Climate Change, Indoor Air Quality and Health

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1. Introduction and problem statement

In the United States, Americans spend an estimated 90% (EPA 2009) - 92% (Bernstein et al. 2008) of their time in indoor environments. The quality of our indoor environments is a key determinant to the quality of life and health. With climate change, attention to building quality has increased as the indoors is expected to become more of a refuge against heat and climate events. Improving building quality also offers an opportunity for more efficient use of energy. In the United States, estimates of proportional energy use attributed to buildings range from 38.9 % (EPA 2009) to 48% (Architect 2030, 2010). Furthermore within 30 years, the majority (up to three-quarters) of our built environment is projected to be replaced with new and renovated construction (Architect 2030, 2010). There is a clear imperative for designing energy efficiency into building operations. How we construct and change these indoor environments to accomplish this imperative has the potential to contribute to or possibly subtract from the overall well-being of those who live, work or go to school in these indoor spaces.

Background

The anthropogenic contributions to climate change will be a subject of continuing inquiry. However, the current national dialogue around climate change has shifted from mainly a debate about the phenomena and projections of impact to a discussion of actions to reduce green house gas emissions and mitigate atmospheric/global warming, and measures to adapt to likely global warming consequences. This shift coincided with national policy for economic stimulus, creating a focus and allocating resources for “green” programs. These actions provide an opportunity to substantially improve the quality of indoor environments and to advance public health. But it is critical to fully recognize the complex relationships among 1) indoor environmental quality, 2) energy efficiency, 3) environmental sustainability and 4) human health. Without an in-depth appreciation of the interwoven nature of these relationships and definite actions to integrate all four elements into planning, there is likelihood for adverse effects to the quality of our indoor environments and associated threats to health, especially to the most “at health risk” populations.

The public health and clinical communities share responsibility to serve the health needs of the population, especially the young, the old, the immune compromised, and the socio-economically disadvantaged. As programs are developing health professionals will need to work with environmental experts to craft a national response to climate change. This response should: 1) prepare for anticipated health consequences from climate change by identifying programs designed to prevent and/or minimize outcomes; and 2) recognize the potential for and propose measures to avoid unintended health risks that may be coincident with energy efficiency measures. However leadership in the environmental, energy, public health and health provider communities will need to be nurtured and educated on the complex inter-connectedness among energy efficient actions, environmental sustainable materials and occupant health.

With recognition that developing policy and new resources will affect indoor environments and the potential for public health benefit, the Center for Indoor Environments and Health at the University of Connecticut Health Center (UCHC) assembled a team to identify some aspects of climate change and adaptive measures that would likely affect indoor air quality and the health of occupants. Paula Schenck, MPH (Assistant Director, Center for Indoor Environments and Health (CIEH)) is the primary author. A. Karim Ahmed, Ph.D. (Director, International Programs, National Council for Science and the Environment and Adjunct Professor, Occupational & Environmental Medicine, UCHC) contributed to the discussion of sources and provided insight into the science underlying climate change mitigation and adaptive measures. Anne Bracker, MPH CIH (senior industrial hygienist, CIEH) provided a focus on the unique vulnerabilities of our workforce and identified critical needs for training. Robert DeBernardo, MD MBA, MPH (an allergist affiliated with the CIEH) contributed to the discussion on surveillance and prevention. Martin Cherniack, MD MPH (Director of Occupational and Environmental Medicine Center, UCHC) guided the authors on role of health providers and provided a comprehensive internal review. Paul Schur, MPH (Director of Environmental Health, retired State of Connecticut) and Paul A. Weinberger, MS (with expertise in energy and environmental technology) provided independent reviews and contributed suggestions to the final paper.

This manuscript has six subsequent sections. The first briefly identifies the current consensus on climate change and health as it relates to indoor air quality and diseases of most concern. The next section summarizes the agents of concern to human health in the indoor environment and the potential impact from adaptive building measures to global warming. The next segment describes green building programs, suggests an expanded definition and identifies questions that need to be resolved in order to make current certification processes effective for indoor air quality. The fifth section discusses environmental public health and healthcare community involvement and leadership with specific recommendations to address indoor environment. After a brief concluding section and list of references, a chart summarizing key components of trainings for professional communities with tasks that impact on buildings and health is presented in Appendix A.

2. Climate change and health as relates to indoor environment

Consensus scientific groups have concluded that climate change will affect human health (Confalonieri et al. / IPCC 2007, US Global Change Research Program 2009, NIEHS 2010). Identified agents of concern include overall heat, ultraviolet penetration, biological materials such as pollens, molds and infectious agents, and air pollutants, especially ozone and particulate matter. Exposures to these agents are generally expected to increase with climate warming trends.

National Institute of Environmental Health Sciences 2010 report

Contributing to the discussion on health, the National Institute of Environmental Health Sciences (NIEHS) convened an interagency working group with representatives (among others) from federal entities with charters in many related fields- EPA, Centers for Disease Control and Prevention (CDC), US Department of Health and Human Services, US Department of Agriculture, National Oceanic and Atmospheric Administration, NIEHS and the University Corporation for Atmospheric Research with a charge to identify the research needs on human health effects of climate change. The report – *A Human Health Perspective on Climate Change*- outlines relationships between human health effects and climate change, and identifies suggested areas for future research.

The report is organized by disease outcome. It identifies specific agents including allergens such as pollen and mold spores and components of air pollution such as particulate matter as agents of concern. Although the NIEHS report does not specifically address indoor contaminants or transformations of outdoor constituents in the indoors, it identifies pertinent relationships between outdoor air pollutants and health outcomes. The report calls for "careful analysis of mitigation and adaptation co-benefits and strategies". Quality indoor environments can be a recognized co-benefit of energy efficiency. However, there are unrecognized obstacles to fully developing this co-benefit.

