HEALTH EFFECTS OF INDOOR AIR POLLUTION: THE GLOBAL PICTURE

Kirk R. Smith
Environmental Health Sciences, School of Public Health
University of California, Berkeley (krksmith@berkeley.edu)

ABSTRACT

This year, the World Health Organization (WHO) published the results of an effort that brought together about 100 specialists from approximately 30 institutions worldwide to conduct the first large-scale coherent multi-risk-factor Comparative Risk Assessment (CRA) ever done. Previous risk estimates, such as those for indoor air pollution (IAP), had been done independently from one another, leading to incompatible criteria for accepting evidence of exposure-response relationships and approaches for establishing exposure. In addition, the separate assessments used different base years, different estimates of background disease rates, different population estimates, and different groupings of populations/countries/regions. Among the nearly 30 major risk factors examined were hypertension, cholesterol, tobacco, alcohol, unsafe sex, several kinds of occupational risks, lead exposure, climate change, and outdoor air pollution. At 1.6 million premature deaths annually, mainly in women and young children, IAP was found to be one of the 10 most important causes of ill-health in the world today and was ranked fourth after poor nutrition, unsafe sex, and dirty water in poor countries as a cause of ill-health.

Substantial uncertainty is associated with these estimates, however, and there is urgent need to improve the quality and extent of exposure and epidemiological risk assessments to reduce the uncertainty associated with the main disease outcomes: pneumonia in children, chronic obstructive pulmonary disease and lung cancer in adults, and to establish whether other diseases, for which is limited but intriguing evidence today, can be causally linked: TB, asthma, heart disease, cataracts, and low birth weight.

New studies, such as the first randomized intervention trial in air pollution history, are promising to throw more light on this question. This trial, in highland Guatemala, is examining pneumonia and asthma related endpoints as well as adult heart-rate variability and pulmonary health. New technology is also greatly improving the capacity to estimate IAP exposures over large populations for small particles, the best single measure of risk.

The WHO CRA also estimated the rate at which fuel-based household pollution would decline worldwide without intervention, which is a function of population and economic trends. The decline was estimated to be only 6-10% per decade, barely sufficient to make up for population increases. Thus there is need to find cost-effective interventions that can be effectively applied. The Chinese improved stove program, which has introduced nearly 200 million stoves, may provide useful lessons for other countries.

INTRODUCTION

What is a health effect? Or, rephrased slightly, "What metric can we use to compare the health impacts on occupants in different indoor environments as well as compare the these health impacts with other health risks in society?"

At one end of the spectrum of health measures lies the definition in the World Health Organization's 1946 Constitution:

> "Health is a state of complete physical, mental, spiritual, and social well-being and not merely the absence of disease or infirmity" [1]

This sweeping statement will strike a familiar chord for some in this room. Such a broad measure could encompass much of the research and control of air quality in buildings that address comfort, irritation, and feelings of ill-ease, which are difficult to class as actual diseases, i.e., the kind of disease that would be listed in an international comparative database. Nevertheless, they do affect people's performance and other objective parameters. The WHO definition, nevertheless so broad that it is hard to see how it could be operationized.

In particular, how would such a broad definition of health be used for simple comparisons across populations? Surveys of perceptions, which would seem the only way to derive mental and spiritual well being, bring results that are stubbornly orthogonal to physical measures. Australian Aborigines, for example, who by any physical measure suffer significant ill-health by comparison to white Australians, typically rank themselves far healthier than their better-off neighbors, many of whom rank themselves in poor health in spite of having better objectively measured physical health than 99 % of all humans who ever lived.

It can be argued, however, that one should take people's own assessment at face value and act accordingly. This might well be the appropriate view to take in conducting an evaluation of a particular "sick building." To feel comfortable and be productive, the people who work in a building need to know that their values and concerns are being addressed. As noted, however, using self-defined metrics does not work well in the aggregate. Would we really want a global public health system, for example, that switched resources from objectively determined serious disease states in poor countries to address the rich hypochondriacs of the first world, because they were stressed after reading about the newest health hazard? I believe not. One day we may have a way to objectively apply the WHO definition across cultures and regions, but today we do not.

At the other end of the measurement spectrum lie simple measures of death such as mortality. Death is clearly related to health, but by itself is misleading. First, everyone dies and if they don't die of one thing then they die of another. Thus, health is never achieved for we can, and probably will, chase death to the end of time. Second, of course, is that the age of death is important. The death of an 88 year old is sad, but rarely tragic. Indeed, we often call deaths of the old as "natural". There is no "natural" death for a 28-year old, however. Something went wrong. The economic,

---

[1] "Spiritual" was added in 1999.

social, and emotional impact is much greater, even though the death certificate is the same length. Finally, of course, death fails as a measure of ill-health because it does not include non-fatal illness and injury, conditions that affect health but may not change death rates.

