Impact of Improved Stoves on Indoor Air Quality in Ulaanbaatar, Mongolia

Report

313/05

November

ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

PURPOSE

The Energy Sector Management Assistance Program (ESMAP) is a global technical assistance partnership administered by the World Bank and sponsored by bi-lateral official donors, since 1983. ESMAP's mission is to promote the role of energy in poverty reduction and economic growth in an environmentally responsible manner. Its work applies to low-income, emerging, and transition economies and contributes to the achievement of internationally agreed development goals. ESMAP interventions are knowledge products including free technical assistance, specific studies, advisory services, pilot projects, knowledge generation and dissemination, trainings, workshops and seminars, conferences and roundtables, and publications. ESMAP work is focused on four key thematic programs: energy security, renewable energy, energy-poverty and market efficiency and governance.

GOVERNANCE AND OPERATIONS

ESMAP is governed by a Consultative Group (the ESMAP CG) composed of representatives of the World Bank, other donors, and development experts from regions which benefit from ESMAP's assistance. The ESMAP CG is chaired by a World Bank Vice President, and advised by a Technical Advisory Group (TAG) of independent energy experts that reviews the Programme's strategic agenda, its work plan, and its achievements. ESMAP relies on a cadre of engineers, energy planners, and economists from the World Bank, and from the energy and development community at large, to conduct its activities.

FUNDING

ESMAP is a knowledge partnership supported by the World Bank and official donors from Belgium, Canada, Denmark, Finland, France, Germany, the Netherlands, Norway, Sweden, Switzerland, and the United Kingdom. ESMAP has also enjoyed the support of private donors as well as in-kind support from a number of partners in the energy and development community.

FURTHER INFORMATION

For further information on a copy of the ESMAP Annual Report or copies of project reports, please visit the ESMAP website: **www.esmap.org**. ESMAP can also be reached by email at **esmap@worldbank.org** or by mail at:

ESMAP
c/o Energy and Water Department
The World Bank Group
1818 H Street, NW
Washington, D.C. 20433, U.S.A.
Tel.: 202.458.2321
Fax: 202.522.3018

Impact of Improved Stoves on Indoor Air Quality in Ulaanbaatar, Mongolia

November 2005

Shannon C. Cowlin[*]

Rachel B. Kaufmann[†]

Rufus Edwards[‡]

*Kirk R. Smith**

Energy Sector Management Assistance Program (ESMAP)

*Environmental Health Sciences Division, University of California at Berkeley.

† Human Development Network, World Bank, Washington, DC.

‡ Environmental Health, Science and Policy, University of California at Irvine

Table of Contents

List of Tables

List of Figures

Acknowledgments

The authors would like to thank everyone at the Improved Stoves Project Implementation Unit in Ulaanbaatar, Mongolia, for selecting homes for inclusion, sharing resources, and providing indispensable support throughout the study. Salvador Rivera, World Bank Task Manager of the Improved Household Stoves in Mongolian Urban Centers project, provided invaluable support at every stage of the project from its initial conception to production of the final report. T. Bulgan from Ecography Company provided invaluable strategic management by arranging transport, purchasing fuel, providing translation, hiring field staff, and generally making all aspects of this project come together. She also provided access to all available technical information on stoves and provided the team access to all current and prior research. The Mongolian Nutrition Research Center lent the scales used in the study. The local World Bank office in Ulaanbaatar provided resources, advice, and support while the field team was on the ground in Ulaanbaatar. Gian Allen and Tracy Allen of EME Systems and Seema Bhangar from the University of California, Berkeley, worked tirelessly to retrofit and test the UCB (University of California Berkeley) Particle Monitors so that there were sufficient numbers to go to Mongolia.

Additionally, Seema Bhangar provided training sessions on operation and calibration of the equipment, the thoroughness of which was greatly appreciated when problems were encountered in the field. Finally, Tracy Allen was in constant communication with the field team in an attempt to mitigate any problems encountered during the sampling period. Previous versions of this report were reviewed by Douglas Barnes, David Evans, and Nikhil Desai of the World Bank, Randy van Straaten of Balanced Solutions, René Massé of Groupe de Recherche et d'Échanges Technologiques, and D. Oyuntstetseg of the Project Implementation Unit. The authors would like to thank these reviewers for their careful reading and thoughtful comments and suggestions. Special thanks to ESMAP staff, Nidhi Sachdeva for formatting this report and to Marjorie K. Araya for coordinating the publication process.

Abbreviations and Acronyms

μm	micrometer
μg/m^3	microgram per cubic meter
ANOVA	analysis of variance
ARI	acute respiratory infection
ºC	degrees Celsius
cm	centimeter
CO	carbon monoxide
CO_2	carbon dioxide
CV	coefficient of variation
DF	degrees of freedom
EPA	Environmental Protection Agency (United States)
ESMAP	Energy Sector Management Assistance Program
IAP	indoor air pollution
IAQ	indoor air quality
kg	kilogram
m	meter
m^3	cubic meter
mg	milligram
N	number in sample
nm	nanometer
NO_x	nitrogen oxides
PE	photoelectric
PIU	Project Implementation Unit
PM	particulate matter
ppm	parts per million
SO_2	sulfur dioxide
TSP	total suspended particles
vmd	volume mean diameter
WHO	World Health Organization
UNICEF	United Nations Children's Fund

Executive Summary

Ulaanbaatar, Mongolia, is the coldest capital city in the world, with average winter low temperatures of –20° Celsius. Many families there live in *gers*, traditional Mongolian dwellings consisting of a wooden frame beneath several layers of wool felt. In the *ger* districts of Ulaanbaatar, cooking and heating energy is provided through indoor coal combustion in metal stoves with chimneys, and in wintertime, such stoves may be in use both day and night. Over the last several years, new stove designs with improved fuel efficiencies have been introduced into many homes.

To test the impact of the improved stoves on indoor air quality, 24-hour monitoring of particulate matter (PM) and carbon monoxide (CO) was done in 65 Mongolian *gers*. The primary analyses focused on 58 households, 20 with original (or traditional-type) stoves, 18 with the improved stove type TT-03, and 20 with the improved stove type G2-2000.

In addition to indoor pollutant concentrations, information on other relevant factors was collected, which included home sizes, indoor and outdoor temperatures, age of stove in use, amount of fuel used and number of refuelings, position of monitors relative to chimneys, and number of cigarettes smoked in the home. Analysis of variance showed that these factors did not differ significantly by stove type except that traditional stoves tended to be older than improved stoves. Multivariate regression methods were used to test for statistically significantly different indoor PM and CO concentrations between homes with different stove types while controlling for selected characteristics.

In homes with all stove types, the average level of indoor concentrations of PM and CO exceeded Mongolian national standards for 24-hour concentrations, and in the case of PM, the excess exposure was large. The Mongolian national standard for 24-hour CO is 2.6 parts per million (ppm), and the average of 24-hour CO concentrations over all households was 9.5 ppm. The Mongolian national standard for 24-hour average total suspended particles is 150–200 micrograms per cubic meter ($\mu g/m^3$), and the average 24-hour observed PM concentration was 730 $\mu g/m^3$ over all households. The indoor pollutant levels also exceeded air quality guidelines set by the World Health Organization and standards set by the U.S. Environmental Protection Agency.

For both PM and CO, no statistically significant decrease was found in homes with improved stoves for 24-hour average concentrations, 15-minute maximum concentrations, or 2-hour averages during the morning refueling period. However, there was a nonsignificant trend toward lower CO levels with improved stoves, which would be consistent with an improvement in combustion.

Although the number of refuelings during the day did not vary by stove type, coal consumption was significantly lower in households with G2-2000 and TT-03 stoves than in households with unimproved stoves, with an average decrease of 5 kilograms per day seen in homes with improved stoves.

Amount of fuel use, in turn, was found to be positively correlated with PM and CO concentrations. For coal use and all measures of CO, these correlations were significant. For wood use, only the correlation with CO during the two-hour morning refueling period was significant.

Calculations based on the fuel use findings suggest that improved stoves could decrease indoor 24-hour average CO concentrations by 11 percent. However, reductions of this size were not statistically verifiable, given the sample size of this study.

It is possible that high levels of ambient air pollution are largely responsible for the high indoor pollutant levels. Future studies should assess winter levels of ambient air pollution, the portions of indoor air pollution attributable to various sources, and actual personal exposures. Such information would help to clarify where protective measures are likely to be most helpful in reducing exposure and improving health.

In Mongolia, respiratory diseases are the primary cause of morbidity and mortality among children and the fifth leading cause of death for the overall population. Given the high burden of respiratory disease in Mongolia, and the well-known connection between air quality and respiratory health, efforts to reduce air pollution levels should receive priority.

1

Background

1.1 The city of Ulaanbaatar, Mongolia, is the coldest capital city in the world, with average winter low temperatures of –20° Celsius (C). Heating is critical in these conditions, and in the city of Ulaanbaatar, heat is generated primarily through combustion of coal. For apartments and commercial buildings in the city center, steam heat and electricity are provided by 3 large, coal-fired power plants and between 160 and 250 coal-fired boilers (Spickett and others 2002; Energy Sector Management Assistance Program [ESMAP] 2002). On the periphery of Ulaanbaatar are the *ger* districts, where there are between 80,000 and 100,000 additional households using individual coal stoves for heating and cooking (Spickett and others 2002; ESMAP 2002). These sources contribute to high levels of urban air pollution, particularly during periods of temperature inversions, which are observed in the winter months when coal combustion is at peak levels.

1.2 Within the *ger* districts on the outer edges of Ulaanbaatar, many homes are *gers,* the traditional Mongolian dwellings consisting of a wooden frame beneath several layers of wool felt. Other homes in these districts are generally wood constructions of variable quality and levels of insulation. These households in the *ger* districts consume approximately 0.4 million tons of coal per year in addition to the 5.4 million tons consumed by commercial coal combustion. By-products of coal combustion known to have detrimental health effects include carbon monoxide (CO), sulfur dioxide (SO_2), and particulate matter (PM) (Sinton, Smith, Hu, and Liu 1995).

1.3 In various studies of households with indoor combustion sources around the world, indoor pollutant concentrations have been observed at levels that far exceed ambient levels and maximum pollutant standards set forward for protection of health (Bruce, Perez-Padilla, and Albalak 2000). In the case of biomass fuels, elevated indoor particulate concentrations have been linked to increased incidence of acute respiratory infections (ARIs), chronic bronchitis, and a range of other health effects (Bruce, Perez-Padilla, and Albalak 2000). Lung cancer from household coal combustion has been established in Chinese studies (Chen, Hong, Pandey, and Smith 1990), and, given the similarly high pollution levels, it can be expected that indoor coal combustion produces similar risks for other diseases as those due to biomass fuel combustion. Stoves used in Mongolian households have closed combustion chambers and chimneys vented to the outdoor environment. Combustion products are primarily released to the indoor environment during refueling and as fugitive emissions. To prevent heat loss during periods of extremely low temperatures, homes are designed to have minimal air exchange between the indoor and outdoor environments. This further increases exposure to pollutants emitted indoors because they are allowed to accumulate without rapid losses to the outdoor environment.

1.4 Those most affected by exposure to products of combustion from indoor cook stoves are often elderly people, unemployed women, and preschool-age children, because they spend much of their time in the home. Although child mortality is decreasing in Mongolia, respiratory diseases are the primary cause of morbidity and mortality among children aged 0–19 years and the fifth leading cause of death for the overall population, at 44.29 deaths per 100,000 (Ministry of Health, Mongolia 2003; Directorate of Medical Services and Government Implementing Agency, Mongolia 2003). In 2002, the Mongolian Directorate of Medical Services and Government Implementing Agency reported the mortality rate for children under-5 as 39 per 1,000 live births. However, the United Nations Children's Fund (UNICEF) estimated the under-5 mortality rate as considerably higher, at 71 per 1,000 in 2002 (UNICEF 2003). In comparison, UNICEF's 2002 under-5 mortality rate estimates for China and Russia, Mongolia's nearest neighbors, were 39 per 1,000 and 21 per 1,000, respectively, and 8 per 1,000 live births for the United States (UNICEF 2003). An estimated 80 percent of such deaths in Mongolian infants were attributed to pneumonia in 1993, and ARIs are a particular concern in winter (Manaseki 1993).

1.5 More than one-third of Mongolia's population resides in Ulaanbaatar, and a demographic shift toward greater urbanization in recent years is increasing the number of pollution sources there. A larger number of urban families translates to more cooking and heating stoves, more motor vehicles, and probably to increased industrial and power plant emissions as well. In recent years, the population of Ulaanbaatar has increased between 2 percent and 4 percent annually, which translates to a 10 percent increase between 1999 and 2002 alone (National Statistical Office of Mongolia 2003). Available data on ambient air pollution in Ulaanbaatar are not fully consistent but give a general impression of increased pollution in the winter months and rising levels in recent years (Spickett and others 2002). Mongolia is reported to have one of the highest per capita rates of greenhouse gas emissions in the world (ESMAP 2002). In addition, expenses for winter fuel were estimated to total at least 17.5 percent of the average Ulaanbaatar *ger* household's annual income, with poorer families spending a higher proportion of income on fuel (ESMAP 2002).

1.6 To partly address the latter issues, the World Bank–administered ESMAP undertook the Improved Household Stoves in Mongolian Urban Centers project, which promotes the design and dissemination of stoves with improved fuel efficiency. In contrast to traditional stoves, the improved stoves typically have smaller combustion chambers, air intakes that force air through the burning coal from underneath, adjustable air intakes and cook-top openings, and internal chimney baffles to slow the upward movement of hot exhaust so that it can provide additional room heating before exiting the chimney. Some of these differences are summarized in the schematic diagram shown in figure 1.1, which compares traditional stoves to newly designed G2-2000 stoves. In laboratory tests, the G2-2000 stoves required 23 percent less fuel than the traditional stoves to heat *gers* to similar levels (ESMAP 2002). After these preliminary tests, the G2-2000 stoves were distributed free of charge to 40 families in the community in 1997. Two years after deployment, only 19 of the 40 families could be found, and those families reported satisfaction with their improved stove's heating performance (ESMAP 2002). In addition, these families reported an average reported fuel savings of 34 percent for coal and 15 percent for wood. Additional improved stoves have been introduced by this project into the market. The most popular of these is model TT-03, shown in figure 1.2, which has metal flanges on each side to improve heat radiation into the room as well as room air pass-throughs, a clay interior lining to hold heat, and a chimney valve to help control the burn rate. Another new design, the Bona 2, is currently available in Ulaanbaatar, and a fourth design called the IB-1 has been discontinued because of low customer satisfaction. For each available model, there are two designs, which differ slightly depending upon whether the stove is intended for installation in a *ger* or a home with solid construction. Kits for retrofitting existing traditional stoves have also been made available. By the end of 2003, 2,740 improved stoves of all designs had been introduced into Ulaanbaatar households, 836 of which were the G2-2000 design and 998 of which were the TT-03 design. Residents of other *aimags* (provinces) were also using improved stoves purchased in Ulaanbaatar.

Figure 1.1: Air Flow in Traditional and Improved Stoves

The left side shows a traditional stove with a large combustion chamber in which air flow is across the coal bed. The right side shows an improved (G2-2000-type) stove with a smaller combustion chamber and a grate and air inlet that directs air flow through the coal bed from underneath.

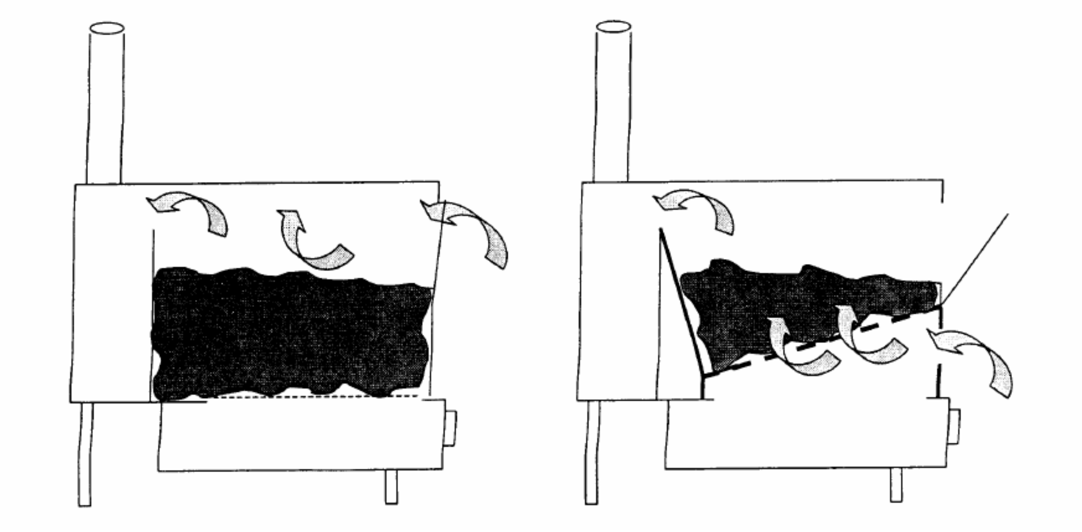


Figure 1.2: The TT-03 Stove

1.7 The primary focus of the ESMAP project is the impact on air pollution emissions from improved stoves at the global (greenhouse gas emissions) and urban levels. Early laboratory testing confirmed that G2-2000 stoves and kits were effective in reducing chimney stack emissions of SO_2, CO, carbon dioxide (CO_2), and dust; the kits were also effective in reducing emissions of nitrogen oxides (NO_x) (ESMAP 2002). It was thought that the improved stoves might also decrease exposure to indoor air pollution (IAP) by reducing the necessary number of refueling instances and more completely combusting the fuel used. A recent qualitative study of perceived benefits revealed that users of improved stoves reported faster ignition, less smoke, and fewer refueling instances (Gordon 2003).

