CLIMATE CHANGE AND INDOOR AIR QUALITY

Contractor Report

Prepared for:

U.S. Environmental Protection Agency, Office of Radiation and Indoor Air

by

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INTRODUCTION

When it comes to climate change, the only certainty is uncertainty. As pointed out by the Intergovernmental Panel on Climate Change (IPCC), there are many speculative predictions about the timing, magnitude, and patterns of climate change. Nonetheless, the IPCC (2007) states that warming of the climate system is indisputable and based on current practices green house gas emissions are expected to grow. Ebi et al. (2008) noted that the impact of climate change will vary on a regional basis in the United States. It follows that the impacts of climate change on indoor air will also vary by region. The indoor air of homes, as well as other built structures, is often directly, or indirectly, affected by environmental conditions outside the structure. Since adults, as well as children, spend the majority of their time indoors (Klepeis et al. 2001; Field et al. 1998; Wiley et al. 1991), concentrations of pollutants within a home significantly contribute to overall exposures. Indoor air quality often reflects outdoor air quality. In addition, indoor air quality will also be impacted indirectly by changes in the occupant's behavior (as the occupant adapts to climate change) that will affect the production and persistence of pollutants (e.g., carbon dioxide, nitrogen oxides, sulphur oxides, aldehydes, lead, volatile organic compounds, semivolatile organic compounds, biological pollutants, etc.) generated within the home or building. For example, behavioral changes that reduce air exchange rates, such as the use of a room air conditioner in a home with low air exchange rates, often results in higher concentrations of indoor air pollutants than what exists outdoors.

CHANGES IN RESIDENTIAL VENTILLATION PATTERNS

Extension of growing season and moderate weather

Longer spring and fall warm temperate periods will extend the time periods windows may be kept open, especially in northern regions of the United States or among lower income individuals, resulting in increased air exchange rates that will translate into more outdoor aeroallergens and other air pollutants (e.g., ozone, particulate matter, etc.) equilibrating with the residential air. Increased use of window or whole house fans that increase the air exchange rates of the home will also increase exposure to outdoor aeroallergens and other air pollutants. Under these conditions, many of the climate change related exposures and health effects are similar to what have been documented and projected for outdoor-related climate change related adverse health effects (NIEHS 2010, Ebi et al. 2008, Wilby 2007, MMWR 2006).

For instance, in a recent review of the expected effects of climate change on respiratory allergic diseases, D'Amato and Cecchi (2008) highlight expected changes in Europe that that may have negative, climate change related, health effects on atopic individuals. These factors that include an earlier start of the pollen season, an extended duration of the growing season, an increase in long distant transport of pollen and pollution, and increased pollen production may be similar to climate change related events in the United States. While there are still many factors to investigate regarding climate change and the magnitude and duration of aeroallergen exposures, increases in carbon dioxide, humidity, and rainfall will undoubtedly increase allergy-related respiratory diseases in the indoor environment (Ariano et al. 2009, Schmier and Ebi 2009, D'Amato et al. 2007, Singer et al. 2005, Beggs 2004) as well as increase the allergenicity of the pollen (Shea et al. 2008, D'Amato et al. 2007, Beggs and Bambrick 2005).

As mentioned above, increased air exchange rates impact exposures to outdoor pollutants such as particulate matter. Over the past 10 years, research examining the infiltration of pollutants from the outdoor air to the indoor environment has provided new insights (e.g., Abt et al. 2000, Monn 2001) into the relative contribution of outdoor sources. Researchers have discovered that fine particles ($PM_{2.5}$), which have the greatest adverse health effects among the various particle size fractions, generally have higher infiltration rates into homes as compared to coarse and ultra fine particles (UFP) (Liu and Nazaroff 2003, Long et al. 2001, Liu and Nazaroff 2001) and can exceed indoor-outdoor ratios of 0.5 (Meng et al. 2005, Wallace 1996). While UFPs have been found to have lower infiltration rates as compared to $PM_{2.5}$, indoor concentrations generally follow outdoor concentrations and depending on the size fraction can have indoor-outdoor ratios similar to those for $PM_{2.5}$ (McAuley et al. 2010, Nazaroff 2010).

