INDOOR-OUTDOOR AIR PARTICULATE STUDY IN A SOWETO HOME

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1. INTRODUCTION

Air quality is increasingly becoming an important aspect of environmental exposure to pollutants. Although in South Africa attention has heretofore been focused on industry's contribution to air pollution, indoor air pollution is a factor receiving increasing attention. In the USA, extensive research is in progress to measure and improve indoor ambient air quality. It has been established that many people spend most of their time inside buildings where air quality may be markedly different from that outdoors. Those segments of population most susceptible to health ills from air pollution (the old, the infirm and the very young) spend almost 100% of their time indoors.

Of course the composition of the atmosphere in terms of gross constituents (e.g. oxygen and nitrogen) is essentially the same indoors as outdoors, but the types and quantities of contaminants indoors can be quite different from those outdoors. Unreactive pollutants such as carbon monoxide readily penetrate the indoor environment, but indoor sources, such as unvented gas stoves and attached garages, may cause indoor concentrations to exceed those outdoors.

Indoor activities and materials can produce significant concentrations of indoor pollutants not normally found outdoors[1]. Efforts to conserve energy in houses invariably requires improved sealing of openings and other methods of reducing air exchange between indoors and outdoors. These measures tend to accentuate differences between indoor and outdoor air quality.

In southern Africa determination of outdoor and indoor air quality relationships in homes have been carried out to a very limited extent to date. It is hoped therefore that the present experiment, that has been carried out in Soweto to determine indoor and outdoor ambient air quality, will open greater avenues of investigation of indoor-outdoor air quality. The present experiment focuses on the concentrations of suspended particulates outdoors and indoors in a typical Soweto home and how these concentrations vary in a 24 hour cycle during a typical winter's day.

2. SAMPLING SITE

The site, a typical Soweto four-room house, was chosen at the heart of Soweto and is representative of the amount and intensity of pollution to which residents are exposed. Further, being at the centre of Soweto, the pollution levels would not be greatly affected by changes in wind direction. The area was not particularly densely populated. Specifically it is an area where not more than one family lived in the same yard and therefore not more than one coal-burning stove was used at a time. The conditions are thus not extreme but what one would find randomly. A site was chosen at Mofolo Central shown in Figure 1. The site was 6 km from the closest city limit. An unpaved road ran in front of the house, carrying a light traffic density of 2 vehicles per hour. Twenty metres to the north west was a paved road carrying heavy traffic. In Soweto, peak commuter periods are from 05h00 to 08h00 and 16h00 to 20h00. The site was 3 km North of the main Potchefstroom Road. Towards the North, 200 m distant, is Mofolo Park, lying in a shallow valley.

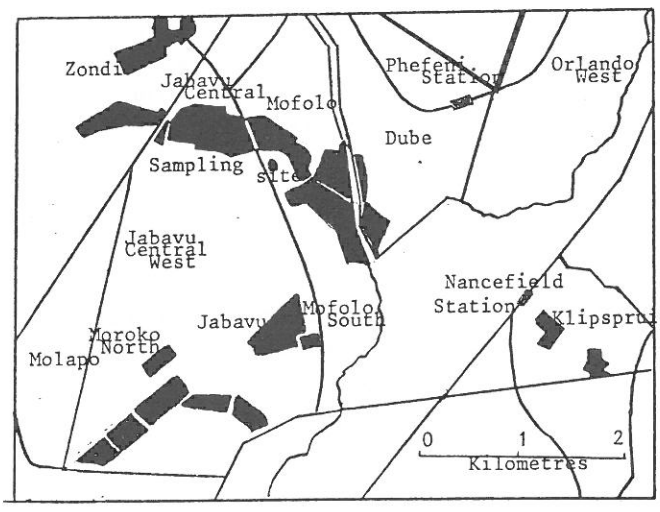

FIGURE 1: Map of Soweto showing location of indoor-outdoor sampling site.

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The house is a semi-detached four roomed house with an outside toilet. It is surrounded by a pre-cast concrete wall and a steel gate. In front of the house is a lawn and a cemented driveway. The home consists of two bedrooms, a kitchen and a dining room. There were two outside doors, and a window in each room. Windows and the top half of the front door were generally left open during the day and shut at night. Both the bedrooms and the dining room were used for sleeping at night. All the rooms had ceilings, made of ceiling board in the kitchen and wood in the others. Low installation of the ceilings resulted in air bricks being blocked off from the living space, inhibiting interchange of air to some extent. Coal burning was used for cooking, while electricity was used for space heating and lighting. No other form of heating appliance was used, save for an electric kettle for boiling water.