1.8 This report describes a pilot study undertaken collaboratively by the World Bank and the Environmental Health Sciences Division of the University of California, Berkeley, to measure IAP levels in households using different types of coal-fired heating stoves and develop an understanding of the degree to which introduction of improved stoves changed indoor air quality (IAQ) in terms of CO and PM. The specific objective was to determine the relationship between IAQ and improved stove types in *gers* in Ulaanbaatar.

2

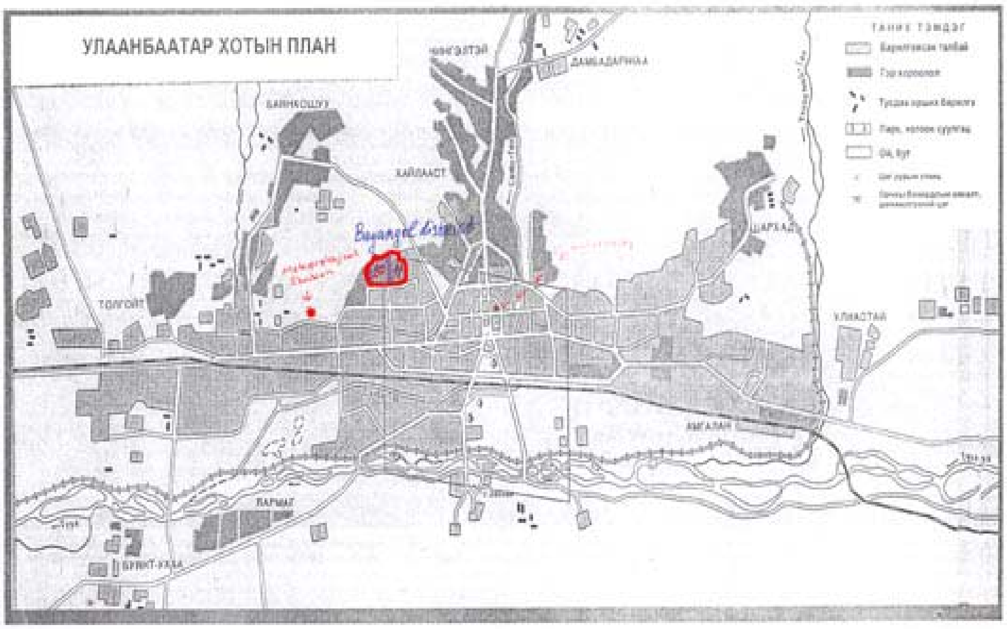
Data Collection and Analysis

Study Site and Home Selection

2.1 The field work took place in January 2004. The study used a stratified sampling design. The original sampling plan involved 24-hour sampling in 75 *gers*, 25 each with the traditional, TT-03, and G2-2000 stove types. These stoves were chosen for study because they are the most widely distributed among the available models. No prior data on IAP levels related to Mongolian stoves were available that could guide the choice of sample size (N). In the absence of other information, N = 25 was selected because samples of this size and larger will often give results approximating normal distributions. 24-hour sampling was used to ensure that the entire range of daily IAP levels would be measured, simplify logistics, reduce the coefficient of variation (CV) introduced by diurnal changes in temperature and household activities, and correspond better to health-based standards. Only *ger* households were included in the study to minimize the number of structural factors that might influence IAQ in the study. All homes included in the study were *gers* located just outside central Ulaanbaatar in two adjacent subdistricts of the Bayangol district, the 10th and 11th *khoroos* (subdistricts). The study area is shown in figure 2.1. Adjacent districts were selected to minimize variability between households that could be attributed to geographical conditions. Finally, it was desired that only households with stoves that had been in use for six months or longer be included because it is thought that stove efficiency and emissions of the stove could change as the stove ages and as the operators become more familiar with the technology. Thus, the criteria used in selecting homes for the study were that the home was in the 10th or 11th *khoroo* of Bayangol, Ulaanbaatar, the housing structure was a *ger*, the stove used was one of the three types of interest for the study, and the stove had been in use for six months or longer.

Figure 2.1: Map of Central Ulaanbaatar and Study Area

The red outline indicates the study area, and the red dot indicates the ambient temperature monitoring site.



2.2 Households with improved stoves were selected from a list of homes maintained by the Improved Household Stoves Project Implementation Unit (PIU). Households with traditional stoves were selected by *khoroo* civic leaders. More than 100 households were visited to select the final homes that best met the criteria. Attempts were made to sample one or more homes with each stove type on each sampling day to minimize the confounding and variability-enhancing effects of temporal variability in meteorological and background ambient pollutant conditions. This was not possible on all days because of difficulties in locating homes or residents not being present to give consent when sampling teams arrived. For these reasons and because some IAQ monitors failed during the study period, the final number of *gers* sampled was 65, 22 of which had traditional stoves, 20 had TT-03 stoves, and 23 had G2-2000 stoves. Table 2.1 shows the number of stoves sampled on each deployment day and the average ambient temperatures on those days.

Table 2.1: Number of Households with Each Stove Type Sampled on Each Deployment Date

Deployment date	Average ambient temperature (°C)[a]	Stove type Traditional	 TT-03	 G2-2000
1/6/2004	−22.0	1	1	1
1/7/2004	−22.7	2	2	3
1/8/2004	−20.4	1	3	4
1/9/2004	−25.1	1	0	2
1/10/2004	−18.9	3	4	1
1/12/2004	−21.8	3	2	2
1/13/2004	−17.6	2	2	1
1/14/2004	−20.5	4	2	1
1/15/2004	−24.8	1	2	3
1/16/2004	−26.9	2	1	3
1/17/2004	−27.4	2	1	2
Total		22	20	23

[a] Information on outdoor temperatures, measured at three-hour intervals at a municipal monitoring site (see figure 2.1), was provided by Ecography Company. The average daily temperature for each monitor deployment date was calculated by averaging reported values between 11:00 and the following 8:00.

Field Team and Questionnaire

2.3 A team of local staff was assembled to conduct the field work. Field team training and responsibilities are described in annex 1.

2.4 An informed consent and data collection form was developed and translated into Mongolian. The form was used to record measurements and to collect information from the senior household member present during the first household visit; it included items on fuel use, cigarette smoking, reload times, and whether the usual *ger* temperature was maintained. This form is found in annex 2.

Monitoring Equipment

2.5 Two monitors were deployed in each household monitoring session: one UCB Particle Monitor (University of California, Berkeley) and one HOBO Carbon Monoxide Data Logger (Onset Corporation, Bourne, MA). The UCB particle monitor is a prototype particle monitor designed for ease of use in monitoring indoor air particle levels in developing-country settings. Although not yet available commercially, it is expected to retail for US$300–500, which is 10–30 times less than currently available commercial monitors with similar capabilities. The UCB particle monitor is a programmable continuous particle monitor that is passive and therefore does not require air-pump calibration and other skilled handling. In addition to measurements of PM, the UCB also logs temperature and relative humidity. The UCB particle monitor has two independent sensors (ionization and photoelectric [PE] light-scattering chambers) for measurement of PM. The UCB has been validated in experiments that compared its results against those of a frequently used, commercially available particle monitor that also measures particles by light scattering, the DustTrak (TSI Incorporated, Shoreview, MN). In an experiment that tested the ability of the UCB to measure mass concentrations of both fine (volume mean diameter [vmd] < 300 nanometers [nm]) and coarse particles (vmd = 2,090 nm), the UCB results were highly correlated with those of the DustTrak, with regression coefficients (R^2) greater than 0.99 for both PE and ionization response. In a second experiment that tested the UCB's measurement of airborne particulate mass concentrations, similar correlations between the UCB and DustTrak were obtained using combustion aerosols, with R^2 greater than 0.99 for concentrations up to 120 milligrams per cubic meter (mg/m^3) (Edwards and others submitted for publication).

2.6 The measurements based on the PE light-scattering sensor are presented in this report. The PE sensor is most sensitive to particle sizes corresponding roughly to $PM_{2.5}$—that is, particles smaller than 2.5 micrometers (μm) in diameter (Litton, Smith, Edwards, and Allen 2004). As combustion-derived particles are nearly all in the lower size ranges, it was expected that the PE sensor would pick up most of the emissions. The UCB monitor does not, however, have a sharp cutoff at 2.5 μm, as does an impactor or cyclone used with an air pump. This disadvantage was considered to be offset by the advantages of being able to simultaneously deploy multiple, inexpensive, data-logging devices that operated silently and did not require field calibration. In a strict sense, however, the particle masses reported can be considered lower than what would be found in an active device designed to measure PM_{10} and somewhat greater than what would be recorded by one measuring $PM_{2.5}$. Data are reported as mass concentrations in mg/m^3.

2.7 The protocol for use of the UCB monitor is in annex 3.

2.8 The HOBO CO monitors used in the study are commercial data-logging devices available at relatively low cost (approximately US$200). CO data were collected using channels 1 and 2 of the monitor, which cover the ranges 0.2–124.3 parts per million (ppm) and 1–497.1 ppm, respectively. The typical accuracies of channels 1 and 2 at 20°C are reported by the manufacturer to be ±4.5 ppm ±7 percent of reading and ±6 ppm ±7 percent of reading, respectively. The devices for this study were purchased new and calibrated before and after use in Mongolia at the University of California, Berkeley.

2.9 The protocol for use of the HOBO CO monitor is in annex 4.

Stove Fuel

2.10 The households were not provided with monetary compensation for their participation in this study; however, they were provided with ample fuel for use during the sampling period. Coal is the primary fuel used in these stoves. Before sampling began, one truckload of coal was purchased, which was then bagged for families participating in the study. This quantity of coal was sufficient for provision of 1.5 bags (approximately 45 kilograms [kg]) to each participating household. This amount was significantly greater than the amount expected to be used in 24 hours, so that families would not have to skimp or use coal from other sources during the monitoring period. Provision of coal from a single lot to all families eliminated variability in emissions attributable to varying coal composition. Families also consume wood and other fuels such as paper, primarily under cold start conditions as a starter fuel, and 2 bags of wood (approximately 20 kg) were also supplied to each household. Because it was not possible to supply wood of consistent origin (all from the same tree) to each household, wood was purchased each morning before deployment of equipment.

First Home Visit and Equipment Deployment

2.11 At each home, the study purpose and design were explained in Mongolian to the household members, and verbal consent was obtained and noted via the interviewer's signature on the household data sheet. The respondent's name and relationship to the head of household were also noted on the data form. After obtaining consent, team members measured the *ger* using a tape measure. Figure 2.2 shows the structure of a *ger*'s wood support system. The volume of each *ger* was approximated by modeling the structure as an inverted cone atop a cylinder, though the upward slope from the central hub was typically at a shallower angle than that of the rafters. Measurements taken for each household were the height at wall, height at center, and the *ger* diameter.

Figure 2.2: The Wooden Support Structure of a *Ger*, Showing the Door and Frame, Walls, Rafters, Roof Ring, and Belly Bands

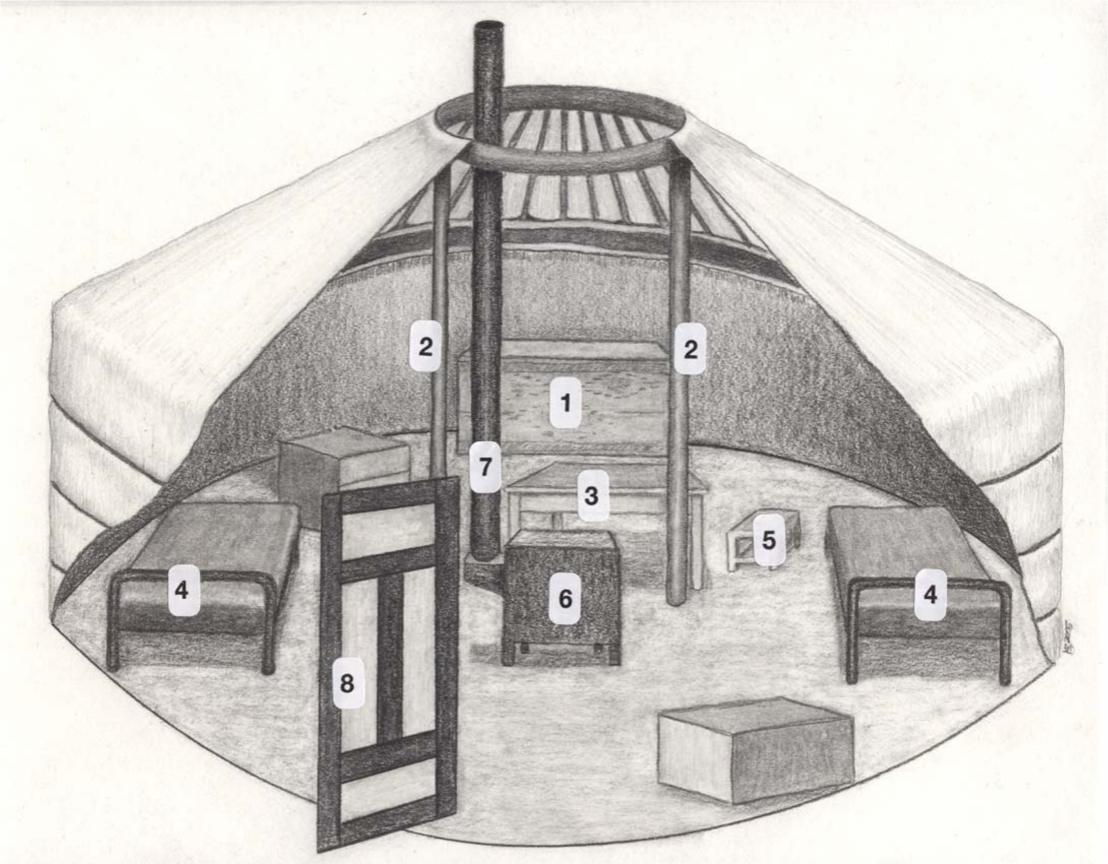
Source: http://www.coyotespaw.com/artifs/MongoliaYurt-Ger.htm. Used by permission.

2.12 The coal and wood were then provided to the residents, and the quantity was measured using a scale designed for measuring weights of mothers and their young children. According to operating instructions for this scale design, measurements were obtained by first weighing one team member and then resetting the scale to zero and reweighing the team member while he held the bag of fuel. The scale then automatically calculated the weight difference, which was the weight of the fuel. The bags were marked either "1" or "2," and the residents were asked to use only the fuel provided, starting with the bags marked "1," during the period that the monitors were in the home. Household members were informed that they would be able to keep any fuel remaining at the end of the study and were asked to not modify their typical fuel use patterns during the monitoring period.

2.13 After conducting the launching procedure for the monitors as described in annexes 3 and 4, the monitors were hung from a roof rafter at the junction of the center hub. In a typical *ger*, the stove is in the center of the room, and there is a table placed close to the stove directly across from the door, as shown in figure 2.3. This was reported to be the warmest place in the *ger*, and it was therefore anticipated to be the region least affected by air currents induced by opening the door. As such, the monitors were hung in this general region of the *ger* at a height of 1.6 meters (m) from the floor. This height was selected as representative of standing adult breathing height and as a location that would minimize disturbance to residents. The monitors were hung back to back from string as shown in figure 2.4. The preferred location for monitor placement was at 180° from the door. In some homes, there was a light at that location; in these instances, the monitors were hung at approximately 210°. The field team noted the equipment numbers, location where equipment was suspended, and time of deployment.

2.14 Before the field team left each home, they asked the residents to not disturb the monitors and to use only the coal and wood provided. Finally, the residents were given a form to record the times when the stove was refueled and when meals were cooked. They were also asked to record the number of cigarettes smoked in the household each day on this form.

Figure 2.3: Cutaway View of a *Ger*, Showing Typical Layout of Some Furnishings



Note: Objects in figure are (1) chest, (2) roof support pole, (3) table, (4) bed, (5) stool, (6) stove, (7) chimney, (8) door (ajar; hinge on right side).

Figure 2.4: Actual Arrangement of HOBO (on Left) and UCB Monitors as Hung from Roof Rafter at Center Hub

Second Home Visit and Equipment Collection

2.15 After 24 hours, a field team returned to the household. At that time, the team confirmed that the equipment had not been moved and noted whether the monitors were still functioning before removing them and recording the time of removal. The bags of coal and wood were reweighed, and the amount of fuel used was calculated by subtraction. Also during this visit, the information on smoking and refueling and cooking instances was reviewed with the householders. Householders were asked if they had kept the *ger* at its usual temperature and if they had used any fuel other than that provided for the study. Two homes reported using additional fuel; one household had used 10 pieces of ebony wood and the other household did not provide details on the additional fuel used. Most householders said that they had kept their home at its usual temperature, but 23 householders had kept it warmer and 2 had kept it colder.

Data Processing

2.16 Data were downloaded from the UCB and HOBO monitors using protocols described in annexes 3 and 4. These data were then exported to an Excel spreadsheet and cropped to include only the first 24 hours after monitor deployment. However, in seven households, the monitoring period was between 1 and 19 minutes less than 24 hours as a result of slightly premature equipment collection. All information gathered on the data collection sheet was entered into Excel spreadsheets and the data entry was double-checked. *Ger* measurements, which had been recorded in inches, were converted into centimeters (cm). It was noted that some stove ages were given as less than six months, with some households clarifying that the stove itself was older than that, but was new to this particular home. Approximately one year after study completion, the PIU verified or updated the ages of all stoves where it was unclear whether the stove age or date of installation was reported. For five households who had moved out of the area, the originally reported dates were used.