Several criteria for a useful measure of ill-health to be used for international comparisons can be derived from the above discussion:

- It should be objectively derived and not subject to personal, local, temporary, and unrepeatable valuation.
- It should combine death and disease
- In recognition of their universal importance in all societies, age and sex should be considered when weighing the impact of death and illnesses.
- No other factors should be considered so the measure is blind to income, race, nation, class, religion, etc.

Thus the illness and premature death of a 50-year old stockbroker in Sydney should be counted the same as that of the 50-year-old farmer in Bangladesh..

The only measure that has ever been seriously proposed to meet all these criteria is lost time. Premature death can be measured as the lost life years from the life expectancy of a person of that particular age and sex. Illness can be measured as a duration (years) times a severity factor, that would vary from low values (e.g., 0.05) for minor illnesses or injuries to large values (e.g., 0.9) for major ones. The total lost life years from premature death and illness is then the measure of impact from a disease or risk factor within a population.

The idea is that very few things other than time are given pretty much equally to everyone on Earth – certainly not income or wealth the loss of which is used as a measure of ill-health in certain sectors (the courts, for example). We are each granted "three score and ten." The fact that some of us, the farmers in Bangladesh for instance, are not been able to live it completely is an indication of their ill-health. We believe that if they had the nutrition, education, environment, medical care, and so on of stockbrokers in Sydney, they would live just as long and just as disease-free. The degree to which they do not, the lost life years, is a measure of their ill-health that meets all the criteria above.

There are several different ways of calculating lost-life years, each with certain methodological and presentational advantages and disadvantages. Here I use the Disability-Adjusted Life Year (DALY) mainly because by doing so I can tap the only complete coherent worldwide health database, the Global Burden of Disease database, published annually by the World Health Organization.

BURDEN OF DISEASE DATABASE

Until relatively recently, the health community lacked a coherent, consistent, and comprehensive dataset describing the extent and distribution of ill-health. Simple questions such as how many died of what disease at which age in which part of the world could not be answered reliably. Just asking each of the expert groups how many deaths were caused by their particular disease produced irreconcilable results.

The sum of all disease groups' estimates invariably came to many more deaths than the known total. This is because of the natural tendency of interest groups to cite the higher end of uncertainty ranges, differences in treating evidence among groups, and true conceptual difficulties, especially with assigning deaths from multiple causes to one disease category, for example whether tuberculosis deaths in an HIV-positive population should be accounted to HIV or tuberculosis.

This is quite primitive compared to other major datasets used by modern society. We expect that import statistics will match export statistics by region and commodity. So with energy and food production and consumption, the net of births minus deaths and population growth, financial flows, etc. If any of these data do not balance, we send them back to be fixed. Until the mid-1990s, however, we had to live with a health database that did not balance.

Without such data, trying to determine the number attributable to any one risk factor was lost in a sea of inconsistent and competing claims. Imagine, for example, trying to determine what fraction of energy is produced by coal if one had neither a reliable number for total energy use nor an agreed upon way to distinguish coal from oil?

In the early 1990s, however, through an exercise originally promoted by the World Bank at Harvard University but now incorporated into the statistical apparatus of the World Health Organization. To do so, it was necessary to bring together diagnosticians, disease experts, demographers, epidemiologists, statisticians, and others with relevant angles of view in a number of different fora around the world and impose a kind of consensual "discipline" never before attempted. No longer could one disease group claim large numbers of deaths unchallenged, because they would have to take into account the often directly conflicting estimates of other disease groups who also had evidence among the same populations. Since all the groups were engaged together and obliged not, in sum, to exceed the known number of deaths, coherence and consistency were enforced.

The first complete publication of the Global Burden of Disease database occurred in 1996 (Murray and Lopez 1996) using 1990 data. The WHO now publishes yearly updates of the GBD, which comes out in summary form in its annual World Health Reports with detailed versions available on the web.[2] These delineate some 200 causes of death and illness (including injury) by age and sex, separately for 14 regions of the world.

