PARTICULATE MATTER IN THE HOSPITAL ENVIRONMENT

L MORAWSKA

Centre for Medical and Health Physics, Queensland University of Technology, 2 George Street, Brisbane, Queensland 4000, Australia

Fax: +61 7 3864 1535

M JAMRISKA

Centre for Medical and Health Physics, Queensland University of Technology, George Street, Brisbane, Queensland 4000, Australia

P FRANCIS

Respiratory Medicine, Royal Children's Hospital, Herston, Queensland 4029, Australia

ABSTRACT

Investigations of particle concentration levels and size distribution were conducted in the complex hospital system of the Royal Children's and the Royal Brisbane Hospitals. The aim of the measurements was to provide an indication of particulate sources in the hospital environment and relate particle characteristics to the operating parameters of the hospitals. The measurements were performed using the most advanced instrumentation for size classification in the submicrometer and supermicrometer levels. The conclusions from the investigation were (i) that indoor concentration levels of particle numbers are closely related to outdoor concentration levels, indicating that outdoor particulates were

the main contributor to the indoor particulates in the hospitals under investigations and (ii) that the performance of filtration/ventilation systems is the most critical parameter in reducing general particulate concentration levels in those hospital units where medical procedures can result in generation of potentially hazardous organic aerosols.

KEY WORDS

hospital particulates, particle size distribution, filtration/ventilation performance

INTRODUCTION

Control of airborne infectious agents in a hospital environment is a very important aspect of hospital design, operation and the maintenance procedures employed. Airborne pollutants such as organic aerosols including blood-borne pathogens, DNA fragments, tuberculosis droplets, and also other pollutants such as latex allergens, laser produced aerosols and gases and many others are typical to a modern hospital environment (Spengler and McCarthy, 1996). Particles of outdoor origin, such as combustion products, dust or biocontaminants, which penetrate to indoor hospital environments, can themselves be irritants but can also act as carriers of adsorbed pollutants of indoor origin. New challenges are presented for building designers and building managers by the modern health care system.

The greatest number of atmospheric aerosol particles are in the size range below 1 μm (submicrometer particles). Studies of fine particles in health care facilities are important as they can not only provide general information about indoor air quality in these facilities, but can also give a good insight into the nature of pollution and could contribute to identification of pollution sources. Size distribution of particles generated by many sources are usually quite specific for these sources and can often be used as markers of the source (Morawska, et al 1995). In particular, size distribution of particles generated by a

particular source is usually characterised by one peak in a specific size range of a unimodal distribution. If there are more than one peak present in a particle size distribution, the spectrum is multimodal (for example bimodal with two peaks), which indicates that particles contributing to the spectrum have been generated by several sources.

Limited literature data on size distribution of particles in hospital environments indicated that some procedures result in generation of aerosols in a very specific size range, while others do not. For example, measurements of size distribution of aerosols produced during major surgical orthopaedic procedure (Yeh et al., 1995) showed that some amount of blood-associated, inhalable aerosols were produced during the procedures. The absolute mass concentration of these aerosols was low and comparable among different procedures. The studies showed that two or three modes with peaks at 0.3, around 3.0 and > 10 μm in aerodynamic diameter were present. The mass resolution (the smallest size interval for which mass was measured) of those measurements was not as high as the resolution of the measurements presented in this work due to different instrumentation used (mainly cascade impactors). The maximum concentration detected was of the order of 0.4 mg m^{-3} but more often was up to an order of magnitude lower. Higher concentrations were detected only for very short periods of time during certain procedures.

Literature data on the effect of cleaning procedures in a hospital environment (decontamination) showed that the chemicals tested during the procedures did not pose a respiratory health hazard to the personnel (Schultz, et al 1995) in terms of particle generation. In this study mannequins were contaminated with a solvent or particulate, and then decontaminated, exposing the personnel conducting the decontamination, to acetone, p-xylene, iron oxide or zinc oxide.

