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Promoting Health and Advancing Development through Improved Housing in Low-Income Settings

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ABSTRACT *There is major untapped potential to improve health in low-income communities through improved housing design, fittings, materials and construction. Adverse effects on health from inadequate housing can occur through a range of mechanisms, both direct and indirect, including as a result of extreme weather, household air pollution, injuries or burns, the ingress of disease vectors and lack of clean water and sanitation. Collaborative action between public health professionals and those involved in developing formal and informal housing could advance both health and development by addressing risk factors for a range of adverse health outcomes. Potential trade-offs between design features which may reduce the risk of some adverse outcomes whilst increasing the risk of others must be explicitly considered.*

KEYWORDS *Housing, Household energy, Sanitation, Development, Health*

INTRODUCTION

Housing has historically been recognized as potentially important both for improving public health[1] and advancing development, but the public health and housing communities rarely work together to ensure that the design and construction of housing capitalize on that potential. As a consequence, opportunities to address these agendas simultaneously are often lost.

The home is more than a simple shelter; it forms the foundation for household and community life. It is a place for rest and relaxation, for socializing, for everyday functions. A house needs to protect against the elements (including extreme weather); to have sound structure; to be free of hazards, including pests and disease vectors; to provide adequate facilities for sleeping, personal hygiene, the preparation and storage of food; to provide an environment for comfortable relaxation; and to offer facilities for communication and social exchange with friends, family and others.

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However, the adequacy of housing is seldom assessed using such a broad definition. Even in high-income settings, decent housing is typically judged with reference to a set of minimum standards for specified hazards. For example, the UK Home Health and Safety Rating System provides a system for assessing a range of more than 20 specific health risks in the home.[2] In low-income settings, many of the same hazards apply, but their nature and relative magnitudes vary. Nearly half of the world's population survive on less than $2 per day.[3] There are dramatic differences between rich and poor in energy use, wealth and health. Radically new solutions are needed rapidly to raise billions out of poverty and improve their health. This means that opportunities to exploit socioeconomic, health and environmental goals simultaneously and synergistically must be grasped.

Housing is a key development priority. Although the proportion of urban residents living in slums declined from 39 to 33 % between 2000 and 2010, the absolute numbers are increasing in part because of the rapid pace of urbanization.[4] The population living in slums stands at 828 million and is set to increase further. It is anticipated that by 2030, 56 % of the developing world's population will be living in an urban environment. Between 2010 and 2030, the urban population of Africa is likely to increase by 85 % and that of Asia by 46 %. In total, the urban population of Africa and Asia is anticipated to grow by 1.2 billion.

Housing solutions need to be affordable and acceptable to the poorest half of the world's population. This has led to calls for a $1,000 house[5] based on principles of affordability, comfort and sustainability.

This paper makes the case that housing should be both a health and development priority, and that health considerations should form a key part of any strategies to design and build/modify houses for and with disadvantaged populations. It suggests which features of housing design and services are particularly likely to improve health whilst satisfying these principles. The design features that can reduce disease and injury risk should be implemented in an integrated fashion as determined by the prevailing epidemiological patterns of disease in the community. The public health community should capitalize more fully on the opportunities to advance health through closer working with those involved in designing and constructing formal and informal housing. By working together to achieve both health and development goals, better use can be made of limited resources, and substantial burdens of disease can be averted.

Mechanisms by which Housing Affects Health

Housing can affect health in many ways, both direct and indirect, through a range of mechanisms. In some cases, there are trade-offs between design features which may reduce the risk of some adverse outcomes whilst increasing the risk of others. There are also constraints on the use of some approaches including cost and availability of materials or energy supply. Some of these issues are summarized in Table 1.

Protection against Heat and Cold The first function of housing is protection against the elements, including low and high temperatures. For many low-income settings, the primary concern is protection against heat.

There is an extensive body of literature about the hazards associated with both low[1,6–8] and high *outdoor* temperatures[9,10] but surprisingly little evidence on the degree to which housing protects against such risks. Problems of indoor cold and fuel poverty[8] have been the focus of public health concern in Europe[11], New Zealand[12] and other temperate climates, but to date of very little focus in low-income settings, even though cold is a problem of many low-income populations especially at high altitudes or high latitudes.

The studies that have attempted to quantify the variation in risks of heat-related mortality in relation to dwelling type are from high-income settings.[13] Living in upper

TABLE 1 Framework for assessing the impact of housing features on health in low-income settings

Housing features	Health outcomes that may be affected	Mechanisms of effects	Potential trade-offs and constraints
Lack of screened housing, ceilings and open eaves	Malaria and other vector-borne diseases (VBDs), fly-borne diseases, e.g. trachoma and diarrheal diseases	Prevention of house entry by insect vectors	Reduced ventilation, increased thermal stress and indoor air pollution
Lack of efficient, low-emission cook stoves or clean fuels (e.g. liquified petroleum gas (LPG)/biogas, etc.)	Acute respiratory infections in children, chronic obstructive pulmonary disease, Ischemic heart disease (IHD), burns/scalds, etc.	Exposure to products of incomplete combustion leading to high levels of particulates, carbon monoxide (CO), Polycyclic aromatic hydrocarbons (PAHs), etc.; accidents with fires	Barriers include costs (low-emission stoves, LPG) and intermittent supply of LPG
Lack of safe and clean (electric) lighting	Burns and household air pollution from kerosene and other lamps	Indirect effects through inability to study, lack of physical security	No or unreliable electricity supply
Lack of ventilation, inappropriate albedo(e.g. white paint may increase reflection of sunlight and reduce heating)	Heat-related mortality and morbidity (converse in high altitude sites)	Thermal stress/cold exposure at high altitudes	See above
Fragile or inappropriate structure for location	At risk from extreme weather. Also, injuries, sexual violence, mental ill-health, VBDs	Robbery, physical attack, susceptibility to landslide, flood, storm, etc. Elevated housing may also protect against some VBDs	Cost may be prohibitive, ventilation may be reduced by smaller and more secure windows, etc.
Lack of clean water supply, washing facilities, toilet	Diarrheal disease, trachoma, intestinal parasites, respiratory infections, etc. Improving provision of water, sanitation and hygiene can improve nutritional status by reducing malnutrition due to diarrhea and intestinal parasites	Ingestion of pathogens; poor hygiene	Poorly maintained latrines or inadequate drainage may provide opportunities for mosquito and fly breeding

