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Interventions to Reduce Child Exposure to Indoor Air Pollution in Developing Countries: Behavioral Opportunities and Research Needs

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Comment on This Article

Abstract

Indoor air pollution caused by the indoor burning of biomass fuels has been associated with increased risk of acute respiratory infections among children less than five years old in developing countries. Enough evidence of this association exists to support the design, implementation and evaluation of interventions to reduce child exposure to indoor air pollution. This paper reviews the published literature on three technical intervention options: access to cleaner burning fuels, improved cook stoves and modification to housing characteristics. It highlights the sustainability challenges related to the uptake and maintenance of technical interventions and discusses the potential for behavioral interventions to reduce child exposure to indoor air pollution in contexts where technical interventions are least likely to succeed in the short term. It further highlights the need for technical interventions to be inclusive of and sensitive to behavioral outcomes and processes and also discusses both quantitative and qualitative research needs in relation to evaluation options.

Keywords: **indoor air pollution**, **child illness**, **acute respiratory infection**, **program evaluation**, **child health**

Introduction

Approximately half the world's population and 75 percent of households in developing countries are reliant on biomass fuels such as wood, cow dung and crop residues for their domestic energy requirements (The World Resources Institute 1998). When burned indoors in the absence of adequate ventilation, the incomplete combustion of biomass fuels releases smoke that contains numerous pollutants such as carbon monoxide (CO), particulate matter and other organic compounds into the living environment (Smith 1987). Because of their unique physiology and the lengths of time that they spend in close proximity to biomass fires, children less than five years old have been identified as a particularly vulnerable group.

Figure 1. Young children sitting next to an open fire in rural South Africa

Of particular importance is the association between indoor air pollution and Acute Respiratory Infections (ARI) such as pneumonia among this group. Given the disproportionate burden of child ARI in developing countries (De Francisco 1993; Victora et al. 1994; Victora et al. 1999; Kirkwood et al. 1995), the high reliance on biomass fuels in developing countries, and the strength of the evidence associating indoor air pollution with child ARI (Zhang and Smith 2003; Smith et al. 2000; Bruce et al. 2000; De Koning et al. 1985), urgent calls have been made to evaluate interventions that aim to reduce child exposure to indoor air pollution (von Schirnding et al. 2002).

To date, interventions designed to reduce indoor air pollution exposure have been largely technical in nature and have, justifiably, targeted the source of

indoor air pollution (i.e., biomass fires) through access to cleaner burning fuels, improved cook stoves and household modification. However, interventions have yielded mixed results in terms of indoor air pollution reduction with many context-specific factors implicated in their success or failure (see Ballard-Tremmer and Mathee 2000; Budds et al. 2001; Barnes et al. 1994). Comparative reviews are further complicated by the wide global, regional and local variations in relation to exposures, the underlying nature of the problem, the manner in which it is understood and intervention efforts to reduce it.

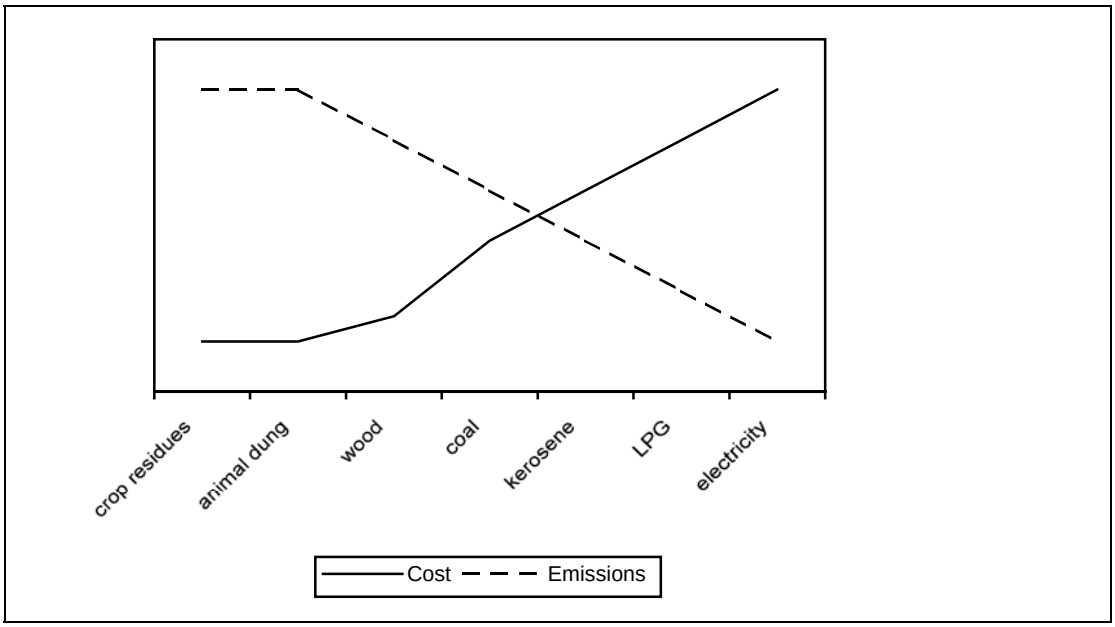
This paper reviews and discusses the sustainability challenges experienced by three popular technical intervention categories in developing countries. It highlights opportunities, in the short term, for behavioral interventions in contexts where the dissemination, uptake and maintenance of technical interventions are likely to be hindered by poverty. It also discusses opportunities to broaden the focus of technological interventions to be more inclusive of and sensitive to behavioral outcomes and processes as well as the need for properly designed evaluation studies to determine the impact of interventions.