THE WHO COMPARATIVE RISK ASSESSMENT

With such a database a broad set of additional analyses can be done that were not possible before. Among these are systematic examinations of more distal risk factors for ill-health, as compared to the proximate causes such as particular diseases. Indoor air pollution (IAP) is a more distal cause of death than lung cancer, for example, and poor building ventilation would be more distal still. Even though only lung cancer would be listed on a death certificate and in the GBD database itself, some fraction nevertheless is attributable to IAP and, with appropriate data and modeling, the total burden of lung cancer and other diseases due to IAP can be estimated.

---

[2] http://www3.who.int/whosis/menu.cfm?path=whosis,burden,burden_estimates&language=english

Managed by WHO, the largest Comparative Risk Assessment (CRA) exercise ever attempted was initiated in 2000. Attributable burdens of disease for 26 important risk factors were calculated by 100 investigators from about 30 institutions worldwide. Two questions were asked; how much ill-health would not exist today if exposure to the risk factor was as low as feasible in the past (attributable risk); how much ill-health in the future would be eliminated if the risk factor were brought under control today (avoidable risk)?

Under the principle of "consensual discipline," the WHO CRA groups met together twice over a year period during their deliberations to hammer out agreements about the quality and quantity of evidence that would be expected from each. In between, the CRA management/editorial team at WHO maintained close contact with all groups and produced databases needed by all groups (e.g., GBD-2000, population projections). The differences in data available were substantial in many cases. The hypertension group, for example, had large blood pressure surveys over many parts of the world for use in developing exposure distributions as well as dozens of large double-blind placebo-controlled randomized interventions (the "gold standard" of epidemiology) for determining exposure-response levels. The climate change group, by contrast, had none of either and, in addition, had to forecast far forward in time.

The first two draft CRAs from each group were shared among the groups and the third version was sent for extensive outside peer review. The final versions thus reflect not only "consensual discipline" among the groups, but also the disciplines imposed by blind peer review and strong editorial management. Unlike previous single-factor risk assessments, which have been in isolation, the WHO CRA was the first to conduct the analyses in a way that the results are coherent and comparable. The summary results of the CRA were released in the World Health Report (2002) and published in Lancet (Ezzati, et al., 2002) and are being published in detail in three volumes this year (Ezzati, et al., 2004).[3]

WHAT IS INCLUDED UNDER "INDOOR AIR POLLUTION"

To answer the question of how much ill-health is caused by any risk factor, it is necessary to define the "counterfactual" condition. For some risk factors, this is fairly straightforward. The counterfactual condition for smoking is no smoking, i.e, the attributable risk of tobacco smoking is the ill-health that would not exist today if there had been no smoking in the past. We know this is possible, although it would be costly and difficult to achieve. What about outdoor air pollution, however? As there is no realistic way in which people could have been exposed to zero air pollution in the past, we have to define some degree of pollution as the feasible counterfactual level to compare what did happen to what might have happened. For air pollution, for example, it might be the best in the world, some cost-effective level, or natural levels.

What is the counterfactual level for IAQ? What feasible global distribution of IAQ existing in the past could be compared with the actual distribution to determine the attributable burden today? This would be difficult to do not only because of huge

[3] The full CRA database can be downloaded from http://www.who.int/whr/2002/annex/en/

data gaps around the world, but also because of potential trade-offs between types of ill-health. These will be explored below.

A number of the risk factors in the WHO CRA having important links to IAQ. These I divide into two categories as follows:

I. Those can nearly entirely be linked to indoor sources of pollution

Indoor air pollution from combustion of solid fuels
Environmental tobacco smoke
Carcinogens, particles, and noise in occupational settings
A portion of lead exposure

I. Pollution from outdoor sources that can be prevented from coming indoors

Outdoor air pollution
More lead exposure
Mosquitos (malaria)

The estimated burden of disease attributable to the component of each of these risk factors due to indoor air pollution is summarized in Table 1. Following is a discussion of each:

I. Fully attributable to indoor air pollution:

Indoor air pollution from use of solid fuels (IAP)

Although a number of indoor air pollutants and their sources are known to affect health, the WHO CRA exercise required that to be included in the CRA a significant database must be developed on the distribution of the risk factor worldwide (exposure) and the health risk (exposure-response relationship). Although these criteria might be met for radon, bio-aerosols, moisture, sick buildings, and a few other health-related indoor air pollutants in parts of North America, Europe, and the developed Asia-Pacific, we could not find sufficient data to extrapolate to exposures elsewhere in the world.

