Climate Change and Potential Effects On Microbial Air Quality in the Built Environment

Prepared for:
The Indoor Environments Division
Office of Radiation and Indoor Air

On behalf of:
U.S. Environmental Protection Agency
Washington, D.C. 20460

Prepared by:
Philip R. Morey, Ph.D., CIH
ENVIRON International Corporation
Gettysburg, PA
717-337-2324
pmorey@environcorp.com

Date:
September 15, 2010

This report presents the findings, recommendations and views of its author and not necessarily those of the U.S. Environmental Protection Agency.

Contents

1.0 LEGIONELLA

Legionella species are normally present in outdoor environmental reservoirs such as lakes or streams. However, these bacteria can colonize and amplify in man-made water reservoirs including potable water systems and cooling towers. Inhalation of water droplets containing Legionella species dispersed from cooling towers and potable water outlets (e.g., showerheads) can cause lung infections (Legionnaires' disease) which may be fatal. Approximately 18,000 cases of Legionnaires' disease occur annually in the USA (Squier, et al., 2005) with a case fatality rate of about 20% for community acquired disease and up to 40% for hospital acquired disease. This translates into an annual fatality total of about 4,000 to 5,000 in the USA (Squier et al., 2005; Benin et al., 2002). The risk of a Legionnaires' disease outbreak caused by exposure to mists or drift generated outdoors from a cooling tower is usually recognized by facility operators of modern commercial and public buildings. However, the risk of exposure to Legionella aerosols from potable water outlets, especially in residences and hotels, is often overlooked.

Studies during the past five years have suggested that increases in community acquired Legionnaires' disease may be associated with climate change (Fisman et al., 2005; Ng et al., 2008; Neil and Berkelman, 2008; Phillips, 2008). In the eastern USA and in Europe, Legionnaires' disease increases have been associated with rainfall and warm and humid weather. Wet humid weather six to 10 days before the occurrence of disease symptoms was, in one study (Fisman et al., 2005), the best predictor of Legionnaires' disease. The incidence of disease, not surprisingly, was also found to be higher during warm summertime months. Enhanced reporting of disease occurrence and better diagnostic tests for Legionnaires' disease did not appear to be responsible for the increased risk of Legionnaires' disease associated with wet-humid and warm weather.

A possible link between severe wet humid weather patterns and increased incidence of Legionnaires' disease may be the dispersal of organic sediment into municipal water systems and the resulting increased turbidity of drinking water supplies. It is well known that potable water in pipes in buildings can be contaminated by Legionella species entering from public water systems (States et al., 1987). If future work confirms that climate change-severe weather events (e.g., excessive precipitation and flooding) are associated with increased Legionnaires' disease incidence, mitigation efforts involving better filtration or appropriate chemical treatment (e.g., chlorination) of mains water entering buildings as well as better maintenance of potable water systems pipage in buildings may ameliorate the disease risk.

It has been estimated that 80% of Legionnaires' disease outbreaks are associated with potable water systems in buildings (Keane, 2009). It is also well known that Legionella species are ubiquitous in natural waters as well as in man-made water systems. With regard to climate change, it is important to note the growth of Legionella species is most rapid in the 85 to 110°F range. A general recommendation for building operators with regard to control of Legionella growth in plumbing systems is to keep the cold water supply temperature below 68°F (Keane, 2009). The personal experience of the author, however, indicates that the cold-water temperature in buildings in warm climates such as in Honolulu or Miami can be in the 78 to 82°F range, thus approaching the lower optimal growing range for Legionella amplification.

The cold water for many public water systems originates from water stored in large lakes or reservoirs. In Colorado, it has been estimated that by 2050 the outdoor air temperature could rise by at least 2.5°F to 5.5°F (McCurry, 2009). It would be logical to suspect that the temperature of water stored in reservoirs will also rise. Indeed, in a presentation on "Climate Change and Municipal Water Supplies" (Stickel, 2009), some tentative data is provided suggesting that the water temperature in an Oregon reservoir has risen about 0.3°F during the past decade. Additional historical (since 1965) data on raw water temperature is available from the Portland Water Bureau (M. Sheets, 2010), and perhaps from other water authorities, to determine if warming is occurring in municipal water systems. If verified, this means that the temperature of mains water entering buildings will rise resulting in physical conditions in water pipes wherein Legionella and other microorganisms can more readily amplify. A temperature-monitoring program in municipal water supplies and in cold water entering buildings is needed to determine if climate change is affecting the Legionella amplification potential in potable water systems.

2.0 GEOGRAPHICALLY EMERGING PATHOGENS OTHER THAN LEGIONELLA THAT HAVE THE POTENTIAL TO AFFECT THE INDOOR ENVIRONMENT

The IOM (2008) Global Climate Change report provides background information on the potential dispersal of pathogenic microbial agents into new geographic areas. El Niño type weather changes have affected the dispersion of both vector and non-vector disease agents such as those causing malaria, cholera, and hantavirus pulmonary syndrome (IOM, 2008, pg. 16). Some disease causing agents that were once geographically restricted such as the fungus Batrachochytrium dendrobatidis, which infects amphibians, are now worldwide in distribution. It should be recognized that dispersal of disease causing pathogens may also be caused by human activity (e.g., dispersal of spores on vehicle tires) as well as by natural weather events (e.g., dispersal by wind).