Interventions and the Sustainability Challenge

Access to Cleaner Burning Fuels

The energy ladder model has been used to categorize domestic fuels along a hierarchy according to their ease of use, technological advancement and, importantly for this discussion, the concentrations of emissions they produce. At the bottom of the ladder are biomass fuels such as cow dung and crop residues, followed by wood and coal. Petroleum-based fuels such as kerosene and liquid petroleum gas (LPG) are situated higher up the ladder. Electricity is situated at the top of the ladder and is considered to be the safest fuel in terms of indoor air quality. As fuels become safer, however, they also increase in cost (Smith 1987).

Figure 2. The energy ladder model



From an indoor air pollution perspective, several observational studies have highlighted the association between cleaner burning fuels and improved indoor air quality. For example, Brauer et al. (1996) (rural Mexico) compared particulate emissions (PM_{10} and $PM_{2.5}$) in homes using biomass only, LPG only and a combination of biomass and LPG. Indoor concentrations were compared to measurements taken outdoors where concentrations were considered to be lowest. Results showed that concentrations of PM_{10} were highest in biomass-only homes (12.4 times higher than outdoors), followed by LPG and biomass-combination homes (6.3 times higher than outdoors) and LPG-only homes (1.8 times higher than outdoors). Concentrations of $PM_{2.5}$ showed a similar trend (Brauer et al. 1996). Similarly, Röllin et al. (2004) found that concentrations of PM_{10} and CO (measured in kitchens and on children) were significantly higher in un-electrified homes compared to homes where electricity was used in rural South African villages (Röllin et al. 2004).

In terms of fuel type (used as a proxy for indoor air pollution) and child ARI, a case control study in Argentina found that, compared to healthy controls, children living in homes that burned coal for heating were 9.9 times more likely to develop lower respiratory infections (LRI) than those homes using electricity. The risk was reduced to 2.2 times among children who lived in homes that burned LPG (Cerqueiro et al. 1990). Similarly, in Nigeria, Johnson and Aderele found that the risk of ARI was 12.2 times higher among children exposed to wood smoke than those exposed to kerosene and LPG (Johnson and Aderele 1992).

It was initially thought that as developing countries progressed economically and household incomes increased, there would be a natural progression up the energy ladder towards a higher reliance on cleaner burning fuels such as LPG and electricity. This was supported by the progression of developed countries away from biomass towards the use of cleaner fuels (Smith et al. 1994). Studies showing evidence of movement up the energy ladder in developing countries, however, have been generally limited to urban contexts (Hosier and Dowd 1987; Leach 1987; Smith et al. 1994) where access to modern fuels is better and fuel policies (and concomitant pricing structures) are more regulated. The trend tends to be slower in poorer, rural areas of developing countries, and some rural contexts have even witnessed a reversal “down” the energy ladder away from cleaner burning fuels to an increased reliance on biomass fuels.

