The Built Environment, Climate Change, and Health

Opportunities for Co-Benefits

Margalit Younger, MPH, Heather R. Morrow-Almeida, MPH, Stephen M. Vindigni, MPH, Andrew L. Dannenberg, MD, MPH

Abstract: The earth's climate is changing, due largely to greenhouse gas emissions resulting from human activity. These human-generated gases derive in part from aspects of the built environment such as transportation systems and infrastructure, building construction and operation, and land-use planning. Transportation, the largest end-use consumer of energy, affects human health directly through air pollution and subsequent respiratory effects, as well as indirectly through physical activity behavior. Buildings contribute to climate change, influence transportation, and affect health through the materials utilized, decisions about sites, electricity and water usage, and landscape surroundings. Land use, forestry, and agriculture also contribute to climate change and affect health by increasing atmospheric levels of carbon dioxide, shaping the infrastructures for both transportation and buildings, and affecting access to green spaces. Vulnerable populations are disproportionately affected with regard to transportation, buildings, and land use, and are most at risk for experiencing the effects of climate change. Working across sectors to incorporate a health promotion approach in the design and development of built environment components may mitigate climate change, promote adaptation, and improve public health. (Am J Prev Med 2008;35(5):517–526) Published by Elsevier Inc. on behalf of American Journal of Preventive Medicine.

Introduction

Evidence indicates that the global climate is changing, resulting in elevated temperatures, rising sea levels, heavier precipitation events (e.g., floods, storms, hurricanes, and cyclones), additional heatwaves, and more areas affected by drought.[1] Possible health consequences include morbidity and mortality related to heat, extreme weather events, vectorborne and waterborne infections, mental stress, food and water shortages, respiratory diseases, international conflict, and air pollution.[2,3] Greenhouse gas (GHG) emissions, composed mainly of carbon dioxide, methane, nitrous oxide, and fluorinated gases,[4] increased 70% from 1970 to 2004,[5] contributing to these changes. Carbon dioxide (CO_2) emissions, in particular, accounted for 77% of total anthropogenic GHG emissions in 2004.[5] Because these emissions are largely a result of human activity,[1] changes in policies and behaviors can help reduce GHG emissions, climate change, and adverse health consequences.

The built environment influences human choices, which in turn affect health and the global climate. Distinct from the natural environment, the built environment is comprised of manmade components of people's surroundings, from small-scale settings (e.g., offices, houses, hospitals, shopping malls, and schools) to large-scale settings (e.g., neighborhoods, communities, and cities), as well as roads, sidewalks, green spaces, and connecting transit systems. The development of the built environment involves many sectors, including urban planning, architecture, engineering, local and regional governments, transportation design, environmental psychology, and land conservation. Neighborhood design not only influences health by affecting physical activity, respiratory and cardiac health, injury risk, chronic disease risk, social connectedness, and mental health,[6] but many current community design practices also adversely contribute to global climate change.

The UN Intergovernmental Panel on Climate Change has noted the relationship between components of the built environment and climate change, reporting that global GHG emissions have grown largely as a result of the following sectors: energy supply, transportation, industry, land use and forestry, agriculture, and buildings.[5] Strategies that aim to reduce atmospheric CO_2 include decreased use of motor

From the National Center for Environmental Health/Agency for Toxic Substances and Disease Registry, CDC (Younger, Morrow-Almeida, Vindigni, Dannenberg); Office of Workforce and Career Development, Career Development Division, Public Health Prevention Service, CDC (Morrow-Almeida); and Emory University, School of Medicine (Vindigni), Atlanta, Georgia

Address correspondence and reprint requests to: Margalit Younger, MPH, Office of Policy, Planning, and Evaluation, NCEH/ATSDR, CDC, 4770 Buford Highway, MS F-61, Atlanta GA 30341. E-mail: myounger@cdc.gov.

0749-3797/08/$–see front matter
doi:10.1016/j.amepre.2008.08.017

vehicles, increased energy efficiency in buildings, and reduced deforestation.[7] Based on these strategies, the current study focuses on three built environment components: transportation, buildings, and land use (including forestry and agriculture).

These aspects of the built environment may disproportionately affect vulnerable populations, such as children, the elderly, people with disabilities, racial and ethnic minorities, and people of low SES, particularly when effects on health are not incorporated into built environment decision making. These populations are also among the groups most susceptible to health effects caused by climate change.[8] The health effects experienced by vulnerable populations are highlighted in this article.

Because the built environment constitutes an important contributor to climate change and health outcomes, alternative practices offer opportunities both for improved health and reduced climate change. This article presents the current evidence and potential co-benefits of alternative practices, and illustrates built environment strategies that minimize the effects of climate change and improve health (Table 1). Opportunities for partnerships between health sectors and non–health sectors sharing similar goals are also examined. Finally, next steps and areas for further research are suggested.

Transportation

Transportation, a key feature of the built environment, encompasses roads, highways, airports, railroads, public transit, ports, and bicycle trails, as well as the interaction of these systems with cities and communities. Transportation accounted for 28% of total U.S. GHG emissions in 2006, of which 94% was from energy-related CO_2 emissions. Furthermore, transportation was the largest end-use sector producing energy-related CO_2 emissions in 2006, nearly all of which was caused by petroleum combustion.[9] Three aspects of the transportation sector contribute to GHG emissions: fuel efficiency of vehicles, carbon content of fuel, and vehicle miles traveled.[10] Of these, vehicle miles traveled affects GHG emissions directly through the built environment.

Transportation infrastructure and systems affect both GHG emissions and public health. Transportation patterns are related to pedestrian and motor vehicle fatalities and nonfatal injuries.[11] Motor vehicle crashes account for more than 40,000 deaths and almost 3 million injuries a year in the U.S.[12] In addition, injury rates among pedestrians and bicyclists are higher in the U.S. than in Germany or the Netherlands, although Germany and the Netherlands have substantially greater rates of walking and bicycling.[13] By reducing distances between destinations and decreasing vehicle miles traveled, transportation designs can be altered, thereby affecting injury rates among drivers, pedestrians, and bicyclists, as well as climate change.

