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INDOOR AIR QUALITY STUDY

MARAGUA AREA, KENYA

An indoor air pollution study was carried out in Maragua, Maragua District, Central Province, Kenya, in coordination with the University of Nairobi and Kenyatta University, both located in Nairobi. The project was linked to two ARI studies, which are supported by the World Health Organization and the U.S. National Academy of Science.

Repeated 24-hour measurements of respirable suspended particles and nitrogen dioxide were carried out in 36 randomly selected houses where most of the cooking was done on open fires using firewood or crop residuals as fuels. In three houses hourly pollution measurements were made between 6 a.m. to 10 p.m. to observe the times at which peak values occurred. A questionnaire was used to collect information on demographic, house, fuel and cooking characteristics.

The mean of the 24-hour average RSP measurements was 1400 $\mu g/m^3$. During the seven hours per day on average during which the fire was burning levels were estimated to reach 3000 - 4000 $\mu g/m^3$. In the evening peak levels up to 36000 $\mu g/m^3$ were observed. The average RSP concentrations and the peak levels during the evening indicate that health effects due to excessive exposure to smoke from biomass combustion are likely to occur among pre-school children and women. Also, the concentrations of selected polycyclic aromatic hydrocarbons in the particulate material was found to be high.

The average concentrations of NO_2, CO, COHb and formaldehyde were respectively 90 ppb, 8 ppm, 0.5% and < 0.1 ppm. These levels were significantly lower than found in other indoor air pollution studies in developing countries. Low CO_2 concentrations pointed to high ventilation rates.

Analysis of variance showed little or no correlation between pollution levels and house characteristics. Also very homogeneously distributed concentrations were found among the houses. This corroborates the observation that no relation could be detected between ARI incidence and pollution levels or housing characteristics. To draw such conclusions a subgroup with lower exposure levels would have to be included in the study.

CONTENTS

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2. PREFACE

A review made by WHO some years ago of the scientific literature on indoor air pollution caused by burning biomass fuels for cooking and heating showed quite a relatively serious problem (WHO, 1984). Not only are the levels of different air pollutants in rural houses high but this problem appears to exist in rural areas in Asia, Africa and Latin America and is therefore widespread. It is conservatively estimated that some 500 million persons, mostly women and children, are exposed to levels of indoor air pollution that are well above those considered safe.

The extent and severity of health effects associated with biomass fuel combustion is not well defined and WHO is undertaking a number of field surveys to provide better information and data in this area. To accomplish these surveys cooperation was developed between the Respiratory Infections Programme and the Unit for Prevention of Environmental Pollution. The indoor air pollution surveys are being carried out in different countries where Acute Respiratory Infection studies in children are in progress in order to be able to correlate the data and information produced. In this document the results of the first of the cooperative studies, which was carried out in Maragua, Kenya, are reported.

The study involved the cooperation of the Ministry of Health and two Universities in Nairobi as well as the Agricultural University in Wageningen, the Netherlands. Sections of this report were prepared by different experts involved in the project both in Kenya and the Netherlands. The final report was assembled by WHO staff using the various contributions.

The ultimate purpose of this field survey described above (and others to be implemented in the future) is to consider and evaluate in more detail the health implications of indoor air pollution and to engage the health sector in advocating solutions to eliminate or prevent the problem. Such activities will involve the preparation of guideline documents, training of rural health workers and cooperation in international efforts to bring about technological changes such as the introduction of clean stoves, improved housing design and community participation in implementing these changes.

3. INTRODUCTION

Indoor air pollution is increasingly being associated with acute respiratory infections in children. In developing countries, indoor air pollution is mainly due to biomass fuel combustion in dwellings that are often poorly ventilated. Air Pollutants from biomass fuel combustion include carbon monoxide (CO), nitrogen oxides (NO_x), formaldehyde (HCHO) and respirable suspended particles (RSP). The RSP contain polycyclic aromatic hydrocarbons (PAH's), some of which are known to be carcinogenic (WHO, 1984).

The air pollution study was carried out in the Maragua area, within the epidemiology and aetiology study supported by the World Health Organization and the National Academy of Sciences (NAS), USA. The WHO epidemiological study is conducted in an area of 12,000 children below five. The NAS study is a two-year longitudinal study among children aged below five years on acute respiratory infections (ARI). The study population is within 250 households and comprises 470 children aged below five years.

Important characteristics of the households of the study population for the air pollution study are summarized below:

(i) The average household has seven members. Forty-six percent of the mothers have five or more children while 14 percent have nine or more children. Sixty-five percent of repeat births occurred within 30 months of the previous birth.

(ii) The houses have dirt floors in 94 percent with walls usually made of mud and wood. Seventy-nine percent of the roofs consist of iron sheets while 20 percent are thatched. On average, each house has three rooms.

(iii) In 97 percent of the homes cooking is done using wood. Cooking is carried out within the house in 58 percent of the homes and in a separate kitchen in 42 percent. Lighting is provided in the homes by kerosene lanterns.

(iv) Eighty-four percent of the population have lived in their present homes for eight or more years.

More detailed information on the households in the indoor air pollution study is given in Appendix I.

4. OBJECTIVES OF THE STUDY

(i) Measure carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), respirable suspended particles (RSP) with their associated polycyclic aromatic hydrocarbons (PAH's), as an indicator of air pollution in a representative number of houses in the Maragua area;

(ii) Evaluate the main factors contributing to high indoor air pollution exposure for children aged below five years in the study population;

(iii) Explore the feasibility of assessment of the relationship between the level of indoor air pollution and the incidence of ARI.

5. SELECTION OF THE HOUSES

Thirty-six households were randomly selected from the 250 in the area within the following groups stratified according to the roofing and kitchen arrangements:

(i) Iron roof with attached kitchen - 9 households;

(ii) Iron roof with detached kitchen - 8 households;

(iii) Grass roof with attached kitchen - 10 households;

(iv) Grass roof with detached kitchen - 9 households.

The size of most houses is between 25 and 35 square meters. Typical examples of the houses are given in figures 1 and 2.

Figure 1. Houses in the Muranga district, Kenya (iron roofs)

Most of the families have only a small area of land of about two to four acres where they grow corn and beans for own consumption and some cash crops like bananas and coffee. The women do the actual farming as well as the collection of the firewood, the cooking, the upbringing of the children etc., etc. Many men have a job in Nairobi, and they are at home only during the weekend.

Most of the cooking is done above an open fire using three stones. An aluminium pan, mostly for preparing tea or porridge or a pot made of special clay for cooking corn and beans is put on the stones about 20 centimeters above the fire. An example of the fireplace is given in figure 3. Most of the fuel that is used is wood of different types and quality, but sometimes agricultural wastes from bananas (stem), sisal (stem) and corn (corn-cob) are used.

Figure 2. House in the Muranga district, Kenya (thatched roof).

Figure 3. Typical fireplace for cooking.

Only in a few houses a simple stove is present but without a chimney. The smoke of the fire circulates through the whole house as the walls between the rooms do not reach up to the roof. The windows, mostly simple open spaces in the mud wall, the outside door and an open space between the wall and the lower rim of the roof, provide ventilation.

