1791 Tullie Circle, NE. Atlanta, Georgia 30329-2305, USA
www.ashrae.org

ASHRAE Position Document on

COMBUSTION OF SOLID FUELS AND INDOOR AIR QUALITY IN PRIMARILY DEVELOPING COUNTRIES

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COMMITTEE ROSTER

The ASHRAE Position Document on "Combustion of Solid Fuels and Indoor Air Quality in Primarily Developing Countries" was developed by the Society's Combustion of Solid Fuels and Indoor Air Quality in Primarily Developing Countries Position Document Committee formed on September 16, 2013 with Paul Francisco as its chair.

Paul W. Francisco, *Chair*
University of Illinois
Champaign, IL, USA

Jill Baumgartner
McGill University
Montreal, QC, Canada

Chandra Sekhar
National University of Singapore
Singapore, Singapore

Kirk R. Smith
University of California
Berkeley, CA, USA

Dean Still
Aprovecho Research Center
Cottage Grove, OR, USA

Cognizant Committees

The chairperson of Environmental Health Committee also served as ex-officio members.

Zuraimi Sultan, *Ex-Officio*
Cognizant Committee Chair
Environmental Health Committee
National Research Council Canada
Ottawa, ON, Canada

HISTORY

of

REVISION / REAFFIRMATION / WITHDRAWAL DATES

The following summarizes the revision, reaffirmation or withdrawal dates

10/03/2016 —BOD approves Position Document titled *Combustion of Solid Fuels and Indoor Air Quality in Primarily Developing Countries*

Note: Technology Council and the cognizant committee recommend revision, reaffirmation or withdrawal every 30 months.

CONTENTS

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"Combustion of Solid Fuels and Indoor Air Quality in Primarily Developing Countries"

ABSTRACT
Household solid fuel (biomass and coal) combustion for cooking and heating is one of the most significant contributors to the global burden of disease, especially in low- and middle-income countries (LMICs). As an organization with a focus on the standards and practice that impacts indoor air quality, ASHRAE is concerned with this issue. However, although indoor air quality is clearly within ASHRAE's purview, ASHRAE has not historically focused on LMICs and to date has not made commitments in this area. Addressing this issue requires the expertise of a broad range of fields other than ASHRAE's, making collaboration key. The recently published WHO Indoor Air Quality Guidelines describes the breadth of this issue. ASHRAE's expertise in ventilation and air cleaning technologies can be an important contributor to the ongoing efforts to solve problems related to household solid fuel combustion. ASHRAE should support other organizations through research and standards, especially related to ventilation and air exchange measurement and technologies.

EXECUTIVE SUMMARY

Based on the Disability Adjusted Life Years (DALYs) approach, which includes both years lived with illness or injury and years of life lost due to premature mortality, household air pollution from solid cookfuels was found to be the largest environmental health risk and the third greatest risk factor overall for the global burden of disease, with 4.3% of global DALYs (Lim et al. 2012; Smith et al. 2014). The largest impacts are in South Asia and Sub-Saharan Africa where household air pollution from solid cookfuels is among the top risk factors of any type regionally. In Southeast and East Asia, it is within the top five risk factors. In recent years, there has been a rapid rise in scientific research and national policies have focused on the impact of more efficient stoves and cooking fuels. Global and local modeling studies have estimated the impact of household solid fuel combustion on outdoor air, which can be significant in some countries. Other efforts to address the issue include making cleaner fuels available and managing the air primarily through ventilation.

ASHRAE is not in a position to be the primary leader in this area; however, ASHRAE's knowledge base provides the opportunity to play an important supportive role with leadership in key areas.