Climate change and extreme weather events already appear to be involved in the establishment of microbial pathogens in new geographic niches. The emergence of Cryptococcus gattii on Vancouver Island (British Columbia) and its expansion into the Pacific northwest mainland provide an example of a serious and emerging indoor and outdoor environmental risk (Kidd et al., 2007; Byrnes et al., 2009).

Cryptococcus gattii can cause life-threatening infection in humans and animals (Datta et al., 2009; Byrnes et al., 2009). Prior to 1999, Cryptococcus gattii infections were unknown in British Columbia, as the distribution of this pathogen was restricted to tropical and subtropical areas. Since 1999, likely associated with El Niño/Southern Oscillation warming, this pathogen established itself on Vancouver Island. Subsequently, Cryptococcus gattii and its genetic variants expanded their range to include mainland British Columbia as well as Washington and Oregon in the USA.

Cryptococcus gattii is found in the top 15 centimeters of soil (Kidd et all, 2005), on trees, in wood chips, in mulch, and in other natural reservoirs. Like Aspergillus fumigatus, its spores are readily aerosolized by soil disturbance (Kidd et al., 2007). It is well know that construction activities involving soil excavation are risk factors in the development of nosocomial Aspergillus fumigatus infections (Streifel, 1988). The infection risk from newly emerging pathogens like Cryptococcus gattii and perhaps other microorganisms such as Histoplasma capsulatum should be considered by public health authorities as a potential consequence of climate change.

The risk of Cryptococcus gattii exposure in and around buildings includes new “green” landscaping such as installation of roof gardens (ASHRAE, 2009A, Strategy 2.6) and indoor atrium plantings where extensive use of mulch and organic soils (possible reservoirs of newly emerging pathogens) occurs. Dust suppression during construction and renovation are the primary environmental tools for control of nosocomial Aspergillus fumigatus infection. For newly emerging pathogens like Cryptococcus gattii, public health authorities should consider similar dust control actions to lower infection risk in both indoor and outdoor environments.

3.0 AIR-CONDITIONING AND CLIMATE CHANGE

Air-conditioning enables people to decouple their indoor environment from the outdoor atmosphere. Comfortable temperature and moisture (humidity) levels in indoor air can be provided by a well-designed, operated, and maintained air-conditioning system. In buildings located in geographical areas with hot or warm humid climates or seasons, provision of a comfortable indoor air environment is almost totally dependent on air-conditioning.

Global warming and climate change could have severe impacts on air-conditioning in buildings. These impacts include the abandonment of air-conditioning systems because they are too expensive to operate and secondly, the under-maintenance of air-conditioning systems leading to increased moisture and mold growth indoors. In buildings without central forced air systems especially in residences, a greater use of portable air-conditioning units will occur. These portable units are also likely to be under maintained.

It has been estimated that the operation of buildings worldwide consumes about 50% of all energy generation (Roaf et al., 2009, pg. 213). In the USA, the majority of building energy consumption is used to operate air-conditioning systems. If air-conditioning was abandoned in buildings because of energy cost or availability, the indoor climate in many modern buildings would become unlivable or unacceptable for comfortable occupancy especially in geographical areas with hot or warm humid climates or seasons. Most modern buildings have no or little provision for natural ventilation or other means of providing for a comfortable indoor environment in the absence of air-conditioning. In the USA, it is unlikely that air-conditioning in the current building stock will be abandoned. Rather, under conditions of energy scarcity and high cost associated with climate change, it is likely that in order to save on cost, air-conditioning systems will be poorly designed and operated and severely under maintained.

For the past 20 years, it has been known that building related symptoms (sick building syndrome complaints) are more frequent in air-conditioned as compared to naturally ventilated buildings (Burge et al., 1987; Zweers et al., 1992). Air-conditioning involves dehumidification of the ventilation air stream, which results in wet surfaces such as on or in drain pans and on cooling coils. In addition, air-conditioning results in moist surfaces in air supply ducts and in some building components thermal gradients, which can facilitate condensation and microbial growth. Dust and dirt which accumulate over time on HVAC airstream surfaces contain nutrients for microbial growth and provide a hydrophilic niche (dust and dirt absorb moisture) for this growth (West and Hanson, 1989; Morey et al., 2009).

It has been hypothesized that wet-moist surfaces in air conditioning equipment results in uncharacterized microbial exposures leading to building related symptoms (Mendell et al., 2008). Under-maintenance of air conditioning systems in buildings as a result of increasing HVAC operational costs and energy constraints could exacerbate microbial IAQ problems. Some examples of HVAC air conditioning problems that could be exacerbated by global warming-climate change follow.

Figures 1 and 2 show an exterior view and an interior view of a fan coil unit (FCU) which provides conditioned air to an apartment located in a building in the middle Atlantic states. Room air enters the FCU through the return air grille located near the bottom of the enclosure shown in Figure 1. Conditioned (ventilation) air enters the room through the grille at the top of the FCU enclosure in Figure 1. Figure 2 shows an interior view in this severely under maintained FCU. Metal surfaces are wet and heavily corroded. Mold growth is visible on most airstream surfaces. It should be noted that ventilation air passes directly over the wet, corroded, and moldy interior surfaces as air travels through the FCU to be delivered to the breathing zone of room occupants.