Climate change and air quality have an interactive relationship. Climate change affects air quality by altering local weather patterns, such as temperature and wind speed, which affect the distribution of air pollution. Anthropogenic sources of air pollution (e.g., motor vehicles) promote climate change through their emission of CO_2, volatile organic compounds (VOCs), and nitrous oxide.[14] The combination of VOCs, nitrous oxide, and sunlight form ozone and smog, which are harmful to health.[15,16] Although no direct health effects are attributed to increased ambient levels of CO_2,[17] high concentrations of indoor CO_2 are associated with drowsiness, headaches, poor concentration, and increased heart rate; and extremely high concentrations of CO_2 (>5000 parts per million [ppm]) potentially lead to oxygen deprivation and serious health effects.[18] Other byproducts of fossil fuel combustion (e.g., ozone and fine particulate matter) contribute to air pollution and associated respiratory illnesses.[14,19,20]

Exposure to air pollutants is linked to chronic obstructive pulmonary disease hospitalizations,[21] respiratory and cardiovascular morbidity and mortality,[22] acute asthma care events,[23] diabetes mellitus prevalence,[24] lung cancer risk,[25] birth defects,[26] lung impairment, fatigue, headaches, respiratory infections, and eye irritation.[20] Air pollution health effects are particularly associated with SES and age. Asthmatic children living in areas with low SES were found to be more affected by air pollution than asthmatic children in high-SES regions.[27] Emergency room visits for air pollution–related asthma were highest among young children and the elderly.[28] Thus, increased exposure to air pollutants, which climate change may intensify, can exacerbate respiratory illnesses for those most vulnerable, such as children,[29] athletes, asthmatics, and people with cardiac or pulmonary conditions.[14]

Transportation infrastructure affects physical activity as well. A study of five pedestrian and bicycling trails in Nebraska found the average cost per user in 2002 was $235, but resulted in medical cost savings of $622 per person from engaging in physical activity.[30] Trails offer multiple co-benefits, by improving physical activity levels, providing alternative transportation routes, and preserving green space. Walking, bicycling, and using mass transit (which often includes walking) for commuting purposes can increase physical activity,[31,32] which in turn enhances psychological well-being and reduces risks of mortality, cardiovascular disease, stroke, colon cancer, diabetes mellitus, and depression.[33] Less time in automobiles reduces exposure to busy traffic and "road rage"[34,35] and decreases the likelihood of obesity,[36] while simultaneously reducing GHG emissions.

Table 1. Relationships among the built environment, climate change, and health

Built environment category	Link to greenhouse gas emissions and climate change	Built environment strategies	Impacts	Health co-benefits
Transportation	• Fuel consumption associated with personal and commercial vehicle use • Number of vehicle miles traveled per capita • Long distances between homes, jobs, schools, and other destinations • Long distances from farm and factory to market	• Increase proportion of people and goods transported on rails rather than roads • Promote telecommuting • Decrease air travel • Decrease distances between destinations (denser and mixed-use development) • Increase facilities and opportunities for transit use, walking, and bicycling • Promote safe routes to school programs • Promote use of food and goods from local suppliers • Develop infrastructure for alternative fuel generation and distribution	• Improved air quality from reduced motor vehicle emissions • Increased physical activity from walking and bicycling • Enhanced social capital	• Reduced motor vehicle injuries and fatalities from reduced motor vehicle travel • Reduced levels of respiratory illnesses (e.g., asthma) due to improved air quality • Reduced likelihood of cardiovascular diseases, some cancers, and osteoporosis, due to increased physical activity • Improved mental health and decreased depression and anxiety, due to enhanced social capital
Buildings	• Energy use in producing and transporting construction materials ("embedded energy") • Energy use in construction practices • Energy use in heating and cooling • Energy use in building operations, such as lighting and elevators • Building site choices that promote automobile dependency and sprawl	• Increase use of sustainable, local, and/or recycled construction materials and reuse of older buildings • Increase heating and cooling efficiency through site orientation, insulated windows, green roofs, and natural ventilation • Decrease electricity use by occupants by providing convenient stairs, compact florescent bulbs, day-lighting, and motion sensor light switches • Adopt LEED guidelines for energy-efficient buildings • Use less square footage when designing and building houses • Reduce drive-through services that typically involve idling automobiles	• Improved air quality from reduced coal-generated electricity • Increased physical activity from stair use • Decreased heat island effects	• Reduced levels of respiratory illnesses (e.g., asthma) due to improved air quality • Reduced likelihood of cardiovascular diseases, some cancers, and osteoporosis, due to increased physical activity • Improved mental health and productivity from use of day-lighting • Reduced susceptibility to heat-related illnesses due to decrease in heat island effects
Land use, forestry, and agriculture	• Deforestation associated with logging, agriculture, and sprawling development • Separation of land uses, which increases travel • Buildings constructed in vulnerable areas, such as coastal regions and flood plains	• Develop mixed-use communities following smart growth and LEED-ND principles • Preserve and expand parks, trails, and green space • Encourage community gardens and farmers' markets • Reduce construction in coastal locations, flood plains, and other vulnerable areas • Provide incentives to protect, manage, and sustain forests • Coordinate regional planning • Support sustainable logging and agriculture • Reduce demand for meat consumption	• Increased physical activity from walking and bicycling in mixed-use communities • Improved social capital from use of parks and trails and contact with nature • Improved nutrition and social capital from locally grown food • Increased multi-use forests for recreation and commercial use	• Reduced likelihood of cardiovascular diseases, some cancers, and osteoporosis, due to increased physical activity • Improved mental health and decreased depression and anxiety, due to improved social capital • Reduced fatal and nonfatal injuries from severe weather events

LEED, U.S. Green Building Council's Leadership in Energy and Environmental Design rating systems; LEED-ND, for neighborhood development

Communities highly dependent on automobiles pose mobility barriers for children, the elderly, those without vehicles, and people with mobility impairments. Accessible, walkable, and safe neighborhoods with mixed-land use, good connectivity, public transit options, and recreational facilities encourage people with limited mobility or special needs to stay physically active, independent, and involved in community activities.[37,38] Among the elderly, exercise is associated with lower rates of functional decline[39] and dementia,[40] and may

enable seniors to remain independent longer.[38] Aspects of the built environment that facilitate physical activity for all populations offer the co-benefit of reducing motor vehicle associated pollution, thereby diminishing both health hazards and the GHG emissions contributing to climate change.