ASHRAE's positions at present are:

- ASHRAE is committed to partnering with clean-energy organizations and initiatives to provide expertise on home ventilation strategies.
- ASHRAE is committed to supporting research on ventilation/air change measurement and air cleaning options that are feasible in locations where common equipment and supplies are not available or easily accessible.
- ASHRAE is committed to developing standard methods of test for measurements of air change that are feasible in settings where common measurement equipment and supplies are not available or easily accessible.
- ASHRAE is committed to developing guidelines for proper design to achieve effective natural ventilation.
- ASHRAE is committed to pursuing strategic alliances, through mechanisms such as MOUs, with other organizations for all activities, including technical assistance and leveraging of research funding, in order to bring knowledge of local infrastructure, cultural norms, and regional/climatic challenges.

1. THE ISSUE

Household air pollution (HAP) from solid fuel combustion results in serious pollution and is a major component to the global burden of disease. Efforts to address the issue include improving stoves, making cleaner fuels available, and managing the air primarily through ventilation.

2. BACKGROUND

Household solid fuel (coal or biomass) combustion for cooking and space heating is a widespread source of air pollution exposure. In high-income countries, households use solid fuels primarily for space heating. In other areas solid fuels are used solely for cooking, while in others, for both cooking and heating, sometimes using the same stove. Over 40% of the world's population (about 3 billion) uses solid fuel for cooking in this decade (Bonjour et al., 2013), and many of these people (approximately 1.3 billion) also live without access to electricity (UNDP).

Based on the Disability Adjusted Life Years (DALYs) approach, which includes both years lived with illness or injury and years of life lost due to premature mortality, household air pollution from solid cookfuels was found to be the largest environmental risk factor and the third greatest risk factor overall for the global burden of disease, with 4.3% of global DALYs (95% confidence interval of 3.4-5.3%) from this source (Lim et al. 2012; Smith et al. 2014). The global distribution is far from uniform, however. The largest impacts are in South Asia and Sub-Saharan Africa where household air pollution from solid cookfuels is among the top risk factors of any type regionally. In Southeast and East Asia, it is within the top five risk factors. In other developing regions it is still important, but not so large compared with other risk factors. In contrast, there are so few people cooking with coal or biomass in North America and Western Europe that the disease burden is too low to quantify. (See http://www.healthdata.org/data-visualization/gbd-compare). In recent years, there has been a rapid rise in scientific research and national policies have focused on the impact of more efficient stoves and cooking fuels (for example the relatively recent shift in research priorities of the NIH, the development of cookstove standards by ISO, and the national cookstove programs of India, Nepal, and Peru). Wood-fired heating has been studied mainly in North America – with a focus on Native American populations – and Europe, but is also of research and policy interest in temperate regions with access to forests. Updated wood heating stoves standards, for example, are being promulgated by the US EPA. Global modeling studies have estimated the impact of household solid fuel combustion on outdoor air, which can be significant in some countries.

Studies of air pollution exposure and household concentrations have shown that the most critical mitigation strategy is to improve the quality of the combustion process itself, as it is difficult to sufficiently reduce exposures with just a chimney or general ventilation. In fact, even outdoor cooking over an open fire will create unhealthy exposures. The recent WHO Indoor Air Quality Guidelines (http://www.who.int/indoorair/guidelines/hhfc/en/) specifies Emissions Rate Targets for PM2.5 and CO that are necessary for cookstoves to meet health protective air quality guidelines (http://www.who.int/phe/health_topics/outdoorair/outdoorair_aqg/en/). These were calculated in a probabilistic manner based on several factors including the measured distribution of air change rates in typical village households. However, there will be significant benefits from ventilation in some locations, depending on outdoor air pollution, climate, technology, infrastructure, incomes, and cultural norms.