The specific focus of the work presented here was on submicrometer particles, their concentration and size distribution. The investigations were conducted in the complex hospital system of the Royal Children's and the Royal Brisbane Hospitals, with aims to (i) perform cross sectional measurements of particle concentration and size distribution in the hospitals; and (ii) relate these characteristics to the operating parameters of the hospitals' ventilation and filtration systems. While chemical and morphological characterisation of measured particles could provide important information, this was beyond the scope of this study and is not included in the paper.

There were two rounds of measurements performed in the hospitals. The first round of measurements was performed in various units of the two hospitals and the results for the Royal Children's Hospital were presented earlier (Morawska, et al 1995). Data analysis from these measurements revealed unusual spectral characteristics in some of the hospital units, particularly the surgical theatres. The spectra differed significantly from outdoor spectra in peak location, and it appeared that this was due to the presence of indoor sources. Further investigations were conducted to identify possible indoor sources, including chamber experiments and a second round of hospital measurements, this time conducted only in the surgical theatres of the Royal Children's Hospital. This paper presents the summary of both runs of the hospital measurements, summary of the chamber measurements and data interpretations from the overall study program.

METHODS

The measurements were performed at the Royal Children's and Royal Brisbane Hospitals which are adjacent to each other and located in a central part of the city of Brisbane.

Royal Children's Hospital

The Royal Children's Hospital (RCH) consists of three buildings of different age and hosting different units. The nine year old surgical block hosts, among others, the surgical theatres, Intensive Care Unit and Transplant Care Ward. Nursing, Administration, Respiratory Unit, Infectious Diseases Unit and Bone Marrow Transplant Unit are located in the three year old Woolworths Building. The youngest building, the two year old Coles Building, hosts, among others, the Canteen and Oncology Unit. The units listed above are those which were selected for the particulate investigations project. The units selected for the investigations represent the three main types of environments from the point of efficiency of the air filtration and ventilation systems: low, medium and high efficiency.

Air supply for the buildings is based either on return and/or outdoor air filtered through appropriate filters including dry media extended surface throwaway filters, HEPA and NEPA filters. Air exchange rate in various units was set to comply with the standards, with higher rates applied to the area's requiring higher air quality levels. The following filters are used in the hospitals:

A Dry Media Extended Surface - Throwaway; Efficiency: >85% No 4 Dust

B NEPA (Econocell) filters; Efficiency: 90-95% No 1 Dust

C HEPA; Efficiency: >99.99% for hot DOP

D Electrostatic agglomerator; Efficiency: 80-85% No 1 Dust

E HEPA filters; Efficiency: 90-95% No 1 Dust

Filters were tested according to the Australian Standard AS 1324.1 –1996, and presented efficiency values are based on information provided by manufacturers.

Royal Brisbane Hospital

The Royal Brisbane Hospital (RBH) is situated adjacent to the RCH and is located closer to a main arterial road than the RCH. The RBH is significantly older than the RCH, however, the ventilation and filtration systems are very similar for both hospitals and are managed by the same maintenance team.

Table I gives a summary of air ventilation and filtration systems used in different units of the hospitals.

Chamber Measurements

Chamber experiments were conducted to assess whether the detergents commonly used in hospitals, could contribute to the generation of airborne particulates. The chamber measurements were performed in the experimental chamber of volume 3 m^3. The inner walls of the chamber were painted with latex paint and had a very smooth surface. Air introduced to the chamber was filtered by a HEPA filter.

Instrumentation

The size characteristics of airborne aerosols were measured with a TSI Model 3934 Scanning Mobility Particle Sizer (SMPS), in the size range from 0.017 to 0.7 μm, and with a TSI Model 3310 Aerodynamic Particle Sizer (APS), in the size range from 0.5 to 30 μm.

Both instruments were placed on a portable trolley for easy transport between sampling sites.

Calibration of the SMPS and APS instruments is performed routinely by the measurement of aerosols of known size distributions. Various aerosols for the purpose of calibration, are

generated by a TSI Model 3475 Condensation Monodisperse Aerosol Generator. The SMPS instrument is also routinely cross validated against a second SMPS located at the Environmental Aerosol Laboratory of the Queensland University of Technology.

