see figures 50 and 51).

For the 0.5**μm** size range particle concentrations in B1 increased by floor level, lobby, and decreased by stairwell. Particle concentrations in B4 increased by floor level, lobby, and were variable by stairwell. In B2 and B3 particle concentrations were variable by floor level, lobby, and stairwell (see figures 52 and 53).

For the 0.3**μm** size range particle concentrations in B1 decreased in accordance with an increase in floor level, lobby, and decrease by stairwell. In B2, B3 and B4 particle concentrations were variable by floor level, lobby, and stairwell (see figures 54 and 55).

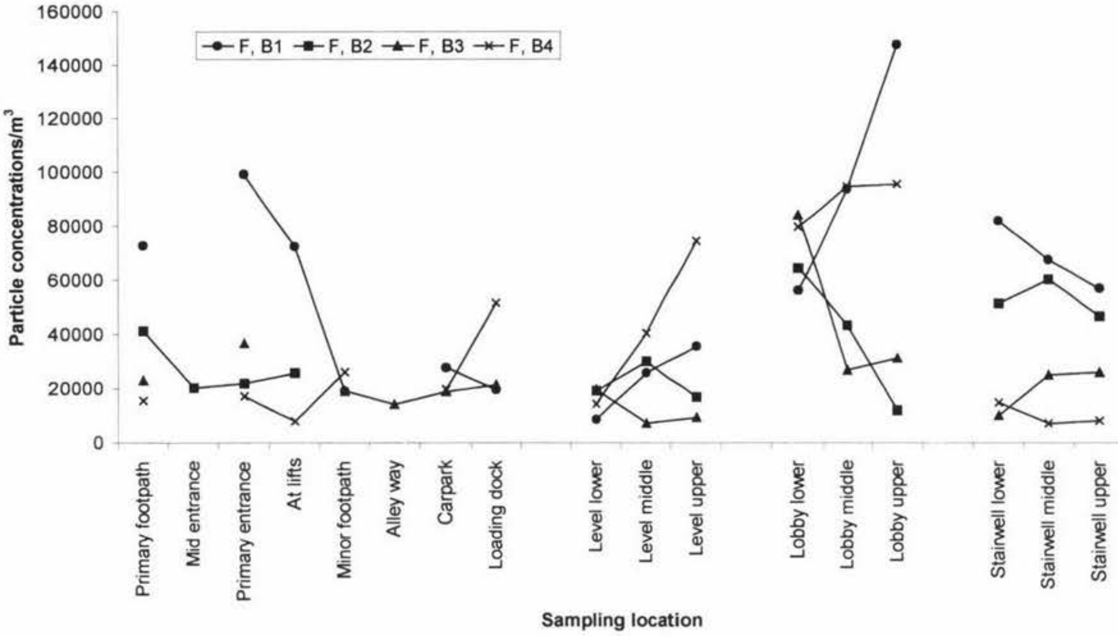


Figure 46. Particle concentrations of 5μm measured at exterior and interior locations in the four participant buildings on Friday.

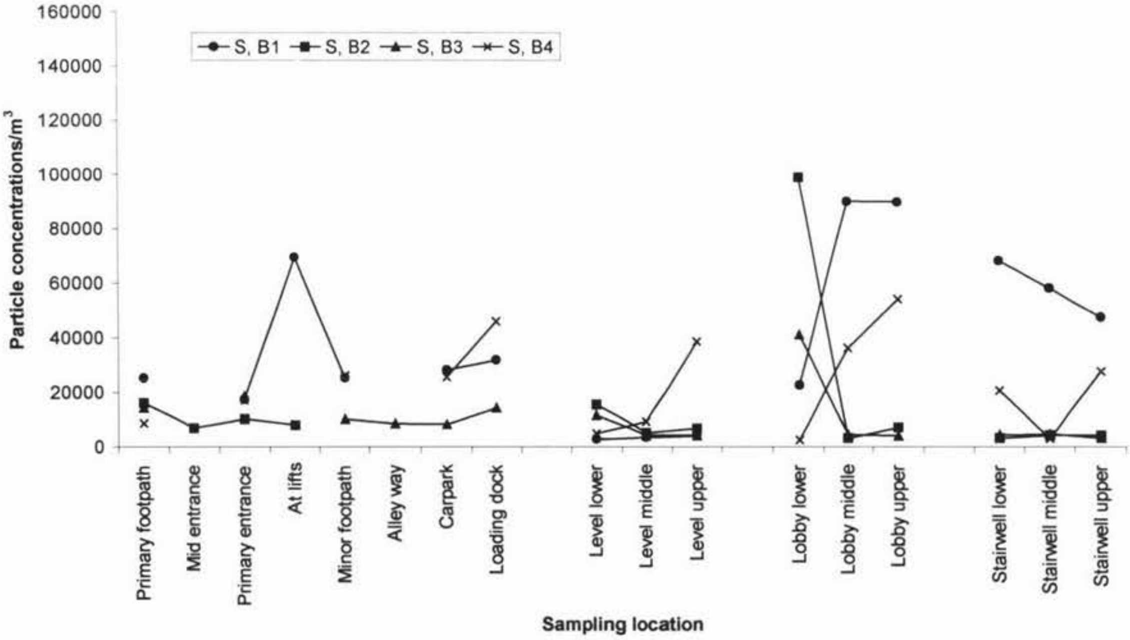


Figure 47. Particle concentrations of 5μm measured at exterior and interior locations in the four participant buildings on Sunday.

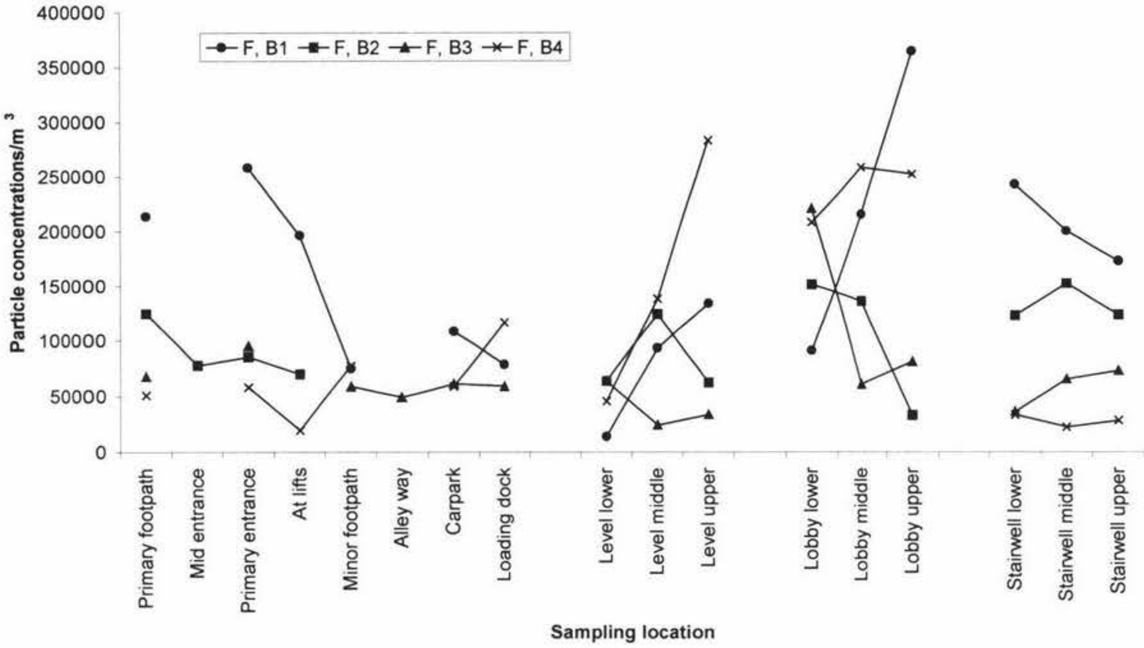


Figure 48. Particle concentrations of 3μm measured at exterior and interior locations in the four participant buildings on Friday.

