Review of interventions to reduce the exposure of women and young children to indoor air pollution in developing countries

by

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Abstract

In this paper we aimed to facilitate discussion about potential interventions for reducing human exposure to indoor air pollution in low-income countries within a conceptual framework that may be applied to a wide variety of interventions. Potential interventions are assessed according to three subsystems of the household energy system: the source (emissions), the local environment (concentrations) and the user (exposure). Eight criteria are identified that may be used to assess potential interventions - either the benefit of the intervention or the restrictions preventing greater use. These criteria are Exposure level, Cost, Local environmental impact, Regional and global environmental impacts, Safety concerns, Impact on local employment, Acceptance and suitability, and Market readiness. These critera are applied to 23 possible interventions.

Based on the evaluation it appears that the most effective interventions and most beneficial to the user and society as a whole would be a shift from wood or charcoal to kerosene, LPG, biogas or grid electricity. Other more progressive alternatives such as ethanol (gel) fuel, or possibly biomass gasification, could not be effectively evaluated, but should be considered in greater detail in the future. Another intervention that appears to offer promising benefits is the use of a cooking window. This intervention, which is a form of hood built into a window (thus without a chimney), needs further investigation and evaluation. Of particular concern is the applicability of the cooking window to a range of different housing types. User based interventions were the most difficult to evaluate are relevant data is scarce. It was evident from the analysis that further attention should be given to the collection and compiling of data so that informed decisions may be made.

The authors emphasize a number of elements to guide the formulation of policy for any particular policy context. It is in analysing and understanding the social aspects of the policy context that specific policy instruments may best be developed and refined. In general policies that emphasize an integrated approach, aim at empowering people and encourage local participation, avoid unnecessary subsidies but address market failures where necessary should be developed.

Contents

1. Introduction

The aim of this paper is to facilitate discussion about potential interventions for reducing human exposure to indoor air pollution in low-income countries (LIC) within a conceptual framework that may be applied to a wide variety of interventions. This main goal may be divided into the following sub goals:

- To establish a conceptual framework for categorizing and assessing potential interventions, and establish criteria for evaluation (covered in sections 2 and 3)
- To review and compile experience to date through published literature, reports, and experience obtained via networks and contacts (sections 3, 4 and Appendices A through C)
- To identify technical and programmatic factors which can guide good practice (section 5), and
- To identify priorities for research, development and dissemination for the next 3-5 years which can maximize progress towards implementation (section 4, 5, and 6)

A central theme of the paper is that both exposure levels and the subsequent health impact and potential solutions to these problems are highly dependent on the local context and the specific needs of a particular household energy system. Successful policies must be able to capture this local specificity and build on the particular ways in which the people who count – the people exposed to high levels of health-damaging pollution in the home – respond to the problems they face and the opportunities they perceive. This is not to suggest that the issues can only be understood or addressed at the micro-level: indeed, an enabling local policy environment is an essential pre-requisite to many local initiatives. It is however argued that the household energy system, and exposure to indoor air pollution are complex processes that vary in crucial details over small distances. This needs to be understood and entrenched into the approach to interventions that 'outsiders' (whether from national governments or the international aid community) attempt to place on the ground. A single issue, technology-driven approach to indoor air quality is doomed to failure, as it is likely to try to impose a solution on the ground (as stressed for cooking stoves in general by Soussan 1993). Such an approach would limit the choices available to the local community and frequently demands of them changes that affect numerous other aspects of their lives. It is argued in this paper that the key to success is to adopt project approaches that broaden the range of secure and sustainable choices available to the local actors and thus to enable them to devise their own solutions. Poverty itself deprives people of choices as has been mentioned elsewhere (Ballard-Tremeer 1999) and there are always legitimate barriers to alternative actions not followed (conceptual, social, practical, and economic obstacles for instance). Our role should be to increase the options available through providing the missing inputs (including knowledge where needed) and contribute to the development of the local institutions that empower all sections of the community to have secure and safe access to resources that increase well being and meet their basic needs. This paper, therefore, attempts to review and synthesise available information for as wide a range of interventions as possible with a view to increasing the ability for communities to choose themselves from a range of available options.

The following approach to the discussion will be followed:

- Establish the boundaries for the technology assessment (section 2)
- Suggest a framework for assessing potential interventions (section 3)
- Consider and evaluate a wide range of possible interventions, summarising the state of knowledge and highlighting gaps in knowledge (section 4)
- Briefly explore the policy framework for the successful implementation of a range of interventions (section 5)

Note that in this paper interventions (changes that can be made) are distinguished from policies (how one brings about the changes). The focus of this paper will be on the interventions and sections 3 and 4 will develop this in some detail, although reference will be made to the policy framework into which, and through which, the interventions could be implemented. Section 5 will cover the policy issues further but it is not possible within the scope of this paper to make more than a brief exploration of current trends and experiences. Nevertheless, it is not the intention of the authors to suggest a (continuation of a) 'technology push' approach. Rather, interventions should be based on a 'demand pull' and shift from isolated targets towards integrated interventions.

2. The household energy system and exposure

It is perhaps obvious that the main purpose of the household energy system is to meet the energy needs of the household. In general, these needs may be classed in 6 categories: warmth, heat, light, mechanical power, communication and comfort. It is in the combustion of fuel to meet these needs that source emissions are generated, and the chain from emissions to eventual health effects begins.

We start by summarising a number of well-known facts about the mechanisms of exposure: the combustion of (cooking) fuels generates air pollution in the form of particulate matter and gases. The quantity of each pollutant released is dependant on the combustion conditions, and the pollutant emission rates vary strongly with time, and, depending on the stove geometry, with each other (Ballard-Tremeer & Jawurek 1996 and Ezzati et al 2000). The concentration of the pollutant in the air, measured on a mass per volume basis, depends on emission rate (the source adding the pollutant), and ventilation (the sink removing or distributing the pollutant). Depending on the ventilation conditions, concentrations will have both a temporal and spatial variation. Human exposure to the cocktail of pollutants is determined by the amount of pollutant experienced by the people exposed and the time spent exposed to this concentration. 'Dose' is the measure of the quantity of pollutant deposited in the body and depends on exposure as well as the pollutant characteristics (such as particle size) and rate of breathing. Field experience has shown that breathing rate can vary widely – cooks have been observed, for example, to blow vigorously on the fire during the preparation of a meal to keep the fire burning well or to change fire power (temperature) rapidly to meet cooking needs. The deep breaths required will have a large effect on dosage. The health effects depend, however, not only on dose, but also on the toxicity of the pollutant, and the individual response of the person's body to the pollutant.

In this paper we will concern ourselves mainly with interventions that influence emission source strength, pollutant concentrations, and exposure. Although a linear model of exposure shows clearly the main causal relationship between the factors (emissions → concentrations → exposure) and allows population health effects to be estimated (as in Wang & Smith 1999), it should be pointed out that the systems that each of these factors represent (the source, the living environment, and the user respectively) are interdependent – changes in one affects the others. From this point of view, exposure within the household (energy) system is shown in figure 1 below. The block arrows represent the interrelation between the sub-systems whereas the dotted arrows represent the principal path of exposure. Exposure is a complex product of the three subsystems making up the household energy system: source (direct emissions such as a stove), living environment (dispersal of emissions such as air currents in the kitchen), and the user (behaviour and habits such as cooking without pot lids or the use of combined cooking and sleeping places). Interventions in any of these inter-linked areas will influence exposure levels.

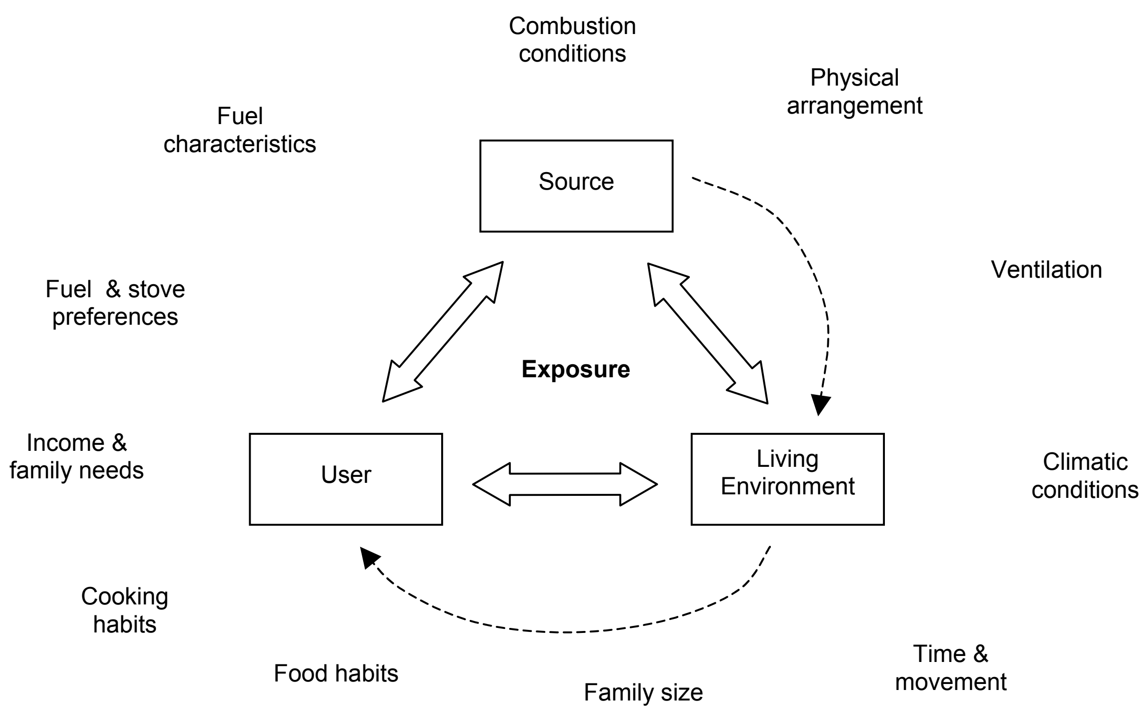


Figure 1: Exposure within the household energy system. A (limited) number of influences on the sub-systems are shown surrounding the three interrelated sub-systems. Dotted arrows show the main path of exposure

A number of important socio-economic factors are shown surrounding the three sub-systems in figure 1. This is illustrated by findings of fieldwork conducted during the 'Macro-Scale Experiment' of the South African Department of Minerals and Energy in 1997, where 80 % of respondents strongly agreed with the statement 'a fire or coal stove in the home brings and keeps my family together' (van Niekerk 1998). Interventions in the household energy system may go to the very centre of life, and as claimed by van Niekerk (1998),

> *"the fact that technology transfer in Africa has persistently failed could be attributed to the way in which social and religious factors have been disregarded. There is a gap or clash between the intentions of those who want to improve the quality of life of communities, and the perceptions, responses, and social and cultural patterns of those people."*

Although one may expect large variations between regions and cultures, it is frequently true that *home is where the hearth is*. Because of this, interventions may have a profound influence on socio-economic development and visa-versa – the importance of local empowerment and local participation in interventions should not be underestimated. Another notable finding from the South African 'Macro-Scale Experiment', is that 84 % agreed strongly that 'fire causes smoke that makes us sick' adding weight to the argument for empowerment: the motivation to reduce exposure is there, but for a variety of legitimate reasons, alternatives are not chosen. These reasons are of a conceptual, social, practical, and economic nature for instance.

There are also many influences beyond the household system that impact on decision-making and need consideration in developing intervention policies: government policy (incl. pricing policy), cultural pressures, and business interests to name a few. These factors will be revisited in later sections below.

