HAPI

Health
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Air Quality, Health, and Place

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Photo by Ann Forsyth

The HEALTH AND PLACE INITIATIVE (HAPI) investigates how to create healthier cities in the future, with a specific emphasis on China. Bringing together experts from the Harvard Graduate School of Design (HGSD) and the Harvard School of Public Health (HSPH), it creates a forum for understanding the multiple issues that face cities in light of rapid urbanization and an aging population worldwide.

Health and Places Initiative
http://research.gsd.harvard.edu/hapi/
Harvard Graduate School of Design

The Research Briefs series summarizes recent research on links between human health and places at the neighborhood or district scale and provides background for a number of other forthcoming products—a set of health assessment tools, planning and urban design guidelines, urban design prototypes, and neighborhood cases. While the Research Briefs draw out implications for practice, it is these other tools that really provide specific, real-world guidance for how to create healthy places.

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Big Ideas

- Air pollution causes health issues, such as premature deaths, chronic obstructive pulmonary disease, cancer, and respiratory diseases.
- Traffic and industry are two main sources of outdoor air pollution. Household or building pollutants (fuel smoke, radon, VOCs, etc.) are main sources or indoor air pollution. City design and climate change can exacerbate existing air pollution.
- Vulnerable Groups: Lower income groups suffer greater health effects from air pollution than others regardless of exposure. Women and children, especially poor women and children in low-income countries, are more at risk of indoor air pollution from biomass fuels (e.g. coal or wood used for cooking). Children are more vulnerable to the respiratory effects of traffic-related air pollution and biomass fuels. Older adults are more vulnerable to heart attack or stroke, and air pollution increases those risks.
- Outdoor air quality in China's cities and indoor air pollution in rural areas are at concerning levels.
- The health effects of air pollution can be mitigated through a combination of careful urban design and planning, building design, regulatory measures, and individual behaviors.

What the Research Says

Health Issues

Several health problems have been consistently related to air pollution as demonstrated in multiple literature reviews (see Table 1).

Table 1. Health problems related to air pollution

Health problem	Pollutant or Source
Premature deaths[1]	Traffic air pollution, biomass fuels (BMFs), environmental tobacco smoke, particulate matter
Cardiovascular effects/Chronic obstructive pulmonary disease[2]	Particulate matter: environmental tobacco smoke, BMFs, dusty roads, dust storms, forest fires, nitrogen oxides and ozone from fossil fuel combustion, and volatile organic compounds (VOCs)
Cancer (especially lung cancer)[3]	Environmental tobacco smoke, radon, asbestos, some BMFs, VOCs, mercury, dioxin, industrial processes, solvents, paint thinners, fuel
Respiratory diseases, infections, allergies, asthma, and lung function[4]	Environmental tobacco smoke, indoor allergens (e.g. dust, pets, pests, mold), VOCs, biomass fuel particulates, industrial sources (sulfur dioxide), dust from storms or roads, forest fires, particulate matter, diesel exhaust, smog (ozone), pollen induced aeroallergens
Headache, dizziness, muscular weakness, nausea[5]	VOCs (especially formaldehyde), carbon monoxide from BMFs or motor vehicles, boilers, furnaces
Neurological: learning disabilities, nervous system damage[6]	Lead from leaded fuel, metal processing

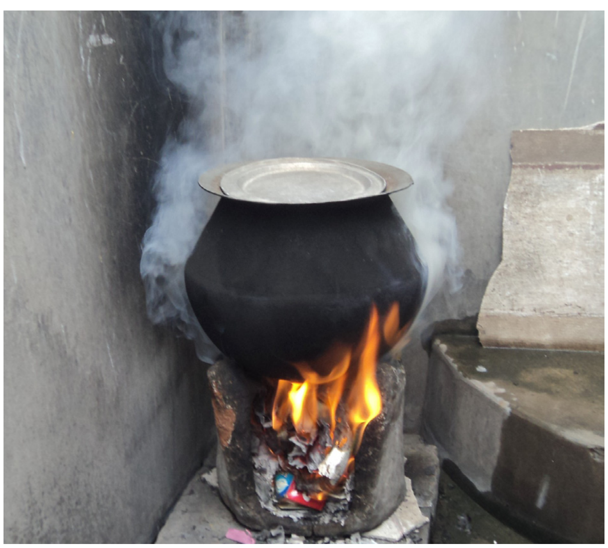
1. D'Amato 2010, 97; Laumbach and Kipen 2012, 6; Perez-Padilla et al. 2010, 1080
2. D'Amato 2010, 96; Zhang et al. 2010, 1111; Laumbach and Kipen 2012, 10; Perez-Padilla et al. 2010, 1080; Samet 2010, 323; Vrijheid et al. 2011, 598
3. Perez-Padilla et al. 2010, 1080-1081; Zhang et al. 2010, 1111; Samet 2010, 323
4. D'Amato et al. 2010, 95-96; Zhang et al. 2010, 1111; Laumbach and Kipen 2012, 10; Perez-Padilla et al. 2010, 1080-1081; Samet 2010, 322-323
5. D'Amato 2010, 97; Perez-Padilla et al. 2010, 1080-1081; Samet 2010, 322-324
6. Samet 2010, 322