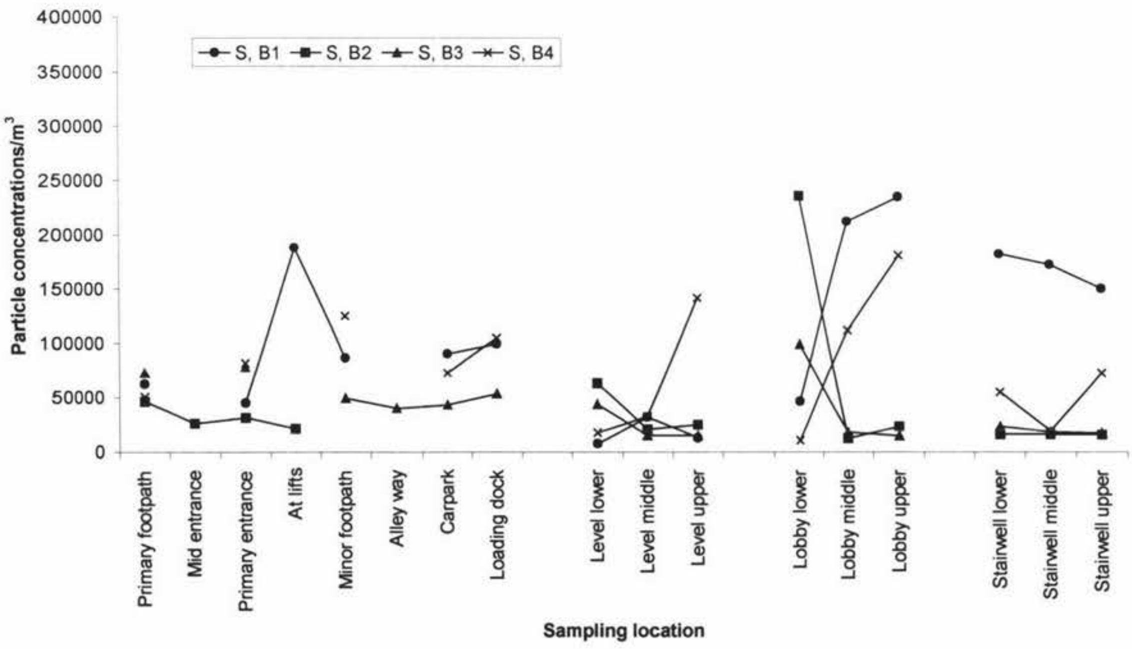


Figure 49. Particle concentrations of 3μm measured at exterior and interior locations in the four participant buildings on Sunday.

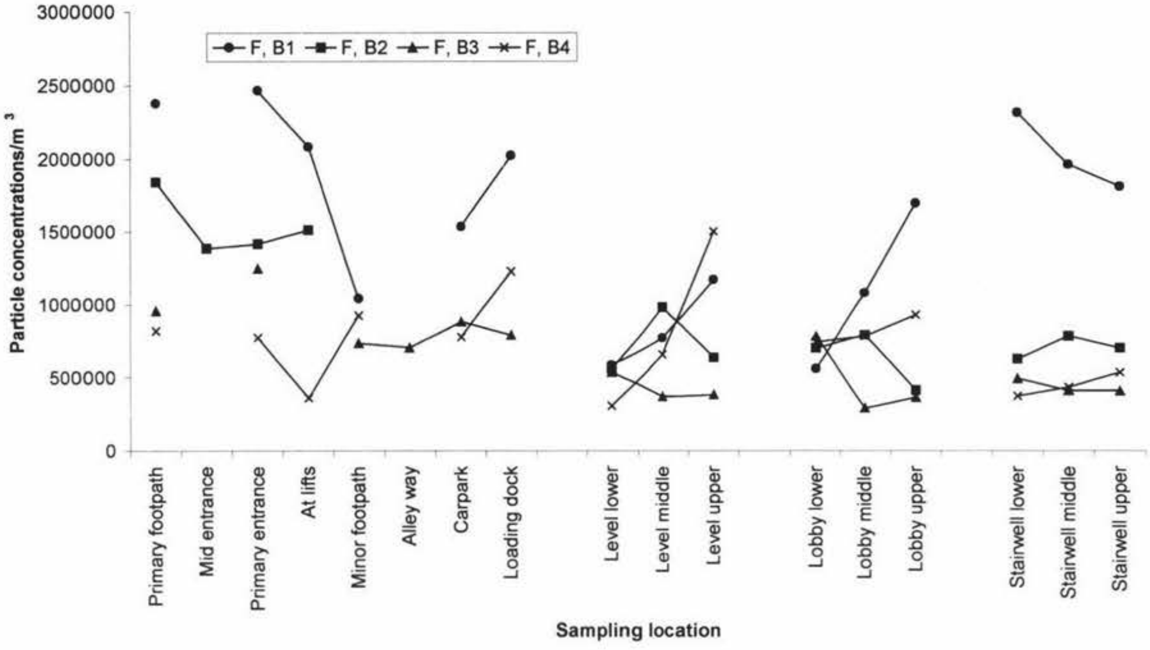


Figure 50. Particle concentrations of 1μm measured at exterior and interior locations in the four participant buildings on Friday.

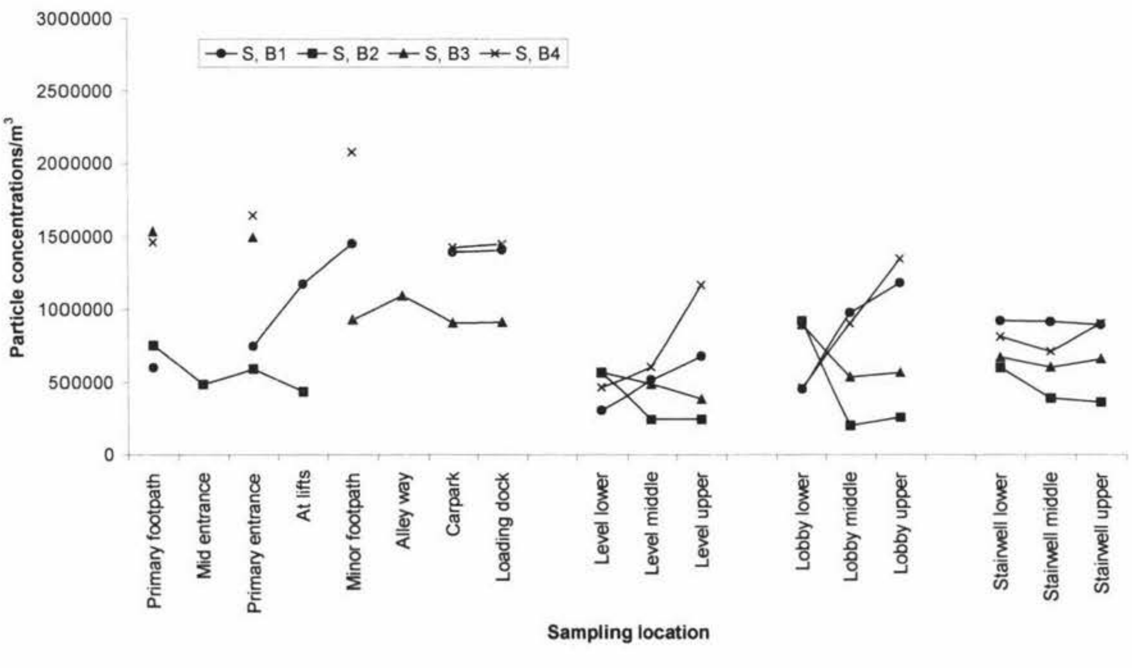


Figure 51. Particle concentrations of 1μm measured at exterior and interior locations in the four participant buildings on Sunday.

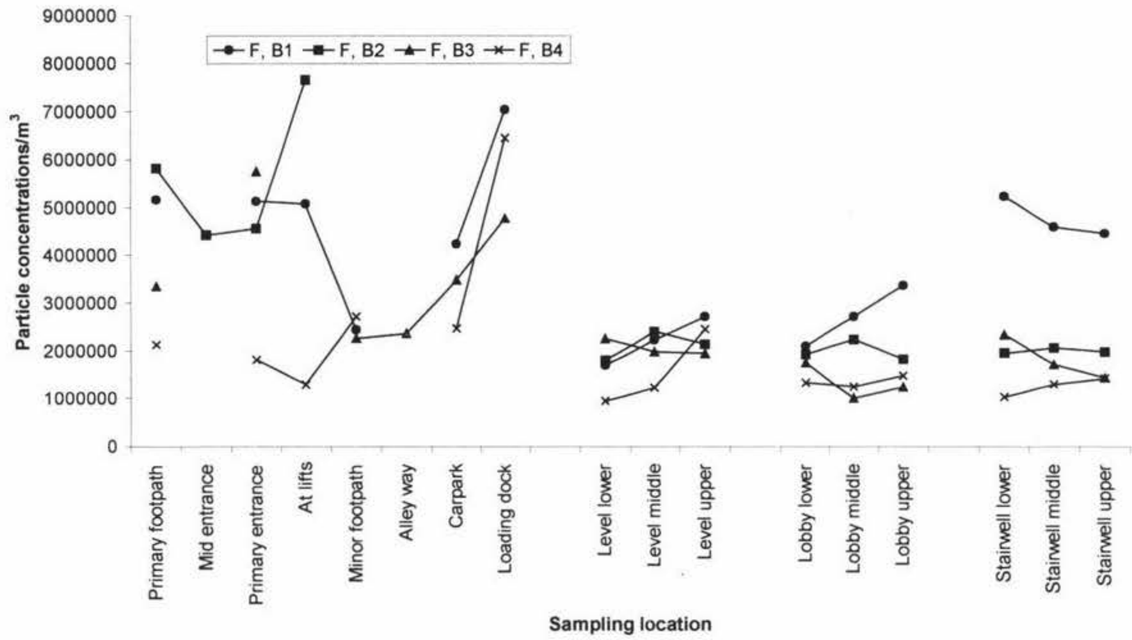


Figure 52. Particle concentrations of 0.5μm measured at exterior and interior locations in the four participant buildings on Friday.