3. A framework for considering interventions

The household energy system described in the previous section, and any changes that may be made to the system to reduce exposure to harmful pollutants (interventions) may be evaluated from several perspectives, including the degree of emission reduction. In this section we suggest a framework for evaluating potential interventions from technical, economic, and social perspectives. The eight evaluation criteria we have selected are either measures of benefit or possible restrictions to their use. Benefits include: level of reductions in pollutant exposure, reductions in negative local environmental impacts, level of global or regional impact, and local employment creation potential. Restrictions include: cost, safety, acceptance and suitability, and market readiness. Joshi (1992) has used a “matrix of restrictions” for evaluating a range of technical interventions and in some ways the framework used here is similar. Joshi’s resource restrictions and technical restrictions are however included within the cost criteria used in our study, since the effect of both those restrictions, in the main, result in increased costs.

Interventions take place against the background of socio-economic development. There is currently much talk of development and low-income countries are frequently described as ‘developing’ or ‘less developed’. The current buzz-words include ‘sustainable development’ and along with economic indicators, a number of environmental indicators may be used to assess levels of sustainability (see for example the World Economic Forum’s Pilot Environmental Sustainability Indicators (WEF 2000)).

In this paper we define an intervention as a purposeful change in the household system that may bring about an improvement in well-being, and in particular well being as healthy levels of indoor air pollution. What this means for socio-economic development is illustrated in Figure 2 below. The aim of interventions are to produce improvements in a wide variety of aspects with the specific purpose of improved well-being.

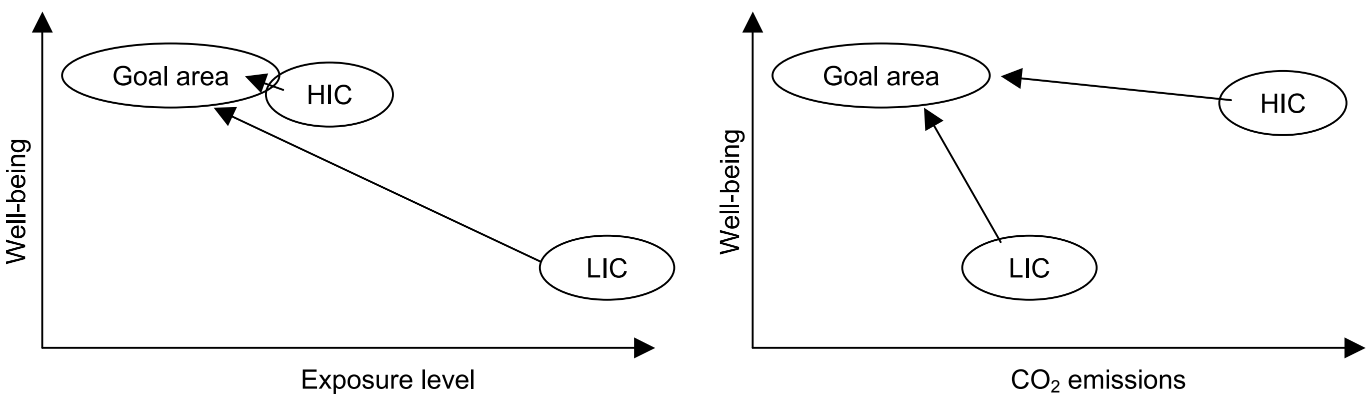


Figure 2: Two examples of socio-economic development: exposure to indoor pollution levels, and emissions of the greenhouse gas CO_2. Note that both ‘high-income countries’ (HIC) and ‘low-income countries’ (LIC) are in need of ‘development’.

The following criteria are proposed for the assessment of interventions and are defined and discussed below. The discussions focus on useful units for quantitative comparisons between interventions, as well as highlight difficulties in the use of the criteria in question. The following criteria are proposed:

1. Exposure level
2. Cost
3. Local environment
4. Regional and global environment
5. Safety concerns
6. Local employment
7. Acceptance and suitability
8. Market readiness

3.1 Exposure level

Emissions, concentration levels and exposure levels for indoor air pollution in low-income countries have up to now been measured only in a limited number of cases, and comparative data is scarce. In addition a large range of indicators of exposure or the potential for exposure have been used. These include source emission factors, source emissions per task, peak source emissions, average living environment concentrations, and of course exposure levels as experienced by the people exposed.

From an experimental point of view, probably the best and the most representative method of assessing exposure levels and changes as a result of an intervention is to make measurements through placing a personal pollutant concentration monitor on the cook or others in the cooking environment. This may introduce, however, many confounding factors that can make it hard to differentiate the effects of the intervention from other variables. To differentiate the real effects of the intervention under these circumstances requires large sample sizes and therefore high costs.

On the other side of the spectrum, it is possible to compare direct source emission levels on a rate basis or as an emission factor (mass pollutant emitted per mass of fuel burned). For the measurement of emission levels the pollutant emission factor, or the pollutant source strength, is the most commonly used measure and has been used in both direct and indirect measurement studies (see, Smith et al 1992; Ahuja et al 1987; and Young 1992:12 for indirect calculation of source strength; and Nangale 1992; and Butcher et al 1984 for direct measurement calculations). It is theoretically possible to convert room/chamber concentration data to source emission data (see Ahuja et al. 1987), and visa versa (Ballard-Tremeer & Jawurek 1999) but whether this process leads to useful predictions is questionable since many assumptions must be made. In presenting results on emissions the total mass of pollutant emitted per test (cooking task), or mass of pollutant per unit of energy delivered to the pot is to be preferred. This mass is more directly related to human exposure. Emission factors, because of their denominator term (mass of fuel burned) include the effects of efficiency and thus can favour less efficient cooking devices. Joshi et al (1989, 1991) use the mass emitted per fixed task, but generally report both it and emission factor. However, they define the task not as the simulated cooking cycle of the Water Boiling Test, but the transfer of a fixed amount of energy to the pot. The danger of this definition (in particular the use of a fixed transfer of energy) is that for wood fuelled cooking devices the indicator could mix the effects of transient emission rates, firepower and time. It seems that 'emission per unit of energy delivered to the pot' calculated over a typical cooking task, would be the least prone to error or misinterpretation and is used in this paper for comparisons between possible interventions where data is available.

Between exposure levels and source emissions in experimental complexity come pollutant concentrations, and relatively many studies report concentration levels. Air pollution standards are also quoted as concentrations. Concentrations are a product of source and sink – source being the emissions from the combustion process and sink being the removal or dispersal of the pollutants. It is risky to compare concentrations and draw conclusions about the source emissions without knowing that the sinks are also comparable in nature. Nevertheless, for some interventions (those that change living environment or user behaviour) concentration comparisons are the practical units.

It is beyond the scope of this paper to discuss in detail the questions of which pollutants to measure and what characteristics of the emissions are of most importance. However, these questions are of great importance and require careful attention. Two cases may be used to illustrate potential difficulties: Firstly, comparing an open 'three-stone' fire to an enclosed improved stove, it is not uncommon that enclosed stoves have very high peak emissions but for a short time (at the start of the combustion), and open fires to have comparatively low but fairly constant emissions through the burn cycle (see Ballard-Tremeer & Jawurek 1996). A stove may thus have lower average emissions but a higher peak emission factor in comparison to an open fire. Is the stove an improved stove? Secondly, carbon monoxide (CO) and Total Suspended Particulates (TSP) have been found to correlate well on a total emission basis, but instantaneous correlations appear to be dependent on stove type (Ballard-Tremeer & Jawurek 1996 and Ezzati et al. 2000) – more enclosed stoves have better instantaneous correlations between pollutants than more open cooking devices. So is it sufficient to measure CO and use it as an indicator of TSP?

In the discussions that follow, use will be made of a wide range of source emission, concentration, and exposure data so as to provide some basis for comparison and decision-making. It should however be stressed that there is a need for more consistent reporting format for the development of a useful and comparative interventions database.

The WHO air quality guideline recommends that a concentration of 230 $\mu g/m^3$ of suspended particulate matter not be surpassed more than seven days a year (Bruce 1999). This level is exceeded by many times in developing countries. Studies in India and Nepal have, for example, reported room concentrations for cooking ranging from 4,000 to 21,000 $\mu g/m^3$. The revised air quality guidelines for Europe set by the WHO recognise the growing evidence that relatively small increases above the level of 20$\mu g/m^3$ of PM_{10} have an adverse impact on health. This, as stressed by Bruce (1999), suggests that rural dwellers may be exposed daily to concentrations of particulate matter as much as 200 times the level at which adverse health effects are being detected.

What about efficiency?
Cooking device efficiency has not been selected in this paper as an assessment criterion as and of itself. There are a number of reasons for this:

Firstly, the efficiency of a cooking device is believed to be a secondary aspect. From both the user's perspective and that of the government or international aid community the desired benefits are exposure reduction, reduced cost, and lower deforestation etc. Efficiency certainly does have an effect on operating costs and deforestation, but it is not the aim in itself.

Secondly, it has sometimes been assumed that efficiency is a sufficient measure for gauging emissions - that improving efficiency will naturally lead to reduced emissions, and there is a danger of overstressing the importance of this factor. A number of studies have shown that this clearly is not the case (Smith 1992:173,182; Ahuja et al 1987:267; Nangale 1992:18). In fact it has been recognised that a conflict exists between high efficiency and low emissions (Shelton 1982:874). The reason for this is simply explained - efficiency is influenced by two largely independent factors: combustion efficiency, and heat transfer efficiency. Combustion efficiency, a measure of how well the fuel is burnt, relates directly to emissions. Poor combustion efficiency means that the fuel is not completely burnt and therefore the products of incomplete combustion are emitted from the stove. However, *heat transfer efficiency* (how well the energy released from the wood is transferred to the pot) can be improved while, at the same time, decreasing *combustion efficiency*. This often yields an improved *overall efficiency* but increased emissions (See Smith 1992:173,182; and Ahuja et al 1987:267).

3.2 Cost

From the users' perspective cost appears to be one of the most important determining factors in the choice of a fuel/stove combination (Dutt & Ravindranath, 1993). Although not all features of alternative cooking systems are quantifiable, economic comparisons can be made on the basis of capital and operating expenses. A useful index, as proposed by Dutt & Ravindranath (1993) is the annualised life-cycle cost. This index allows for the comparison of any number of alternatives by annualising the capital investment over the lifetime of the device for a given discount rate. Annual fuel costs and maintenance costs are added giving the annual cost of owning and operating the cooking system. Since stoves and fuel costs frequently do not have a monetary value, annualised life-cycle costs may be evaluated from a societal perspective by ignoring internal cash flows and including external costs such as foreign exchange rate requirements.

Even though a given intervention may be attractive on an annualised life-cycle basis, from the user's perspective the upfront capital investment costs may exclude users, and cause people to use alternatives with higher annual (operating) costs than alternatives. An example is the use of candles and batteries for lighting and entertainment in preference to alternatives that have lower annualised costs such as solar electricity (PV) (Mcnelis et al 1988). Micro-credit systems are usually used for the sale of PV solar home systems to lower entry costs. What is clear is that although the annualised life-cycle cost gives a useful comparison for international aid agencies or national governments, this measure is unlikely to make any difference to the user. It is worth mentioning that from the perspective of government or development agency it is probably easier (and more sustainable) to tackle appliance cost barriers than fuel cost barriers.

Cost data, where available, will be given in this paper as capital cost, appliance lifetime, and operating costs. Annualised life-cycle costs for any given discount rate may be calculated from this data and is reported here where the data is available for specific locations. Fuel costs, which, together with cooking device efficiency, and maintenance requirements determine operating costs, are strongly dependent on availability and logistics of supply. When costs are dominated by fuel consumption rather than by stove cost, the annualised life-cycle cost depends weakly on the discount rate. Such is the case for all cooking systems except those that run on LPG, electricity and biogas. This suggests that the more efficient stoves are likely to be more cost effective, despite their initial expense. For example, even if the cost of a kerosene stove is doubled to, say $14, to achieve a fuel saving of only 10 %, the annualised life-cycle cost will be lower than that of an open fire (Dutt & Ravindranath 1993). This will hold unless discount rates are very high.