6. STUDY DESIGN

The air pollution survey had three components as follows:

6.1 Administration of a questionnaire

A questionnaire (Appendix II) was administered to the mother of the under five-year old child in each household studied. The information collected concerned house characteristics, fuel used for cooking, duration of fires, types of food cooked and activities of the mother and children (five years and under) during the time of the air pollution measurements.

6.2 24-hour average measurements

In all 36 houses 24-hour average measurements for RSP and NO_2 were performed twice with an interval between the two measurements of about one week. For measuring the RSP level the pump/filter method followed by weighing was used. This method consists of the following elements:

A Dupont P 2500 constant flow unit was used as air mover. This pump has an electronic flow correction to compensate for increasing resistance due to filter loading. An extra battery was installed (5V, 4 A-h) to allow a sampling time of 24 hours.

A PAS-6 filterholder was used as sampling head. Although such a filterholder has been designed for measuring total suspended particles, the cut-off diameter of the particles measured is lower (ter Kuile, 1984). An illustration of the filterholder and further technical details are given in Appendix III, figure 1. Glass-fibre filters (Whatman 6F/A, 2.5 cm) were employed.

A digital microbalance (Mettler, 0.1 mg) was used at the Department of Chemistry, Kenyatta University. Before weighing the filters were placed for at least 24 hours in a desiccator containing a saturated potassiumcarbonate solution.

At the beginning and the end of each sampling period the flow of the pumps was checked with a Brooks flowrator (rotameter type R-6-15-A, glass). The flowrators were calibrated against a soapbubble meter. The pump and battery were installed in a wooden box for protection and noise reduction. Attached to this box was an aluminium pole through which the sampling tube was led to the PAS-6 filterholder. The sampling height was 80 cm, corresponding with breathing height during the preparation of the meal. An illustration of the measuring unit is given in Appendix III figure 2.

In 20 filters the amount of polycyclic aromatic hydrocarbons (PAH) was determined by the Dutch standard method (NVN 2798, 1986). The glass-fiber filters were kept in the dark in a refrigerator at -18°C for a period of about six months before analysis. The filters were extracted in cyclohexane under ultrasonification. Aliquots of the extracts were injected into a liquid chromatograph with a Vydac 201 TP B5 column and the PAH were detected by fluorescence (254 nm). Only the less volatile PAH (4 rings or more) have been analysed as the more volatile ones tends to evaporate from the filters and carcinogenicity for the individual compounds is only found for the less volatile PAH (IARC, 1983).

For 24-hour average measurements NO_2 Palmes diffusion tubes were used, in which triethamolamine is used as absorbent. Atmospheric NO_2 is transferred from the open end of the tube to the absorbent at the closed end by molecular diffusion. After adding the "Saltzmann" reagent the NO_2 can be analysed spectrophotometrically (540 nm); the method has been described in detail by Boleij et al (1986). The tubes were placed in pairs on the same support to which the PAS-6 folterholder was attached and at the same measuring height (Appendix III).

6.3 Daily pollution pattern measurements

To observe the variations in concentrations during the day in three houses between 6 a.m. and 10 p.m. each hour several instantaneous measurements were made. Three different types of houses not far apart were chosen (iron roof with attached kitchen; iron roof with detached kitchen; thatched roof with attached kitchen). Spot measurements of RSP (piezobalance), CO and CO_2 (Dräger tubes) were made each hour. Formaldehyde and CO in expired breath were occasionally assessed. Each hour observations on time budgets and activity patterns were made in the three houses. The same measurements were occasionally performed during house visits for the 24-hour average measurements.

The instantaneous RSP levels were measured using a direct reading piezobalance : Thermo Systems Inc., model 3500, Respirable Aerosol Mass Monitor, with a 50% cut-off diameter of 3.5 μm. The principle of the piezobalance is based on a change in vibration frequency of a crystal after loading with respirable particles from a known amount of air. The respirable particles are precipitated on the crystal by impaction after preseparation by a cyclone.

The carbon dioxide, carbon monoxide, formaldehyde and CO in expired breath measurements were made using Dräger indicator tubes. The indicator tubes were used together with a hand operated pump. With the pump a measured amount of air can be pulled through the tube filled with an absorbent and reagent giving a colour reaction. A scale has been printed on the table for direct reading. The relative standard deviation of this method is about 10 - 20 percent. The tubes that were used included:-

	Catalogue number
- CO	CH 25601
- CO_2	CH 30801
- formaldehyde	6733081
- + activator tube	5935010
- COHb	CH270

7. FIELDWORK

The equipment was prepared, charged and stored in a room at the Maragua Rural Health Training Centre, the same centre from where the fieldwork of both ARI-studies were carried out. Here also the filters and Palmes tubes were stored after sampling.

Two groups of fieldworkers each placed 6 sets of equipment for the 24-hour average measurements. The sets were collected the next day. Both groups of fieldworkers were composed of at least one local ARI-fieldworker, one technician or staff member from the Kenyatta University, Department of Chemistry, Nairobi, and one teamworker of the Dutch Agricultural University. Most days one or both groups were accompanied by staff members of the Health Centre or the ARI research team from Nairobi, who were interested in seeing the actual fieldwork.

The local ARI fieldworkers were of great help because they were very familiar with the families from the regular visits. They acted as interpreters and assisted with completing the questionnaires.

Prior to the first installation of measurement equipment in each house an appointment was made during which an explanation about the measurements was given to the occupants and permission was asked. None of the families contacted refused to cooperate in the study.

The following time schedule was used for the fieldwork:

		1st measurement	2nd measurement
1.	placing equipment in first of 6 houses	Th. 18/4	We. 24/4
2.	collecting equipment in first 2 groups of 6 houses	Fr. 19/4	Th. 25/4
3.	placing equipment in second 2 groups of 6 houses	Sa. 20/4	Fr. 26/4
4.	collecting equipment in second 2 groups of 6 houses	Su. 21/4	Sa. 27/4
5.	placing equipment in third 2 groups of 6 houses	Mo. 22/4	Tu. 30/4
6.	collecting equipment in third 2 groups of 6 houses	Tu. 23/4	We. 1/5

In this way a total of 36 houses was monitored. The second measurements about a week later were scheduled on different days of the week. The night between collecting and replacing the equipment was used for recharging the batteries.

During the first visit when the equipment was placed, the demographic part of the questionnaire as well as the part on house characteristics was completed. At the same time the fieldworkers explained to the mother which questions about activities during the period of measurement of the mother and children participating in the ARI-study, were going to be asked the next day. On the following day during collection of the equipment the questionnaire was completed.

On the first day of the fieldwork, spot measurements were made in all 12 houses. After evaluation of these first results the decision was made that only in case of a burning fire it was useful to do spot measurements on CO, CO_2 and RSP-levels.

CO in expired breath in order to assess the COHb level was only performed if the ambient CO concentration in the kitchen exceeded 10 ppm and the mother had been in the kitchen for at least 30 minutes before the field team arrived.

Formaldehyde was only measured when the fire was burning vigorously and a high concentration (more than 2000 $\mu g/m^3$) of RSP was found. As only one RSP Piezo balance was available, one team used the monitor on "placing day", the other team on "collecting day".

8. RESULTS

The analysis and interpretation of the data collected in Maragua has been partially completed. Data on burning time of the fires are not yet included in the analysis.