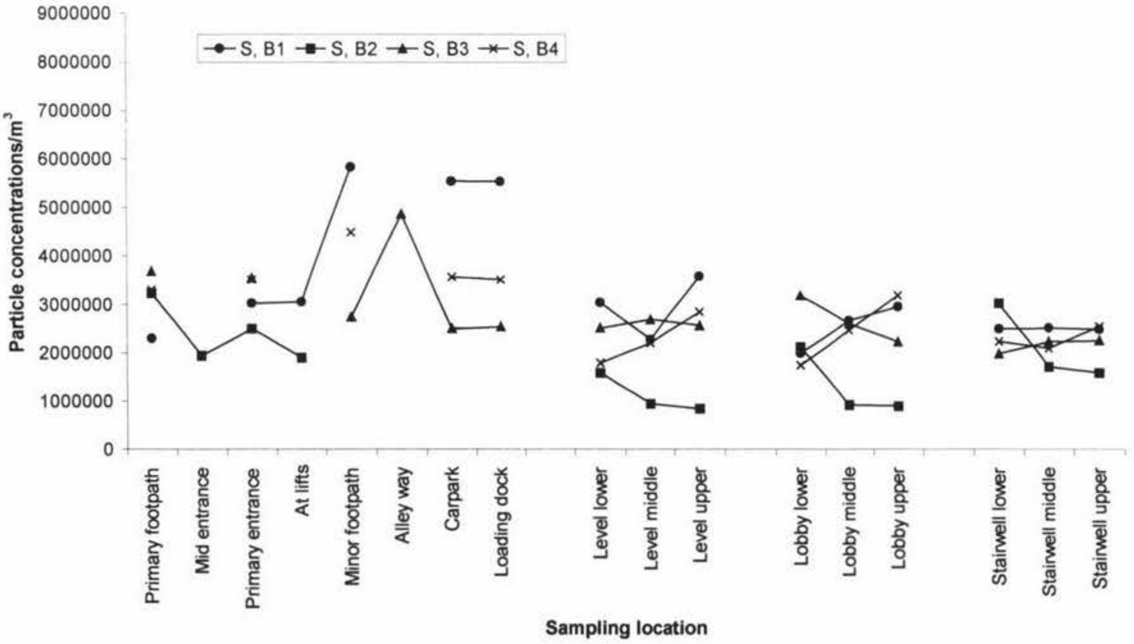


Figure 53. Particle concentrations of 0.5μm measured at exterior and interior locations in the four participant buildings on Sunday.

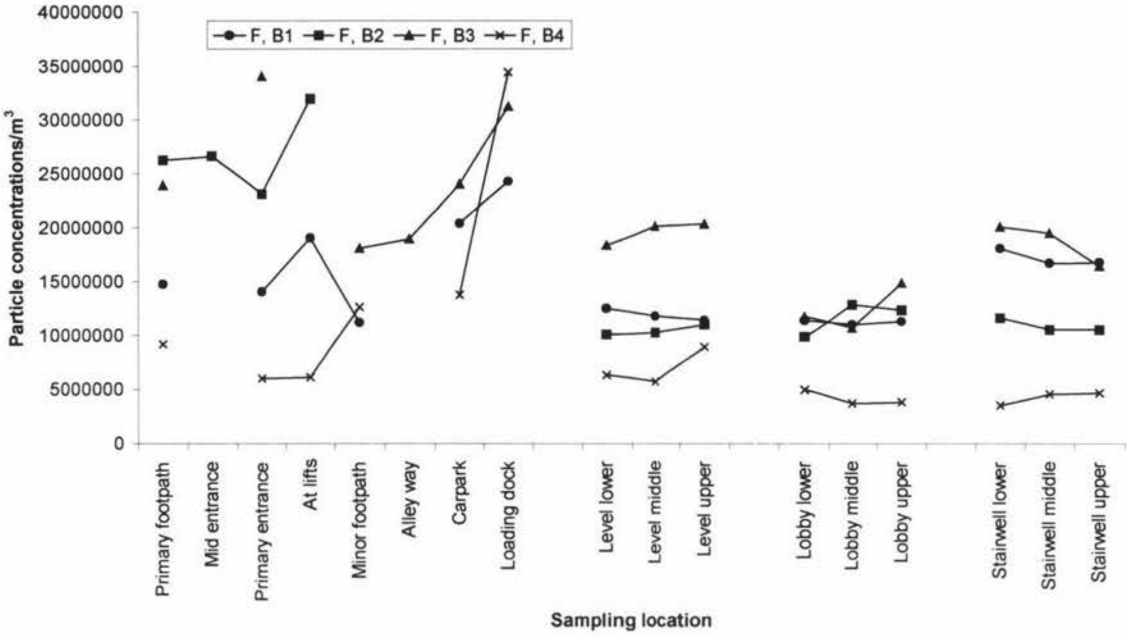


Figure 54. Particle concentrations of 0.3μm measured at exterior and interior locations in the four participant buildings on Friday.

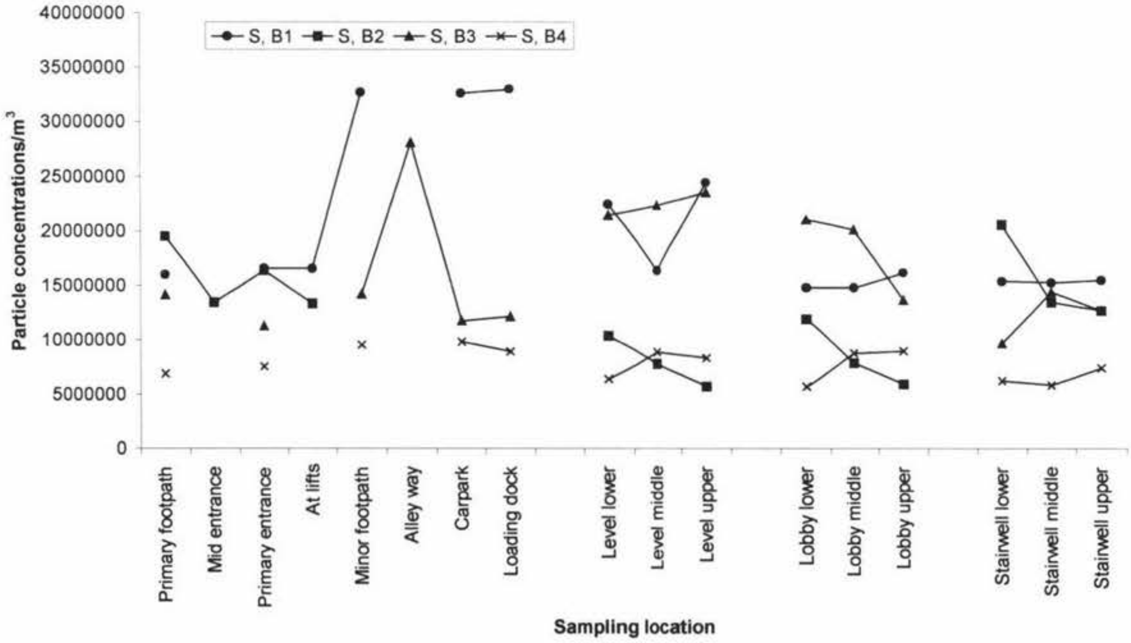


Figure 55. Particle concentrations of 0.3μm measured at exterior and interior locations in the four participant buildings on Sunday.

6 DISCUSSION

6.1 Section One: Occupancy and Particle Concentrations.

6.1.1 Introduction

This section explores the influence of occupants on particle concentrations in the office environment by comparing a working day (Friday) with a non-working day (Sunday). In addition, the non-existence of a vertical gradient of particles between the heights of 1.2 metres and 1.8 metres within five size bands is discussed. Specific attention is given to the deposition of particle concentrations over a 48-hour period from the occupants' departure on the working day of Friday. The variations in particle concentrations between zones, floor levels and the four participant buildings are also discussed.

6.1.2 Occupant Influence on the Generation and Deposition of Particles 5μm

The results of the study showed that in all four participant buildings, particle concentrations reduced by a large number from Friday to Sunday in the 5μm band. Friday was a working day where there all floor levels were at occupation capacity with the exception of four zones in B3. On Sunday there was minimal occupancy (if any) on all floor levels in the four participant buildings except on L3 of B2. Overall the lack of the presence of occupants resulted in particle concentrations on Sunday that were approximately 50% of particle concentrations measured on the Friday.

There were two areas where a large decrease in 5μm particle concentrations did not occur. The first area was B2, L3 where particle concentrations on Sunday were 81% of Friday concentrations. These elevated levels were attributed to the presence of approximately 60% of the total office personnel working after hours on Sunday. The second area was in B3 on L15 and L10. Low occupancy levels at the time of sampling on Friday explain the small decrease in particle concentrations. On Friday L10 had low occupancy in two zones of the floor (approximately 3 people) and level 15 had two zones of meeting rooms not in use. Removing these particle concentration measurements of the unoccupied zones on both floor levels from the analysis resulted in particle concentration decreases from Friday to Sunday that were aligned with results from the remaining levels of the buildings.