2.17 Typical analysis of UCB PE readings calculates the mass concentrations as a function of a predeployment 20-minute calibration period inside a sealed plastic bag, which is assumed to represent zero concentration background. Upon examination of the UCB PE data collected in the *gers*, it became clear that 20 minutes had been insufficient to allow background concentrations to reach zero in the bag (from impaction of the particles inside the plastic bag). This was due to the high ambient levels of particle pollution in the *gers* where the zeroing procedure was conducted. Thus, an alternate calculation was devised to assess the relative contribution to indoor PM by stove use rather than the absolute amount of PM. This involved looking at all 1-minute PE values for the 24-hour monitoring period, selecting the first percentile value, and using this value as the baseline for that individual 24-hour sample. Then the reported concentrations were the PM contributions above this baseline concentration. Because the baseline period was typically at night, when there should have been no or minimal stove or human activity that would have produced airborne particulates, the measured concentrations above baseline should represent the contribution in PM attributable to the stove in the *ger*.

Statistical Analysis

2.18 The investigation focused on the impact of household stove type on IAQ, which was evaluated according to three time-based parameters for both PM and CO: a 24-hour average, the maximum observed 15-minute concentration, and a 2-hour average following the first morning stove refueling. For each parameter of interest, bivariate statistical testing was conducted using analysis of variance (ANOVA) and multivariate testing was conducted using regression models. In the multivariate models, independent but potentially influential variables were included as covariates as appropriate. These variables included *ger* volume, difference between 24-hour average indoor and outdoor temperatures, age of the stove, distance between the stove and the monitors, and number of cigarettes smoked in the household during the monitoring period. ANOVA was used to determine if the mean values of all potential covariates differed across households according to stove type. However, to take a conservative approach, covariates were retained in the multivariate models even if nonsignificant. All statistical tests were conducted with $\alpha = 0.05$ and power $(1 - \beta)$ of 0.8.

2.19 The rationale for the inclusion of covariates in the regression models was as follows: For CO, increased *ger* volume could result in decreased concentrations because the pollutant mass would be distributed in a greater air volume. The same dilution effect would exist for PM, but a competing effect could result from a decrease in PM removal. A major mechanism of particle removal from an indoor environment is deposition on surfaces; an increased volume would result in a decreased surface to volume ratio, which increases the average distance a particle has to travel before it can be deposited, thus increasing a particle's atmospheric lifetime. The age of the stove can alter pollutant concentrations if stove performance changes over time or if user familiarity changes stove use practices over time. Because improved stoves became available more recently than traditional stoves, a stove age by stove type interaction term was initially included in the models and then dropped because it was nonsignificant for all IAQ tests. Cigarettes smoked in the home are additional sources of products of incomplete combustion and could increase measured concentrations. Monitor distance from the stove could bias the results if the indoor environment is not well mixed. Finally, the difference in indoor and outdoor temperatures could affect measurements if, on different days of the study, colder outdoor temperatures required increased stove use to maintain a comfortable indoor temperature. Whether or not the *ger* was kept at its usual temperature was not included as a covariate because this factor was found to be unrelated to stove type, fuel use, or IAQ, and both actual fuel use and temperature were already included explicitly in the models.

2.20 Because improved stoves are hypothesized to reduce coal use, the relationships between stove type and amount of fuel used and number of refuelings over the 24-hour day were also modeled using ANOVA and regression. If the majority of emissions from the stove occur during refueling events, the number of times the stove is opened could influence IAP concentrations. Similarly, the relationships between fuel use and IAQ were modeled. Fuel use rates were not included as covariates in multivariate analyses of the stove type–IAQ relationships because it was thought possible that decreased fuel use might be the mechanism by which any IAQ improvements would be achieved. If that were the case, then including fuel use rates as covariates could attenuate the observed impacts of stove type on IAQ and lead to incorrect conclusions.

2.21 The data from the 2 households reporting use of nonstudy fuel were not included in the analysis because the weight (and, in one case, type) of extra fuel used was unknown. In addition, the data from 5 of the 65 households were not used in the primary analyses because of UCB equipment failure, as evidenced by data gaps during the monitoring period or nonoperational equipment upon collection. The UCB failures meant that both PE and indoor temperature readings were lacking. Thus, the final effective sample size was 58 households: 20 with traditional stoves, 20 with G2-2000 stoves, and 18 with TT-03 stoves. However, the regression models for CO were also rerun, including the 5 households lacking PE data, to determine if the larger sample size (N = 63) would yield materially different results. The results from these models, which are not presented, did not alter any inferences regarding the relationship between stove type and any measure of IAP.

3

Results

Household and Environmental Factors

3.1 The independent household and environmental factors studied included *ger* volume, average indoor temperature, average ambient temperature, age of the stove, distance between the stove and the monitors, and number of cigarettes smoked in the household during the monitoring period. Over all households (N = 58), the values for these variables showed wide ranges. *Ger* volume ranged from 29 to 61 m^3, average indoor temperature ranged from 10.6 to 28.6 °C, stove age ranged from 0.2 to 33.6 years, monitor distance from chimney ranged from 36 to 142 cm, and the number of cigarettes smoked ranged from 0 to 80.

3.2 These factors were analyzed to determine if there was any systematic variation between stove types. Table 3.1 shows the means and standard deviations by stove type and over all households, and it also shows the probability that true means for each stove type are statistically equal. The mean values of *ger* volume, average indoor temperature, average ambient temperature, number of cigarettes smoked, and distance of monitors from the stove did not differ significantly by stove type. Stove age did differ significantly by stove type, with improved stoves being newer than traditional stoves; this was expected because improved stoves have been available only since 2000 and some traditional stoves are more than 15 years old.

Table 3.1: *Ger* and Environmental Characteristics by Stove Type

Stove type		Traditional (N = 20)	G2-2000 (N = 20)	TT-03 (N = 18)	Total (N = 58)	Probability > *F* (DF = 55)
Ger volume (m^3)	Mean	42	44	43	43	0.6547
	Standard deviation	8	7	8	8	
24-hour mean indoor temperature (°C)	Mean	22.3	22.1	19.9	21.5	0.1775
	Standard deviation	3.9	4.2	4.5	4.2	
Number of cigarettes smoked	Mean	9	7	7	8	0.8062
	Standard deviation	18	10	8	13	
Age of stove (years)	Mean	7.7	2.5	2.3	4.2	0.0022

	Standard deviation	8.8	0.5	0.8	5.7	
Distance of monitors from stove (cm)	Mean	100	106	109	104	0.3194
	Standard deviation	22	15	18	19	

DF = degrees of freedom

Fuel Use

3.3 The most widely promoted benefit of using improved stoves is a reduction in necessary coal consumption. A summary of all fuel use data is presented in table 3.2. This includes the coal use rate (kg coal/day), the wood use rate (kg wood/day), the ratio of wood use to coal use (kg wood/kg coal), and the number of refuelings. The wood to coal use ratio was included to assess whether a reduction in coal use was compensated for by an increase in wood use. Over all homes (N = 58), coal use rates ranged from 7.7 to 35.3 kg/day, wood use rates ranged from 0 to 16.1 kg/day, the ratio of wood use to coal use ranged from 0 to 0.69, and the number of refuelings ranged from 2 to 14. Table 3.2 shows that the mean coal use rate for G2-2000 and TT-03 stoves is significantly decreased, by 5 kg/day, when compared to traditional stoves. Wood use rate, the ratio of wood use to coal use, and the number of refuelings were not significantly different by stove type.

3.4 Further tests to search for statistically significant differences in fuel use between stove types were done using multiple regression, which accounted for possible correlation between measured household characteristics. The multiple regression covariates included *ger* volume, 24-hour mean indoor temperature, ambient temperature, stove age, and stove type. The regressions showed that number of refuelings, wood use rate, and the ratio of wood use to coal use were not statistically significantly different between households with different stove types, and no other covariates were shown to be significant predictors of these rates. The multiple regression for coal use, however, again showed that both G2-2000 and TT-03 stoves were statistically significant predictors of decreased coal use. When adjusting for covariates, a G2-2000 or TT-03 stove in the home corresponded to a decrease in coal usage of 5.5 kg per day and 4.8 kg per day, respectively. No other covariates were shown to be significant predictors of coal use. Tables 3.3–3.5 show coefficients and statistical significance from the multiple regressions for coal use rate, wood use rate, and number of refuelings. The R^2 values for each model indicate the percentage of variability in fuel use that was explained by the factors in the model.

Table 3.2: Fuel Use Rates and Ratios for Each Stove Type

Stove type		Traditional (N = 20)	G2-2000 (N = 20)	TT-03 (N = 18)	Total (N = 58)	Probability > *F* (DF = 55)
Coal use rate (kg/day)	Mean	26.4	20.5	20.9	22.7	0.0055
	Standard deviation	5.4	5.3	7.4	6.6	
Wood use rate (kg/day)	Mean	5.9	5.9	5.2	5.7	0.7385
	Standard deviation	3.6	3.6	2.0	3.2	
Wood use rate/coal use rate	Mean	0.22	0.30	0.27	0.26	0.2651
	Standard deviation	0.12	0.18	0.11	0.14	
Number of refuelings	Mean	7	7	7	7	0.8014
	Standard deviation	2	3	3	3	

Table 3.3: Coal Use Rate: Multivariate Regression Estimates (N = 58, Model $R^2 = 0.20$)

Covariates	Estimate	Standard error	*t*	Probability > *t*
Constant	22	10	2.09	0.0414
TT-03	−4.8	2.3	−2.09	0.0413
G2-2000	−5.5	2.2	−2.54	0.0141
Ger volume (m^3)	0.018	0.12	0.15	0.8841
Stove age (years)	0.047	0.16	0.29	0.7753
24-hour outdoor temperature (°C)	0.091	0.28	0.33	0.7460
24-hour indoor temperature (°C)	0.25	0.22	1.13	0.2650

Table 3.4: Wood Use Rate: Multivariate Regression Estimates (N = 58, Model R^2 = 0.05)

Covariates	Estimate	Standard error	*t*	Probability > *t*
Constant	3.9	5.4	0.71	0.4810
TT-03	−0.50	1.2	−0.42	0.6775
G2-2000	0.071	1.1	0.06	0.9505
Ger volume (m^3)	−0.0012	0.064	−0.02	0.9852
Stove age (years)	0.049	0.085	0.57	0.5718
24-hour outdoor temperature (°C)	−0.16	0.15	−1.07	0.2914
24-hour indoor temperature (°C)	−0.078	0.12	−0.68	0.4984

Table 3.5: Number of Refuelings: Multivariate Regression Estimates (N = 58, Model R^2 = 0.04)

Covariates	Estimate	Standard error	*t*	Probability > *t*
Constant	1.8	4.5	0.41	0.6847
TT-03	−0.070	0.99	−0.07	0.9434
G2-2000	−0.30	0.94	−0.32	0.7502
Ger volume (m^3)	0.023	0.053	0.43	0.6680
Stove age (years)	0.042	0.071	0.59	0.5549
24-hour outdoor temperature (°C)	−0.093	0.12	−0.77	0.4466
24-hour indoor temperature (°C)	0.084	0.095	0.88	0.3813

24-Hour Average Pollutant Concentrations

3.5 Table 3.6 shows the average 24-hour concentrations for CO (ppm) and PM (mg/m^3 above baseline) by stove type, and histograms of the 24-hour means for all households are shown in figures 3.1 and 3.2. Although the mean CO values were lower for both types of improved stove than for the traditional stoves, the difference was not statistically significant in the bivariate ANOVA. Compared to traditional stoves, TT-03 stoves had slightly lower PM levels and G2-2000 had slightly higher levels, but these differences also did not vary significantly by stove type in bivariate analysis. Multiple regressions were run testing the effect on CO and PM from stove type, stove age, number of refuelings, *ger* volume, monitor distance from chimney, number of cigarettes smoked, and difference between 24-hour indoor temperature and 24-hour outdoor temperature. Tables 3.7 and 3.8 show the estimates and significance for the covariates. The model for 24-hour CO concentrations showed that there was not a statistically significant difference in CO concentration between stove types and that no other covariates were statistically significant predictors of CO. Similarly, the multiple regression model for 24-hour PM concentration showed that there was not a statistically significant difference in PM between stove types, and no other covariates were shown to be significant predictors of 24-hour PM.

3.6 Two homes had noticeably higher levels of CO than the other homes. These homes had 24-hour CO concentrations of 35 and 38 ppm while levels at all other homes were less than 25 ppm. To test the impact of these outlying values on the results, the regression model was rerun with these two homes removed from the dataset. No changes in the statistical significance of stove type on 24-hour CO and PM were observed. Because of this, and because there is no evidence that the two outlying data points are erroneous, these data points were retained, and all reported summaries and model results include these homes.

Table 3.6: 24-Hour Mean Pollutant Concentrations by Stove Type

Stove type		Traditional (N = 20)	G2-2000 (N = 20)	TT-03 (N = 18)	Total (N = 58)	Probability > *F* (DF = 55)
24-hour CO concentration (ppm)	Mean	11.6	7.8	8.9	9.5	0.1515
	Standard deviation	9.7	3.0	2.3	6.2	
24-hour PM concentration (mg/m^3 above baseline)	Mean	0.7	0.8	0.6	0.7	0.3437
	Standard deviation	0.5	0.4	0.3	0.4	

Figure 3.1: Histogram of 24-Hour Mean CO Concentration (ppm) (N = 58)

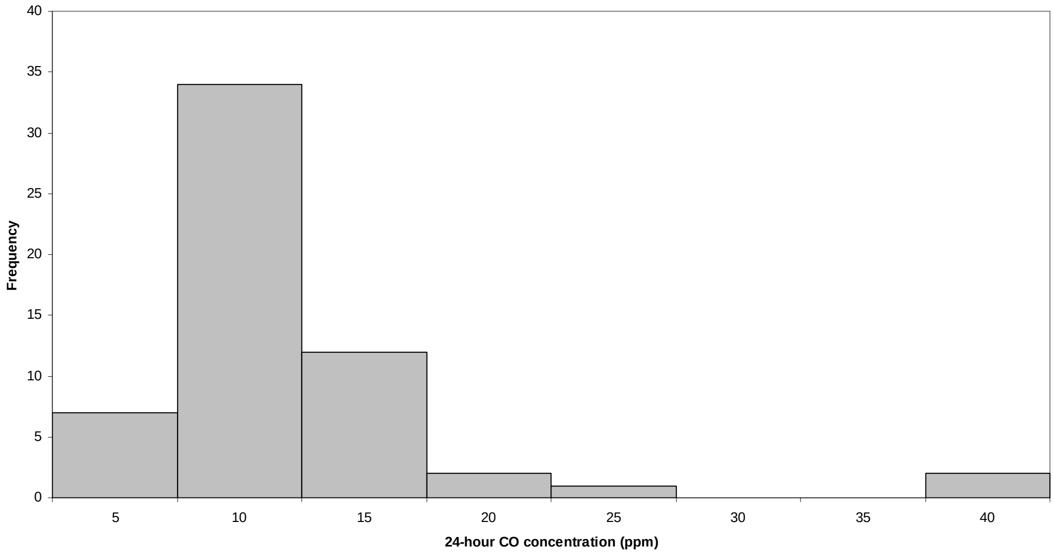


Figure 3.2: Histogram of 24-Hour Mean PM Concentration (mg/m^3 above Baseline) (N = 58)

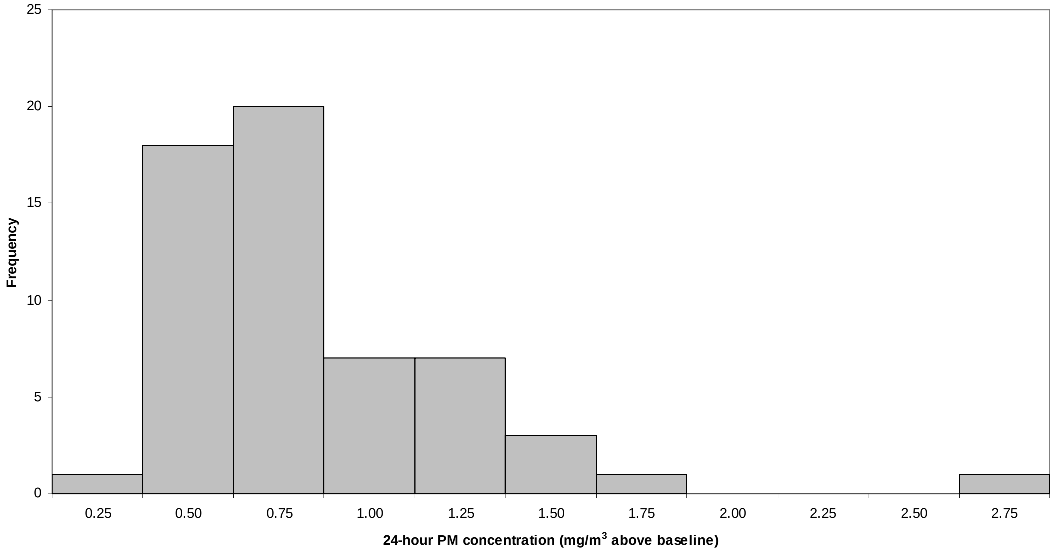


Table 3.7: 24-Hour Mean CO Concentration (ppm): Multivariate Regression Estimates (N = 58, Model R^2 = 0.20)

Covariates	Estimate	Standard error	*t*	Probability > *t*
Intercept	9.4	11	0.87	0.3861
TT-03	−1.4	2.2	−0.62	0.5412
G2-2000	−2.7	2.1	−1.30	0.2009
Stove age (years)	0.12	0.17	0.71	0.4793
Number of refuelings	0.44	0.31	1.39	0.1704
Ger volume (m^3)	−0.20	0.12	−1.60	0.1150
Distance of monitors from chimney (cm)	0.018	0.048	0.38	0.7062
Number of cigarettes smoked	−0.014	0.065	−0.22	0.8301
24-hour average temperature difference (indoor − outdoor, °C)	0.11	0.16	0.67	0.5073

Table 3.8: 24-Hour Mean PM Concentration (mg/m^3 above Baseline): Multivariate Regression Estimates (N = 58, Model R^2 =0.18)

Covariates	Estimate	Standard error	*t*	Probability > *t*
Intercept	1.1	0.72	1.54	0.1298
TT-03	0.018	0.15	0.12	0.9024
G2-2000	0.26	0.14	1.85	0.0710
Stove age (years)	0.020	0.011	1.78	0.0818
Number of refuelings	0.020	0.021	0.94	0.3521
Ger volume (m^3)	−0.0053	0.0083	−0.63	0.5294
Distance of monitors from chimney (cm)	−0.00031	0.0032	−0.10	0.9234
Number of cigarettes smoked	0.0062	0.0044	1.43	0.1593
24-hour average temperature difference (indoor − outdoor, °C)	−0.011	0.011	−1.05	0.3008

Maximum Pollutant Concentrations

3.7 The maximum 15-minute concentrations experienced during the 24-hour period were calculated for both CO and PM. The 15-minute peaks for CO and PM occurred within 0 to 11 minutes of one another for all households. None of the 15-minute maximums were observed during the overnight period bounded by 17:30 and 09:00. In 15 households, the 15-minute maximum CO concentration occurred between 09:00 and 11:00; in 18 households, this maximum occurred between 11:01 and 13:00; in 2 households, this maximum occurred between 13:01 and 15:00; and in the remaining 23 households, this maximum occurred between 15:01 and 17:30. Histograms of 15-minute maximum CO and PM are shown in figures 3.3 and 3.4.

