The global burden of disease from unhealthy buildings: preliminary results from comparative risk assessment

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ABSTRACT
In recent years, the World Health Organization has published a database with detailed estimates of the global burden of death and morbidity by disease, age, sex, and region. Just this year, a WHO-organized international team expanded this effort by systematically estimating the individual burdens for some two dozen more distal risk factors by age, sex, and region, including, *inter alia*, malnutrition, hypertension, tobacco use, obesity, unsafe sex, and several environmental and occupational risk factors. Here I define, aggregate, and compare those diseases and risk factors that can be attributed to *unhealthy buildings*. These include portions of the burden from indoor and outdoor air pollution, fires, vector-borne diseases, several occupational hazards, poor water/sanitation, and lead. Although a number of assumptions must be made leading to uncertainties in the results, an overall estimate of the impact of unhealthy buildings on global health is derived. I find that about 11% of the entire global burden of disease can be attributed to unhealthy buildings, a proportion second globally only to the aggregate risk factor of malnutrition. Most of this impact occurs to women and young children. In addition, I briefly discuss but do not attempt to attribute a portion to unhealthy buildings of other quantified risk factors that are associated with the built environment, including physical inactivity, falls, road traffic accidents, and climate change.

INTRODUCTION
What is a Healthy Building? How do we distinguish a healthy building from one that is not? To answer this question in a systematic way, it helps to first break it down into two deceptively simple sub-questions 'What is a building?' and 'What is health?' The first, although important, I leave to others.[1] The second, I rephrase slightly as, 'What metric can we use to compare the health impacts on occupants in different buildings as well as compare the health impacts on building occupants 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'[2]

This sweeping statement will strike a familiar chord for many in this room. Such a broad measure could encompass much of the research and control in buildings that address comfort, irritation, and feelings of ill-ease, which are difficult to class as actual diseases, 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

[1] An important part of this question, for example, lies in the system boundaries involved. Does a healthy building have to be made of materials that pass through a low-impact material supply train; does it have to be sited such that it can use a low-pollution transport system; should it have a greenhouse-neutral AC system, etc.

[2] 'Spiritual' was added in 1999.

WHO definition is, nevertheless, so broad that it is hard to see how it could be operationized. As stated, for example, it might even encompass such qualitative systems as *feng shui*.

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 neighbours, many of whom rank themselves in poor health in spite of having better 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 do not 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 person 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 person, however. Something went wrong. The economic, 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 male 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, which 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, there was 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.[3] 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 modelling, the total burden of lung cancer and other diseases due to IAP can be estimated.

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 (2002) and are being published in detail in three volumes this year and next.

THE BURDEN FROM UNHEALTHY BUILDINGS

Unfortunately, unhealthy buildings were not chosen as a separate risk factor for systematic examination and thus the CRA does not allow me to easily answer the question posed in the title. Nevertheless, enough related work was done to make a start.

First, however, 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

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

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 the situation of buildings? What feasible global distribution of 'healthy buildings' existing in the past could be compared with the actual distribution to determine the attributable burden today? This would be difficult to do in the case of buildings not only because of huge 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 unhealthy buildings. These I divide into three categories as follows:

- Those can nearly entirely be linked to unhealthy buildings:
    - Indoor air pollution
    - Carcinogens and particles in occupational settings
    - Fires[4]
    - Malaria, chagas, and dengue[4]
- Several others of the risk factors examined have large building-related components:
    - Outdoor air pollution
    - Lead exposure
    - Remaining occupational hazards (noise, accidents, ergonomics)
    - Poor water/sanitation/hygiene
- Still others have significant relationships with the built-environment, depending on assumptions:
    - Lack of physical activity
    - Falls[4]
    - Motor vehicle accidents[4]
    - Climate change

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

Fully Attributable to Unhealthy Buildings
Indoor air pollution (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) 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

[4] The burdens from fires, malaria, Chagas, dengue, falls, and motor vehicle accidents are found in the main GBD database.