Experimental Procedures

Experimental procedures included sequential outdoor and indoor air measurements. Outdoor air samples were taken about every two hours to monitor changes to ambient air characteristics. Several indoor air samples were collected between each two outdoor samples measured outside of the hospital (local data). Continuous monitoring of outdoor air was also conducted at a permanent air monitoring research station located 2 km away from the hospital to monitor any significant changes in outdoor levels. Based on these data and in comparison with the local outdoor air data, it could be concluded that there was not observed any significant change in the particulate concentration outdoors within two hours intervals.

At each sampling site, three consecutive measurements were taken to provide a check for sampling stability. The duration of one SMPS test was 120 seconds and the duration of one APS test was 20 seconds.

There were two runs of measurements conducted in the hospitals. During the first run in the RCH and RBH a number of different hospital units were investigated. During the second run the measurements were performed only in the surgical theatres of the RCH, with the objective to identify the sources of particulates in the theatres. A detailed account of activities conducted in the theatres was undertaken as well as a number of measurements which were conducted in the vicinity of the HVAC (heating, ventilation and air conditioning) inlets and outlets for the theatres. These measurements were conducted only for the theatres in which no surgical procedures were underway at the time of

measurement.

Experimental procedure for the chamber measurements included cleaning the chamber by flushing it with air passing through a HEPA filter, introducing the tested detergents into the chamber and monitoring the particle concentration in the chamber. The detergents investigated were AIDAL PLUS (containing 2.1% of glutaraldehyde) and commercially used POW (U.I.M. Chemical Group, Rocklea, Brisbane).

A laminated board (dimensions: 0.5 m x 0.7 m) was washed with a tested detergent and introduced into the clean chamber (kept under positive pressure) together with an open container filled with 1 L of the detergent (open surface dimensions: 0.15 m x 0.20 m). The particle size distribution and concentration of air samples was measured before the detergent was introduced to the chamber and for approximately two hours after.

RESULTS

Particle concentration levels and size distribution in the RCH and RBH measured during the first part of the program

Average particle concentrations in the submicrometer range and in the larger particle range for all the investigated locations as well as a summary of size characteristics of the spectra are presented in Table II for the Royal Children's Hospital and in Table III for the Royal Brisbane Hospital.

Figures 1 to 5 present particle size distributions in the SMPS range from selected hospital units and from outdoor measurements. Figure 4 presents both SMPS and APS spectra. Overall, there were close to two hundred size spectra obtained for both hospitals from

these measurements. Only those which are representative for certain types of areas or environments are shown here.

Chamber measurements

Possible indoor sources of airborne particulates in the two hospitals were investigated. Taking into account that unexpected particle size distributions were present in all the identified areas (surgical theatres), regardless of the activities in these areas, the conclusion was that there could be a common source or a common factor responsible for these characteristics. After detailed analyses of possible sources common to all of the investigated areas, the only one identified was detergent related. The hypothesis that cleaning procedures using detergents were a contributor to indoor particulate matter in the hospitals, had some merit as well as some drawbacks. In particular it did not seem likely that even if particulates were generated during cleaning procedures, their concentration levels would remain relatively high and stable for long periods of time after the conclusion of the procedures.

The chamber measurements conducted for the two detergents used most commonly in the hospitals, showed that the presence of the detergents or the detergent cleaned surfaces in the chamber had no effect on particle concentration in the chamber. Thus the conclusion from the chamber measurements was that the cleaning procedures using the detergents do not contribute to airborne particulates in the hospital environment.

Particle concentration levels and size distribution in the RCH measured during the second part of the program

Average particle concentrations in the submicrometer range and in the larger particle range for the investigated surgical theatres in the RCH, as well as summary of size characteristics of the spectra are presented in Table IV.

DISCUSSION

Particle concentration levels in the RCH and RBH measured during the first part of the program

Several conclusions about particle concentration levels can be drawn from the results presented in Tables II and III.

Particle concentration in outdoor air during the measurements ranged from 7.0×10^3 to 1.3×10^4 particles cm^{-3} in the SMPS range and from 5.4 to 16 particles cm^{-3} in the APS range.