We were, however, able to find sufficient data to develop global exposure distributions for two major combustion-related indoor air pollutants, environmental tobacco smoke (ETS – see below) and smoke from household use of solid fuels. In addition, there are now sufficient numbers of epidemiological studies in the peer-reviewed biomedical literature to conduct formal meta-analyses of the major health endpoints associated with each of these forms of IAP. Although having many common disease endpoints, because the causes, exposure distributions, and potential interventions related to these two sources are so different, the CRAs were conducted separately (Smith, et al., 2004)

The resulting burden calculated for IAP only relates to exposures in households, which nevertheless account for the largest time spent by humans indoors in nearly all cultures. Exposures in schools, vehicles, and other non-occupational settings are not included.

Although the exposure measure utilized in these calculations was use of dirty fuels, properly ventilated households with well-operating flues and chimneys could have essentially eliminated the exposures even without substituting clean fuels. This is not inconsistent, however, with the equally valid alternative attribution of this burden 100% to lack of clean fuels. Total attributable risks do not add to 100%, and may be higher or lower.

Environmental tobacco smoke (ETS)

The ETS CRA did not pass peer review in time for inclusion in the final WHO CRA, here and is now being redone. Here, therefore, I use the rule of thumb that ETS health impacts are about 5% of the impacts of the associated active smoking, which as been determined to be 4.0% of the global burden. In Table 1, therefore, ETS adds 0.2% to the global burden of IAP.

Carcinogens, particulates, and noise in occupational settings:

Taking the approach that properly ventilation and control in work environments would have prevented essentially all these airborne exposures, I also assign 100% of this risk factor to indoor pollution.

Lead

Much lead exposure around the world still comes from the lead added to petrol, although other sources are becoming relatively more important in regions where lead-free fuel has been in use the longest. Among the most important of these other sources are lead in pipes and lead in paint, the complete absence of which would be on any list of healthy building characteristics. Exactly what constitutes indoor "air," is a matter of definition. Here, I assume that the flaking of paint and other sources of lead exposure that at some point pass through indoor "air" make up 25% of the global lead health burden (Pruss-Ustun, et al., 2004)

II. Pollution from outdoor sources that can be prevented from coming indoors

Outdoor air pollution:

The main sources of outdoor air pollution are outdoors,[4] but the main exposures occur indoors because most people spend most of their time inside structures. These exposures are generally less than they would have been if people had not been inside. Thus, buildings serve to protect us from outdoor pollution. The degree of protection, however, varies substantially by type of pollutant and structure. Ozone levels, for example, are much lower indoors, while particle levels vary more by housing type. The well-ventilated housing of the tropics, for example, may protect little compare to tight housing in colder climes. Conservatively, for urban outdoor levels of small

[4] Although in many areas of the world, both in developed and developing countries, there can be important sources of exposure from what is called "neighborhood pollution," which is the local pollution caused by venting of indoor sources of pollution, mostly sold fuels.

particles, the pollutant used as the exposure indicator in the CRA, a mean global protection factor of 10% is assumed here. In other words, if urban buildings had protected us better indoors from particles coming from outside the burden of outdoor air would have been 90% of what it is now, without any changes in outdoor sources. (Cohen et al., 2004).

Lead exposure

Similarly, I appropriate 10% of lead burden to lack of protection indoors from lead sources outdoors.

Mosquitoes

Although the mosquito-borne diseases, such as malaria, might be attributed to failure to control habitat as well, they are also clearly related to lack of indoor air quality achievable by screening.[5] Most malaria globally is caused by mosquitoes biting at night in houses. Indeed, it is household screens that are given the most credit in eliminating malaria in North America and Western Europe, for example. Some other major mosquito-borne diseases, dengue for example, are carried by mosquitoes that do not bite at night, however, and thus cannot be attributed so directly to poor household indoor air.