8.1 Analysis of 24-hour RSP data

8.1.1 Summary of statistics and analysis of variance

Complete data sets of repeated measurements are available for 30 homes; in 6 homes the results of one measuring period are missing due to technical failures (4 times) or the absence of the family during the second measuring time (2 times). The individual data are given in Appendix IV. Summary statistics of the results are presented below:

	n	AM ($\mu g/m^3$)	SD ($\mu g/m^3$)	GM ($\mu g/m^3$)	GSD ($\mu g/m^3$)	min ($\mu g/m^3$	max ($\mu g/m^3$)
series I	35	1391	853	1150	1.9	189	3212
series II	32	1402	1140	1048	2.2	242	4379
series I + II	67	1397	997	1099	2.0	189	4379

n = number
AM = Arithmetic mean
AS = Standard Deviation of the AM
CM = Geometric Mean
GSD = Geometric Standard Deviation
min = minimum
max = maximum

A histogram of the results is presented in figure 4.

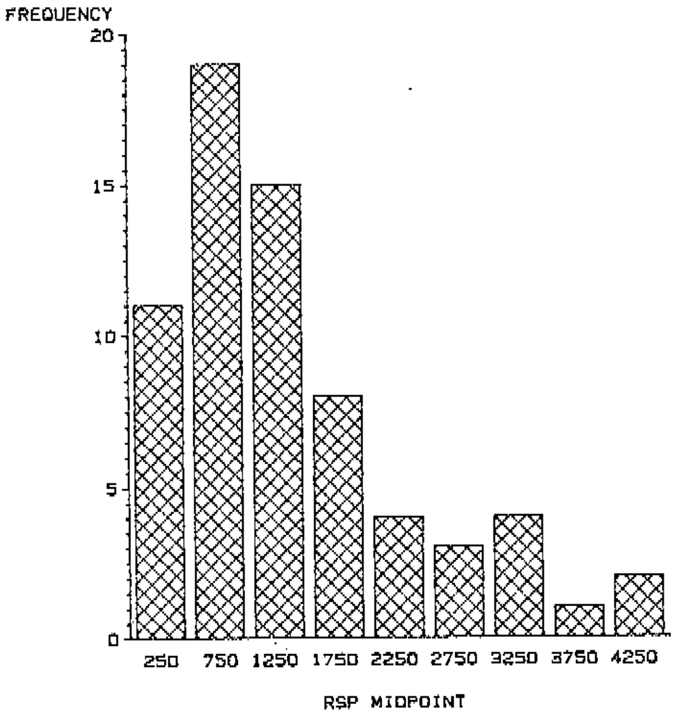


Figure 4. Histogram of 24-hour average RSP levels (μg/m³)

A cumulative distribution of the levels is plotted in figure 5.

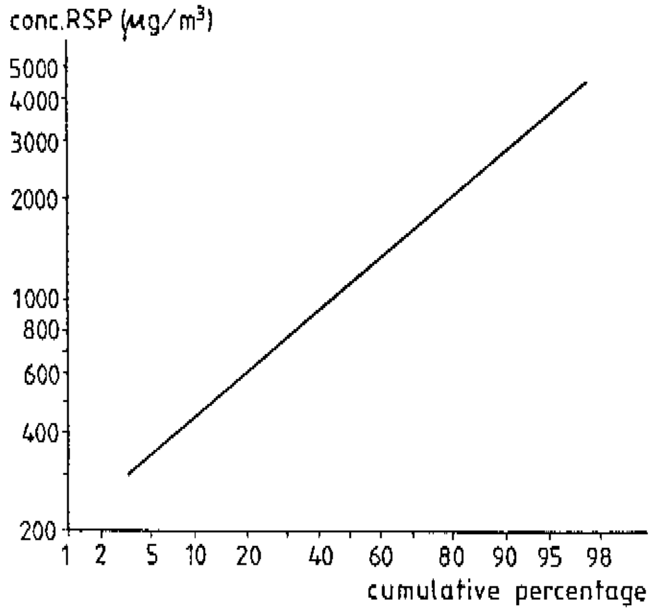


Figure 5. Cumulative frequency distribution 24-hour average RSP levels

Figures 4 and 5 indicated a lognormal distribution of the data. This was confirmed by the probability plot correlation coefficient test (Filliben, 1975). Analysis of variance (SAS Institute Inc., 1985) of the two series of measurements showed that 69% of the total variance was attributed to "within" house variance (difference of RSP concentration between the first and second series of measurements in the same house). Only 31% of the total variance is caused by the differences of RSP levels between the houses. This means that the average difference of RSP levels between different days in the same house is larger than the difference in RSP level between the houses.

8.1.2 Correlation between RSP levels and housing characteristics

The mean of the RSP levels for the various subcategories of house characteristics are shown below. Individual data are given in Appendix IV.

House type	Number of houses	Mean RSP ($\mu g/m^3$)	Standard Deviation
Iron roof	17	1537	1097
Thatched roof	19	1294	916
Attached kitchen	19	1209	918
Detached kitchen	17	1643	1053
Iron roof Attached kitchen	9	1187	1026
Iron roof Detached kitchen	8	1909	1078
Thatched roof Attached kitchen	10	1229	841
Thatched roof Detached kitchen	9	1468	1050

Analysis of variance (SAS Institute Inc., 1985) using the log transformed data did not show significant differences in mean concentration between the different house types. A tendency was found for detached kitchens and iron roofs to have somewhat higher RSP levels. No significant differences could be detected because most of the variance was within houses probably due to the variation in burning time of the fire.

8.1.3 Chemical analysis of RSP filters

Twenty filters containing respirable suspended particles were analysed. The results of this analysis are summarized below giving the total coefficient of variation, filter load for each of the substances analysed and the corresponding air concentrations.

			Filter content		Air concentrations 1)		
Compound	CV_t 2)	n	AM (µg/m³)	SD	AM (ng/m³)	Max.	Min. (ng/m³)
1. Fluoranthene	29	20	178	209	254	779	34
2. Pyrene	57	20	545	551	779	2387	103
3. Benz[a]anthracene	40	20	191	141	273	838	36
4. Chrysene	17	20	183	114	262	801	34
5. Benzo[b]fluoranthene	33	20	74	54	106	324	14
6. Benzo[k]fluoranthene	33	20	25	19	36	109	5
7. Benzo[a]pyrene	37	20	60	50	86	263	11
8. Benzo[ghi]perylene	21	18	176	124	252	771	33
9. Dibenz[a,h]an	34	18	100	89	143	438	19
10. Indeno[1,2,3-cd]pyrene	19	19	36	23	51	158	7

1) The air concentrations were calculated on the basis of the mean PAH content of the 20 filters and the mean, maximum and minimum of the complete RSP data set.

2) Total coefficient of variation on the basis of four duplicate measurements.