Transportation in the U.S. has been influenced by policies encouraging highway expansion,[41] decreasing fuel efficiency standards,[42] and providing purchasers of trucks and sport utility vehicles with considerable tax deductions.[43] Although strategies to reduce the contribution of transportation to climate change have focused on technologic improvements (e.g., alternative fuels or more efficient vehicles), personal transportation choices and the policies that influence those choices must also be considered. Policies that influence personal transportation choices include those that facilitate increased use of mass transit options, land-use planning that results in decreased travel distances between destinations, and workplace options that reduce travel (e.g., telecommuting). "Complete streets" can be designed to accommodate all users, including pedestrian, bicycle, and vehicular traffic.[44] Communities can be planned and redeveloped with "smart growth" principles to account for various modes of travel.[45] A decaying shopping mall in Denver, for instance, has been transformed into a mixed-use community with access to the city's light-rail system, thus providing convenient travel alternatives that promote health and reduce climate change.[46] Personal choices such as walking, bicycling, reducing vehicle miles traveled, combining trips, and living in transit-oriented mixed-use developments not only reduce CO_2 emissions, but also increase levels of physical activity.

Buildings

Global CO_2 emissions from energy use in buildings grew approximately 3% per year between 1999 and 2004.[47] Residential, commercial, and industrial buildings account for 43% of U.S. CO_2 emissions, with most (71%) of these emissions caused by electricity consumption in residential and commercial buildings.[48,49] Coal, the predominant energy source consumed by the electric power sector, produced 83% of U.S. CO_2 emissions in 2006 and contributed to methane emissions as well.[9] Buildings affect GHG emissions through various aspects of their design, location, orientation, and use, such as their relationship to each other and the neighboring landscape, the material composition and design elements of their interiors and exteriors, and the energy and water resources used by their occupants. A building's energy use is also affected by features of its surrounding environment (e.g., sunlight, wind, trees, and water), which in turn affects its GHG emissions.

Various building aspects influence the health of users. For example, design characteristics of hospitals, such as better lighting, layout, and ventilation, have resulted in reduced stress and fatigue in patients and staff, as well as improvement in overall health.[50] Similarly, building placement relative to residential and commercial areas influences whether occupants must depend on automobiles or are able to walk, bicycle, and use public transit to other destinations,[51–53] and has been shown to have a considerable impact on BMI.[54]

The conditions of a building affect the health of its occupants. Mold, pests, lack of safe drinking water, and inadequate heating or cooling, waste disposal, and ventilation systems result in adverse health effects, including respiratory illnesses, asthma, infectious diseases, injuries, and mental health disorders. These conditions, which are characteristic of substandard housing, predominantly affect vulnerable populations, specifically people of low SES and racial minorities.[55] Moreover, susceptibility of poor and minority populations to hazards may be increased due to underlying health conditions,[56] such as asthma[57] and cardiovascular disease.[58] Therefore, maintaining the conditions of a building improves the health of its occupants.

Decisions to use sustainable building materials and operation practices can promote health and protect the environment by mitigating the *urban heat island effect* (higher temperatures in metropolitan areas than in surrounding areas),[59] conserving resources, and allowing safe disposal of contaminated or hazardous waste products.[60] Environmentally friendly supplies (e.g., recycled materials) can be substituted for products that use nonrenewable resources. Buildings constructed with locally produced materials support local economies and reduce transportation-related air pollution.[61] In addition, building and landscape designs can encourage routine physical activity by providing accessible, attractive stairwells with clear signage[62,63] and outdoor walking paths.

Carbon dioxide emissions from buildings are primarily caused by the use of electricity to provide heating, cooling, lighting, water, information management, and entertainment systems.[48] Because of their long life expectancies, buildings affect the environment and public health for many years. Commercial buildings last an estimated median of 70–75 years. One fourth of existing commercial floor space was constructed prior to 1960. Similarly, approximately one fourth of existing residential housing in 2003 had been built before 1949.[49] Both older building renovation and new construction offer opportunities to promote energy efficiency and support healthier working and living for future decades.

Energy-efficient materials may cost more initially, but offer long-term savings.[48] Although strained budgets can limit opportunities to use environmentally friendly, sustainable ("green") technologies and building mate-

rials, forward-thinking clients, architects, and developers are working together to design and build energy-efficient buildings. For instance, as part of its Office of Sustainability Initiatives,[64] Emory University is renovating existing university buildings for energy efficiency and constructing new buildings according to green building standards.[65] The Yang and Yamazaki Environment and Energy (Y2E2) building at Stanford University is another example of energy efficiency and innovation in an academic setting.[66,67]

In the last several years, there have been efforts to green the healthcare industry and promote sustainability and health. Health Care Without Harm, an international coalition of hospitals and healthcare organizations, supports green building practices and ecologically sustainable policies.[68] Environmental conferences, such as CleanMed, bring together healthcare leaders to discuss ways to green health care.[69] In addition, the Green Guide for Health Care, a toolkit for healthcare institutions, was developed to aid in the design and construction of sustainable buildings that promote the health of staff, patients, and visitors, as well as the environment.[70] Creation of a green hospital at the University of Pittsburgh includes constructing innovative buildings and retrofitting existing buildings using green practices, altering procedures in waste management and housekeeping, supporting strategies that improve air quality, and promoting water and energy conservation.[71] Sustainable hospitals can recover incremental costs after 1 year and accrue financial benefits during subsequent years.[60] These activities illustrate the involvement of the healthcare sector in the green movement, thereby mitigating climate change and promoting human health.

Mitigation strategies, such as reducing overall meat consumption and supporting local farmers' markets and community gardens, ease the burden of food production an GHG emissions by decreasing the distance goods are transported and the demand for deforestation. LEED rating systems consider the development of sustainable sites, water savings, energy efficiency, material choice, and quality of indoor environments.[72] LEED-ND for neighborhood development considers location and connectivity, pattern and design, and construction on a community scale.[73] Through tax rebates, LEED incentives, energy-efficient appliances, and reuse of existing materials, clients and developers are beginning to realize economic benefits from promoting sustainability and health through building decisions.[74]

Compared to a standard building, a LEED-certified building uses 32% less electricity and reduces annual average CO_2 emissions by 350 metric tons (385 tons).[75] Through specific energy-saving strategies, such as building sites, building form, material selection, window location, day-lighting, and energy-efficient systems for heating, cooling, and ventilation,[76] the impact of climate change can be lessened. Sustainable and healthy building design principles are cost effective,[77] promote health, conserve energy, protect the environment, and mitigate the GHG emissions that contribute to climate change.[78]