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.[5]

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. Thus, I am accounting 100% of the burden from this risk factor to unhealthy buildings. 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.

Carcinogens and particulates in occupational settings

Taking the approach that properly ventilated work environments would have prevented essentially all this exposure, I also appropriate 100% of this risk factor to unhealthy (workplace) buildings. Designating such workplaces as coal mines as 'buildings' may seem odd, but as a human-built enclosed environment, subject to being made in a healthy or unhealthy manner, they qualify.

Fires

Nearly all the burden assigned to fires comes from failures of one sort or another to design structures to be fire resistant and to incorporate proper escape routes. Thus, 100% of this burden is also assigned to unhealthy buildings.

Malaria, Chagas, and dengue

These are the three most important structure-related vector-borne diseases, although there are others as well. Chagas disease, which is carried by insects living in the cracks of adobe/mud walls, is directly attributable to poor housing. Although the mosquito-borne diseases, such as malaria and dengue, might be attributed to failure to control habitat as well, they are also clearly related to lack of healthy housing with screening. Indeed, it is household screens that are given the most credit in eliminating malaria in North America and Western Europe, for example. Depending on mosquito species, of course, not all biting occurs in structures, but for the rough estimates here, I am taking 100% of these diseases to be attributable to unhealthy buildings.

Partly Attributable to Unhealthy Buildings

Outdoor air pollution

The main sources of outdoor air pollution are outdoors, 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 particles, the pollutant used as the

[5] As the ETS CRA did not pass peer review in time for inclusion in the final WHO CRA, here I use the rule of thumb that ETS health impacts are about 5% of the impacts of the associated active smoking, which has been determined to be 4.1% of the global burden. In Table 1, therefore, ETS adds 0.2% to the global burden of IAP.

exposure indicator in the CRA, a mean global protection factor of 10% is assumed here. In other words, if urban buildings had been more healthy (protected us better 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.

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. Here, 25% of the global lead health burden is assumed to be of this type.

Remaining occupational risks (noise, accidents, and ergonomics)

Clearly, (workplace) building design and operation have a direct impact on the degree to which the risk factors of noise, accidents, and poor ergonomics burden the world. It is difficult, however, to generalize across the hundreds of thousands of workplace types and scales in different part of the world. Here, 50% is conservatively assigned to lack of healthy structures, reflecting the need also to redesign the localized work area itself (machinery, chairs, etc).

Poor water/sanitation/hygiene

Easy access to affordable, reliable, clean water and proper sanitation indoors would be on any list of healthy building characteristics in rich countries. The unfortunate reality, of course, is that a large fraction of the world has neither and what is available is usually divorced from housing (wells, standpipes, latrines, etc.). It is tempting, however, to reflect the Millenium Goals and other statements of basic human needs to say that no housing can be truly called 'healthy' without these characteristics. Reflecting the well-established need for hygiene education for these facilities to have their full effect, however, I assign only 85% of this burden to unhealthy housing itself.

Other Factors Having Significant Relationships with the Built-Environment, Depending on Assumptions (but not quantified here)

Lack of physical activity

As shown in Table 1, this risk factor is important globally and is clearly related to the design of the built-environment, including, buildings, workplaces, and their connecting infrastructure. Studies in the US, for example, show that most of the obesity epidemic in children seems to be due not to shifts in diet, but changes in physical activity in the last 40 years. The degree to which healthy building design alone could have actually reduced this impact is difficult to determine, however, and is not attempted here.

Falls

Falls, as shown in Table 1, have a rather surprising impact globally. Undoubtedly a significant fraction could have been prevented by better incorporation of safety considerations in buildings and their infrastructure, particularly in those places frequented by young children and the elderly. No attempt is made here to determine this fraction, however.