The home was occupied by three persons, two adults and one teenager. Only one was employed; he left for work at 05h00. There was not much going in and out of the home. There were no smokers and no children could play about in the house or yard, thereby raising dust. A small dog had free access to all rooms at whatever time. The cleaning of the house was done in the morning, save for a brief cleaning of the kitchen in the afternoon when the stove was cleaned and the fire started. The coal stove was left burning all night to keep the house warm, but died off in the early morning and was restarted at around 04h00.

3. METHOD

The experimental apparatus for sampling is shown in Figure 2, consisting of a Stacked Filter Unit (SFU) dichotomous sampler[2], pulsation damper, pump, gas meter and flow meter. The SFU holds two Nuclepore filter membranes in series, with 8.0 and 0.4 μm diameter pore sizes, respectively. The first filter has an effective 50% cut-point of ~3 μm aerodynamic diameter (μmad), effectively separating particles into two size ranges, greater than and less than 3 μmad (see Figure 4). Following Yocom's review[3], we shall refer to the coarse particles, > 3 μmad and <15 μmad, trapped on the first filter, as Inhalable Particulate Matter (IPM), and fine particles, < 3 μmad, trapped on the second filter, as Respirable Particulate Matter (RPM). Sampling intervals were intended to be 4 hours, commencing every fourth hour over a thirty hour period. In practice, clogging of the fine filter necessitated terminating some of the samples after ~2.5 hours.

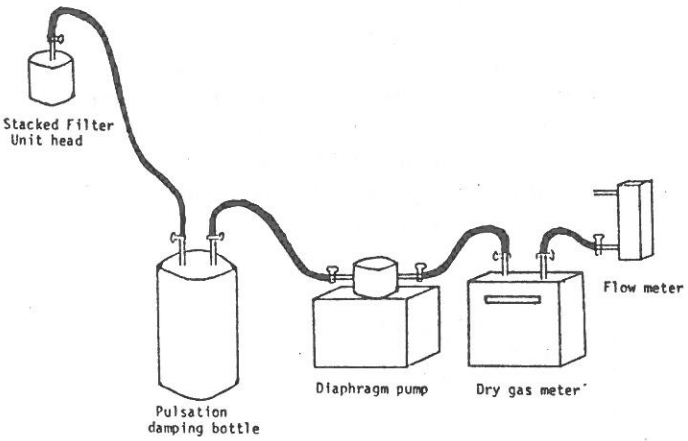

FIGURE 2: Stacked filter unit (SFU) sampling train.

Filter masses were determined before and after exposure with an electronic balance with 0.01 mg precision. Suitable precautions were taken to eliminate electrostatic effects and to allow for humidity conditioning.

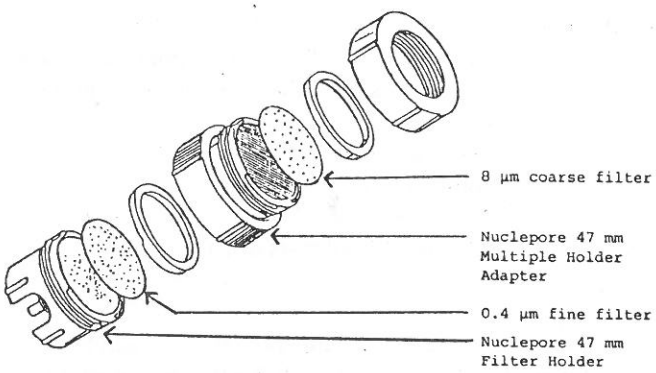

FIGURE 3: Components of the stacked filter unit dichotomous aerosol sampler.

Size segregated samples were also collected using single orifice 9-stage cascade impactors and analysed by Particle Induced X-ray Emission (PIXE). Details of the techniques are described elsewhere[4].

4. RESULTS AND DISCUSSION

The SFU filters, which were scheduled to sample for 4 hours had to be replaced after sampling for 2.5-3.5 hours, due to the very high concentrations of the fine particles, which caused clogging of the filters.