The lowest particle concentration in both the SMPS and APS ranges in the RCH was in the Oncology Unit (Coles Building) and the Bone Marrow Transplant Unit (Woolworths Building) and in the RBH in the Isolation Rooms (Building 9), the Drug Preparation Unit

(Building 56), the Minor Operating Theatre and in the Intensive Care Unit. For all these units, outdoor air was filtered through high efficiency NEPA or HEPA filters.

The concentrations in the APS range for all the units except for the Minor Operations Theatre and the Intensive Care Unit, were between 1.2×10^{-2} and 1.8×10^{-1} particles cm^{-3}. These values are lower than 3.5×10^{-1} particles cm^{-3} which is the limit for Class 10 000 clean spaces (the term 10 000 clean space refers to space with less than 10 000 particles larger than 0.5 μm per cubic foot of air) (Willeke and Baron, 1993).

The hospitals do not use this classification, however, the comparison can be made since the APS measurement range complies with the range regulated by the standard (particles larger than 0.5 μm). Thus, according to these measurements, all these units can be classified as class 10 000 clean spaces. Particle concentrations in the SMPS range were very low for both these units, however, there are no standards referring to this range.

Particle concentrations significantly below outdoor concentration in the APS range were also in the Infectious Diseases Unit, Surgical Theatres, Intensive Care Unit and in the Transplant Care Ward of the Royal Children's Hospital. In the SMPS range, however, concentration was relatively low only in the Intensive Care Unit, and in the other three units, it ranged between over one thousand to over four thousand particles cm^{-3}. While the Surgical Theatres and the Intensive Care Unit use NEPA filters, the Infectious Diseases Unit and the Transplant Care Ward uses Dry Media Extended Surface filters.

In the Administration and the Respiratory Units of the RCH which use Dry Media filters and return air ventilation as well as in the Casualty-Waiting Area and in the Patients Ward of RBH which use electrostatic agglomerators, particle concentrations in both SMPS and APS ranges were not much below outdoor concentrations.

In the Canteen (RCH) concentration in the SMPS range was higher than outdoor, indicating presence of indoor sources, most likely related to the food preparation process.

Particle size distributions in the RCH and RBH measured during the first part of the program

While particle concentration is a parameter characterising air quality in general terms, it does not provide information on contamination sources and in particular, on outdoor and indoor relative contribution to indoor air pollution. An insight into this aspect can be obtained from analysis of particle size distribution spectra.

Figure 1 shows outdoor sample number 1. The shape and location of the peak in the spectrum near 0.03 μm, indicates relatively fresh car combustion emissions. Recent studies showed (Morawska et al., 1997) that the typical location of the peak for particulates from the vehicle combustion process is in the range from 0.025 to 0.040 μm. This peak could be expected in the spectra since the hospital is located close to a busy road intersection. The peak near 0.1 μm is only occasionally encountered in outdoor spectra and is related to diesel emissions according to the studies on emissions from diesel vehicles (Ristovski, et al 1997). Outdoor air sample 1 was followed by sampling in the Respiratory Unit (Figure 2) and then the Canteen. In both these units not only were the particle concentrations of the same order as the outdoor concentration, but the size distributions also show similar bimodal characteristics. The relative dominance of the first peak in the spectrum from the Canteen could be related to changes in the outdoor size distribution or to contributions from very fine particles which are often generated during food preparation processes.

Figure 3 presents size distributions in the Surgical Theatre 1. Particle concentrations for all the surgical theatres and the Transplant Care Unit in the RCH were significantly lower than for outside air and the spectral shapes were very different to outdoor spectral shape. A unimodal symmetrical peak (in log normal scale) suggested that the particles were generated by a source, most likely indoor, specific to the hospital environment, and is not present in the outdoor spectra. An alternative hypothesis was that the air filtration process was selective, thus resulting in changes of spectral characteristics. This could not be verified as the fractional efficiency characteristics of filters used were not available.