Figure 3.3: Histogram of 15-Minute Maximum CO Concentration (ppm) (N = 58)

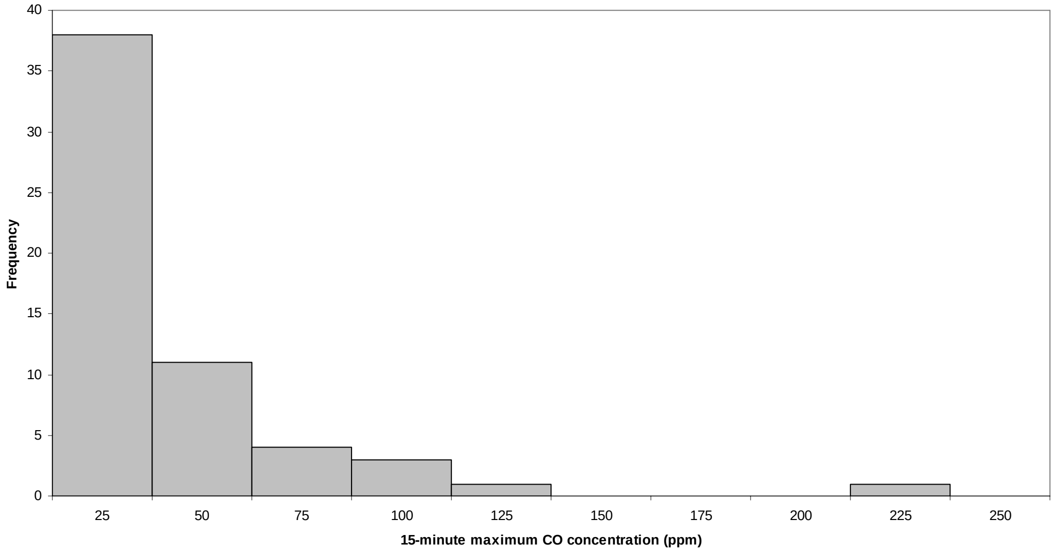
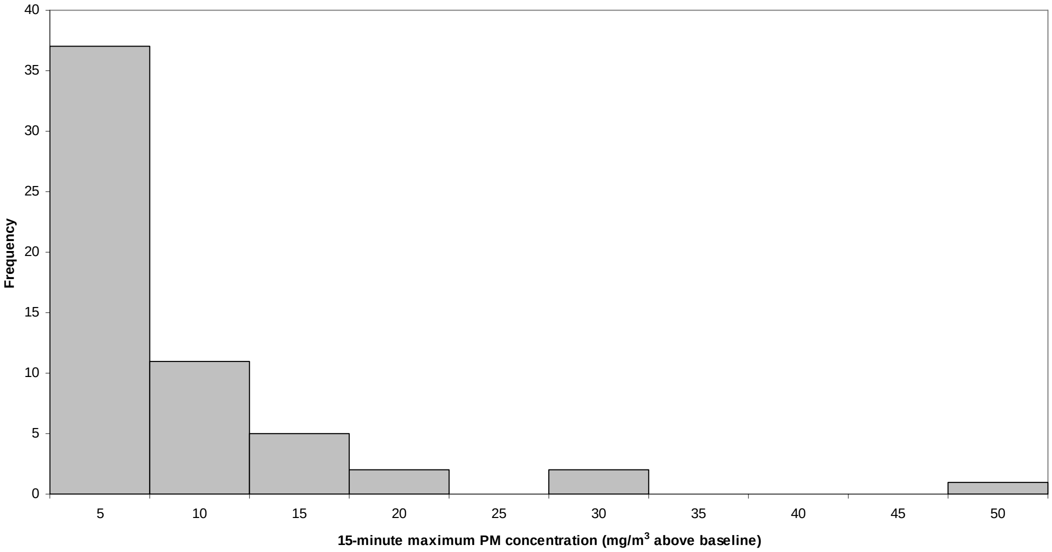


Figure 3.4: Histogram of 15-Minute Maximum PM Concentration (mg/m^3 above Baseline) (N = 58)



3.8 The maximum 15-minute concentrations of CO and PM are reported by stove type in table 3.9. CO levels were lower for improved stoves, but the difference was not statistically significant in bivariate analysis. PM levels were slightly lower for TT-03 stoves and slightly higher for G2-2000 stoves compared to traditional stoves, but these differences were also nonsignificant in bivariate analysis. Similarly, multivariate regression including stove type, stove age, *ger* volume, monitor distance from chimney, and difference between 24-hour indoor temperature and 24-hour outdoor temperature showed there was not a statistically significant difference in these values between stove types. Estimates of covariates from the multiple regression models and their significance are shown in tables 3.10 and 3.11. Stove age and *ger* volume were statistically significant predictors of maximum 15-minute CO concentration. An increase in stove age of one year corresponded to a 2.0 ppm CO increase, and a *ger* volume increase of 1 m^3 corresponded to a CO decrease of 1.3 ppm. None of the covariates were statistically significant predictors of maximum 15-minute PM concentration.

Table 3.9: Maximum 15-Minute CO and PM Concentrations by Stove Type

Stove type		Traditional (N = 20)	G2-2000 (N = 20)	TT-03 (N = 18)	Total (N = 58)	Probability > *F* (DF = 55)
Maximum 15-minute CO concentration (ppm)	Mean	43.1	25.6	28.8	32.6	0.1711
	Standard deviation	47.9	11.5	18.4	31.1	
Maximum 15-minute PM concentration (mg/m^3 above baseline)	Mean	6.2	7.1	5.8	6.4	0.8634
	Standard deviation	6.5	9.9	6.2	7.6	

Table 3.10: 15-Minute Maximum CO Concentration (ppm): Multivariate Regression Estimates (N = 58, Model R^2 = 0.25)

Covariates	Estimate	Standard error	*t*	Probability > *t*
Intercept	110	50	2.21	0.0341
TT-03	−7.4	10	−0.71	0.4802
G2-2000	−4.7	9.8	−0.48	0.6328
Stove age (years)	2.0	0.78	2.56	0.0135
Ger volume (m^3)	−1.3	0.57	−2.28	0.0266
Distance of monitors from chimney (cm)	0.22	0.23	0.96	0.3396
24-hour average temperature difference (indoor − outdoor, °C)	−1.1	0.74	−1.51	0.1369

Table 3.11: 15-Minute Maximum PM Concentration (mg/m^3 above Baseline): Multivariate Regression Estimates (N = 58, Model R^2 = 0.04)

Covariates	Estimate	Standard error	*t*	Probability > *t*
Intercept	19	14	1.34	0.1872
TT-03	0.20	2.9	0.07	0.9462
G2-2000	1.8	2.7	0.67	0.5064
Stove age (years)	0.062	0.22	0.29	0.7765
Ger volume (m^3)	−0.12	0.16	−0.77	0.4448
Distance of monitors from chimney (cm)	−0.039	0.063	−0.62	0.5386
24-hour average temperature difference (indoor − outdoor, °C)	−0.086	0.21	−0.42	0.6795

Morning Refuel Pollutant Concentrations

3.9 Because the traditional and modified stoves all have chimneys meant to vent most emissions to the outdoor environment it was expected that much of the emissions to the indoor environment would occur during and immediately after refueling. In an attempt to examine emissions during cold start conditions, when emissions would be expected to be highest, a two-hour period coinciding with the first morning fueling instance was examined for each household. This two-hour period began with the minute coinciding with a spike in either PM, CO, or indoor temperature after a sustained period of nonactivity. This pattern is illustrated for a typical household in figure 3.5. In 3 households, the two-hour morning refueling period began between 04:00 and 06:00; in 28 households, this period began between 06:01 and 08:00; for 17 households, this period began between 08:01 and 10:00; and for 3 households, this period began between 10:01 and 10:30. Seven households were omitted from this portion of the analysis because of significant overnight fueling activity or monitor collection times falling within this two-hour period. Histograms of two-hour morning refueling CO and PM are shown in figures 3.6 and 3.7.

Figure 3.5: 24-Hour Monitoring Data for a Typical Household, Showing PM, CO, and Temperature

Morning refueling period is indicated by two vertical lines at 07:48 and 09:47.

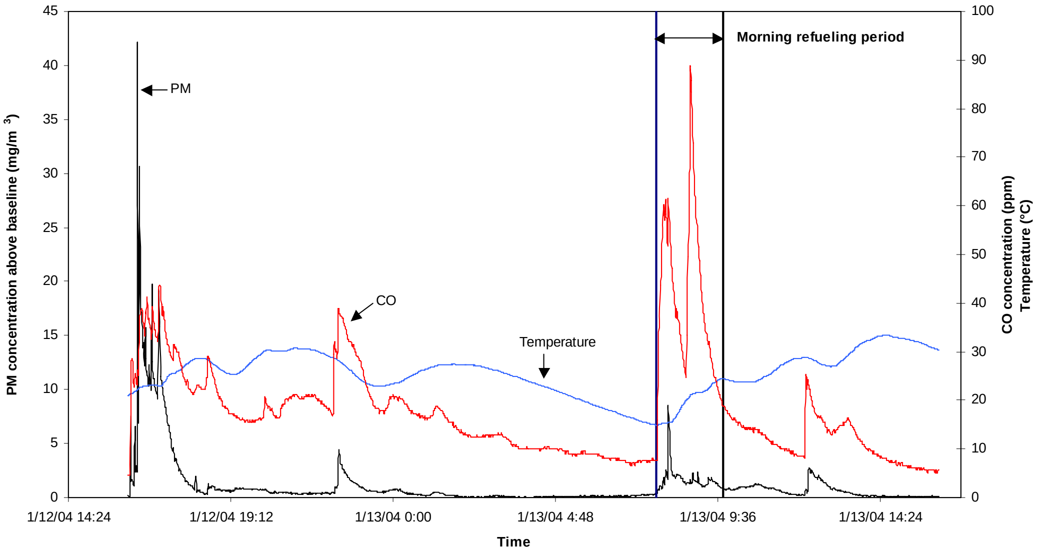


Figure 3.6: Histogram of Two-hour Morning Refuel CO Concentration (ppm) (N = 51)

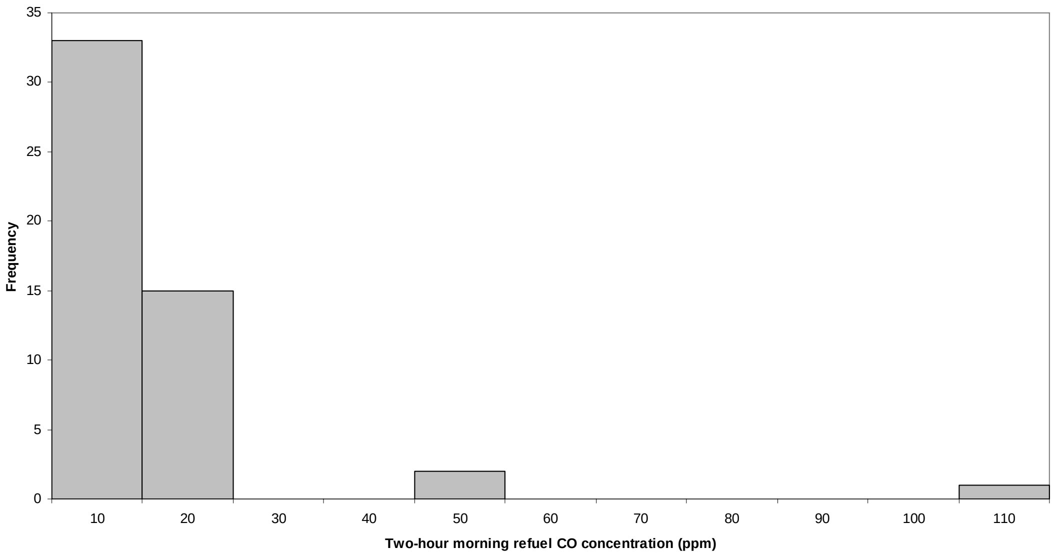
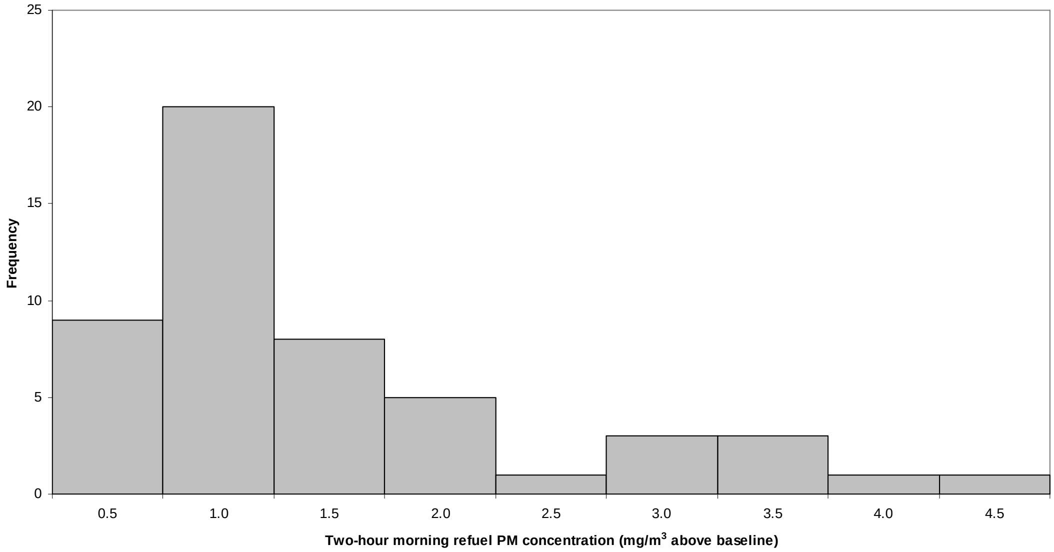


Figure 3.7: Histogram of Two-Hour Morning Refuel PM Concentration (mg/m^3 above Baseline) (N = 51)



3.10 The mean PM and CO concentrations during the two-hour morning refueling period are summarized in table 3.12. CO concentrations were lower for improved stoves than for traditional stoves, but the difference was not statistically significant in bivariate analysis. PM was similar for traditional and G2-2000 stoves and comparatively lower for TT-03 stoves, but this difference was also nonsignificant in bivariate analysis. Multivariate regression models were constructed to assess the impact of stove and household characteristics on these concentrations while controlling for stove type, stove age, *ger* volume, monitor distance from chimney, and difference between 24-hour indoor temperature and 24-hour outdoor temperature; the covariate estimates and their significance are presented in tables 3.13 and 3.14. No covariates were shown to be statistically significant predictors of morning refuel CO or PM concentrations.

