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The Indoor Environmental Side of Resilience

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Resilience is becoming increasingly recognized as a critical goal for buildings and communities, particularly in the face of recent floods, tornadoes, and earthquakes. Fortunately, the costs in lives, livelihoods and quality of life from natural, technological, and human-caused hazards can be reduced by better managing disaster risks. Many efforts are in progress to increase resilience and improve a community's ability to maintain and restore vital services. Among these efforts is a multi-faceted program at NIST (the National Institute of Standards and Technology) to assist communities and stakeholders on issues related to buildings and the interdependencies of physical infrastructure systems.

The NIST Community Disaster Resilience Planning Guide (NIST 2015) addresses resilience of buildings and infrastructure systems at the community scale and provides guidance on establishing long-term goals and plans for recovery of the built environment following a disaster with consideration of social needs. This column summarizes a longer report exploring the role of indoor environmental quality (IEQ) in the context of community resilience, referred to in that report as indoor environmental resilience (IER) (Persily and Emmerich 2015). This work is motivated by the fact that many of the disasters being considered will also affect IEQ. These effects include both increased airborne contaminant concentrations associated with the disaster or its aftermath and challenges in providing acceptable environmental conditions during an event or afterwards during recovery.

In considering resilience in the context of the indoor environment, it is important to note what the indoor built environment is expected to provide to occupants. Two key objectives are to maintain thermally comfortable conditions and to limit the concentrations of airborne contaminants to safe and comfortable levels. The indoor environment, primarily via the building enclosure, is also intended to isolate the building occupants from the exterior environment, specifically precipitation, pests and threats to physical security. Finally, the indoor environment is expected to provide amenities such as light, power and food storage to support the intended activities of the occupants.

The role of IEQ issues in the context of disasters has been identified in two prominent documents. The National Climate Assessment summarizes the impacts of climate change on the U.S., now and in the future, and highlights several anticipated changes that are relevant to IEQ (Melillo et al. 2014). Under extreme weather, the increased frequency of heat waves, heavy downpours, floods and hurricanes are all noted. The discussion of human health mentions vulnerable people and communities, wildfire smoke, increased levels of pollen, and impacts on asthma and allergies. Disruptions in energy production and delivery are noted under infrastructure. The Institute of Medicine published a study on climate change and indoor environmental health in 2011, which noted that climate change may worsen existing IEQ problems and introduce new ones, and, there are opportunities to improve public health while mitigating or adapting to alterations in IEQ induced by climate change (IOM 2011). It also noted several problematic indoor exposures including: indoor contaminants; dampness, moisture and flooding; infectious agents and pests; thermal stress; and, building ventilation, weatherization, and energy use.

The report summarized in this column identifies and discusses the elements of IER through a review of existing information, programs and other technical resources related to events that are likely to impact IER. For each event, existing standards and guidelines are described, as well as other programs and activities to support planning and response strategies.

SCOPE OF INDOOR ENVIRONMENTAL RESILENCE

The first step in this effort was to consider the extreme events with the potential to impact IEQ and which may merit planning in support of increased community resilience. Table 1 lists the events considered, along with the associated indoor environmental exposures.

Each of the events listed in Table 1 was analyzed by examining available information on these events and their impacts on IEQ, technical gaps in understanding these impacts, existing standards, and how the events are being addressed by various guidance documents. The report also discusses two other issues that are relevant to IER: pandemics and the role of healthcare facilities, and indoor environmental conditions in safe rooms and shelter-in-place facilities.

While the amount of available technical information varies across the events considered, it is clear that these topics have received growing interest in recent years due to high profile events, such as heat waves, hurricanes and major storms, wildfires and terrorist attacks, as well as government initiatives in response to these events. Despite the attention given to these issues, the impact of IER issues is not always fully appreciated. For example, during the period of 1979 to 2003, more people in the U.S. died from extreme heat than from hurricanes, lightning, tornadoes, floods, and earthquakes combined (CDC 2012).

This review identified important knowledge gaps meriting research, as well as the need for improved and more relevant standards and guidance. Additionally, much of the existing knowledge needs to be better integrated into a more comprehensive community resilience approach to maximize its impact. The important research gaps include the following, organized by the type of event:

- Heat waves: Development and evaluation of passive building design approaches and retrofit measures to avoid overheating during heat waves. Such research needs to consider a variety of building types (e.g., single family and high-rise residential, institutional) and building occupants (i.e., beyond healthy adults).
- Power outages: Definition of short term acceptable ventilation and IAQ conditions (beyond thermal comfort) for living and working in buildings temporarily during power outages that impact HVAC system function.
- Floods: Coupled thermal/airflow/moisture simulation tools to better predict conditions that will lead to the potential for mold growth.
- Wildfires: Infiltration of smoke into buildings and the use of air cleaning to create clean air shelters in buildings.
- Airborne CBR releases: Building protection approaches based on design and system operation in new and existing buildings. Tools to identify buildings most likely to be impacted by outdoor releases. Determination of how clean is clean enough after decontamination. Tools to support deciding between evacuation and sheltering in place.
- Pandemic response in healthcare facilities: Evaluation and comparison of options to create surge airborne isolation space and temporary negative pressure isolation space, and the impacts on overall building operation.
- Sheltering in place: Development of guidance for community-wide sheltering in response to events such as heat waves, CBR releases, wildfires, and power outages.

Several topics for potential standards development are summarized below. Some are motivated by the fact that most published standards and guidance relevant to IEQ consider only normal operating conditions for buildings and healthy adult occupants, e.g., ASHRAE Standards 55, 62.1 and 62.2, which cover thermal comfort and ventilation (ASHRAE 2010, 2013a and 2013b). A need exists to develop standards and guidance to address these requirements during or following a disaster, when indoor conditions may not be consistent with normal operation and building use. Specific standard and guidance needs identified in this effort include the following:

- Thermal “comfort” standards or guidelines that address occupant safety (including other than healthy adults) during heat waves and power outages.
- Ventilation standards or guidelines that cover extreme conditions, which are beyond the scopes of Standards 62.1 and 62.2, including separate requirements for safe rooms and shelter-in-place facilities.
- Continuation of current efforts underway at the U.S. Consumer Product Safety Commission and UL to address CO emission limits from portable generators.
- Guidance for homeowners and volunteers engaged in mold/wet building cleanup following large scale flooding events.

- Guidance to support deciding between evacuation and sheltering-in-place in response to wildfires and CBR releases.
- Standards for portable air cleaner performance to reduce indoor particulate exposure during wildfires, and guidance on system selection.

As efforts to increase community disaster resilience continue, the indoor environmental impacts need to be considered and their proper role identified. The report summarized in this paper provides the background to initiate these discussions.

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Table 1

Events relevant to indoor environmental resilience

Type of event	Indoor environmental exposure
Heat waves	High indoor temperatures/heat stress High levels of outdoor pollution
Storms causing power failure	Lack of heating, cooling, ventilation leading to heat/cold stress and elevated indoor contaminant levels CO exposure from portable generators
Floods and mold exposure	Microbial growth affecting occupants and remediation workers
Wildfires	Particulate and other contaminant exposure
Airborne releases of chemical, biological or radiological agents	Exposure to agent