floors of older buildings confers a higher risk of heat-related death, although it may be possible to mitigate this risk by appropriate ventilation and insulation. However, even for these settings there is no quantitative evidence about health risk in relation to indoor temperature, merely an indication of more hazardous dwelling forms. In low-income settings, there is no direct evidence of this kind.

With regard to thermal 'comfort', it has long been known[14] that occupants' thermal responses adapt to changing ambient conditions. This makes the use of a 'passive design' approach more feasible which involves minimizing the energy needed to heat or cool the building whilst permitting adequate ventilation to prevent build up of indoor pollutants as outlined in Box 1.

Box 1. Protective housing design features for temperature control

Good passive design for temperature control is based on the following major principles:

- Appropriate solar control
  - Orientation of frequently used zones towards the equator, to allow maximum solar gain when it is needed to heat the dwelling, and to more easily exclude solar energy when it is not.
  - Suitable type and size of glazing to 'trap' solar energy inside a dwelling when it is needed.
  - Adequate shading to protect the dwelling from unwanted solar gains
- Thermal mass to store solar energy when required, and provide a heat sink when cooling is needed.
- Insulation to reduce unwanted heat losses or heat gains through the roof, walls, doors, windows and floors.
- Appropriate ventilation design to minimise heating loads but allow cooling when required. This design may include evaporative cooling methods.
- Zoning to allow different thermal requirements within a dwelling to be addressed.

In applying such general principles of protective design, attention needs to be paid to local context and potential trade-offs in risks must be acknowledged (e.g. good ventilation helps protect against over-heating risk, but may increase risks of vector borne disease transmission).

Case study example
The Witsand Community Energy Project (Witsand, Capetown)[53]

The Witsand Project was initiated by the City of Cape Town and addresses the site of a former informal settlement on the outskirts of the city. Phase one of the project, completed in 2003, built 400 new homes. The second phase aims to construct an additional 1,600 homes by 2013. The project includes a range of housing models and the site layout is designed to maximise passive measures, including passive solar and wind benefits. The houses are built in a manner that incorporates aspects of the major principles noted above – appropriate orientation, glazing, insulation and thermal mass.

Monitoring of temperatures in the new dwellings indicate that they were consistently ~ 5 deg. C warmer in winter and ~ 5 deg. C cooler in summer as compared with nearby informal housing .

Household Energy and Household Air Pollution Energy in the home is critical for basic needs—cooking, warmth, lighting—yet well into the twenty-first century some 3 billion still rely on solid fuels (wood, dung, crop wastes, charcoal and coal) burned in open fires or traditional stoves that are highly inefficient and emit high levels of air pollution into and around the home.[15] Many of these same homes, for around 1.3 billion people, have no electricity (and more have inadequate/intermittent power), and use candles or simple kerosene lamps for lighting which also cause significant pollution in the home.[16] These cooking and lighting technologies also pose a high risk for burns, scalds and fires, and child poisoning from unsafe storage of liquid fuel, mainly kerosene.[17] The collection of solid fuels can take as much as several hours per day[17], may take children away from school and in insecure settings places women at risk of gender-based violence.

Globally, solid fuel use (SFU) is highest in developing countries (Figure 1), and is closely related to poverty[16] and other associated household environmental health risks.[18] SFU is greatest in rural areas, reaching 95 % or more in many sub-Saharan African countries, but is also common in urban areas with up to 70 % SFU in cities of the least developed countries.

The main health consequences of these patterns of energy use in developing countries arise from household air pollution (HAP), caused by the inefficient combustion of solid fuels, and also from use of kerosene. Levels of HAP in the home are high, with typical average fine particle ($PM_{2.5}$) levels in the range