Table 3.12: Average CO and PM Concentrations from Two-Hour Morning Refueling Period after a Period of Nonactivity

Stove type		Traditional (N = 20)	G2-2000 (N =1 5)	TT-03 (N = 16)	Total (N = 51)	Probability > *F* (DF = 48)
CO concentration during morning refueling (ppm)	Mean	17.1	6.3	8.5	11.2	0.0698
	Standard deviation	22.4	3.4	3.9	14.9	
PM concentration during morning refueling (mg/m^3 above baseline)	Mean	1.5	1.4	1.0	1.3	0.2534
	Standard deviation	1.0	1.0	0.9	1.0	

Table 3.13: Two-Hour Morning Refuel CO Concentration (ppm): Multivariate Regression Estimates (N = 51, Model R^2 = 0.23)

Covariates	Estimate	Standard error	*t*	Probability > *t*
Intercept	47	26	1.82	0.0753
TT-03	−4.9	5.2	−0.94	0.3525
G2-2000	−5.9	5.2	−1.14	0.2590
Stove age (years)	0.59	0.38	1.54	0.1318
Ger volume (m^3)	−0.51	0.29	−1.72	0.0919
Distance of monitors from chimney (cm)	−0.016	0.11	−0.14	0.8865
24-hour average temperature difference (indoor − outdoor, °C)	−0.26	0.39	−0.66	0.5120

Table 3.14: Two-Hour Morning Refuel PM Concentration (mg/m^3 above Baseline): Multivariate Regression Estimates (N = 51, Model R^2 = 0.14)

Covariates	Estimate	Standard error	*t*	Probability > *t*
Intercept	4.6	1.8	2.52	0.0155
TT-03	−0.47	0.37	−1.27	0.2091
G2-2000	0.061	0.37	0.17	0.8681
Stove age (years)	0.0090	0.027	0.33	0.7412
Ger volume (m^3)	−0.024	0.021	−1.14	0.2589
Distance of monitors from chimney (cm)	−0.0068	0.0080	−0.84	0.4030
24-hour average temperature difference (indoor − outdoor, °C)	−0.033	0.028	−1.21	0.2339

Pollutant Concentrations and Fuel Use

3.11 The impact of reported coal and wood use on IAQ was examined by constructing regressions of CO and PM concentrations against fuel use for each of the three time periods of interest: 24-hour, 15-minute maximum, and 2-hour morning refuel. The bivariate regression estimates of fuel use impact on CO concentrations are shown in table 3.15. All regressions showed a positive correlation between fuel use and CO concentration. Each correlation was statistically significant for coal use, and each correlation for wood use was significant or nearly so. The correlations between number of refuelings and CO concentrations were not significant. The largest influence of fuel use on CO was seen in the 15-minute maximum concentration; an increase in coal use of 1 kg/day corresponded to a 1.8 ppm 15-minute maximum CO increase, and an increase in wood use of 1 kg/day corresponded to a 2.5 ppm 15-minute maximum CO increase. For 24-hour average CO concentration, an increase in coal use of 1 kg/day corresponded to a 0.26 ppm 24-hour average CO increase, and an increase in wood use of 1 kg/day corresponded to a 0.50 ppm 24-hour average CO increase.

3.12 24-hour, 15-minute maximum, and 2-hour morning refuel PM concentrations were also regressed against coal use rate and wood use rate. The bivariate regression estimates of fuel use impact on PM concentrations are shown in table 3.16. None of the correlations between fuel use rates and PM were statistically significant, although all correlations between fuel use and PM concentrations were positive except for number of refuelings and 15-minute maximum PM. As with CO, the biggest influence of fuel use on PM concentrations was seen in the 15-minute maximum values. For this interval, an increase in 1 kg/day of coal use corresponded to an increase of 0.11 mg/m^3 PM, and an increase of 1 kg/day wood use corresponded to an increase of 0.27 mg/m^3 PM. Increased coal use of 1 kg/day corresponded to an increase of 0.01 mg/m^3 24-hour average PM, and increased wood use of 1 kg/day corresponded to an increase of 0.03 mg/m^3 24-hour average PM.

Table 3.15: Fuel Use Impact on Indoor CO Concentrations: Bivariate Regression Estimates

Independent variable	Dependent variable	Estimate	Standard error	*t*	Probability > *t*	R^2
Coal use rate (kg/day)	24-hour CO concentration (ppm)	0.26	0.12	1.27	0.0396	0.07
	15-minute maximum CO concentration (ppm)	1.8	0.58	3.14	0.0027	0.15
	2-hour morning refuel CO concentration (ppm)	0.70	0.32	2.17	0.0346	0.09
Wood use rate (kg/day)	24-hour CO concentration (ppm)	0.50	0.25	1.98	0.0527	0.07
	15-minute maximum CO concentration (ppm)	2.5	1.3	1.94	0.0578	0.06

	2-hour morning refuel CO concentration (ppm)	1.4	0.64	2.17	0.0350	0.09
Number of refuelings	24-hour CO concentration (ppm)	0.50	0.28	1.76	0.0841	0.05
	15-minute maximum CO concentration (ppm)	1.8	1.5	1.21	0.2322	0.02
	2-hour morning refuel CO concentration (ppm)	1.0	0.75	1.36	0.1787	0.03

Table 3.16: Fuel Use Impact on Indoor PM Concentrations: Bivariate Regression Estimates

Independent variable	Dependent variable	Estimate	Standard error	*t*	Probability > *t*	R^2
Coal use rate (kg/day)	24-hour PM concentration (mg/m^3 above baseline)	0.011	0.0082	1.36	0.1786	0.03
	15-minute maximum PM concentration (mg/m^3 above baseline)	0.11	0.15	0.69	0.4936	0.01
	2-hour morning refuel PM concentration (mg/m^3 above baseline)	0.019	0.022	0.87	0.3909	0.02
Wood use rate (kg/day)	24-hour PM concentration (mg/m^3 above baseline)	0.030	0.017	1.76	0.0843	0.05
	15-minute maximum PM concentration (mg/m^3 above baseline)	0.27	0.32	0.83	0.4078	0.01
	2-hour morning refuel PM concentration (mg/m^3 above baseline)	0.064	0.044	1.46	0.1511	0.04

Number of refuelings	24-hour PM concentration (mg/m^3 above baseline)	0.021	0.020	1.06	0.2925	0.02
	15-minute maximum PM concentration (mg/m^3 above baseline)	-0.01	0.38	-0.03	0.9789	0.00
	2-hour morning refuel PM concentration (mg/m^3 above baseline)	0.034	0.054	0.64	0.5249	0.01

4

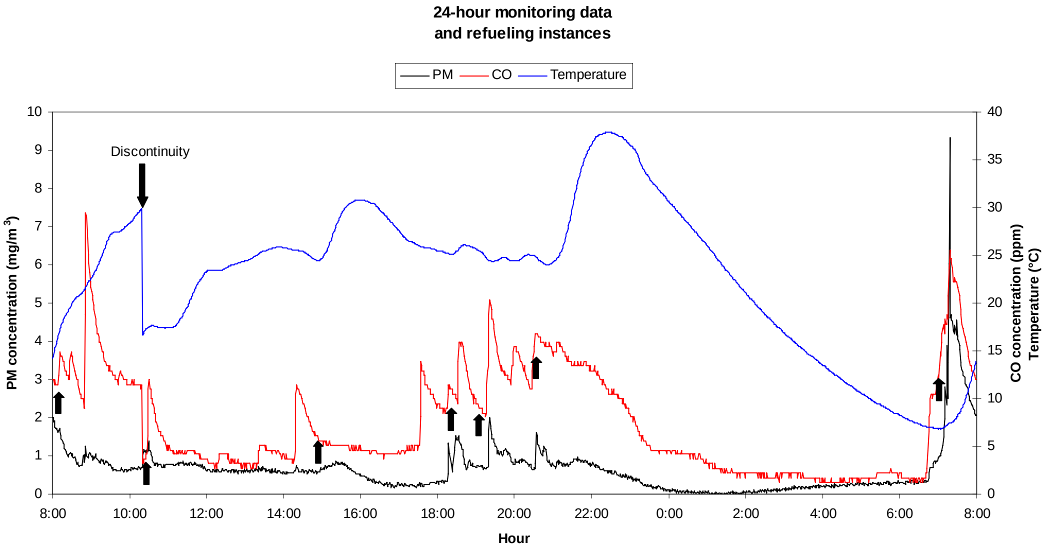
Discussion

4.1 This study attempted to assess the impact of improved stoves on indoor air pollution. Both improved stove types showed a tendency to decrease indoor CO concentrations for all intervals, which would be consistent with the improved stoves having more complete combustion of fuel, but neither showed statistically significant differences in either bivariate or multivariate analysis. Examination of PM concentrations observed for different stove types revealed that the TT-03 stove had a consistent trend toward lower PM levels than the traditional stove in the bivariate analyses, but not in the multivariate analyses, and the G2-2000 stove consistently had equal or higher PM levels than the traditional stoves in both bivariate and multivariate analyses. Again, none of these findings was statistically significant.

4.2 Both the traditional and improved stove types studied have chimneys venting the bulk of combustion byproducts to the outdoor environment. As such, the finding that stove type did not have a large impact on IAP is not unexpected. With closed, vented stoves, the greatest quantity of pollutants emitted to the indoor environment is likely to occur at times when the combustion chamber is opened. This was observed to occur during refueling and cooking, and when the chamber is opened to redistribute fuel. Figure 4.1 illustrates the impact of refueling on indoor levels of PM and CO in a typical household. The values are plotted on an 08:00 to 08:00 scale, with a discontinuity at 10:20 when the monitor was deployed and removed. The shaded arrows show the participant-reported refueling instances. In all cases, there is a nearby spike in both PM and CO, the offset of which may be attributable to approximations in participant reporting.

Figure 4.1: 24-Hour Monitoring Data for a Typical Household, Showing PM, CO, Temperature, and Refuelings

Data are on a scale from 08:00 to 08:00, with a discontinuity at 10:20 indicated by a black arrow. The shaded arrows represent the reported refueling instances.



4.3 If the majority of emissions being released to the indoor environment occur when the combustion chamber is opened for refueling or cooking, indoor concentrations will be largely dependent on behavioral patterns. For the same amount of fuel consumed, indoor emissions may be different if the fuel is introduced in small versus large batches, or if the stove's top aperture (intended for cooking) is opened instead of the side door. One example of behavioral variability was seen in the overnight periods: In some homes, the stove was not refueled for 8 hours or more during the night, and in others, the interval between refuelings was much shorter. Such behavioral variation may have influenced the amount of variation seen in the monitoring data. The relationship between number of refuelings and IAP was examined for all time intervals. The correlations between CO concentration and number of refuelings were positive in all cases, though statistical significance was approached for only the 24-hour time interval. This is the time interval where a relationship is expected, because the number of reported refuelings corresponds to the entire day's stove activity. Examination of the morning refueling period allowed for comparison of stove performance with some of the behavioral variability removed, because all stoves were experiencing a cold start. Indoor CO concentrations observed during these periods again showed a trend toward lower emissions with improved stove types. These 2-hour morning refueling CO concentrations also showed significant positive correlation with wood use, which follows from wood primarily being used as a starter fuel.

4.4 Physical factors may also have played in a role in IAQ variation. It was noted that this variation, as measured by the standard deviation, tended to be larger for the traditional stoves than for the improved stoves. Traditional stoves are often home made and, in this study, were often older than the improved stoves. Variations in design characteristics and maintenance of the traditional stoves might have accounted for emissions that were more variable than those of the improved stoves, which were of a more consistent design and age.

4.5 The minimum detectable difference in a stratified study depends on the sample size and the CV within each stove group. The CV (standard deviation/mean) for the 24-hour PM concentrations was 0.73 for traditional stoves, 0.48 for G2-2000 stoves, and 0.44 for TT-03 stoves. The CV for the 24-hour CO concentrations was 0.60 for traditional stoves, 0.39 for G2-2000 stoves, and 0.49 for TT-03 stoves. With the originally planned sample sizes of 25 and a CV of 0.5 in each stove group, the minimum detectable difference would have been 40 percent. To detect a 25 percent difference in indoor pollutant concentrations with a CV of 0.5 in each stove group, the sample size required for each group would be approximately 64; to detect a 10 percent difference, the sample size would be 394 in each group, more than the number of homes that had received such stoves in Bayangol.

4.6 In this study, only coal use rate (kg/day) was consistently and significantly associated with stove type. Coal consumption was lower by 5 kg/day in households with both G2-2000 and TT-03 improved stoves. Given that stove type was associated with coal use, and coal use was associated with IAQ, one might expect a relationship between stove type and IAQ. For example, the average 24-hour CO concentration in homes with traditional stoves was 12 ppm, and the estimated effect on 24-hour CO concentration relative to coal use was 0.26 ppm/kg/day. Applying these factors, a 5 kg/day reduction in coal use would equate to a reduction in mean 24-hour CO of 1.3 ppm. This is an 11 percent reduction, which is below the detectable difference, given the CV in the measurements and the sample sizes in this study. Similar calculations can be made for the 15-minute maximum and 2-hour morning refuel time periods. For these periods as well, it is apparent that any real differences in IAP related to stove type would have been too small to be statistically significant, given the sample size and CVs in this study.

4.7 One important source of IAP in *gers* is likely outdoor air pollution. Odor and visibility impairment due to high outdoor pollution levels were observed over the study period, but no ambient monitoring was conducted at the time of this study by any local agency because of lack of functioning equipment. As a result, the magnitude of outdoor impacts on indoor concentrations cannot be quantified. However, the observed high levels of IAP may reflect ambient conditions more than indoor sources.

4.8 With high background levels precluding normal UCB baseline calibration, absolute indoor PM concentrations could not be computed. Still, in most homes, the baselines used were likely close to ambient levels. This is because most homes did not experience overnight fueling activity. In that scenario, with stoves remaining closed, indoor PM levels are expected to decline through settling and air exchange with the outdoors until they reach the ambient level. However, some homes did have overnight fueling (and conceivably some stoves had leaks that released PM as the stoves smoldered after the final evening fueling), which would have elevated the *ger*'s baseline level above ambient conditions. Thus, there could have been some noise in some of the baseline PM measures used in the study. Such noise would have attenuated the observed relationships between stove type and PM. Unfortunately, because the amount of noise is unknown, the impact, if any, on the study results cannot be quantified.

~~4.9~~ The study had several limitations. As mentioned previously, the planned sample size was adequate to detect differences of 40 percent or more, but not smaller differences that may have existed; the high background PM concentrations prevented an absolute quantitative assessment of indoor levels; and the PE method of measuring particle concentrations does not have a clear measured particle cutoff diameter for easy comparability with standards and other sampling data.

4.10 The data have no known biases, but it is always possible that undetected errors exist. For example, it is conceivable that selection bias played a role in disguising the effect of stove type on indoor air pollution, because the selection of homes for inclusion in the study was not done randomly. As an illustration, if socioeconomic status differed between owners of different stove types, that may have affected the result for rate of fuel use, with poorer households electing to use less fuel and keep the remainder. In fact, it is unclear how or whether socioeconomic status related to stove ownership in this study sample, because some owners of improved stoves had purchased their stoves and some had received them for free during the initial period of the program. Fuel was provided to households in an attempt to mitigate this factor. Undetected confounding of results by other unmeasured factors related to choice of stove type and IAP is also theoretically possible, although the study controlled for known potential confounders (such as smoking, *ger* size, and temperature) in the analysis.

4.11 In any study, potential errors exist in participant-reported information. For example, as noted above, for five homes, it was uncertain whether the reported age referred to the stove itself or the length of time it had been in its current home. This could be important, because it is possible that stove aging, user familiarity with the technology, or both could affect emissions, with the latter factor being potentially important for improved stoves. For example, greater familiarity with the technology might correspond to more efficient operation by users, and stove age might correlate with physical factors such as development of leaks or soot buildup in chimneys. Although both factors are reflected in the duration of stove use, this analysis focused primarily on the effect of stove aging in that the actual time since first use was analyzed. Additional analytic models included a time by stove type interaction term to determine if aging (or perhaps user familiarity) had a differential impact according to stove type. However, no impact of time or time by stove type was found. Potential user-reported error also exists for the number of refuelings and number of cigarettes smoked. For some homes, all of the pollutant spikes align with reported refuelings; for others, there are several small spikes that do not match with reported refuelings. These additional spikes may be due to unreported refueling or cooking instances, opening the combustion chamber to redistribute fuel, opening the combustion chamber for some other reason, or another, unknown source.

4.12 Although householders were asked to use a normal amount of fuel and keep their homes at the usual temperature, 25 reported that the temperature was warmer or colder than usual. It is not known whether this change in temperature was related to ambient conditions on that day or unusual fuel use, and this factor was not statistically related to fuel use rates. It remains possible that the amount of fuel use in the study differs slightly from that typically experienced.

4.13 Sulfur is a known component of some coal, and exposure to airborne SO_2 poses a health risk. However, initial attempts to measure SO_2 in *gers* showed that levels were below 0.2 ppm, the limit of detection of the available equipment. Therefore, routine SO_2 measurements were not carried out in this study, and the analysis did not assess whether airborne SO_2 levels differed by stove types. The coal used in the study was derived from the Nalaikh mine within Mongolia, which is thought to contain approximately 0.5–0.6 percent sulfur. According to the PIU, this coal is popular for home heating because of a high caloric value.

4.14 Finally, this study set about determining the relationship of IAQ and stove type, which may or may not be a reasonable proxy for any individual's exposure, depending on amount of time spent in the home and usage practices. For example, if the combustion chamber is opened to the room via the aperture in the top of the stove, the short-term levels of exposure are likely to be much greater than if the combustion chamber is opened using an opening in the side of the stove, as recommended for refueling. Measuring an individual's IAP exposure could involve keeping time-activity diaries, and measuring an individual's total (indoor and ambient) air pollution exposure could also require the use of personal monitors.

4.15 Despite some limitations, this study provides valuable information on typical IAP levels seen in Ulaanbaatar *ger* households in wintertime. In addition to providing objective measurements with high-quality instruments, the sample design included full 24-hour monitoring periods. These extended monitoring periods provided information about household IAP levels during all phases of households' daily life, and allowed ascertainment of maximum IAP levels and IAP levels under cold start conditions. This is the first published study to provide such information for Mongolia, in addition to being the first study to quantitatively assess IAP in relation to stove type.

5

Conclusions

5.1 In summary, in no case was there shown to be a statistically significant difference in CO or PM in homes with different stove types, despite the finding that households with improved stoves used less coal and the positive correlations between coal use and CO concentrations. However, the tendency for improved stoves to reduce fuel usage and reduced fuel usage being correlated with reduced IAP suggest that the improved stoves could potentially have a beneficial impact on IAQ, albeit at a level below that was not detectable with the sample sizes in this study. The positive correlations between IAP and fuel use were observed despite the presence of chimneys venting bulk emissions to the outdoor environment and despite high levels of ambient pollution that may have contributed substantially to the observed levels of indoor pollution. For the current study, evidence of significantly decreased indoor pollution may have been obscured in part by high background pollution levels, the large variability seen in homes with similar stove types, and the relatively small sample size.