8.2 Analysis of 24-hour average NO_2 data

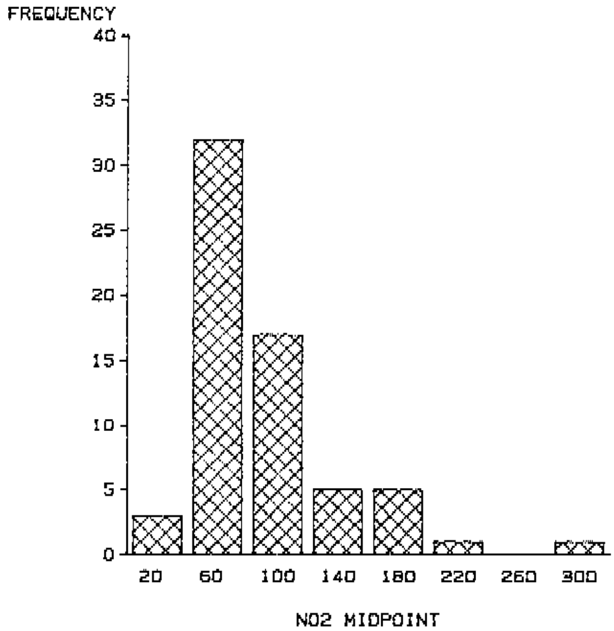
8.2.1 Summary statistics and analysis of variance

Again complete dat a sets of repeated measurements are available for 30 homes. The individual data are given in Appendix IV. Summary statistics are presented below.

	n	AM	GM	SD	GSD (ppb)	min (ppb)	max (ppb)
series I	33	99	54	86	1.7	20	281
series II	31	81	40	40	1.5	31	211
series I + II	64	90	47	80	1.6	20	281

n = number
AM = Arithmetic
SD = Standard Deviation
GM = Geometric Mean
GSD = Geometric Standard Deviation
min = minimum
max = maximum

Figure 6. Histogram of 24-hour average NO_2 levels (ppb)



The NO_2 data were found to be lognormally distributed. Analysis of variance (SAS Institute Inc., 1985) of the two series of measurements showed that 67% of the total variance was due to "within house" variance and 33% to between house variance.

8.2.2 Correlation between NO_2 levels and house characteristics

The mean of the NO_2 levels for the various subcategories of house characteristics is given below. Individual data are given in Appendix IV.

House type	Number of Houses	Mean NO_2 conc. (ppb)	Standard Deviation
Iron roof	17	102	60
Thatched roof	19	79	32
Attached kitchen	19	85	41
Detached kitchen	17	95	55
Iron roof Attached kitchen	9	87	48
Iron roof Detached kitchen	8	116	67
Thatched roof Attached kitchen	10	83	36
Thatched roof Detached kitchen	9	74	29

Also for the log transformed data no sifnificant differences could be detected for any of the house types. A tendency was found for houses with thatched roofs to have somewhat lower concentrations than those with iron roofs.

8.3 Correlation between RSP and NO_2 levels

In figure 7 the RSP concentrations are plotted against the NO_2 concentrations.

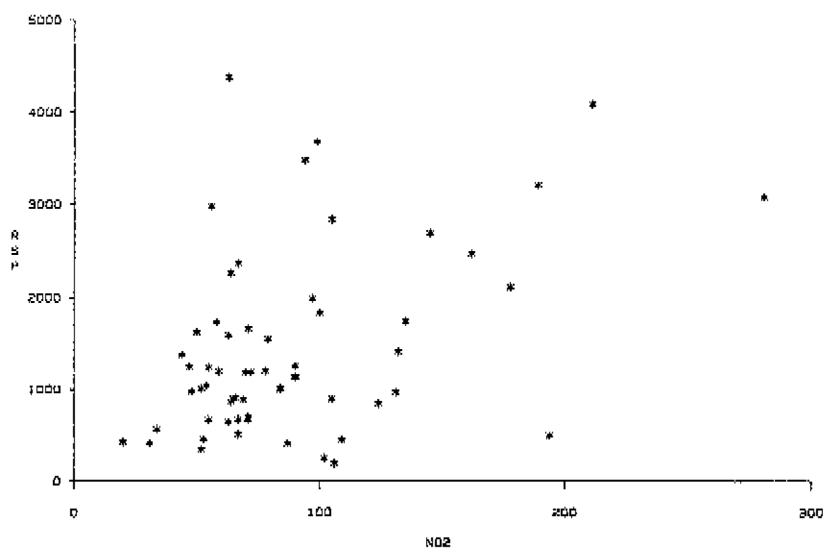


Figure 7. Relation between RSP ($\mu g/m^3$) and NO_2 (ppb)

Correlation coefficients of r = 0.61 and r = 0.32 respectively were calculated for the first and second measurements period.

8.4 Daily pollution pattern measurement

Hourly measurements were made in one of each of three types of homes to observe when the highest values of CO and RSP would occur. The information obtained is summarized below:

(i) Housetype : Iron roof - attached kitchen

Time	CO (ppm)	CO_2(%)	RSP ($\mu g/m^3$)	Fire condition
7.26	5	0.06	1400	Moderate
8.34	0	0.08	50	High
9.34	1	0.08	0	Low
10.34	3	0.04	600	Low
11.34	2	0.04	550	Low
12.34	1	0.04	150	Very low
13.34	0	0.03	0	No
14.34	0	0.05	-	
15.34	-	0.06	-	
16.34	-	0.04	-	
17.34	-	0.04	-	
18.34	6	0.10	1050	Moderate
19.46	30	0.08	36700	High
21.20	12	0.10	3300	Low

(ii) Housetype : Iron roof - detached kitchen

Time	CO (ppm)	CO_2(%)	RSP ($\mu g/m^3$)	Fire condition
8.00	10	0.06	1500	Moderate
8.54	12	0.07	1200	Moderate
9.56	3	0.04	100	No
10.56	0	0.04	0	No
11.56	0	0.04	0	No
12.56	28	0.15	3250	Moderate
13.56	15	0.04	0	Low
14.56	10	0.06	1400	Low
15.56	-	0.04	0	No
16.56	50	0.07	1900	Moderate
17.56	50	0.07	6650	High
18.56	98	0.15	3450	Moderate
20.19	5	0.04	750	Low

(iii) Housetype : Grass roof - attached kitchen

Time	CO (ppm)	CO_2 (%)	RSP ($\mu g/m^3$)	Fire condition
6.58	20	0.10	9350	Moderate
8.22	5	0.06	1000	Low
9.22	2	0.05	0	No
10.22	7	0.06	1500	Moderate
11.22	4	0.04	150	Very low
12.22	10	0.04	0	Very low
13.22	0	0.03	250	No
14.22	0	0.05	0	No
15.22	0	0.04	0	No
16.22	0	0.04	0	No
17.22	50	0.10	12250	High
18.22	20	0.08	4050	Low
19.27	5	0.08	150	Moderate
20.02	4	0.06	0	Very low

As expected, the levels of pollutants are highest during cooking times in the morning (6 to 8 hours), lunch time (12 to 14 hours) and evening (17 to 21 hours) in all the three house-types. The levels of the indoor air pollutants and especially those of RSP were highest in the evening. This is possibly because of the fact that fires were lit for the longest period and the windows were shut at that time. This is significant because it is the time when most of the family members especially the children are likely to be indoors. CO_2 concentrations were equal to outdoor concentrations (0.04%) when no fire was burning.

Most formaldehyde concentrations were below the detection limit of the method used (0.1 ppm). Formaldehyde was only detected in the evening, with levels of 0.75 ppm in house 408, 0.2 ppm in house 406 and 0.8 ppm in house 378. At these periods, it was also noted that the levels of CO were elevated in expired breath, measuring 1 ppm in house number 408, 1 ppm in house number 406, and 2 ppm in house number 378.