Also of interest to the subject of this paper, the research needs enumerated in the chapter on asthma, respiratory allergies and airway diseases call out these specific actions which are coincident with actions endorsed in this report:

"

- identifying ..populations and communities at increased risk of climate-related respiratory disease..
- studying the health effects of airborne and indoor dust on asthma exacerbation, including changes in dust composition resulting from climate change..
- examining chemicals used in energy efficiency technologies to ensure that they do not contribute to lung sensitization, asthma, or other respiratory disease..
- developing decision support tools including health impact assessments of the burden of respiratory disease attributable to climate change for help in identifying and selecting air quality mitigation and adaptation policies that will promote health benefits.. " (Portier et al. 2010, p15)

3. Environment and agents of concern in the indoor environment

Temperature

Atmospheric temperature and outdoor pollutants are contributors to indoor air quality. Extremes of temperature in particular are associated with increased cardiovascular health risk (Langrish et al. 2009, Bhaskaran et al. 2009.) A review of emergency room use and hospital admissions during the 2006 heat wave in California identifies that prior acclimation to heat seems to mitigate health care utilization (Knowlton et al. 2009). Surveillance in France during heat wave events in Europe identified the over 75, elderly at risk (Josseran et al. 2009). As the older US population will increase- the over 65 population is projected to rise from 12% of the population currently to 21% by 2050 – there is an increased risk for heat-related illness in this group with climate change. Indoor shelter is key to protecting against heat-related conditions and risk of death (US Global Change Research Program 2009). Green roofs to reduce urban heat island effects, air conditioning to control heat and humidity, warning systems and available public areas of refuge are measures to address excessive heat.

Outdoor air contaminants and indoor air quality

Programs that sustain and improve outdoor air quality are important to indoor air quality. The National Ambient Air Quality Standards (http://www.epa.gov/air/criteria.html) provide goals for the concentrations of constituents in outdoor air that are known to affect health. The program drives development of less polluting energy generation technology. Because the Clean Air Act established EPA's authority to develop health-based standards for outdoor air, health effects from these pollutants and postulated mechanisms are continually reviewed, elucidated and discussed in the academic and environmental science communities.

Once contained indoors, air becomes a repository of gases, moisture and particles originating from occupants and materials. Pollutants are also formed de novo from the mingling of various constituents in the indoor environment. For example, when contacting materials and gases in the indoor environments, ozone reacts with chemicals producing additional contaminants of concern (Weschler 2006, Wisthaler and Weschler 2010). Indoor levels of pollutants may be 2 to 5 times, and occasionally 100 times higher than outdoors (EPA, 2009). Ventilation systems are designed to filter out some contaminants and mix in enough "fresh" air to maintain a level of quality in the indoor air. The literature on indoor pollutants and indoor transformations is less robust than that addressing ambient air quality health effects but never the less the association of indoor environmental quality with health is established, especially for radon and moisture (Field et al. 2000, Mudarri and Fisk 2007).

Components of indoor air, links with adaptation measures and climate change

The balance of this section briefly discusses selected constituents of indoor air of concern to human health and identifies their links to climate change and energy efficiency actions. Because categories of sources were chosen for discussion based on characteristics, relevance in consideration of health and climate change, and to some extent the existing regulatory framework; some of the categories necessarily overlap.

- ***Biological contaminants*** **–** proliferate in damp areas of homes and business office buildings. Moisture in homes is associated with illness- in particular occupant asthma and respiratory symptoms (IOM 2004; Mudarri and Fisk 2007; WHO 2009). Some possible agents of concern include fungi and fungal products, bacteria –including endotoxin, dust mites, cockroaches, pets and pests. Some fungal organisms found indoors when moisture sources are not controlled belong to the genera: Aspergillus, Cladosporium, Penicillium and Stachybotrys. In some individuals exposure to biological materials contribute to irritant and allergic illness– from respiratory distress, eye and nasal irritations, laryngitis and hoarseness, flu-like symptoms, and headaches to asthma and allergy initiation, aggravation of pre-existing asthma, lower restrictive respiratory disease and skin allergies (Storey et al. 2004, Cox-Ganser et al. 2009; Park et al. 2008).

  Any available water from: leaks in roofs, walls, windows, plumbing; basement seepage; humidity and condensation, encourages biological growth. Climate change will increase heat and humidity in some areas of the United States, likely resulting in an increase in mechanical air conditioning and may increase the generation of biological material indoors. Appropriately sized and adequately maintained ventilation units should help control biological growth by supporting acceptable levels of humidity, limiting condensation on cooler surfaces and addressing pooling water (for example accumulated water in drip catch trays in air conditioners). Climate change is also expected to increase the occurrence of extreme weather events. Mold and bacteria will grow in homes and buildings that are inundated with flood/storm water (CDC 2006) or are exposed to excessive dampness over a prolonged period.

  Climate change and coincident ecological change is expected to affect the presence of indoor infectious contaminants. Legionella bacteria have been found in air conditioning water towers. With excessive precipitation events, turbidity may increase in potable water supplies suggesting that better filtration of water entering buildings would be appropriate as part of the control against Legionnaires disease (Morey 2010). Other human pathogens are associated with soils and dusts and could become more prevalent indoors in green buildings with green roofs and green atriums in some areas of United States, indicating the importance of dust suppression indoors (Morey 2010).

  "Tighter" buildings (less dilution with outside air) may increase the likelihood of airborne spread of person-to-person infections and may call for additional control of infectious agents. Ultraviolet irradiation of ventilation system in plenums where return air is mixed with fresh air is a sometimes used remedy. This adds a maintenance challenge and can pose risks to custodians' health. In general, the overall utility of adding a disinfection process to ventilation to improve indoor air quality has not been established. The exception of "clean rooms" in healthcare and laboratory settings is a limited precedent.

- ***Combustion formed gases*** **–** such as carbon monoxide (CO), nitrogen oxides, and sulfur dioxide gases are from natural gas or wood-burning stoves, oil and gas furnaces, fireplaces, kerosene heaters, lighted candles and other combustion sources within the building structure. Environmental tobacco smoke contains carbon monoxide as well. Vulnerable populations are at more risk, possibly because of variable home maintenance and inappropriate uses of combustion appliances, including kerosene space heaters. Elevated nitrogen dioxide levels are reported more often in lower income housing (Bernstein et al. 2008). Improper ventilation of these gases can lead to occupants' irritant symptoms, respiratory symptoms, effects on lung function and increased risk of respiratory infection. CO poisoning is of particular concern and is a recognized threat to the elderly population. Lower exposures cause sleepiness and flu-like symptoms; while more extreme exposures have brought about severe neurobehavioral effects, coma and death. In general, these gases do not build up high air concentrations in drafty homes and/or properly ventilated buildings. However, weatherization activities that make building structures more energy efficient by sealing windows and other areas of air leakage could increase exposure to these gases and pose a higher health risk to the building's inhabitants (Richardson and Eick 2006). Experience with hurricane Katrina raised a concern over occupational CO exposures from cleanup equipment used indoors (Schulte and Chun 2009).