Place Issues

Rural

In rural areas of low-income countries, biomass fuels (BMFs) or 'solid fuels' such as wood, charcoal, dung, and crop residues used for cooking and heating homes, are a large source toxin and particulates exposure[7].

Example: The World Health Organization (2004) conducted a review and analysis of BMF use in low-income countries, predictors of use, and health effects. They found that lower GNP per capita and rural areas were both significantly correlated with BMF use (Smith et al. 2004, 1446). Furthermore, "Estimates of relative risk obtained from epidemiological studies were combined in meta-analyses for three disease end-points for which there is strong evidence of an association with use of solid fuels: acute lower respiratory infections (ALRI) in children aged <5 years, chronic obstructive pulmonary disease (COPD) and lung cancer (estimates for lung cancer are only for use of coal). More than 1.6 million deaths and over 38.5 million disability-adjusted life years (DALYs) were attributable to indoor smoke from solid fuels in 2000. Cooking with solid fuels is thus responsible for a significant proportion, about 3% of the global burden of disease" (Smith et al. 2004, 1435–1436).



Wood burning stoves are common in low-income countries, and are a major source health problems relating to poor indoor air quality.

Urban

In urban areas, traffic (in-vehicle or outdoors), dust from roads and soils, and industry are important sources of outdoor pollutants[8].

Urban areas experience more allergic respiratory diseases and asthma.

Example: In D'Amato et al.'s (2010, 95) literature review of 100 recent articles on air pollution and risk factors of respiratory allergies they indicate, "The incidence of allergic respiratory diseases and bronchial asthma appears to be increasing worldwide, and people living in urban areas more frequently experience these conditions than those living in rural areas."

People close to major roads may be at a higher risk of health problems due to exposure to ultra-fine particulates.

Photo by Ann Forsyth

Industry and intensive development cause health problems related to air pollution. This is especially the case in China's mega-cities.

7. Laumbach and Kipen 2012; Perez-Padilla 2010, 1079; Pruss-Ustun, Bonjour and Corvalan 2008; Zhang and Gu 2013
8. Hudda and Fruin 2013; Laumbach and Kipen 2012; Wei and Yang 2010; Zhang and Gu 2013

Example: As part of a larger exposure risk assessment program, Hitchins et al. (2000) measured the number of concentrations of particles from vehicle emissions at varying distances from a major road in Australia. They conclude, “From the findings of this study it is clear that exposure to submicrometre [ultra-fine] particles is significantly increased within the investigated distance from 15 to 150m from a major road, compared to the urban average exposure levels (up to approximately seven times higher at 15m, and up to approximately three and a half times higher at 150m). On this basis, it is reasonable to assume that personnel living and working in close proximity to an urban freeway will likely be exposed to levels of submicrometre [ultra-fine] particles beyond ‘normal’ ambient levels. With concern already expressed elsewhere regarding the effect on human health of exposure to airborne particles, future research examining the relative health risk of such levels of exposure would be well targeted” (Hitchins et al. 2000, 58).

Example: Laumbach and Kipen (2012, 4) wrote a clinical review on air pollutions’ respiratory health effects. A clinical review is a selective synthesis of recent research on a medical topic, aimed toward updating and educating those in the medical field. Laumbach and Kipen’s (2012) review of 91 articles found, “In contrast to large-scale industrial sources of air pollution, the sources of BMF and traffic emissions tend to be in close proximity to individual ‘receptors’.”

Traffic is an important source of air pollution in urban areas, and contributes to negative health.

Example: Grahame and Schlesinger (2007) reviewed over 100 articles on the health effects of ambient airborne particulate matter (PM) from emissions from motor vehicles and coal-fired power plants. They were able to conclude, “These studies consistently found statistically significant relationships between vehicular emissions and adverse health outcomes, including all-cause and cardiopulmonary mortality and cancer. These relationships were considerably larger than the typically weaker relationships found with total mass $PM_{2.5}$ in earlier central monitor studies” (Grahame and Schleisinger 2007, 476).