Land Use, Forestry, and Agriculture

Land use, land-use change, and forestry accounted for 12% of U.S. GHG emissions in 2005 and were responsible for 16% growth in net carbon accumulation between 1990 and 2005.[9] Carbon accumulation is important because forests "sequester" CO_2 by absorbing it from the atmosphere, therefore reducing the amount contributing to the overall levels of GHG emissions. In 2005, 85% of net U.S. CO_2 sequestrations were from forests.[9] Deforestation increases the levels of atmospheric CO_2 and promotes climate change.[79] Thus, reducing deforestation offers the greatest and most immediate impact for decreasing carbon emissions.[80]

Agriculture and land-use development have led to increasing rates of deforestation in recent decades.[79] Agriculture accounted for an estimated 10%–12% of total anthropogenic GHG emissions worldwide in 2005,[81] and specifically for 30% of U.S. methane emissions in 2006.[9] Emissions from the agricultural sector come primarily from livestock production (80%), which includes land used for grazing, energy for growing grains for feed, transportation of grain and meat for processing and sale,[82] and methane produced by livestock digestive processes.[83] Livestock production contributes significantly to deforestation, as seen in Latin America, where 70% of once-forested land in the Amazon is now used as pastures and feed crops.[84] Mitigation strategies, such as supporting local farmers' markets and community gardens, ease the burden of livestock production on GHG emissions by reducing the distance goods are transported and the demand for deforestation.

In a traditional urban setting, residential and commercial land uses are mixed, allowing for proximity of home, work, school, and other destinations. Workplace proximity is a major influence on the commuting decision to walk, particularly for women.[85] Similarly, situating schools near residential areas encourages students to walk or bike to school, thereby yielding the co-benefits of physical activity and reduced GHG emissions.[86–88] Parents who walk their children to school accrue the health benefits of physical activity, as well as the advantages of interacting with other parents and strengthening community ties.[89] In general, walkable communities are associated with higher physical activity levels, lower obesity prevalence, lower car dependency,[90] and higher levels of social capital.[91]

The location of community resources is particularly relevant for vulnerable populations. A disparity often exists because poor people and ethnic minorities live

far from high-quality schools, supermarkets, and employment opportunities,[92] resulting in a cycle of poverty that is difficult to escape.[93] Situating community facilities, such as libraries, parks, health centers, and fire and police departments, near residential and commercial areas can have a positive effect on the health of all residents.

Unlike traditional neighborhoods, sprawling developments outside of city centers feature low-density land use, extensive road systems, a lack of centralized community centers, and a greater distance between destinations such as home and work. These factors contribute to increased automobile dependence and decreased ability to walk, bike, or use mass transit,[94] as well as loss of farmland and forests.[95] Highways, which link suburbs to downtown areas, are often routed through low-income neighborhoods, thereby creating a physical barrier that interferes with community cohesion.[92] Poor people and people of color are disproportionately affected because they often live near highways, which are major sources of air pollution.[96] Urban sprawl affects air and water quality, physical activity level, mental health, and social capital, resulting in elevated risk of respiratory, cardiovascular, and chronic diseases, cancer, psychological and emotional disorders, and injuries. In addition, the increased driving time typical of urban sprawl contributes to climate change.[56,97]

Increasing density in urban areas is only part of the solution to urban sprawl. Although most urban environments offer sidewalks, mixed-land use, public transportation options, and connectivity, these aspects may be undermined by factors that pose health threats, such as crime,[98,99] waste or industrial sites,[100] and inadequate infrastructure maintenance.[92] Neighborhood indicators characteristic of underprivileged communities (e.g., the lack of nearby walkable destinations, or sidewalks in disrepair) are significantly associated with obesity.[101] Living in disadvantaged neighborhoods is linked to higher rates of cardiovascular and stroke mortality.[102] When these areas are redeveloped, gentrification often occurs, causing property values to rise and forcing lower-income residents to move out.[93] Involvement by health professionals and adequate representation of vulnerable populations in zoning and planning decisions represent important opportunities to benefit public health and climate change.

Improved urban green space planning and management can help mitigate climate change while offering considerable co-benefits for human health. Urban green spaces reduce atmospheric CO_2 levels through direct sequestration and accumulation of carbon by trees and shrubs. In addition, urban green spaces decrease building heating and cooling needs, thus reducing fossil fuel consumption.[103] Lack of contact with nature can influence the mental, physical, and emotional health of the public, particularly children.[104] Urban green spaces such as parks and trails provide access to nature and encourage physical activity, thereby helping combat obesity and its co-morbidities, such as hypertension, osteoarthritis, sleep apnea, and stroke.[105] Access to green space decreases aggression and violence, improves mental fatigue,[106] and increases social capital and community building.[107] Finally, exposure to nature reduces pain in patients undergoing bronchoscopy,[108] improves attention among children with attention deficit disorder (ADD),[109] and increases the life span of the elderly.[110]

Improved land-use planning can be a cost-effective way to mitigate climate change and promote public health. Specific approaches for reducing GHG emissions include creating new green spaces (e.g., on roofs and along streets and railroad lines),[111] maintaining existing green spaces, conserving natural lands through controlled development, and planting trees with high growth rates for additional green cover.[103] Land-use planning is particularly relevant for cities. Dark, impervious surfaces on buildings and roads and the lack of shade and vegetation cause urban areas to have higher average temperatures than rural areas, resulting in the urban heat island effect. This effect decreases the relief available from nighttime cooling and amplifies the susceptibility of urban residents to heat-related illnesses, including those anticipated to occur more frequently under climate change scenarios.[59]

Reuse of previously developed land such as *greyfields* and *brownfields* is also an important method for mitigating climate change and its health implications. Greyfield sites, such as underutilized shopping centers, can be redeveloped into valuable real estate assets because they are usually located along well-traveled areas with good infrastructure.[112] Similarly, brownfield sites, which are properties contaminated with hazardous substances,[113] can be decontaminated and redeveloped into healthy communities that feature mixed-land use and connectivity. In addition to economic benefits, such projects help preserve existing agricultural and forest lands.

Discussion

The built environment offers opportunities to improve health and livability while reducing the GHG emissions that underlie climate change. This article contributes to a growing dialogue addressing the impacts of climate change on human health, by highlighting built environment strategies that minimize the effects of climate change and concurrently improve health. Research on these relationships, although needed, is difficult because built environment data are infrequently collected and usually local in nature. By contrast, climate change indicators such as temperature, weather, wind, and precipitation trends are often measured on a macro-

scale level.[114] Although work is underway to identify key indicators for the built environment[115,116] and climate change,[117,118] using these divergent data to describe and understand the relationships among the built environment, climate change, and human health is a complex challenge for researchers.