The failure to progress to the use of modern fuels in developing countries, particularly rural contexts, may be due to a number of factors. First, from a supply perspective, it is expensive and logistically difficult to set up energy dissemination chains in rural areas for households to access cleaner fuels such as electricity and LPG. Second, from a demand perspective, it is estimated that approximately 50 percent of households collect biomass either free of charge or at a minimal monetary cost from within their village or very close by (Leach 1987). Consequently, even if households have access to cleaner burning (but more expensive) fuels such as electricity or LPG, the likelihood of using free biomass instead of, or in combination with, cleaner burning fuels is increased. In addition, the costs of purchasing appliances to use modern fuels is prohibitive. Consequently, even though households may use modern fuels such as electricity almost immediately for lighting and entertainment purposes (e.g., radios), they

continue to use biomass fuels for cooking and space heating purposes, functions that have the most direct impact on indoor air quality (Mathee et al. 2000).

Third, due to global and regional inequality, much of the world's poor are likely to remain so and thus continue to rely on biomass fuels for their domestic energy requirements. Consequently, estimates indicate that the reliance on biomass fuels has remained consistent over the last three decades with approximately 50 percent of the world's population and up to 95 percent of rural populations still reliant on them (The World Resources Institute 1998).

While it is not the intention of this paper to oversimplify the complex determinants of household energy patterns in the developing world, the point is that it is unlikely that many of the poorest households in developing countries will progress up the energy ladder towards the exclusive use of cleaner burning fuels in the foreseeable future.

Improved Cook Stoves

Intervention efforts have also focused on removing the polluted air out of the living environment instead of replacing the fuels themselves. The dissemination of improved cook stove(s) (ICS) gained momentum out of the concern in the 1970s that the over-reliance on wood fuel was depleting natural forest resources at an unsustainable rate. It was envisaged that the resulting deforestation and contributions from biomass fires to greenhouse gas emissions would have significant impacts on global climate patterns (Ahuja et al. 1987). The second concern was that as natural forest resources became depleted, people (mostly rural women) would have to walk increased distances to collect wood. Studies showed that women in some rural contexts were spending an average of two hours collecting fuels and carrying loads of 24 kilograms of wood per day, with significant health and welfare implications (Bembridge and Tarlton 1990).

Third, in areas where biomass fuels were purchased, fuel expenditure accounted for a significant proportion of poor households' energy budgets. Traditional open fires are highly inefficient. The answer, it was believed, was to improve the efficiency of the burning process through the use of ICSs. People would consequently use proportionally fewer units of fuel per burning resulting in cost savings in contexts where fuels were bought, and time savings where fuels were collected. It would also have the added environmental benefit of reducing deforestation.

Governments and donor agencies in developing countries enthusiastically embraced improved cooking appliances with over 129 million ICSs disseminated in China alone (Smith et al. 1993). Current estimates indicate that over 160 million ICSs have been disseminated in developing countries. Indeed, observational studies in developing countries have shown indoor air pollution reductions in homes using ICSs (such as the improved "Jiko" in Kenya, the "Plancha" in Guatemala or "Chula" in India) compared to homes using traditional open fires or rudimentary three-stone methods. One study highlighted a lower risk of ARI among children living in households using ICSs compared to children living in households using traditional fires.

Table 1. Examples of improved stove studies

Study	Stove type(s)	Indoor air quality	Health outcomes
(Reid et al. 1986) Nepal	Improved "Chulo" vs. traditional stoves	PM_{10} during cooking: Improved = 1 130 µg/m^3 Traditional = 3 140 µg/m^3 CO during cooking: Improved = 67 ppm Traditional = 300 ppm	Not reported
(Pandey M. R. et al. 1990) Nepal	Improved "Tamang" vs. traditional stoves	RSP during cooking (1 hr): Tamang = 3000 µg/m^3 Traditional = 8200 µg/m^3 CO during cooking (1hr): Tamang = 11.6 ppm Traditional = 82.5 ppm	Not reported
(Albalak et al. 2001) Guatemala	Improved "Plancha" vs. LPG/open biomass fire vs. open biomass fire	$PM_{3.5}$ (14 hr): Plancha = 330 µg/m^3 LPG/open fire = 1200 µg/m^3 Open fire = 1930 µg/m^3	Not reported
(Ezzati et al. 2000) Kenya	Improved wood stoves vs. improved charcoal vs. traditional 3-stone fire	Improved wood stoves reduced PM_{10} by 48% compared to 3 stone method during burning period.	Not reported
(McCracken and Smith, 1998) Guatemala	Improved 'Plancha' Vs traditional stoves	Plancha emits 87% less PM2.5 and 91% less CO per KJ of useful heat delivered.	Not reported
(Wafula et al. 2000) Kenya	Improved 'Jiko' Vs traditional 3-stone fire	Not reported	Child ARI significantly less in Plancha vs. traditional 3-stone (OR=2.6)