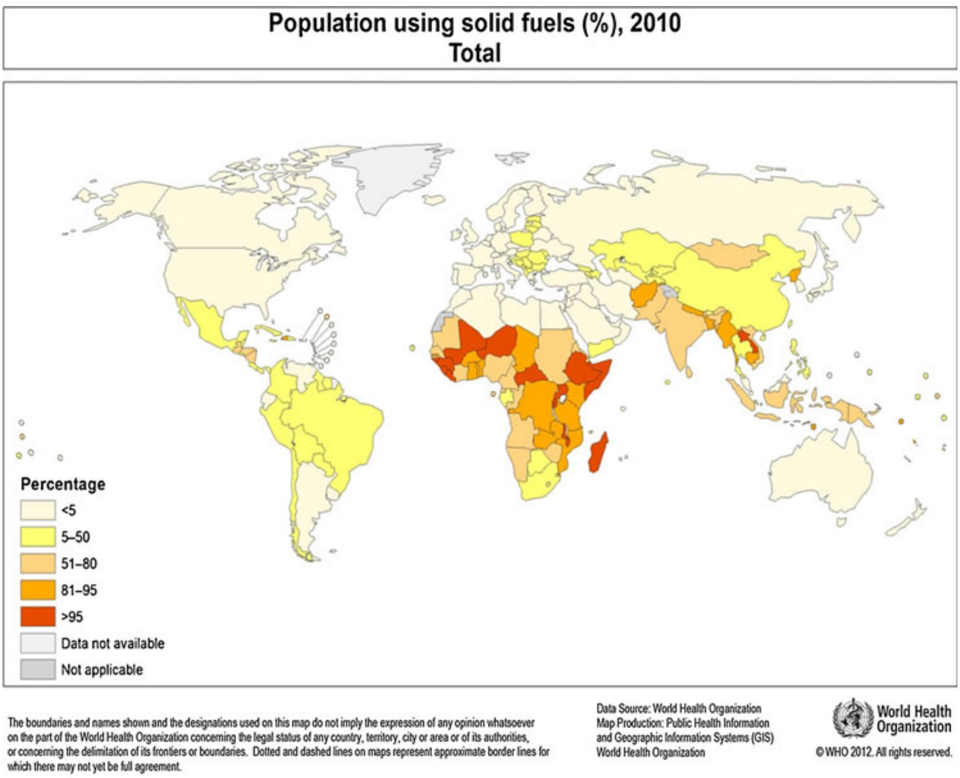

FIGURE 1. Percentage of population using solid fuels.

TABLE 2 Risks of different health outcomes from exposure to household solid fuel use

		Females		Males	
Outcome	Age group	Odds ratio	95 % CI	Odds ratio	95 % CI
Acute lower respiratory infection[78]	0–59 months	1.78	1.45, 2.18	As for females	
Chronic obstructive pulmonary disease[18,79,80]	Adult >15	2.70	1.95, 3.75	1.90	1.15, 3.13
Lung cancer (coal use)	Adult >15	1.98	1.16, 3.36	1.31	1.05, 1.76
Low birth weight[81]	N/A	1.52	1.28, 1.80	As for females	
		Mean reduction in birth weight=93.1 g	64.6, 121.6		
Stillbirth[81]	N/A	1.51	1.23, 1.85	As for females	

No studies are available from developing countries on Cardiovascular Disease (CVD) end points, although effects on 'intermediate' stage and risk factors such as blood pressure have been reported.[78,81] Based on the exposure response relationship published by Pope et al.[82] on multiple source combustion pollution and CVD risk, interpolated risks consistent with the reduction in exposure to HAP of 200 $\mu g m^{-3} PM_{2.5}$ of 1.20 for women and 1.073 for men, respectively, have been proposed[27]

200–500 $\mu g m^{-3}$, at least 20 times the WHO annual guideline level (10 $\mu g m^{-3}$). Even when cooking takes place outdoors, exposures of women and children can be considerable. A substantial and growing body of evidence now links these exposures to a wide range of important respiratory and other health outcomes.

FIGURE 2. Entry of *A. gambiae* through open eaves.

The estimated risks obtained from published systematic reviews are summarized in Table 2 and other risks in the Appendix 1.

Pests and Disease Vectors Many vector-borne diseases are transmitted indoors. Understanding how arthropods exploit our homes can provide simple ways of reducing the incidence of major vector-borne diseases like malaria[19], lymphatic filariasis, Chagas disease and dengue.

In Africa, the major vector of malaria, *Anopheles gambiae*, has adapted to feeding indoors, where over 80 % of transmission typically occurs. In other parts of the tropics, there tends to be a greater proportion of outdoor biting, but transmission indoors is still important, as illustrated by the successful control of malaria using long-lasting nets or indoor residual spraying. Since the home is where a large proportion of transmission occurs, changing the local architecture of houses can markedly reduce malaria transmission.[19]

In Africa, *A. gambiae* enters houses through open eaves (Figure 2), whilst culicine mosquitoes, vectors of urban lymphatic filariasis and some arboviruses, enter through the doors.[20] Blocking the eaves or installing ceilings to prevent mosquitoes entering the living area are simple ways to reduce transmission.[21] In a recent large-scale randomized controlled trial, house screening with untreated fly-screen mesh, installed as ceilings or as full screening on the doors and windows, reduced anaemia due to malaria in young Gambian children by around 50 %.[22] Since anaemia due to malaria is a major killer of young children, house screening has the potential to substantially reduce malaria deaths in this age group. In urban Africa, malaria transmission is about 95 % lower than in rural areas[23], with few vectors entering houses. Whilst there are many reasons for this, one likely explanation is that in urban situations houses are often well built having fewer entry points thus reducing the entry of mosquitoes, and thieves.

Raising homes above the ground on stilts may also be protective against mosquito house entry since many host-seeking mosquitoes fly less than 1 m above the ground[24–26] In São Tomé, wooden houses built on stilts had half the number of *A. gambiae* compared with houses that were built at ground level.[27] Whilst the disappearance of malaria in Europe and North America was related to a combination of factors[28], it was partly due to improved housing. Screened homes helped reduce malaria in the southern USA, whilst housing people away from their animals, and building homes that were well lit, warm and airy reduced the numbers of mosquitoes resting in European houses. The decline in malaria seen in many countries over the past decade is partly a result of development and the improvement in people's homes. The thatched-roofed housing once typical of rural Africa is far less common today than in the past. Modern metal-roofed houses with concrete walls and well-fitted windows and doors are likely to lead to fewer mosquitoes entering and resting indoors than in traditional houses. Housing features that may protect against spread of Chagas disease are described in Box 2.

Box 2. Housing measures to protect against Chagas disease

Chagas disease is transmitted by a number of different species of triatomid bugs, with the major vectors being highly adapted to the domestic environment. They are drawn to houses for many of the same reasons as humans; for shelter and a nearby food source and are commonly found in cracked walls in bedrooms and where roofs are made of palms. Emerging from their hiding places they feed on people at night when they are sleeping and provide easy meals.

Solutions are straightforward yet difficult to administer. The ideal house would have no cracks or crevices for shelter and at the same time be well lit and ventilated.[54 55] These are the improvements an intervention study in Paraguay performed on existing houses and found a 96.4% reduction in infestation. [56] Unfortunately the characteristics of local materials and temporary nature of homes are not conducive to providing such protection. Earth, a widely used wall material in rural housing is prone to cracking and water erosion. Rendering sufaces blocks cracks that would otherwise be used by Triatominae. If the plaster is white or another light colour it can help accupants identifly slow moving blood fed bugs and recognise fecal deposits, a sign of infestation.