Indoor air quality is impacted by the infiltration of pollutants from outdoor air as well as from indoor emission sources. Increases in outdoor temperatures and longer periods of home air conditioner (AC) usage, with the house closed and air-sealed to minimize leakage (i.e., recirculation air conditioning with no mechanical outdoor air ventilation), result in longer periods of reduced air exchange rates. However, even during these periods of reduced air exchange, the quality of indoor air is impacted by the quality of outdoor air, but to a lesser extent than the examples provided above when the air exchange rates were higher.

INCREASED TEMPERATURE

Hyperthermia is already the leading cause of weather related death in the United States (MMWR 2006). As temperatures in some areas of the country increase, hyperthermia related deaths will also increase particularly in individuals of low socioeconomic status who lack finances to cool their homes. The elderly, young children, pregnant women, and individuals with chronic medical conditions will also be at higher risk. In addition to hyperthermia, increasing indoor air temperatures typically increases the emissions rates of volatile organic compounds (VOCs) from building materials, furnishings, carpeting, personal care products, cleaning and deodorizing products, etc. as well as the interactions between indoor pollutants.

INCREASED HUMIDITY

Willett et al. (2007) have identified a significant global-scale increase in surface specific humidity, which they attribute primarily to human influence. The researchers noted that the specific humidity has increased in response to rising temperatures and that these changes may be predictive of increased intensity of precipitation. Increased precipitation, leading to moldy interiors of homes as well as increased humidity indoors, has the potential to significantly increase airborne exposure to fungi, including mycotoxin-producing fungi, and the microbial volatile organic compounds (MVOCs) they produce. In addition, increased dampness can increase the release of chemicals and particles from building materials; and increase the amount of bacteria, dust mites, cockroaches and other pests (all of which can be allergenic) in the indoor environment (NAS 2004).

CHANGES IN BUILT ENVIRONMENT

The characteristics of the built environment play a major role in determining indoor air quality. These factors include insulation, HVAC type, air exchange rates, building materials, building type, and numerous other factors. The majority of the world's population now resides in cities and the rate of growth of cities is expected to outpace the rate of growth of less urban areas (United Nations 2010). The influx of people into cities as well as the continued build-up of the urban environment increases the need for higher density housing that will in turn increase the number of multi-tenant buildings. In addition to changes in the built environment in response to direct environmental pressures (e.g., increased temperature, humidity, etc.) and population driven housing demand, **global climate change will exert a significant impact on indoor air quality as a result of changes in home construction practices (e.g., energy efficiency, etc.) intended to reduce our carbon footprint.**

Increased Air Conditioner Usage

The Department of Energy's U.S. Energy Information Administration reports that the percentage of homes with central air conditioning has grown from 23% in 1978 to 47% in 1997 (DOE 2010). By 2007, the U.S. Census Bureau reported that over 86% of the occupied homes in the United States had some form of air conditioning (U.S. Census Bureau 2008).

Weatherization and Energy Efficiency

EPA (2010) websites state that "Weatherization and other energy efficiency upgrades can have negative impacts on occupant health and safety if not accompanied by appropriate indoor air quality - IAQ - protections." The EPA indicates that these negative impacts include increased carbon monoxide, tobacco smoke, and hundreds of volatile organic compounds, etc. Methods to increase air exchange rates such as providing a small percentage of outdoor make-up air for HVAC applications has the potential to dilute and remove indoor-generated pollutants, yet without proper filtration, it can increase indoor air pollution from outdoor sources depending on weather conditions and outdoor air quality.