9. ARI incidence

The number of ARI episodes per child below five years in a 42-week period are shown in Appendix I. The average number of ARI episodes for the various house types are given below:

House type	Number of houses	ARI episodes	Standard deviation
Attached kitchen	20	7.7	2.5
Detached kitchen	17	7.2	2.1
Thatched roof	19	7.5	2.4
Iron roof	18	7.5	2.5

The results indicate that there is no difference between the average number of ARI episodes per child and various house characteristics. This was confirmed with statistical analysis (SAS Institute Inc., 1985). Also no relation was found between the number of ARI episodes and the RSP and/or NO_2 levels measured in the houses.

10. QUALITY CONTROL

The use of the PAS-6 filterholder for measuring RSP was validated by comparing the results of PAS-6 measurements in three houses with those of the RSP levels obtained from simultaneous measurements using a filter head with a 10 mm cyclone preseparator (Casella). The results for both measuring methods were within 10% of one another.

For measuring RSP constant flow pumps were used. The flow was checked at the beginning and the end of the measurement. If the flow change after 24 hours exceeded 5% of the original flow, the results were considered inaccurate and not used for further analysis.

To evaluate the precision of the 24-hour average RSP concentrations in five houses duplicate samples were taken. The results of these measurements are given in below

House number	concentration set 1	concentration set 2	% difference
1.	1282	1117	13.8
2.	1684	1507	11.1
3.	3034	3485	13.8
4.	433	388	11.0
5.	526	433	19.4

On the basis of the percentage of difference the total Coefficient of Variation (CV_t) was calculated. A value of 9.8% was found, which means that the total error is less than 25% in at least 95% of the samples.

On the basis of 4 duplicate determinations of the PAH, an average CV_t of 32 was found with a standard deviation of 12.

All NO_2 measurements were done in duplicate which resulted in a CV_t of 30%. Even though CV_t-values were less than 10% can be achieved (Boleij et al, 1986) the CV_t of 30% is considered quite satisfactory.

11. DISCUSSION AND CONCLUSIONS

Respirable suspended particles

The 24-hour average RSP concentrations found in this study are very high. The mean RSP levels in Kenya are 20 times higher than indoor RSP levels from cigarette smoke in Dutch homes (Lebret, 1985). During the 24-hour measurement period the fires were burning for 5 to 12 hours with an average of about 7. In case the fire was out, hardly any RSP was detected. This means that the average concentration during the 7 burning hours is about 3500 to 4000 $\mu g/m^3$. This suggests that in many homes even the occupational standard for RSP of 5000 $\mu g/m^3$ which holds for an averaging time of 8 hours and a healthy population, is exceeded. The occupational standard only covers inert nuisance dust, while woodsmoke contains active constituents. The WHO recommendation for exposure to particulate matter for the general population gives a maximum of 100 - 150 $\mu g/m^3$ with an averaging time of 24 hours. Most mothers and children under five years of age stay about 50% of the time near the burning fire. This gives an average daily exposure of about four hours, mostly during the evening when very high peaks can occur.

The geometric standard deviation of the RSP concentrations in the homes is relatively low indicating a low variation in the concentrations. Analysis of variance showed that 2/3 of the total variance is caused by the difference in RSP level between the first and second measurement in the same house. Only 1/3 of the variance is attributed to the difference in RSP concentrations between the houses. In combination with the relatively low overall variance this indicates that exposure to RSP is homogeneous among the population. Burning hours were not yet included in the analysis. This factor probably would be the most important component of variance. Little or no difference could be detected for the various house characteristics on which the sample stratification was based. This is explained by the fact that most of the variance was within the houses and only little among the houses.

The instantaneous RSP measurements made during the home visits gave concentrations up to 4000 $\mu g/m^3$, depending on the intensity of the fire and the ventilation. In the evening under low ventilation conditions, concentrations up to 36000 $\mu g/m^3$ were found. Under these conditions it was hard to remain in the kitchen for more than a few minutes, because of the discomfort caused by the dense smoke. Although sampling conditions and techniques of other studies mentioned (WHO, 1984, p.19) might be different, our findings are comparable with the reported data. Smith et al. (1983) found mean TSP concentrations during cooking of 6000 $\mu g/m^3$ in four villages in Northern India with personal measurements near the mother during 45 minutes or shorter. Davidson et al. (1986) measured in 18 houses in various villages in Nepal at different altitudes. Sampling was done during 1 - 2 hours of stove operation at a height of 0.7 m, one meter from the fireplace. The average RSP concentration found was 4700 $\mu g/m^3$.

Early studies in Kenya by Hoffman and Wynder (1972) and Clifford (1972) observed concentrations ranging from 1500 to 7800 $\mu g/m^3$ with an average of 4000 $\mu g/m^3$. A high correlation was found between concentration and elevation because the wood fires were used for heating as well as for cooking.

Polycyclic aromatic hydrocarbons

In general the air concentrations of the various PAH were very high. These high concentrations reflect the high RSP concentrations. Only for benzo[a]pyrene air concentrations have been measured in similar situations (WHO, 1984, p.19). Generally, BaP concentrations in air observed in the past were somewhat lower than in this study, however sampling time was much shorter and only during the burning of the fire in the other studies.

In western societies similar concentrations can only be found in heavily cigarette smoke polluted environments (IARC, 1985). In this study a mean filter concentration of 80 μg benzo[a]pyrene per gram respirable dust was found. Dasch (1982) found benzo[a]pyrene contents of filterable fireplace emissions between 3 and 141 μg benzo[a]pyrene per gram of particulate matter for various kinds of wood.

For 6 of the measured PAH (substances 3, 5, 6, 7, 9, 10) there is sufficient evidence that they are carcinogenic to experimental animals (IARC, 1983). All measured PAH are major components of the total content of PAH in soot. The human carcinogenicity of soot in the form of lung cancer is demonstrated by several cohort studies of mortality among chimneysweeps (IARC, 1985). Although a thorough evaluation of the carcinogenic risk is not possible the levels observed in this survey can be considered as a real threat to the population.

Nitrogen dioxide

The 24-hour average NO_2 concentration is approximately 90 ppb. These levels are somewhat higher than the weekly average NO_2 concentration found in Dutch kitchens where unvented gas cookers and water heaters are used (Lebret, 1985). At these levels in some studies minor lung function changes and chronic non-specific lung disease symptoms were found (Fischer et al., 1985; Lindvall, 1986).

Also for NO_2 no influence of house characteristics would be detected. As for RSP this is caused by the fact that most of the variance was within houses and only little among the houses.

Some correlation is found between NO_2 and RSP levels. That no better correlation exists, is explained by the fact that different processes in the fire lead to NO_2 and RSP emissions respectively.

Daily pollution pattern measurements

The CO concentrations found during cooking are much lower than recorded in other studies in developing countries (WHO, 1984, p.19). This might be due to differences in sampling locations. We were able to measure CO concentrations up to 400 ppm directly above the fire in the smoke plume. However, these concentrations are not likely to be inhaled as people tend to avoid the direct inhalation of smoke. These peak levels of up to 400 ppm are still much lower than the CO concentrations of up to 3000 ppm found by Sofoluwe (1968) in Nigeria. Our low CO concentrations are confirmed by the low COHb found in the exposed mothers.