Figures 3 and 4 show interior views of the cooling coil section serving a guest room in a hotel located in the Western States area. Considerable dust and debris including skin scales have accumulated over years in this severely under-maintained FCU. Ventilation air passes over these wet and dirty airstream surfaces to be delivered to the breathing zone of the unsuspecting guest room occupant.

The consequences of poor design and under-maintenance of HVAC systems providing air conditioning to some buildings in the Southeast States are shown in Figures 5 to 7. Mold growth occurs on the metal surface (molds grow on fine dust and oil film) of a fan motor in an air-handling unit where access for purposes of cleaning is difficult or impossible (Figure 5). The dirty visually moldy airstream surface of a supply air duct with a porous liner is shown in Figure 6. Because of poor filtration, dirt and dust readily accumulated on the moist (the air-conditioned air is humid), fibrous surface and then mold growth readily occurs. In the view in Figure 6, visible mold on the airstream surface is white or gray while the few areas without mold are yellow which was the original color of the duct liner surface. Figure 7 shows a photomicrograph of mold (mostly Cladosporium species) growing on the dirt present on the airstream duct surface. Because operation and maintenance of air conditioning systems are often “out of sight and out of mind” it is likely that the kinds of conditions shown in Figures 1-7 will become more severe as climate change and higher energy costs make it more difficult to efficiently operate air conditioning systems.

Because of potential climate change and increasing energy costs, air conditioning systems in new and existing buildings must be designed, operated, and maintained so that HVAC components can be kept clean and can be operated efficiently so as to provide people with a comfortable living/working environment. A new and practical IAQ Guide is available to help achieve the above objectives including “Control of Moisture and Dirt in Air-Handling Systems” (ASHRAE 2009B), “Facilitate Access to HVAC Systems for Inspection, Cleaning and Maintenance” (ASHRAE 2009C), and “Provide Particle Filtration and Gas-Phase Air Cleaning Consistent With Project IAQ Objectives” (ASHRAE 2009D).

4.0 OUTDOOR AIR VENTILATION AND CLIMATE CHANGE

For centuries, it has been recognized that indoor air in occupied buildings is almost always more contaminated by human-sourced pollutants than the outdoor atmosphere around the building. In order to prevent the degradation of indoor air from people and their activities early builders realized that a continuous source of outdoor air ventilation was required. Inventors of both roof vents for exhaust of fire smoke and operable windows for intake of outdoor air were familiar with the concept of outdoor air ventilation to reduce indoor air pollutant levels.

Over two centuries ago, Benjamin Franklin recognized that outdoor air ventilation in buildings was important in the prevention of infectious disease as well as providing for occupant comfort (Morey et al., 2010). He wrote that outdoor and "cool air does good to persons in the smallpox and other fevers. It is hoped that in another century or two we may find that it is not bad for people in health" (Morey and Woods, 1987). Subsequently, it was realized in the mid-19th century that Mycobacterium tuberculosis and other infectious bioaerosols were most prevalent in crowded indoor environments where the amount of outdoor air ventilation was limited. Thus, by the end of the 19th century building codes recommended large amounts of outdoor air ventilation to minimize disease risk from airborne contagion. Current ventilation standards (ASHRAE 62.1-2010) recommend provision of at least a minimum level of outdoor air ventilation to dilute pollutants both from human sources (e.g., body odors) and from building materials (e.g., VOCs).

It is well-known that respiratory infections ranging from rhinovirus that causes the common cold (Dick et al., 1987) to agents which caused the severe acute respiratory syndrome (SARS) epidemic in 2003 (Li et al., 2007) can be transmitted by the aerosol route. Providing outdoor air to indoor environments to reduce the risk of contagion by dilution has been recognized in ventilation codes for more than 100 years. A likely consequence of climate change/global warming will be a tendency of building operators to reduce outdoor air ventilation because of increasing energy costs needed to condition (e.g., heat, cool, dehumidify) the outdoor air entering the HVAC system. Thus, reduction in outdoor air ventilation in modern crowded buildings could result in elevated levels of bacterial and viral agents that cause infectious disease (IOM, 2008, pg. 162).

A subtle effect of decreased outdoor air ventilation in buildings is the likely increase in levels of indoor allergens (especially from pets) and dusts containing endotoxins (Dales et al, 2008). A substantial increase in dust removal by cleaning will become important to lower levels of dusts containing allergens in poorly ventilated and maintained buildings. It should be recognized that over the last decade, many commercial building operators, school districts, etc., have decreased their cleaning budgets and housekeeping staff. Housekeeping/cleaning efforts will become more important as outdoor air ventilation in buildings declines.

A likely effect of climate change will be the expansion of desert areas, which is already occurring in the Southwestern States. One of the consequences of desertification will be weather change involving more dust storms. In a recent paper, Chen et al. (2010) showed that dust storms (See Section 5.0 for more on dust storms) can provide an effective transport mechanism for bioaerosols such as the Avian Influenza Virus. In the Southwest States, it is well known that dust storms provide a mechanism for airborne transport of molds, bacteria, and even nematodes as well as for other contaminants such as arsenic (from past use of arsenic trioxide as a pesticide) that may be present in the soil.