- ***Fibrous insulating materials*****–** are used to maintain energy efficiency of heating systems in buildings. Contact with fibrous insulating materials can cause dermatitis and has been indicated with pulmonary disease (McDonald et al. 2000). At one time asbestos was commonly used as a fire-resistant component of ceiling tiles and insulation material in building plenums, air ducts, furnaces, boilers and around hot water pipes. Although asbestos-containing material is not indicated in new buildings, certain types of friable asbestos fibers, if improperly contained in buildings including within ventilation systems, would be a health risk to its inhabitants. Materials (not previously identified as containing asbestos) when disturbed during weatherization and retrofit activity pose a hazard to construction crews.

- ***Formaldehyde*** **–** can be found in the indoor air of homes and buildings where wall paneling is made of pressed-wood products that contain urea-formaldehyde resins. Formaldehyde is a colorless gas with a pungent odor and corrosive chemical activity that may cause eye irritations, nose bleeds, persistent headaches and breathing difficulties. It is known to aggravate asthma and cause severe allergic responses in some individuals. It is a potent sensitizer and is considered to be a probable human carcinogen based on life-time animal bioassay studies. Severe illnesses related to formaldehyde exposure were reported by inhabitants of mobile homes that were used as temporary shelters after Hurricanes Katrina and Rita in the Gulf Coast (2005) and the upper Mississippi River floods in Iowa (2008). An increased reliance on emergency housing may follow increasing occurrences of catastrophic climate events.

- ***Lead* –** is a health problem among young children in low-income, inner-city homes. Sources of lead in homes occur mostly through formation of dust particles flaking from lead-painted walls or from tracking lead-contaminated soil from outdoors. Lead exposure may occur from windblown lead-contaminated dust during hot summer months from open windows or through cooling window fans. Extreme weather events with associated increase in mud and dirt tracking in homes may add to indoor lead exposures. An exploration of seasonal variability in lead dust levels in homes indicated a linear relationship between lead loading in indoor dust and precipitation rates (Petrosyan et al. 2006). Healthy homes programs remediate homes to intervene on occupant lead exposure. In addition precautions against worker lead exposure are appropriate mandatory during weatherization and retrofit activities.

- ***Ozone* –** there are two chief sources of indoor ozone: copy machines and electrical appliances, such as air "purifiers" and other electronic devices; and outdoor air infiltrating indoors during hot summer months. Outdoor ozone levels rise in cities with warmer temperatures because of the "urban heat effect" (i.e., urban regions are generally 5 to 6 degrees Celsius higher than rural areas). Here the photochemical oxidation of hydrocarbons with nitrogen oxides to form ground-level ozone is considerably enhanced at higher temperatures. Indoor ozone can have an interactive health impact with other air pollutants, such as nitrogen oxides, fine particulate matter and formaldehyde. Ozone affects pulmonary function in both healthy individuals and those with respiratory disease. Young children, the elderly and those with chronic respiratory or cardiovascular problems are more vulnerable to ozone. For those with asthma and other allergic disease, exposure to ozone can contribute significantly to the allergic response (Bernstein et al. 2008).

- ***Particulate matter and smoke* –** Particulate matter is a criteria pollutant in outdoor air regulated under the Clean Air Act. Additional indoor sources of particles include environmental tobacco smoke; heating boilers and stoves; building materials; house dust; and consumer products. Health effects associated with fine particulate matter include respiratory symptoms, asthma exacerbations and heart arrhythmias. The Children's Health Study in Southern California has shown associations between reduced lung development and function in children and particulate pollution (Gauderman et al. 2004). With an increase in desert area in the US from a warming climate, atmospheric levels of particulate matter are expected to increase. In addition, forest fires, whose occurrences may increase with climate change, will add episodic particle pollution to outdoor air, increasing the contaminant burden indoors. Beyond the obvious burden of death and immediate healthcare utilization, forest fires adverse effects include irritant and respiratory symptoms (Kunzli et al. 2006).

Smoke and particles are generated indoors by the burning of wood in fireplaces, cooking and heating stoves. Wintertime wood burning is expected to increase as a means to lesson reliance on oil and gas. This practice increases outdoor pollution and has been reported to contribute substantially to indoor pollutants (Washington State Department of Ecology 1997). In colder climates wood burning (including individual units outdoors) has been proposed as an adaptive measure to maintain power during expected power outages caused by extreme weather. Unless appropriate controls are imposed, this practice will contribute to poor air quality and negative health effects (Belanger et al. 2008). Wood smoke can contain carbon monoxide, particulate matter and other irritating or toxic components including acrolein, benzene, formaldehyde, and polycyclic aromatic hydrocarbons. Some of these materials are characterized as severe respiratory irritants and/or probable human carcinogens.

Although not in widespread use in the US, smoky cook-stoves are major causes of death and disability in households in developing countries. The risk of morbidity and mortality from pneumonia is increased for children in homes where biomass fuels are in use (Dherani et al. 2008). Because black carbon (BC) forms from biomass fueled cook-stoves (and appliances that burn diesel fuels), this source of indoor pollution has become a major concern not only to reduce direct health consequences but importantly for the potential mitigating impacts to climate change of reduced BC emissions. The warming effect from BC emissions has been assessed as the second or third largest contributor to global warming and may be responsible for as much as a quarter of the global warming over the last century (ALA 2007, Wallack and Ramanathan 2009).