Adaptation strategies, although not the focus here, merit attention because they can help prepare the built environment to better withstand the effects of climate change. An example of an adaptation strategy is a policy that limits situating buildings in flood plains or low-lying coastal regions because of the increased risk of flooding from heavy precipitation and rising sea levels.[119] Some adaptation strategies may have a negative impact on climate change. For example, although air conditioning in buildings is an important adaptation strategy to reduce heat-related illnesses caused by higher temperatures,[120] the energy used to cool a building contributes to GHG emissions and climate change.[121] Although some literature discusses adaptation strategies for various built environment components to address climate change effects,[122–124] more research on this interplay is needed, especially in relation to health impacts.

Future research could include cost–benefit analyses of the impact of built environment interventions on GHG emissions and public health. For instance, a light-rail transit line in Charlotte NC with 15 stations covering 9.6 miles averaged 14,000 daily riders in its first year (2007), exceeding projections by 55%.[125] Estimates suggest this transit line will save $12.6 million dollars in total healthcare costs over 9 years.[126] Possible research projects from this transit system include climate change–impact assessments by measuring transit users' vehicle miles traveled, the health outcomes for residents and transit riders, and social cohesion and economic impacts on the city. Similar monitoring and evaluation research may be conducted for GHG emissions associated with larger projects such as new buildings, transportation systems, land-use patterns, and major infrastructure changes, as well as for smaller projects such as new sidewalks, bicycle lanes, and parks. Research that examines how built environment interventions both affect the health of vulnerable populations and reduce climate change is encouraged.

Because health systems will need to address the effects of climate change on public health, it is important for healthcare providers to become leaders in the built environment discussion. Co-benefits from promoting these changes will directly improve health. CDC scientists have described how ten public health functions can help alleviate and respond to the health effects of climate change.[8] As part of this response, individual physicians can be models for behaviors that promote sustainability. It has been shown that physicians with healthier personal habits are more likely to encourage patients to adopt similar habits.[127] This effect may hold true for behaviors related to sustainability through transportation choices, energy use, and involvement in local policies affecting land use and community design. Healthcare providers can collectively and individually influence the built environment and climate change through their actions and leadership.

Decisions about the built environment are routinely made by city planners, architects, political leaders, financiers, and public service officials. Because the built environment affects health, public health professionals should be included in land use and transportation decision-making processes. Health Impact Assessment is a tool that can be used by public health practitioners to assist planners and developers in understanding the health impacts of the decisions they make about land use and transportation planning.[128] Fostering such multidisciplinary collaboration can help maximize the positive health impacts of infrastructure changes and reduce their negative effects.

Potential for collaboration exists among scientists, politicians, urban and transportation planners, healthcare providers, and concerned individuals across numerous agencies and organizations. These partnerships can promote the concept that built environment interventions will yield the co-benefits of mitigating climate change and promoting public health. Although some of the impacts of climate change cannot be predicted or fully understood today, the precautionary principle suggests there is enough evidence to justify proceeding with known mitigation strategies to counter the effects of climate change. Through careful planning of transportation systems, buildings, and land uses, built environment programs can support climate change mitigation and enhance human health.

Conclusion

The built environment, climate change, and public health are closely connected. Built environment strategies that promote climate change mitigation through transportation infrastructure, building construction, and land-use planning provide opportunities both to improve health and reduce climate change. By combining various built environment strategies through complimentary policies and programs, multiple co-benefits emerge. Encouraging leadership and collaboration among various professions within the built environment, climate change, and public health fields is an important step toward reducing GHG emissions, thereby mitigating climate change effects and promoting healthier living.

The authors thank Howard Frumkin, George Luber, Margaret Kelly, Arthur Wendel, Sarah Heaton, and Jamie Rayman for their thoughtful comments on this manuscript.

No financial disclosures were reported by the authors of this paper.