Key Considerations:

- Reducing emissions is the most important factor for achieving good indoor air quality.
- The most serious impacts from household solid fuel combustion are in LMICs where cooking with solid fuels in unvented stoves is common.
- Impacts of space heating in LMICs are less well-characterized, but are coming to be better understood in developed countries which commonly use vented stoves.
- Improved combustion through modern biomass stoves is being promoted by a number of agencies
- There are many organizations working on improving combustion in these regions, and ASHRAE is not well-suited to enter this space.
- Solutions are not only technical, but also must take into consideration cultural and economic aspects.
- Clean fuels such as gas (liquefied petroleum gas and natural gas) and electricity, which already provide cooking energy to the richest 60% of the world, are starting to be provided to more of the poorest 40% and probably provide the best long-term solution for all.
- Biogas and bioethanol offer ways to obtain the clean-burning characteristics of gas using local renewable biomass sources in some areas. Biomass pellets made locally can also be burned more cleanly that loose biomass.
- Solar cookstoves can be used effectively for certain cooking tasks in some geographic areas and are often effective in institutional settings.
- Improved combustion venting, and home ventilation, can be beneficial in some locations.
- The contribution of solid fuel combustion to outdoor air pollution must be taken into account when ventilation is considered as a strategy for improving indoor air quality.

3. RECOMMENDATIONS

ASHRAE's positions at present are:

- ASHRAE is committed to partnering with clean-energy organizations and initiatives to provide expertise on home ventilation strategies.
- ASHRAE is committed to supporting research on ventilation/air change measurement and air cleaning options that are feasible in locations in which common equipment and supplies are not available or easily accessible.
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Appendix A – TECHNICAL REVIEW

A.1 Overview

It is thought that humanity began cooking with wood nearly 2 million years ago at the time we moved from the trees to living on the ground. Indeed, control of fire is probably the best transition point to indicate the change from pre-human to human state (Wrangham 2009). Today, in spite of much progress globally, about 40% of the world's population still cooks with solid fuels, with wood being joined by agricultural residues as well as coal in a few areas.[1] Although 60% of households now use modern fuels – gas and/or electricity – to cook, the increase has not kept up with population growth. Indeed, today, at a worldwide population of three billion, the number of people using solid cookfuels is probably greater than at any time in human history (Bonjour et al. 2013).[2]

Much of this solid fuel is burned in simple stoves – often just a pit, three rocks, or a U-shaped volume in a block of clay. Locally produced metal stoves, which are also common around the world, rarely have designs that improve combustion or are made of durable materials. Although most cooking is done indoors, there are hundreds of millions who cook outdoors in courtyards or other semi-enclosed arrangements, often seasonally. Indoors or outdoors, the vast majority of such cooking is done without flues, chimneys, or other venting arrangements to remove smoke from the living environment. Given that even outdoor cooking produces unhealthy exposures to pollution in household environments, the preferred term for this risk factor is now household air pollution (HAP), not indoor air pollution (Smith et al. 2014).

The simple design of traditional biomass cookstoves combined with extreme heterogeneity of natural biomass typically results in both poor combustion efficiency (conversion of fuel chemical energy to heat and radiation) and poor thermal transfer efficiency (transfer of this released energy into the cooking vessel) and, therefore, low overall energy efficiency. Burning biomass in such conditions produces a vast range of organic and inorganic compounds mainly as incomplete combustion products. These products – here termed "smoke" – cause of most of the ill-health associated with biomass burning.

A.2 Health Effects

The health effects produced by cookstove smoke have been extensively reviewed by several international expert groups (Lim et al. 2012, WHO 2014a, WHO 2014b, GBD 2015, Smith et al. 2014). Household air pollution from cooking with solid fuels is estimated to be the largest single environmental risk factor globally, exceeding poor water, inadequate sanitation, and ambient air pollution in its burden of ill-health. Globally, evaluations by different groups estimate that between 3.5-4 million premature

