PARTICULATE MATTER AND GASEOUS CONTAMINANTS IN INDOOR ENVIRONMENTS IN AN ISOLATED NORTHERN COMMUNITY

Michael Guggisberg [1], Patrick A. Hessel, PhD [2], Dennis Michaelchuk, MA [2], Martin Atiemo, PhD, PEng, Dip Th[3]

ABSTRACT

Objectives. Globally, 86% of exposure to particulate matter (PM) occurs indoors. Wood furnaces and smoke curing are known sources of PM in isolated communities in northern Canada.
Study Design. Three homes with wood furnaces, three with oil furnaces, and nine tipis (smoke curing huts) in Deline, Northwest Territories were sampled for carbon monoxide, carbon dioxide, total hydrocarbons, formaldehyde, and for PM of less than 10 microns in diameter (PM_{10}).
Results. All gaseous contaminants were below relevant air quality standards. In contrast, all but one environment had PM_{10} concentrations above standards. The presence of smokers correlated with higher PM_{10} levels within fuel categories. PM_{10} did not differ significantly between heating types (means, 0.12-0.53 mg/m^3). Exposures to PM_{10} in tipis averaged 2.3 mg/m^3.
Conclusion. Residents were exposed to substantial concentrations of PM_{10} from cigarette smoking, wood stoves, and smoke curing. Concentrations were within the range where respiratory symptoms have been observed. Measures to reduce exposure should consider prevention of adverse health effects and preservation of traditional activities.

Key words: Particulate matter, PM_{10}, Indoor air quality, Wood stoves, Smoke curing

INTRODUCTION

Half the world's population relies on wood and other biomass fuels for cooking and heating. These are predominantly burned in open fires, or simple stoves (1). Concentrations of particulate matter (PM) in poorly ventilated houses can exceed relevant standards (1,2). The

[1] Department of Environmental Sciences, Swiss Federal Institute of Technology Zurich, Switzerland
[2] Department of Public Health Sciences, University of Alberta, Edmonton, Canada
[3] Industrial Hygiene Consulting Service, Saskatchewan, Canada

World Health Organization estimated that 86% of global exposure to PM takes place indoors (1). Since most emissions are released into the living area, women and children are at greatest risk (3). Gas- and kerosene-fuelled devices are also sources of indoor pollutants (4).

Ambient air pollution may be responsible for two million excess deaths per year in developing countries(5). Respiratory health effects are also observed at high indoor concentrations of wood smoke (5,6). Recently, the adequacy of current national air quality standards for PM have been questioned, since health effects have been demonstrated at the accepted levels (7,8).

Epstein equated the health status of Aboriginal populations in developed countries with that of developing countries (9). Mortality for respiratory conditions in the Northwest Territories (NWT), where 62% of the population is aboriginal (10), was 34% higher than the national rates (11). Respiratory diseases accounted for >10% of inpatient hospital visits and 25% of visits to community health clinics (10). In an aboriginal community in northwestern Ontario, childhood respiratory infections accounted for almost 50% of all episodes of illness (12).

In the study region, smoke curing of fish and meat is part of the traditional lifestyle. This process is often completed in small huts called tipis. A smoldering fire producing a high smoke density is required (13). Tipis are also used for tanning animal hides. The present study was prompted by concern about the potential for respiratory diseases associated with wood smoke exposures.

MATERIAL AND METHODS

Study location

The study community, Deline (formerly Fort Franklin), is located 544 km northwest of Yellowknife in the NWT. Average January temperatures are –24.0°C and the heating season is from September to May. Access to the community is limited to air services and a winter road.

Housing quality in Deline is typical of that in the Western Arctic and below the average for the NWT (14). In 2000, 46% of houses in Deline were classified as having "problems." Most of these problems related to the suitability of the housing – referring to the number of people in the house relative to the size of the house and the number of bedrooms. There were six or more people per household in 14.5% of the houses in Deline, compared to 7.8% in the NWT and 11.9% in the Western Arctic. Nearly one-in-five houses (18.5%) in Deline were classified as needing major repairs, compared to 14.3% in the Northwest Territories and 16.5% in the Western Arctic.

In 1994, the population of Deline was 573, with 90% classified as Native Indians. Lifestyles ranged from traditional to modern. Half of the males regularly trapped and hunted, spending up to 10 hours per day outside. Women and children spent most of their time inside during the heating season. Males and females were actively engaged in smoke curing meat and fish, and tanning hides. Ethics approval was obtained from the Ethics Review Board at the University of Alberta.