It has long been recognized in ASHRAE ventilation standards that cleaning (filtration) of the outdoor air entering HVAC systems is often required to provide acceptable indoor air in occupied spaces (ASHRAE 62.1 – 2010). If climate change driven desertification increases and if the findings of Chen et al., (2010) are repeated, it will be necessary to find better methods of cleaning the outdoor air entering HVAC systems, especially in the U.S. Southwest. ASHRAE (2009E) has provided a general strategy for "Location of Outdoor Intakes to Minimize Introduction of Contaminants into Ventilation Air."

In summary, a dustier atmospheric condition associated with climate change will require building operators to pay more attention to providing cleaner ventilation air as well as a less dusty indoor environment.

5.0 POSSIBLE CONSEQUENCES OF CLIMATE CHANGE/SEVERE WEATHER EVENTS AFFECTING THE BUILT ENVIRONMENT

Because of concerns over high energy consumption during the manufacturing of some building structural components, emphasis has recently been placed on the use of "green" construction materials. The manufacturing process for steel, aluminum and concrete generally requires the consumption of more energy (more fossil fuel use; thus, more carbon dioxide generation) than the fabrication of building materials from cellulose and wood fibers (e.g., glulam beams, manufactured wood siding, oriented strand board, etc.) (UNEP, 2007, pp. 17 and 20). While cellulosic/manufactured wood products are less demanding in terms of energy consumption, they are subject to biodeterioration in damp/wet conditions. Figure 8 shows spray-on, cellulose-containing fireproofing that was applied wet to ceiling structural components in a new building. Within a month after application, abundant mold growth including Aspergillus and Stachybotrys (Figures 9 and 10) species occurred in the insulation necessitating its costly removal (See also, Godish and Godish, 2006). The pipe on the right side of Figure 8 was installed by the construction contractor to transport ozone to the above ceiling area in a failed attempt to inhibit mold growth in the cellulosic insulation. In summary, the use of environmental friendly green construction products, if not carefully considered, can result in unanticipated biodeterioration and IAQ problems when these materials are installed in damp-wet building niches.

In the mid-20th century, steel and masonry materials such as brick, concrete block, clay tiles, and plaster were primarily used in the construction of exterior walls while wood studs covered by plaster were commonly used for interior wall systems (Ellringer et al., 2000). Materials used in the construction of modern buildings commonly contain cellulose and wood fiber products (e.g., paper-faced wallboard and manufactured wood) for both interior and exterior walls. Fleecy-porous products such as carpet are commonly used today as interior finishes. Dutch researchers (Adan et al., 2005; see also Loftness et al., 2007) have proposed a classification system (“resistant, fairly resistant, or sensitive”) for construction and finishing materials based on susceptibility to biodeterioration. Thus, sensitive materials such as carpet should not be used in intermittently wet locations such as bathrooms (See also, Figure 11). Paper-faced gypsum wallboard should not be used as part of the building envelope where moisture incursion often occurs (Adan et al., 2005). As severe weather events involving heavy rainfall become more common, a carefully developed product labeling scheme based on biodeterioration resistance would be helpful to commercial and residential builders in minimizing indoor mold problems. Loftness et al. (2007) also point out that the use of fungicides to increase the resistance of materials to biodeterioration often does not work in the long term (See also, Lem et al., 1989) and may result in increasing risk of chemical exposure.

Extreme weather events involving intense precipitation (rain and snow), flooding, and wind damage appear to be associated with climate change (IOM, 2008, pp. 89 and 117; Patz et al., 2008). These types of weather events can be catastrophic to building systems. Figures 12-14 provide one example of the catastrophic damage that can occur in a building affected by hurricane winds and intense precipitation. Most of the windows (glass façade) were blown out by hurricane force winds (Figure 12). Plastic sheeting (Figure 12, arrows) had been placed over much of the remaining envelope structure to keep out subsequent rains during building restoration. Almost all paper faced gypsum wallboard was removed because of water damage and subsequent mold growth (Figures 12 and 13). Wood shims under a bathtub in Figure 14 (arrows) were “fairly resistant” to the catastrophic water damage. Concrete floors, ceilings, and metal studs, sill plates and pipes were “very resistant” to water damage.

Roaf et al. (2009, pg. 80) has pointed out that modern buildings need to have better protection from grade level water entry or flooding. Also in geographic areas subject to hurricanes and strong wind damage, the building envelope needs to be made more “robust” so as to limit window blowout and subsequent water entry (Roaf et al., 2009, pp. 110 and 112). Serious consideration needs to be given to development of standards for robust building construction, especially in geographic areas subject to severe weather events. Robust construction standards for building materials should include a biodeterioration concept similar to that proposed by Adan et al. (2005) as well as attention to quickly drying-out wetted building infrastructure (IICRC, 2006). The U.S. EPA Indoor airPLUS Construction Specifications

Section 1, *Moisture Control*, provide a starting point on how recommendations on robust and biodeterioration-resistant construction practices might be formulated (EPA 2009).

Moisture damage and subsequent mold growth, especially in residences, may also be caused by heavy snowfall like that which occurred in the Middle Atlantic States in February, 2010. Melting snow and frozen gutters can result in ice dams and entry of water into the building envelope. Practical and simple actions to minimize entry of snow moisture into the building envelope could be added to the EPA Indoor airPLUS (2009) document. These actions could include recommendations such as the removal of snow from the building foundation area as well as use of "snowrakes" with long handles to remove snow from roof areas near gutters.