Removing any fibrous materials such as grass roofs or stick walling and replacing these with materials that offer plane, smooth surfaces like concrete walls and flooring and corrugated metal roofing would be the most effective improvement but it comes with trade-offs. Thick, non-porous concrete reduces ventilation, natural lighting and cooling capacity. Corrugated metal roofing heats the house to extremes during the day and leaves the occupants with no protection from the cold night. A good compromise, however, is to regulate the spacing of materials to allow passages for light and air but eliminate habitats for Triatominae. Curtis [57] suggested wooden flooring with spacing of 1cm that ventilates the room and does not provide crevices small enough for resting insects.

Perhaps the best preventative method for infestation is improve the house's contruction and ideally reduce the level of maintenance required. Stable foundations allow the house to be constructed and maintained properly. A properly constructed house with stable foundations permits higher ceilings with thinner walls which in turn results in better ventilation and lighting. Stable foundations and improved construction also serve to protect the house from water erosion, something that could create cracks in the walls. Overhanging eaves also provide protection from rain water seeping into the walls and eroding them. Connections of different materials such as where the roof meets the wall or the doorframe and wall meet are where deformation and eventually cracks are most likely to appear. Homebuilders need to choose materials with similar rates of heating expansion and cooling shrinkage otherwise there will be warping at these connections.

Crowding and Space Overcrowding is not an issue of building design, but of building use: it is determined more by the lack of (economic) opportunity of the occupants than by any aspect of design or construction. There is no clear evidence-based definition of overcrowding, as the evidence of adverse health effects is consistent with a continuum of risk with increasing levels of crowding. There are also some advantages to high levels of occupancy—security, extended family social support—but these are generally outweighed by the hazards which are outlined in Box 3. In view of the lack of evidence regarding optimum levels of occupancy, rigid guidelines about space do not seem appropriate until the evidence is obtained to make this possible. However, the observation that subjective assessments of crowding and lack of privacy may increase the risk of ill health suggests housing designs should be flexible enough to cope with changes in family size for example by using modular approaches which allow extra rooms to be added when these are needed and can be afforded (see Box 4).

Box 3. Crowding and health

People who live in dwellings which are over-crowded or in multiple occupation appear to be at greater risk from a range of hazards. However, establishing epidemiological relationships is complicated by a number of analytical issues including differences in cultural practices; confounding by socio-economic factors; and the fact that over-crowded dwellings may also be in substandard condition. Overcrowding is often linked with poverty from which its effects can be difficult to separate. For low income settings, particular risks appear to relate to childhood infections.

Overcrowding has been associated with hygiene risks and the spread of infectious disease, including measles, mumps, chickenpox, diphtheria and most respiratory conditions [58 59] spread through air, and conditions such as scabies spread by physical contact. There is some evidence that TB risk may be linked to overcrowding both for levels of transmission and mortality. [60 61] For a range of other infectious illnesses there is a need to take socio-economic status into account. Meningococcal disease affects young children, in overcrowed conditions and young adults living in shared accommodation. [62 63] Otitis media has been reported to have a strong association with overcrowding in Greenland, [64] and hepatitis B risk with large household size in a New Zealand study. [65]

Patterns of contact between members of a household, sanitary conditions and access to washing facilities all help determine risk of spreading infection within a dwelling. Childhood diarrhea is particularly common where facilities for washing and cooking are shared and responsibility for cleaning these common areas is unclear.

There is also a suggestion that some infectious agents from childhood play a part in the onset of disease in adults, although currently there is an uncertain causal link for some of the outcomes. Helicobacter pylori infection has consistently been associated with overcrowding in childhood homes although the mode of transmission is unclear. [66 67] H. pylori causes type B gastritis and is strongly associated with gastric and duodenal ulcers, and restricted or delayed growth, as well as being implicated in stomach cancer. [68]

Psychological effects may also be important. Crowding enforces social contact, which may not always be desired or appropriate and has implications for both adults and children in leading to mental health problems. A number of authors have made the link between overcrowding and mental illness. [69] Parents are less verbally responsive to their children and speak in less complex ways- this may explain the relationship between overcrowding and delayed development as it still holds even when controlling for socio-economic status. [70] Difficulties were found in behavior at school, poor academic achievement, elevated blood pressure (boys) learned helplessness (girls) and impaired parent-child relationships in a study in India. [71] Objective indicators of overcrowding are not related to ill health in Bangkok, however subjective aspects are, for example housing satisfaction, and a perceived lack of privacy. [72]

A number of authors have also raised concerns about the effect of overcrowding on infant health. At 6 months wheeze in infants was elevated in overcrowded conditions in a Bristol study.[73] In another study pre-term infants (on return home) when compared to full term infants had an elevated rate of upper respiratory disease and diarrhea and vomiting associated with overcrowding. Overcrowding has been implicated in sudden infant death syndrome (SIDS), however the authors of a New Zealand study which looked at this felt that it was more likely to be social disadvantage than overcrowding as such.[74] Overcrowding has also been associated with increased risk of accidents and injuries, injuries, with violent deaths and with increased mortality in general.[58]

Box 4. Incremental and modular architecture

Perhaps the best form of upgrading the homes of low-income house owners is with modular architecture. The simplicity of a single unit belies its overall importance. The quintessential modular unit is low-cost, locally sourced, easily replicable, installed and maintained. Units must also interrelate, a trait that means buildings can be added to at a later stage. This is certainly useful for homeowners who want to see their living standards rise with their income. This adaptability to suit individual's needs is perhaps missed from many more formalized housing solutions. Incremental building means occupants can build what they can afford.