Housing and tipis

In 1994, 76% of the residents lived in one-family houses (15). Most homes (60%) were built after 1981 and a few (8%) before 1960. More than half of the population (56%) was likely to be exposed to indoor pollutants from oil furnaces and 17% from wood heaters. Only a few (4%) lived in homes heated by electricity. The remaining people used a mixture of these fuels (23%).

The tipis are cone-shaped, with a base diameter of five to seven metres and a height of approximately seven metres. The door is usually open when in operation. Curing of meat and the tanning of hides is usually done from mid-September to mid-October: drying of fish from July to October. Initially, the meat is removed from the hides. The meat is put on a rack located inside the tipi, about 1.5 metres off the ground over the fire, and smoked and dried for 24 hours. Meanwhile, the leather is soaked in a concentration of animal brain tissues to soften the hide, and hung outside to dry. The dry hides are spread over the same rack as the meat and smoked for about a week. For most of this work the occupants take a squatting position, with the head about a metre above ground level. During preparative work, the workers prefer to have the fire pit filled with large quantities of hot coals under light smoke conditions. Later, when the tipis are in full operation, the workers enter the tipi long enough (about 15 minutes every two hours) to ensure that the smoke density is optimal.

Air quality measurements

Sampling was conducted from September 29 to October 3, 1994. Six homes and nine tipis were sampled for carbon dioxide (CO_2), carbon monoxide (CO), total hydrocarbons (THC), formaldehyde, and for particulate matter of less than 10 microns in diameter (PM_{10}).

Three houses with wood furnaces (one with no cigarette smokers and two with smokers) and three houses with oil furnaces (one with cigarette smokers and a five-year old furnace, two with smokers and 25-year-old furnaces) were examined. Standard methods for sampling and analysis were used (16,17). Measurements for gases were taken in the breathing zone at fixed locations. Periodic readings were taken over a 24-hour period using a portable Gastec hand pump (Levitt Safety Limited, Oakville, Ontario) with low-range detector tubes for CO_2 (detection limit: 100 ppm), CO (detection limit: 1 ppm), THC (detection limit: 100 ppm), and very low-range detector tubes for formaldehyde (detection limit: 0.05 ppm). Total suspended particles (TSP; diameter < 25-40 µm) were measured using a 37-mm filter cassette with a PVC filter with 0.8-µm pore size, aspirated for 24 hours at 5 to 10 liters per minute, depending on the dust concentrations (cassette: B30812M, AME, South Dakota; pump: Air-Sample Pump, SKC Inc., Pittsburgh, Pennsylvania). The mass of dust was analyzed gravimetrically (detection limit: 25 µg). Additionally, instantaneous short-term measurements (5-10 minute intervals) of PM_{10} were collected using the "Miniram" aerosol sampler (Model PDM3 from MIE Inc., Massachusetts).

The same pollutants were examined in tipis during full operation, using the same devices and procedures described above. Smoke concentrations were measured inside the tipis near the open door and also in the back sections. Breathing zone and general area samples were taken. To obtain vertical smoke density profiles, measurements were made at different heights. For the horizontal profile, samples were taken on the horizontal plane at three feet above the ground, starting five feet outside the door, passing over the smoldering fire and proceeding to the back of the tipi.

Data on tobacco exposure and housing characteristics were obtained by a questionnaire based on an existing instrument (18). Questions on wood smoke exposure were added. Questionnaires were obtained from 78% of the population (15).

Data analysis

Concentrations were expressed as means and standard deviations (SD). Student's t-test for independent samples was used to compare mean concentrations in different environments. The chi-square test was ap-

Table I. Characteristics of residents and homes grouped by heating system in Deline, NWT, Canada. All characteristics except 'air exchange rate' are from a study described in detail elsewhere (reference 12).

	Fuel used for heating Oil %(n=227)	Wood %(n=67)
Smoking habit		
Non-smokers	56.0	64.2
Current smokers	44.0	35.8
Pack-years[a], mean and SD	7.32 ± 15.64	6.93 ± 13.77
Environmental tobacco smoke		
No exposure	21.0	26.2*
< 4 hrs per day	39.7	20.0
≥ 4 hrs per day	39.3	53.8
Use of humidifier	25.1	32.8
Drafts in house	49.3	31.3*
Number of people sharing a heated room, mean and SD	1.48 ± 0.82	1.82*± 1.01
Number of air exchanges per hour, mean and SD	0.37 ± 0.10	0.17 ± 0.05

a includes ex-smokers and current smokers
* $p<0.05$

plied to test percentages for independence. To measure air exchange rates, PM_{10} concentrations were sampled over time and exchange rates were estimated using the slopes of the decay curves.