3.3 Local environment

The effects of the household energy systems and any interventions on the environment include deforestation, loss of soil nutrients, and the build-up of lead through the disposal of batteries.

In the 1970s development workers became acutely aware of the global fuelwood crisis (Aprovecho Institute 1984) and efficiency soon became the principal concern of development organizations (Bialy 1991:3; Joseph 1991:145) - thus technical and scientific issues relating to efficiency became the focus of intensive research (Karekezi 1992:91). It is often assumed that deforestation and the collection of firewood are directly linked. Studies in Nepal in 1979 for example predicted that that from the then estimated total forest area of 6.4 million ha, all accessible forest in the country (50% of total forest area) would be completely exhausted by 1990 (ERDG 1979). In the case of massive dissemination of improved stoves, the report predicted, this disaster would be delayed by 3 years only. The prediction was based on the assumption that all fuelwood was derived from accessible forests. According to FAO predictions Nepal still had over 5 million ha of forest area in 1993 (RWEDP 1997). A number of reasons for the apparent discrepancy between supply and demand are given in the accompanying box:

The following factors should be taken into account when considering the deforestation impact of various household energy interventions (from Ballard-Tremeer 1997):

- Clearing woodland for agriculture and the use of wood for building are, in many areas, the main contributors to deforestation rather than the use of wood for fuel (Krugmann 1989; Kristoferson & Bokalders 1991; Barnes 1990; Liengme 1983). In many areas a progression can be seen: initially fuelwood gathering is confined to dead wood. Rural overcrowding leads to a large demand for wood and a diminishing supply because of the clearance of fields and the cutting of live trees for building. Wood gatherers are soon forced to use wood from the remaining live trees which reduces supplies even further. Commenting on the disappearance of forests in southern Natal, South Africa, Gandar writes: "It is wrong to lay all the blame on the firewood crisis but the chances are that it was the last nail in the forest's coffin." (Gandar 1987). Wood used as fuel is therefore not the sole contributor to deforestation.
- With large population growth rates, savings from more efficient fuel usage are overtaken in a very short time (Baldwin 1984).
- The introduction of improved stoves in rural areas leads to changes in cooking operations and quantities of food prepared and therefore does not directly decrease fuel consumption (Bialy 1991:17; Smith & Ramakrishna 1991:231-232). A stove which is enjoyable to use will usually be used more frequently and for longer periods. This may lead to better hygiene and nutrition, but seldom decreases overall fuel consumption. An example of the difficulty in predicting the reaction of a population to energy related changes is that in South Africa 75% of coal-using households continue to use coal after having been provided with electricity (Sithole et al 1991:2).
- In urban areas the use of wood can cause deforestation surrounding the city. As fuelwood needs to be transported further the use of charcoal becomes more and more attractive. Since the efficiency of the total process (from wood to heat for cooking), even with the most efficient kiln and stove is significantly below that of a wood stove, this frequently leads to increased deforestation.
- In spite of the issues mentioned above, deforestation from the use of wood for fuel does appear to be a problem in many areas. Taking South Africa as a whole for example, it is estimated that the 3 million rural households currently use 10 million tonnes of wood annually, whereas 6 million tonnes is considered to be sustainably available (DME 1996).

For biomass-based fuels, a comparison of land requirements, based on the yield of a typical tropical forest plantation and the energy requirements for a 6 person household (say), provides a useful indication of local environmental stress and is reported in this paper.

Soil nutrients are lost either through the removal of biomass for combustion (the combustion of dung for example) or through subsequent erosion and loss of topsoil. Another effect on the local environment could be the build-up of lead through the disposal of lead-acid batteries but relevant data does not appear to be available.

3.4 Regional and global environment

An example of a regional environmental effect of household energy interventions is acidification or ‘acid rain’, caused (predominantly) by the burning of fossil fuels. Acidic deposition, or acid rain as it is commonly known, occurs when emissions of sulphur dioxide (SO_2) and oxides of nitrogen (NO_x) react in the atmosphere with water, oxygen, and oxidants to form various acidic compounds. This mixture forms a mild solution of sulphuric acid and nitric acid. Sunlight increases the rate of most of these reactions. These compounds then fall to the earth in either a wet form (such as rain, snow, and fog) or a dry form (such as gas and particles).

The main adverse effects of acid rain are the acidification of surface water and resulting loss of aquatic life, damage to trees and reduced biomass growth rates, and loss of soil nutrients through greater ability of the water to dissolve chemicals in the soil and wash them away.

From a global perspective if woodfuel is used in a sustainable way (i.e. tree re-growth is in balance with tree cutting) the emitted CO_2 under complete combustion will be recaptured leading to no net CO_2 added to the atmosphere. However, when combustion is incomplete, the emission of products of incomplete combustion will increase the global warming impact of the biomass use. Thus, the combustion efficiency is essential in reducing emissions from stoves. It is noted that the above discussion only covers emissions from combustion. Tree cutting, wood transportation and such like also cause emissions of greenhouse gases.

3.5 Safety concerns

Interventions may introduce or reduce risks faced by the users beyond health impacts from the emissions. The evaluation of interventions should therefore take into account any particular risks posed, and actions taken to eliminate or minimise potential safety concerns. Potential risks include burning, scalding, electrocution, fire hazard and poisoning.

3.6 Local employment

Although users gather a large proportion of wood fuels, the woodfuel trade is also significant; in particular in urban areas and for industrial consumption. Estimates of employment numbers for any particular intervention may be made and compared to that of a base case. In addition, some interventions may lead to possibilities for cottage industries that were not possible before. This criteria indicates ultimate benefit to local society and economy.

3.7 Acceptance and suitability

The household energy system must meet a variety of needs such as heat for cooking, warmth, lighting, mechanical power, communication, and comfort. These services can be offered by a variety of fuels. From a cooking point of view, stoves are frequently required to grill, bake, boil, simmer, and fry, and according to local requirements allow the use of special pots or pans. Of equal importance from the users perspective is the cooking speed and degree of control. The non-cooking functions of the stove are also important. In addition, acceptance of any particular intervention could be strongly dependent on local culture – for example problems of the placement of windows in kitchens that frequently serve as sleeping quarters for women and traditionally have very small windows.

In spite of cultural differences it is sometimes proposed that it is possible to construct a fuel preference ladder based on the assumption that the desired fuel is both available and affordable (Dutt & Ravindranath 1993). Yet even for meeting a single need the use of fuelwood appears to be entrenched. Relatively wealthy households in urban (electrified) Java, for example, continue to use wood for cooking (Fitzgerald et al, 1989). The same behaviour has been observed in South Africa. Even in highly industrialised countries fireplaces are highly prized – predominantly for their social use (Dutt & Ravindranath 1993).

Crewe (1992) has listed a number of features that are likely to be of concern to users:

- Durability
- Attractive appearance
- Cleanliness
- Easy maintenance
- Low fuel consumption
- Low smoke emissions
- Low price
- Convenience
- Quick cooling
- Safety
- Portability
- Flexibility

> "One frequently hears questions like 'if you had a stove that used only half the fuel you currently use, would you cook on it?' This is not the real question. The question might more accurately be, 'if you had a stove that used less fuel would you be willing to chop your wood into 20 cm (8 inch) lengths, control the damper and clean the flue?' Technicians are not in a position to evaluate these types of tradeoffs. Only if the woman is given the necessary information will she be able to make an accurate evaluation of the new stove's potential for being adopted (Hoskins as quoted by Foley, Moss and Timberlake 1984:58)."

3.8 Market readiness

A number of potential interventions promise to be able to deliver exposure reductions at a low cost and with minimal environmental damage. These interventions however do not yet offer a reliable user-friendly product. Some argue that this remains the case with wood-burning stoves and that the 'dream stove' still remains to be developed (Luo & Hulscher 1999:5).

3.9 Summary and the cost/benefit matrix

The following eight assessment criteria have been proposed:

1. *Exposure level*
2. *Cost*
3. *Local environment*
4. *Regional and global environment*
5. *Safety concerns*
6. *Local employment*
7. *Acceptance and suitability*
8. *Market readiness*

It is perhaps possible to create a cost/benefit matrix allowing comparisons between various interventions. For the purpose of this comparison, a base case is defined as a traditional three stone open fire burning wood used for cooking indoors. According to the intervention assessment criteria, this base case evaluated as follows in table 1:

Table 1: the reference case for the evaluation of interventions

Evaluation criteria relative to an open fire burning wood for cooking indoors									
	Cost								
Exposure level (%)	Appliance (US $)	Lifetime (years)	Annual fuel cost (US $)	Local environment (%)	Regional and global environment (%)	Safety concerns --, -, 0, + ++	Local employment --, -, 0, + ++	Acceptance and suitability --, -, 0, + ++	Market readiness --, -, 0, + ++
100	0	∞	70*	100	100	0	0	++	++

* *As given by Dutt & Ravindranath 1993, based on prices in Bangalore, India. Annual fuel use, which is based on efficiency and the assumption that a family of 6 has two identical meals a day. Fuelwood is priced a 5.55 cents per kilogram, equivalent to the cost of plantation wood in India.*

4. Preliminary assessment of potential interventions

In this section we consider a number of potential technical/hardware and behavioural/social interventions. For clarity the assessments are presented in summary form here. Alternatives are considered according to the three subsystems of the household energy system discussed in section 2. That is: interventions at the source, interventions at the level of the living environment, and potential interventions that are more behavioural aimed at the user. The reader is referred to Appendices A, B and C, which cover the full range of interventions one by one in detail.

The interventions that are to be considered are:

Source

Improved cooking devices
- Chimneyless improved biomass stoves
- Improved stoves with chimneys

Alternative fuel-cooker combinations
- Briquettes and pellets
- Charcoal
- Kerosene
- LPG
- Biogas
- Producer gas
- Solar cookers (thermal)
- Other low smoke fuels
- Electricity

Reduced need for the fire
- Efficient housing
- Solar water heating
- Partially pre-cooked food

Living Environment

Improved ventilation
- Hoods / fireplaces
- Windows / ventilation holes

Kitchen design and placement of the stove
- Shelters / cooking huts
- Stove at waist height

User

Reduced exposure through operation of source
- Fuel drying
- Use of pot lids
- Good maintenance
- Sound operation

Reductions by avoiding smoke
- Keeping children out of smoke

Assessment of each potential intervention is made according to the eight criteria described in section 3 above. Policy aspects (the ‘how’) will be covered in the next section (section 5), while this section discusses the interventions (the ‘what’) in three broad categories: source based interventions, environment based interventions and user based interventions.

4.1 Source based interventions

The range of source based interventions considered in some detail in Appendix A are summarized in table 2 below. It is clear that the maximum benefits in terms of exposure levels can be achieved through the use of alternative fuels: Kerosene, LPG, Biogas, Producer gas or Electricity. Solar cookers are excluded because of the very low levels of social acceptance in many areas.

Charcoal gives a reasonable reduction in exposure levels, but from both a cost, local environment and global environment perspective appears highly undesirable – in view of the popularity of charcoal especially in urban areas of African cities, careful attention should be given to confirming the validity of these figures in a local context.

Biogas is very beneficial from an exposure level, cost, and environmental point of view, but is unfortunately limited to a specific set of circumstances – namely sufficient cattle and water.