5.2 The Mongolian national standard for 24-hour total suspended particles (TSP) concentration is 150–200 $\mu g/m^3$ (Mongolian Agency of Standardization and Metrology 1998). The U.S. Environmental Protection Agency’s (EPA) primary standard for 24-hour $PM_{2.5}$ is 65 $\mu g/m^3$ (EPA 1997). (The World Health Organization [WHO] has not yet formally set a standard for PM.) The 24-hour mean, PE-measured PM concentration above baseline in homes with traditional stoves is 700 $\mu g/m^3$, which is an order of magnitude greater than the U.S. standard. This 24-hour mean measured value also far exceeds the Mongolian standard, which is set for total particles. Given that the study equipment captures only particle sizes with a cutoff between PM_{10} and $PM_{2.5}$, the TSP level in Mongolian homes must be even higher. No stove type showed 24-hour averages below these standards.

5.3 The Mongolian standard for 24-hour CO concentration is approximately 2.6 ppm; the WHO guideline for CO exposure during an 8-hour period is 10 ppm (WHO Regional Office for Europe 2000); and the EPA’s 24-hour primary CO standard is 9 ppm (EPA 2000). The *gers* with traditional stoves sampled in this study had a pooled mean 24-hour CO concentration of 11.6 ppm. Homes with improved stoves had 24-hour mean values of 8.9 ppm for TT-03 stoves and 7.8 ppm for G2-2000 stoves, but these values were not statistically significantly different from the traditional stoves.

5.4 For homes with each stove type, the average of the 15-minute maximum CO concentration was below the WHO 15-minute exposure guideline of less than 100 ppm to avoid acute poisoning (WHO Regional Office for Europe 2000). Similarly, comparison of average of 2-hour CO concentrations during morning refueling times showed that none exceeded the WHO guideline for 1-hour CO exposure, which is 30 ppm (WHO Regional Office for Europe 2000).

5.5 Overall, residents of *gers* using traditional coal-burning stoves indoors are being exposed to levels of CO and PM that are in excess of Mongolian national standards and guidelines set by WHO and the EPA, which are set to protect against detrimental health effects from chronic exposure. It follows that these residents are being regularly exposed to unsafe levels of both pollutants. Although the improved stoves have been previously shown to reduce chimney stack emissions and coal use, this study did not find evidence that transition to improved stoves would directly result in significant improvements of indoor PM and CO concentrations or bring levels below guidelines set to protect human health. Given the high background levels, reducing ambient air pollution might have a greater impact. The burden of respiratory disease in Mongolia is high. In addition to overt morbidity and mortality, recent research indicates that exposure to air pollution during childhood leads to lasting lung function deficits (Gauderman and others 2004). Given these concerns, efforts to reduce air pollution levels in Mongolia should receive high priority.

5.6 It would be important for a future study to assess winter levels of ambient air pollution and determine the portions of IAP attributable to various sources, because this information would clarify what protective measures are likely to be helpful in reducing exposure. Real-time personal exposure monitoring would be useful in this context. Any further studies on stoves could consider such stove attributes as level of insulation and include user familiarity with the stove and chimney condition in addition to the factors included in this study, as well as greater consideration of user behavior. Future studies comparing improved and traditional stove designs should use stoves of comparable ages in all groups. Consideration could also be given to home characteristics other than stove type that might influence the amount of IAP present, such as amount of air exchange with the outdoors. This factor is presumably related to insulation amount and type, as well as to whether the home possesses a closed entryway, a wintertime add-on to some *gers*. Knowledge of air exchange between the *ger* and the outdoors and ambient monitoring may also elucidate the contribution of urban pollution levels to indoor concentrations and help target efforts to reduce human exposure.

Annex 1

Field Team

The protocol was approved by the University of California, Berkeley, Committee for Protection of Human Subjects. The overall study design was the responsibility of the World Bank Task Leader (Rachel Kaufmann). Ecography Company and the PIU assembled a field team and established links with *khoroo* staff and community. Field team tasks included explaining the purpose of the study and obtaining informed consent from respondents, assisting the World Bank Consultant (Shannon Cowlin) with measurement of fuel and dwelling, and installation of monitoring equipment. In addition to the field work, the Consultant was responsible for all data management and analysis. Before the field work began, a meeting was held with the Task Leader, Consultant, members of the PIU, and members of the community employed to assist in the study. At this meeting, the purpose of the study was explained to participants. Each element of the consent and monitoring forms was explained, along with the importance of obtaining informed consent from each of the households. Minor modifications were made to the field work forms in response to suggestions made at that time.

For the first several days of sampling, the field staff worked in one team to ensure standard practice among all field members. During this time, explanations and consents given and received in Mongolian were translated into English for the consultant to ensure that participants were sufficiently informed of their rights and risks. For the remaining days of sampling, field workers were split into two teams in order to sample a greater number of households.

The local field team included Mr. Erdene Urt, Mr. Shatar, Mr. Yatantsoo, Ms. Bolormaa (translator), and Mr. Jagaa and Mr. Enkhbold (drivers). PIU staff included Mrs. D. Oyuntstetseg (director), Mrs. Khandarmaa (project assistant), Mr. Erdenebat (technical engineer), Mrs. Enkhjargal Tsogoo (social marketing specialist), Mrs. Erdenechimeg (accountant), and Mr. Ochirbold (driver).

After completion of the field work, the Task Leader and PIU manager (Mrs. D. Oyuntstetseg) held a meeting with representatives of the Ministry of Health, Ministry of Nature and Environment, Public Health Institute, State Professional Inspection Agency, Central Laboratory for Environmental Monitoring, the municipality of Ulaanbaatar, WHO, and United Nations Development Programme to share preliminary results from this study.

Annex 2

Consent and Data Collection Form

Introduction and Purpose

Introduction and Purpose
Hello. My name is ________________ and I am working with the Improved Stoves Project Office. We are doing an evaluation to see if improved stoves produce less indoor smoke than traditional stoves. We are interested in this because coal stoves can lead to high levels of smoke, which can lead to health problems. Therefore, we will be measuring air quality in some *gers* with improved stoves and in some *gers* with traditional stoves.

Procedures
If you want to join this study we will visit you two times in your home. The first time we will measure the size of your *ger* and set up some equipment. This should take about one half-hour. We will be leaving 2 machines that will measure the smoke in the air. These machines are small and do not make any noise. These machines will be there for 24 hours. Our second visit we will take out the machines, which should take about 15 minutes. We will also be asking about how much you smoked during the period when the machines are in your home and at what times you refueled your stove. You don't need to do anything except make sure someone is at home when we come.

Risks and Benefits
You can choose to join the study or you can chose not to join the study. There are no known risks to your household if you join the study. You will help us, because you will give us important information about the connection between improved stoves and smoke in the *ger*. You can stop participating at any time without any penalty.

Cost/Payment
The amount of coal and wood that you will use for the 24-hour period will be provided to you. Any coal or wood remaining at the end of the 24-hour period will be left with you.

Confidentiality
All the information you give us will be kept private. We may look at the data we collect in several ways, but we will not keep your names in our records and we will not use your names when we discuss the study or publish results.

Right to refuse or withdraw
If you have any questions, please ask me at anytime. If you want to stop participating, please let me know.

Persons to contact
If you have any questions, you may contact the Program office at 314 524. A woman named Shannon Coulter-Burke from the University of California in the United States is directing this study, so you may also contact the University of California at Berkeley's Committee for

Protection of Human Subjects at 1 510 642 7461 or send email to subjects@uclink.berkeley.edu.

Identification Number ________ **Fill at first visit**

Ask: Do you agree to participate? Yes_____ No_____ (check one)

Signature of interviewer________________________Date ___________________

Ask: Name of household head ___________________________________

Ask: Respondent name ____________________ Respondent's relationship to head _____________

Ask: When stove installed ____________ (month, year) Type of stove________________

Measure: Height of *ger* at wall ____________ (in) Width of *ger*_________________ (in)

Height of G*er* at Center ____________(in)

Measure: 1)Weight of coal _____________ (kg) 1) Weight of wood ______________(kg)

2)Weight of coal _____________ (kg) 2) Weight of wood _______________(kg)

Time when equipment installed _____________ (24 hour format)

Say: We will return at this time tomorrow to pick up the equipment. Please use only the fuel we gave you between now and then. You can keep any extra fuel that you don't use. Please do not mix it with other fuel because we will need to weigh the amount remaining when we come back. Please write down the times that you refuel the stove. Please also write down the number of cigarettes that are smoked in the *ger* each day.

Fill at second visit

Time when equipment removed _____________ (24 hour format) Date _____________

Is HOBO in same position? Yes____ No____ Is UCB in same position? Yes____ No____

Ask: Respondent name __________________Respondent's relationship to head _________

Measure: 1) Weight of coal _____________ (kg) 1) Weight of wood _______________(kg)

2) Weight of coal _____________ (kg) 2) Weight of wood _______________(kg)

Ask: Besides the coal and wood we gave you, did you use any other fuel in this *ger* in the last 24 hours?

Yes ________ No______ Not Sure ______ (check one)

If Yes, **Ask:** What other fuel did you use?

____

Ask: During the last 24 hours, when did you open the stove to light or reload it? (probe for estimates of times in 24-hour format)

____

Ask: Did you keep the *ger* at the usual temperature or did you keep it warmer or colder than usual?

Usual _______ Warmer _______ Colder ______ (check one)

Ask: Did anyone smoke in this *ger* in the last 24 hours? Yes____ No___ Not Sure ___ (check one)

If Yes, **Ask:** About how many cigarettes were smoked inside the *ger*? ___________

Say: That is all we need to ask. Thank you very much for participating in the study.

Annex 3

UCB Monitor Protocol

The UCBs should be launched at the deployment site to collect UCB readings at 1-minute intervals. Once at the deployment location, the steps to launch the UCB are:

1. Connect the UCB to the computer.
2. Open HyperTerminal.
3. Select (C)lock and set the time as two-digit year, month, day, hour, minute.
4. Select (P)arameters and set the sampling interval to one minute.
5. After approximately one minute, UCB readings will display on the screen at approximately 5-second intervals.
6. Watch the temperature readings, and wait until the change in temperature is less than 0.1 °C in 1 minute.
7. Select (N)ew run; the UCB's memory pointers will be set to zero and the monitor will record data according to parameters specified.
8. Place the UCB in a plastic bag and set it in an undisturbed place for 20 minutes for predeployment calibration.
9. Remove the UCB from the plastic bag and hang in an appropriate location.

Data Download

1. When the UCB is collected, it should again be placed in a plastic bag for 20 minutes for postdeployment calibration.
2. Remove the UCB from the plastic bag and connect it to the PC.
3. Select *Capture text* from the *Transfer* menu and specify file directory and name for data offload.
4. Select (O)ffload and the data will be offloaded to both the screen and the file.
5. Select *Capture text* and *Stop* from the *Transfer* menu.

Annex 4

HOBO Monitor Protocol

Launching

The HOBOs should be launched at the deployment site to collect CO readings at one-minute intervals. Once at the deployment location, the steps to launch the HOBO are:

1. Connect the HOBO to the computer.
2. Open the Boxcar Pro software.
3. Select *Launch* from the *Logger* menu.
4. Check the battery status and do not launch if below approximately 60 percent.
5. Select *Enable/Disable Channels* and select channel 1 and channel 2 to be enabled and channel 3 to be disabled. Select *Apply*.
6. Select *1 minute* from *Interval Duration.*
7. Type in label for data collection (HOBO CO ID#_HHID).
8. Make sure the *Delayed Start* is not selected.
9. Select *Start*.
10. Select *Continue* from screen when prompted.
11. Select *OK* for old data to be erased from logger.
12. Detach cable from logger and press *OK*.
13. Check that the logger is on by verifying that the LED is flashing at approximately two-second intervals.
14. Hang monitor in appropriate location.
15. Record deployment time.

Data Download

The HOBO data can be downloaded at the deployment site or at a later time and location.

1. Connect the HOBO to the PC.
2. Open Boxcar Pro software.
3. Select *Readout* from the *Logger* menu.

4. A window appears that reads *Connecting* and *HOBO found*. Another window will then appear that reads *Offload*; wait for the data to download to desktop.
5. Unplug the logger when prompted, then select *OK*.
6. When the *Save as* window appears, select the appropriate directory file name, and select *Save*. Boxcar Pro will then display a plot of the data.

References

Bruce, N., R. Perez-Padilla, and R. Albalak. 2000. "Indoor Air Pollution in Developing Countries: A Major Environmental and Public Health Challenge." *Bulletin of the World Health Organization* 78: 1078–92.

Chen, B. H., C. J. Hong, M. R. Pandey, and K. R. Smith. 1990. "Indoor Air Pollution in Developing Countries." *World Health Statistics Quarterly* 43: 127–38.

Directorate of Medical Services and Government Implementing Agency, Mongolia. 2003. "Health Indicators, 2002." Ulaanbaatar.

Edwards, R., K. R. Smith, B. Kirby, T. Allen, D. Litton, and S. Hering. Submitted for publication. "An Inexpensive Particle Monitor for Monitoring Combustion Smoke Concentrations in the Developing World: Laboratory Characterization." *Journal of the Air and Waste Management Association*.

Energy Sector Management Assistance Program (ESMAP). 2002. "Improved Space Heating Stoves for Ulaanbaatar, Mongolia." Report 254/02. World Bank, Washington, DC.

Gauderman, W. J., E. Avol, F. Gilliland, H. Vora, D. Thomas, K Berhane, R. McConnell, N. Kuenzli, F. Lurmann, E. Rappaport, H. Margolis, D. Bates, J. Peters. 2004. "The Effect of Air Pollution on Lung Development from 10 to 18 Years of Age." *New England Journal of Medicine* 351: 1057–67.

Gordon, J. 2003. "Perceptions of the Health Effects of Stoves on the Ger Population, Ulaanbaatar, Mongolia. Interim Report." Unpublished student paper (London School of Hygiene and Tropical Medicine).

Litton, C. D., K. R. Smith, R. Edwards, and T. Allen. 2004. "Combined Optical and Ionization Measurement Techniques for Inexpensive Characterization of Micrometer and Submicrometer Aerosols." *Aerosol Science and Technology* 38: 1054–62.

Manaseki, S. 1993. "Mongolia: A Health System in Transition." *British Medical Journal* 307 (6919): 1609–11.

Ministry of Health, Mongolia. 2003. "Health Sector 2002: Reducing Maternal Mortality." Ulaanbaatar.

Mongolian Agency of Standardization and Metrology. 1998. "Mongolian National Standard. Ambient Air Quality. General Requirements." MNS 4585:1998. , Ulaanbaatar.

National Statistical Office of Mongolia. 2003. *Mongolian Statistical Yearbook, 2002*, table 3.5, page 43. Ulaanbaatar.

Sinton, J. E., K. R. Smith, H. Hu, and J. Liu. 1995. "Indoor Air Pollution Database for China." Human Exposure Assessment Series WHO/EHG/95.8. World Health Organization (WHO) Office of Global and Integrated Environmental Health and United Nations Environment Programme, Geneva.

Spickett, J., A. Baker, B. Burma, Sh. Enkhtsetseg, N. Suvd, Ch. Nyamragchaa, B. Ichinkhorloo, D. Nyamkhorloo, D. Oyunbileg, D. Tserenjav, S. Tsegmid, and G. Tuvshinjargal. 2002. "Preliminary Health Risk Assessment of Environmental Pollution in Ulaanbaatar City, Mongolia." World Health Organization, Ministry of Health, and Public Health Institute, Ulaanbaatar.

UNICEF. 2003. "The State of the World's Children, 2004." New York.

U.S. Environmental Protection Agency (EPA). 1997. "Revisions to the National Ambient Air Quality Standards for Particulate Matter." *Federal Register* 62: 38651–701.

———. 2000. "Air Quality Criteria for Carbon Monoxide." EPA 600/P-99/001F. Washington, DC.

World Health Organization (WHO), Regional Office for Europe. 2000. *Air Quality Guidelines for Europe*. 2nd ed. WHO Regional Publications, European Series, No. 91. Copenhagen.