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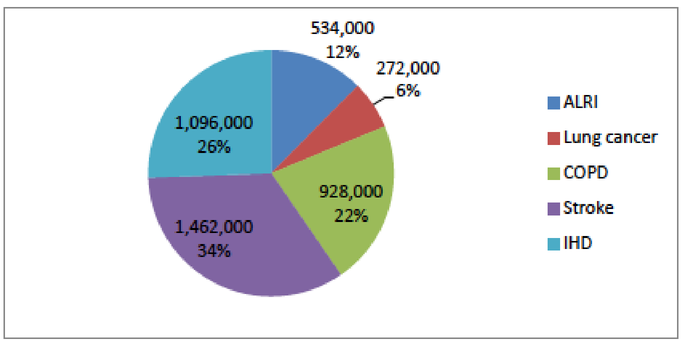
[1] Although sharing many issues with biomass fuels, coal poses additional challenges due to the great variety of coals in different areas sometimes with quite different compositions, including in some cases toxic contaminants such as sulphur, arsenic, fluorine, lead, mercury, etc. This report does not address these additional hazards of coal, but readers are referred to the review in WHO, 2014b.

[2] Most research that has been done on the topic of residential solid fuel use has been in the cooking context and so that is the primary focus of this discussion. Readers are referred to Chafe et al. , 2015 for further discussion.

deaths annually are attributable to HAP, with individual estimates overlapping in terms of their uncertainty bounds (see Figure 1). In a number of poor countries, HAP is the greatest risk of all, exceeding the risks of smoking, malnutrition, and blood pressure, but in nearly all poor countries it is among the top 4 risk factors, even including unsafe sex or risks for malaria.[3] These estimates are based on reviews of the global epidemiological literature indicating that significant proportions of six major diseases can be attributed to household air pollution: pneumonia in young children and, in adults, chronic obstructive pulmonary disease (COPD), heart disease, stroke, cataracts, and lung cancer. There is substantial additional evidence of other effects as well, including other cancers, still birth, low birth weight, birth defects, prematurity, tuberculosis and cognitive impairment. As these are well-established already as health impacts of smoking, it is likely that with more research they will be firmly associated with HAP as well since those now linked to HAP are also largely the most important impacts from smoking. Appendix B briefly summarizes the evidence supporting an association between HAP and a number of adverse health impacts in children and adults.

***Figure 3**. Deaths attributable to HAP in 2012, by disease*



Percentage represents percent of total HAP burden (add up to 100%).
HAP: Household air pollution; ALRI: Acute lower respiratory disease; COPD: Chronic obstructive pulmonary disease; IHD: Ischaemic heart disease.

Figure A1. Deaths Attributable to HAP in 2012, by Disease. (*Source - WHO - Burden of disease from Household Air Pollution for 2012* (WHO 2014a))

Among the thousands of chemicals found in woodsmoke, hundreds are hazardous including organic compounds known to be mutagens, immune system suppressants, inflammation agents, central nervous system depressants, cilia toxins, endocrine disrupters, and neurotoxins. Several others are firmly established as human carcinogens, including benzene, formaldehyde, poly-aromatic hydrocarbons, and dioxin (Naeher et al. 2007). In addition, there are toxic inorganic pollutants such as carbon monoxide and nitrogen oxides. Minus nicotine, woodsmoke is much like that from burning tobacco and, as noted in Appendix B, the health impacts are quite similar in type, if not in quantity.

As in studies of the health impacts of tobacco smoke, the best single indicator of the health risks of HAP is thought to be $PM_{2.5}$, particles under 2.5 micron in size, which penetrate deep into the lung. Second in importance for health is probably carbon monoxide. In general, the two pollutants are thought to

[3] Institute of Health Metrics and Evaluation, Global Burden of Disease website: http://www.healthdata.org/results/country-profiles

produce different health effects. As measured in woodsmoke, however, it should always be recognized that they are just indicators of a large range of other health-threatening pollutants that are in the smoke.

Because of the vast array of traditional biomass fuel types and stove characteristics, not to mention size, shape, and moisture contents in fuels used across the world in different seasons, there is not good characterization of "average" traditional stove emissions. Nevertheless, measurements show that typical wood-fired traditional cookstoves release $PM_{2.5}$ equivalent to 300-500 cigarettes being smoked per hour.