Table 1. Global burden of disease and death due to indoor air pollution

Risk Factor	% of Global Total	% due to IAP	Total IAP Burden	% in <5 year	% in Women /girls	In Poor Nations	In Mid-Income Nations	In Rich Nations	1000 Total Deaths	% due to IAP	1000 Deaths from IAP	% of Total
Solid Fuel	**2.9**	**100**	**2.9**	**83**	**52**	**78**	**20**	**2**	**1619**	**100**	**1619**	**45%**
ETS	**4.0**	**5**	**0.20**	**83**	**52**	**28**	**28**	**44**	**4907**	**5**	**245**	**7%**
Workplace	**0.48**	**100**	**0.48**	**0**	**13**	**17**	**57**	**28**	**389**	**100**	**389**	**11%**
Lead	**0.9**	**25**	**0.23**	**75**	**45**	**46**	**43**	**11**	**234**	**25**	**58.5**	**2%**
Subtotal	**8.3%**	**46%**	**3.8%**	**72%**	**47%**	**66%**	**26%**	**8%**	**7149**	**32%**	**2312**	**65%**
OAP	**0.6**	**10**	**0.1**	**12**	**44**	**35**	**50**	**15**	**799**	**10**	**79.9**	**2%**
Lead	**0.9**	**10**	**0.1**	**75**	**45**	**46**	**43**	**11**	**234**	**10**	**23.4**	**1%**
Mosquitoes	**2.9**	**100**	**2.9**	**84**	**53**	**98**	**2**	**0**	**1158**	**100**	**1158**	**32%**
Subtotal	**4.4**	**69%**	**3.1**	**82%**	**53%**	**95%**	**4%**	**1%**	**2191**	**58%**	**1261**	**35%**
TOTAL	**12.7%**	**54%**	**6.9%**	**77%**	**49%**	**79%**	**17%**	**5%**	**9340**	**38%**	**3573**	**100%**

TOTAL GLOBAL BURDEN FROM INDOOR AIR POLLUTION

As shown in Table 1, about 6.9% of the global burden of disease can be attributed in this fashion to IAP (4th column). This is due to lost life years from illness and 3.6 million premature deaths annually (second from last column). About four-fifths is due to solid fuel combustion and failure to protect against mosquitoes. One-fourteenth of the global burden may not seem large, but it is exceeded by relatively few other categories. For example, all addictive substances together (tobacco, alcohol, drugs) make up but 9% and total sexual/reproductive risks come to 7%. In terms of

[5] One of the major interventions found to be effective in poor parts of Africa and elsewhere is indoor air quality control at the sub-household level by the bed net.

individual diseases, none reach this impact for it is more that of all cancers or HIV/AIDS and three times the burden of TB or road traffic accidents.

Like other environmental risks, most (66%) of the impacts of IAP occur in the poorest countries and most (72%) fall on young children. Unlike growing epidemics such as HIV/AIDS, therefore, the overall burden of unhealthy buildings is likely to fall slowly as economic conditions improve. Such improvements are not guaranteed of course and may slow and/or not be shared by the poor. Some parts of the world, such as West Africa, have actually suffered reversals in per capita income in recent years, presumably with increases in poverty-related impacts, such as IAP.

As with many important risk factors, most of those within the IAP category are a strong function of poverty. Just as with other such risk factors, however, it does not mean that we have to wait until people are rich to solve it. The trick in international health is to find the most effective levers to help people become healthy before they become wealthy. We know that several of the components of IAP, including clean fuels, better ventilation, and screens/nets, are just these kinds of cost-effective tools. We may wish to examine the total health benefits of general housing improvements as well.

Unlike malaria and household solid fuel use, some IAP problems, of course, do not go away with economic growth. ETS, outdoor air pollution, and airborne occupational hazards are examples of problems plaguing even rich countries. Dealing effectively with them will require new kinds of coordination among several professions and regulatory agencies, facilitation of which is one of the major purposes of a conference like this.

REFERENCES

Cohen AJ, Anderson HR, Ostro B, Pandey KD, Krzyzanowski M, Kuenzli N, Gutschmidt K, Pope CA, Romieu I, Samet JM, Smith KR, (2004, in press) *Mortality impacts of urban air pollution,* in Ezzati et al., *op cit.* vol. 2.

Ezzati M. *et al*. (many others) Selected major risk factors and global and regional burden of disease. *Lancet* **360**, 1347-60 (2002).

Ezzati M, Rodgers AD, Lopez AD, Murray CJL, eds, (2004, in press) Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors, 3 vols, Geneva, World Health Organization.

Murray, C. J. L. and A. D. Lopez, Eds. (1996). The Global Burden of Disease: a Comprehensive Assessment of Mortality and Disability from Diseases, Injuries, and Risk Factors in 1990 and Projected to 2020. Global Burden of Disease and Injury Series. Cambridge, Harvard School of Public Health on behalf of the World Health Organization and the World Bank.

Pruss-Ustun A, Fewtrell L, Landrigan P, Ayuso-Mateos JL (2004, in press) *Exposure to lead in the environment*, , in Ezzati et al., *op cit.* vol. 2.

Smith, K. R., S. Mehta, M. Feuz (2004, in press). *Indoor air pollution from solid fuel use,* in Ezzati et al., *op cit.* vol. 2.

WHO (2002). *World Health Report: Reducing Risks, Promoting Healthy Life,* Geneva, World Health Organization.