Further attention should be given to alternative fuels such as ethanol and biodiesel (grouped in this paper, because of a lack of research data, under ‘other low smoke fuels’). These may be produced from energy crops such as sugarcane and rapeseed and are thus non-fossil fuels, but as liquids benefit from easier combustion conditions for complete combustion. Ethanol is in some areas socially unacceptable because of alcohol taboos, but these could possibly be overcome by the production of gel fuels.

Table 2: Evaluation of source based interventions summarized.

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
			Cost							
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, -, 0, +, ++)*	*Local employment (--, -, 0, +, ++)*	*Acceptance and suitability (--, -, 0, +, ++)*	*Market readiness (--, -, 0, +, ++)*
Reference (open fire)	*100%*	*0*	*-*	*70*	*100%*	*100%*	*0*	*0*	*++*	*++*
Source based interventions										
Improved cooking devices										
Chimneyless improved biomass stoves	50 to 150	4 to 7	3	60	60 to 80	70%	-	+	+	++
Improved stoves with chimneys	33 to 100	8 to 21	3	70	80 to 100	70%	+	+	+	++
Alternative fuel-cooker combinations										
Briquettes and pellets	75 to 100				60 to 120	100%	0	+	+	+
Charcoal	10 to 30	1.5 to 6	1	130	140 to 160	1000%	-	+	+	++
Kerosene	0 to 2	6 to 10	3	33	0%	50%	--	--	++	++
LPG	0 to 2	50	7	28	0%	50%	0	--	++	++
Biogas	0 to 2	15	7	0	-50 to 0	-150%	0	+	+	++
Producer gas	0 to 2					50 to 200%	-	+	++	
Solar cookers (thermal)	0%	2 to 10	1 to 5	0	0%	0%	0		--	-
Other low smoke fuels	0 to 150									-
Electricity	0%	40	5	96	0%		0	-	++	++
Reduced need for the fire										
Efficient housing		150 to 400	20		100%	70%	-	++	++	++
Solar water heating	70%	5 to 10	5		70%	70%	0	+		++
Partially pre-cooked food									--	

4.2 Living environment based interventions

The evaluation of living environment based interventions was hampered by a lack of information about the effects of potential interventions. Where data is available it is presented in table 3 below and is based on best estimates. Notable appears to be the benefit of a cooking window (a type of enclosed 'fume cupboard') as based on findings of Nyström (1994). Further investigation of the potential of this intervention for exposure reduction should be considered.

Table 3: Evaluation of living environment based interventions summarized.

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, -, 0, +, ++)*	*Local employment (--, -, 0, +, ++)*	*Acceptance and suitability (--, -, 0, +, ++)*	*Market readiness (--, -, 0, +, ++)*
Reference (open fire)	*100%*	*0*	*-*	*70*	*100%*	*100%*	*0*	*0*	*++*	*++*
Environment based interventions										
Improved ventilation										
Hoods / fireplaces	50%	5 to 15	10	-	100%	100%	-	+	?	++
Windows / ventilation holes	15%	5 to 15	10	-	100%	100%	-	+	?	++
Kitchen design and placement of the stove										
Shelters / cooking huts	10 to 100				100%	100%				+
Stove at waist height	?				100%	100%	+			++

4.3 User based interventions

Objective information about potential user based interventions is even scarcer than that available for living environment based interventions. Attention should be given to evaluating the potential for interventions at this level to make a contribution to exposure reduction. It is to be expected, however, that reductions through changes in the behaviour of the user are unlikely to bring as large decreases as a fuel switch (source based intervention) or installation of a cooking window (environment based intervention). In view of this these interventions should perhaps be best seen as important supporting measures for interventions in other subsystems.

Table 4: Evaluation of user based interventions summarized.

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, -, 0, +, ++)*	*Local employment (--, -, 0, +, ++)*	*Acceptance and suitability (--, -, 0, +, ++)*	*Market readiness (--, -, 0, +, ++)*
Reference (open fire)	*100%*	*0*	*-*	*70*	*100%*	*100%*	*0*	*0*	*++*	*++*
User based interventions										
Reduced exposure through operation of source										
Use of pot lids	50 to 100	0	-	35 to 70	50 to 100	50 to 100	--	0	0	++
Good maintenance		0	-		50 to 100	50 to 100	0	0	0	++
Sound operation		0	-		50 to 100	50 to 100	0	0	0	++
Reductions by avoiding smoke										
Keeping children out of smoke	?				100%	100%	+	+	-?	
Separating cooking and living areas	?				100%	100%	+	0	-?	

5. The policy context – how to bring about the desired results

> In India and other countries, well-intended interventions in household energy have been primarily supply orientated. That is, the interventions simply supplied devices, and no integration with development processes was aimed at. The National Programme for Improved Stoves in India is illustrative of this approach. The programme was launched in 1983 and was target-oriented and subsidy driven. It was assumed that the stoves would save 30-50 % of woodfuel equivalent. Until March 1999, a total of 23 million stoves have been installed. However, impact studies show that the maximum lifetime of the stoves is 2 to 3 years, and most users do not replace their stoves after this period. This implies that by now only some 6 million stoves may be functional. The number equals 4% of the rural households and hence, the national impact can only be small. Indeed the annual fuelwood saving for the country is estimated at 1.44-2.4 million tonnes, which is 0.6-1 % of the total fuelwood actually being used. From Venkata Ramana P (1999).

As has been stressed earlier, this paper emphasizes that both exposure levels and the subsequent health impact and potential solutions to these problems are highly dependent on the local context and the specific needs of a particular household energy system. Consequently, if policies are to be successful they must be able to capture this local specificity and build on the particular ways in which the people exposed to high levels of health-damaging pollution in the home respond to the problems they face and the opportunities they perceive. It is believed that the key to success is to adopt project approaches that broaden the range of secure and sustainable choices available to the local actors and thus to enable them to devise their own solutions. That is one of the reasons that an extensive list of alternative interventions has been presented.

The process of devising appropriate policy for a particular situation starts with a careful analysis of the policy context: the chains of cause and effect that from the human activity, through their impact on the physical world, to their ultimate impact on human values. The next step focuses on the social context of the intended policy: first one lists feasible options for the activity (in this case cooking with wood in an open fire) and the motivating factors which contribute to people choosing one option over another. The next step in describing the social context, after the feasible options and motivations for these choices have been explored, is to work out a similar table listing potential options. Potential options are those that are possible but not feasible for the people concerned. One is then in a position to identify the missing inputs or resources (money, information, appropriate technologies and so on) and the restrictions (laws, cultural limitations, community restrictions). Our role should be to increase the options available through providing the missing inputs and contribute to the development of the local institutions that empower all sections of the community to have secure and safe access to resources that increase well being and meet their basic needs.

It is perhaps useful to summarize a number of criteria that may be used to formulate an effective policy:
- Integrated/holistic approach
- Aiming to empower people / emphasising local participation
- Avoiding unnecessary subsidies
- Avoiding market failures

a) An holistic approach
The dependence of people on dangerous and environmentally damaging forms of energy use is, above all, caused by poverty. Policies that promote economic growth and development on a broad basis (for example job creation, health care and education) will also reduce the use of more dangerous and environmentally damaging fuels.

b) Empowering people and emphasising local participation
Poor people are frequently trapped. They lack the power to make their lives better and are confined to repeating behaviour that they frequently know to be bad for them. In urban areas people frequently spend a significant portion of their incomes on energy and are thus eager to find cheaper alternatives. Experience shows that if options are available and reliable, people will generally select the fuel combination most appropriate for their daily needs. An important aspect of enabling choice involves telling people about the health and environmental costs, alternatives and benefits of different fuels as well the economic costs.

Experience has repeatedly shown that participation of community organizations and local social units is crucial for the success of energy interventions. Grassroots organizations are familiar with, and understand, local resources and needs. With the input of these organizations, support can be tailored to the needs of the community. Involvement also encourages a sense of ownership and thus commitment to the success of the plans.

c) Avoiding unnecessary subsidies

Indiscriminate subsidies on fuels frequently benefit higher-income households more than those for whom they are intended. The reason for this is that wealthier households frequently use significantly more energy than poorer households do. In addition, subsidies can become a drain on a government's resources and sometimes discourage efficient fuel use.

d) Avoiding market failures

Carefully targeted subsidies on appliances, or financial support, can be justified where the costs and risks of start-up are high and where they are aimed specifically at preventing market failures. A more powerful mechanism that is receiving growing attention is the provision of affordable micro-credit facilities for people that would not qualify for loans. Some form of financial support for the purchase of efficient appliances that reduce fuel (and health) costs in the long term can be a powerful instrument for change.

6. Summary, conclusions and recommendations

In this paper we have aimed to facilitate, stimulate and provoke discussion and debate over potential interventions for reducing human exposure to indoor air pollution in low-income countries (LIC) within a conceptual framework that may be applied to a wide variety of interventions. Potential interventions are assessed according to three subsystems of the household energy system: the source (emissions), the local environment (concentrations) and the user (exposure). Eight criteria have been identified and these have been used to assess either the benefit of the intervention or the restrictions preventing greater use by those exposed.

Based on the evaluation it appears that the most effective interventions and most beneficial to the user and society as a whole are a shift from wood or charcoal to kerosene, LPG, biogas or grid electricity. Other more progressive alternatives such as ethanol (gel) fuel, or possibly biomass gasification, could not be effectively evaluated, but should be considered in greater detail in the future.

Another intervention that appears to offer promising benefits is that of a cooking window. This intervention, which is a form of hood built into a window (thus without a chimney), needs further investigation and evaluation. Of particular concern is the applicability of the intervention to a range of different housing types.

The authors have emphasized a number of elements to guide the formulation of policy for any particular policy context. It is in analysing and understanding the social aspects of this context that specific policy instruments may best be developed and refined.

Appendix A: Source based interventions

Reductions in exposure at the pollution source include:

a) Improvements made to the traditional cooking device,
b) Alternative fuel-cooker combinations, and
c) A reduced need for the fire.

a) Improved biomass cooking devices

Without changing the fuel, there are basically two ways of reducing exposure levels through improved cooking devices: improvements to the combustion characteristics of the stove but without making use of a chimney, and the addition of a chimney to remove the source emissions from the room, and potentially reduce them at the same time through greater completeness of combustion. These two interventions are discussed below.

- **Chimneyless improved biomass stoves**

During the 1940s and 50s stove development work focused on the four-fold problem of health, cleanliness, fuel economy and forest economy (Kristoferson & Bokalders 1991; Karekezi 1992:91). Smoke removal from the kitchen was often the primary concern for development organizations (Ahuja et al 1987:248). This focus led to the development of large-mass, mud stoves with chimneys. These were assumed to be fuel-efficient, but often used more fuel than open fires (Baldwin 1987). In the 1970s development workers became acutely aware of the global fuelwood crisis (Aprovecho Institute 1984). Studies by Dr Sam Baldwin in West Africa published in *Vita News* (1984) set the direction for much of the stove development work in subsequent years. He described a number of ideas that at the time were revolutionary. The large-mass mud stoves promoted by many development organizations increased fuel consumption, were time-consuming to build, and were easily broken. Low mass, metal or ceramic chimneyless stoves on the other hand were low in cost, fuel-efficient, and allowed for rapid production (Baldwin 1984; Ouedraogo et al 1983:1-3).

Some improved chimneyless cookers have lower emissions than traditional cooking fires (but not always). Typical emission levels are rarely better than 50 % of traditional fires. Improved stove designs should always be tested to check whether they do indeed have lower emissions than the traditional methods of cooking.