CHANGES IN OCCUPANT BEHAVIOR

Increased Air Conditioning Usage

The Department of Energy's U.S. Energy Information Administration also reported that the percent of homeowners with central air conditioning who indicated using air conditioning "all summer long" increased from 33% to 52% between 1978 and 1997, respectively (DOE 2010). Not surprisingly, the southern portion of the United States had the highest percentage (69%) of homeowners with central air conditioning in 1997 who reported using it "all summer long". As outdoor temperatures and allergens increase, air conditioner usage will undoubtedly increase, which will in turn adversely increase the concentrations of some indoor air pollutants.

Changes in Temporal Mobility (Activity Patterns)

Several studies performed in California have shown that individuals as early as the late 1980s and early 1990s spent a significant amount (87%) of their time indoors (Klepsis et al. 2001, Jenkins et al. 1992). These percentages were fairly constant over the various regions of the United States for that time period (Klepsis et al. 2001, Field et al. 1998). Residential occupancy comprises the majority (generally over 65%) of the time spent indoors (Klepsis et al. 2001, Field et al. 1998, Jenkins et al. 1992) with individuals more vulnerable to air pollution (e.g., children and the elderly) spending even a greater percentage of time in the home (Field et al. 1998, Liu et al. 1993). The EPA's Consolidated Human Activity Database (CHAD) may be a useful resource for determining if time spent indoors continues to increase as outdoor temperatures increase.

EMPHASIS ON RADON-222 (RADON)

Other than smoking related mortality, radon-induced lung cancer is likely the leading environmental cause of cancer mortality in the United States. Table 1 presents the ranking for radon induced lung cancer mortality versus cancer mortality for all causes. Overall, radon-induced lung cancer is the seventh leading cause of cancer mortality in the United States.

Table 1. Estimated U.S. Cancer Mortality for 2009 by Cancer Type*.

CANCER TYPE	ESTIMATED U.S. DEATHS\YR
1. Lung and Bronchus	159,390
2. Colon	49,920
3. Breast Cancer	40,610
4. Pancreas	35,240
5. Prostate	27,360
6. Leukemia	21,870
>> Radon Induced Lung Cancer	21,000
7. Non-Hodgkin Lymphoma	19,500
8. Liver and Bile Duct	18,160
9. Ovary	14,600
10. Esophagus	14,530
11. Urinary Bladder	14,330
12. Kidney and Renal Pelvis	12,980
13. Stomach	10,620
14. Myeloma	10,580
15. Melanoma	8,650

*Adapted from Jemal et al. 2009

Unlike many other indoor air pollutants that are correlated to outdoor air pollution, radon gas concentrations in the home are related primarily to ingress of radon from ground sources (EPA 1991) and to a lesser extent both waterborne radon entering the home and emanation of radon from building materials. The EPA (1994) states "that the primary factors that influence radon entry include 1) the radon content of the soil, 2) the pressure differential between the interior of the home and the soil, 3) the air exchange rate for the home, 4) the moisture content surrounding the home, and 5) the presence and size of entry pathways." These factors can be affected by climate change to varying degrees. Climate change may also affect the depositional environment within the home resulting in changes to the delivered dose by radon decay products. The relative concentration of radon to its decay products, and the ability to deliver dose, is impacted by numerous factors including building ventilation rate, decay product attachment to aerosols, and particle deposition rate on surfaces (Sun et al. 2010, Sun et al. 2009, Roos 2002, Nazaroff and Nero 1988). All of these factors could be impacted by housing as well as behavioral changes driven directly or indirectly by climate change. For example, the increased use of ceiling fans for cooling would tend to increase deposition of radon decay products and reduce the delivered radon-related dose to the lungs (Sun et al. 2010, Sun et al. 2009). Alternatively, increased use of air conditioning, may reduce the use of ceiling fans, and therefore enhance the delivered dose by radon progeny.

Increased Air Conditioning and Fan Usage

Increased use of AC, necessitated by increasing temperatures, generally leads to higher radon concentrations resulting from decreased air exchange rates, particularly for tightly-sealed homes, and in some cases differences in pressure differentials between the interior of the home and the soil. As noted above, increases in temperature will increase the percent of homes with air conditioning as well as the duration of air conditioning usage. The use of air conditioning contributes to “closed house conditions” which in turn results in higher radon concentrations. In addition, the use of forced air HVAC tends to reduce the stratification of radon between floors thus increasing the radon concentrations on the upper floors where residents spend a greater percentage of time.