Vulnerable Groups

Lower income groups suffer greater health effects from air pollution than others regardless of exposure.

Example: Deguen and Zmirou-Navier (2010, 27) conducted a European review of social inequalities and health risks related to air quality. Using specific search criteria, a total of 129 articles were found to be relevant to their literature search, of which 23 explored the modification of the relation between air pollution and some health event by socioeconomic status. They conclude, “Some studies found that poorer people were more exposed to air pollution whereas the reverse was observed in other papers. A general pattern, however, is that, irrespective of exposure, subjects of low socioeconomic status experience greater health effects of air pollution.”

Women and children, especially poor women and children in low-income countries, are more at risk of indoor air pollution.

Example: Perez-Padilla et al.’s (2010, 1081) general review article on the health effects of indoor air pollution illustrates the interactions between poverty, exposure to solid fuel smoke, and ill health. Crowded living conditions with poor ventilation, coupled with solid fuel use, increases exposure to the pollutants contained in solid fuel smoke, which in turn leads to negative health effects (especially for women and children).

Example: Fullerton et al. (2008) reviewed over 70 articles on indoor air pollution from BMF smoke in low-income countries. They conclude, “Indoor air pollution from BMF disproportionately affects women and children and is the cause of significant global mortality and morbidity” (Fullerton et al. 2008, 849).

Children are more vulnerable to the respiratory effects of traffic-related air pollution and BMF.

Example: Laumbach and Kipen’s (2012) clinical review identified a number of studies which showed children living in areas more polluted by traffic have reduced lung growth, and exacerbation and likely causation of asthma (Laumbach and Kipen 2012, 6–7).

Older adults are more likely to suffer from cardiovascular disease (see Physiology and Psychology of Aging), and therefore more vulnerable to heart attack and stroke (Table 1) related to air pollution.

China

China has troubling levels of both outdoor and indoor air pollution, with associated health effects. However, only some of the air quality problems are modifiable through neighborhood-level urban planning and design approaches. Rather, public policy needs to be changed to include air quality and building regulations.

Outdoor Air Pollution

Example: Zhang et al. (2010) reviewed how air and water pollution affects health in China. Their study included English and Chinese papers from the past 10 years, Chinese health and statistical yearbooks of the past 15 years, government reports of the past 5 years, and Chinese disease data for morbidity and mortality 1985–2007. They found, “Air quality in China’s cities is among the worst in the world...” (Zhang et al. 2010, 1110). Furthermore, “Outdoor air pollution in China originates from many sources, including residential and industrial coal combustion, a growing transport sector, chemical releases from industry, outdoor burning of agricultural waste, and dust from construction, roads, and deserts” (Zhang et al. 2010, 1112).

Example: Wang and Mauzerall (2006) evaluated the public health impacts of air pollution in the Zaozhuang Municaplity, located in the Shandong Province of eastern China. This municipality is heavily dependent on coal for energy. The authors estimate emissions of air pollutants for the year 2000, model three scenarios for the year 2020, simulate air pollution concentrations, estimate exposure and health impacts, and ultimately quantify the economic costs of those impacts. In conclusion, “Our assessment indicates that the economic costs of the health impacts from air pollution arising from coal combustion in eastern China was large in 2000 and is potentially enormous in 2020 if no additional controls are implemented. Public health would clearly benefit from BACT [best available emission control technology] and ACGT [advanced coal gasification technologies] and hence better air quality. Furthermore, ACGT are even more useful in controlling local air pollution than end-of-pipe controls and provide an opportunity to sequester CO_2 [carbon dioxide] underground. Our marginal health benefit calculation suggests that if the primary air pollution control objective is to minimize the total health damages of air pollution from energy use and if NH_3 [ammonia] emissions remain the same, the model region should focus on reduction in primary PM [particulate matter] and SO_2 [sulfur dioxide] emissions” (Wang and Mauzerall 2006, 1719).

Example: Wei and Yang (2010) synthesized the research findings of over 40 different empirical sampling studies of heavy metal contaminations in urban and agricultural soils, and urban road dusts in China. They found “The integrated pollution index (IPI) indicates that the urban soils and road dusts of the developed cities and the industrial cities have higher contamination levels of the heavy metals. The comparison of the IPIs of heavy metals in urban soils and urban road dusts of Shanghai, Hangzhou, Guangzhou and Hong Kong reveals that the contamination levels of the metals in urban road dusts are higher than that in urban soils in the cities” (Wei and Yang 2010, 99).