- ***Radon*** **–** is an odorless and colorless radioactive gas that infiltrates into the indoor air from home and building soil foundations. Factors that direct the potential for radon gas accumulation in buildings include the specific geographic location and characteristics of the building foundation and soil barriers. The Iowa radon lung cancer study reported that cumulative radon exposure in homes is significantly associated with lung cancer risk (Field et. al. 2000). Some studies show a multiplicative interaction of radon with tobacco smoking (EPA 2003). Even though radon has a short radioactive half-life (3.8 days), it is the second leading cause of lung cancer in the United States. Radon’s health effects are primarily due to its radioactive daughter products – polonium 214 and 218. Both are alpha particle emitters that produce deposition on human lung linings. Without proper remediation to vent off ground-level radon gas on an ongoing basis, radon can accumulate in some buildings above established action levels (greater than 2 to 4 picocuries/liter) and produce unacceptable exposure and organ radiation. While acting directly to address a potential serious health threat, assessing the risk for radon exposure and if indicated incorporating mitigation measures in new building design may have the ancillary benefit of reducing the likelihood of other soil gases emanating and /or moisture penetrating below grade building assemblies into occupied space (ASHRAE 2009).

- ***Volatile organic compounds (VOCs) and other chemical emissions***– VOCs will increase at higher ambient temperatures. They are found in common household and office building materials, furnishings, finishes and a variety of commercial products. Well-sealed indoor air environments can concentrate chemical emissions. Specific sources of volatile compounds include dry-cleaned clothes, cleaners, paints, paint strippers, solvents, adhesives, furniture coatings, fragrances, carpets, pesticide sprays, and stored fuels. Under damp conditions, fungi amplify indoors, produce VOCs, and are detected by a commonly recognized moldy, musty odor.

  Some chemicals (including phthalates and pesticides) that may emit from indoor materials can have irritant, allergic, toxic or carcinogenic properties. Spray polyurethane foam insulation, used in weatherization, may be concerning because of irritant properties and specific effects of components on respiratory health and asthma. Exposure during application is a particular hazard to weatherization crews.

  Since specific guidance is often lacking in new building design and renovation, general practices of minimal time for “off-gassing” before occupancy and reliance on labeling/certification programs for material selection may not be adequate to eliminate/reduce occupants’ exposure to health-concerning chemicals (ASHRAE 2009, Wargo 2010)**.** Control of moisture to inhibit biological growth is the only effective means to eliminate biologically generated VOCs indoors.

4. “Green buildings”, indoor air quality and health

Energy policy and regulation

The imperative to reduce greenhouse gas emissions has focused appropriate attention on energy use in buildings. With climate change, the need for air conditioning is expected to outstrip savings from reduced heating demand, potentially adding to the energy burden. As the existing building stock is replaced with new and renovated construction, attention to energy efficiency is paramount. This fuels a developing industry that fosters development of energy efficient and environmentally sustainable buildings within the architecture, construction, manufacturing, consulting and engineering sectors.

Public health is cited as an ancillary benefit from this energy policy. Models that assess the co-benefits to health from energy reform rely on reduction of outdoor pollutants coincident with changes in energy production and use (Smith and Haigler 2008) and with reduced residential energy consumption (Levy et al. 2003). Costs associated with indoor air quality exposures are considered less, if at all; so the assessments may miss identifying some health risks in the design of some energy-efficient buildings. Health effects research that broadly elucidates the cost of poor indoor environmental quality is not generally available. A notable exception is the study of Mudarri and Fisk (2007) which estimated that annual cost of asthma attributable to dampness and mold exposure in homes between $2.1-4.8 billion.

Model energy codes are available to planning agencies, and some state and local jurisdictions have adopted energy codes for housing and commercial buildings. EPA offers a fact sheet (http://www.epa.gov/cleanenergy/documents/suca/buildingcodesfactsheet.pdf) that presents the advantages of energy codes to energy efficiency, overall environment and economic status. Building codes are variable among states (and municipalities), often difficult to enforce, and give limited, if at all, attention to indoor air quality. Coupling codes with indoor air guidance for construction such as found in EPA’s Indoor Air Plus program (EPA 2009) could be an important addition to these efforts. Countless state and municipal (Bernstein 2008, Bernstein and Lamb 2003) actions independent of codes mandate attention to energy utilization in buildings especially (but not exclusively) when public funds support building construction and renovation.

Green building-definition and attributes

EPA defines green building as follows:
“Green building - also known as sustainable or high performance building - is the practice of:

- Increasing the efficiency with which buildings and their sites use and harvest energy, water, and materials; and
- Protecting and restoring human health and the environment, throughout the building life-cycle: siting, design, construction, operation, maintenance, renovation and deconstruction. ” (EPA 2009)

Building design and/or retrofit activities with structured attention to the factors noted in the definition directly affect the indoor environmental quality of the structure.

In addition to demonstrating energy efficiency and environment sustainability, buildings with a "green building" label should have two other attributes: be health-supportive and utilize green technology. The four attributes are noted below.

- ***Energy efficiency*** requires establishing defensible energy use benchmarks and a means of attaining and measuring reductions in energy use. The EPA Energy Star program for homes provides a method to establish initial benchmarks and set appropriate goals. Models are used to determine the energy conservation benefit of design elements. A review of energy use information to determine actual building performance is important.

- ***Sustainability*** "is the ability to achieve continuing economic prosperity while protecting the natural systems of the planet and providing a high quality of life for its people." (EPA-d 2009). In practice, consideration of resources (especially energy and water), characteristics of materials (renewability, hazard), and the sources of building materials (local verses long distance, etc.) underlie sustainability determination. Life cycle modeling could be a strong tool to contrast "sustainability" of alternative designs; however establishing criteria that underlie life-cycle approaches is a prerequisite. The National Institute of Standards and Technology Building and Fire Research Laboratory is currently exploring metrics and tools for assessing life cycle and economic performance (Helgeson and Lippiatt 2009).

- ***Health-supportive*** is more than producing buildings that serve to minimize overall health impacts to the environment (including from climate change). For buildings to be *health-supportive* the design should foster an environment that supports occupants' health, well being and productivity. Aesthetics, lighting, acoustics, thermal comfort, material choice, and indoor air quality are areas contributing to a health-supportive design. Attention to minimizing occupant exposures through ventilation, source control, material selection and maintenance planning - is critical in building design to provide indoor air quality.

- ***Green technology*** uses the principals of sustainability, risk/ hazard control and life cycle impacts to develop new materials and processes. For example green technology principles dictate that an updated and thorough systems analysis of building materials would be conducted, including a cradle-to-cradle accounting of materials and energy use of the facility. In carrying out such an analysis, all aspects of indoor air impacts on human health would be included in a systematic manner. Furthermore green building design should recognize, utilize and incorporate ways to adapt to future technologies.