There were large temporal variations in the measurements of 5μm particle concentrations between zones and floor levels. Previous research shows that particles of the size range of 5μm settle out of the atmosphere by gravity within hours or minutes and are only found near the source depending on the height of release (Dockery & Spengler, 1981; Fisk et al., 1999; Jansson et al., 1999). Therefore the movement of an occupant in any of the participant buildings could have had an instantaneous and significant effect on particle concentration in their immediate vicinity. Intermittent occupant activity such as walking from a desk to a printer or bathroom facilities, prior to or at the time of sampling, could have generated and re-suspended settled particles and affect particle concentrations. Jamriska & Morawska, 1996 and Fisk et al., 1999 have also showed large temporal variations in indoor particle concentrations.

6.1.3 Occupant Influence on the Generation and Deposition of Particles 3μm

The deposition behaviour of particles in the size band of 3μm was similar to that of the 5μm size band. The Sunday concentrations measured in each building as a percentage of Friday concentrations were less which suggests that particles in this size band will also have had sufficient time to settle by gravity over the 48 hour period between sampling on Friday and on Sunday. It is of note however that the particle concentrations in the 3μm band on Sunday were 99% of Friday for L3, B2 that was 60% occupied on Sunday compared to 81% for the 5μm band. This suggests that particles in the 5μm band may settle more quickly than the 3μm band after they have been generated or re-suspended by occupant activity.

6.1.4 Occupant Influence on the Generation and Deposition of Particles 1μm

Particle concentrations on Sunday as a percentage of Fridays for all four buildings were higher than those percentages for the 5μm and 3μm band. There were some instances where 1μm particle concentrations decreased due to deposition, and some instances were there were increases in particle concentrations.

This can explained to some extent by the behaviour of fine particles of 1μm and below. Fine particles have lifetimes in the atmosphere in the order of days and can be transported over long distances. They are generally too large to coagulate into larger particles which prevents them from settling within hours or minutes as the 5μm and 3μm particles do. Particles within the 1μm band only had a period of 48 hours to settle by gravity and it is possible for some of the particles measured on Sunday more time for settling may be needed due to their composition.

However as particles of 1μm and less travel over long distances and easily penetrate the building envelope (Dockery & Spengler, 1981) particle concentrations over a period of 48 hours would have been confounded by particles entering through unintentional pathways due to the air exchange rate. Particle concentrations may have been removed rather than settled taking the time scale of 48 hours. This may explain why on Sunday there were more particles present on some floor levels in the participant buildings.

B2 is of particular interest as 1μm particle concentrations measured on Sunday were a small percentage of Friday measurements. This may be attributed to the operation of the ventilation fans from 8am to 2pm on the Sunday. It is proposed that the operation of the ventilation fans maintained a positive pressure in the building relative to the outdoor environment and this reduced the possibility of the rapid infiltration of small particles through the building envelope. On L3 of B2 however the concentration of particles on Sunday as a percentage of Friday concentrations was 100%. It is suggested this lack of reduction on the measurement day of Sunday may be a result of the presence of occupants working in the space generating particles due to the operation of photocopiers, fax machines, coffee making facilities, and lift car movement.

6.1.5 Occupant Influence on the Generation and Deposition of Particles 0.5μm

Particle concentrations on Sunday as a percentage of Friday concentrations were over 100% for B1, B3, and B4. This suggests that particles in this size range of 0.5μm, not only do not readily settle, but particles from the outdoors are able to easily penetrate due to air changes occurring in the building. CO_2 levels decreased for all buildings from Friday to Sunday. The reduction in CO_2 levels indicate that air changes occurred for all four participant buildings over the 48-hour period and thus a portion of particles generated within the space on Friday are likely to have settled, and a portion are likely to have been flushed from the building over the weekend period. Air changes would have also resulted in the introduction of particles from outdoor sources.

While 0.5μm particle concentrations on Sunday as a percentage of Friday were over 100% for B1, B3, and B4, in B2 however particle concentrations on Sunday as a percentage of the concentrations measured on Friday were below 40% for L8 and L10 and below 90% for L3. A high percentage of 90% for L3 supports the suggestion that the presence of occupants may contribute to particle levels. The low percentage of 39% for L8 and L10 (relative to the other participant buildings) suggests that particles from the outdoor air will not easily infiltrate the indoor built environment when the building is positively pressurised by the operation of ventilation fans. It also suggests that a portion of these particles will settle within 48 hours when undisturbed by occupant activity.

6.1.6 Occupant Influence on the Generation and Deposition of Particles 0.3μm

The particle concentrations as a percentage of Sunday concentrations were similar to those of the 0.5μm band with greater particle concentrations measured on Sunday than Friday for B1, B3 and B4 in the 0.3μm size. B2 showed a decrease in particle concentrations from Friday to Sunday except for L3 where there was 60% occupancy.

6.1.7 Variations in Particle Concentrations between Floor Levels in Buildings.

The results of the study showed large variations in particle concentrations between the floor levels in each of the four buildings. The variations in particle concentrations between floor levels could be attributed to several factors.

The first factor that may cause variations in particle concentrations across floor levels is occupant density. This study shows two examples of how occupant density may have influenced particle concentrations. In B3 on L10 and L15 several zones were unoccupied and this resulted in reduced particle concentrations relative to other floor levels measured on the Friday. The other example of occupant density possibly affecting particle concentrations is the high particle concentrations on Friday measured where a meeting was in progress with approximately 50 people attending. At the time of measurement it was a break period and occupants were congregating with refreshments and this may explain why B4, L11 had the highest particle concentrations measured when compared with all other floor levels.

The second factor that may account for variations in particle concentrations between floor levels is the affect of occupant and researcher movement prior to or at the time of sampling. The influence of the researcher or an occupant working after hours on the Sunday is particularly important as this could jeopardise attempts to establish baseline levels for comparison with measurements on Friday resulting in erroneous data.

6.1.8 Variations in Particle Concentrations Between Buildings

The results of the study also showed large variations in particle concentrations between each of the four participant buildings. The variations in particle concentrations between the four participant buildings could also be attributed to several factors.

The first factor is the different locations of the buildings. Even though all four buildings were located with the CBD of Wellington there was approximately 250 metres between each building (see figure 34).

Building age and renovation may also have affected indoor source concentrations and infiltration through the building envelope. B2, B3, and B4 had had major renovations since construction and thus it is possible that furnishings such as carpets and partitions that can operate as sinks for particles or be a source of particles due to the slow deterioration of the material would not be as advanced as B1 where major renovation has not taken place.

A third factor is that sampling was performed over four consecutive weeks rather than on the same two days due to equipment constraints. This means that weather conditions were slightly different on each of the eight days of sampling. Rainfall on the day of sampling, the temperature, and wind run has been shown to influence particle concentrations. There were periods of rainfall on the Sunday visit to B1, on the Sunday visit to B2, on the Friday and Sunday visit to B4.

The highest levels of rain fall (8.2mm) were on Friday of the visit to B4. The results showed that the concentration of particles measured in B4 on the Friday were lower than the other three participant buildings for the size band of 0.3μm on all three levels and the size band of 0.5μm on L1 and L6. L11 of B4 was higher for the 0.5μm size band and the effect of the rain fall may have been counteracted by the presence of the large number of occupants. Nieto et al. (1994) found that up to one third of respirable particles may be removed during short periods of heavy rain.

However, even though there were variation in the total number of particles between each building the relative proportions of each size band to the total number of particles were very similar. In all four participant buildings the smaller size particles of 0.5 and 0.3μm accounted for the 70-90% of particles present in the indoor environment. Fracastoro & Tronville, (1999) have shown that more than 99% in number of the particles present in the indoor built environment are of an aerodynamic diameter below the size band of 1μm.

6.1.9 Summary

In all four participant buildings, particle concentrations reduced by a large number from Friday to Sunday in the 5μm and 3μm size bands. This suggests that the presence of occupants in the office environment affected particle levels due to their activity. Particle concentrations of 1μm were variable with some increases in concentrations and some decreases in concentrations in the office buildings. Particle concentrations of 0.5μm and 0.3μm on Sunday as a percentage of Friday were above 100% for all participant buildings except B2 which had ventilation fans in operation on the Sunday. The increase in particle concentrations suggests that fine particles below 1μm behave independent of occupant activity. Although there were large temporal variations in all areas of all participant buildings there no statistically significant vertical gradient between the measurement heights of 1.2m and 1.8m. This implies that particles are well mixed within this band width.

6.1.10 Vertical Gradient of Particle Concentrations for all particle size bands.

There was no statistically significant vertical gradient in particle concentrations between the measurement heights of 1.2m and 1.8m in all four participant buildings. This suggests particles are mixed within this band width and that occupants may be exposed to a similar concentration of particles whether they are standing or sitting. This may be due to the nature of the work where occupants move up and down regularly to access photocopiers, fax machines, tea and coffee making facilities, and meet with clients.

6.2 Heating, Ventilating, and Air Conditioning Pathway

6.2.1 Introduction

This section investigates the concentrations of particles as they travel from the immediate area surrounding the buildings' entrances, through the HVAC system, and onto the three floors selected for sampling in each building.