Severe weather events involving increased precipitation (e.g., El Niño rains; hurricanes) and floods can affect microbial IAQ in buildings. Growth of Peziza in a wet building has been associated with a case of hypersensitivity pneumonitis or "El Niño lung" (Wright et al., 1999). In portions of a California dormitory chronically wetted by El Niño rains in 1997-1998, the dominant mold in indoor air changed from Cladosporium cladosporioides to Penicillium chrysogenium (Morey et al., 2003) presumably because of growth of Penicillium species on water-damaged cellulosic materials in the building envelope. Studies in New Orleans homes after hurricane Katrina showed that Penicillium/Aspergillus dominated the mold spores found in both the indoor and outdoor air (MMWR, 2006). Other studies (Solomon et al., 2006) showed that Penicillium/Aspergillus and Cladosporium spores were dominant in the outdoor air at flooded home sites. These New Orleans studies collectively suggested that mold taxa in the outdoor air around flooded homes were heavily influenced by spore emissions from mold growth on furnishings and construction materials in the water-damaged homes.

Lloyd's London has prepared a report on insurance loss risk associated with climate change (Lloyd's 360 Risk Project, 2007). In a section of the Lloyd's report on "Increased Frequency and Intensity of Floods" it is noted that by 2070, today's "100-year-flood" may begin to recur every 10 to 50 years. As Roaf et.al. (2009, pg. 80) point out, modern buildings need to be better protected from flooding. An appropriate governmental response to repeated severe flooding events would be the enactment and enforcement of zoning codes that prevent construction of buildings within 100-year flood plains.

If severe weather events involving increased precipitation and flooding/water damage to the built environment continue (latest example – Nashville, TN floods in May 2010) an appropriate public health response would be increased involvement of NIOSH/CDC in documenting possible disease outcomes and in providing practical guidance on restoration activities. Airborne mold characterization in the Katrina NIOSH/CDC (MMWR, 2006; Solomon et al., 2006) studies primarily involved spore trap sampling where species identification is not possible. Changes in bioaerosol exposure in and around flood damaged homes may be subtle, involving replacement of a normal phylloplane species such as Cladosporium cladosporioides by Cladosporium sphaerospermum or Cladosporium halotolerans (See AIHA, 2008, Chapter 4). This kind of species change which may be important in exposure assessment is not detectable by spore trap sampling. Thus, future studies to elucidate possible health effects associated with bioaerosol exposures in geographical areas with severely water-damaged buildings should include culture based sampling for fungal species as well as sampling for glucans and endotoxin.

One of the less obvious consequences of climate change in some geographic areas is the potential for severe drought, expanded desertification, and associated changes in microbial air quality in the atmosphere (See also Section 4.0). Lehner et al. (2006) point out that in Europe, while an increase in the frequency of 100 year floods may occur in northern geographical areas, other regions, primarily in Mediterranean countries may experience severe drought conditions.

Griffin et al. (2007) estimate that two billion metric tons of dust including PM_{10}, $PM_{2.5}$, and soil microbes enter the Earth's atmosphere each year. Limited studies have been made on the microbiology of the atmosphere as affected by dust storms from the Gobi (Chen et al., 2010;

Chen and Yang, 2005), Saharan (Griffin et al., 2007; Schlesinger et al., 2006), and USA Southwest (Proctor, 1935). Not surprisingly, all studies showed that the concentration of microorganisms in the atmosphere on "dust storm days" was elevated when compared to "clear" days. One of the most interesting microbial-dust storm studies occurred on a May 11, 1934 flight over Boston in a Curtis-Robin plane. During this flight, the pilot collected air samples using a filtration sampler with a sterilized oily-lens paper collection medium. The results of sampling on May 11, 1934 showed that elevated concentrations of molds identified as Aspergillus and Penicillium occurred in the "upper atmosphere" which on that day was thought to be associated with a dust storm likely from the USA Midwest or Southwest. In the Eastern Mediterranean, Schlesinger et al. (2006) found that the Aspergillus fumigatus level in the atmosphere was about 7 colony forming units per cubic meter (CFU/m^3) on "dust days" (dust from Saharan Desert) compared to non-detectable on "clear days". Penicillium chrysogenum concentrations on dust days were about 38 CFU/m^3 as compared to 1.5 CFU/m^3 on clear days.

It should be realized that the upper layer of soil which is affected by dust storms is a natural reservoir for pathogenic fungi such as Aspergillus fumigatus, Histoplasma capsulatum, Coccidioides immitis, and most recently in the Pacific Northwest for Cryptococcus gattii. A subtle effect with public health consequences in geographical areas undergoing desertification will be increased exposure of people to fungal pathogens on dust storm days. As noted in Section 4.0, protection of people in indoor environments during dust storm periods will depend on enhanced HVAC filtration and more efficient removal of settled dusts from interior surfaces.

REFERENCES

Adan, O. C. G., M. Sanders, and R.A. Samson, 2005. Sustained Fungal Control Through Interior Finish Performance Requirements. Bioaerosols, Fungi, Bacteria, Mycotoxins, and Human Health, pp. 482-490, Saratoga Springs, NY.