Hardly any formaldehyde was found. Only in cases of heavy smoke emission and poor ventilation (mostly during the evening) some formaldehyde was detected (0.1 - 0.2 ppm), and the maximum level only once reached 0.7 ppm. The concentrations are much lower than found in Papua New Guinea by Cleary and Blackburn (1968) and Anderson (1978). They found average formaldehyde concentrations of respectively 0.7 and 1.2 ppm during the night. Generally measuring methods for formaldehyde are difficult and interferences are likely. Our method (Dräger tubes) has also limitations in the specificity. The indication of the tube is based on a reaction of formaldehyde acid. The colour of the tube changes from white to pink. Acetaldehyde, acrolein, diesel fuel, furfuryl alcohol and styrene turn the indicating layer yellow to brown. This brown colour occurred several times.

The CO_2 concentrations found in this study were between 0.04% and 0.20%, which is not unusually high. The CO_2 level depends on the intensity of the fire and the ventilation rate (number and size of windows, open or closed; number of doors, open or closed; presence of an open space between wall and roof). These low CO_2 concentrations indicate that there is a high ventilation rate in the houses. In case there was no fire burning in the house, the CO_2 concentration was equal to the normal outdoor concentration even if there were three or more people in the kitchen, where the measurement was taking place. This also points to a high ventilation rate. This high ventilation could be responsible for the relative low concentrations of CO and formaldehyde and the fact that there is little or no difference in pollution levels in houses with different kitchen and roof arrangements. The ventilation, however, would have some influence on the RSP concentration too. The RSP levels on the other hand are comparable with other findings and point to a very high emission during cooking. After extinguishing the fire, the RSP concentration dropped steeply and reached a level of 10 $\mu g/m^3$ after only a few minutes.

ARI incidence

RSP and NO_2 are known to affect ARI incidence. In this study RSP levels are much higher than NO_2 levels in terms of effective dose. However, no relation could be detected between the attack rate of ARI incidences and the measured RSP levels nor with the NO_2 levels or a combination of RSP and NO_2 levels. Also no correlation was found with the house characteristics. This is explained by the fact that the pollution levels were very homogeneously distributed among the houses in which the children lived with hardly any influence of the house characteristics on the variation of the levels. In the ongoing ARI study in the Maragua area the effect of smoke is only likely to be detected if an intervention is incorporated in the study to create a subpopulation with lower exposure levels. An alternative might be to find a control population, which is comparable in all respects with the exception of the pollution levels to which the population is exposed.

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APPENDIX I

HOUSEHOLD CHARACTERISTICS AND ARI

Serial Number	Household Number	Number in Household	Children 5 yrs	No. of rooms	Thatched roof	Corrugated roof	Attached kitchen	Detached kitchen	No. of windows	No. of people smoking tobacco	No. of cigarettes (Father)	No. of cigarettes (Mother)	ARI episodes
1	004	7	1	2	1	-	-	1	3	0	-	-	8.2
2	008	5	2	3	1	-	1	-	3	1	Not sure	0	11
3	016	8	2	3	-	1	1	-	2	1	Not sure	0	9.65
4	078	5	3	3	-	1	-	1	3	1	5	0	9.2
5	084	9	2	8	-	1	1	-	7	1	Not sure	0	4.75
6	092	3	1	4	1	-	1	-	4	1	Not sure	0	10.2
7	100	6	2	3	-	1	-	1	3	0	0	0	6.8
8	122	10	2	4	1	-	-	1	4	0	0	0	8
9	146	5	1	4	1	-	1	-	4	1	10	0	2.2
10	184	5	3	2	1	-	1	-	0	1	Not sure	0	7.6
11	204	10	3	4	-	1	-	1	4	1	Not sure	0	6.1
12	208	9	2	3	1	-	-	1	3	1	Not sure	0	11.35
13	232	6	1	2	1	-	-	1	1	0	0	0	7
14	248	4	2	1	1	-	-	1	1	1	6	0	6.95
15	264	9	2	2	1	-	1	-	2	0	0	0	8.4
16	278	9	2	8	-	1	-	1	7	1	6	0	7
17	302	7	3	3	-	1	1	-	3	1	Not sure	0	7.6
18	312	5	3	3	-	1	1	-	3	1	Not sure	0	7.3
19	348	9	2	4	-	1	1	-	4	1	Not sure	0	8.1
20	352	10	2	4	1	-	-	1	3	1	Not sure	0	4.1
21	354	11	1	3	-	1	-	1	3	1	Not sure	0	5.1
22	396	5	3	2	-	1	1	-	2	0	0	0	6.7
23	435	7	2	4	1	-	1	-	4	1	4	0	7.5
24	443	7	2	2	1	-	1	-	2	0	0	0	7.8
25	447	7	2	4	-	1	1	-	4	0	0	0	8.4
26	483	4	3	1	1	-	-	1	2	1	Not sure	0	6
27	523	3	1	1	1	-	-	1	2	0	0	0	7.7
28	565	7	2	4	-	1	-	1	4	0	0	0	5.2
29	567	3	2	1	1	-	1	-	2	1	Not sure	0	4
30	633	9	2	6	-	1	-	1	5	0	0	0	5
31	635	4	2	3	1	-	1	-	3	1	6	0	7.3
32	649	7	2	3	1	-	1	-	3	0	0	0	8.6
33	655	4	1	2	-	1	1	-	1	1	Not sure	0	5.1
34	691	9	1	3	1	-	1	-	3	1	0	0	7.7
35	695	4	2	1	-	1	-	1	1	1	Not sure	0	7
36	732	3	1	2	-	1	-	1	1	1	Not sure	0	12
37	734	3	1	3	-	1	1	-	2	1	Not sure	0	14

APPENDIX II

Questionnaire "FIELD STUDY INDOOR AIR QUALITY"

1. Household identification number ☐☐☐

2. Name of head of household ....

3. Number of rooms used in dwelling house ☐

4. a. Number of people living in the dwelling house ☐☐
   Code: number of people = 1 - 98; don't know = 99
   b. Number of chidren younger than 5 years living in the dwelling house ☐
   Code: number of children = 1 - 8; don't know = 9

5. Type of floor (material of construction) in the dwelling house ☐
   Code: Dirt = 1; Cement = 2; Other = 3 (Specify ....)
   Don't know = 9

6. Type of roof (material of construction) in the dwelling house ☐
   Code: Thatch= 1; Iron sheet = 2; Asbestos = 3; Paper Board = 4
   Tile = 5; Other = 6 (Specify..........); Don't know = 9

7. Type of wall (material of construction) in the dwelling house ☐
   Code: Mud = 1; Wood = 2; Stone or Brick = 3; Other = 4
   (Specify ....); Don't know = 9

8. Finish of wall ☐
   Code: Rough = 1; Smooth = 2

9. Is cooking done within the dwelling house ☐
   Code: No = 0; Yes = 1; Don't know = 9

10. Size of the room in which the cooking is taking place (in m^2) ☐☐
    Code: number of m^2 = 1 - 98; Don't know = 99

11. Number of doors in the room in which the cooking is taking place ☐
    Code: Number of doors 1 - 8; Don't know = 9

12. a. Number of windows in the room in wich the cooking is taking place ☐
    Code: Number of windows = 1 - 8; Don't know = 9
    b. Are the windows normaly open or closed during the cooking periods? ☐
    Code: normaly open = 1; normaly closed = 2; Don't know = 9