6.2.2 Location of Outdoor Air Intake

The results of the study showed particle concentrations at the exterior location points at footpath, mid entrance, entrance and lift lobbies were generally higher on the Friday than the Sunday for all particle sizes for all four participant buildings. The high concentrations of particles recorded at exterior sampling points to the four participant buildings on Friday are likely to be due to the presence of combustion products from high volumes of vehicle traffic. In addition there is likely to have been higher pedestrian traffic on the footpath and more occupants and visitors entering the participant buildings on a Friday than on a Sunday.

B1 in particular had high particle concentrations on Friday and this could be attributed to the close proximity to a busy road and four way intersection causing high concentrations of combustion products from vehicles. In addition B1 is ranked as having the seventh highest pedestrian activity of all four participant buildings. These high concentrations were further compounded by road works involving the drilling of asphalt and footpath being carried out 20 metres opposite the entrance.

The results also showed that on the Fridays for all four participant buildings the outdoor levels were however lower at the outdoor air intake points of half way up the building and on the roof than at ground level. This suggests that there is an advantage to having an outdoor air intake at a higher level than the ground and this has previously been shown by Bearg (1993).

6.2.3 Filtration Efficiency

In general it was shown that the standard filters used in all four participant buildings were effective at filtering the large particle sizes of 5μm and 3μm and less effective at filtering the smaller size bands of 1μm, 0.5μm, and 0.3μm. In B4 at the 5μm band and in B2 at the 3μm band the actual number of particles increased after passing through the filters. This was unexpected and perhaps could be attributed to the physical disturbance caused when opening the access door and placing the isokinetic probe inside.

In B4 the filters serving the upper tower were less effective in filtering particles than the HVAC system as the base of the tower. This may account for the resultant high concentrations on level 11. However to identify the cause for the high levels in L11, B4 it would have been useful to have a measurement taken directly under the diffuser at a height of 2.5m rather than 1.8m. This would have identified if the filtration system and ductwork was the cause or if in fact the cause of the high particle levels were due to occupant activity as previously suggested.

6.2.4 Summary

There were large variations in particle concentrations between each of the sampling locations along the HVAC pathway. Particle concentrations were higher in the immediate area surrounding the building entrances than at the outdoor air intake. Particle concentrations decreased after passing through the filters however the filters effectiveness reduced as the size of the particles became smaller. There was a large increase in particle concentrations between the measurement location of after filtration to measurement location of under the diffusers at 1.8m on the three floors sampled in each building.

6.3 Stack Effect Pathway

6.3.1 Introduction

Pressure differentials result when heated air escapes through the upper levels of the building resulting in a lower pressure at the base of the building. Air is then often drawn in from the outdoor environment through various pathways until the pressure differential between the indoor and outdoor environment is equalised.

Bearg (1993) states that over the period of a day warm buoyant air travels from the lower floors by unintentional pathways to the upper floors carrying particles with it. This would then result in the agglomeration of particles at higher concentrations in the upper floors than lower floors until they are able to exfiltrate. Thus particle levels would be high at the uppermost floor levels and less concentrated at the lower levels.

6.3.2 Lobbies and Floor Levels

Particle concentrations measured in B1 and B4 on Friday were shown to increase as the floor level increased up the tower for all size bands except 0.3μm, which was reasonably stable throughout the three floors measured. Particle concentrations also increased in lobby areas. Lobby concentrations were higher than floor concentrations in the 5μm and 3μm band this may be due to the operation of lift cars and occupants passing at this point to access photocopiers, bathroom facilities, and tea making facilities.

In B2 and B4 on Friday there was no clear rise in particle concentrations in conjunction with a rise in floor level or lobby. The smaller particle sizes of 0.3μm and 0.5μm on Friday were reasonably stable however the larger particle sizes of 5μm, 3μm, and 1μm were more variable.

The results showed that particle concentrations were often high at the ground floor lobby in comparison to other lobby levels for all four participant buildings. This may be attributed to the activity of people entering and exiting the building and the movement of the lift cars. An insufficient flushing of particles in this area due one entrance point and sealed windows in all four participant building entrances may compound the build up of particles.

6.3.3 Stairwells

The only pattern of a stack effect where particle concentrations increased by stairwell was shown in B4 for the size bands of 1μm, 0.5μm, and 0.3μm and in B2 for the size bands of 5μm and 3μm. In all other participant buildings particle concentrations were variable. In B1 particle concentrations were higher at the lowest floor level than the highest floor level for all size bands except 0.3μm and this may be due to the settling of particles which would remain undisturbed unless occupants needed to access the stairwells to use bathroom facilities. Where particle concentrations were lower in the stairwells and floor lobbies this may be due to fewer particle sources in the stairwell and little holding of particles on the linoleum floor finish, unlike carpet which can act as a sink, and therefore allow re-suspension of particles. In addition if the stairwells were well sealed for fire purposes then it is possible concentrations would remain unaffected by pressure differentials.

On Sunday in all four participant buildings, particle concentrations in the stairwells were reasonably stable for the 1μm, 0.5μm and 0.3μm size band. Particle concentrations were more variable however for the 5μm and 3μm range and this may be possibly attributable to researcher movement during sampling. These fluctuations are supported by previous research that has shows that occupant activity does not have such a marked influence on lower particle sizes as the larger particle sizes of 5μm and 3μm (Jansson et al., 1999).

6.4 Particle Concentrations and Health Effects

Although the potential health effects of particles present in the occupied space can only be fully assessed with knowledge of the chemical/and or biological composition of each particle, which was beyond the scope of this study, a characterisation of particle concentrations by size provides an indication of their potential health affect to the occupant.

The size of the particle and its resultant deposition time is significant as the size of a particle will determine how long it remains in the air. Thus the period of time the occupant will be exposed to them and the potential for health problems is dependent on deposition in the body.

The results suggest that occupant activity results in an increase in the number of particles present in the space for the 5μm and 3μm size bands however these size bands settle within hours. If inhaled these particles will deposit in the head airways and tracheobronchial region to be removed by nose wiping, blowing, and sneezing. Examples of common particles of this size that are most likely to have been in the indoor environments of the four participant buildings include various pollens, spores, moulds, animal and human hair, and fibres.

The study also showed that particles below 1μm accounted for between 70-90% of the total number of particles present in each participant building. This raises significant concerns with regards to their potential health effects on the occupant as the study shows that particles of 1μm and below have longer settling times than 5μm and 3μm particles which increases the likelihood of inhalation and deposition in the gas exchange region of the occupants. Particles that may have been present in the four commercial office buildings are bacteria, dust mite faeces when disintegrated, human epithelial cells, asbestos, ground talc, man-made mineral fibres, automobile emissions, cigarette smoke and coffee roast soot.

6.5 Implications of Findings for Further Study

The low concentrations of B2 on Sunday in comparison to the other three participant buildings in particular for the size bands of 1μm and below suggest that there may be benefits to maintaining a building at positive pressure relative to the outdoors at all times. This could be further explored by measuring occupant SBS symptom complaints on a Monday morning after fans have been in operation over the weekend preventing infiltration of particles through the building envelope, and on a Monday when the ventilation fans have been out of operation could be compared.

Baseline levels of self-reported Sick Building Syndrome symptoms in a building where fans are usually in operation over the weekend period could be established by the completion of a questionnaire over several Monday mornings. The ventilation fans could then be turned off over a weekend period to determine if the increase of particles in the space due to infiltration caused a difference in SBS symptoms self-reported by occupants on a Monday morning. Previous studies have linked particles with SBS symptoms (Raw et al., 1993; Gyntelberg et al., 1994) and also shown that a reduction in airborne particle levels in buildings result in reduced self reported symptoms. A study conducted by Mendell et al. (1999) provides grounds for further investigation of the benefit of maintaining a building at positive pressure over a weekend period.

A non-significant difference in particle concentrations between the heights of 1.2m and 1.8m means that in future studies the sampling height may be approximated and taken anywhere between 1.2m and 1.8m and yet a representative measurement of occupant exposure to particles concentrations can be achieved. Approximating the measurement height will result in a reduction of sampling time in each zone. This is particularly relevant to current sampling methodology, as there would no longer be a need to change tripod mountings and take multiple measurements in one sampling location. As a direct result a floor level could be separated into a larger number of zones for increased representative data or alternately more floor levels could be studied within each participant building.

An additional advantage of a non-significant difference in particle concentrations between 1.2m and 1.8m is that the researchers personal PM cloud compromising the data collected could be further minimised. The removal of the researchers personal cloud is especially applicable on the Sunday (non-working day) when the building is unoccupied. Due to the methodology used to sample in this study it is possible that particles were unintentionally introduced or settled particles re-suspended by the researchers during the measuring activity of moving and mounting instruments, and by the flow of air carrying particles as a result of the opening and closing doors.

Further study is necessary at several heights over a wider band to explore the possibly of significant vertical gradients present in a sample office space beyond the heights of 1.2m and 1.8m

6.6 Limitations of the Study

6.6.1 Occupant Density

Occupancy rates could not be controlled in this field study. Ideally the number of occupants would have been the same on all floor levels and the activity performed identical in so far that the occupants remain stationary for the majority of the time with movement at predetermined times only. However in this field experiment with four separate commercial environments this was not feasible. As with all studies the pool of sampling environments available for investigation was largely dictated by the willingness of building management and tenants to co-operate.