The winning entries for Vijay Govindarajan and Christian Sarkar's $300 House [75] competition show how affordable and recognized modular architecture is. Compressed Earth Blocks (CEB) are one of the most common modular units. Simple to make and made from readily available soil, the traditional techniques have been modernised using either hand or motor operated presses. The combination of traditional techniques and new technology forgoes the high costs of largescale industry and puts the power in local laborers' hands. Entries using "Hyper Wattle" and "Super Adobe" testify to this reinvention of the old. The former uses a wire mesh to keep that retains the insulating straw. Using a fabric to give structure to any assortment of fragments is a very basic example of a unit. Filled with a wide variety of resources and requiring no machinery, it needs only a low level of skill.

Modular architecture has potential advantages for making a healthy home. Health impact assessments rely on accurate measurements of the domestic environment. When one knows the characteristics of a single module, the potential health impacts can be assessed far more easily than for a more informal design. Standardising the home makes it easier to create consistent design features for better health.

In many emerging economics many people are escaping poverty and experiencing an increase in their standard of living. The transition from a low to middle-income life means a gradual change in living conditions. An incremental approach to architecture in line with the developing living standards of the occupant is perhaps the best method for ensuring that it evolves with changing circumstances.[76 77] If a home can be built gradually it becomes more adaptable to the changing situations of its occupant. Formal social housing can suffer from being too rigid in function, often being superfluous to the inhabitant's needs and at worst unaffordable.

Damp and Mold Damp and mold growth in the home have been consistently linked to a number of health outcomes, including nausea and vomiting and general ill health as well as respiratory illness (see also Appendix 2).[29–31] Housing that is damp and prone to condensation tends to result from inadequate ventilation or insulation and to be associated with poor maintenance of the dwelling and with the socioeconomic deprivation of the householder. However, there is a dearth of evidence about the effects of damp and mold in low-income countries.

Water and Sanitation Considerable reductions in diarrheal disease are associated with water supply and sanitation[32] (Figure 3). Yet, 783 million people still lack improved provision of drinking water, and 2.5 billion lack sanitation.[33,4] Considerable health benefits can be attributed to improved water supplies and sanitation: significant reductions in the risk of diarrheal disease are associated with water supply [relative

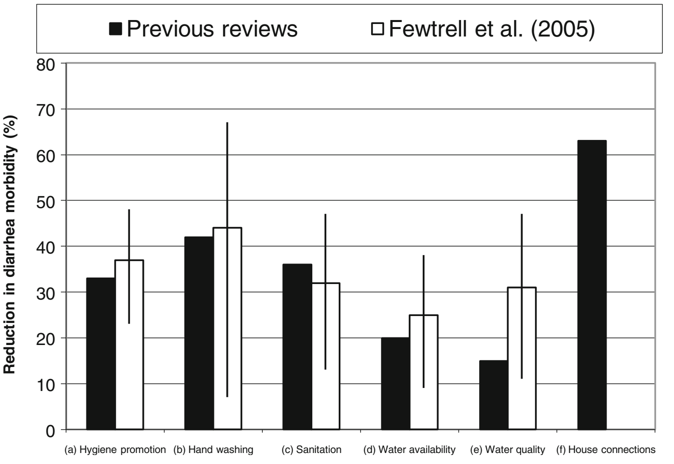

FIGURE 3. Results of reviews of the effect on diarrhea of water, sanitation and hygiene interventions. Results of the previous reviews are for the better quality studies. The reduction for household drinking water connections is in addition to reductions for water quality and availability of public sources. Source: Bartram & Cairncross 2010.[84]

risk, 0.75; 951 % confidence interval (CI), 0.62–0.91] and sanitation (relative risk, 0.68; 95 % CI, 0.53–0.87; Figure 3).[32]

However, unlike sanitation coverage, which is assessed at home, a water source is considered accessible when it is hundreds of metres from the place of use[4] In practice, water usage is constrained by the time taken (mainly by women) collecting water or the high costs paid to vendors. Household water connections greatly increase domestic water consumption, and much of this additional water is used for hygiene:[34] water scarcity and lack of hygiene promote endemic diarrhea, trachoma and other water and excreta-related diseases which disproportionately burden the poorest of the poor.[35]

Rainwater harvesting provides an alternative. A recent review suggests that rainwater consumption reduces the risk of diarrhea when compared with unimproved water supplies.[36] However, rainwater from thatched roofs is not potable; it brings the risk of leptospirosis from rat urine. Where the dry season lasts several months, rainwater use requires a large storage tank, which makes rainwater collection relatively expensive, and largely confining it to the monsoon belt of Southeast Asia, and small islands.[37]

Trials of treating water at the point-of-use (household-level chlorination, filtration or solar disinfection) have found large reductions in diarrhea[38], but this effect is not seen in blinded trials, undermining the evidence for effectiveness.[39] Endemic diarrhea is more frequently water-washed (spread person-to-person through lack of hygiene) than water-borne (in drinking water). Furthermore, the effectiveness of water quality interventions depends on a possibly unrealistic level of compliance[40]; greater health benefits are likely from investing in water supply infrastructure. For example, as well as reducing diarrhea, uninterrupted piped water removes the need for water storage containers, common breeding sites for *Aedes aegypti* mosquitoes which transmit dengue viruses in urban and peri-urban areas.[41]

Sanitation technology can include cheaper non-sewered options such as upgraded pit latrines in which flies and odours are controlled by ventilation, or pour-flush toilets flushed by hand using a few litres of water. These require a pit emptying service when used in urban settings. Preventing direct access to fecal waste is needed to avoid creation of mosquito and fly breeding sites in latrines—primarily *Culex* vectors of filariasis, and in sub-Saharan Africa, the latrine fly, *Chrysomya putoria*, a putative vector of diarrheal disease