Criteria 1: exposure level
A number of studies on the emission reduction potential of improved stoves have been carried out and has shown that the difference between a traditional and improved stove in terms of total suspended particles emitted can be striking. A study comparing traditional and improved stoves in Nepal in 1989 showed a reduction of suspended particulates of almost 3 (Pandey et al. 1989). Other studies have shown smaller or insignificant reductions. Direct source emission measurements have shown that improved stoves do not always reduce emissions and sometimes can increase them appreciably (see for example Ballard-Tremeer & Jawurek 1996, Uma & Oanh 1999). In terms of total suspended particulate emissions for improved cookstoves used in China, Smith & Wang (1999) use an emission factor of approximately 0.7 kg/GJ compared to 1.1 kg/GJ for the traditional stove – a reduction of almost 40%.

Criteria 2: cost
Improved stoves have a wide range of costs, depending on design and country. A device cost of an improved stove typically costs US$ 4 to 7 (see for example Hulscher & Luo 1999 for Thailand and South East Asia, Dutt & Ravindranath 1993 for typical data from India, and Ezzati et al. 2000 for recent data from East Africa). Traditional stoves are either free or US$ 1 to 2. A single pot ‘dream stove’ proposed by Grover (1999), has been estimated to cost in the region of US$ 8 to 12. Operation costs are strongly dependant on fuel efficiency. Dutt and Ravindranath (1993) have estimated an annualised life-cycle cost for a typical improved stove to range from US$ 50 to 70 as discount rate ranges from 6 to 150 %, compared to an open fire with an annualised life-cycle cost of US$ 71. These costs are based on a fuel saving of 50% over a traditional cooking device, a plantation fuel cost of US$ 3.5 per GJ, and a stove lifetime of 3 years.

Criteria 3: local environment
Traditional stoves/fires have been estimated to require between 650 and 850 square metres per household per year (based on a forest yield of 15 tonnes per hectare per year, see Dutt & Ravindranath). A very good chimneyless improved stove that uses in real usage 40 % less wood (Young 1992) would thus roughly require between 400 and 500 m^2 per household.

Criteria 4: regional and global environment
Measurements and calculations by Smith & Wang (1999) estimate global warming potential (GWP) for an improved biomass stove at approximately 70 kgC-CO_2/GJ in comparison to 100 kgC-CO_2/GJ for a traditional biomass stove fuelled with sustainably harvested wood, and over 300 kgC-CO_2/GJ for non-sustainably harvested wood.

Criteria 5: Safety concerns
Neutral, although with some single pot chimneyless stoves the risk of a heavy and hot pot falling or being pulled over by a child is higher than for a three-stone fire.

Criteria 6: local employment
Improved stoves may be expected to be fairly neutral with respect to formal employment in wood collection. Many chimneyless stoves are manufactured by local artisans (potters and metal-workers) thus providing additional income.

Criteria 7: acceptance and suitability
Experience has shown that unless the improved stove adds extra utility, demand is low. However where stoves meet the needs and are correctly priced demand appears to be high (Young 1992).

Criteria 8: market readiness
Although improved stoves have been disseminated since the early 1950s, and chimneyless stoves at lease since the 1970s, a wide variety in quality and success of programmes still exists worldwide. Nevertheless high quality chimneyless improved stoves are available on the market – for example the Sri Lanka Anagi which has a high level of local penetration. A number of new designs are currently being developed. Shell Renewables are, for example developing a small chimneyless one pot stove together with Tom Reed (personal communication J van der Ven, Shell International Renewables). This cooker uses a small solar electric module to power an electric fan. Purchase costs of such a stove may be expected to be significantly higher than those mentioned above.

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--,-, 0,+, ++)*	*Local employment (--,-, 0,+, ++)*	*Acceptance and suitability (--,-, 0,+, ++)*	*Market readiness (--,-, 0,+, ++)*
Reference (open fire)	*100%*	*0*	*-*	*70*	*100%*	*100%*	*0*	*0*	*++*	*++*
Chimneyless improved biomass stoves	50 to 150	4 to 7	3	60	60 to 80	70%	-	+	+	++

- **improved biomass stoves with chimney**

Chimneys remove emissions from the room and are therefore a great addition to an improved stove. But in some areas smoke gets trapped in villages that are built in valleys and then comes in through the door or windows.

Criteria 1: exposure level
Concentrations of carbon monoxide (CO) and exposure rates to total suspended particulates (TSP), experienced by household cooks during cooking have been monitored by Ramakrishna et al (1989) in nearly 200 households in 13 villages in three regions of India. Roughly half used traditional open-combustion stoves and the other half used one of seven different kinds of improved stoves disseminated in these areas. In all cases except one, CO concentrations were significantly lower in kitchens using improved stoves, whether fitted with flues or not. No conclusions could be drawn however, because of high sample variability, about the degree of TSP exposure improvement, if any, represented by three improved stoves. In the case of three other improved stoves with larger sample sizes, no significant differences were found.

Other findings include:
Visser (1996): CO concentration 22.6 ppm (25 mg/m^3) with traditional stoves compared to 13.0 ppm (15 mg/m^3) for stoves with chimneys in Bangladesh.

Reid et al (1986): Statistically significant reductions: 3.14 mg/m^3 to 1.13 (Reid et al. 1986) - thus a two-thirds reduction through the use of a stove with a chimney, CO reductions were approximately three-quarters of traditional fires.

Smith and Lu in Bendahmane (1997 *op cit*): Guatemala PM10 levels, 2.5 mg/m^3 for open fires, 1 mg/m^3 for improved stoves, a saving of almost two-thirds.

Other studies carried out in India and cited by Smith (1989) did not show statistically significant reductions.

Emission levels for coal stoves with chimneys are also noteworthy: In an assessment of greenhouse gas reductions and health benefits for a range of alternatives in the power and household energy sectors by Wang & Smith (1999) the following emission/dose levels were calculated for a coal stove in China: household TSP emissions of approximately 5.1 kg/GJ, and a corresponding particulate dose of roughly 400 mg/GJ. The TSP emissions are significantly high than all other options considered (a factor of five higher than a traditional biomass stove), but particulate dosage levels lower (compared to a traditional biomass stove with a dose of roughly 630 mg/GJ).

Criteria 2: cost
In India, stoves with chimneys cost between 2 and 3 times that of a basic chimneyless stove, and may save less fuel than a traditional stove in actual usage (Young 1992) even though savings are indicated from laboratory tests.

Criteria 3: local environment
Stoves with chimneys are believed to be fairly neutral with respect to deforestation since fuel savings over traditional fires are minimal.

Criteria 4: regional and global environment
Global warming potential is expected to be similar or slightly higher than those for chimneyless improved stoves. Thus, GWP is likely to be approximately 70% of a traditional biomass stove fuelled with sustainably harvested wood.

Criteria 5: Safety concerns
Neutral

Criteria 6: local employment
As for chimneyless improved stoves local manufacture is usually encouraged. Thus local artisans (potters and metal-workers) could generate additional income through sales of stoves.

Criteria 7: acceptance and suitability
Large numbers of improved stoves with chimneys have been disseminated. Where the stoves provide direct benefit to the users the stoves appear to be fairly desirable, and suitable for preparation of a range of types of food. According to Young (1992) “chimney stoves are very problematic and their high cost is a significant deterrent to households.”

Criteria 8: market readiness
Good.

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--,-, 0,+, ++)*	*Local employment (--,-, 0,+, ++)*	*Acceptance and suitability (--,-, 0,+, ++)*	*Market readiness (--,-, 0,+, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Improved stoves with chimneys	33 to 100	8 to 21	3	70	80 to 100	70%	+	+	+	++

b) Alternative fuel-cooker combinations

The discussion considers the following interventions:

- (Specially shaped) briquettes and pellets
- Charcoal
- Kerosene
- LPG
- Biogas
- Producer gas
- Solar thermal
- Other low smoke fuels (torrified wood, paper/wax combinations, ethanol gel etc.)
- Electricity, including
    - Solar PV and Small Scale Wind Turbines
    - Decentralised Biomass Generation
    - Mini Hydro Power
    - Coal or gas fired power stations

In essence good combustion requires four conditions: a burnable fuel + enough oxygen + a high enough temperature + long enough time for the combustion reaction to take place. Bearing in mind these four conditions it is fairly evident why gas fuels are the easiest of fuels to burn (easy mixing with oxygen), followed by vapours (for example vaporised kerosene), then liquids, then solids. Uniform solids (charcoal or briquettes/pellets for example) are easier to burn well than inhomogeneous solids like collected and roughly cut wood. This basic principal governs combustion and emission characteristics for the range of fuels considered here.

- **(Specially shaped) briquettes and pellets**

Principle: make more homogeneous *and* allow more oxygen to reach combustion site. Beehive shapes, blocks with holes, and pellets, are all possible. This practice has been practiced for many years for the upgrading of biomass residues such as sawdust and crop residues and a range of methods are available: from agglomerate formed without pressure but with some form of binder (such as molasses) and very high density briquettes formed by ram or screw presses at high temperatures.

Criteria 1: exposure level
Data for exposure levels for wood briquettes or pellets appears not to be available. Some data however exists for coal briquettes as follows:

Nyström (1994): Coal briquette produces high levels of CO at the beginning of cooking (70ppm). Lighting takes an additional 0.2 kg of wood. After 1.5 hours CO production comes down one third and stays at about 20ppm. Wood however, in the same chamber increases CO gradually and stabilises in the kitchen after about one hour at 30ppm

Wang & Smith (1999): coal briquettes – household TSP emissions of approximately 1.2 kg/GJ compared to a traditional biomass stove of 1.1 kg/GJ. When compared to coal stove emissions coal briquettes are very favourable and illustrate the benefits that may come from briquetting: coal stove TSP emissions are over 5 kg/GJ.

Hong CJ (1992): measurements in China (stove all unvented) TSP: Coal briquettes emission levels were approximately 60 % of those for firewood although CO levels were approximately 240% of those of firewood.

Criteria 2: cost
Costs for production vary widely with cost of feedstock and production process. Nevertheless, if one assumed at the feedstock is free one could estimate with reasonable confidence that fuel costs similar to those for charcoal may be achievable.

Criteria 3: local environment
Local environmental benefits may be considerable if waste biomass or harmful biomass wastes are used for making the briquettes. An example is cotton stalks that are frequently burned in the fields to prevent disease attacking subsequent crops – law frequently requires this. Briquetting of the stalks can provide a fairly good quality fuel as well as eliminate the disease threat. The main problem is the collection of the low-density (bulky) crop residues to a central processing point.

Criteria 4: regional and global environment
Data is not available. It could be fairly beneficial if waste (crop residue) streams are used for fuel.

Criteria 5: Safety concerns
Neutral

Criteria 6: local employment
High-density briquettes require sophisticated and costly equipment and is unlikely to be applied in rural areas. This could further remove money from deprived areas. On the other hand low density briquettes can provide more opportunities for local employment.

Criteria 7: acceptance and suitability
Data not readily available, but assuming an improved ease of use it is expected to be positive

Criteria 8: market readiness
High density briquetting machines and/or mobile units are not well developed for applications in low income countries. There are however a number of initiatives working in this area.

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, 0, +, ++)*	*Local employment (--, 0, +, ++)*	*Acceptance and suitability (--, 0, +, ++)*	*Market readiness (--, 0, +, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Briquettes and pellets	75 to 100				60 to 120	100%	0	+	+	+

- **charcoal**

Criteria 1: exposure level
Charcoal has substantially lower particulate emissions than 'raw' wood, but similar carbon monoxide emissions. From a health standpoint, a shift from wood to charcoal reduces the overall health impact by a factor of two. During charcoal making, however, large amounts of products of incomplete combustion are emitted (Smith 1992). Ezzati et al (2000) recently measured mean suspended particulate emission concentration reductions of 87% during the burning period, and 92 % during the smoldering phase compared to a three stone fire.

Criteria 2: cost
Charcoal stoves typically cost between US$ 1.5 and US$ 6 (Kenya, Ezzati et al 2000) depending on whether it is a traditional cooker or an improved stove. This is similar to figures given for India (Dutt & Ravindranath 1993). Annual fuel costs as estimated by Dutt and Ravindranath are approximately US$ 130.