The impact of occupant movement is also a limitation of the study in that it could be argued that short term instantaneous monitoring might not provide the best representation of the average concentrations in a building over a period of time particularly for the larger particle sizes of 5µm and 3µm.

6.6.2 Particle Composition

The inability to characterise the chemical/and or biological composition of the particles in each building indoor environment meant that it was difficult to explain the source of a high episode of particle concentrations. Future studies that incorporated identification of particles in addition to size selective count sampling as performed in this study would allow for more accurate assessment of the effect of particles present in the office environment on the occupants' health.

6.6.3 Heating, Ventilating and Air Conditioning Pathway

A limitation of this study was the inability to sample particle concentrations in the ductwork and directly at the diffusers in addition to the measurement taken at 1.8m below the diffusers. This would have allowed for high particle concentrations in a particular area to have been more conclusively attributed to either occupant activity or to the possibility of the ductwork contributing to the high levels of particles in the occupied space.

6.6.4 Stack Effect Pathway

The agglomeration of particles in the upper levels of the building attributed due to the stack effect could be confounded if there were low occupancy rates on the lower floors when compared with the higher floors. The hypothesis of a stack effect carrying air laden with particles would be supported, but in fact incorrectly attributed. The second possible confounding factor is that particle concentrations are strongly affected by unintended and uncontrolled particle sources such as unauthorised smoking, liquid spills, or irregular episodes of high occupant activity such as occupants congregating at a refreshment break due to a seminar. It is near impossible for such events to be monitored and as a result these incidences may lead to erroneous interpretation of the collected data.

6.6.5 Missing Data

It could be argued that reduced access to some of the zones on the Sunday made some of the data less representative due to the reduced sample numbers. In defence it is proposed that provided the entire floor was unoccupied on the Sunday, and consistent particle concentrations are assumed across the entire floor then it is plausible to assume that measurements sampled in two zones would be representative of the entire floor. This assumes that infiltration rates are the same across the entire building envelope. This however may not be the case as wind currents on different corners of the building may affect infiltration rates. Although ideally unrestricted access is desired, there will always be some barriers that are determined by tenant co-operation.

6.7 Particles and Environmental Parameters

Environmental parameters were measured in addition to particle concentrations to determine if the building met established standards and investigate possible relationship with particle concentrations. The environmental parameter of CO_2 was measured at all sampling locations in the morning. Carbon dioxide is generated indoors primarily through human metabolism. Sufficient ventilation is needed to maintain these levels below 800ppm in office environments. This was achieved in B2, B3, and B4 however on Friday in all zones on L5 of B1 CO_2 concentrations levels were above the recommended guidelines. Comparison of CO_2 concentrations with particle concentrations on Level 5 showed that particle concentrations were consistently higher relative to the other floor levels. This suggests that high CO_2 levels measured in a building may be indicative of high particle concentration levels accumulating in the buildings over the period of a working day.

Spot measurements were made of relative humidity and temperature. Relative humidity, which in addition to temperature affects thermal comfort, was within the ASHRAE standard 55-1992 of between 25-60% for all buildings and ranged from approximately 35% - 52% on Friday. Temperature levels were for the majority within the comfort range of 18-22°C for winter in occupations that are primarily sedentary. It is acknowledged that spot measurements taken in the morning are not as representative as data logging over a period of time due to the peaking of CO_2 and temperature in the afternoon at approximately 3pm. However spot measurements were considered appropriate for this study.

6.8 Section Two: Procedure Development

The procedure developed resulted in an initial high response rate to allow for the identification of suitable buildings for this study. Some respondents were unaware of the definition of mechanical ventilation and this should be defined more clearly to avoid unnecessary time and expense. It was confirmed that an information sheet should not replace a personal meeting where building management and tenant concerns can be raised and rapport formed with the building management. Occupants were co-operative and genuinely interested in the sampling process. At all times it was stressed that this was routine sampling and the building was safe for occupancy.

The methodology used to collect data can be applied to a wide range of buildings independent of density, age, construction etc. The checklist was invaluable in that it provided a document in which to make all recordings. This ensured no information or data was lost and activities that may affect particle concentrations could be noted such as occupants walking by at the time of sampling.

7 Conclusions of the Study

7.1 The Influence of People on Particle Concentrations

An important finding of this study was that the presence of occupants in the office environment affected particle concentrations of 5μm and 3μm due to their activity and use of office facilities. Particle concentrations for the size bands of 5μm and 3μm decreased within the order or 50% from Friday to Sunday. This result is in accordance with previous studies conducted by Micallef et al. (1998) and Jansson et al. (1999) which showed increases in coarse-mode particle concentrations of fifty to a hundred fold caused by occupant activities.

The study found that particle concentrations of 1μm were much less affected by occupant activity in the buildings studied and possibly more affected by the air exchange rate over the 48 hours sampling period. Overall particle concentrations of 1μm in the four participant buildings were variable with some increases in concentrations and some decreases in concentrations. Particle concentrations of 0.5μm and 0.3μm on Sunday as a percentage of Friday were above 100% for all participant buildings except B2 which had ventilation fans in operation on the Sunday. These large temporal variations in particle concentrations suggest that fine particles below 1μm behave independent of occupant activity.

The study was also similar to previous findings by Jamriska & Morawska (1996) and Fisk et al. (1999) and showed large temporal variations among all zones of the participant buildings over the two sampling days.

7.2 The Vertical Gradient of Particles Between 1.2m and 1.8m

There was no statistically significant vertical gradient between the measurement heights of 1.2m and 1.8m. This implies that particles are well mixed within this band and that whether an occupant was standing or seated the exposure level to particle concentrations was the same for the four buildings sampled.

7.3 The HVAC System and Particle Concentrations

The filtration systems in each of the four participant buildings were effective at reducing particles in the 5μm and 3μm band. However the filtering efficiency of the media deteriorated markedly as particle sizes (1μm, 0.5μm, and 0.3μm) became finer.

The study also showed there is a possible benefit from operating ventilation fans over the weekend period to maintain positive pressurisation of the building. The presence of small particles (1μm, 0.5μm, and 0.3μm) decreased in the office space of B2 and this may be attributable to fan operation. The implication of this with regards to occupant health is significant as particles of the size bands $<1\mu m$ present the highest hazard to occupant health due to their ability to penetrate and deposit in the gas exchange region.

7.4 The Thermal Stack Effect and Particle Concentrations

Results regarding the agglomeration of particles in the higher floor levels due to the operation of the stack effect were inconclusive with other factors potentially confounding the collected data such as occupant density. In future studies these factors should be carefully monitored or eliminated if at all possible.

7.5 Conclusions

Overall the results of the study were consistent with other researchers findings. Occupant activity influenced particle concentrations of 5μm and 3μm but not below 1μm and there were large temporal variations in particle concentrations between zones, floors, buildings, and measurement days. The filtration efficiency of standard filter media decreased as the particle size decreased below 1μm. A more details analysis of factors that may confound particle concentrations along the stack effect pathway may have allowed for a more representative summary of particle concentrations which then could be attributed to the existence of pressure differentials and explored accordingly.

8 APPENDIX A

Massey University

Thursday 23rd March 2000

«Name»
«Company_Name»
«Address1»
«Address2»
«City»

Dear «Title» «SName»

CALL FOR AIR CONDITIONED OFFICE BUILDINGS FOR ENVIRONMENTAL STUDY

I am an assistant lecturer studying towards a MApplSc at Massey University. I am conducting a research project in indoor air quality and particles. Research shows airborne particles have a detrimental affect on the indoor environment, occupant health, and electronic equipment. We plan to profile particle concentrations within and outside commercial office buildings in order to identify building components and activities that contribute to particle levels in the occupied space.

We are seeking office buildings with full mechanical ventilation for investigation. Air samples will be taken in selected areas of the building to measure particle concentrations, temperature, carbon dioxide levels, and relative humidity levels. Areas to be sampled include the plant room and a number of occupied floors. Access to these areas will be required for no more than two working days and interruption to occupants will be minimal. Occupants will not be required to actively participate in the study. Measurements will be made with instruments that have a noise level below that of speech. Prior to commencing the study a meeting with building management will be necessary to formalise consent, outline methodology and gather preliminary data

The anonymity of the building will be assured at all times. All buildings will be identifiable by a coded number only and it will not be possible to identify a particular building in any publications that will result from this study. Access to collected data will be restricted to the Massey staff directly involved with the study. Building management will be provided with aggregate data results and results specific to their building. Data will be stored in the Massey University Institute of Technology and Engineering research archive.

Participation in this research is entirely voluntary and, if you agree to participate, you may withdraw your consent at any time. The researcher will be unobtrusive and considerate, and respect sensitive areas of the building.

If you are interested in participating in this research or would like to further discuss the study please contact myself on telephone (06) 350 4901, fax (06) 350 5640, or email K.Cleaver@massey.ac.nz.

Thank you in anticipation.

Yours sincerely

Katie Cleaver
Assistant Lecturer
Building Technology

✂ ....