Figure 4 presents both SMPS and APS spectra measured in Surgical Theatre 1 and demonstrates that the particle concentration in the submicrometer range is significantly higher (over four orders of magnitude) than the concentration in the range above 1 μm.

Figure 5 shows the size distribution in the Intensive Care Unit. In this unit and also in the Bone Marrow Transplant Unit, the Oncology unit, and the RBH Isolation Room and Drug Preparation room, particle concentration was too low for conclusive size spectral analysis.

Particle concentration levels and size distribution in the surgical theatres of the RCH measured during the second part of the program

From the comments presented in the third column of Table IV it can be seen that the measurements were performed during different surgical procedures as well as in unused theatres.

Outdoor concentration levels for these measurements were significantly lower in the SMPS range (up to thirty times) and comparable in the APS range in relation to respective outdoor concentration levels during the first set of hospital measurements.

Inspecting the data presented in the fourth column of Table IV it can be seen that indoor particle concentrations in all of the surgical theatres were low and not exceeding 200 particles cm^{-3}. For the first set of hospital measurements these values were in the range from 1.9×10^3 to 4.6×10^3 particles cm^{-3} (see Table II).

Comparing the data on particle size characteristics presented in terms of spectral modality and CMD for indoor and outdoor spectra in the SMPS range, it can be seen that the spectra differ in both these characteristics. While outdoor spectra had one characteristic peak located between 0.020 to 0.030 μm, indoor spectra were not necessarily unimodal and if there was more than one peak identified, the one with the smallest CMD was usually above 0.030 μm.

Ratios of indoor to outdoor particle concentrations

In order to account for differences in the outdoor concentration levels in the SMPS range between the first and the second experimental run and to explain the differences in indoor concentrations for the two runs, ratios of indoor to outdoor concentration levels for the SMPS and APS ranges were calculated and are presented in the last columns of Tables II, III and IV.

Using the ratios in submicrometer range from Tables II and III for surgical theatres only, an average value of (17.8 ± 12.1)% can be obtained. This value applies to surgical theatres in both hospitals, when the outdoor concentration of particles was very high. The average value of the ratio for surgical theatres calculated from the data presented in Table IV is (14.7 ± 9.5)%. Table IV presents results of measurements conducted when the outdoor concentration of particles was very low. While the difference in indoor concentration levels

of particles in the submicrometer range between the two measurement runs was more than an order of magnitude, the two values of indoor to outdoor concentration ratios levels are very close. The conclusion which can be drawn from this is that indoor concentration levels are closely related to outdoor concentration levels, indicating that outdoor particulates were the main contributor to the indoor particulates in the hospitals under investigations.

The average value of the indoor to outdoor concentration ratio in the submicrometer range for all measurements in the surgical theatres is (16.3 ± 10.9)%. The average value for the ratios in the supermicrometer range for all surgical theatres is (8.1 ± 5.4)%. While both values are associated with large errors, there is a clear indication that outdoor contributions to indoor particle concentration is higher in the submicrometer than the supermicrometer range. This would indicate lower efficiency of the filtration/ventilation system used in the surgical theatres for submicrometer particles. The possibility that outdoor particles could enter the rooms studied due to improper pressure difference was excluded as the theatres and surrounding area are kept under positive pressure.

Analysis of particle number concentration and size distribution spectra collected during different activities (surgical procedures, cleaning, normal occupancy) shows that there were not any detectable differences in particle number and size distribution related to different procedures. Thus, indoor sources did not result in generation of a detectable number of airborne particulates. The differences in filtration/ventilation efficiency with particle size range could explain the differences between the indoor and ambient spectral characteristics encountered in these measurements. Filtration process is size selective and the differences in size characteristics upstream and downstream filter can be expected. This difference varies between the filters. Evaluation of the changes to size characteristics for individual filters is a complex task, not necessarily justified for common

control of filtration systems.