RESULTS

Houses were generally well heated (temperatures >21°C). Relative humidity was fairly low (35%-40%) (19). Residents often perceived houses as being dry and about one-third periodically used humidifiers (often when someone was ill) (Table I). Environmental tobacco smoke (ETS) was common. Although more than half were non-smokers, most were exposed to ETS. As a proxy for the maintenance status of the houses, the occurrence of drafts during windy weather was assessed. Drafts were more common in oil-heated homes. The occupancy rate (people per heated room) was significantly higher for wood-fuelled residences (1.8) than oil-heated houses (1.5). Air exchange rates for houses were below, or bordered on, recommended standards (i.e., 0.4-0.7 changes per hour (20)). Air exchange rates for tipis averaged 2.4 per hour.

Concentrations of gases in homes and tipis were below standards; concentrations of formaldehyde were below the detection limit (Table II). Levels of CO and CO_2 were higher in tipis. Concentrations for THC were moderately elevated in residences.

PM_{10} concentrations were highest in fully operational tipis (2.3 mg/m^3), but lower during preparative work (0.43 mg/m^3) (Table III).

Table II. Concentrations of gaseous air pollutants found in residential and occupational environments in Deline, NWT, Canada. Means ± SD are expressed in parts per million (ppm). Some values were below the limit of detection (<).

Pollutant	Residential Oil	Residential Wood	Tipis	Outdoors	Standard
CO_2	405 ± 137	408 ± 58	744 ± 627	350	3500[a]
CO	2.50 ± 1.38	2.83 ± 1.33	6.67 ± 6.89	<1.00	11[a], 50[b]
Total Hydrocarbons	374 ± 178	292 ± 111	172 ± 115	<100	
Formaldehyde	<0.05	<0.05	<0.05	<0.05	0.1[a]

[a] 8-hr average for Canadian (8)
[b] 8-hr, time-weighted average for workplace (18)

Homes with wood furnaces had higher levels of TSP than those with oil furnaces, regardless of the presence of smokers. This was not observed for PM_{10} The presence of smokers correlated with higher mean values within the same fuel category for TSP and PM_{10}. Cooking (frying) and a high level of general activity (i.e., walking, cleaning) also increased PM_{10} levels. The ratios of ambient particulate levels to their standards were 12.3 for TSP and 1.4 for PM_{10} in light, windy conditions. Concentrations for indoor samples varied substantially (i.e., for houses with old oil furnaces: PM_{10} mean: 0.53 mg/m^3, SD: 0.81 mg/m^3). Mean levels of PM_{10} did not differ between housing types. However, 60% of PM_{10} readings in residences and 32% of breathing zone samples in tipis were above relevant standards (21,22). Exposures peaked at 2.6 mg/m^3 in houses and 27.0 mg/m^3 in tipis.

The horizontal smoke profile of tipis in full operation showed a bimodal distribution (Figure 1). Outdoor concentrations of PM_{10} increased near the open tipi door. Above the fire, about a metre in from the door, values peaked for the first time (26.8 mg/m^3), and peaked again in the back of the tipi (108.0 mg/m^3 of PM_{10}). Both vertical

Table III. Concentrations of total suspended particles (TSP) and PM_{10} in residential and occupational environments in Deline, NWT, Canada. Means ± SD are expressed in mg/m^3.

Pollutant	Residential: Oil-heated, New furnace, Non-smokers	Residential: Oil-heated, Old furnace, Smokers	Residential: Wood-heated, Non-smokers	Residential: Wood-heated, Smokers	Tipis	Outdoors	Standard
TSP	0.16 ± 0.17	0.34 ± 0.26	0.72 ± 0.35	1.14 ±1.47	6.91 ± 4.15	0.56 ± 0.65	0.15 [a]
M/S-Ratio [b]	1.1	2.3	4.8	7.6	2.0	12.3	3.5 [d]
I/O-Ratio [c]	0.3	0.6	1.3	2.0	12.3	1.0	0.05 [e]
PM10	0.12 ± 0.06	0.53 ± 0.81	0.16 ± 0.06	0.32 ± 0.18	2.29 ± 3.33	0.07 ± 0.01	0.15 [a]
M/S-Ratio [b]	0.8	3.5	1.1	2.1	0.7	1.4	3.5 [d]
I/O-Ratio [c]	1.7	7.6	2.3	4.6	32.7	1.0	0.05 [e]