RESPONSE FORM

I would like to participate, please contact me with further information. ☐

I would like to further discuss the study prior to participation (if at all), please contact me. ☐

I do not wish to participate, please do not contact me. ☐

CONTACT DETAILS

Name: ....

Building name: ....

Postal address: ....

Phone: ....

Fax: ....

Email: ....

The response form can be sent in the enclosed freepost envelope or faxed (06) 350 5640.

9 APPENDIX B

Massey University

Thursday 28th March 2000

«Name»
«Company_Name»
«Address1»
«Address2»
«City»

Dear «Title» «SName»

Thank you for responding promptly to our call for mechanically ventilated buildings for study. We are in the process of gathering responses and will contact you with further information in the near future.

Your willingness to be involved in the study is much appreciated.

Yours sincerely

Katie Cleaver
Assistant Lecturer
Building Technology

10 Appendix C

Massey University

INFORMATION SHEET

We plan to profile particle concentrations within and outside the commercial office building in order to identify building components and activities that contribute to particle levels in the occupied space.

Sampling access to the building including occupied floor space will be required for no more than two working days and interference to occupants will be minimal. Access to the following locations is required, where possible:

- Outdoor air intake
- Filters
- Heating coil
- Supply air ductwork
- Return air ductwork
- Coffee Room
- Toilets
- Loading dock
- Services foyer
- Outdoor air supply dampers
- Supply fan
- Cooling coil
- Cooling tower
- Return air plenum
- Stairwell Entrance/Lobby Lift
- Basement/Carpark
- Services lift
- Designated occupied floor levels

Particle measurements will be made with a MetOne 3113 particle counter which has a noise level below that of speech (40dB). Each particle sample taken using the MetOne 3113 particle counter will be a maximum duration of one minute.

The anonymity of the building is assured by the study procedure. All buildings will be identifiable by a coded number only. Access to collected data will be restricted to the Massey staff directly involved with the study. Building management will be provided with aggregate data results and results specific to their building.

Participation in this research is entirely voluntary and, if you agree to participate, you may withdraw your consent at any time. The researcher will be unobtrusive and considerate, and respect sensitive areas of the building.

Contact details for the researcher are as follows:

Katie Cleaver
Assistant Lecturer
Institute of Technology and Engineering
Massey University
Private Bag 11222
PALMERSTON NORTH

K.Cleaver@massey.ac.nz
Phone (06) 350 4901
Fax (06) 350 5640

11 Appendix D

Massey University

CONSENT FORM

I have read the information sheet and have had the details of the study explained to me.

My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I understand I have the right to withdraw the building from the study at any time and to decline to answer any question. I also understand I have the right to restrict the researcher access to sensitive areas in the building if necessary.

I agree to provide information to the researcher on the understanding that my identity and the building's identity will not be discernable in published data.

The information gathered will be used only for this research and publications arising from this research project.

I agree to participate in this study under the conditions set out in the information sheet.

Signed: ....

Name (in full): ....

Affiliation: ....

Date: ....

12 APPENDIX E

BUILDING DATA SHEET

Building name: ________________________________ Building code: _________

Building street address: ____

City: ____

CONTACT INFORMATION

Building contact:

Owner ____

Manager: ____

Services engineer: ____

Contact Person: ____

Title: ____

Postal address: ____

City: ____

Phone: ________________ Fax: ________________ Email: ________________

Building researcher contact:

Name: ____

Postal address: ____

City: ____

Phone: ________________ Fax: ________________ Email: ________________

Research supervisor contact:

Name: ____

Postal address: ____

City: ____

Phone: ________________ Fax: ________________ Email: ________________

SAMPLING INFORMATION

Testing dates: ____________________ ____________________

Floors to be tested:

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**

BUILDING RELATED INFORMATION

BUILDING : GENERAL

Year original building completion: ______

Year recent renovation/building addition: ______

Total building area (m2): ______

Gross floor area (m2) tower floor: ______

Gross floor area (m2) podium floor: ______

No of floors tower: ______

No of floors podium: ______

Number of floors below grade: ______

Number of floors above grade: ______

FLOOR USES FOR ALL FLOORS

Floor Number Primary use: Secondary use:

____

____

____

____

____

____

____

Use categories: office, retail, foyer/reception, parking, assembly, laboratory, storage, food service, mechanical, packing/shipping.

PEST CONTROL

Frequency of exterior pesticide application: ______________

Date of last application: ______________

Frequency of exterior pesticide application: ______________

Date of last application: ______________

Frequency of exterior pesticide application: ______________

Date of last application: ______________

Floor: ______________________________

Floor: ______________________________

Floor: ______________________________

Floor: ____________________

Floor: ____________________

Type of pesticides used:

Interior: ____________________

Exterior: ____________________

STORAGE OF PESTICIDES?

Storage Room: ____________________

Cleaners cupboard: ____________________

Mechanical room: ____________________

Stairwell: ____________________

Service lift lobby: ____________________

Loading Dock: ____________________

Occupied Floor Space

Floor: ____________________

Floor: ____________________

Floor: ____________________

WATER DAMAGE

Past occurrences and extent of damage:

Basement: ____________________

Roof: ____________________

Mechanical rooms: ____________________

Occupied space:

Floor: Zone: ____________________

Floor: Zone: ____________________

Floor: Zone: ____________________

Current leaks and extent of damage:

Basement: ____________________

Roof: ____________________

Mechanical rooms: ____________________

Occupied space:

Floor: Zone: ______________________________

Floor: Zone: ______________________________

Floor: Zone: ______________________________

FIRE DAMAGE AND EXTENT OF DAMAGE

Date fire occurred: Extent of damage

Basement: ______________________________

Roof: ______________________________

Mechanical rooms: ______________________________

Occupied space:

Floor: Zone: ______________________________

Floor: Zone: ______________________________

Floor: Zone: ______________________________

RENOVATION **Current** **Recent (date) Description:**

Painting

Floor: Zone: ______________________________

Floor: Zone: ______________________________

Floor: Zone: ______________________________

New carpet

Floor: Zone: ______________________________

Floor: Zone: ______________________________

Floor: Zone: ______________________________

Ceiling tiles

Floor: Zone: ______________________________

Floor: Zone: ______________________________

Floor: Zone: ______________________________

Partition replacement:

Floor: Zone: ______________________________

Floor: Zone: ______________________________

Floor: Zone: ______________________________

New furniture:

Floor: Zone: ______________________________

Floor: Zone: ______________________________

Floor: Zone: ______________________________

INDOOR RUBBISH STORAGE

Stairwell: ______________________________

Service lift lobby: ______________________________

Loading Dock: ______________________________

Occupied Floor Space:

Floor: ______________________________

Floor: ______________________________

Floor: ______________________________

SITE CHARACTERISATION

Urban: Commercial ______ Industrial ______ Residential ______

Surroundings:

Park ______ Waterfront ______ Hillside ______

Bush nearby ______

Other buildings: tall medium low

Neighbouring building uses:

____

____

____

BUILDING CONSTRUCTION

BUILDING ENVELOPE (Primary P, Secondary S)

ROOF CONSTRUCTION:		WALL CONSTRUCTION:	
Pitched roof	______	Glass and metal curtain wall	______
Flat roof	______	Reclad	______
Single-ply membrane (butynol)	______	Ceramic tile	______
Inverted membrane	______	Precast concrete panels	______
Shingles	______	Exterior insulation finish system	______
Metal	______	Stone panels	______

Other _______ Siding on frame construction _______
eg. GRP, GRC, other on metal frame

Infiltration rate through cladding: leaky ☐ tight ☐ medium ☐

Additional comments:

____

____

EXTERIOR GLAZING

Pane type: Single _______ Double_______

Approx area operable (open and close) windows (nearest 10%):

_______ at perimeter? yes no

Windows with external shading elements eg overhangs (nearest 10%): _______

OUTDOOR AIR SAMPLES

Sample Location: _______________________________

Date:	....	Time:	....
P sample no.:	....	CO_2 (ppm):	....
Relative humidity (%):	....	Temperature (^oC):	....

Other: ....

Sample Location: _______________________________

Date:	....	Time:	....
P sample no.:	....	CO_2 (ppm):	....
Relative humidity (%):	....	Temperature (^oC):	....

Other: ....

Sample Location: _______________________________

Date:	....	Time:	....
P sample no.:	....	CO_2 (ppm):	....
Relative humidity (%):	....	Temperature (^oC):	....

Other: ....

Sample Location: _______________________________

Date:	....	Time:	....

P sample no.: .... CO_2 (ppm): ....
Relative humidity (%): .... Temperature (°C): ....
Other: ....

Sample Location: ____
Date: .... Time: ....
P sample no.: .... CO_2 (ppm): ....
Relative humidity (%): .... Temperature (°C): ....
Other: ....

Sample Location: ____
Date: .... Time: ....
P sample no.: .... CO_2 (ppm): ....
Relative humidity (%): .... Temperature (°C): ....
Other: ....