Activity Patterns and Spatial Radon Variation

A study of female Iowa residents (Field et al. 1998) found that only a small percentage (6.8% of time for two story homes and 3.5% for three story homes) of time was spent in the basement where the highest radon concentrations generally occur. However, some Iowa home owners, without air conditioning, reported spending more time in the basement during warm periods in the summer. The move to cooler areas of the home (i.e., basement) as temperatures increase will raise the potential for increased radon exposure and to other indoor air pollutants (e.g., molds, carbon dioxide, etc.)

Weatherization and Energy Efficiency

There is widespread, perhaps erroneous in many cases, belief that increased weatherization and energy efficiency of homes significantly contributes to increased residential radon concentrations. For example, the latest ATSDR (2010) statement on radon includes the following statement, “In indoor locations, such as homes, schools, or office buildings, levels of radon and radon progeny are generally higher than outdoor levels and may be particularly high in some buildings, especially in newer construction that is more energy-efficient.” However, in their book, “Radon’s Deadly Daughters”, Edelstein and Makofske (1998) label the belief that radon concentrations in energy efficient homes are differentially elevated as compared to other homes, “the myth of the tight house”. They noted that high insulation rates as well as energy efficient homes, relying on several studies published primarily during the 1980s to support their view, have limited influence on increased radon concentrations. However, the authors concede that tightening homes may increase radon concentrations for homes that have significant sources of indoor radon sources (e.g., waterborne radon, building materials).

Since 1990, numerous studies noted that past and current energy efficiency measures do not necessarily increase radon concentrations (EPA 1994, Chi and Laquatra 1990, Mullen and Nevissi 1990). Nonetheless, continued uncertainty remains about the impact of weatherization and energy efficiency on residential radon concentrations. In late fall of 2009, Senator Mark Udall wrote to the Secretary of Energy, Steven Chu, and EPA Administrator, Lisa Jackson, expressing his concern about the Department of Energy’s ongoing weatherization program in regard to indoor pollutants, including radon (attached). In a March 2010 letter of response to Senator Udall, Steven Chu and Lisa Jackson indicated that both the DOE and EPA will assure that weatherization practices will do no harm and will evaluate the effect of weatherization on indoor radon (attached). If energy efficiency and weatherization guidelines include consideration of air exchange rates and ventilation, climate change driven housing guidelines for energy efficiency should have less of an effect on residential radon concentrations. However, if outdoor make-up air, with increased air pollutants, is used to reduce residential radon concentrations, indoor air quality may suffer unless the air is filtered prior to use.

Weather-related influences

Numerous weather-related factors influence the ingress of radon into buildings including wind, barometric pressure, temperature, and rainfall. All of these factors will potentially be influenced by climate change to differing degrees based on geography. For example, increased wind can exert small pressure differences between the lower levels of a dwelling and the outdoors (Steck 2009). Increased precipitation can also act to impede radon emanation, “capping” the soil outdoors and directing it toward the unsaturated soil near or under the building. In addition, if the soil is not saturated, low and moderate levels of soil moisture provide a greater radon source that can penetrate through holes in the substructure of a building (Schumann et al. 1989).

High Density Housing

Many cities and urban areas are moving toward a higher percentage of high density housing driven by population increases as well as efforts to reduce greenhouse emissions. Condominiums and other high density type housing units are often constructed of concrete including some units with concrete construction on all sides (i.e., walls, ceiling, floor). While the radium content of the concrete is not high, the large concrete surface area and low air exchange rates in the units have contributed to elevated radon exposures for some occupants (Lawrimore 2010, Broadhead 2008). Concrete, as a source of radon exposure, may be an increasing problem as more high density housing is constructed.

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