13. Presence of an open space between the walls and the roof in the room in which the cooking is taking place ☐
    Code: No = 0; Yes = 1; Don't know = 9

14. What fuel is usually used for cooking within the dwelling house or kitchen ☐
    Code: Firewood = 1; Charcoal = 2; Gas = 3; Electricity = 4;
    Other = 5 (Specify ....); Don't know = 9

15. What fuel was used for cooking within the dwelling house or kitchen during the 24 hours of measuring ☐
    Code: Firewood = 1; charcoal = 2; Gas = 3; Electricity = 4;
    Other = 5 (Specify ....); Don't know = 9

16. What is the light source in the dwelling house
    Code: None = 0; Lantern = 1; Paraffin candle = 2; Cooking fire = 3; Electric light = 4; Other = 5 (Specify ....); Don't know = 9

17. Number of times that cooking was taking place during the 24 hours measuring period.
    Code: Number of times = 1 - 8; Don't know = 9

18. Number of hours the fire was on (not only for cooking) during the 24 hours of measuring.
    a. First meal (Breakfast)
       Code: Not relevant = 0; Number of hours = 1-8; Dont know=9
    b. Second meal (Lunch)
       Code: Not relevant = 0; Number of hours = 1-8; Don't know=9
    c. Third meal (Supper)
       Code: Not relevant = 0; Number of hours = 1-8; Don't know=9
    d. Others
       Code: Not relevant = 0; Number of hours = 1-8; Don't know=9

19. Kind of food that is prepared during the 24 hours measuring period
    a. First meal (Breakfast)
       Code: Not relevant=0; Tea=1; Porridge=2; Ngima and stew/milk=3; Isyo=4; Other=5; Don't know=9
    b. Second meal (Lunch)
       Code: Not relevant=0; Tea=1; Porridge=2; Ngima and stew/milk=3; Isyo=4; Other=5; Don't know=9
    c. Third Meal (Supper)
       Code: Not relevant=0; Tea=1; Porridge=2; Ngima and stew/milk=3 Isyo=4; Other=5; Don't know=9
    d. Other
       Code: Not relevant=0; Tea=1; Porridge=2; Ngima and stew/milk=3 Isyo=4; Other=5; Don't know=9

20.a. Activities of the mother during the period of cooking during the 24 hours measuring period
    Code: Stayed less than 25% of the time the fire was on in the same room as the fire place = 1
    Stayed between 25% and 75% in the same room = 2
    Stayed more than 75% in the same room = 3; don't know = 9

  b. Is this the average situation ?
    Code: Yes = 1; No = 2; Don't know = 9

21.a. Activities of the first and oldest child participating in the NAS study during the period of cooking during the 24 hours measuring
    Code: Stayed less than 25% of the time the fire was on in the same room as the fire place = 1
    Stayed between 25% en 75 % in the same room = 2
    Stayed more than 75% in the same room = 3; don't know = 9
  b. What is the age of the child ?
    Code: age = 0 -5; not relevant = 8; don't know = 9
  c. Is this an average situation ?
    Code: Yes = 1; No = 2; don't know = 9

22.a. Activities of the second and youngest child participating in the NAS study during the periods of cooking during the 24 hours measuring period ☐
Code: Stayed less than 25% of the time the fire was in the same room as the fire place = 1;
Stayed between 25% and 75% in the same room = 2
Stayed more than 75% in the same room = 3; don't know =9

b. What is the age of the child ? ☐
Code: age = 0 - 5; not relevant = 8; don't know = 9

c. Is this the average situation? ☐
Code: Yes = 1; No = 2; don't know = 9

23. Code which animals are present in dwelling units
Code: Not present = 0; Present = 1; Don't know = 9

Dogs ☐

Cats ☐

Cattle ☐

Goats ☐

Chicken ☐

Sheep ☐

Other (specify ....) ☐

24. How many people smoke a tobacco product in the home ☐
Code: None = 00; Number of smokers = 1-98; don't know = 9

25. Does the father smoke cigarettes ☐☐
Code: None = 00; Number of cigarettes/day = 01-77;
Not appropriate = 88; Don't know = 99

26. Does the mother smoke cigarettes ☐☐
Code: None = 0; Number of cigarettes/day = 01 77;
Not appropriate = 88; Don't know = 99

27. How many people in the household have chronic respiratory problems (long standing history of cough, difficulty in breathing, chest pain) ☐
Code: None = 0; Number of people with chronic respiratory problem = 1-8; Don't know = 9

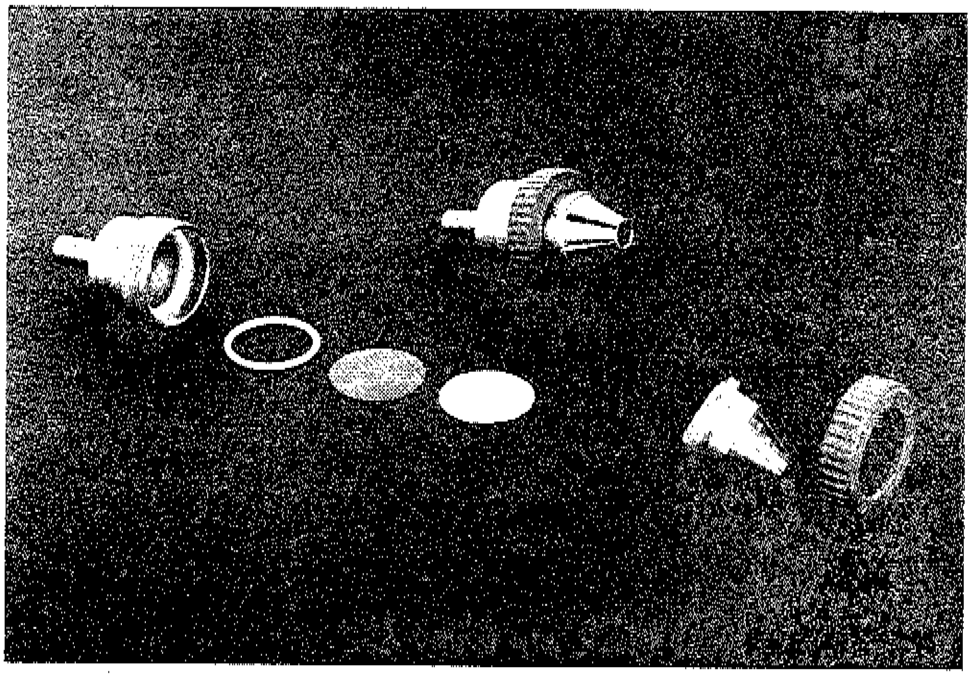

Figure 1.
PAS-6 filter holder

Determination of the cut-off diameter in a windtunnel showed it to be in the inhalable range. As suspended particles emitted from wood and biomass combustion are respirable (Cooper, 1980; Dash, 1982; Smith, 1983) the particles measured with the PAS-6 can be considered respirable.