Criteria 3: local environment
A large amount of the energy of the original wood is lost while making charcoal. Even assuming efficient production of the charcoal (30 % on weight basis) and combustion in a highly efficient charcoal stove (6 MJ of energy delivered to the pot per kilogram of fuel burned), the efficiency will be only 60 % of that reached in an open fire. Dutt and Ravindranath (1993) estimate a land requirement of between 800 and 1300 m^2/household per year for charcoal (between 1 and 2 times that for firewood). The local environment is further stressed through the use of stem wood and not branches in the commercial production of charcoal.

Criteria 4: regional and global environment
Smith et al (1999) have shown that charcoal fuel cycles are among the most greenhouse-gas-intensive in the world. According to Smith et al, the global warming commitment of a non-renewable charcoal fuel cycle 3.9-6.2 times that of a fossil fuel cycle producing the same energy and even if the wood is harvested renewably the charcoal fuel cycle warming commitment remains 2-4 times greater than produced by burning an equivalent energy content of kerosene or LPG.

Criteria 5: Safety concerns
Since smoke is reduced the risk of carbon monoxide poisoning is probably increased since users have fewer warning signs of high emissions.

Criteria 6: local employment
Charcoal production is a significant, estimated to employ approximately double the number of people as required for a commercial fuelwood enterprise producing an equivalent amount of energy.

Criteria 7: acceptance and suitability
In urban areas, charcoal is popular in many parts of the world.

Criteria 8: market readiness
Both traditional and modern charcoal kilns are commercially available.

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--,-, 0,+, ++)*	*Local employment (--,-, 0,+, ++)*	*Acceptance and suitability (--,-, 0,+, ++)*	*Market readiness (--,-, 0,+, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Charcoal	10 to 30	1.5 to 6	1	130	140 to 160	1000%	-	+	+	++

- **Kerosene**

Criteria 1: exposure level
In South Africa, cooking tests conducted on kerosene stoves showed TSP levels were hard to resolve from background levels (Graham and Dutkiewicz 1998). This is as one would expect and reflected in the figures given in Smith & Wang (1999).

From a health standpoint, kerosene results in a reduction of the overall health impact by a factor of 4 (Smith 1992)

Criteria 2: cost
Kerosene cookers typically cost between US$ 6 and 10 and typically have a three-year lifetime. Annual fuel use, as estimated by Dutt & Ravindranath (1993) costs US$ 33. Annualized life-cycle costs therefore are approximately half of those estimated for a three stone fire.

Criteria 3: local environment
Kerosene may be considered to bring positive benefits to the local environment when compared to wood usage. This results from the reduction in demand for wood.

Criteria 4: regional and global environment
Kerosene, from a global warming point of view, has been estimated to have a global warming potential of roughly 80 kgC-CO_2/GJ, slightly higher than that for LPG, and roughly half of that of an improved biomass stove (taking into account a full range of greenhouse gases) (Smith et al 1999).

Criteria 5: Safety concerns
Kerosene ingestion is the commonest cause of childhood poisoning in South Africa, and is expected to increase, in association with predictions for fuel use patterns in the country (Ellis et al; 1994). Childhood paraffin poisoning is a major public health problem in South Africa with at least 16 000 hospitalizations each year.

Criteria 6: local employment
RWEDP estimates that the number of people employed locally on an energy basis is roughly 10 % of those employed in the supply of Fuelwood.

Criteria 7: acceptance and suitability
Kerosene is, in general, a versatile and desirable fuel. Cost and availability appear the main constraints to wider use.

Criteria 8: market readiness
Kerosene cookers are widely available. Gravity fed stoves are an interesting recent development.

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--,-, 0,+, ++)*	*Local employment (--,-, 0,+, ++)*	*Acceptance and suitability (--,-, 0,+, ++)*	*Market readiness (--,-, 0,+, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Kerosene	0 to 2	6 to 10	3	33	0%	50%	--	--	++	++

- **LPG**

Criteria 1: exposure level
In South Africa, cooking tests conducted on LPG ring burners showed TSP levels were hard to resolve from background levels (Graham and Dutkiewicz 1998). This is as would be expected, since combustion is virtually 100 % efficient. This is confirmed by data from Hong (1992) where CO and TSP concentrations for LPG the same as (or in the case of CO, below) background levels.

From a health standpoint, a shift from wood to LPG reduces the overall health impact by a factor of 50 (Smith 1992).

Criteria 2: cost
Gas cookers typically cost approximately US$ 50 and typically have a seven-year lifetime. Annual fuel use, as estimated by Dutt & Ravindranath (1993) costs US$ 28. Of importance is the fact that fuel must be bought in units of 1 cylinder. At low discount rates (say 12 %) annualized life-cycle costs therefore are a little more than half of those estimated for a three stone fire. At discount rates of 75 % or 150 % annualized life-cycle costs are 2 to 3 times that of a wood fire.

Criteria 3: local environment
Neutral

Criteria 4: regional and global environment
From a global warming point of view, an LPG stove would have a global warming potential of about 30 kgC-CO_2/GJ, roughly 3 times less that a biomass stove burning renewably harvested wood (Wang & Smith 1999).

Criteria 5: Safety concerns
Neutral

Criteria 6: local employment
RWEDP estimates that the number of people employed locally on an energy basis is roughly 10 to 20 % of those employed in the supply of Fuelwood.

Criteria 7: acceptance and suitability
Highly desirable and costs and supply problems are the main constraints

Criteria 8: market readiness
Good

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, 0,+, ++)*	*Local employment (--, 0,+, ++)*	*Acceptance and suitability (--, 0,+, ++)*	*Market readiness (--, 0,+, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
LPG	0 to 2	50	7	28	0%	50%	0	--	++	++

- **Biogas**

Biogas is the conbustable gas produced by the anaerobic digestion of animal dung and other organic wastes. The gas is burned in specially designed gas rings. In some countries biogas digesters have been extensively promoted. China for example has over 6 million small biogas plants in operation (personal communication XJ Yoa, Chinese Academy of Agricultural Engineering, Institute of Energy Environment Protection). India has also extensive experience in biogas digestors although relatively small percentages of installed units appear to be working (in one state for example an estimated 35 % were functioning; of the others, 3 % were not operating because of technical defects, 29 % for lack of dung, 16 % did not appear to be digesting, and 52 % were not operating as a result of "lethargy, lack of interest, and lack of knowledge regarding the importance of biogas" (Dutt & Ravindranath 1993).

Criteria 1: exposure level
Biogas burns with very low particulate and CO emissions – a result of an extremely high combustion efficiency – of the order of 99% (based on CO emission level, Smith et al 1999). Hong (1992) therefore found, as we would expect that TSP and CO concentrations were equivalent to outdoor levels.

Criteria 2: cost
An individual biogas system (a 2 m^3/day family digester) typically cost approximately US$ 15 and typically have a seven-year lifetime. Annual fuel costs are zero (obviously not including the farm costs). Biogas favors wealthy families since a minimum amount of dung is required. There also are water requirements.

Criteria 3: local environment
Biogas has a good effect on the local environment since the effluent has been stabilized, is odorless and is a high quality fertilizer.

Criteria 4: regional and global environment
According to Wang and Smith (1999), the global warming potential of biogas is negative. The reason for this is that the emissions of CO_2 and CH_4 that would have taken place during the natural breakdown of the dung is captured and converted efficiently to CO_2. From a global warming point of view, a biogas plant is estimated to have emissions of the order of -150 kgC-CO_2/GJ.

Criteria 5: Safety concerns
Neutral

Criteria 6: local employment
Neutral

Criteria 7: acceptance and suitability
Generally acceptable although cultural problems may exist with using dung for cooking. The use of human excrement is a problem.

Criteria 8: market readiness
Good

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--,-, 0,+, ++)*	*Local employment (--,-, 0,+, ++)*	*Acceptance and suitability (--,-, 0,+, ++)*	*Market readiness (--,-, 0,+, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Biogas	0 to 2	15	7	0	-50 to 0	-150%	0	+	+	++

- **Producer gas**

Producer gas may be produced from coal or biomass by gasification (combustion in an atmosphere with insufficient oxygen for complete combustion.

Criteria 1: exposure level
Since producer gas is usually produced some distance from its point of use, and piped to households, the particulate dose is virtually zero. For small-scale, village power systems exposure may be higher, but information is not currently available.

Criteria 2: cost
Data not readily available. Since a piped infrastructure is required for distribution of the gas, coupled with the need for safety equipment, costs may be expected to be relatively high.

Criteria 3: local environment
Fair

Criteria 4: regional and global environment
From a global warming point of view, producer gas made from coal would have a global warming potential of roughly 150 kgC-CO_2/GJ, over twice that of a biomass stove burning renewably harvested wood (Wang & Smith 1999).

Criteria 5: Safety concerns
The gas is predominantly carbon monoxide and thus leaks could be dangerous.

Criteria 6: local employment
Systems need to be manufactured in fairly high tech workshops, but the skills should be present or easily acquired in most developing countries.

Criteria 7: acceptance and suitability
Since users will be able to cook on a versatile and clean gas, acceptance should be high

Criteria 8: market readiness

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, -, 0, +, ++)*	*Local employment (--, -, 0, +, ++)*	*Acceptance and suitability (--, -, 0, +, ++)*	*Market readiness (--, -, 0, +, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Producer gas	0 to 2					50 to 200%	-	+	++	

- **Solar cookers (thermal)**

Criteria 1: exposure level
Zero

Criteria 2: cost
Awaiting data from a contact

Criteria 3: local environment
Good

Criteria 4: regional and global environment
Excellent

Criteria 5: Safety concerns
Neutral

Criteria 6: local employment
Although some components of solar cookers need to be manufactured in the cities (reflective surfaces) most devices can be assembled in rural areas (occasionally from discarded materials). Consequently solar thermal cooking devices offer fair opportunities for local employment.

Criteria 7: acceptance and suitability
Strong resistance to solar cooking appears to exist as pointed out by Joshi (1992). Focusing solar cookers requires fairly constant tending, and cooking times are prolonged. Further, it is difficult to prepare food in the morning or late in the evening, even though these are the traditional meal preparation times in many areas.

Criteria 8: market readiness
Up to now solar cookers haven't made a big impact on the market and part of the blame may be laid on the dissemination of products that are not technically ready.

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--,-, 0,+, ++)*	*Local employment (--,-, 0,+, ++)*	*Acceptance and suitability (--,-, 0,+, ++)*	*Market readiness (--,-, 0,+, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Solar cookers (thermal)	0%	2 to 10	1 to 5	0	0%	0%	0	+	--	-

- **other low smoke fuels (low smoke coal, torrified wood, paper/wax combinations, ethanol gel etc.)**

The discussion below focuses on the opportunities from low smoke coal. Other options such as torrified wood (partially carbonised wood), paper/wax combinations and ethanol gel warrant further consideration. In particular, ethanol (as liquid or gel) and other liquid fuels such as biodiesel are of great interest. These will have emission characteristics similar to kerosene, but bring the benefit of being renewable: they may be produced from energy crops such as sugarcane and rapeseed and are thus non-fossil fuels, but as liquids benefit from easier combustion conditions for complete combustion. Ethanol is in some areas socially unacceptable because of alcohol taboos, but these could possibly be overcome by the production of the fuel in a gel form.