The vast majority of all cooking in the world is done by women, who also are nearly always the primary caregivers for infants (children before walking age). As a result, these two groups receive the highest exposure to cookstove smoke, although older children and men are also exposed. As a result, a perfect storm of risk is created: a highly polluting activity, done multiple times daily, at times and places when the most vulnerable people in the world are present – poor women and their youngest children.

A.3 Outdoor Air Considerations

It is now recognized that in many countries, household solid fuels are a major source of ambient particle pollution as well as exposure to particulate matter by people in the immediate household environment. Merely exhausting the smoke to outside does not eliminate its hazard. It comes back into the house, goes next door, pollutes the village air, and travels downwind to become part of the background pollution that can affect vast areas in some countries. For example, in India, household biomass use has been estimated to be responsible for 25-50% of all ambient particle pollution in the country in recent studies (Lelieveld et al. 2015). In Northern China, similar percentages have been estimated (Lelieveld et al. 2015, Liu et al. 2016). Table 1 shows examples of measured outdoor winter-time $PM_{2.5}$ levels from six studies in five countries. This table shows that average winter-time outdoor $PM_{2.5}$ levels have been measured as high as 250-450 $\mu g/m^3$, in Ulaanbaatar, Mongolia, and that outdoor levels are often very high in other locations. These high levels are in contrast to those found in other locations such as Kocaeli City, Turkey, with a measured average of about 22 $\mu g/m^3$, or New York City, with a measured average of about 17 $\mu g/m^3$.

The very high levels of $PM_{2.5}$ in some locations during winter is heavily influenced by heating, showing that there are significant climate considerations regarding the impacts of solid fuel use on outdoor air. Annual levels may be much lower, especially in locations where heating is needed less. Brauer. et al (2016) reports that the rural and urban mean annual concentrations of PM2.5 in Uganda is 18 $\mu g/m^3$, in Rwanda is 17 $\mu g/m^3$, in Mexico is 12 $\mu g/m^3$, and in Sri Lanka is 17 $\mu g/m^3$. Biomass burning from cooking has been shown to contribute 2.8 $\mu g/m^3$ in southern sub-Saharan Africa. South Asia showed the highest regional concentration of outdoor PM2.5 from household cooking (8.6 $\mu g/m^3$) (Chafe et al. 2014).

Clearly, when outdoor levels are extremely high, ventilation will be of little value since the makeup air will also be heavily polluted. Since the outdoor levels are often largely due to the use of the stoves of interest, solving the outdoor problem requires making the stoves much cleaner which in turn would mean that there would be less pollution that ventilation would need to remove and therefore ventilation would be less necessary.

Table A1. Measured outdoor $PM_{2.5}$ concentrations in various locations around the world.

Location	Sample	Time period	Range or average, μg/m^3
Ulaanbaatar, Mongolia (Ochir et al. 2014)	Four locations	Jan. 22 – Mar. 2, 2013	280-450
Shaanxi province, China (Zhu et al. 2010)	Three rural sites	Winter, 2007-2008	268
Agra, India (Massey et al. 2012)	At five urban roadside homes	Winter, 2007-08 and 2008-09	212
	At five urban homes		157
Guangzhou City, China (Huang et al. 2007)	Nine sites	Winter, 2004-2005	124
Koaceli City, Turkey (Pekey et al. 2010)	At 15 homes	Dec. 16, 2006 – Jan. 20, 2007	22
New York City, NY, USA (Kendall et al. 2002)	At 8 homes	12 days in winter	17

The community effect of household air pollution has several major implications. First, it indicates that simple venting is not a widespread solution in that it just moves the smoke from one place to another instead of eliminating it. Second, it indicates that community solutions should be sought – just providing clean fuels to a few homes in a village may not have much health benefit if they are receiving smoke exposures from their neighbors. Third, it indicates that cleaning up household combustion must be part of any strategy to address the severe ambient pollution that plagues countries like India and China.