The successful dissemination and uptake of ICS interventions at the household level are generally context specific and are linked to a number of factors including the design of the stove (to meet household domestic energy needs such as cooking, heating and food curing), marketing strategies, subsidization, commercialization processes (including local job creation), user perceptions, community participation and local energy policies (see Budds et al. 2001; Barnes et al. 1994; Larson and Rosen 2002). In addition, of particular concern in developing countries is the financial inability of low-income households to maintain the stoves after they have been disseminated.

Even if the initial purchases of stoves are subsidized, maintenance costs are often prohibitive. It is estimated that only 10 percent of ICS programs worldwide are still working after two years (Manibog 1984) and the stoves that are in use are often poorly maintained resulting in significant variability in efficiencies and emissions under conditions of actual use compared to initial laboratory testing. Consequently, the intended cost, time-saving and indoor air pollution reduction motivations of ICSs over traditional fires is often significantly reduced after stoves have been installed. (Ezzati et al. 2000; McCracken and Smith 1998; Albalak et al. 2001).

In addition, research has shown that ICS programs are more likely to succeed in contexts where biomass fuels are purchased (people are motivated by cost savings for purchasing fuels) and where fuels are scarce (women are motivated by time savings in collecting less wood) (Ramakrishna et al. 1989; Barnes et al. 1994). This means that a significant proportion of the world's population where access to ICSs is poor, who cannot afford the maintenance of ICSs and who live in contexts where biomass is collected for free close to the living environment are unlikely to benefit from the indoor air pollution reduction potential of ICSs.

Dwelling Modification

Concentrations of indoor air pollutants are thought to be affected by characteristics of the dwellings in which fires are burned. For example, a cross-sectional study in India found that in addition to fuel type, the strongest predictor of indoor air pollution in the living environment was having a kitchen separate from the living area as well as improved ventilation (Mehta et al. 2002). Similarly, a study in Guatemala found that larger burning environments reduce concentrations of pollutants ($PM_{3.5}$) by every unit increase in volume (Albalak et al. 2001). A study in West Kenya showed that the provision of enlarged eaves (between roofs and tops of walls) and windows reduced $PM_{3.5}$ by 62 percent (Bruce et al. 2002).

Modifying household characteristics (such as providing separate kitchens, enlarging cooking environments and improving sources of ventilation) in poor contexts are expensive and therefore have been slow to be incorporated into development programs. In addition, there may be unintended consequences such as reduced privacy, increased security risk and negative effects on indoor temperatures (particularly in cold climates).

Discussion

Behavioral Opportunities

Despite significant development efforts and evidence of their effectiveness, the costs to governments, donor agencies and households associated with technical intervention efforts are still prohibitive for many of the poorest people in developing contexts. This is particularly true among the rural poor in developing countries where biomass is abundant, obtainable free of charge and where access to improved technology is poor. If we are to assume that take-up of current technology-based interventions is impeded by the slow regional and household socio-economic growth in developing countries, then fuel, ICS and household modification interventions must be viewed as medium- to long-term strategies. Cheaper, short-term strategies are needed to reduce child indoor air

pollution exposure *until* access to cleaner burning fuels and ICS programs are more accessible and sustainable.