Buildings and illness

In discussing buildings and effect on health, two types of illnesses are considered: building related-disease and non-specific building-related illness (NSBRI), sometimes called sick building syndrome. NSBRI is a condition where individuals develop symptoms from a build-up of irritants in the environment probably associated with poor ventilation. The indoor air quality may affect multiple individuals who share the same environment. These non-specific symptoms commonly include headache, drowsiness, and burning and irritation of the eyes, nose and throat and sometimes cough. The offending substances can be biological or chemical but generally are at a concentration too low to cause identifiable disease, but at sufficient levels to cause mucous membrane irritation, respiratory symptoms, central nervous system symptoms, and skin complaints. The illnesses usually resolve without long-term consequences outside the environment, but not always immediately. Building-related disease is a more severe condition. Clear diagnostic criteria and recognized patho-physiology characterize building-related illnesses. Individual susceptibility is often a factor. These conditions develop because of exposure to infective, toxic, irritant or immunological agents in the buildings that trigger or exacerbate disease. Specific diseases of identified concern with indoor air quality include: asthma, hypersensitivity pneumonitis; sarcoidosis; rhinitis/sinusitis; laryngitis; and dermatitis (adapted from Center for Indoor Environments and Health Guidance for Clinicians Course: Mold and Moisture http://www.video.uchc.edu/MoldMoisture/).

Poisonings from inhaling specific chemicals such as carbon monoxide are recognized as health risks associated with indoor exposures. However syndromes related to inhalation of toxins from biological sources are not well defined and there is no consensus as to the nature, patho-physiology or cause of these syndromes. Limitations in exposure assessment- defining the route, mode and amount of exposure; and in separating building influences from other (non-environmental) factors when assessing health impede efforts to understand relationships of biological toxins with indoor air exposures. However, with an increasing number of building occupants who attribute cognitive and neurological impairment to exposure to biological (fungal in particular) toxins, the possibility of indoor environments contributing to the risk should not be dismissed.

Green building certification

There is a growing reliance on voluntary building certification programs. Private organizations offer certification programs that include training of practitioners in the program. The American National Standards Institute recently certified one of the commercially available programs (ANSI 2010). The certification programs proffer points for specific building elements and design processes that impact a building's performance. Certification programs have been criticized for supporting building designs that could be inadequate relative to indoor environment and health (Walsh 2010, Wargo 2010). The programs vary in their indoor air quality requirements and in the flexibility that is allowed on how a building may attain points. Depending on the choices that the design team makes, the systems may unintentionally support building designs that are inadequate relative to indoor air quality and health. For example, building designs that earn their "green" labels may or may not adequately consider moisture and sources of bioaerosals- critical elements to consider to sustain indoor air quality supportive of occupants' health.

Improvements to certification programs to secure attention to indoor air quality might address the following questions:

- What elements should be mandatory? What priorities underlie prerequisite actions and minimum point determinations? What criteria establish the priorities?
- Is the tension between energy conservation and indoor air quality resolved adequately? (Here is one example- Variable (based on occupancy) ventilation control is an energy saving measure. However, in some climates, humidity control (at least during some seasons) may be indicated irrespective of space use to control biological amplification and bioaerosols. A means to address moisture- possibly decoupling dehumidification from temperature control- may be needed in the heating, ventilation and air conditioning design to achieve quality indoor air quality.)
- How will construction be monitored in particular during operations critical to air quality (such as roof membranes, material storage)?
- Should building performance relative to indoor air quality criteria be monitored before attaining certification? What measures? How long?
- Are maintenance concerns (including impacts to maintenance staff) adequately anticipated?
- Are independent third party assessments cost-effective?
- Should building and building systems commissioning be required?
- Should certifications expire/ have to be renewed? What time frame?

Weatherization and retrofit construction

Weatherization programs seek to reduce air leakage in homes and raise heating efficiency. Currently with support of stimulus funds, weatherization is encouraged with assistance available to low income families (US Department of Energy Weatherization Assistance Program). There are a number of indoor air quality considerations that should be added to weatherization activities. Unintended, but not unlikely, consequences of tightening the air flow in homes include an added potential for humidity with development of damp areas and/or wet spots from condensation, and building up of air contaminants. Lead dust contamination from leaded window replacement, if not removed correctly, will increase lead exposure for the workers and possibly for the building occupants. Application of spray polyurethane foam insulation material pose health risks to applicators in particular and possibly to occupants if the material continues to emit troubling chemicals. Weatherization assessments should anticipate these concerns and be coupled with resources that instruct home owners on remedies for the possible/probable indoor air problems that may arise with areas of dampness in the home and higher levels of contaminants (Richardson and Eick 2006).

Available guidance

Climate change has forced attention on buildings, as an opportunity for energy savings, but also as an opportunity to use the tools and technologies to build structures well suited for their anticipated use that increase value to society. The national priority for energy efficiency is established; programs are in development or implementation; and with current political and public will, energy efficiency and sustainability will continue to move forward. Prioritizing occupant health adds complexity and some technical challenge. But guidance is available. ASHRAE 's "Indoor Air Quality Guide; Best Practices for Design Construction and Commissioning" provides detailed information and is currently available as a free download (ASHRAE 2009). The choice is to continue with programs as currently defined with inadequate anticipation of occupant health risks from "green building " design or integrate "*health- supporting environments*" into the definition of green buildings.

5. Recommendations and outlook on public health and health provider roles

In our society, the public health and clinical communities are charged to foster our quality of life by protecting and improving health. Public health practitioners address health from a population viewpoint and although clinicians focus primarily on the health needs of individuals, they assume public health responsibilities. Both groups have important roles in responding to climate change. In this section, we suggest where leadership from public health and health provider communities could act to address potential health impacts associated with environmental exposures, especially with climate change adaptive measures focused on energy conservation in buildings.

Green buildings and public health practice

Public health practitioners, especially with expertise in environment, bring a perspective that has been missing in many of the architecture, construction and engineering communities that have assumed leadership on “green buildings”. We suggest public health involvement to:

- Begin a process to establish minimum mandatory criteria on indoor air quality in “green buildings” that includes: ventilation, moisture, radon resistance and potential for emission of concerning chemicals.