A.4 Technological Approaches/Stove Design

There are three major approaches to reducing the health impacts of HAP globally. As use of solid fuels is a problem primarily of poverty, the first approach is just to hope that development will take care of it. Unfortunately, although the number of people using modern clean fuels has steadily risen with development, the total using solid fuels has not fallen overall for decades, although it is improving in some areas such as China. This approach is thus not working.

The second major approach is to attempt to burn biomass fuels more cleanly, to "Make the Available Clean" (Smith and Sagar 2014). Everything else remaining the same, better energy efficiency means less fuel burned and thus less smoke. Designing and disseminating more efficient stoves is one approach. Improving fuel efficiency is almost always beneficial and has other benefits beyond reducing pollution such as reducing impacts on forests and fuel gathering time for women, and, where fuels are purchased, saving money. Unfortunately, however, the needed reduction in smoke emissions to bring $PM_{2.5}$ down to acceptable levels is an order of magnitude, or more, greater than what can be achieved by simple improvements in fuel efficiency. Thus, what is needed is redesign of stoves to improve combustion efficiency (the percent of fuel chemical energy that is converted to heat and radiation during combustion)[4] – perhaps well above 99% as is common with gas and liquid fuels. Although much progress has been made, such efficiency improvements have been an insurmountable challenge using unprocessed biomass available easily via gathering. Even the best available unvented loose-biomass stoves produce $PM_{2.5}$ at rates that are higher in lab tests than are allowable to protect health according to the WHO, never mind in real households (WHO 2014b). Nevertheless, the attraction of using local biomass as fuel continues to drive innovation in this arena. The best available loose-biomass stoves vented with chimneys have been able to meet the WHO Intermediate Indoor Air standard for $PM_{2.5}$ (see Appendix C for a description of stove technologies and Appendix D for a discussion of WHO activities) in lab conditions (Still et al. 2015a), though field testing has yet to be completed to determine whether the stoves can be successful in real world conditions.

As with fuel efficiency in automobiles, there is typically a large gap between expectations from lab results and those achieved under conditions of actual use (Carter et al, 2014). Bridging this gap – making stoves sufficiently robust and improving testing protocols such that field performance more closely matches lab results – is another urgent need.

The third major approach is to accelerate the historical trend for households to move to clean fuels over time, i.e., to gas and electricity, i.e., to "Make the Clean Available" (Smith and Sagar 2014). Due to the lack of contaminants, uniformity of composition, and ease of premixing with air, nearly any gaseous fuel can be burned quite cleanly with inexpensive stoves. Liquefied petroleum gas (LPG) and natural gas are the primary modern gaseous fuels that today provide clean cooking worldwide. There are financial and infrastructure barriers to making them available for a larger proportion of the world's poor, but the health advantages of doing so are substantial. In addition, electric induction stoves have brought the efficiency of electric cooking into a range that they are now being promoted in poor populations with access to electricity in some countries.

In the interstices of the two large-scale approaches are a range of technical innovations that can play roles in reducing exposures from fuels. Gas fuel from local sources is one such approach. Primary among these is biogas made from anaerobic digestion of animal dung to produce a methane-rich fuel. This has made some impact in India and China and shows promise for further expansion. Less well developed to date, but also showing progress, is bio-ethanol from fermentation of cassava, sugar cane, or other plantation crops. Ethanol has been shown to burn quite cleanly in household stoves, but the main concern is how competition from other sectors would affect its price to households. Finally, processing biomass into pellets provides a fuel that can be burned much more cleanly than loose biomass due to being uniform in size, shape, composition, and moisture and thereby allowing optimization of stove design for combustion efficiency. To rely on biomass pellets, however, would require development of local fuels cycles including central collection of biomass.

Solar energy shows promise for some cooking needs, but is hampered at present by lack of affordable energy storage to enable cooking when the sun is low or at night, which is the primary need in most

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[4] Often approximated by the fraction of fuel carbon converted to CO_2,- i.e., modified combustion efficiency (Jetter et al., 2012)