Low smoke coal:

Criteria 1: exposure level
The South African Department of Minerals and Energy (DME) has commissioned several studies of emissions from low smoke coal relative to bituminous coal as part of a programme of investigation into the feasibility of using low-smoke coal as a short to medium term air pollution reduction strategy in South Africa. The results of the studies were variable. For example, in a laboratory-based study, low-smoke fuels were shown to have lower particulate emissions, but were high for the least combustible fuels, with additional use of starting fuels being required. A study undertaken in a total of 45 dwellings in the township of Evaton during 1992 indicated that the US EPA standards for TSP over 24 hours were exceeded most of the time in respect of both bituminous coal and two formulations of low-smoke coal (Dickson et al; 1995). A further study comparing indoor air quality associated with the use of bituminous coal and three formulations of low-smoke coal was conducted in a total of eight dwellings in the township of Qalabotjha in the Free State (Taljaard 1998). The eight dwellings were of three broad classes (brick dwellings on dirt roads, brick dwellings on tarred roads and informal dwellings on dirt roads). On a rotational basis the four coal formulations were supplied to each of the households daily. Amongst other pollutants, samples of Total Suspended Particulates (TSP) were measured over two shifts of around 5 hours per day for a period of 12 days.

As can be seen from the table below, which gives the average levels of TSP for the measurement periods in each class of dwelling, the results indicated that levels of indoor air pollution when low-smoke coals were used, were not markedly different to levels measured when using ordinary coal. One of the brands of low smoke coal (Low Smoke Coal 1) appeared to generate distinctly higher levels of indoor TSP, relative to ordinary coal. The sample sizes may however have been too small to generate conclusive results.

Table: Average TSP levels measured during the use of ordinary and low-smoke coals (µg/m3)

	Coal	Low Smoke Coal 1	Low Smoke Coal 2	Low Smoke Coal 3
Brick dwellings on dirt roads	694	754	606	643
Brick dwellings on tarred roads	198	539	216	206
Informal dwellings on dirt roads	370	466	372	289

Criteria 2: cost
In a report submitted to the South African DME, it was suggested that the cost of low smoke fuels to coal merchants or local distributors could be at least twice that of bituminous coal (Dickson et al; 1995). The findings of an assessment of user attitudes to the pricing of various coal formulations indicated that there would be resistance to any low-smoke coal priced higher than normal bituminous coal (Hoets; 1994).

Criteria 3: local environment
In South Africa where almost a million households use coal at home (DME 1996), the coal has a low sulphur content (less than 1%) but a high ash content (up to 40%)

Criteria 4: regional and global environment
From a global warming point of view, a low-smoke coal stove would have the same warming impact as a normal coal stove: 350 kgC-CO_2/GJ, roughly 4 times that of a biomass stove burning renewably harvested wood (Wang & Smith 1999).

Criteria 5: Safety concerns
Depending on local supplies of coal, other health effects may be a problem including fluoride poisoning.

Criteria 6: local employment
Depending on the processes local employment opportunities could be similar to those for charcoal. An industry for appropriate stoves may also be developed.

Criteria 7: acceptance and suitability
As a substitute for coal acceptance could be fairly high. However experience has shown that this depends strongly on the combustion characteristics (ease of lighting, heat production, and time that the fire remains hot for example) and smell.

Criteria 8: market readiness
Good, although for particular feedstock characteristics, processes may need adapting.

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--,-, 0,+, ++)*	*Local employment (--,-, 0,+, ++)*	*Acceptance and suitability (--,-, 0,+, ++)*	*Market readiness (--,-, 0,+, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Other low smoke fuels	0 to 150									-

- **Electricity**

A detailed discussion of large-scale power generation technologies such oil, natural gas, landfill-gas and renewable technologies such as large-scale electricity generation with solar, wind, hydro or biomass lie outside the scope of this paper. The reader is referred to Wang and Smith (1999) for further details on relevant emission levels associated with these technologies. The effect of electrification from a more socio-economic perspective is considered here. It should be pointed out that Photovoltaics (the direct generation of electricity from the sun) as well as small-scale wind generators would be very costly for cooking applications although they offer the possibility of providing services such as high quality lighting, and radio and TV, naturally with zero emissions, thereby displacing candles, batteries and kerosene lamps. The introduction of lead-acid batteries in areas where there is no provision for recycling could produce problems with the build-up of lead.

Also of interest is the innovation of the Intermediate Technology Development Group (ITDG) of a household cooker used to absorb the base load of village micro-hydro schemes used in Nepal. A low power heating-element is used to heat a thermal store continuously during off-peak times, and a fan is used to extract the heat when required for cooking. This creative solution to the problem of varying electricity demand, is naturally only applicable in very specific circumstances.

From a purely energetic point of view, electricity is not the best source of energy for providing heat (space heating and cooking).

Criteria 1: exposure level
The South African experience has shown that the mere provision of electricity does not guarantee its exclusive use. Despite the connection of several million dwellings in South Africa in recent years no dramatic decline in the use of fuels such as coal, wood and kerosene is expected in the short to medium term. Research has shown that in practice households commonly use electricity for lighting, refrigeration and entertainment, but less for cooking and space hearing. Even after several years of being supplied with electricity households may continue to use multiple fuels for various tasks. In a survey conducted among children living in homes supplied with electricity in the township of Sebokeng, for example, the continuing use of coal for space heating and cooking was reported for 48% and 45% of households respectively (Terblanche 1998)

In the township of Lebohang, ambient air quality has been monitored in association with a community-wide electrification programme. Preliminary results from the monitoring programme appear to indicate an increase in levels of pollution in the ambient air subsequent to electrification. Eskom officials suggest that the increases may be due to an influx of people into the area following electrification, and the consequences of legislation enacted at the time, which led to the eviction of large numbers of labourers from near-by farms and their accommodation in the Lebohang area (R Rorich, Eskom, personal communication A Mathee).

Criteria 2: cost
One of the key reasons given for the extended transition to electricity as a domestic fuel is cost. However, some studies in South Africa have shown that in electrified homes, energy consumption constitutes 4 % of the household budget, but that in un-electrified homes 15 % of the budget is spent on energy. Apart from self-collected wood without an explicit cost, electricity was the most cost-effective energy source. However, when looking at cooking and space heating in combination, coal and wood burning stoves appeared to be more cost-effective than electricity in high-lying areas of the country (Graham and Dutkiewicz 1998). It should be stressed that these figures are from the users' perspective, not from that of society or the electricity utility.

Criteria 3: local environment
Low negative impact, although in the specific areas where coal mining takes place the impact on the local can be high.

Criteria 4: regional and global environment
The reader is referred to Wang and Smith (1999) for estimations of the global warming potential of large scale generation techniques. Because of higher efficiencies of combustion in large coal-fired power stations, emissions are lower than the equivalent emissions from coal burning stoves.

Criteria 5: Safety concerns
Neutral

Criteria 6: local employment
Low from large-scale

Criteria 7: acceptance and suitability
High

Criteria 8: market readiness
Good

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--,-, 0,+, ++)*	*Local employment (--,-, 0,+, ++)*	*Acceptance and suitability (--,-, 0,+, ++)*	*Market readiness (--,-, 0,+, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Electricity	0%	40	5	96	0%		0	-	++	++

c) Reduced need for the fire

Discussed in this section:

- efficient housing reducing need for heating
- solar water heating
- partially pre-cooked food (such as parboiled rice)

Discussion starts here:

- **efficient housing reducing need for heating**

Thermally efficient housing can reduce or eliminate the need for heating. This can lower a family's exposure to fire emissions substantially. Improving a house's thermal efficiency need not be costly – some measures, such as correct solar orientation cost nothing at the time of construction. If a house has reduced ventilation as a result of improved thermal insulation it is essential that the household understands the implications, and that a hood or fireplace is provided if the family intends to cook indoors.

Criteria 1: exposure level
Problems exist with ventilation. Nyström (1994), "WHO states on indoor environment that "recent trends have been towards tighter buildings in the interest of energy economy" (WHO 1990:65). The report continues that today's typical air change rates generally fall under one air change for "loose buildings" and down to 0.25 air changes per house in energy –efficient domestic buildings, which is below hygenic requirements. It is likely that new construction in Vietnam will approach the same development; houses will become tighter with better building techniques, the need to save energy and the replacement of wooden window frames with aluminium. WHO concludes "If indoor pollution of the air environment is appreciable then this developing situation must give rise to serious health concern. Very air tight buildings imply, as a mandatory complement, mechanical systems to ensure minimum safe ventilation standards are actually met in cold weather (WHO 1990:65).

Criteria 2: cost
Costs range from medium to high. Some initiatives in energy efficient low cost housing in South Africa, requiring virtually no space heating even during the cold winter months when average outside temperatures drop to 2°C, can be constructed for additional costs of approximately 10% relative to a normally insulated house, in practice roughly US$ 150 to 400.

Criteria 3: local environment
Low

Criteria 4: regional and global environment
Good

Criteria 5: Safety concerns
As mentioned above, the risk exists for asphyxiation as a result of reduced ventilation.

Criteria 6: local employment
Using local labour for construction and local materials opportunities for job creation are high.

Criteria 7: acceptance and suitability
High

Criteria 8: market readiness
Good

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--,-, 0,+, ++)*	*Local employment (--,-, 0,+, ++)*	*Acceptance and suitability (--,-, 0,+, ++)*	*Market readiness (--,-, 0,+, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Efficient housing		150 to 400	20		100%	70%	-	++	++	++

- **solar water heating**

Solar water heaters are easy to build and potentially easier to use than solar cookers and may reduce the need for heating water over a fire thereby reducing cooking times.

Criteria 1: exposure level
Since solar water heaters can fairly consistently provide water at 60 ºC, we can assume that reductions in cooking/water heating time can be achieved. Assuming a 30 % reduction in the use of the fire we can expect a corresponding 30% reduction in exposure.

Criteria 2: cost
Effective systems can be fairly easily constructed from black piping and plastic drums, costs estimated at US$ 5 to 10.

Criteria 3: local environment
Reductions would be proportional to the reduction in need for heating water. Thus roughly a 30% reduction could be expected.

Criteria 4: regional and global environment
As for local environment

Criteria 5: Safety concerns
Neutral

Criteria 6: local employment
Water heaters could be built to a large extent in a rural industry and installed by local suppliers.

Criteria 7: acceptance and suitability
A constraint may be the need for special housing/roofing requirements.

Criteria 8: market readiness
Good

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, 0, +, ++)*	*Local employment (--, 0, +, ++)*	*Acceptance and suitability (--, 0, +, ++)*	*Market readiness (--, 0, +, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Solar water heating	70%	5 to 10	5		70%	70%	0	+		++

- **partially pre-cooked food (such as parboiled rice)**

This option is mentioned only in passing, but may warrant further attention. Rice itself does not need much tending while it is being prepared. Thus, in the case of rice, this option would probably not result in significant reductions in exposure. The social acceptance and costs could be major constraints.

Appendix B: Living environment based interventions

The word kitchen has many and varied meanings depending on the culture from which it comes. As Nyström (1994) has pointed out, in many languages the word kitchen and stove are one and the same. This frequently leads to neglect or overlooking of the role of the 'kitchen system': stove, kitchen, and dwelling. In fact the kitchen is "missing in research and development work in developing countries. This is not reasonable, because the kitchen is the focal areas for housing, energy and indoor environment" (Nyström 1994:37). This was the case in 1994 and appears to remain so today - very few studies into the description of house and design parameters on indoor air quality exist. As Nyström further points out "the cookstove systems is a subsystem of the kitchen system, which in turn is a subsystem of the dwelling". In this section we will consider interventions at the kitchen and dwelling system levels.

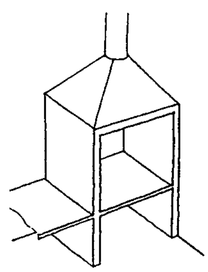
a) Improved ventilation

Studies carried out by the Lund Centre for Habitat Studies have considered the influence of the kitchen on indoor climate, the level of natural ventilation, the distribution of CO in the dwelling while cooking with different fuels, the use of a cooking hood and cooking window (these studies Nyström 1994 *op cit*).