The benefits of sanitation accrue to the individual household, and also to the community: for example, when transmission of diarrhea and intestinal worms has been removed from the public domain, household-related risk factors for infection emerge, such as the frequency of water supply interruption, poor sullage disposal and absence of a washstand; these indicate the need for environmental interventions to address disease transmission in the home as well as the community.[42,43] For example, design features of a house, such as locating a washstand within easy reach of a latrine, may enable handwashing with soap[44] which can reduce diarrheal disease by up to 47 %.[45]

Water supply and sanitation, like the best housing, comes at a cost: in the 1920s in the UK, relocation of inhabitants from an overcrowded slum to a purpose-built modern dwelling resulted in an increase in the death rate, predominantly from infectious diseases. The high rental costs of these new properties left less money available for food, resulting in nutritional deficiencies and increased disease susceptibility.[46] Household water purchase or connections to main water or sewers often cost the poor more than the wealthy and could have a similar effect.[35]

Cost-Effectiveness and Cost Benefits

Cost-effectiveness and cost–benefit analyses (CBA) of improved efficiency cookstoves have been reported for a range of scenarios[15,16,47] and in case studies. Results, especially for CBA, are favourable, although the valuation of health benefits in CBAs has shown these to make a relatively small contribution to the overall benefit to cost ratio. The mid-range costs of improved wood-burning and charcoal-burning stoves are $15 and $14, respectively, compared with $90 for propane (LPG) and $300 for electric stoves, putting the latter two options out of the reach of many poor families without subsidies or low cost loans.[47] Time efficiency and opportunity costs of time are critical factors that determine whether improved cooking technologies result in increased private returns compared with traditional cooking stoves. Although health benefits are valued by families, they may not be as important as the daily costs of fuel purchase and time spent cooking.[47]

The cost of full house screening is around $10 per person (assuming four people per house) and would be similar to insecticide-treated bednets or indoor residual spraying if it remained effective for 3–4 years.[22] In the case of water and sanitation technologies, costs are relatively low (Table 3) but still beyond the reach of the poorest. An important question for future analysis is the potential of greater economic efficiency for integrated interventions and delivery. It is also important to evaluate the cost-effectiveness of strategies to improve access to health-enhancing housing features for the poorest including microfinance and conditional cash transfers. Subsidies of improved cooking stoves and fuel through carbon funds may be justified on the basis of greenhouse pollutant reductions but will depend on assumptions about emissions of greenhouse pollutants including black carbon[47], and better data are needed for a range of technologies and locations.

Addressing Trade-offs

It is largely accepted that our environment affects our health. Designing a dwelling can be thought of as designing a habitable internal environment which is conductive to good health.[48] However the independent effect of housing on health after taking into account confounding factors such as poverty is not fully established and requires further rigorous research.[49,50] When trying to implement healthy housing policy, the most feasible solution is to relate the two fields through the environment. For example, health experts are able to predict what constitutes a healthy environment, while housing experts have the ability to recreate the ideal conditions.

Creating these ideal healthy domestic conditions is about achieving equilibrium rather than simply stacking ‘positive’ healthy design features. Almost all design strategies interrelate and sometimes will unintentionally conflict. For example, screening openings may reduce the ingress of disease vectors, but they also increase the internal temperature and reduce airflow through the house. Any newly implemented strategy must therefore be considered for its unforeseen repercussions, negative or otherwise, on the entire internal environment.

TABLE 3 Costs and cost-effectiveness of water supply and sanitation technologies (US dollars) (adapted from[83])

Intervention	Construction cost (US$ per capita)	Amortization lifetime (years)	Amortized annual cost (US$ per capita)	Operation and maintenance cost (US$ per capita)	Cost-effectiveness ($US/DALY, Disability Adjusted Life Year)
Water supply					
House connections	150.00	20	7.50	10.00	94.00
Hand pump or standpost	40.00	20	1.00	1.00	223.00
Water regulation and advocacy	US$0.02 to US$0.10 per capita per year				47.00
Sanitation	≤60.00	5	≤12.00	n.a.	≤270.00
Sanitation promotion	2.50	5	0.50	n.a.	
Hygiene promotion	1.00	5	0.20	n.a.	11.15

These health trade-offs are perhaps the trickiest problem to deal with when creating a healthy house. Perhaps the best answer is to first categorize which design strategies reduce which health hazards and then to prioritize those design strategies that reduce the most serious health hazards to the local population. The negative impact of house screening on ventilation may be worthwhile overall if it reduces a serious threat of malaria transmission in an endemic area.

Different contexts call for different responses to health needs and different design strategies. Table 4 relates design strategies and health effects through environmental effects. It also shows how certain strategies are dependent on the regional climate and environment.

Targeting Low-Income Groups

Targeting the poor is likely to yield the greatest benefits. So for example a program to provide clean water and sanitation together with clean household fuels and nutritional interventions to children younger than 5 in three regions (Latin America and the Caribbean, sub-Saharan Africa and South Asia) at 50 % coverage would yield 30–75 % greater heath benefits if targeted first at poor households than if the same program of interventions was targeted towards the wealthier households.[18]

Incorporating Socioeconomic Issues

In most city contexts, to address health concerns in housing, there is a need to incorporate many non-health issues. Often the most important is access to income-earning opportunities. Individuals or households with very limited incomes choose to live in very poor conditions (dormitories with hot beds which people rent for a few hours, on the pavement, whole households in a small room) because these allow them easy access to where they can earn incomes—often walking so there are no transport costs either. There is also the trade-off between housing quality and cost. Many low-income urban dwellers spend a significant proportion of their income on renting accommodation—and put up with poor quality overcrowded accommodation because it is cheaper and leaves more income for food purchase or other needs.[51]

Perhaps the most successful initiatives to integrate health principles into housing improvements have been support for 'slum'/squatter upgrading, especially where this includes good quality infrastructure provision (piped water to each home, toilets connected to sewers or septic tanks) and good quality health care and emergency services. Box 5 shows features of traditional and improved homes in Laos PDR.