ASHRAE 62.1-2010. Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

ASHRAE 2009A. Indoor Air Quality Guide. Strategy 2.6, Consider Impacts of Landscaping and Indoor Plants on Moisture and Contaminant Levels, ASHRAE, Atlanta, GA.

ASHRAE 2009B. Indoor Air Quality Guide. Strategy 4.1, Control Moisture and Dirt in Air Handling Systems, ASHRAE, Atlanta, GA.

ASHRAE 2009C. Indoor Air Quality Guide. Strategy 4.3, Facilitate Access to HVAC Systems for Inspection, Cleaning, and Maintenance, ASHRAE, Atlanta, GA.

ASHRAE 2009D. Indoor Air Quality Guide. Strategy 7.5, Provide Particle Filtration and Gas-Phase Air Cleaning Consistent With Project IAQ Objectives, ASHRAE, Atlanta, GA.

ASHRAE 2009E. Indoor Air Quality Guide. Strategy 3.2, Locate Outdoor Air Intakes To Minimize Introduction Of Contaminants, ASHRAE, Atlanta, GA.

Benin, A., R. Benson, and R. Besser, 2002. Trends in Legionnaires' disease 1980-1998: Declining Mortality and New Patterns of Diagnosis, Clin. Infec. Dis. 35, 1039-46.

Burge, S., A. Hedge, S. Wilson, J. Bass, and A. Robertson, 1987. Sick Building Syndrome: A Study of 4373 Office Workers; Ann. Occup. Hyg. 31, 493-504.

Byrnes, E.J. III, R.J. Bildfell, S.A. Frant, T. G. Mitchell, K.A. Marr, and J. Heitman; 2009. Molecular Evidence That The Range Of The Vancouver Island Outbreak Of Cryptococcus gatti Infection Has Expanded Into The Pacific Northwest In The United States. J. Infec. Dis. 199, 1081-86.

Chen, Y.-S. and C.-Y. Yang, 2005. Effects of Asian Dust Storm Events on Daily Hospital Admissions for Cardiovascular Disease in Taipei, Taiwan. J. Toxicology and Environmental Health, Part A, 68, 1457-1464.

Chen, P-S., F.T. Tsai, C.K. Lin, C.-Y. Y. Yang, C.-C. Chan, C.-Y. Young, and C.H. Lee, 2010, Ambient Influenza and Avian Influenza Virus During Dust Storm Days and Background Days. Environ. Health Perspectives, (http://dx.doi.org/).

Dales, R., L. Liu, A.J. Wheeler, and N.L. Gilbert, 2008. Quality of the Indoor Residential Air and Health, Canad. Med. Assoc. J., 179, 147-152.

Datta, K., K.H. Bartlett, and K.A. Marr, 2009. Cryptococcus Gattii: Emergence in Western North America: Exploitation of a Novel Ecological Niche, Interdisciplinary Perspectives On Infectious Diseases, Vol. 2009, Article 10 176532, 8 pages.

Dick, E.C., L.C. Jennings, K.A. Mink, C.D. Wartgow, and S.L. Inhorn, 1987. Aerosol Transmission of Rhinovirus Colds, J. Infectious Diseases, 156, 442-448.

Ellringer, P.J., K. Boone, and S. Hendrickson, 2000. Building Materials Used in Construction Can Affect Indoor Fungal Levels Greatly, Amer. Ind. Hyg. Assoc. J. 61, 895-899.

EPA, 2009. Indoor airPLUS Construction Specifications. U.S. Environmental Protection Agency 402/K-08/003 Washington, D.C.

Fisman, D.N., S. Lim, G. Wellenius, C. Johnson, P. Britz, M. Gaskins, J. Maher, M. Mittleman, C. Spain, C. Haas, and C. Newbern, 2005. It's Not The Heat, It's The Humidity: Wet Weather Increases Legionellosis Risk in the Greater Philadelphia Metropolitan Area, Jour. Inf. Dis. 192, 2066-73.

Godish, T. and D. Godish, 2006. Mold Infestation of Wet-Spray-Applied Cellulose Insulation. J. Air and Waste Mgt. Assoc. 56, 90-95.

Griffin, D.W., N. Kubilay, M. Kocak, M.A. Gray, T.C. Borden and E.A. Shinn, 2007. Airborne Desert Dust and Aeromicrobiology Over the Turkish Mediterranean Coastline. Atmospheric Environment 41, 4050-4062.

IICRC, 2006. Standard And Reference Guide For Professional Water Damage Restoration S500. Institute Of Inspection, Cleaning And Restoration Certification, Vancouver, WA.

IOM, 2008. Global Climate Change and Extreme Weather Events, Institute of Medicine, Washington, D.C.

Keane, T., 2009. Legionnaires' Disease – the Disease of Modern Plumbing Systems and Costly Litigation, Legionella Risk Management, Inc., www.legionellae.org.

Kidd, S.E., P.J. Bach, A.O. Hingston, S. Mak, Y. Chow, L. MacDougall, J.W. Kronstad, and K.H. Bartlett, 2007. Cryptococcus gatti Dispersal Mechanisms, British Columbia, Canada. Emerging Infectious Diseases 13, 51-57.

Lehner, B., P. Doll, J. Alcamo, T. Henrichs, and F. Kaspar, 2006. Estimating the Impact of Global Change on Flood and Drought Risks in Europe: Continental, Integrated Analysis. Climate Change 75, 273-299.