- Provide input on occupant health benefits and costs for use in development of standard tools for assessing life cycle and economic impacts of building performance.

- Expand research to define the benefits and costs of health-supporting indoor environments.

- Participate in efforts that evaluate climate change mitigation and adaptation measures and discuss the need to develop/add additional metrics to address indoor environment and occupant health.

- Explore applicability of environmental impact assessments (EIA) as a tool in assessing green building design and develop a specific template for including occupant health-supportive measures in the assessment. (Health Canada suggests including climate change and health considerations in EIA).

- Develop specific guidance for local and regional planning efforts on climate change adaptation that 1) facilitates community participation, and 2) addresses the threat of “green buildings” to indoor environmental quality and occupant health.

- Engage building and housing agencies in development of appropriate minimum codes and healthy homes programs

- Develop programs and resources that serve to educate:
    - the public on what measures they can take and how they can evaluate actions that may have consequences to indoor air quality and their health;
    - local health departments on working with state and municipal agencies developing green building programs, and on responding to public's IAQ concerns;
    - healthcare practitioners on IAQ involvement in health; and
    - emergency response workers on occupational exposures

- Develop targeted training programs in collaboration with building scientists, engineers, industrial hygienists and environmental experts for:
    - building owners, architects, design teams and contractors;
    - housing and institutional personnel;
    - local and state public health staff, local and regional planners, and public health responders; and
    - green jobs workforce.

  A chart identifying key components of the trainings for each of these groups is presented in Appendix A.

- Consider hosting a nationwide clearinghouse for surveillance information on health outcomes from indoor exposures

Surveillance, sentinel case model and prevention

Climate change is a gradual ongoing process over time. Consequently, one would not expect to see a sudden change in the health status of the population, but a gradual adverse effect of the same diseases that are currently attributable to the current environment, especially the indoor environment. These would include a gradual increase in a number of environmentally related diseases over time, especially respiratory diseases such as asthma, chronic obstructive lung disease and hypersensitivity pneumonitis.

These gradual health changes due to climate phenomenon are not going to be recognized unless one is first aware that it may occur, and then to take specific steps to identify the cause. Surveillance, sentinel case definition and identification, and prevention need to be the mainstay of the public health and medical communities. The diagnosis of an individual with a "sentinel" illness associated with exposures in a particular environment may indicate that these exposures may also deleteriously act on others. Intervention in the environment to limit identified exposures is an opportunity for primary prevention. Public health surveillance systems currently in place for a number of diseases need to be expanded. Environmental public health tracking efforts that consider both large scale (climate data) and small scale (specifics of indoor environments) information could be used in incidence and prevalence studies.

Physicians and laboratories- clinical and environmental- must be made aware of and report any sentinel case that may lead to a cluster of illness in a specific building or community. Educational programs on climate change-driven indoor exposures and population healthcare needs should be available to individual and group physicians. The public needs to become educated as to changes that they can make to the indoor environment to prevent building-related illnesses.

Health information technology

Health information technology (IT) is thought to be a mandatory component to successful healthcare reform. American Recovery and Reinvestment Act (ARRA), through the Act's Health Information Technology for Electronic and Clinical Health provisions allocated billions of dollars, mostly for incentives to accelerate electronic health record development. Healthcare reform is relying on assumed efficiencies created from health IT. This advantage is expected to accrue not only from improved processing of medical benefits but also from improved health outcomes. The intention is that this investment in health IT should improve health surveillance and analysis, management and decision support (DeBor and Wah 2010).

Choosing which data to collect in electronic records is critical to the utility of the IT system. In the clinical setting, environmental contributors to health would be addressed with the patient's medical history. However in today's time-stressed primary care setting, this topic is generally given inadequate attention. Providers confronted with more specific health concerns and others in specialty fields such as allergy and occupational medicine are more likely to explore environment, but possibly not the subtleties of indoor exposures. If current IT efforts to establish a universal/or recommended template for electronic health record are successful, public health leadership is needed now to influence inclusion of information that reveals environmental exposures in the home, school, office and work environments. Incorporating geo-coding into health records may be reasonable. If accomplished this could contribute to surveillance efforts to establish a potent database on indoor environments and health. Moreover it would be advantageous to have health and associated environmental data in the same system.

Coupled with collecting information, efforts are needed to develop "decision support models" to utilize these data both in clinical care and public health practice. Algorithms using the information could be developed to guide providers to improve individual clinical care. In situations where exposures indoors play a role in illness, data from electronic health systems that include health information and environmental characterization would allow integration of environmental intervention into medical treatment, an element that would work to improve health outcome. Other decision support models utilizing a pool of information without personal identifiers could support healthy housing and healthy workplace public health initiatives. As Knowlton demonstrated in his assessment of the 2006 heat wave, surveillance data (limited to emergency department and hospital utilization records) can be a tool in understanding the health impacts of catastrophic climate events and in suggesting appropriate public health planning responses (Knowlton et al. 2009). With our concern over climate change and possible consequences from energy efficient buildings, decision models could be developed collaboratively with public health professionals, clinicians, building scientists and engineers to respond to the implications of energy conservation to occupant health.

Access to sensitive and vulnerable groups through community health centers

Community health clinics (CHC) have been significant beneficiaries of ARRA, with $2 billion directly allocated in 2009 and 2010 for new sites and infrastructure. CHC are a critical part of the healthcare "safety net" for the poor and/or uninsured populations (California Healthcare Foundation 2009). School based health centers also provide "safety net" health care to poor children in urban and rural schools (Mansour et al. 2008). CHC, given resources and care management decision tools, respond well to the health needs of some of our most vulnerable population. Of interest to indoor air quality, use of asthma management plans, an important tool in addressing environmental contributors to the disease, substantially increased after implementation of a decision support model (Hicks at al. 2006, Landon et al. 2007). In this way, CHC are positioned to provide care and (with support from academic health centers (Markuns et al. 2009)) education to targeted communities on how to make their indoor environments health-supporting. CHC may also be in a unique position to engage the community in local response planning for climate change adaptation. Other associated initiatives such as healthy homes programs could be integrated into CHC and clinic care portfolios.

Clinicians' public health leadership

Preventive measures for respiratory and other environmentally related disease should place special emphasis on control of indoor air quality. This becomes especially relevant considering that these effects could be exacerbated by climate change. The following list of activities suggested for health providers builds on recommendations of various medical societies, and the previous discussion.