[a] Japanese indoor standard for $PM_{3.5}$(reference 20)
[b] Measured concentrations divided by referring standard
[c] Indoor concentrations divided by outdoor level
[d] Workplace threshold limit value for inorganic carbon particles (reference 22)
[e] Year-weighted average for ambient PM_{10} (reference 23)

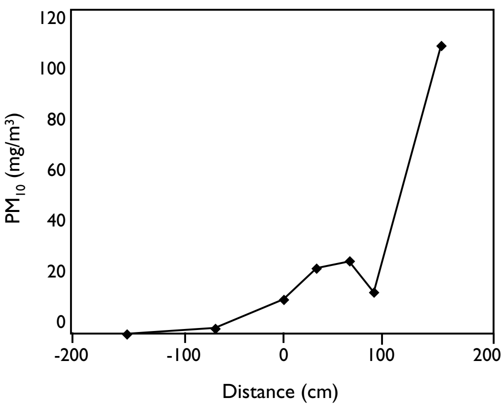

Fig 1. Horizontal profile of PM_{10} concentration in a tipi in full operation from outside the door of the tipi (negative numbers) and inside the tipi (positive numbers) at a height of one metre above ground.

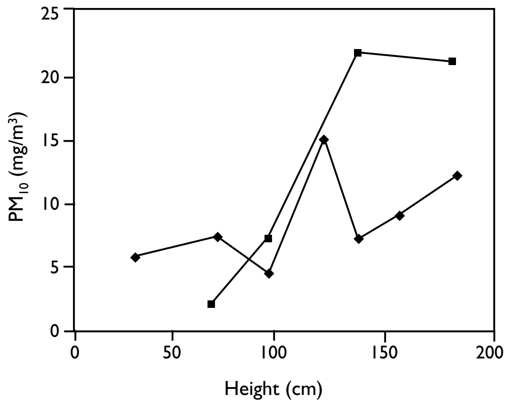

Fig 2. Vertical profiles of PM_{10} concentrations in a tipi in full operation at the door of the tipi (diamonds) and at the back, behind the fire (squares).

profiles showed a maximum concentration at rack-height, about 1.5 metres off the ground: 15.2 mg/m^3 near the door and 22.0 mg/m^3 in the back (Figure 2). Both concentrations were within, or somewhat above, the adequate smoke concentrations of 9.1-18.2 mg/m^3 for curing fish and meat (13). In general, values for the vertical profiles near the door showed lower concentrations than those obtained in the back.

DISCUSSION

All environments were subject to pollution by PM. All except one of the means were above the relevant standards. The concentrations of TSP were lower for houses with oil furnaces than those with wood stoves, regardless of the smoking habits of the occupants. Furnace type did not influence levels of PM_{10}. However, smoking resulted in higher mean levels within the same category of furnace. Ambient TSP and PM_{10} were 12.3 and 1.4 times above recommended standards, respectively. For houses without indoor sources of PM, the indoor/outdoor ratio for particulates of outdoor origin were slightly below one, likely due to sedimentation (24). Ratios for PM_{10} and TSP in wood-heated homes were above one, suggesting indoor sources.

Factors that influence indoor air quality are the volume of indoor air space, the sources of air pollutants, the decay rate (i.e., sedimentation, chemical reactions), the air exchange rate, and outdoor concentrations of pollutants (23). Wood stoves are not necessarily a source of indoor air pollutants. Airtight stoves can be maintained with negligible release of particles (25). Non-airtight stoves, however, are major sources of indoor particulates. Traynor et al. reported indoor concentrations of TSP between 24 and 71 μg/m^3 in homes with airtight wood stoves, 28-1500 μg/m^3 with non-airtight stoves, and 19-24 μg/m^3 in homes without stoves (26).