TABLE 4 A framework for assessing healthy design strategies

Category	Design Strategies >	Environmental Effects >	**Health Effects,** Reduction of	Potentially Conflicting Strategies/Disadvantages				High Altitude Tropics	Low Altitude Tropics	Deltaic Tropics
Building Envelope	**Materials & Construction.** Foundations, roof, walls, doors, windows etc.	Controls internal heating/cooling loads	Vector-borne disease transmission, radon levels, indoor air pollution	Ventilation Strategies	Cooling Strategies	Acoustic Strategies	Lighting Strategies	Thicker walling to retain heat, a centralized plan to reduce external surface area, the need for maximum solar gain restricts orientation possibilities. The north face should be as small as possible and the south as large as possible.	Building footprints are as open as possible to reduce solar gain and increase ventilation. Thin walls. The North face should be as large as possible and the south side as small as possible.	Water-resistant materials to ensure against damp and structural damage. Metal materials should be chosen carefully as salt erosion is a common problem.
Lighting	**Natural lighting.** Top/Sidelighting	Luminance - Reduces need for electrical lighting	Damp and mold, may influence health outcomes related to heat loss and gain, eye-strain	Building Envelope Strategies	Shading Strategies	Glare Control	-	Direct solar gain to heat the building (more openings, more insulation materials)	As little solar gain as possible (less openings, less insulating materials)	-
	Electric lighting*	Luminance	Safety & security hazards, eye-strain, air pollution effects and burns from kerosene lamps	Glare Control	Energy Efficiency	An attractant of insect pests	-	-	-	-
	Shading.	Controls internal heating/cooling loads	Light-sensitivity sufferers, Eye-strain	Ventilation Strategies	Cooling Strategies	Natural Lighting Strategies	-	See above in Building Envelope-Materials and Construction row.	See above in Building Envelope-Materials and Construction row. Typically recessed windows and external shading devices.	-
Heating	**Solar gain.** Direct/Indirect gain	Increases heating loads, Thermal comfort	Illness relating to cold, damp and mold	Building Envelope Strategies	Cooling Strategies	Shading Strategies	-	Higher altitudes may need to consider solar gain more due to the slightly cooler climate.	-	
Cooling	**Ventilation.** Stack/Cross/Night ventilation	Increases air quality, humidity and cooling	Balance needed between reductions of vector-borne disease transmission and increases in damp, mold household air pollution and thermal stress	Noise Control	Natural Lighting Strategies	Fire Safety	Security	A trade-off between reducing heat loss but not losing fresh, ventilated air. Passive ventilation should be possible due to difference in internal/external air temperatures but should be very carefully moderated.	As much as possible but difficult to do due to little wind and lack of difference between internal/external air temperatures. Stack ventilation is a better solution for low altitude tropics where natural air flow is low.	Coastal regions are likely to be particularly humid and so need good air circulation throughout the house.
	Earth sheltering	Helps to stabilise large shifts in daily temperature, Thermal comfort	Illness relating to cold, damp and mold	Water Drainage	Natural Lighting Strategies	Ventilation Strategies	Structural Loads/ Soil Conditions	Earth sheltering is an effective strategy to stabilise large shifts in day to night temperatures. Ground is often inclined to allow one side of the house embedded and the other exposed to sunlight and ventilation.	-	Areas are prone to flooding and unstable ground conditions due to a higher water table.
Acoustics	**Noise-cancelling*** Materials, wall partitions etc.	Noise control	may influence health outcomes related to heat loss and gain	Building Envelope Strategies	Cooling Strategies	Lighting Strategies	Overcrowding	-	-	-

*Electric lighting and noise control are more likely to be health concerns in urban rather than rural populations due to issues arising from closer proximity to neighbours.

Box 5. Housing case study: low altitude rural Lao PDR

Relevant contextual factors:
Houses in the Lao PDR are normally constructed from locally available, natural materials. In rural areas they are raised on stilts approximately 1.4m above the ground and are built around a wooden frame with bamboo thatch walls and floors (see figure below). Various roofing materials may be utilised but palm leaf thatch, wooden tiles and corrugated iron sheeting are common. House eaves are normally open and homes in low-income rural areas rarely have any kind of ceiling. Cooking using biomass fuels takes place either within the main living area of the house or in a side room. The open veranda provides a cool, shaded area for people to sit during the day and water storage containers may be kept here or below the house.

A typical house in a low altitude rural village of Khammouane Province, south-central Lao PDR.

Relative impacts of refurbishment of existing housing and new house construction:
With increasing socioeconomic status, residents often decide to increase the size of their house, the number of rooms and degree of elevation above the ground. They might choose to build the walls and floors from more durable hard-wood and the area below the house is often enclosed with walls made from wood or brick, turning a single-storey raised house in to a two-storey house built on the ground (see figure below).

An improved house in Khammouane Province, south-central Lao PDR. The residents of the house have enclosed the open space below the house with brick and replaced wooden-shutter windows with glass. The walls and floors are constructed from pre-dried hardwood.

How could housing design address locally relevant health outcomes?
Improvement in the quality of house construction materials from bamboo thatch to hardwood walls and floors is expected to reduce house entry by mosquito vectors of diseases such as malaria and Japanese encephalitis which are prevalent in rural areas. The use of pre-dried timber for walls and floors will create a surface with fewer holes available for mosquitoes to enter. Raising houses above the ground on stilts may also have an impact on mosquito house entry rates as host-seeking females typically fly close to the ground when searching for a blood meal. The tradition of raising houses on stilts also reduces the risk of flood damage in lowland areas where flooding commonly occurs during each rainy season. Risk of respiratory infection may be increased in traditional houses where cooking takes place within the main living area compared with houses where the cooking fire is located outdoors or in a separate outhouse.