The sun was not visible through the smog long after

it had risen. By 10h00 the sun was fairly visible. However, the visible smog, smoke and dust did not clear completely throughout the sampling period, even at midday. There were fires burning all day, despite the temperature being warm from midday through the afternoon. Although some coal fires are left burning through the day, there are far more that are left burning through the night.

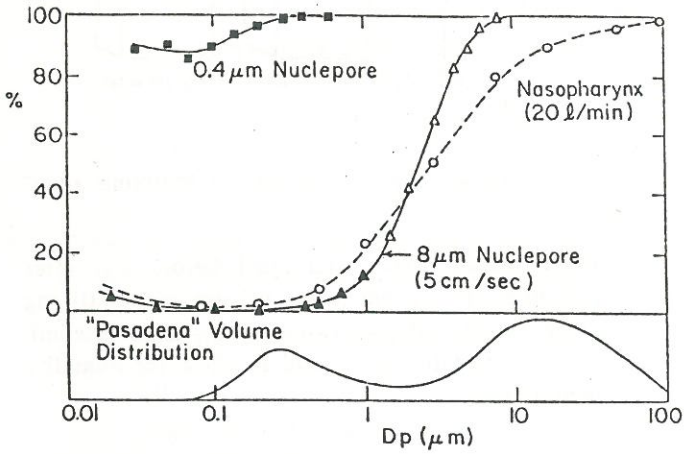

FIGURE 4: Aerosol collection efficiencies for 0.4 and 8.0 μm pore diameter Nuclepore membrane filters. X axis scale is in units of particle aerodynamic diameter. Particle deposition in the human nasopharynx region is superimposed. The 8.0 μm filter 50% cutpoint occurs at the minimum in the natural bimodal aerosol mass distribution.

Indoor and outdoor temperatures are compared in Figure 5. When the indoor and outdoor temperatures were the same, this indicates that doors and windows

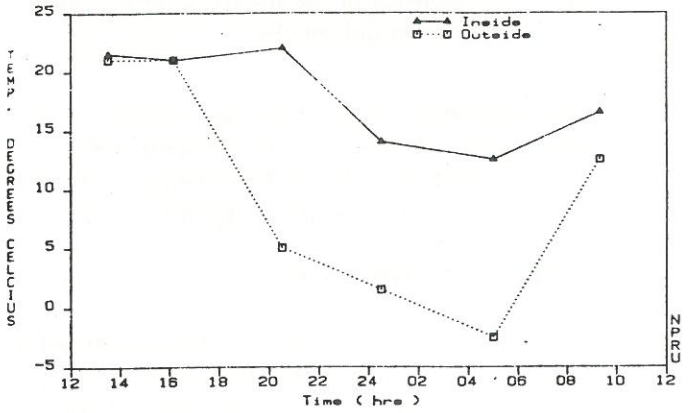

FIGURE 5: Temperature variation for inside and outside.

of the house were open and that unimpeded air exchange was taking place. Conversely, when there was a large temperature differential we assume that air infiltration was restricted. We interpret particulate concentrations with these observations in mind.

The particulate concentration measured indoors and outdoors are compared in Figures 6 and 7 for RPM and IPM respectively. Indoor/outdoor ratios (I/O) are presented in Table 1.

TABLE 1: Indoor-outdoor relationships for the fine (Respirable Particulate Matter) and coarse (Inhalable Particulate Matter) in a Soweto home

	Fine (<3.5 μmad)			Coarse (<15 μmad)		
Sampling interval	Indoor ($\mu g/m^3$)	Outdoor ($\mu g/m^3$)	I/O ratio	Indoor ($\mu g/m^3$)	Outdoor ($\mu g/m^3$)	I/O ratio
16h00-19h40	105	98	1.07	1227	2193	0.56
20h30-24h00	55	92	0.60	982	1724	0.57
00h30-04h00	80	100	0.80	438	641	0.68
05h00-08h40	137	236	0.58	1130	1713	0.66
09h20-12h40	52	28	1.82	727	376	1.93
13h30-17h00	34	34	0.98	66	141	0.47
Mean	77	98	0.98	762	1131	0.81

RPM concentrations outdoors are almost constant throughout the period from the late afternoon until the early hours. A sharp maximum of 236 $\mu g/m^3$ was recorded between 05h00 and 08h00. This coincides with the interval during which coal fires are started for breakfast and for warming the house. The meteorological inversion is also most stable at this time. The lowest concentrations were recorded in the late afternoon period. Maximum dilution of ground level pollutants occurs at this time, due to vertical mixing. In addition, coal smoke generation is at its lowest during the warmer hours of the day.