References

1. Intergovernmental Panel on Climate Change. Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon S, Qin D, Manning M, et al., eds. Cambridge UK and New York: Cambridge University Press, 2007. www.ipcc.ch/ipccreports/ar4-wg1.htm.
2. McMichael AJ, Woodruff RE, Hales S. Climate change and human health: present and future risks. Lancet 2006;367:859–69.
3. Patz JA, McGeehin MA, Bernard SM, et al. The potential health impacts of climate variability and change for the United States: executive summary of the report of the health sector of the U.S. national assessment. Environ Health Perspect 2000;108:367–76.
4. Patz JA. Climate change. In: Frumkin H, ed. Environmental health: from global to local. San Francisco CA: Jossey-Bass, 2005.
5. Intergovernmental Panel on Climate Change. Climate change 2007: mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, eds. Cambridge University Press: Cambridge UK and New York, 2007. www.ipcc.ch/ipccreports/ar4-wg3.htm.
6. Ewing R, Kreutzer R. Understanding the relationship between public health and the built environment. A Report Prepared for the LEED-ND Core Committee. Design, Community & Environment, Lawrence Frank and Company, Inc., 2006. www.usgbc.org/ShowFile.aspx?DocumentID=1480.
7. Pacala S, Socolow R. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. Science 2004; 305:968–72.
8. Frumkin H, Hess J, Luber G, Malilay J, McGeehin M. Climate change: the public health response. Am J Public Health 2008;98:435–45.
9. Energy Information Administration. Emissions of greenhouse gases in the United States 2006. Washington DC: Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, 2007. DOE Publication No. DOE/EIA-0573(2006). www.eia.doe.gov/oiaf/1605/ggrpt/.
10. Ewing R, Bartholomew K, Winkelman S, Walters J, Chen D. Growing cooler: the evidence on urban development and climate change. Washington DC: Urban Land Institute, 2007.
11. Balbus J, Triola DY. Transportation and health. In: Frumkin H, ed. Environmental health: from global to local. San Francisco CA: Jossey-Bass, 2005.
12. U.S. Department of Transportation. Traffic safety facts 2005. Washington DC: National Highway Traffic Safety Administration, National Center for Statistics and Analysis, 2005. DOT Publication No. DOT HS 810 631. www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/TSFAnn/TSF2005.pdf.
13. Pucher J, Dijkstra L. Promoting safe walking and cycling to improve public health: lessons from the Netherlands and Germany. Am J Public Health 2003;93:1509–16.
14. Bernard SM, Samet JM, Grambsch A, Ebi KL, Romieu I. The potential impacts of climate variability and change on air pollution-related health effects in the United States. Environ Health Perspect 2001;109(S2): 199–209.
15. U.S. Environmental Protection Agency. Ground-level ozone. 2008. www.epa.gov/air/ozonepollution/.
16. U.S. Environmental Protection Agency. Ground-level ozone: health and environment. 2008. www.epa.gov/air/ozonepollution/health.html.
17. Bransford KJ, Lai JA. Global climate change and air pollution: common origins with common solutions. JAMA 2002;287:2285.
18. Wisconsin Department of Health and Family Services, Division of Public Health. Carbon dioxide. 2005. www.dhfs.state.wi.us/eh/chemfs/fs/CarbonDioxide.htm.
19. Brunekreef B, Holgate ST. Air pollution and health. Lancet 2002; 360:1233–42.
20. Bell ML, Samet JM. Air pollution. In: Frumkin H, ed. Environmental health: from global to local. San Francisco CA: Jossey-Bass, 2005.
21. Peel JL, Tolbert PE, Klein M, et al. Ambient air pollution and respiratory emergency department visits. Epidemiology 2005;16:164–74.
22. Diez Roux AV, Merkin SS, Arnett D, et al. Neighborhood of residence and incidence of coronary heart disease. N Engl J Med 2001;345:99–106.
23. Friedman MS, Powell KE, Hutwagner L, Graham LM, Teague WG. Impact of changes in transportation and commuting behaviors during the 1996 Summer Olympic Games in Atlanta on air quality and childhood asthma. JAMA 2001;285:897–905.
24. Brook RD, Jerrett M, Brook JR, Bard RL, Finkelstein MM. The relationship between diabetes mellitus and traffic-related air pollution. J Occup Environ Med 2008;50:32–8.
25. Nyberg F, Gustavsson P, Jarup L, et al. Urban air pollution and lung cancer in Stockholm. Epidemiology 2000;11:487–95.
26. Ritz B, Yu F, Fruin S, Chapa G, Shaw GM, Harris JA. Ambient air pollution and risk of birth defects in Southern California. Am J Epidemiol 2002;155:17–25.
27. Lee JT, Son JY, Kim H, Kim SY. Effect of air pollution on asthma-related hospital admissions for children by socioeconomic status associated with area of residence. Arch Environ Occup Health 2006;61:123–30.
28. Villeneuve PJ, Chen L, Rowe BH, Coates F. Outdoor air pollution and emergency department visits for asthma among children and adults: a case-crossover study in northern Alberta Canada. Environ Health 2007;6:40.
29. Shea KM. American Academy of Pediatrics, Committee on Environmental Health. Global climate change and children's health. Pediatrics 2007;120:e1359–67.
30. Wang G, Macera CA, Scudder-Soucie B, et al. Cost analysis of the built environment: the case of bike and pedestrian trails in Lincoln Neb. Am J Public Health 2004;94:549–53.
31. Besser LM, Dannenberg AL. Walking to public transit: steps to help meet physical activity recommendations. Am J Prev Med 2005;29:273–80.
32. Wener RE, Evans GW. A morning stroll: levels of physical activity in car and mass transit commuting. Environ Behav 2007;39:62–74.
33. USDHHS. Physical activity and health: a report of the Surgeon General. Atlanta GA: USDHHS, CDC, National Center for Chronic Disease Prevention and Health Promotion, 1996. www.cdc.gov/nccdphp/sgr/sgr.htm.
34. Harding RW, Morgan FH, Indermaur D, Ferrante AM, Blagg H. Road rage and the epidemiology of violence: something old, something new. Stud Crime Prev 1998;7:221–8.
35. Parker D, Lajunen T, Summala H. Anger and aggression among drivers in three European countries. Accid Anal Prev 2002;34:229–35.
36. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. Am J Prev Med 2004;27:87–96.
37. Clarke P, George LK. The role of the built environment in the disablement process. Am J Public Health 2005;95:1933–9.
38. Berke EM, Koepsell TD, Moudon AV, Hoskins RE, Larson EB. Association of the built environment with physical activity and obesity in older persons. Am J Public Health 2007;97:486–92.
39. Wang L, van Belle G, Kukull WB, Larson EB. Predictors of functional change: a longitudinal study of nondemented people aged 65 and older. J Am Geriatr Soc 2002;50:1525–34.
40. Larson EB, Wang L, Bowen JD, et al. Exercise is associated with reduced risk for incident dementia among persons 65 years of age and older. Ann Intern Med 2006;144:73–81.
41. Savitch HV. How suburban sprawl shapes human well-being. J Urban Health 2003;80:590–607.
42. Transportation Research Board, National Research Council. Effectiveness and impact of corporate average fuel economy (CAFE) standards. Committee on the Effectiveness and Impact of CAFE Standards.. Washington DC: National Academy Press, 2002. www.nap.edu/openbook.php?isbn=0309076013.
43. Hicks KE, Dabbs D. Begin year-end tax planning with a look at vehicle purchases. Optometry 2005;76:619–21.
44. Complete the Streets. Let's complete America's streets! www.completestreets.org.
45. Smart Growth America. How is smart growth achieved? www.smartgrowthamerica.org/sghowto.html.
46. Geller A. Smart growth: a prescription for livable cities. Am J Public Health 2003;93:1410–5.
47. Levine M, Ürge-Vorsatz K, Blok K, et al. Residential and commercial buildings. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, eds. Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge UK: Cambridge University Press, 2007.
48. Brown MA, Southworth F, Stovall TK. Towards a climate-friendly built environment. Arlington VA: Pew Center on Global Climate Change, 2005.
49. U.S. Department of Energy. 2007 buildings energy data book. Oak Ridge TN: D&R International, Ltd., 2007. buildingsdatabook.eren.doe.gov.
50. Ulrich R, Quan X, Zimring C, Joseph A, Choudhary R. The role of the physical environment in the hospital of the 21st century: a once-in-a-