Calculation of the average values of the indoor/outdoor relation in surgical theatres from the data presented in Tables II and III, for other than surgical theatres hospital units shows, that for the units using less efficient filtration/ventilation systems (RCH : respiratory and administration unit, RBH - casualty/waiting area) the ratios are (75.0 ± 6.2)% and (61.2 ± 13.8) for submicrometer and supermicrometer regions respectively. These values indicate that filtration/ventilation efficiency is comparable in both ranges and outdoor particulates contribute significantly to indoor particulate concentration levels.

On the other hand, for units such as Bone Marrow and Oncology (RCH) and Isolation Room (RBH), using more efficient systems the ratios are (1.3 ± 0.5)% and (1.7 ± 0.9)% indicating very low penetration of outdoor particles to the indoor hospital environment.

From the results presented here, it appears that the performance of filtration/ventilation system is the most critical parameter in reducing general particulate concentration levels and of particular importance in those hospital units where medical procedures can result in generation of potentially hazardous organic aerosols. While there was no evidence of increased concentration levels of particulates as a result of the surgical procedures conducted during the measurements presented here, trace concentration of pathogens, allergens or bacteria could have been introduced to the air. Those substances could be identified only by specific biological tests.

Decrease of background concentration levels of particulates results in decreases of the number of carriers for organic or microbiological aerosols in hospitals and ultimately in lowering potential heath risk due to inhalation of these aerosols. Thus control for particulates in hospital environments has a direct implication on microbiological and

infection control.

ACKNOWLEDGEMENT

This work was conducted with financial support from the Clean Air Society of Australia and New Zealand (postgraduate scholarship for M Jamriska).

The authors thank Don Glynn, Engineering Maintenance Supervisor, Department of Engineering and Building Services, Royal Brisbane Hospital, for his help in providing information on the hospital filtration and ventilation systems as well and help and suggestions in selecting sampling sites.

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TABLE I Ventilation and filtration systems used in the investigated units of the Royal Children's and Royal Brisbane Hospitals

SAMPLING LOCATION		FILTRATION/VENTILATION		
		Filters*	System	Air Change [ACH]
COLES BUILDING, RCH				
Level C	CANTEEN	A	R/A (Return Air)	15 - 20
Level E	ONCOLOGY	B	O/A (Outside Air)	10+
SURGICAL BLOCK, RCH				
Level D	SURGICAL THEATRES 1-6	B	O/A	20 - 22
Level D	INTENSIVE CARE UNIT	B	O/A	12 - 15
Level E	TRANSPLANT CARE WARD	A	R/A	10 - 12
WOOLWORTHS BUILDING, RCH				
Level G	ADMINISTRATION	A	R/A	10 - 12
Level E	BONE MARROW TRANSPLANT UNIT	C	O/A	15 +
Level E	RESPIRATORY UNIT	A	R/A	12 - 15
Level D	INFECTIOUS DISEASES UNIT	A	O/A	12 - 15
BUILDING No. 7, RBH				
Level A	CASUALTY - WAITING AREA	D	R/A (+ O/A)	10 - 15
Level B	MINOR OPERATIONS THEATRE	B	O/A	20 - 22
Level E	PATIENTS WARD	D	R/A	6 - 10
Level G	INTENSIVE CARE UNIT	B	O/A	10 - 15
BUILDING No. 9, RBH				
Level D	ISOLATION ROOMS	B	O/A	15 - 17
BUILDING No. 56, RBH				
Level D	DRUG PREPARATION UNIT	E	R/A	35

* Description of filters is provided in section 2.1

TABLE II Particle concentrations in the investigated units of the Royal Children's Hospital