Indoor RPM concentrations are comparable to outdoor concentrations during the afternoon (I/O ~ 1.0, see Table 1 – Figure 6). This is expected, since windows and doors were open during this period. At night, when windows and doors were closed, I/O dropped to 0.6 - 0.8, but indoor RPM still followed the gradually increasing trend of outdoor RPM concentrations. The increasing outdoor concentrations are attributed to the build-up of coal smoke beneath the stable surface inversion. The lower indoor concentrations are a consequence of the 1 to 2 hour time lag induced by building resistance to infiltration of outside air.

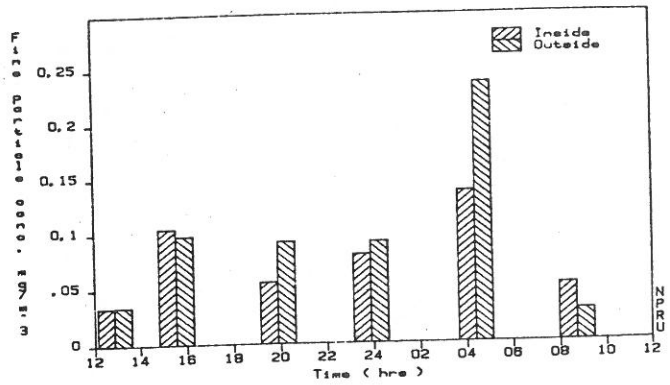

FIGURE 6: Fine particle concentration vs time of day.

The late morning was the only period during which the indoor concentrations exceeded outdoor concentrations, for both fine and coarse particulates (I/O = 1.82 and 1.83, respectively). This indoor excess is attributed to internal sources, probably dust raised by sweeping of the rooms and cleaning of the coal stove.

The mean RPM values for Soweto were 77 and 98 $\mu g/m^3$ for indoors and outdoors, respectively, a factor of two or more higher than reported for the mean RPM concentrations in the Harvard Six Cities Study[5]. Furthermore, unlike several other studies of indoor air quality in the USA[3,5] where smoking was indicated as a major contributor to RPM, the Soweto results indicate that outdoor pollution would be the major contributor, even if there were smokers in the house.

Coarse particulate concentrations (IPM) indoors decreased from late afternoon up until midnight, were high again in the early morning and then dropped to even lower values during daytime (Figure 7). Outdoor IPM concentrations followed the same pattern, reaching a maximum in the early afternoon late evening period. Lowest concentrations were recorded during midday to late afternoon. This pattern coincides with periods of maximum use of coal stoves and provides evidence that coal smoke was the major source of these particles. I/O values were stable within the range 0.47 to 0.68, except for the period morning to midday when the house was being cleaned. We attribute these values of I/O, slightly below unity, even when doors and windows were open, as being due to reduced turbulence inside the house, which would have allowed for more rapid settling of coarse particles.

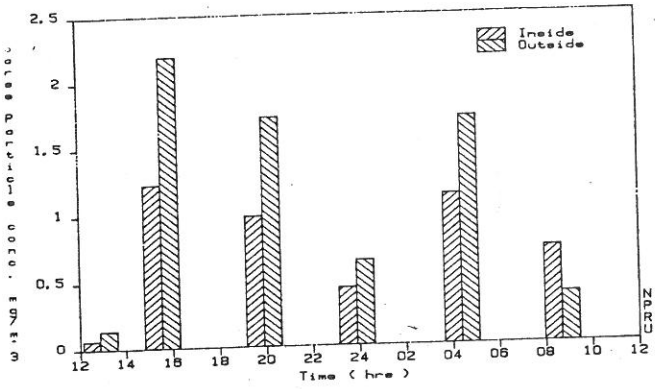

FIGURE 7: Coarse particle concentration vs time of day.