Table 2. Behavioral opportunities to reduce exposure to indoor air Pollution

Behavioral cluster	Practices	Studies
Tending fires	• Dry wood//dung before burning • Use smaller pieces of wood • Use pots that correctly fit open fires • Reduce duration of burning.	(Manibog 1984): Laboratory research has shown that well tended fires display much higher levels of efficiency and lower emission characteristics than previously thought, and in some cases are comparable to efficiency figures obtained from some ICS programs.
Stove maintenance and use	• Fix holes in stove and/or flues • Clean and maintain stoves and flues • Use pots that correctly fit stove openings	Reid et al (1986): PM reduced from 4900 to 1100 µg/m^3 and CO from 500 to 31 parts per million (ppm) when correct fitting pots were used. The study found that cleaning stove flues (by removing 1.5 liters of soot) reduced CO from 500 to 56 ppm (Reid et al. 1986).
Ventilation use	• Fix and maintain broken windows • Promote double ventilation.	None
Safer child location practices while fires are burning	• Keep children away from fires	• Pandey et al. (1989): Study found that the number of episodes of ARI were positively associated with the amount of time that children spent close to fires (n=233). • Armstrong & Campbell (1991): Carriage on mothers' backs while cooking associated with higher risk of ARI (OR between 0.5 – 1.9) compared to children not allowed in burning room. • Carriage on caregivers' backs found to be an independent risk factor for ALRI morbidity (OR=2.55) (O' Dempsey et al. 1996) and mortality (OR=2.02) (De Francisco et al. 1993). • Mtango and colleagues (1992): The study found that children who died of ARI were 2.78 times more likely to have slept in the same room where indoor cooking was done after controlling for confound.

Behavior change has been identified as a potential short-term intervention to reduce child exposure to indoor air pollution (Favin et al. 1999; Barnes and Mathee 2002). Although very little information exists about the effectiveness of "behavior-only" strategies (i.e., without technology), several behavioral clusters are thought to affect exposure. These include (but are not limited to) behaviors

directed at tending fires, maintaining and using stoves (where stoves are available), the use of ventilation to reduce concentrations of pollutants and keeping children away from fires. Table 2 highlights potential behavioral intervention opportunities and the rather scant evidence supporting them.

To date, one study in rural South Africa (in which the author is involved) is evaluating the effectiveness of a behavior change intervention to reduce child exposure to indoor air pollution. The study is taking place in a poor, un-electrified rural village where biomass (wood and cow dung) is used by most households. Based on two phases of formative research (Barnes et al. 2004a; 2004b), an intensive environmental health education campaign was developed to influence two clusters of behaviors: child location and ventilation practices while indoor fires were burning. Using a before-after design (with comparison group), researchers are currently analyzing the impact of the intervention on selected burning behaviors, child exposure to selected pollutants and respiratory health over a 12 month period (2003-2004).

Although still under analysis, preliminary results[1] are showing significant reductions in child exposure to respirable particulates and CO one year after the intervention. Average child CO exposures (24 hour), for example, were reduced from 129 (in 2003) to 72 ppm (in 2004) in the intervention group while those in the comparison group remained the same. The intervention, however, appears to have had a negligible impact on children's respiratory health. This can be explained, in part, by the fact that, despite decreases in exposure, levels still remain far above international guidelines.

Lessons from the South African study indicate that although behavioral interventions are relatively cheap and easily implemented, they require much planning—particularly to determine which behaviors to focus on and develop communication strategies to promote protective behaviors. In addition, their impact may be limited by the fact that, by their very nature, they may not focus on completely removing smoke from the living environment but rather reducing *exposure* to it. Despite the limits of behavior-only approaches, they may, nonetheless be useful in contexts where no other intervention options exist.

In line with calls for technical interventions to be more people-centered (Budds et al. 2001), like water and sanitation efforts have attempted in the past, scope exists for behavioral outcomes to be included in the design and implementation of technical interventions in contexts where they are feasible. For example, the inclusion of safer child location practices together with ICS and cleaner fuel interventions may further enhance the effectiveness of such programs. Similarly, the proper use and maintenance of ICSs could also possibly be improved with a behavioral focus. A "behavior-first" (Favin et al. 1999) approach, which contextualizes technical interventions in relation to human behavior, has been noticeably absent in prevention designs. Exposure-reducing behaviors (in addition to technology) may be particularly relevant given the fact that many homes with access to ICSs and access to cleaner burning fuels still experience poor air quality because of the sustainability challenges outlined above.

Research Needs

From an evaluation perspective, a number of research gaps are evident in the literature. First, evaluations of interventions have been limited to simple cross-sectional "snapshot" studies that have compared populations exposed to an intervention with those populations not exposed to the intervention. This offers little information about the situation before the intervention was introduced, why the intervention is sustained in certain contexts (and not in others) and the effects of the intervention over time.

Second, the impact of indoor air pollution on respiratory health is a function of the complex interplay between indoor air quality, the amount of time that children spend breathing smoke and factors related to children's susceptibility (including socio-economic status, aspects of nutrition, birth weight and history of infection). Evaluation studies have tended to limit outcome measurements to either indoor air quality or child respiratory health with very few, if any, evaluating the impact of interventions on both indoor air quality and child ARI. Given the range of factors that could influence this relationship, there is a need for studies that include both indoor air pollution exposure and child ARI outcomes while taking into account the range of confounding factors that affect both.