Reporting findings on a test flat of 40m^2, simulating conditions in multi-storey buildings in Hanoi in which wood is frequently used for cooking, Nyström found typical average ventilation rate of 560 m^3/h (+- 130 m^3/h). Since the kitchen was better ventilated than the other rooms, airflow appeared to be from the kitchen to the other rooms. The air change rate was 5 changes per hour (compared to the Swedish legislation of 0.5 changes per hour), air speed in kitchen was approximately 0.1m/s.

- **hoods, fireplaces**

The fireplace is a fairly common feature of Western homes. They can be constructed in such a way that a fire can provide warmth, light and a place for cooking (preferably with a fire build on a grate). A typical arrangement for a hood is shown in the diagram below (source Nyström 1994). A hood allows the use of portable stoves without chimneys or with short chimneys. However a constraint includes the difficulty in working out the right size of chimney connected to the hood.



Hood

Criteria 1: exposure level
Ramakrishna et al (1999), in a study of nearly 200 households in 13 villages in India found reductions in TSP in only one case of all those measured: the combination of traditional stove with a fireplace-like hood in which TSP exposure rates were significantly lower.

Criteria 2: cost
Costs could be estimated to be roughly equal to those for a stove with a chimney: in the range US$ 5 to 15.

Criteria 3: local environment
No effect

Criteria 4: regional and global environment
No effect

Criteria 5: Safety concerns
A hood system can be considered to be relatively safe provided they are made from the right materials

Criteria 6: local employment
Fair chances exist for local manufacture of hoods.

Criteria 7: acceptance and suitability
Fair, although problems of integration into traditional huts and houses may lower acceptance. The proper functioning of hoods appears to be a point for concern. Nyström (1994) notes that in periurban areas of Hanoi, hoods are frequently removed "because they do not seem to serve any purpose".

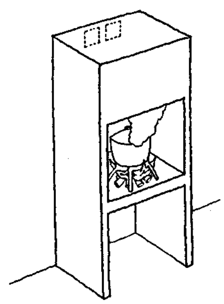
Criteria 8: market readiness
Good

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, -, 0, +, ++)*	*Local employment (--, -, 0, +, ++)*	*Acceptance and suitability (--, -, 0, +, ++)*	*Market readiness (--, -, 0, +, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Hoods / fireplaces	50%	5 to 15	10	-	100%	100%	-	+	?	++

- **windows / holes**

A wide range of windows can be installed ranging from those aiming predominantly to bring light into the dwelling to those designed specifically for removing smoke (shown in the diagram below, source Nyström 1994).



Cooking window

Criteria 1: exposure level
Commenting on the effect of ventilation, Nyström (1994), stated that "if the windows to the windward side and on the balcony side were opened the CO pollution decreased about one half in the kitchen and 6 times in the living room of the test flat being considered." Referring specifically to cooking windows, she states: "studies showed that a cooking window was more efficient than the hood. In all cases the CO concentrations in the kitchen and living room in the flat equipped with a window. Cooking on a coal stove in a closed flat produced a CO concentration in the kitchen of 9ppm with cooking window, and 32 ppm with the hood. With the cooking window, the CO was distributed evenly over the flat (around 9ppm), but the living room with the hood reached over 60 ppm. These levels dropped with the opening of a window (in kitchen with hood) from 64 to 19 ppm in the living room and from 32 to 26 ppm in the kitchen. With the hood, CO levels were 30ppm lower when cooking on wood than on coal. Effectiveness of window increased as the opening area was reduced.

Typical ventilation levels: 40 m^3 house. Air exchange of 25 per hour, more than 1000 m^3 dilution air per hour… even with these conditions the available air dilution is 40 to 70 times below what would be needed to keep RSP concentration from exceeding standards (Smith 1992)

Nyström (1994): Use of cooking window: measurements in living room: 2-3 ppm CO – similar to outside air in separate hut. In sealed room, living room concentrations were 5 ppm when firing with a coal stove. Three times higher with wood. In totally closed flat with hood (reference flat), from one hour's cooking levels reached 64 ppm in the living room – almost 3 times higher than in the kitchen. Nyström concludes that a separate kitchen or a sealed kitchen, and the use of a cooking window.

Criteria 2: cost
Because of a simplified design, costs can be expected to be lower than that for a complete hood, but insufficient data is readily available for give more than an estimate, say, US$ 5 to 15.

Criteria 3: local environment
No effect

Criteria 4: regional and global environment
No effect

Criteria 5: Safety concerns
A window system can be considered not to introduce additional safety concerns

Criteria 6: local employment
Fair chances exist for local manufacture of hoods.

Criteria 7: acceptance and suitability
Fair, although problems of integration into traditional huts and houses may lower acceptance. The proper functioning of hoods appears to be a point for concern. Nyström (1994) notes that in periurban areas of Hanoi, hoods are frequently removed “because they do not seem to serve any purpose”.

Criteria 8: market readiness
Good

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, 0,+, ++)*	*Local employment (--, 0,+, ++)*	*Acceptance and suitability (--, 0,+, ++)*	*Market readiness (--, 0,+, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Windows / ventilation holes	15%	5 to 15	10	-	100%	100%	-	+	?	++

b) Kitchen design and the placement of the stove

The interventions related to shelters, cooking huts, and the placement of the stove will not be discussed in detail here.

- **shelters / cooking huts**

A separate cooking hut takes the smoke away from living areas. This is already part of many cultures, but in many cultures women and young children are expected to live and sleep in the same hut as the cooking place. The conclusion drawn from summer and winter measurement by Nyström was that ideally the kitchen should be separated from the rest of the dwelling, a sealed room placed along the façade to prevent transmission of smoke to the flat.

- **stove at waist height**

Lifting the cooking surface from ground level means that a cook doesn’t need to lean over a fire while tending it and attending to the food, and so she breathes in less smoke.

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, 0,+, ++)*	*Local employment (--, 0,+, ++)*	*Acceptance and suitability (--, 0,+, ++)*	*Market readiness (--, 0,+, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	++	++
Shelters / cooking huts	10 to 100				100%	100%				+
Stove at waist height	?				100%	100%	+			++

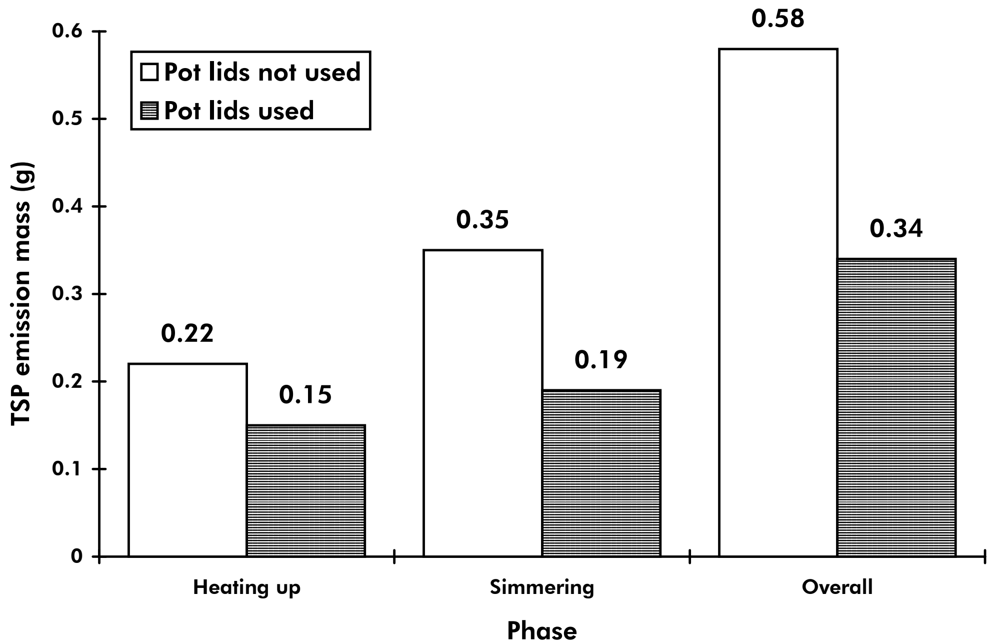
Appendix C: User based interventions

Source emissions may be reduced through improved control or operation of the cooking device. This includes the use of air-dried fuel, the use of pot lids when cooking, and good maintenance. Lastly, sound operation of some stoves can lead to emission reductions. The user may also limit exposure to source emissions by avoiding them. These interventions, such as keeping children away from smoky areas (though shared childcare for example) or by cooking out of doors are, however, likely to be impractical and could be unacceptable culturally.

a) Reduce exposure by operation/control of the source

- **Use of pot lids**

Criteria 1: exposure level
The use of a pot lid reduces total emissions from a fire. Lids have been found to reduce the fuel consumed during simmering by a factor of three and overall emission levels by up to 50 % as shown in the following figure (from Ballard-Tremeer 1997):



Criteria 2: cost
No cost

Criteria 3: local environment
Reduced deforestation because of reduced fuel needs. Could be up to 75%

Criteria 4: regional and global environment
Combustion characteristics do not change through the use of a hood, but power levels are reduced. The maximum reduction in comparison to a traditional open fire could be up to 75%

Criteria 5: Safety concerns
Safe

Criteria 6: local employment
No impact

Criteria 7: acceptance and suitability
Fair. To a large extent people already use pot lids and the practise could probably be fairly easily encouraged.

Criteria 8: market readiness
Excellent!

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, 0, +, ++)*	*Local employment (--, 0, +, ++)*	*Acceptance and suitability (--, 0, +, ++)*	*Market readiness (--, 0, +, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	*++*	*++*
Use of pot lids	50 to 100	0	-	35 to 70	50 to 100	50 to 100	--	0	0	++

- **Good maintenance**

People should be encouraged to repair cooking devices as soon as they become damaged. The performance of a stove – especially one with a chimney – is very susceptible to cracks and poor joins and could thus emit extra smoke into the living space.

- **Sound operation**

Residual ash may restrict the access of oxygen to the combustion zone and therefore increase noxious emissions because gases are less completely burned. Stoves and chimneys should always be kept clear of ash.

There is an optimum size and quantity of fuel that will lead to the best performance for a stove. Operators should be aware that overfilling a stove might increase emissions substantially.

Paraffin lamps and cookers are very susceptible to maladjustment and will emit noxious fumes. Wicks should be carefully trimmed.

Summary

	Evaluation criteria relative to an open fire burning wood for cooking indoors									
		Cost								
	Exposure level (%)	*Appliance cost (US $)*	*Lifetime (years)*	*Annual fuel costs (US $)*	*Local environment (%)*	*Regional and global environment (%)*	*Safety concerns (--, 0, +, ++)*	*Local employment (--, 0, +, ++)*	*Acceptance and suitability (--, 0, +, ++)*	*Market readiness (--, 0, +, ++)*
Reference (open fire)	*100%*	*0*	-	*70*	*100%*	*100%*	*0*	*0*	*++*	*++*
Good maintenance		0	-		50 to 100	50 to 100	0	0	0	++
Sound operation		0	-		50 to 100	50 to 100	0	0	0	++

b) Reductions by avoiding smoke

- **Keeping children out of smoke**

Children are especially susceptible to combustion emissions and when the baby is carried on the back while the mother is tending the fire, the child is exposed to high levels of smoke. This should be avoided.

Children should be encouraged to play away from the smoke of fires. This may be problematic if the mother is the only child-minder.

- **Separate cooking and living areas**

This intervention is included here as well as in the section for living environment (appendix B) because it is equally relevant to both categories. The reader is referred to that section for further details.

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