Indoor Air Pollution

Example: Zhang and Smith (2007) researched household air pollution from coal and biomass fuels in China. To do so, they reviewed approximately 200 articles in both English and Chinese journals reporting health effects, exposure, and fuel/stove interventions in China. Overall, they found, “Solid fuels are still the dominant source of energy in Chinese households, leading to pollutant levels generally exceeding China’s IAQ [indoor air quality] standards and contributing significantly to the national burden of ill health” (Zhang and Smith 2007, 854).

Things for Certain (or semi-Certain)

Using biomass fuel for cooking (e.g. wood, dung), traffic pollution, and (unregulated) industrial pollution are major causes of respiratory problems (see Table 2).

Table 2. Sources of pollution, related pollutants, and known health effects

Pollutant Source	Pollutants	Health Effects
Burning Biomass Fuels (BMFs)[9]	Particulate matter, carbon monoxide, nitrogen oxides, volatile organic compounds, allergens	Chronic obstructive pulmonary disease (COPD), lower respiratory tract infections (especially for women and children), lung cancer (coal smoke exposure), asthma (especially children, moderate evidence)
Traffic Pollution (vehicle emissions, road dust)[10]	Particulate matter, including ultrafine particulate matter, carbon monoxide, nitrogen oxides, ozone, volatile organic compounds, allergens, carcinogens, lead	COPD and asthma (adults)
Industrial Emissions and Intensive Development (e.g. Chinese mega-cities)[11]	Particulate matter, nitrogen dioxide, sulfur dioxide, ozone, carbon monoxides	Premature death, all cause, respiratory and cardiovascular deaths, hospital admissions

9. Laumbach and Kipen 2012, 10; Perez-Padilla 2010, 1082; Samet 2010, 32.
10. Laumbach and Kipen 2012, 10; Samet 2010, 321.
11. Atkinson et al. 2012, Pascal 2013, Shang et al. 2013.

Things up in the Air

There is some uncertainty as to how traffic-related air pollution and biomass fuel use is related to some health effects (see Table 3).

Table 3. Sources of pollution, and unknown health effects or relationships[12]

Pollutant Source	Unknown Health Effect or Relationship
Burning Biomass Fuels (BMFs)	Increase risk of tuberculosis, upper airway cancer, low birth weight, perinatal mortality, cardiovascular diseases
Traffic pollution (vehicle and industrial emissions, road dust, background ambient air pollution - especially fine particulate matter from emissions)	Exactly how much asthma risk is attributable to traffic related air pollution (TRAP), respiratory outcomes beyond asthma, how it causes asthma (allergic, irritant, and/or other), whether neonatal exposures to TRAP are a critical window to cause childhood asthma, increase risk of tuberculosis

12. Laumbach and Kipen 2012, 10; Perez-Padilla et al. 2010, 1082; Wang and Mauzerall 2006; Wei and Yang 2010; Zhang et al. 2012.

Implications

In these HAPI Research Briefs we aimed to find implications for planning and design at roughly the neighborhood level. These could include quantifiable standards, more qualitative but yet evidence-supported insights, and other good practices. Not every topic has a full complement of these implications. In the case of air quality, the majority of the reviewed articles refer to various types of interventions that could alleviate the negative health impacts of air quality issues.

Standards and Insights

There are four basic approaches to reducing air pollution exposures at the urban scale:

- Reducing the number of sources
- Cleaning up the emissions at the source (e.g. via regulations)
- Increasing the distance of vulnerable users from sources
- Filtering or protecting people from sources (e.g. technology, air conditioning)

Comprehensive planning and policy changes at a local level can have promising results in improving air pollution. However, these associations are quite complex, and related to larger trends of changing technologies and behaviors.

Several authors proposed mixed-use areas as a way of reducing commuting and improving air quality. However, this may be too simple as multi-worker households and general job mobility make it very hard to match jobs and work places. Also, mixed-use zoning can have its own problems with vehicle idling and industry mix (e.g. dry cleaners).

Example: London's 2003 congestion charging scheme (CCS) has been credited with significantly reducing air pollution in central London, and increasing life expectancy (Beevers and Carslaw 2005, Tonne et al. 2008). But this impact on travel behavior and air pollution is diluted when one considers the larger trends in technology, policy, and norms that were happening at the same time (Atkinson et al. 2009, Givoni 2012).

Promising solutions appear to be:

Reducing polluting sources from biomass cooking through improving technology, especially in low-income countries. Much of this involves changing technologies rather than changing urban planning and design approaches.

Example: Low-cost, improved wood burning stoves can improve air quality in rural areas in low-income countries (Perez-Pedilla et al. 2010, 1083–1084).