Joint UNDP/World Bank

ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

LIST OF REPORTS ON COMPLETED ACTIVITIES

Region/Country	*Activity/Report Title*	*Date*	*Number*
	SUB-SAHARAN AFRICA (AFR)		
Africa Regional	Anglophone Africa Household Energy Workshop (English)	07/88	085/88
	Regional Power Seminar on Reducing Electric Power System Losses in Africa (English)	08/88	087/88
	Institutional Evaluation of EGL (English)	02/89	098/89
	Biomass Mapping Regional Workshops (English)	05/89	--
	Francophone Household Energy Workshop (French)	08/89	--
	Interafrican Electrical Engineering College: Proposals for Short- and Long-Term Development (English)	03/90	112/90
	Biomass Assessment and Mapping (English)	03/90	--
	Symposium on Power Sector Reform and Efficiency Improvement in Sub-Saharan Africa (English)	06/96	182/96
	Commercialization of Marginal Gas Fields (English)	12/97	201/97
	Commercilizing Natural Gas: Lessons from the Seminar in Nairobi for Sub-Saharan Africa and Beyond	01/00	225/00
	Africa Gas Initiative – Main Report: Volume I	02/01	240/01
	First World Bank Workshop on the Petroleum Products Sector in Sub-Saharan Africa	09/01	245/01
	Ministerial Workshop on Women in Energy	10/01	250/01
	Energy and Poverty Reduction: Proceedings from a Multi-Sector And Multi-Stakeholder Workshop Addis Ababa, Ethiopia, October 23-25, 2002.	03/03	266/03
	Opportunities for Power Trade in the Nile Basin: Final Scoping Study	01/04	277/04
	Énergies modernes et réduction de la pauvreté: Un atelier multi-sectoriel. Actes de l'atelier régional. Dakar, Sénégal, du 4 au 6 février 2003 (French Only)	01/04	278/04
	Énergies modernes et réduction de la pauvreté: Un atelier multi-sectoriel. Actes de l'atelier régional. Douala, Cameroun du 16-18 juillet 2003. (French Only)	09/04	286/04
	Energy and Poverty Reduction: Proceedings from the Global Village Energy Partnership (GVEP) Workshops held in Africa	01/05	298/05
	Power Sector Reform in Africa: Assessing the Impact on Poor People	08/05	306/05
	The Vulnerability of African Countries to Oil Price Shocks: Major Factors and Policy Options. The Case of Oil Importing Countries	08/05	308/05
Angola	Energy Assessment (English and Portuguese)	05/89	4708-ANG
	Power Rehabilitation and Technical Assistance (English)	10/91	142/91
	Africa Gas Initiative – Angola: Volume II	02/01	240/01
Benin	Energy Assessment (English and French)	06/85	5222-BEN
Botswana	Energy Assessment (English)	09/84	4998-BT
	Pump Electrification Prefeasibility Study (English)	01/86	047/86
	Review of Electricity Service Connection Policy (English)	07/87	071/87
	Tuli Block Farms Electrification Study (English)	07/87	072/87
	Household Energy Issues Study (English)	02/88	--
	Urban Household Energy Strategy Study (English)	05/91	132/91
Burkina Faso	Energy Assessment (English and French)	01/86	5730-BUR
	Technical Assistance Program (English)	03/86	052/86
	Urban Household Energy Strategy Study (English and French)	06/91	134/91
Burundi	Energy Assessment (English)	06/82	3778-BU

Region/Country	***Activity/Report Title***	***Date***	***Number***
Burundi	Petroleum Supply Management (English)	01/84	012/84
	Status Report (English and French)	02/84	011/84
	Presentation of Energy Projects for the Fourth Five-Year Plan (1983-1987) (English and French)	05/85	036/85
	Improved Charcoal Cookstove Strategy (English and French)	09/85	042/85
	Peat Utilization Project (English)	11/85	046/85
	Energy Assessment (English and French)	01/92	9215-BU
Cameroon	Africa Gas Initiative – Cameroon: Volume III	02/01	240/01
Cape Verde	Energy Assessment (English and Portuguese)	08/84	5073-CV
	Household Energy Strategy Study (English)	02/90	110/90
Central African Republic	Energy Assessment (French)	08/92	9898-CAR
Chad	Elements of Strategy for Urban Household Energy The Case of N'djamena (French)	12/93	160/94
Comoros	Energy Assessment (English and French)	01/88	7104-COM
	In Search of Better Ways to Develop Solar Markets: The Case of Comoros	05/00	230/00
Congo	Energy Assessment (English)	01/88	6420-COB
	Power Development Plan (English and French)	03/90	106/90
	Africa Gas Initiative – Congo: Volume IV	02/01	240/01
Côte d'Ivoire	Energy Assessment (English and French)	04/85	5250-IVC
	Improved Biomass Utilization (English and French)	04/87	069/87
	Power System Efficiency Study (English)	12/87	--
	Power Sector Efficiency Study (French)	02/92	140/91
	Project of Energy Efficiency in Buildings (English)	09/95	175/95
	Africa Gas Initiative – Côte d'Ivoire: Volume V	02/01	240/01
Ethiopia	Energy Assessment (English)	07/84	4741-ET
	Power System Efficiency Study (English)	10/85	045/85
	Agricultural Residue Briquetting Pilot Project (English)	12/86	062/86
	Bagasse Study (English)	12/86	063/86
	Cooking Efficiency Project (English)	12/87	--
	Energy Assessment (English)	02/96	179/96
Gabon	Energy Assessment (English)	07/88	6915-GA
	Africa Gas Initiative – Gabon: Volume VI	02/01	240/01
The Gambia	Energy Assessment (English)	11/83	4743-GM
	Solar Water Heating Retrofit Project (English)	02/85	030/85
	Solar Photovoltaic Applications (English)	03/85	032/85
	Petroleum Supply Management Assistance (English)	04/85	035/85
Ghana	Energy Assessment (English)	11/86	6234-GH
	Energy Rationalization in the Industrial Sector (English)	06/88	084/88
	Sawmill Residues Utilization Study (English)	11/88	074/87
	Industrial Energy Efficiency (English)	11/92	148/92
	Corporatization of Distribution Concessions through Capitalization	12/03	272/03
Guinea	Energy Assessment (English)	11/86	6137-GUI
	Household Energy Strategy (English and French)	01/94	163/94
Guinea-Bissau	Energy Assessment (English and Portuguese)	08/84	5083-GUB
	Recommended Technical Assistance Projects (English & Portuguese)	04/85	033/85
	Management Options for the Electric Power and Water Supply Subsectors (English)	02/90	100/90
	Power and Water Institutional Restructuring (French)	04/91	118/91
Kenya	Energy Assessment (English)	05/82	3800-KE
	Power System Efficiency Study (English)	03/84	014/84
	Status Report (English)	05/84	016/84

Region/Country	***Activity/Report Title***	***Date***	***Number***
Kenya	Coal Conversion Action Plan (English)	02/87	--
	Solar Water Heating Study (English)	02/87	066/87
	Peri-Urban Woodfuel Development (English)	10/87	076/87
	Power Master Plan (English)	11/87	--
	Power Loss Reduction Study (English)	09/96	186/96
	Implementation Manual: Financing Mechanisms for Solar Electric Equipment	07/00	231/00
Lesotho	Energy Assessment (English)	01/84	4676-LSO
Liberia	Energy Assessment (English)	12/84	5279-LBR
	Recommended Technical Assistance Projects (English)	06/85	038/85
	Power System Efficiency Study (English)	12/87	081/87
Madagascar	Energy Assessment (English)	01/87	5700-MAG
	Power System Efficiency Study (English and French)	12/87	075/87
	Environmental Impact of Woodfuels (French)	10/95	176/95
Malawi	Energy Assessment (English)	08/82	3903-MAL
	Technical Assistance to Improve the Efficiency of Fuelwood Use in the Tobacco Industry (English)	11/83	009/83
	Status Report (English)	01/84	013/84
Mali	Energy Assessment (English and French)	11/91	8423-MLI
	Household Energy Strategy (English and French)	03/92	147/92
Islamic Republic of Mauritania	Energy Assessment (English and French)	04/85	5224-MAU
	Household Energy Strategy Study (English and French)	07/90	123/90
Mauritius	Energy Assessment (English)	12/81	3510-MAS
	Status Report (English)	10/83	008/83
	Power System Efficiency Audit (English)	05/87	070/87
	Bagasse Power Potential (English)	10/87	077/87
	Energy Sector Review (English)	12/94	3643-MAS
Mozambique	Energy Assessment (English)	01/87	6128-MOZ
	Household Electricity Utilization Study (English)	03/90	113/90
	Electricity Tariffs Study (English)	06/96	181/96
	Sample Survey of Low Voltage Electricity Customers	06/97	195/97
Namibia	Energy Assessment (English)	03/93	11320-NAM
Niger	Energy Assessment (French)	05/84	4642-NIR
	Status Report (English and French)	02/86	051/86
	Improved Stoves Project (English and French)	12/87	080/87
	Household Energy Conservation and Substitution (English and French)	01/88	082/88
Nigeria	Energy Assessment (English)	08/83	4440-UNI
	Energy Assessment (English)	07/93	11672-UNI
	Strategic Gas Plan	02/04	279/04
Rwanda	Energy Assessment (English)	06/82	3779-RW
	Status Report (English and French)	05/84	017/84
	Improved Charcoal Cookstove Strategy (English and French)	08/86	059/86
	Improved Charcoal Production Techniques (English and French)	02/87	065/87
	Energy Assessment (English and French)	07/91	8017-RW
	Commercialization of Improved Charcoal Stoves and Carbonization Techniques Mid-Term Progress Report (English and French)	12/91	141/91
SADC	SADC Regional Power Interconnection Study, Vols. I-IV (English)	12/93	-
SADCC	SADCC Regional Sector: Regional Capacity-Building Program for Energy Surveys and Policy Analysis (English)	11/91	-
Sao Tome and Principe	Energy Assessment (English)	10/85	5803-STP
Senegal	Energy Assessment (English)	07/83	4182-SE

Region/Country	***Activity/Report Title***	***Date***	***Number***
Senegal	Status Report (English and French)	10/84	025/84
	Industrial Energy Conservation Study (English)	05/85	037/85
	Preparatory Assistance for Donor Meeting (English and French)	04/86	056/86
	Urban Household Energy Strategy (English)	02/89	096/89
	Industrial Energy Conservation Program (English)	05/94	165/94
Seychelles	Energy Assessment (English)	01/84	4693-SEY
	Electric Power System Efficiency Study (English)	08/84	021/84
Sierra Leone	Energy Assessment (English)	10/87	6597-SL
Somalia	Energy Assessment (English)	12/85	5796-SO
Republic of South Africa	Options for the Structure and Regulation of Natural Gas Industry (English)	05/95	172/95
Sudan	Management Assistance to the Ministry of Energy and Mining	05/83	003/83
	Energy Assessment (English)	07/83	4511-SU
	Power System Efficiency Study (English)	06/84	018/84
	Status Report (English)	11/84	026/84
	Wood Energy/Forestry Feasibility (English)	07/87	073/87
Swaziland	Energy Assessment (English)	02/87	6262-SW
	Household Energy Strategy Study	10/97	198/97
Tanzania	Energy Assessment (English)	11/84	4969-TA
	Peri-Urban Woodfuels Feasibility Study (English)	08/88	086/88
	Tobacco Curing Efficiency Study (English)	05/89	102/89
	Remote Sensing and Mapping of Woodlands (English)	06/90	--
	Industrial Energy Efficiency Technical Assistance (English)	08/90	122/90
	Power Loss Reduction Volume 1: Transmission and Distribution System Technical Loss Reduction and Network Development (English)	06/98	204A/98
	Power Loss Reduction Volume 2: Reduction of Non-Technical Losses (English)	06/98	204B/98
Togo	Energy Assessment (English)	06/85	5221-TO
	Wood Recovery in the Nangbeto Lake (English and French)	04/86	055/86
	Power Efficiency Improvement (English and French)	12/87	078/87
Uganda	Energy Assessment (English)	07/83	4453-UG
	Status Report (English)	08/84	020/84
	Institutional Review of the Energy Sector (English)	01/85	029/85
	Energy Efficiency in Tobacco Curing Industry (English)	02/86	049/86
	Fuelwood/Forestry Feasibility Study (English)	03/86	053/86
	Power System Efficiency Study (English)	12/88	092/88
	Energy Efficiency Improvement in the Brick and Tile Industry (English)	02/89	097/89
	Tobacco Curing Pilot Project (English)	03/89	UNDP Terminal Report
	Energy Assessment (English)	12/96	193/96
	Rural Electrification Strategy Study	09/99	221/99
Zaire	Energy Assessment (English)	05/86	5837-ZR
Zambia	Energy Assessment (English)	01/83	4110-ZA
	Status Report (English)	08/85	039/85
	Energy Sector Institutional Review (English)	11/86	060/86
	Power Subsector Efficiency Study (English)	02/89	093/88
	Energy Strategy Study (English)	02/89	094/88
	Urban Household Energy Strategy Study (English)	08/90	121/90
Zimbabwe	Energy Assessment (English)	06/82	3765-ZIM
	Power System Efficiency Study (English)	06/83	005/83
	Status Report (English)	08/84	019/84

Region/Country	Activity/Report Title	Date	Number
	Power Sector Management Assistance Project (English)	04/85	034/85
	Power Sector Management Institution Building (English)	09/89	--
Zimbabwe	Petroleum Management Assistance (English)	12/89	109/89
	Charcoal Utilization Pre-feasibility Study (English)	06/90	119/90
	Integrated Energy Strategy Evaluation (English)	01/92	8768-ZIM
	Energy Efficiency Technical Assistance Project: Strategic Framework for a National Energy Efficiency Improvement Program (English)	04/94	--
	Capacity Building for the National Energy Efficiency Improvement Programme (NEEIP) (English)	12/94	--
	Rural Electrification Study	03/00	228/00

EAST ASIA AND PACIFIC (EAP)

Region/Country	Activity/Report Title	Date	Number
Asia Regional	Pacific Household and Rural Energy Seminar (English)	11/90	--
China	County-Level Rural Energy Assessments (English)	05/89	101/89
	Fuelwood Forestry Preinvestment Study (English)	12/89	105/89
	Strategic Options for Power Sector Reform in China (English)	07/93	156/93
	Energy Efficiency and Pollution Control in Township and Village Enterprises (TVE) Industry (English)	11/94	168/94
	Energy for Rural Development in China: An Assessment Based on a Joint Chinese/ESMAP Study in Six Counties (English)	06/96	183/96
	Improving the Technical Efficiency of Decentralized Power Companies	09/99	222/99
	Air Pollution and Acid Rain Control: The Case of Shijiazhuang City and the Changsha Triangle Area	10/03	267/03
	Toward a Sustainable Coal Sector In China	07/04	287/04
Fiji	Energy Assessment (English)	06/83	4462-FIJ
Indonesia	Energy Assessment (English)	11/81	3543-IND
	Status Report (English)	09/84	022/84
	Power Generation Efficiency Study (English)	02/86	050/86
	Energy Efficiency in the Brick, Tile and Lime Industries (English)	04/87	067/87
	Diesel Generating Plant Efficiency Study (English)	12/88	095/88
	Urban Household Energy Strategy Study (English)	02/90	107/90
	Biomass Gasifier Preinvestment Study Vols. I & II (English)	12/90	124/90
	Prospects for Biomass Power Generation with Emphasis on Palm Oil, Sugar, Rubberwood and Plywood Residues (English)	11/94	167/94
Lao PDR	Urban Electricity Demand Assessment Study (English)	03/93	154/93
	Institutional Development for Off-Grid Electrification	06/99	215/99
Malaysia	Sabah Power System Efficiency Study (English)	03/87	068/87
	Gas Utilization Study (English)	09/91	9645-MA
Mongolia	Energy Efficiency in the Electricity and District Heating Sectors	10/01	247/01
	Improved Space Heating Stoves for Ulaanbaatar	03/02	254/02
	Impact of Improved Stoves on Indoor Air Quality in Ulaanbaatar, Mongolia	11/05	313/05
Myanmar	Energy Assessment (English)	06/85	5416-BA
Papua New Guinea	Energy Assessment (English)	06/82	3882-PNG
	Status Report (English)	07/83	006/83
	Institutional Review in the Energy Sector (English)	10/84	023/84
	Power Tariff Study (English)	10/84	024/84

Region/Country	***Activity/Report Title***	***Date***	***Number***
Philippines	Commercial Potential for Power Production from Agricultural Residues (English)	12/93	157/93
	Energy Conservation Study (English)	08/94	--
	Strengthening the Non-Conventional and Rural Energy Development Program in the Philippines: A Policy Framework and Action Plan	08/01	243/01
	Rural Electrification and Development in the Philippines: Measuring the Social and Economic Benefits	05/02	255/02
Solomon Islands	Energy Assessment (English)	06/83	4404-SOL
	Energy Assessment (English)	01/92	979-SOL
South Pacific	Petroleum Transport in the South Pacific (English)	05/86	--
Thailand	Energy Assessment (English)	09/85	5793-TH
	Rural Energy Issues and Options (English)	09/85	044/85
	Accelerated Dissemination of Improved Stoves and Charcoal Kilns (English)	09/87	079/87
	Northeast Region Village Forestry and Woodfuels Preinvestment Study (English)	02/88	083/88
	Impact of Lower Oil Prices (English)	08/88	--
	Coal Development and Utilization Study (English)	10/89	--
	Why Liberalization May Stall in a Mature Power Market: A Review of the Technical and Political Economy Factors that Constrained the Electricity Sector Reform in Thailand 1998-2002	12/03	270/03
	Reducing Emissions from Motorcycles in Bangkok	10/03	275/03
Tonga	Energy Assessment (English)	06/85	5498-TON
Vanuatu	Energy Assessment (English)	06/85	5577-VA
Vietnam	Rural and Household Energy-Issues and Options (English)	01/94	161/94
	Power Sector Reform and Restructuring in Vietnam: Final Report to the Steering Committee (English and Vietnamese)	09/95	174/95
	Household Energy Technical Assistance: Improved Coal Briquetting and Commercialized Dissemination of Higher Efficiency Biomass and Coal Stoves (English)	01/96	178/96
	Petroleum Fiscal Issues and Policies for Fluctuating Oil Prices In Vietnam	02/01	236/01
	An Overnight Success: Vietnam’s Switch to Unleaded Gasoline	08/02	257/02
	The Electricity Law for Vietnam—Status and Policy Issues—The Socialist Republic of Vietnam	08/02	259/02
	Petroleum Sector Technical Assistance for the Revision of the Existing Legal and Regulatory Framework	12/03	269/03
Western Samoa	Energy Assessment (English)	06/85	5497-WSO

SOUTH ASIA (SAS)