lifetime opportunity. Concord CA: Center for Health Design, 2004. www.healthdesign.org/research/reports/pdfs/role_physical_env.pdf.
51. Saelens BE, Sallis JF, Frank LD. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. Ann Behav Med 2003;25:80–91.
52. Frank LD, Schmid T, Sallis JF, Chapman J, Saelens B. Linking objective physical activity data with objective measures of urban form: findings from SMARTRAQ. Am J Prev Med 2005;28(2S):117–25.
53. Handy SL, Boarnet MG, Ewing R, Killingsworth RE. How the built environment affects physical activity: views from urban planning. Am J Prev Med 2002;23(2S):64–73.
54. Pendola R, Gen S. BMI, auto use, and the urban environment in San Francisco. Health Place 2007;13:551–6.
55. Krieger J, Higgins DL. Housing and health: time again for public health action. Am J Public Health 2002;92:758–68.
56. Frumkin H. Urban sprawl and public health. Public Health Rep 2002;117:201–17.
57. National Heart, Lung, and Blood Institute Working Group. Respiratory diseases disproportionately affect minorities. Chest 1995;108:1380–92.
58. Geronimus AT, Bound J, Waidmann TA, Hellemeier MM, Burns PB. Excess mortality among blacks and whites in the United States. N Engl J Med 1996;335:1552–8.
59. Watkins R, Palmer J, Kolokotroni M. Increased temperature and intensification of the urban heat island: implications for the human comfort and urban design. Built Environ 2007;33:85–96.
60. Berry LL, Parker D, Coile Jr RC, Hamilton DK, O'Neill DD, Sadler BL. The business case for better buildings. Front Health Serv Manage 2004; 21:3–24.
61. Smart Communities Network. Green building principles—environmental impact. 2004. www.smartcommunities.ncat.org/buildings/envirimp.shtml.
62. Kerr J, Eves F, Carroll D. Six-month observational study of prompted stair climbing. Prev Med 2001;33:422–7.
63. Eves FF, Webb OJ. Worksite interventions to increase stair climbing; reasons for caution. Prev Med 2006;43:4–7.
64. Emory University. Office of Sustainability Initiatives. www.emory.edu/sustainability.cfm.
65. Emory University Sustainability Committee. Sustainability vision for Emory. Atlanta GA: Emory University, 2006. www.finadmin.emory.edu/policies/SustyReportFinal.pdf.
66. Sullivan KJ. Sustainable Stanford. Stanford Report, 2008. news-service.stanford.edu/news/2008/march5/y2e2-sustain-030508.html.
67. Pēna M. How Y2E2 slashes energy and water consumption. Stanford Report, 2008. news-service.stanford.edu/news/2008/march5/y2e2-energy-030508.html.
68. Health Care Without Harm. About us. www.noharm.org/us/aboutUs/missionGoals.
69. CleanMed. Conferences for greening health care. www.cleanmed.org.
70. Green Guide for Health Care. About the green guide for health care. www.gghc.org/about.cfm.
71. Institute of Medicine of the National Academies. Green healthcare institutions: health, environment, and economics workshop summary. Washington DC: National Academies Press, 2007.
72. U.S. Green Building Council. LEED rating systems. www.usgbc.org/DisplayPage.aspx?CMSPageID=222.
73. U.S. Green Building Council. LEED for Neighborhood Development. www.usgbc.org/DisplayPage.aspx?CMSPageID=148.
74. Meyerson A. The dollars and cents of green construction. J Accountancy 2005;199.
75. U.S. Green Building Council. Building design leaders collaborating on carbon-neutral buildings by 2030. 2007. www.usgbc.org/News/PressReleaseDetails.aspx?ID=3124.
76. American Institute of Architects. Architects and climate change. www.aia.org/SiteObjects/files/architectsandclimatechange.pdf.
77. Kats G, Alevantis L, Berman A, Mills E, Perlman J. The costs and financial benefits of green buildings: a report to California's sustainable building task force. 2003. www.ciwmb.ca.gov/GreenBuilding/Design/CostBenefit/Report.pdf.
78. Frumkin H. Healthy places: exploring the evidence. Am J Public Health 2003;93:1451–6.
79. Salwasser H. Introduction: forests, carbon and climate—continual change and many possibilities. In: Forests, carbon and climate change: a synthesis of science findings. Portland OR: Oregon Forest Resources Institute, 2006:3–19. www.oregonforests.org/media/pdf/CarbonRptFinal.pdf.
80. Nabuurs GJ, Masera O, Andrasko K, et al. Forestry. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, eds. Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge UK: Cambridge University Press, 2007:541–84.
81. Smith PD, Martino D, Cai Z, et al. Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, eds. Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge UK: Cambridge University Press, 2007:497–540.
82. McMichael AJ, Powles JW, Butler CD, Uauy R. Food, livestock production, energy, climate change, and health. Lancet 2007;370:1253–63.
83. U.S. Environmental Protection Agency. Ruminant livestock: frequent questions. 2007. www.epa.gov/rlep/faq.html.
84. Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales C, de Haan C. Livestock's long shadow: environmental issues and options. Rome Italy: Livestock, Environment, and Development Initiative, Food and Agriculture Organization of the United Nations, 2006.
85. Cerin E, Leslie E, du Toit L, Owen N, Frank LD. Destinations that matter: associations with walking for transport. Health Place 2007;13:713–24.
86. U.S. Environmental Protection Agency. Travel and environmental implications of school siting. Washington DC: Development, Community, and Environment Division, 2003. EPA Publication No. EPA 231-R-03-004. www.epa.gov/smartgrowth/school_travel.htm.
87. Timperio A, Ball K, Salmon J, et al. Personal, family, social, and environmental correlates of active commuting to school. Am J Prev Med 2006;30:45–51.
88. McDonald NC. Active transportation to school: trends among U.S. schoolchildren, 1969–2001. Am J Prev Med 2007;32:509–16.
89. Cohen DA, Inagami S, Finch B. The built environment and collective efficacy. Health Place 2008;14:198–208.
90. Frank LD, Saelens BE, Powell KE, Chapman JE. Stepping towards causation: do built environments or neighborhood and travel preferences explain physical activity, driving and obesity? Soc Sci Med 2007; 65:1898–914.
91. Leyden KM. Social capital and the built environment: the importance of walkable neighborhoods. Am J Public Health 2003;93:1546–51.
92. Lopez RP, Hynes HP. Obesity, physical activity, and the urban environment: public health research needs. Environ Health 2006;5:25–35.
93. Frumkin H. Health, equity, and the built environment. Env Health Perspect 2005;113:A290–1.
94. Ewing R, Pendall R, Chen D. Measuring sprawl and its impact. Washington DC: Smart Growth America. www.smartgrowthamerica.org/sprawlindex/MeasuringSprawl.PDF.
95. Galea S, Vlahov D. Urbanization. In: Frumkin H, ed. Environmental Health: From Global to Local. San Francisco CA: Jossey-Bass, 2005.
96. Gunier RB, Hertz A, Von Behren J, Reynolds P. Traffic density in California: socioeconomic and ethnic differences among potentially exposed children. J Expo Anal Environ Epidemiol 2003;13:240–6.
97. Frumkin H, Frank L, Jackson R. Urban Sprawl and public health: designing, planning, and building for healthy communities. Washington DC: Island Press, 2004.
98. Gómez JE, Johnson BA, Selva M, Sallis JF. Violent crime and outdoor physical activity among inner-city youth. Prev Med 2004;39:876–81.
99. Gordon-Larsen P, McMurray RG, Popkin BM. Determinants of adolescent physical activity and inactivity patterns. Pediatrics 2000;105:E83.
100. Perlin SA, Sexton K, Wong DW. An examination of race and poverty for populations living near industrial sources of air pollution. J Expo Anal Environ Epidemiol 1999;9:29–48.
101. Boehmer TK, Hoehner CM, Deshpande AD, Brennan Ramirez LK, Brownson RC. Perceived and observed neighborhood indicators of obesity among urban adults. Int J Obes 2007;31:968–77.
102. Finkelstein MM, Jerrett M, Sears MR. Environmental inequality and circulatory disease mortality gradients. J Epidemiol Community Health 2005;59:481–7.
103. Jo HK. Impacts of urban greenspace on offsetting carbon emissions for middle Korea. J Environ Manage 2002;64:115–26.
104. Louv R. Last child in the woods: saving our children from nature-deficit disorder. Chapel Hill NC: Algonquin Books of Chapel Hill, 2005.
105. CDC. Overweight and obesity: health consequences. 2007. www.cdc.gov/nccdphp/dnpa/obesity/consequences.htm.
106. Kuo FE, Sullivan WC. Aggression and violence in the inner city: effects of environment via mental fatigue. Environ Behav 2001;33:543–71.
107. Kuo FE, Sullivan WC, Coley RL, Brunson L. Fertile ground for community: inner-city neighborhood common spaces. Am J Community Psychol 1998;26:823–51.