Road traffic accidents

Better design of the built-environment with regard not only to traffic safety itself, but also through land-use planning to reduce the need for use of motor vehicles would have had an effect on this large global risk factor as well. Buildings themselves would have little impact, but as part of the built-environment, a great deal. Here I do not attempt these estimations.

Climate change

Although as yet small in attributable risk, the potential avoidable human health risk from reducing anthropogenic emissions of greenhouse gases (GHG) and other global impacts on climate is substantial. Healthy buildings may some day be defined as those that do not contribute to net GHG emissions themselves while protecting their inhabitants from the extremes of climate (heat waves, tropical storms, etc.) that may be exacerbated by global warming. Malaria and dengue pressures are also thought to be enhanced by global warming, thereby essentially increasing the benefit of healthy housing. At this point, however, it would be difficult to determine the healthy-building fraction.

Table 1 Global burden of disease from unhealthy buildings (UHB) in 2000 (all figures in percentages)

	% OF TOTAL GLOBAL	% TO UHB	UHB BURDEN % OF TOTAL	% IN YOUNG CHILDREN	% IN WOMEN	% IN POOR NATIONS	% IN MID-INCOME NATIONS	% IN RICH NATIONS
Indoor Air Pollution	2.9	100	2.9	83	52	78	20	2
Work#1	0.3	100	0.3	0	13	17	57	28
Fires	0.5	100	0.5	22	57	80	11	9
Vector-borne Diseases	3.0	100	3.0	84	53	98	2	0
I. Subtotal	6.7	100%	6.7	75%	51%	84%	13%	3%
Outdoor Air Pollution	0.6	10	0.1	12	44	35	50	15
Lead	0.9	25	0.2	75	45	46	43	11
Work#2	1.3	50	0.7	0	10	50	40	10
Water/ Sanitation	3.8	85	3.2	77	49	85	13	2
II. Subtotal	6.6	63%	4.2	56%	40%	68%	26%	6%
Physical Inactivity	1.3	?	?	0	47	36	30	34
Falls	0.7	?	?	13	37	45	38	17
Road Traffic Accidents	2.1	?	?	7	30	32	54	14
Climate Change	0.6	?	?	88	51	94	5	1
III. Subtotal	4.7	?	?	16%	38%	43%	39%	18%
TOTAL* I+II	13.3	82%	10.9%	65%	46%	76%	19%	4%

Work #1: Airborne carcinogens and particles.
Work #2: Injuries, noise, and ergonomics.
*There are possibilities for double counting when adding attributable burdens from separate risk factors, but these seem minimal for Groups I and II here.

CONCLUSION: TOTAL GLOBAL BURDEN FROM UNHEALTHY BUILDINGS

As shown in Table 1, the total estimated burden from unhealthy buildings is about 11% of the global total burden of ill-health (fourth column). This includes no contribution from Category III risk factors, such as physical inactivity, which are related to the built-environment but not directly to buildings. One-ninth of the global burden may not seem large, but it is exceeded by few other categories. For example, all addictive substances (tobacco, alcohol, drugs) make up but 9% and total sexual/reproductive risks come to 7%. At about 15%, only the combined impacts of malnutrition in the world exceed unhealthy buildings. In terms of individual diseases, no single disease comes close to this impact for it is twice that of all cancers and more than all cardiovascular diseases combined (all heart diseases and stroke).

Like other environmental risks, most (76%) of the impacts of unhealthy buildings occur in the poorest countries and most (65%) fall on young children. Unlike growing epidemics such as HIV/AIDS and tobacco, therefore, the 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 unhealthy buildings.

As with many important risk factors, unhealthy buildings 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 unhealthy buildings, including clean water, sanitation, better ventilation, and screens are just these kinds of cost-effective tools. We may wish to examine the total health benefits of general housing improvements as well.

Some of the problems of unhealthy buildings, of course, do not go away with economic growth. ETS, road traffic accidents, climate change, and physical inactivity 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.

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