HEATING, VENTILATION, AND AIR CONDITIONING

HVAC OPERATING SCHEDULE HVAC operation - hours per day

Monday ____
Tuesday ____
Wednesday ____
Thursday ____
Friday ____
Saturday ____
Sunday ____

NUMBER OF AIR HANDLERS IN BUILDING

Location Floors served

Air Handler One ____
Air Handler Two ____
Air Handler Three ____
Air Handler Four ____
Air Handler Five ____
Air Handler Six ____
Air Handler Seven ____

Air Handler Eight ______________________________

Air Handler Nine ______________________________

Air Handler Ten ______________________________

Additional localised systems: ______________________________

LOCALISED EXTRACT

Floor **Supply/Return Exhaust** **Dedicated exhaust system only**

____

____

____

____

____

____

____

OPERATING CHARACTERISTICS ON TESTING DAY

FLOOR TIME % outdoor air % recirculated air

____

____

____

____

____

____

____

____

____

____

HVAC pathway

Sample Location: Outdoor Air Intake

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^{o}C): ....

Other: ....

Rate (m^3/ min): ………………

Contamination sources nearby: Location in relation to building:

exhaust outlets ____________________

cooling towers: ____________________

skip bins:

____

vehicle traffic: ____________________

building construction: ____________________

roadworks: ____________________

industrial chimneys: ____________________

water source (fountain): ____________________

pollen sources: ____________________

other: ____________________

BIRD/INSECT SCREEN ON OUTDOOR AIR INTAKE

Size of screen: __________

Mesh gauge: __________

Clear of obstructions: ____________________

Condition: ____________________

Bird signs: ____________________

Positioning ____________________

Sample Location: OUTDOOR AIR SUPPLY DAMPERS

Date: ……………… Time: ………………

P sample no.: ……………… CO_2 (ppm): ………………

Relative humidity (%): ……………… Temperature (°C): ………………

Other: ……………………………………………………………………………………

Damper position: fully open / partially open / fully closed

Sample Location: DIRECTLY BEFORE FILTERS/MIXING PLENUM

Date: ……………… Time: ………………

P sample no.: ……………… CO_2 (ppm): ………………

Relative humidity (%): ……………… Temperature (°C): ………………

Other: ....

Cleanliness: ____________________

Storage: ____________________

Standing water: ____________________

Sample Location: DIRECTLY AFTER FILTERS

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: AT SUPPLY FAN

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Cleanliness: ____________________

Storage: ____________________

Standing water: ____________________

Cleanliness of fan blades: ____________________

Corrosion evidence: ____________________

SAMPLE LOCATION:
Sample Location: AT HEATING COILS

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Cleanliness: ____________________

Storage: ____________________

Standing water: ____________________

SAMPLE LOCATION:
Sample Location: AT COOLING COIL

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Cleanliness: ____

Storage: ____

Standing water: ____

Sample Location: CONDENSATE DRIP PANS/DRAIN PANS

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Cleanliness: ____

Standing water: ____

Leaks: ____

Noticeable odour: ____

Visible growth (slime):____

Drains and traps clear: ____

Sample Location: AT DUCTWORK

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Liner used: ____

Cleanliness (dust/moisture):____

Connections well sealed: ____

Duct dimensions: ____

Duct length: ____

Duct shape: circular rectangular

Type of supply airflow ducting: galvanised ______

flexible ______

fibre board ______

other ______

no ducting used ______

Insulation type ______ inside/outside

Sample Location: COOLING TOWER

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^{o}C): ....

Other: ....

Cleanliness of components: ________________________________

Cleanliness of surface: ________________________________

Water clarity: ________________________________

Carry over of water outside cooling tower: ________________________________

SAMPLE LOCATION:
Sample Location: RETURN AIR DUCTWORK

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^{o}C): ....

Other: ....

Liner used: ________________________________

Cleanliness (dust/moisture): ________________________________

Connections well sealed: ________________________________

Duct dimensions: ________________________________

Duct length ________________________________

Duct shape: circular rectangular

Type of supply airflow ducting:	galvanised	_______
	flexible	_______
	fibre board	_______
	other	_______
	no ducting used	_______

SAMPLE LOCATION:
Sample Location: RETURN AIR PLENUM FLOOR

Date:	....	Time:	....
P sample no.:	....	CO_2 (ppm):	....
Relative humidity (%):	....	Temperature (^oC):	....

Other: ....

Cleanliness (dust/moisture): ____

Tiles well sealed: ____

Storage: ____

OCCUPIED SPACE SAMPLING

Testing dates: ____

Floors to be tested:

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**

FLOOR USES FOR ALL FLOORS

Floor Number Primary use: Secondary use:

____

____

____

____

____

____

____

____

Use categories: office, retail, foyer/reception, parking, assembly, laboratory, storage, food service, mechanical, packing/shipping.

OCCUPIED FLOOR SPACE – LEVEL

FLOOR LOCATION DESCRIPTION

Occupied floor area: _______m^2 Gross floor area: _______ m^2

Floor to ceiling height: _______m^2

Suspended ceiling plenum: _______m^2 Raised floor: _______m^2

Approximate number of private offices: _______

Approximate number of workstations: _______

Approximate number of workstations in partitioned office space: _______

Typical height of partitions: _______m

Approximate number of workstations in open office space: _______

Design floor area per workstation: _______m^2

Space use change (e.g. storage to office):

____

Total number of windows in space: _______

Number of operable windows in space: _______

INTERIOR FINISHES Primary P, Secondary S, Other O

Wall:	plasterboard	_______	Partition:	fabric covered	_______
	wall paper	_______		plastic	_______
	fabric covering	_______		wood veneer	_______
	wood panelling	_______		wood	_______
	metal	_______		metal	_______
	other	_______		other	_______

Suspended ceiling:	plasterboard	_______	Floor:	carpet	_______
	fabric	_______		wood	_______
	wood panelling	_______		other	_______
	fibreglass tile	_______			
	metal tile	_______			
	other	_______			
	Tiled	yes/no		Tiled	yes/no

FURNITURE

Materials used: Primary (P), Secondary (S)

wood	_______	laminate	_______
fabric/textile	_______	metal	_______
wood veneer	_______	paint	_______
other	_______		

SMOKING POLICY

Restricted to private offices _______

Restricted to indoor smoking area _______

Restricted to outdoor smoking areas _______

Activity before measurement days:

Occ No. Total hours/day building occupied

am____

Noon ____

pm ____

Activity on measurement days:

Occ No. Total hours/day building occupied

am ______________________________

Noon ______________________________

pm ______________________________

Air handlers that serve the test floor:

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**

<u>VENTILATION FIXTURES</u>

SUPPLY VENT TYPE:

Linear ceiling diffusers ______ Square or round ceiling diffusers ________

Sidewall diffusers ______ Low sidewall grilles ________

High sidewall grilles ______ Floor grilles ________

Floor or near-floor diffusers ______ Fan coil units or unit ventilators ________

Slots around ceiling luminaires ____ Other ________

Approximate number of supply vents per floor: ________

RETURN VENT TYPE:

Ceiling grilles __________ Ceiling slots _________

Slots around ceiling luminaires __________ High sidewall grilles _________

Low sidewall or floor grilles __________ Other _________

Total number of return vents: __________

Additional Space Conditioning Equipment Operating

	Number of Units:	Total
Space heaters:	______________	___________
Humidifiers:	______________	___________
Dehumidifiers:	______________	___________
Desk fans:	______________	___________
Air cleaners:	______________	___________

Sample Location: LOBBY LEVEL:

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: DESK SPACE ZONE: LEVEL:

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: 1.2 SUPPLY DIFFUSER ZONE: LEVEL:

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: 1.8 SUPPLY DIFFUSER ZONE: LEVEL

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: INDUCTION UNIT ZONE: LEVEL:

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: PHOTOCOPIER ZONE: LEVEL:

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: OTHER ZONE: LEVEL:

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

STACK EFFECT

Vehicle traffic: ____

Peak times: 7-9am ______ 4-6pm ______ Other ______

Steady all day ____________

Sample Location: ____

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (°C): ....

Other: ....

Sample Location: ____

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (°C): ....

Other: ....

Sample Location: ____

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (°C): ....

Other: ....

Sample Location: ____

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (°C): ....

Other: ....

Sample Location: ____

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (°C): ....

Other: ....

Walk off mats: _____

Condition:____

Sample Location: ____

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: AT LOBBY LEVEL

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: AT STAIRWELL LEVEL

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: AT LOBBY LEVEL

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: AT STAIRWELL LEVEL

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: AT LOBBY LEVEL

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

LOADING DOCK STACK EFFECT FOCUS

Number of vehicles: ________________________________

Acitvity at time of sampling:

- trucks idling ________________________________
- trucks stopped ________________________________

VENTILATION SYSTEM/EXHAUST FAN

____

____

Sample Location: ________________________________

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: ________________________________

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: ________________________________

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: ______________________________

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: SERVICES LIFT AREA

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: AT SERVICES FOYER TO FLOOR SPACE

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: AT SERVICES FOYER TO FLOOR SPACE

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

Sample Location: AT SERVICES FOYER TO FLOOR SPACE

Date: .... Time: ....

P sample no.: .... CO_2 (ppm): ....

Relative humidity (%): .... Temperature (^oC): ....

Other: ....

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