Not only the size range of particles is important in evaluating possible health effects but also the chemical composition. The results of size segregated samples of Soweto particles, collected using a cascade impactor, are shown in Figures 8 and 9. Figure 8 compares the particle size distributions for the element silicon at three different times of day. Silicon is the predominant non-carbon component of fly-ash (as well as of soil dust). The curves have the common feature of a primary maximum in the 4 - 8 μmad range. This is as expected, confirming also the predominance of mass in the IPM (coarse filter fraction) of the Stacked Filter Unit samples (IPM/RPM = 11.5). Somewhat surprising is the presence of secondary maxima in the range 0.25 - 0.5 μmad. These secondary maxima are an indication of fine silicon particles

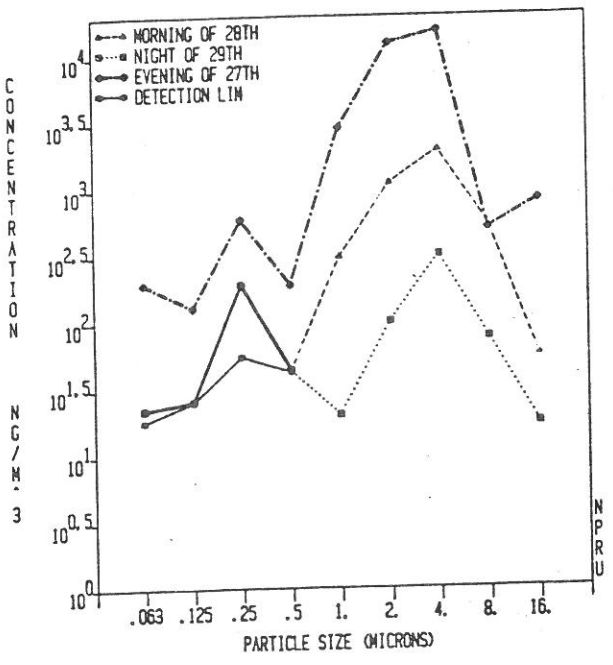

FIGURE 8: Silicon size distribution in Soweto particles.

formed from either a different source from that of the course silicon particles, or still from coal burning, but via a different processes. Evidence of such coal-fired power plants, has been presented previously[6].

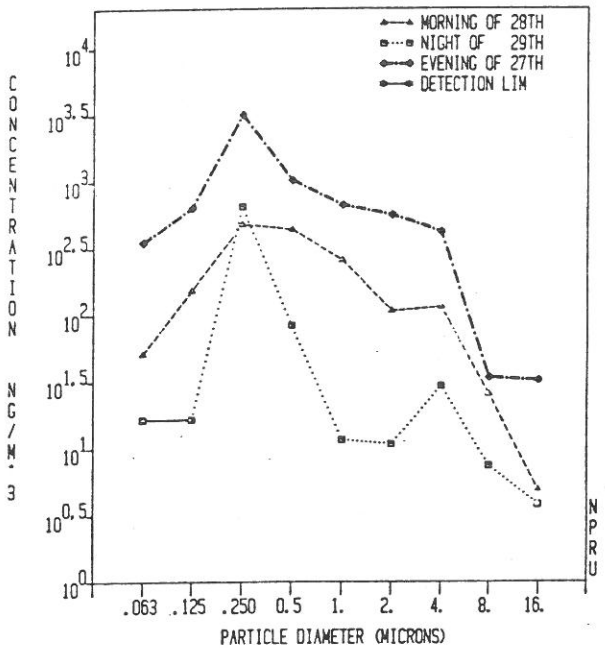

FIGURE 9: Sulphur size distribution in Soweto particles.

For the element sulphur, the size distributions peak in the RPM range, at 0.25 μmad, indicating that the sulphur is present as sulphates resulting from secondary conversion of SO_2 in the atmosphere. The secondary maxima at 4 μmad, coinciding with the peak of the coarse (Si) dust, may be due either to pyrite (FeS) particles from the fly ash, or sulphates adhering to the surface of the predominant IPM particles. Both should be taken into account in evaluating possible health effects of Soweto particles. Such an evaluation is, however, beyond the scope of this paper.

5. CONCLUSIONS

A short term study has been made of indoor and outdoor Respirable Particulate Matter and Inhalable Particulate Matter in a Soweto home during the winter season. Comparison of indoor/outdoor concentration ratios different times of the day showed that the predominant source of indoor particulate matter in both size ranges was ingress of outdoor polluted air. Peak concentrations occurred in the early hours of the morning both outdoors and indoors. The concentration of IPM were found to be more than a factor of two higher than studies in homes in the USA. The source of the high particulate concentrations was attributed to domestic coal burning, aggravated by strong surface inversions during winter nights.

It is concluded that efforts to reduce pollution exposure of Soweto residents would have to focus on reduction of ambient rather than indoor air pollution.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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