Lem, G., T.K. Tan, and A. Toh, 1989. The Fungal Problem in Buildings In The Humid Tropics. International Biodeterioration 25, 27-37.

Li, Y., G.M. Leung, J.W. Tang, X. Yang, C.Y. Chao, J.Z. Lin, J.W. Lu, P.V. Nielsen, J. Niu, H. Qian, A.C. Sleigh, H.-J. Su, J. Sundell, T.W. Wong, and P.L. Yuen, 2007. Role of Ventilation in Airborne Transmission of Infectious Agents in the Built Environment – A Multidisciplinary Systematic Review, Indoor Air, 17, 2-18.

Lloyds London (2007). 360 Risk Project. See section on Increased Frequency and Intensity of Floods authored by Dr. M. Wilson, pp. 17-21; www.lloyds.com/NR/...5ED3.../FINAL360climatechangereport.pdf.

Loftness, V., B. Hakkinen, O. Adan, and A. Nevalainen, 2007. Elements That Contribute To Healthy Building Design. Envir. Health Perspectives 115, 965-970.

McCurry, G. 2009. Estimated Increases in Municipal Water Demands in Colorado Due to Climate Change. Amer. Water Resources Association July 1, 2009, Snowbird, UT.

Mendell, M.J., Q. Lei-Gomez, A.C. Mirer, O. Seppanen, and G. Brunner, 2008. Risk Factors in Heating, Ventilating, and Air-Conditioning Systems For Occupant Symptoms in US Office Buildings: The USEPA BASE Study, Indoor Air 18, 301-316.

MMWR, 2006. Health Concerns Associated With Mold in Water-Damaged Homes After Hurricanes Katrina and Rita – New Orleans Area, Louisiana, October 2005, January 20, 2006, MMWR 55, 41-44.

Morey, P.R. and J.E. Woods, 1987. Indoor Air Quality in Health Care Facilities; Occup. Med. State of the Art Review, 2, 547-563.

Morey, P.R., M.C. Hull, and M. Andrew, 2003. El Niño Water Leaks Identify Rooms With Concealed Mould Growth and Degraded Indoor Air Quality. International Biodeterioration and Biodegration 52, 197-202.

Morey, P.R., T. Rand, and T. Phoenix, 2009. On the Penetration of Mold Into The Fiberboard Used in HVAC Ductwork, Healthy Buildings, 2009, 4 pp., Syracuse, NY.

Morey, P.R., G. Crawford, and R. Rottersman, Indoor Air Quality in Non-Industrial Occupational Environments, in Patty's Industrial Hygiene, 6th Edn., John Wiley & Sons, (In Press).

Neil, K. and R. Berkelman, 2008. Increasing Incidence of Legionellosis in the United States, 1990-2005: Changing Epidemiologic Trends, Clinical Infectious Diseases, 47, 591-99.

Ng, V., P. Tang, and D.N. Fisman, 2008. Our Evolving Understanding of Legionnellosis Epidemiology: Learn to Count, Clinical Infectious Diseases, 47, 600-602.

Patz, J.A., S.J. Vavrus, C.K. Uejio, and S.L. McLellan, 2008. Climate Change and Waterborne Disease Risk in the Great Lakes Region of the U.S., Amer. J. Preventive Med., 35, 451-458.

Phillips, M.L. 2008. Rethinking Legionnaires', www.thelancet.com/infection, Vol. 8, pp. 668.

Proctor, B.E. 1935. The Microbiology of the Upper Air. II. J. Bacteriology 30, 363-375.

Roaf, S. D. Crichton, and F. Nicol, 2009. Adapting Buildings and Cities For Climate Change, 2nd Edition, Elsevier, Amsterdam.

Schlesinger, P., Y. Mamane, and I. Grishkan. 2006. Transport of Microorganisms to Israel during Saharan Dust Events. Aerobiologia, 22, 259-273.

Sheets, M. Portland Water Bureau Raw Water Intake Data at Headworks, Portland, OR., Personal Communication, June 2010.

Solomon, G.M., M. Hjelmroos-Koski, M. Rotkin-Ellman, and S.K. Hammond, 2006. Airborne Mold and Endotoxin Concentrations in New Orleans, Louisiana after Flooding, October-November 2005. Environmental Health Perspectives, (http://dx.doi.org/).

Squier, C., J. Stout, S. Krsytofiak, J.McMahon, M. Wagener, B. Dixon, and V. Yu, 2005. A Proactive Approach to Prevention of Health Care Acquired Legionnaires' Disease; The Allegheny County (Pittsburgh) Experience, Am. J. Infect. Control 33, 360-367.

States, S.J., L.F. Conley, J.M. Kuchta, B.M. Oleck, M.J. Lipovich, R.S. Wolford, R.M. Wadowsky, A.M. McNamara, J.L. Sykora, G. Keleti, and R.B. Yee, 1987. Survival and Multiplication of Legionnella Pneumophila in Municipal Drinking Water Systems, Appl. Environ. Microbiology 53, 979-986.

Stickel, L. 2009. Climate Change and Municipal Water Supplies, Workshop on Scenarios of Future Climate, Portland Oregon Water Bureau.