Region/Country	***Activity/Report Title***	***Date***	***Number***
Bangladesh	Energy Assessment (English)	10/82	3873-BD
	Priority Investment Program (English)	05/83	002/83
	Status Report (English)	04/84	015/84
	Power System Efficiency Study (English)	02/85	031/85
	Small Scale Uses of Gas Pre-feasibility Study (English)	12/88	--
	Reducing Emissions from Baby-Taxis in Dhaka	01/02	253/02
India	Opportunities for Commercialization of Non-conventional Energy Systems (English)	11/88	091/88
	Maharashtra Bagasse Energy Efficiency Project (English)	07/90	120/90
	Mini-Hydro Development on Irrigation Dams and Canal Drops Vols. I, II and III (English)	07/91	139/91

Region/Country	***Activity/Report Title***	***Date***	***Number***
India	WindFarm Pre-Investment Study (English)	12/92	150/92
	Power Sector Reform Seminar (English)	04/94	166/94
	Environmental Issues in the Power Sector (English)	06/98	205/98
	Environmental Issues in the Power Sector: Manual for Environmental Decision Making (English)	06/99	213/99
	Household Energy Strategies for Urban India: The Case of Hyderabad	06/99	214/99
	Greenhouse Gas Mitigation In the Power Sector: Case Studies From India	02/01	237/01
	Energy Strategies for Rural India: Evidence from Six States	08/02	258/02
	Household Energy, Indoor Air Pollution, and Health	11/02	261/02
	Access of the Poor to Clean Household Fuels	07/03	263/03
	The Impact of Energy on Women's Lives in Rural India	01/04	276/04
	Environmental Issues in the Power Sector: Long-Term Impacts And Policy Options for Rajasthan	10/04	292/04
	Environmental Issues in the Power Sector: Long-Term Impacts And Policy Options for Karnataka	10/04	293/04
Nepal	Energy Assessment (English)	08/83	4474-NEP
	Status Report (English)	01/85	028/84
	Energy Efficiency & Fuel Substitution in Industries (English)	06/93	158/93
Pakistan	Household Energy Assessment (English)	05/88	--
	Assessment of Photovoltaic Programs, Applications, and Markets (English)	10/89	103/89
Pakistan	National Household Energy Survey and Strategy Formulation Study: Project Terminal Report (English)	03/94	--
	Managing the Energy Transition (English)	10/94	--
	Lighting Efficiency Improvement Program Phase 1: Commercial Buildings Five Year Plan (English)	10/94	--
	Clean Fuels	10/01	246/01
Regional	Toward Cleaner Urban Air in South Asia: Tackling Transport Pollution, Understanding Sources.	03/04	281/04
Sri Lanka	Energy Assessment (English)	05/82	3792-CE
	Power System Loss Reduction Study (English)	07/83	007/83
	Status Report (English)	01/84	010/84
	Industrial Energy Conservation Study (English)	03/86	054/86
	Sustainable Transport Options for Sri Lanka: Vol. I	02/03	262/03
	Greenhouse Gas Mitigation Options in the Sri Lanka Power Sector: Vol. II	02/03	262/03
	Sri Lanka Electric Power Technology Assessment (SLEPTA): Vol. III	02/03	262/03
	Energy and Poverty Reduction: Proceedings from South Asia Practitioners Workshop How Can Modern Energy Services Contribute to Poverty Reduction? Colombo, Sri Lanka, June 2-4, 2003	11/03	268/03

EUROPE AND CENTRAL ASIA (ECA)

Armenia	Development of Heat Strategies for Urban Areas of Low-income Transition Economies. Urban Heating Strategy for the Republic Of Armenia. *Including a Summary of a Heating Strategy for the Kyrgyz Republic*	04/04	282/04
Bulgaria	Natural Gas Policies and Issues (English)	10/96	188/96
	Energy Environment Review	10/02	260/02
Central Asia and The Caucasus	Cleaner Transport Fuels in Central Asia and the Caucasus	08/01	242/01

Region/Country	*Activity/Report Title*	*Date*	*Number*
Central and Eastern Europe	Power Sector Reform in Selected Countries	07/97	196/97
Central and Eastern Europe	Increasing the Efficiency of Heating Systems in Central and Eastern Europe and the Former Soviet Union (English and Russian)	08/00	234/00
	The Future of Natural Gas in Eastern Europe (English)	08/92	149/92
Kazakhstan	Natural Gas Investment Study, Volumes 1, 2 & 3	12/97	199/97
Kazakhstan & Kyrgyzstan	Opportunities for Renewable Energy Development	11/97	16855-KAZ
Poland	Energy Sector Restructuring Program Vols. I-V (English)	01/93	153/93
	Natural Gas Upstream Policy (English and Polish)	08/98	206/98
	Energy Sector Restructuring Program: Establishing the Energy Regulation Authority	10/98	208/98
Portugal	Energy Assessment (English)	04/84	4824-PO
Romania	Natural Gas Development Strategy (English)	12/96	192/96
	Private Sector Participation in Market-Based Energy-Efficiency Financing Schemes: Lessons Learned from Romania and International Experiences.	11/03	274/03
Slovenia	Workshop on Private Participation in the Power Sector (English)	02/99	211/99
Turkey	Energy Assessment (English)	03/83	3877-TU
	Energy and the Environment: Issues and Options Paper	04/00	229/00
	Energy and Environment Review: Synthesis Report	12/03	273/03

MIDDLE EAST AND NORTH AFRICA (MNA)

Region/Country	*Activity/Report Title*	*Date*	*Number*
Arab Republic of Egypt	Energy Assessment (English)	10/96	189/96
	Energy Assessment (English and French)	03/84	4157-MOR
	Status Report (English and French)	01/86	048/86
Morocco	Energy Sector Institutional Development Study (English and French)	07/95	173/95
	Natural Gas Pricing Study (French)	10/98	209/98
	Gas Development Plan Phase II (French)	02/99	210/99
Syria	Energy Assessment (English)	05/86	5822-SYR
	Electric Power Efficiency Study (English)	09/88	089/88
	Energy Efficiency Improvement in the Cement Sector (English)	04/89	099/89
	Energy Efficiency Improvement in the Fertilizer Sector (English)	06/90	115/90
Tunisia	Fuel Substitution (English and French)	03/90	--
	Power Efficiency Study (English and French)	02/92	136/91
	Energy Management Strategy in the Residential and Tertiary Sectors (English)	04/92	146/92
	Renewable Energy Strategy Study, Volume I (French)	11/96	190A/96
	Renewable Energy Strategy Study, Volume II (French)	11/96	190B/96
	Rural Electrification in Tunisia: National Commitment, Efficient Implementation and Sound Finances	08/05	307/05
Yemen	Energy Assessment (English)	12/84	4892-YAR
	Energy Investment Priorities (English)	02/87	6376-YAR
	Household Energy Strategy Study Phase I (English)	03/91	126/91

LATIN AMERICA AND THE CARIBBEAN REGION (LCR)

Region/Country	***Activity/Report Title***	***Date***	***Number***
LCR Regional	Regional Seminar on Electric Power System Loss Reduction in the Caribbean (English)	07/89	--
	Elimination of Lead in Gasoline in Latin America and the Caribbean (English and Spanish)	04/97	194/97
LCR Regional	Elimination of Lead in Gasoline in Latin America and the Caribbean - Status Report (English and Spanish)	12/97	200/97
	Harmonization of Fuels Specifications in Latin America and the Caribbean (English and Spanish)	06/98	203/98
	Energy and Poverty Reduction: Proceedings from the Global Village Energy Partnership (GVEP) Workshop held in Bolivia	06/05	202/05
	Power Sector Reform and the Rural Poor in Central America	12/04	297/04
	Estudio Comparativo Sobre la Distribución de la Renta Petrolera en Bolivia, Colombia, Ecuador y Perú	08/05	304/05
Bolivia	Energy Assessment (English)	04/83	4213-BO
	National Energy Plan (English)	12/87	--
	La Paz Private Power Technical Assistance (English)	11/90	111/90
	Pre-feasibility Evaluation Rural Electrification and Demand Assessment (English and Spanish)	04/91	129/91
	National Energy Plan (Spanish)	08/91	131/91
	Private Power Generation and Transmission (English)	01/92	137/91
	Natural Gas Distribution: Economics and Regulation (English)	03/92	125/92
	Natural Gas Sector Policies and Issues (English and Spanish)	12/93	164/93
	Household Rural Energy Strategy (English and Spanish)	01/94	162/94
	Preparation of Capitalization of the Hydrocarbon Sector	12/96	191/96
	Introducing Competition into the Electricity Supply Industry in Developing Countries: Lessons from Bolivia	08/00	233/00
	Final Report on Operational Activities Rural Energy and Energy Efficiency	08/00	235/00
	Oil Industry Training for Indigenous People: The Bolivian Experience (English and Spanish)	09/01	244/01
	Capacitación de Pueblos Indígenas en la Actividad Petrolera. Fase II	07/04	290/04
	Estudio Sobre Aplicaciones en Pequeña Escala de Gas Natural	07/04	291/04
Brazil	Energy Efficiency & Conservation: Strategic Partnership for Energy Efficiency in Brazil (English)	01/95	170/95
	Hydro and Thermal Power Sector Study	09/97	197/97
	Rural Electrification with Renewable Energy Systems in the Northeast: A Preinvestment Study	07/00	232/00
	Reducing Energy Costs in Municipal Water Supply Operations “Learning-while-doing” Energy M&T on the Brazilian Frontlines	07/03	265/03
Chile	Energy Sector Review (English)	08/88	7129-CH
Colombia	Energy Strategy Paper (English)	12/86	--
	Power Sector Restructuring (English)	11/94	169/94
Colombia	Energy Efficiency Report for the Commercial and Public Sector (English)	06/96	184/96
Costa Rica	Energy Assessment (English and Spanish)	01/84	4655-CR
	Recommended Technical Assistance Projects (English)	11/84	027/84
	Forest Residues Utilization Study (English and Spanish)	02/90	108/90
Dominican Republic	Energy Assessment (English)	05/91	8234-DO

Region/Country	Activity/Report Title	Date	Number
Ecuador	Energy Assessment (Spanish)	12/85	5865-EC
	Energy Strategy Phase I (Spanish)	07/88	--
	Energy Strategy (English)	04/91	--
	Private Mini-hydropower Development Study (English)	11/92	--
	Energy Pricing Subsidies and Interfuel Substitution (English)	08/94	11798-EC
	Energy Pricing, Poverty and Social Mitigation (English)	08/94	12831-EC
Guatemala	Issues and Options in the Energy Sector (English)	09/93	12160-GU
	Health Impacts of Traditional Fuel Use	08/04	284/04
Haiti	Energy Assessment (English and French)	06/82	3672-HA
	Status Report (English and French)	08/85	041/85
	Household Energy Strategy (English and French)	12/91	143/91
Honduras	Energy Assessment (English)	08/87	6476-HO
	Petroleum Supply Management (English)	03/91	128/91
Jamaica	Energy Assessment (English)	04/85	5466-JM
	Petroleum Procurement, Refining, and Distribution Study (English)	11/86	061/86
	Energy Efficiency Building Code Phase I (English)	03/88	--
	Energy Efficiency Standards and Labels Phase I (English)	03/88	--
Jamaica	Management Information System Phase I (English)	03/88	--
	Charcoal Production Project (English)	09/88	090/88
	FIDCO Sawmill Residues Utilization Study (English)	09/88	088/88
	Energy Sector Strategy and Investment Planning Study (English)	07/92	135/92
Mexico	Improved Charcoal Production Within Forest Management for the State of Veracruz (English and Spanish)	08/91	138/91
	Energy Efficiency Management Technical Assistance to the Comisión Nacional para el Ahorro de Energía (CONAE) (English)	04/96	180/96
	Energy Environment Review	05/01	241/01
Nicaragua	Modernizing the Fuelwood Sector in Managua and León	12/01	252/01
Panama	Power System Efficiency Study (English)	06/83	004/83
Paraguay	Energy Assessment (English)	10/84	5145-PA
	Recommended Technical Assistance Projects (English)	09/85	--
	Status Report (English and Spanish)	09/85	043/85
Peru	Energy Assessment (English)	01/84	4677-PE
	Status Report (English)	08/85	040/85
	Proposal for a Stove Dissemination Program in the Sierra (English and Spanish)	02/87	064/87
	Energy Strategy (English and Spanish)	12/90	--
	Study of Energy Taxation and Liberalization of the Hydrocarbons Sector (English and Spanish)	120/93	159/93
	Reform and Privatization in the Hydrocarbon Sector (English and Spanish)	07/99	216/99
	Rural Electrification	02/01	238/01
Saint Lucia	Energy Assessment (English)	09/84	5111-SLU
St. Vincent and the Grenadines	Energy Assessment (English)	09/84	5103-STV
Sub Andean	Environmental and Social Regulation of Oil and Gas Operations in Sensitive Areas of the Sub-Andean Basin (English and Spanish)	07/99	217/99
Trinidad and Tobago	Energy Assessment (English)	12/85	5930-TR

GLOBAL

Region/Country	Activity/Report Title	Date	Number
	Energy End Use Efficiency: Research and Strategy (English)	11/89	--
	Women and Energy--A Resource Guide The International Network: Policies and Experience (English)	04/90	--
	Guidelines for Utility Customer Management and Metering (English and Spanish)	07/91	--
	Assessment of Personal Computer Models for Energy Planning in Developing Countries (English)	10/91	--
	Long-Term Gas Contracts Principles and Applications (English)	02/93	152/93
	Comparative Behavior of Firms Under Public and Private Ownership (English)	05/93	155/93
	Development of Regional Electric Power Networks (English)	10/94	--
	Roundtable on Energy Efficiency (English)	02/95	171/95
	Assessing Pollution Abatement Policies with a Case Study of Ankara (English)	11/95	177/95
	A Synopsis of the Third Annual Roundtable on Independent Power Projects: Rhetoric and Reality (English)	08/96	187/96
	Rural Energy and Development Roundtable (English)	05/98	202/98
	A Synopsis of the Second Roundtable on Energy Efficiency: Institutional and Financial Delivery Mechanisms (English)	09/98	207/98
	The Effect of a Shadow Price on Carbon Emission in the Energy Portfolio of the World Bank: A Carbon Backcasting Exercise (English)	02/99	212/99
	Increasing the Efficiency of Gas Distribution Phase 1: Case Studies and Thematic Data Sheets	07/99	218/99
	Global Energy Sector Reform in Developing Countries: A Scorecard	07/99	219/99
	Global Lighting Services for the Poor Phase II: Text Marketing of Small “Solar” Batteries for Rural Electrification Purposes	08/99	220/99
	A Review of the Renewable Energy Activities of the UNDP/ World Bank Energy Sector Management Assistance Programme 1993 to 1998	11/99	223/99
	Energy, Transportation and Environment: Policy Options for Environmental Improvement	12/99	224/99
	Privatization, Competition and Regulation in the British Electricity Industry, With Implications for Developing Countries	02/00	226/00
	Reducing the Cost of Grid Extension for Rural Electrification	02/00	227/00
	Undeveloped Oil and Gas Fields in the Industrializing World	02/01	239/01
	Best Practice Manual: Promoting Decentralized Electrification Investment	10/01	248/01
	Peri-Urban Electricity Consumers—A Forgotten but Important Group: What Can We Do to Electrify Them?	10/01	249/01
	Village Power 2000: Empowering People and Transforming Markets	10/01	251/01
	Private Financing for Community Infrastructure	05/02	256/02
	Stakeholder Involvement in Options Assessment: Promoting Dialogue in Meeting Water and Energy Needs: A Sourcebook	07/03	264/03
	A Review of ESMAP’s Energy Efficiency Portfolio	11/03	271/03
	A Review of ESMAP’s Rural Energy and Renewable Energy Portfolio	04/04	280/04

Region/Country	Activity/Report Title	Date	Number
	ESMAP Renewable Energy and Energy Efficiency Reports 1998-2004 (CD Only)	05/04	283/04
	Regulation of Associated Gas Flaring and Venting: *A Global Overview and Lessons Learned from International Experience*	08/04	285/04
	ESMAP Gender in Energy Reports and Other related Information (CD Only)	11/04	288/04
	ESMAP Indoor Air Pollution Reports and Other related Information (CD Only)	11/04	289/04
	Energy and Poverty Reduction: Proceedings from the Global Village Energy Partnership (GVEP) Workshop on the Pre-Investment Funding. Berlin, Germany, April 23-24, 2003.	11/04	294/04
	Global Village Energy Partnership (GVEP) Annual Report 2003	12/04	295/04
	Energy and Poverty Reduction: Proceedings from the Global Village Energy Partnership (GVEP) Workshop on Consumer Lending and Microfinance to Expand Access to Energy Services, Manila, Philippines, May 19-21, 2004	12/04	296/04
	The Impact of Higher Oil Prices on Low Income Countries And on the Poor	03/05	299/05
	Advancing Bioenergy for Sustainable Development: Guideline For Policymakers and Investors	04/05	300/05
	ESMAP Rural Energy Reports 1999-2005	03/05	301/05
	Renewable Energy and Energy Efficiency Financing and Policy Network: Options Study and Proceedings of the International Forum	07/05	303/05
	Implementing Power Rationing in a Sensible Way: Lessons Learned and International Best Practices	08/05	305/05
	The Urban Household Energy Transition. Joint Report with RFF Press/ESMAP. ISBN 1-933115-07-6	08/05	309/05
	Pioneering New Approaches in Support of Sustainable Development In the Extractive Sector: Community Development Toolkit, also Includes a CD containing Supporting Reports	10/05	310/05
	Analysis of Power Projects with Private Participation Under Stress	10/05	311/05
	Potential for Biofuels for Transport in Developing Countries	10/05	312/05

Last report added to this list: ESMAP Formal Report 313/05