Successful initiatives can also include loans to support households to improve and extend their homes. Importantly, they usually include transferring legal tenure of the homes to the occupants who may take better care of their homes than landlords. In many middle-income nations, support for in situ upgrading of informal settlements has become standard practice for municipal authorities and is no longer controversial (as it still is in much of Africa and Asia). Some of the most effective in situ upgrading has been where government agencies supported grassroots organizations within the settlements scheduled for upgrading to design and organize the work—and negotiate with the landowner for the purchase of tenure or long leases.[52] Such initiatives could be combined to greater effect.

CONCLUSIONS

The rapidly increasing number of houses built in developing countries both in rural and urban areas offer real opportunities for improving health by incorporating easily installed, affordable features such as screens on doors, windows and ceilings and considering the most appropriate and affordable ways to provide water and sanitation . Encouraging development professionals, local government officials, public health experts, entomologists, architects, planners, constructors, NGOs and local communities to work together to design and construct homes that protect health is likely to reap rich rewards. Including public health considerations into training courses for these stakeholders could promote the integration of health-protecting design features into housing developments and refurbishment programmes.

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APPENDIX 1. COMMENTARY ON EVIDENCE RELATING TO FURTHER HEALTH OUTCOMES POSSIBLY ASSOCIATED WITH EXPOSURE TO EMISSIONS FROM INDOOR SOLID FUEL USE

Evidence is also emerging for a number of other outcomes, which were not included in Table 1 as current evidence is limited and/or systematic reviews are not available. We are aware of one study to date of HAP exposure and CVD as an endpoint which reported an odds ratio of 2.58 (1.53, 4.32)[85], but several studies of 'intermediate' stages and risk factors such as blood pressure have been reported. The analysis of the relationship between $PM_{2.5}$ from combustion sources (outdoor pollution, second-hand smoke and active smoking) by Pope et al.[82] suggests that HAP exposure (with the dose lying between second-hand and active smoking) would be associated with CVD risk.[86] Based on this assumption, risks consistent with the reduction in exposure to HAP of 200 $\mu g m^{-3} PM_{2.5}$ of 1.204 women and 1.0734 men, respectively, have been proposed.

A small but quite consistent set of studies report an increase risk of cataract.[87,88] Reviews have found inconsistent results for TB, however.[89–91] There is also evidence of links with other cancers, including of the upper aero-digestive tract[92,93] and carcinoma of the uterine cervix. All of these links, if confirmed, are consistent with the effects of tobacco smoke.

Kerosene is used for cooking and/or lighting fuel by some 500 million homes and has often been grouped with 'clean' fuels, but there are concerns about emissions as well as safety. One recent study reported a very elevated risk of TB associated with kerosene use for lighting and cooking[94], and this fuel is well recognized as serious risk for burns, fires and child poisoning.[95] Population data on burns and scalds are lacking. A high proportion of the 200,000 annual global burn deaths occur in developing countries, mostly in the home and associated with both liquid and solid fuel use. For every death, there are many more severe injuries, which are often inadequately treated, with severe lifelong consequences for disability and stigma. Electric lighting, whether powered through external connection or in-home solar photovoltaic units, will not only avoid the risk of burns and poisoning but also has zero emissions at the point of use (home).

Intervention studies are beginning to provide evidence that reducing exposure impacts positively on a number of these conditions. The RESPIRE trial has shown a one third reduction in severe pneumonia with use of a chimney stove that halved child exposure (OR=0·67 (0·45–0·98) p=0.042)[96], while three cohort studies of the impacts of the Chinese national improved stove programme have shown substantial reductions of 25–50 % in lung cancer, COPD[97] and adult pneumonia mortality for long-term improved stove users in coal-burning areas.

Although significant challenges in achieving large scale, exclusive use of much cleaner stoves and fuels remain, renewed efforts coordinated by the UN Foundation Alliance for clean cookstoves[98] are underway to address the critical technological, financing and market development issues involved. Delivery of cleaner, safer and more efficient household energy solutions as part of an integrated health home package including water and sanitation may offer synergistic benefits in terms of health and programmatic efficiency[99], but robust empirical evidence is not yet available.

Questions have been raised about whether a reduction in smoke in the home may increase the risk of vector-borne disease. A systematic review found that, while biting may increase, disease transmission was not affected.[100]

APPENDIX 2. HUMIDITY, CONDENSATION AND MOLD

Humidity in the dwelling can cause condensation which encourages the growth of fungal spores. Damp is also associated with an increase in house dust mites. Both of these are known allergens. This suggests a causal link between respiratory disease, in particular asthma, and damp and mold.[29] In addition, there is an observed dose–response relationship noted with this finding: asthma severity increasing with increasing levels of damp and mold in the home. House dust mites require warmth and humidity to thrive, ideally between 23 and 25 °C with 80–90 % humidity. Keeping a dwelling between 40 and 60 % humidity and improving ventilation decrease the number of mites.

Mold growth occurs when the ventilation is poor and the humidity levels are high. Intervention studies have shown that increasing ventilation and reducing humidity can decrease mold.

Studies use different methods of characterising mold—experts or self-reporting and many do not include confounding factors such as smoking or house type. Even so, there is still a consistent and significant relationship found between respiratory symptoms and damp and mold in dwellings. Whether this is an exacerbation of existing disease or the initiation of new disease is as yet unclear. Reduction of exposure to house dust mites also requires user behaviour for adequate airing of bedding, washing and the fitting of pillow and mattress covers which is unlikely to be practical in low-income settings. Structural factors such as consistent heating and good ventilation do play a role in keeping the exposure down, and further research is needed to better understand the health implications in low-income settings.

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