Streifel, A.J. 1988. Aspergillosis and Construction, pp. 198-217 in Architectural Design and Indoor Microbial Pollution, Ed., R.B. Kundsin, Oxford University Press, New York.

UNEP, 2007. Buildings and Climate Change, United Nations Environment Programme.

West, M. and E. Hansen, 1989. Determination of Material Hygroscopic Properties That Affect Indoor Air Quality. In IAQ 89, The Human Equation: Health and Comfort, ASHRAE, pp. 60-63, Atlanta, GA.

Wright, R.S., Z. Dyer, M.I. Liebhaber, D.L. Krell, and P. Harber, 1999. Hypersensitivity Pneumonitia From Pezizia domiciliana – a Case of El Niño Lung. Amer. J. Respiratory Critical Care Med. 160, 1758-1761.

Zweers, T., L. Preller, B. Brunekreef, and J. Boleij, 1992. Health and Indoor Climate complaints of 7043 office workers in 61 buildings in the Netherlands. Indoor Air 2, 127-136.

FIGURES

Figure 1

Figure 2

Figures 1 and 2: Exterior (Figure 1) and Interior (Figure 2) views of fan coil unit (FCU) which provides conditioned (ventilation) air to the indoor environment. Conspicuous dirt, corrosion, and mold growth are present on the wet surfaces within this under maintained FCU.

Figure 3

Figure 4

Figure 3 and 4: Conspicuous dust and dirt (nutrients for mold growth) occur on the wet internal surfaces of this hotel FCU.

Figure 5

Figure 5: The fine dust and oily film on the metal surface of the fan motor in this undermaintained air-handling unit provide nutrients for the growth of mold which is visible on the fan housing.

Figure 6

Figure 7

Figures 6-7: Visible mold growth occurs on the dirt and dust that accumulates on the moist airstream surface of the porous duct liner in this air-conditioning supply duct. Figure 7 shows a photomicrograph of some of the mold growing on the dust and dirt in the air-conditioning duct

Figure 8

Aspergillus, Stachybotrys, and other molds grew on the wet-applied cellulosic fireproofing that had been sprayed on the ceiling surfaces. Careful consideration must be given to the biodegradation potential of construction materials used in wet/damp niches in buildings.

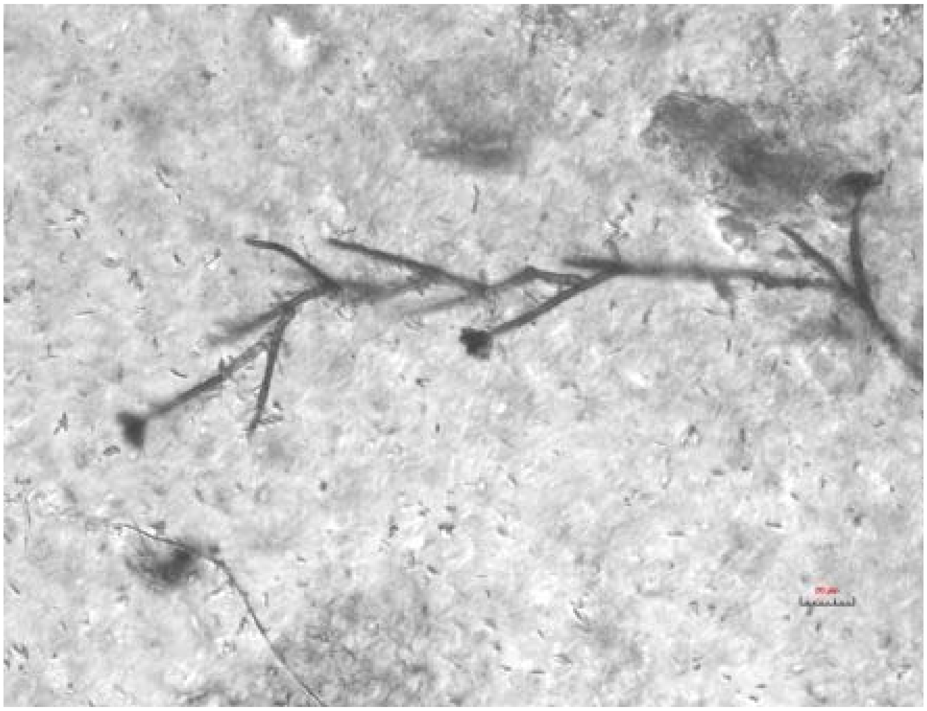

Figure 9

Figure 10

Figures 9-10. Abundant Stachybotrys spores and conidiophores are present in the wet-applied cellulosic fireproofing sprayed on ceilings and beams in a new building. The moldy fireproofing was removed and replaced with a fireproofing containing a minimal amount of biodegradable components. Photos courtesy of Tom Rand, Saint Mary's University, Halifax, Nova Scotia, Canada.

Figure 11

This plant is growing in a well-lighted room along a envelope wall. Moisture infiltrating through the wall and nutrients in the baseboard and carpet provide favorable conditions for plant and microbial growth.

Figure 12

Figure 13

Figure 14

Figures 12-14: Because of moisture and mold damage, most of the biodegradable finishes (eg., paper-faced gypsum board, carpet, manufactured wood, etc.) have been removed from this hurricane damaged building. The wood shims (arrows) beneath the bathtub in Figure 14 were “fairly resistant” to biodeterioration.