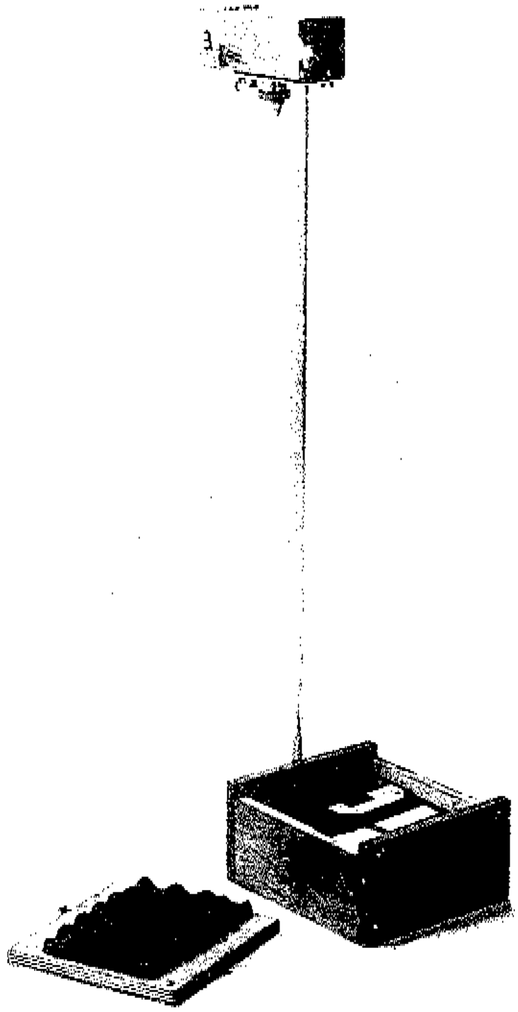

Figure 2
Measuring unit
24 h measurements

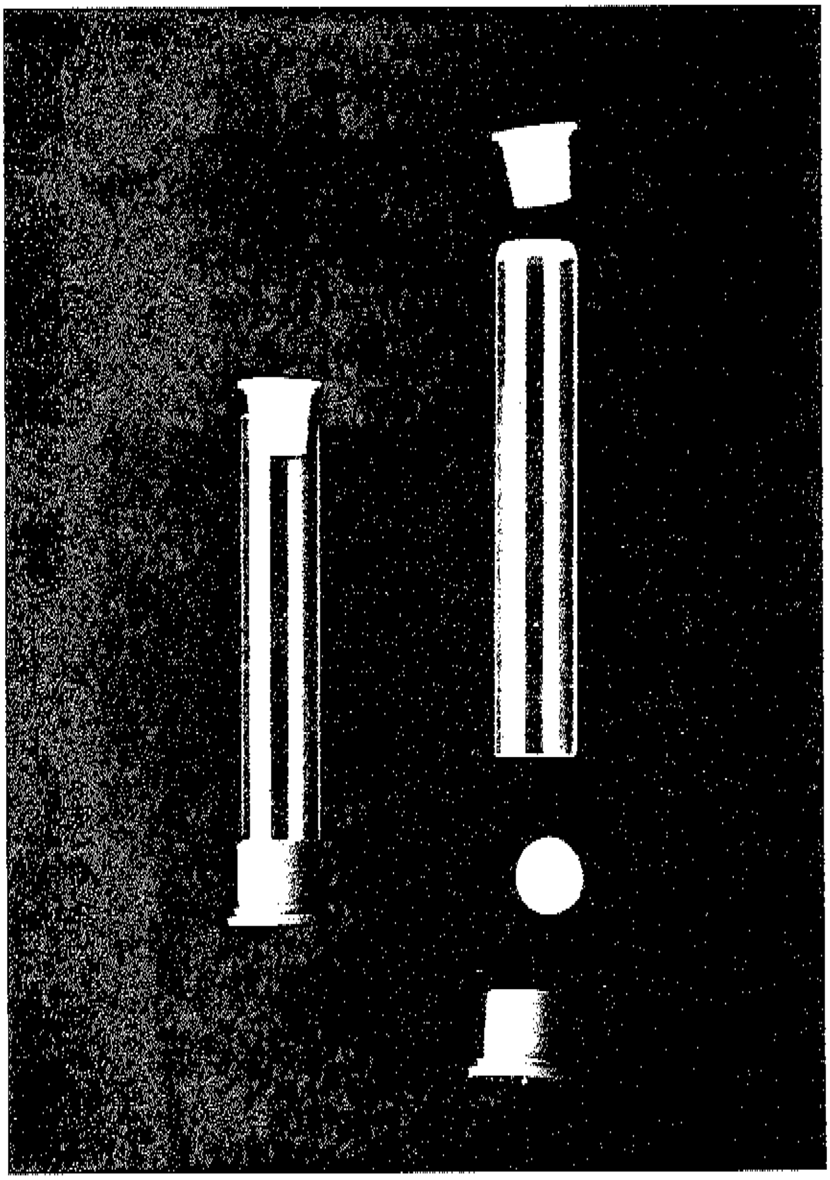

Figure 3. Palmes diffusion tube for measuring NO_2

APPENDIX IV

INDIVIDUAL REPEATED 24-HOUR AVERAGE RSP AND NO_2 MEASUREMENTS

House identification number	RSP (I)	RSP (II)	Kitchen[1)]	Roof[2)]	NO_2 (I)	NO_2 (II)	ARI incidence
122	189	2261	2	2	106	64	8.20
204	893	1624	2	1	105	50	6.10
232	423	1665	2	2	20	71	7.00
248	1199	4379	2	2	72	63	6.95
264	1736	495	1	2	58	194	8.40
732	1968	1011	2	2	97	52	12.00
208	978	2368	2	2	48	67	11.35
278	2977	1382	2	1	56	44	7.00
16	2472	3684	1	1	162	99	9.65
184	645	670	1	2	63	71	7.60
78	3081	2690	2	1	281	145	9.20
138	832	629	-	-	-	-	-
100	3212	4089	2	1	189	211	6.80
352	900	841	2	2	65	124	4.10
396	1208	1192	1	1	78	70	6.70
312	564	410	1	1	34	31	7.30
348	479	383	1	1	-	-	8.10
354	2110	1013	2	1	178	84	5.10
84	3127	753	1	1	-	-	4.75
483	998	886	2	2	84	69	6.00
447	1134	670	1	1	90	67	8.40
443	667	1554	1	2	64	79	7.80
435	1595	1045	1	2	63	54	7.50
567	907	1253	1	2	66	47	4.00
565	1147	242	2	1	90	102	5.20
655	705	456	1	1	71	53	5.10
649	2840	3485	1	2	105	94	8.60
633	1145	1200	2	1	90	59	5.00
635	1749	510	1	2	135	67	7.30
691	446	405	1	2	109	87	7.70
302	-	343	1	1	199	52	7.60
695	1837	-	2	1	100	64	7.00
523	963	-	2	2	131	-	7.70
92	670	-	1	2	55	-	10.20
734	1416	-	1	1	132	82	14.00
146	-	1260	1	2	-	90	2.20
4	1246	-	2	2	55	-	8.20

1) 1 = attached; 2 = detached

2) 1 = corrugated iron; 2= thatched.