Leadership from clinicians is suggested to:

- actively support policy directed to climate change mitigation and adaptation efforts (Martens et al. 1997.)

- take individual responsibility in addressing climate change and become examples for the community. [Nurses are encouraged to adopt individual behaviors- such as purchasing energy-efficient appliances and cars, recycling in the workplace and joining community groups (Afzal 2007). Similarly, a physician continuing education module from the American College of Preventive Medicine (ACPM) identifies recommendations for health professionals to reduce their personal contributions to climate change (Brenner and Parker 2009)];

- increase personal awareness and understanding of the environmental issues so to provide improved care. [Practice suggestions for allergists treating patients seeking advice on indoor air quality specifically suggest consideration of environmental factors that include indoor air quality monitoring methods, interpreting data, and familiarity with "healthy homes"(Bernstein et al. 2008.) ACPM surveyed their membership on environmental health and found that members spent little time with patients on climate change, "hazards found in the home and other indoor environments", or issues related to general environmental health. The organization is offering a series of educational webinars on indoor air quality (ACPM 2008)];

- engage in professional medical society activities that develop policy and practice guidelines so to increase attention on health effects from indoor environmental exposures and intervention in indoor environment as part of overall disease prevention. [This would serve to expand awareness of climate change health consequences from indoor exposures. For example, the American Academy of Pediatrics published a comprehensive paper on climate change and children's health supporting a wide range of climate change mitigation measures including green buildings (Shea et al. 2007). A companion discussion on risks to respiratory health and asthma in children who occupy homes with energy efficient measures where indoor air quality was not addressed adequately (Richardson and Eick 2006) would add t guidance for pediatricians.]

- in collaboration with public health leadership:
  - advocate for inclusion of specific information on environmental contributors to disease in development of electronic medical records and public health survey instruments including National Health and Nutrition Examination Survey, and the Behavioral Risk Factor Surveillance System; and
  - develop a needs assessment and strategy for CHC community engagement on indoor environments.

- develop support for medical education including curricula for undergraduate programs, elective internships and continuing medical education that address climate change and indoor exposures.

6. Conclusions

Reducing green house gas emissions with changes in energy production and use patterns is expected to accrue substantial benefits to public health through improvements in air pollution, reduced occupational hazards, and reduced occurrence of large scale accidents (i.e. oil spills) that is expected to accompany a shift away from reliance on fossil fuel (Smith and Haigler 2008, Levy et al. 2003). In this era of concern and response to climate change, this paper sought to address indoor environments to identify and bring into the discussion possible threats/unintended risks to the health of building occupants from well-intended climate change adaptive measures.

Health consequences to occupants of buildings with poor indoor air quality can be substantial (Mudarri and Fisk 2007). Some agents of concern in the indoor environment are moisture and associated biota, and a number of chemicals and gaseous materials. Public health leadership will support our country's transition to more energy-efficient buildings. While recognizing the critical need to reduce energy burden in buildings, public health also has the perspective to bring indoor environmental quality and occupant health into the dialog and decisions about "green buildings". With developing health IT and treatment models, public health leadership within medicine is in a unique position to suggest and support measures focused on environmental determinants of health.

Moving the country's building stock to green buildings –energy efficient, environmentally sustainable, occupant health-supporting and current with green technologies- is an important climate change adaptive strategy. Indoor environments supportive of occupant health is critical to illness prevention and the well being of our communities. The largest burden of not anticipating the potential for unintended negative consequences to indoor air quality from energy efficiency would likely be born by the most sensitive and vulnerable in our communities. The need isn't to choose between improvements in energy efficiency and indoor air quality, but rather to improve upon the current approach to green buildings to avoid adding health risk from indoor exposures. This paper identifies some concerns, suggests some actions and notes some timely opportunities for leadership and involvement in an effort to aid the needed discussion.

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Appendix A: Trainings for professional communities on buildings and health

A.1 Target Audience: Building owners, Architects, Design teams, Contractors		
Training Topics	***Link to climate change and the indoor environment***	***Key components of "trainings"***
Moisture control in the built environment	Increased flooding, more extreme weather Inadequate humidity control	How to: design buildings that have appropriate drainage, vapor barriers and flashing; and select appropriate and properly sized heating ventilation and air conditioning (HVAC) systems that control humidity (see next item). Elements for maintenance plan including leak repair and HVAC maintenance. Available resources.
Designing heating, ventilating and air conditioning (HVAC) systems for offices and homes	Increase in outdoor temperature, increased concentrations of outdoor allergens, tighter buildings- demand for HVAC increases. Improperly designed or maintained HVAC can contribute to poor IAQ- inadequate dilution and/or humidity control, microbial reservoirs.	How to design HVAC systems for the built environment that address the multiple goals of providing outside air, thermal comfort, humidity control and filtration. The curriculum should highlight moisture control issues- sloped drain pans, avoid internal duct lining, easy access throughout HVAC system. Available resources.
Designing radon remediation systems	Tighter buildings may lead to an increase in indoor radon concentrations.	How to assess need for radon mitigation How to design radon remediation systems to ventilate radon gas in the built environment. Radon-resistant homes-EPA program.
Energy efficient power generation	Buildings increasingly will use energy efficient sources of power. Positive for the indoor environment- less costly to bring in outside air, decreased exposure to combustion products from traditional energy sources.	Regional and local benefits of incorporating wind, solar, geothermal into building design.