SAMPLING LOCATION	AVERAGE PARTICLE CONCENTRATION [particles.cm^{-3}]		PARTICLE SIZE DISTRIBUTION (in submicrometer range)	ratio of concentrations $C_{indoor}/C_{outdoor}$ *3) %	
	Submicrometer particles*	Larger particles**	Count Median Diameter (CMD) of the peaks [μm]	submicrometer particles *	larger particles **
COLES BUILDING					
Level C CANTEEN	1.6×10^{4}	5.8	0.038	130	75
Level E ONCOLOGY	1.1×10^{2}	1.5×10^{-1}	Not Defined	2	3
WOOLWORTHS BUILDING					
Level G ADMINISTRATION	5.3×10^{3}	2.9	0.035	72	54
Level E BONE MARROW TRANSPLANT UNIT	7.1×10^{1}	8.1×10^{-2}	0.061	1	1
Level E RESPIRATORY UNIT	10.5×10^{3}	3.3	0.030; 0.105-0.115	84	43
Level D INFECTIOUS DISEASES UNIT	1.2×10^{3}	8.6×10^{-1}	0.025-0.030; 0.092-0.096	12	15
SURGICAL BLOCK					
Level D SURGICAL THEATRES					
No. 1	4.6×10^{3}	1.3	0.043	39	21
No. 2	2.0×10^{3}	2.5×10^{-1}	0.042	17	4
No. 4	1.9×10^{3}	not detectable	0.058	16	-
No. 5	3.1×10^{3}	$<3 \times 10^{-3}$	0.042	26	0.05
Level E INTENSIVE CARE UNIT	5.6×10^{2}	4.1×10^{-1}	0.055	6	7
Level E TRANSPLANT CARE WARD	4.0×10^{3}	1.0×10^{-1}	0.049	41	18
OUTDOOR					
Outdoor No. 1	12.8×10^{3}	9.1	0.027; 0.090-0.100		
Outdoor No. 2	12.1×10^{3}	6.2	0.025-0.030; 0.095-0.115		
Outdoor No. 3	7.3×10^{3}	5.4	0.030; 0.095-0.120		

* Size range : 0.017 - 0.7 μm

** Size range : 0.5 - 30 μm

TABLE III Particle concentrations in the investigated units of the Royal Brisbane Hospital

SAMPLING LOCATION	AVERAGE PARTICLE CONCENTRATION [particles.cm^{-3}]		PARTICLE SIZE DISTRIBUTION (in submicrometer range)	ratio of concentrations $C_{indoor}/C_{outdoor}$ [%]	
	Submicrometer particles*	Larger particles**	Count Median Diameter (CMD) of the peaks [μm]	submicrometer particles*	larger particles**
BUILDING No. 7					
Level A CASUALTY - WAITING AREA	7.5×10^{3}	$1.2. \times 10^{1}$	0.020; 0.040; 0.070	70	75
Level B MINOR OPERATIONS THEATRE	2.9×10^{2}	7.2×10^{-1}	not defined	3	5
Level E PATIENTS WARD	1.4×10^{3}	1.4×10^{0}	0.020; 0.035-0.045; 0.070	13	9
Level G INTENSIVE CARE UNIT	3.4×10^{2}	7.4×10^{-1}	not defined	32	5
BUILDING No. 9					
Level D ISOLATION ROOMS	5.0×10^{1}	1.8×10^{-1}	not defined	16	1
BUILDING No. 56					
Level D DRUG PREPARATION UNIT	2.2×10^{-1} *1)	1.2×10^{-2}	not defined	$2x10^{-3}$	$8x10^{-2}$
OUTDOOR					
Outdoor No.1 (Next to Building 56)	10.5×10^{3}	1.6×10^{1}	0.020; 0.070-0.080;		
Outdoor No.2 (Next to Building 7)	10.8×10^{3}	1.6×10^{1}	0.020; 0.035-0.060;		

*1) Concentration below SMPS detection limit; presented concentration measured by Condensation Nuclear Counter without classifcation.

* Size range : 0.017 - 0.7 μm

** Size range : 0.5 - 30 μm

TABLE IV Particle concentrations in the investigated units of the Royal Children's Hospital