Many residents of Deline were active smokers, and only about a fourth were unexposed to ETS (15). Burning wood and smoking generate predominantly fine particles ($PM_{2.5}$) (27). After being exhausted or disturbed, fine particles remain airborne for days to weeks, whereas larger particles are suspended for only minutes to days (28). Low air exchange rates prolong the residence time of pollutants inside homes and lead to an accumulation of contaminants from indoor sources. At the same time, low exchange rates prevent infiltration of outdoor pollutants. While most conventional homes have an average air exchange rate of around 1.0 per hour, rates in "tight" homes can be as low as 0.5 per hour during winter and, in "super-tight" homes, between 0.1 and 0.3 per hour (4). The estimated air exchange rates in Deline were similar to those found in "super-tight" homes, with 0.37 exchanges per hour in houses with oil furnaces and 0.17 exchanges per hour for those with wood furnaces. In areas with little industry, ambient PM may primarily consist of earth crustal material and volcanic ash (29), or wind-blown dust (30). In residential areas with a high prevalence of wood-heated houses, wood smoke may account for as much as 90 percent of the particle concentrations during wintertime (31). In Deline, there is no industry and little traffic. Sources of outdoor PM in windy conditions were most likely airborne soil (coarse particles), and exhausts from residential heating systems (fine particles).

The mean smoke density (TSP) for tipis in full operation exceeded the occupational standard for inorganic carbon particles two-fold. The mean PM_{10} value of 2.3 mg/m^3, however, was within the accepted levels, yet above the action limit of 1.8 mg/m^3. Other studies have shown comparable concentrations of TSP, or respirable particles, for similar locations (32).

In tipis, smoke production depended on the state of the fire. Heat convection and currents of air from the open door dispersed the smoke unevenly. Outside air diluted smoke near the door and allowed smoke to leave. Some smoke was pushed back by heat convection, increasing smoke density at rack level. Lack of fresh air in the back sections resulted in an increased smoke density in these areas.

Although indoor concentrations of gaseous contaminants were higher than the outdoor levels, the values remained below relevant standards throughout. For tipis, this may have been a result of the high air exchange rate.

The reported high occurrence of drafts, and the low air exchange rates in the homes seem incompatible. However, people generally wore light clothing inside. The perception of "draft" may have resulted from temperature differentials between unprotected parts of the body and cold surfaces in homes (i.e. walls and windows) (33). Drafts may also have indicated poor insulation, because homes with oil furnaces reported a higher percentage of draftiness, and had higher air exchange rates than those with wood furnaces.

In summary, the residents of Deline were exposed to concentrations of particulates in residential, occupational, and ambient environments, bordering on, or exceeding, relevant standards and within the range where adverse respiratory health effects have been observed (11,27). Sources were predominantly furnaces and smoking for indoor pollutants, airborne dust for ambient TSP, and smoldering fires in tipis.

Measures to reduce residential exposure could include: (1) installation of airtight stoves and/or the maintenance of existing stoves; (2) cleaning and humidifying the air; and (3) restricting cigarette smoking. Working in tipis in a squatting position and minimizing time spent in this environment are readily applicable measures to decrease the exposure. Abandoning the practice of smoke curing is impractical given the importance of this activity to the life and culture of the local population. It may be possible, however, to modify the tipis to create relatively safer spaces for maintaining the fires and monitoring the process.

Acknowledgements

The study was funded by the National Health Research and Development Program of Health Canada. The authors acknowledge Dr. Iqbal Ahmed, Dr. Scott Prior and Ms. Marilyn Fraser for their assistance.

Dr. Patrick A. Hessel
2 North Riverside Plaza, Suite 1400
Chicago, Illinois
USA 60074
phessel@exponent.com