Third, there has been a lack of consistency in the way indoor air pollution exposure has been measured. Studies have focused on a variety of pollutants (for example, particulate matter, CO or a combination) using different monitoring equipment. Studies have also differed in their methodological approach to indoor air pollution monitoring. For example, in measuring particulate matter, some studies have used a time-weighted average approach while other studies have used real-time monitoring. Studies have also differed in their monitoring periods (e.g., duration of a burning fire, 1 hour, 8 hours or 24 hours). This makes comparing effects across studies difficult to achieve.

In addition, most PM monitoring equipment is too large and heavy to attach to young children in order to measure exposure. Consequently, researchers have to measure levels of indoor air quality in the room used for burning, measure child time-location practices in relation to fires and then calculate exposure based on these two estimates. Several studies have attempted to circumvent this by attaching smaller carbon monoxide diffusion tubes to young children. Carbon monoxide has been shown in Guatemala to be an accurate and useful proxy for PM, thus allowing researchers to use carbon monoxide attached to children to measure exposure (Naeher et al. 2001). A study in South Africa, however, found that CO was a poor predictor of PM (Röllin et al. 2004). Evaluators also need to consider methods of assessing child time-activity patterns such as questionnaires and observations that may influence exposure estimates (Barnes et al. 2005).

There has also been a lack of consistency in the way in which ARI has been defined. Some studies have used combinations of symptoms such as shortness of breath and rapid breathing to screen for ARI in field conditions, while others have confirmed cases through formal clinical procedures. Some studies have focused on mortality (death due to ARI vs. living), morbidity (ARI vs. healthy control) or severity of ARI (mild vs. moderate vs. severe). Differing

methodologies and outcome definitions make it difficult to compare the effectiveness of intervention approaches across contexts.

Figure 3. Young girl with a carbon monoxide diffusion tube

Longitudinal studies that measure the impact of interventions on fuel use, indoor air quality, child exposure and child ARI (while taking into account the range of confounding variables) are desperately needed. There is also a need for consistency in methodologies to compare the effectiveness of interventions across contexts.

It is encouraging to note that the World Health Organization is currently supporting an ICS randomized controlled trial in Guatemala (see **http://www.who.int/indoorair/interventions/guatemala/en/**). The study takes into account many of the empirical weaknesses outlined above including the field testing smaller PM equipment (personal communication, Professor Kirk Smith). Studies are also underway evaluating participatory interventions in Kenya (promoting smoke hoods); Sudan (LPG promotion) and Nepal (home insulation and stove design) (see **http://www.itdg.org/?id=smoke_index**). Results from these studies, together with the behavioral work in South Africa, should contribute significantly to the understanding of the impacts of interventions in different contexts.

In addition to quantitative considerations, possibilities also exist for qualitative evaluation methodologies. Qualitative evaluations may be particularly useful for understanding the processes underlying intervention implementation and adoption. Qualitative methodologies could explore the motivations and barriers to adopting interventions in particular contexts, the relative importance of improved health in relation to welfare outcomes (e.g., ease of use, improved quality of life, less smoke irritation), unintentional consequences of interventions, intentions to persist/sustain interventions as well as the process of

intervention implementation (dissemination, communication or training strategy).

Concluding Remarks

Despite significant sustainability challenges, energy-related interventions have shown promise in terms of their potential to reduce child exposure to indoor air pollution. Interventions, however, have had little success in contexts of extreme poverty. This paper highlights what is needed for greater success: cheaper behavioral intervention options to be implemented among the poorest population sectors where technical interventions are unlikely to reach, opportunities for technical interventions to be more inclusive of behavioral processes and outcomes, and quantitative as well as qualitative evaluations. It is hoped that this paper will serve to stimulate further debate on context-specific interventions to improve child respiratory health through indoor air pollution exposure reduction.

Endnote

1. Final results are due to be released in September 2005

Brendon Barnes *is a researcher at the Medical Research Council of South Africa. Trained in public health and psychology, he has a special interest in the health effects of biomass fires and behavior-based approaches to reducing child exposure to environmental threats in developing countries (including indoor air pollution and environmental lead).*

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