Increasing ventilation through building design.

Example: Gu et. al (2011) modeled four different layouts of high buildings to test the effects of uneven building layout on air flow and pollution dispersion in street canyons created by high-rise buildings. They were able to conclude that, "It is found that the uniform street canyon has the extreme of mean and maximum normalized pollutant concentrations" (Gu et al. 2011, 2664).

Example: Kastner-Klein and Rotach (2004) used a detailed model of an urban landscape to test wind flow and turbulence characteristics. They found step backs (or setbacks) on buildings helps airflow, as opposed to a series of tall buildings with flat façades in a street canyon (Kastner-Klein and Rotach 2004, 68).

Locating sensitive uses away from sources of pollution such as busy roads and factories, in the range of 100–500 meters, can reduce respiratory diseases in vulnerable groups.

Example: Zhou and Levy (2007) conducted a meta-analysis (33 included studies) of the spatial extent of traffic related air pollution (TRAP) impacts (four pollutants: carbon monoxide, benzene, nitrogen oxides, and particulate matter). They conclude, "In spite of the above intricacies, the literature allows us to develop some first-order rules of thumb for policy makers and other stakeholders. Omitting the health risk threshold perspective or circumstances with high background concentrations and no significant gradients, the spatial extent of impact for mobile sources reviewed in this study is generally on the order of 100–400m for elemental carbon or particular matter mass concentration (excluding background concentration), 200–500m for NO_2, and 100–300m for ultrafine particle count. From a policy perspective, this might indicate that a 500 meter buffer around a roadway would be appropriately protective under most circumstances" (Zhou and Levy 2007, 8).

Planting and maintaining an urban forest can have benefits for reducing particulates, aesthetics, and ecology.

Example: In a review and analysis of the costs and benefits of urban forests as a way to mitigate pollution, Escobedo et al. (2011, 2083) describe how "managing urban forests for PM_{10} removal in Santiago was just as cost-effective other PM_{10} reduction technologies and policies...However, unlike these other control approaches, urban forests also provide additional ecosystem services (i.e. bundles)" (Escobedo et al. 2011, 2080). Other ecosystem services Escobedo et al. mention include natural areas for human use, aesthetics, habitat provision, food production, shade, wind reduction, increasing water quality, erosion control and stormwater reduction, to name a few.

Air conditioning can decrease the effects of traffic pollution on asthma.

Example: Laumbach and Kipen (2012) conducted a clinical review of 91 articles on the respiratory health effects of air pollution, particularly as it relates to recent literature on biomass smoke and traffic pollution.
In overview, the most relevant findings for the Health and Places Initiative project include (Laumbach and Kipen 2012, 10):

- Children who move from more polluted areas to less polluted locations have been shown to reverse impaired lung function
- Short-term air pollution interventions decrease respiratory morbidity
- Air conditioning can decrease the effects of traffic pollution on asthma

Photo: "London Congestion Charge, Old Street, England". Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons

Comprehensive local policy and planning changes can make a difference in air quality. For example, London's congestion charging scheme.

Photo by Ann Forsyth

Planting street trees and maintaining urban forests can improve air quality, as well as benefit many other health areas.

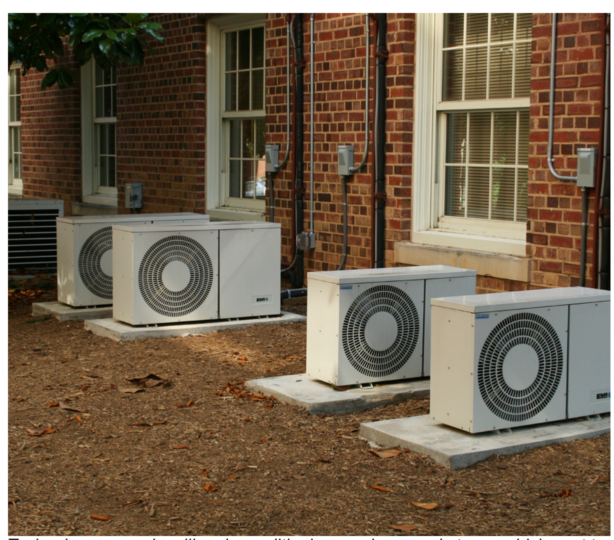


Photo: "2008-07-11 Air conditioners at UNC-CH" by Ildar Sagdejev (Specious) - Own work. Licensed under Creative Commons Attribution-Share Alike 3.0-2.5-2.0-1.0 via Wikimedia Commons

Technology upgrades, like air conditioning—or improved stoves which vent to the outdoors—can improve indoor air quality.

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