REFERENCES

1. World Health Organization. Air quality guidelines. Geneva: WHO, 1999.
2. Environmental Health Directorate. Exposure Guidelines for Residential Indoor Air Quality: A Report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health. Ottawa, Ontario: Minister of Supply and Services Canada (Cat. H49-58/1990E), 1987.
3. Smith KR. Biofuels, air pollution, and health: a global review. New York: Plenum, 1987.
4. Samet JM, Marbury MC, Spengler JD. Health Effects and Sources of Indoor Air Pollution. Part I. Am Rev Respir Dis 1987;136:1486-508.
5. Bruce N, Perez-Padilla R, Albalak R. Indoor air pollution in developing countries: a major environmental and public health challenge. Bull World Health Organ 2000; 78:1078-92.
6. Smith KR, Samet JM, Romieu I, Bruce N. Indoor air pollution in developing countries and acute lower respiratory infections in children. Thorax 2000;55:518-32.
7. Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society. Health effects of outdoor air pollution. Am J Respir Crit Care Med 1996;153:3-50.
8. Hessel PA, Goldsmith JR, Wichmann H-R, Wilson WE, Soskolne CL. Particulate air pollution and health: Emerging issues and research needs related to the development of air quality standards. Can Respir J 1997;4: 323-8.
9. Epstein R. Letter to the editor. Can J Pub Health 1982;73:433-4.
10. Statistics Canada. Census 1996. Ottawa, Ontario: Statistics Canada, 1996.
11. Department of Health and Social Services. The NWT Health Status Report. Yellowknife, NWT: Office of the Chief Medical Health Officer, Department of Health and Social Services, 1999.
12. Harris SB, Glazier R, Eng K, McMurray L. Disease patterns among Canadian aboriginal children. Study in a remote rural setting. Can Fam Physician 1998; 44: 1869-77.
13. Torry Research Station. Fish handling & processing. Burgess, GHO, eds. New York: Chemical Pub Co, 1967.
14. Government of the Northwest Territories. NWT Housing Needs Survey – 2000: Overall Results & Community Detail. Yellowknife: GNWT, 2000.
15. Guggisberg M, Hessel PA, Michaelchuk D, Ahmed I. Respiratory symptoms and exposure to wood smoke in an isolated northern community. Can J Public Health, in press.
16. National Institute of Occupational Safety and Health. Sampling and Analytical Techniques for Contaminants. Washington, DC: NIOSH, 1994.
17. Occupational Safety and Health Administration. Sampling and Analytical Techniques for Contaminants. Washington, DC: OSHA, 1994. (CFR. 1910).
18. Burney PG, Luczynska C, Chinn S, Jarvis D. The European Community Respiratory Health Survey. Eur Respir J 1994;7:954-60.
19. American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE). Ventilation for Acceptable Indoor Air Quality. Atlanta, GA: ASHRAE, 1989. (ASHRAE Standard 62-1989).
20. Spengler JD, Samet JM. A perspective on indoor and outdoor air pollution. In: Samet JM, Spengler JD. Indoor Air Pollution: A Health Perspective. Baltimore, Maryland: The Johns Hopkins University Press, 1991, pp 1-29.
21. Occupational Safety and Health Administration. Air contaminants-Permissible exposure limits standard. Washington, DC: US Government Printing Office. (Code of Federal Regulations, Title 29, sec. 1910.1000, App. 2), 1989.
22. American Conference of Governmental Industrial Hygienists (ACGIH). Threshold limit values for chemical substances and physical agents and biological exposure indices, 1994-1995 Edition. Cincinnati, Ohio: ACGIH, 1995.
23. Boleij JSM, Brunekreef B. Indoor air pollution. Public Health Reviews 1982; X:169-98.
24. US Environmental Protection Agency. National Air Quality and Emissions Trends Report. Research Triangle Park, NC: Office of Air Quality Planning and Standards, 1991.
25. Sexton K, Spengler JD, Treitman RD. Effects of residential wood combustion on indoor air quality: A case study in Waterbury, Vermont. Atmos Environ 1984;18:1371-83.
26. Traynor GW, Apte MG, Carruthers AR, Dillworth JF, Grimsrud DT, Gundel LA. Indoor air pollution due to emissions from wood-burning stoves. Environ Sci Technol 1987;21:691-7.
27. US Environmental Protection Agency. Air quality criteria for particulate matter, Volume 1. (EPA/600/P-95/001aF). Research Triangle Park: EPA, 1996.
28. Jaenicke R. Natural aerosols. In Kneip et al. eds. Aerosols: anthropogenic and natural, sources and transport. Ann N Y Acad Sci 1980;338:17-329.
29. Gordian ME, Ozkaynak H, Xue J, Morris SS, Spengler JD. Particulate air pollution and respiratory disease in Anchorage, Alaska. Environ Health Perspect 1996;104: 290-7.
30. Schwartz J. Air pollution and hospital admissions for respiratory disease. Epidemiol 1996;7:20-8.
31. Larson TV, Koenig JQ. Wood smoke: emissions and noncancer respiratory effects. Annu Rev Public Health 1994;15:133-56.
32. Pandey MR, Boleij JSM, Smith KR, Wafula EM. Indoor air pollution in developing countries and acute respiratory infection in children. Lancet 1989;i:427-9.
33. Winslow C-EA, Herrington LP. Temperature and Human Life. Princeton, New Jersey: Princeton University Press, 1949.