108. Diette GB, Lechtzin N, Haponik E, Devrotes A, Rubin HR. Distraction therapy with nature sights and sounds reduces pain during flexible bronchoscopy. Chest 2003;123:941–8.
109. Taylor AF, Kuo FE, Sullivan WC. Coping with ADD: the surprising connection to green play settings. Environ Behav 2001;33:54–77.
110. Takano T, Nakamura K, Watanabe M. Urban residential environments and senior citizens' longevity in megacity areas: the importance of walkable green spaces. J Epidemiol Community Health 2002;56:913–8.
111. Gill SE, Handley JF, Ennos AR, Pauleit S. Adapting cities for climate change: the role of the green infrastructure. Built Environ 2007;33:115–33.
112. Congress for the New Urbanism, Pricewaterhouse Coopers, Sobel LS. Greyfields into goldfields: from failing shopping centers to great neighborhoods. Washington DC: Congress for the New Urbanism, 2001. www.cnu.org/sites/files/Greyfield_Goldfields_vol2.pdf.
113. U.S. Environmental Protection Agency. About brownfields. Washington DC: Brownfields and Land Revitalization program. 2008. www.epa.gov/brownfields/about.htm.
114. Intergovernmental Panel on Climate Change. The climate research unit global climate dataset. 2007. www.ipcc-data.org/obs/cru_climatologies.html.
115. Brennan Ramirez LK, Hoehner CM, Brownson RC, et al. Indicators of activity-friendly communities: an evidence-based consensus process. Am J Prev Med 2006;31:515–24.
116. Curran A, Grant J, Wood ME. Indicators for community action: built environment and community health. J Rural Community Dev 2006; 2:59–74.
117. Clean Air-Cool Planet, Wake CP. Indicators of climate change in the Northeast 2005. Portsmouth NH: Clear Air-Cool Planet, 2005. www.cleanair-coolplanet.org/information/pdf/indicators.pdf.
118. Department for Environment, Food, and Rural Affairs. Review of UK climate change indicators. London UK: Department for Environment, Food, and Rural Affairs, 2003. www.ecn.ac.uk/iccuk/.
119. O'Connell M, Hargreaves R. Climate change adaptation: guidance on adapting New Zealand's built environment for the impacts of climate change. New Zealand: BRANZ, 2004; Study Report No. 130.
120. Nicol F, Rudge J, Kovats S. Safe and warm; effect of climate change on thermal comfort and health. In: Roaf S, Crichton D, Nicol F. Adapting buildings and cities for climate change: a 21st century survival guide. Burlington MA: Architectural Press, 2005.
121. Roaf S, Crichton D, Nicol F. Adapting buildings and cities for climate change: a 21st century survival guide. Burlington MA: Architectural Press, 2005.
122. Burton I, Diringer E, Smith J. Adaptation to climate change: international policy options. Arlington VA: Pew Center on Global Climate Change, November 2006.
123. Allen Consulting Group. Climate change risk and vulnerability: promoting an efficient adaptation response in Australia. Canberra Australia: Australian Greenhouse Office, Department of the Environment and Heritage, 2005.
124. Marbek Resource Consultants. Impacts of climate change on transportation in Canada: final workshop report. Canmore Alberta: Transport Canada, 2003. www.tc.gc.ca/programs/environment/nwicct/docs/FullWorkshopReport/Full%20Workshop%20Report.pdf.
125. Charlotte Area Transit System. November 24, 2007: where were you? LYNX blue line grand opening. Transitions, Spring 2008. www.charmeck.org/NR/rdonlyres/e5ceyezi652ldgnvz4ek6uhkammrbxvashy6omyzfchkqtb7wp5pcsufrmrtwqm4jtxuhrsjdhy6ejhcp6jo4itonrb/SouthTransSpr08pgsr4.pdf.
126. Stokes RJ, MacDonald J, Ridgeway G. Estimating the effects of light rail transit on health care costs. Health Place 2008;14:45–58.
127. Frank E, Rothenberg R, Lewis C, Belodoff BF. Correlates of physicians' prevention-related practices: findings from the women physicians' health study. Arch Fam Med 2000;9:359–67.
128. Dannenberg AL, hatia R, Cole BL, Heaton SK, Feldman JD, Rutt CD. Use of health impact assessment in the United States: 27 case studies, 1999–2007. Am J Prev Med 2008;34:241–56.