Appendix A: Trainings for professional communities on buildings and health

A.1 Target Audience: Building owners, Architects, Design teams, Contractors		
Training Topics	***Link to climate change and the indoor environment***	***Key components of "trainings"***
"Prevention by design"	The construction of "green buildings" that are more energy efficient and use renewable energy sources should reduce occupant exposure to volatile organic compounds (VOC) associated with traditional building materials.	How to design buildings with appropriate moisture control, HVAC systems and energy efficient power. How to select building materials (insulation, coatings, flooring). Emphasize the importance of reviewing the health hazards of "environmentally safer materials" before use. Limitations, pros and cons of: pre-occupancy time for off-gassing; and long term monitoring.
Indoor air quality (IAQ) components of building certification program	Building certification programs provide architects and building owners with valuable incentives. Energy efficiency endpoints are emphasized. Understanding the process and possible IAQ endpoints should encourage improved building design.	Emphasize current IAQ management plan endpoints: moisture control, drainage, ductwork protection, HVAC production, use of low VOC building materials, minimum ventilation etc.
Public transportation	Decrease in entrainment of idling vehicle combustion products	Importance of locating buildings near public transportation and bike paths.
Weatherization	Weatherization programs for homes and commercial buildings may result in areas in the structure with inadequate ventilation, humidity, and/or unhealthy concentrations of irritants in the air.	Potential effects of weatherization construction on indoor environmental quality. How to minimize emissions (e.g.: lead (window replacement); fibers (ventilation and insulation activities); and foam (insulation activities). How to determine appropriate weatherization goals. Available resources.

Appendix A: Trainings for professional communities on buildings and health

A. 2 Target Audience: Housing and Institutional Facility Personnel		
Training Topics	***Link to climate change and the indoor environment***	***Key components of "trainings"***
Cleaning and disinfection	Tighter buildings may lead to an increase in indoor VOC and irritants. Improved cleaning practices and utilizing "safer" alternatives will improve indoor air quality (IAQ).	Selection of environmentally preferable cleaning products (green cleaners). Knowledge of third party certified labeling and EPA Design for the Environment programs; best practice cleaning methods; proper use of sanitizers and disinfectants; and appropriate materials and equipment.
Green purchasing	Tighter buildings may lead to an increase in indoor volatile organic compounds (VOC), respiratory irritants, lead dust. Improved cleaning practices and utilizing "safer" alternatives will improve IAQ.	How to evaluate and select environmentally preferable furnishings, flooring, paints etc.
Ventilation maintenance	Increase in outdoor temperature, increased concentrations of outdoor allergens, tighter buildings- demand for HVAC increases. Improperly maintained HVAC can contribute to poor IAQ- inadequate dilution, microbial reservoirs.	HVAC systems and moisture control. Importance of drain pan maintenance. Importance of humidity control throughout the calendar year. Selection of appropriate filters. Duct cleaning (pros and cons, criteria).
Mold abatement and moisture control	Tighter homes may create areas conducive to condensation. Increased flooding, more extreme weather.	Clean up practices after a flood or moisture incursion; including safe use of generators and other powered equipment. Worker protection.

Appendix A: Trainings for professional communities on buildings and health

A. 2 Target Audience: Housing and Institutional Facility Personnel		
Training Topics	***Link to climate change and the indoor environment***	***Key components of "trainings"***
Energy efficient power maintenance	Buildings increasingly will use energy efficient sources of power. Positive for the indoor environment- less costly to bring in outside air, decreased exposure to combustion products from traditional energy sources.	How to maintain new energy efficient power equipment, e.g.: solar, wind, geothermal, fuel cells, others.
Integrated pest management (IPM)	Increased moisture/flooding could lead to increased problems with pests.	Detailed IPM training Moisture control and alternatives to pesticides.
Radon	Tighter buildings may lead to an increase in indoor radon concentrations. Construction activities that disturb basement may affect radon exposure.	When and how to test for radon. How to maintain radon mitigation systems. Available resources.
Weatherization	Weatherization programs for homes and commercial buildings may result in areas in the structure with inadequate ventilation, humidity, and/or unhealthy concentrations of irritants in the air	Potential effects of weatherization construction on indoor environmental quality. How to minimize emissions (e.g.: lead (window replacement); fibers (ventilation and insulation activities); and foam (insulation activities). How to determine appropriate weatherization goals. Available resources.

Appendix A: Trainings for professional communities on buildings and health

A.3 Target Audience: Public Health Personnel, Public Health Responders, Local and Regional Planners, Clinicians		
Training Topics	***Link to climate change and the indoor environment***	***Key components of "trainings"***
Public health training on indoor environments and occupant health targeted to specific population needs	Populations susceptible to elevated temperature: obese, elderly, people with hypertension, thyroid disease, cardiovascular disease, chronic respiratory disease. "Green" buildings and/or "weatherized" buildings where IAQ was inadequately addressed.	- Attention to risk factors: Dehydration, weight loss etc. - Information from local and regional plans: including "cool shelters", effective messages. - Use of combustion sources-stoves. - Resources available to general public on indoor air problems including potential moisture and concentration of pollutants from "tighter" homes.
Recognition of environmental or occupational illness associated with the built environment	Nonspecific symptoms/syndromes and building-related illnesses including: asthma, hypersensitivity pneumonitis, heat stress, dermatitis, cancer (radon), etc.	- Consideration of environmental exposures integrated with clinic visits - Environmental and occupational history taking. - Diagnosis of building-related disease - Medical management and control strategies. - Illness prevention approaches including the "sentinel case model". - Physician reporting and disease surveillance.

Appendix A: Trainings for professional communities on buildings and health

A.4 Target Audience: The workforce involved in the "Green Jobs" created in response to climate change		
Training Topics	***Link to climate change and the indoor environment***	***Key components of "trainings"***
Building weatherization	Buildings will need to be more energy efficient	- Health and Safety: Disposal of broken compact fluorescent lights (mercury); insulation removal (mold, fiberglass); safety of new foam insulation (chemical emissions) and new caulking materials.
Installing and maintaining energy efficient equipment	Buildings increasingly will use energy efficient sources of power.	- Health and safety issues associated with the installation or maintenance of geothermal systems, high efficiency heat pumps, solar hot water heaters, solar array installations. - Potential inhalation hazards associated with new refrigerants. - Confined space entry; slips and falls from heights.
Flood cleanup and mold abatement	Increased flooding, more extreme weather	- Health and safety issues associated with exposure to mold contaminated areas and carbon monoxide (internal combustion engines used indoors), electrical hazards, infections. - Pros and cons of available approaches to abatement
Cleaning and disinfection	Tighter buildings will lead to an increase in indoor VOC and irritants. Improved cleaning practices and utilizing "safer" alternatives will improve IAQ	- Many "green" cleaning products have been screened for environmental safety, not worker safety. Importance of selecting third party certified products that insure that the product does not contain known respiratory sensitizers (Association of Occupational and Environmental Clinics list); - Best practice cleaning methods, appropriate materials and equipment