SAMPLING LOCATION :	SAMPLING POINT	ACTIVITY	AVERAGE PARTICLE CONCENTRATION [particles.cm^{-3}] Submicrometer particles*	Larger particles**	PARTICLE SIZE DISTRIBUTION (in submicrometer range) Count Median Diameter (CMD) of the peaks [μm]	ratio of concentrations $C_{indoor}/C_{outdoor}$ [%] submicrometer particles *	larger particles**
Level D	SURGICAL THEATRES						
No.1	in the middle of the room	Used and cleaned 3 hours before measurement	95	2.5×10^{-1}	0.035-0.040; 0.095 - 0.125		
	HVAC outlet *1)	Used and cleaned 3 hours before measurement	78	not detectable*2	0.035; 0.090 - 0.130		
		Average	87	2.5×10^{-1}		20	8
No.2	in the middle of the room	Used and cleaned 24 hours before measurements	16	2.0×10^{-2}	not defined		
	HVAC outlet *1)	Used and cleaned 24 hours before measurements	7	not detectable*2)	not defined		
		Average	12	2.0×10^{-2}		3	1
No. 3		Surgery: Cataract removal +intracellular lens insertion					
	in the middle of the room	Preparation for surgery	38	not detectable*2)	0.025; 0.055; 125 1400.125		
	in the middle of the room	During surgery	39	1.9×10^{-1} 1.9×10^{-1}1.9 x 10	0.025-0.030;		
	in the middle of the room	During surgery	43	not detectable*2)	0.030-0.045		
	in the middle of the room	During surgery	36	not detectable*2)	0.030-0.075		
	in the middle of the room	After surgery	29	not detectable*2)	0.035;		
	in the middle of the room	After surgery, during wet cleaning	59	not detectable*2)	0.033		
		Average	41	1.9×10^{-1}		9	6
No. 4 Surgery:		Excision of Naevus R Tempropriate area					
	in the middle of the room	Preparation for surgery	32	4.3×10^{-1}	0.020; 0.055-085		

	in the middle of the room	During the surgery	22	not detectable[*2)]	0.070-0.090		
	in the middle of the room	After the surgery	25	not detectable[*2)]	0.030-0.040; 80-110		
		Average	26	4.3×10^{-1}		5	14
No.5	Unused for 3 weeks; (repair work done in the plenum - ceiling area 6h prior measurements)						
	in the middle of the room	Unused for 3 weeks	130	2.1×10^{-1}	0.020 -0.030; 60-70;110-145		
	in the middle of the room	Unused for 3 weeks	127	Not measured	0.020-0.030; 55-70;		
	HVAC outlet 1	Unused for 3 weeks	151	Not measured	0.035-0.045; 110-125		
	HVAC outlet 2	Unused for 3 weeks	80	1.3×10^{-1}	0.040-0.045;		
	HVAC inlet	Unused for 3 weeks	132	Not measured	0.030-0.045		
		Average	124	1.7×10^{-1}		28	5
No. 6	in the middle of the room	Used and cleaned 48 hours before measurements	115	3.1×10^{-1}	0.030-0.040;		
	HVAC inlet	Used and cleaned 48 hours before measurements	84	Not measured	0.040-0.050; 90 -110		
		Average	100	3.1×10^{-1}		23	10
Area encapsulating the theatres - entrance area	in the middle of the room	Normal activity	74	3.8×10^{-1}	0.030-0.050		
OUTDOOR							
outside RCH	shielded inside of the Hospital complex usual afternoon conditions -traffic		440	3.2×10^{1}			

* Size range : 0.017 - 0.7·μm

** Size range : 0.5 - 30 μm

[*1)] HVAC (heating, ventilation and air conditioning) outlet - air flows into the room, inlet - air flows from the room

[*2)] Below the APS detection limit

FIGURE CAPTIONS

Figure 1 Particle size distribution of outdoor air sample No. 1 collected with the SMPS. The size distribution is bimodal with the Count Median Diameter (CMD) of the first peak about 30 nm and the second peak about 100 nm.

Figure 2 Particle size distribution in the Respiratory Unit collected with the SMPS

Figure 3 Particle size distribution in Surgical Theatre 1, Royal Children's Hospital collected with the SMPS. The unimodal distribution with CMD of about 35 to 50 nm was typical for all the surgical theatres in both hospitals as well as for the Transplant Care Unit in the RCH.

Figure 4 Particle size distribution collected independently with the SMPS (left hand scale) and the APS (right hand scale) in Surgical Theatre 1

Figure 5 Particle size distribution in the Intensive Care Unit collected with the SMPS