Multifamily Housing Resiliency Audits

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ABSTRACT

Climate change resiliency strategies have the potential to work in tandem with energy efficiency and other climate change mitigation efforts. Increased building resiliency provides tangible and intangible benefits such as safety, comfort, cost savings, and durability. In the wake of severe weather events that disproportionately affected low-income communities and multifamily housing, New Ecology, Inc. has developed a multifamily resiliency audit protocol to complement our energy and water audit protocol. The purpose of the audit is to provide concrete, actionable recommendations that enable building owners to make improvements to resist damage from severe weather and to recover more quickly with less cost and harm should damage occur.[1]

The audit protocol is customizable for building systems and components vulnerable to hazards such as flooding, high winds, extreme heat and cold, heavy precipitation, tornados, wildfire, and other severe weather events. The product is a set of recommendations for mitigation approaches ranked in terms of cost and avoided risk.

We are piloting the new audit in a variety of residential building typologies. While recommended resilience measures will be site- and building-specific, our audit approach is broadly applicable to buildings within all community types. Additionally, community-level resiliency planning and implementation needs to be coordinated with planning and implementation at the level of individual buildings within a community to efficiently achieve overall resiliency improvements and avoid duplicative efforts. Within the context of building-level resiliency audits, we must also understand community-level threats and support systems, both existing and planned. This paper provides an overview of our resiliency audit protocol and hypothetical case studies in two multifamily building types.

Introduction

We view resiliency as the next rung in the sustainability ladder after "green" building. Much in the same way that sustainable development was a new term twenty-five years ago, the definition of which has been in flux since, resiliency is an often ambiguous concept with real-world implications. Our approach to resiliency is to describe it as "weathering the storm," implying protection and quick recovery for buildings and their inhabitants.

As designers and builders, we are making and remaking buildings we expect to last for the next 25-100 years, while the climate is changing and the incidence and severity of disasters is projected to rise (AIANY 2015; ArcGIS 2016; Madsen and Wilcox 2012; MunichRE 2014; National Ocean Service 2014; U.S. Global Change Research Program 2014). The buildings we work on must be able to respond to direct impacts and failures of interdependent systems, such as power grids, transportation networks, and drinking water supplies, extending far beyond the property boundaries to live up to these expectations.

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[1] We have also applied the protocol in evaluating plans and specifications for new construction projects, but that application is outside of the scope of this paper.

The appropriate level of investment in resiliency will vary greatly between buildings depending on risks, building characteristics, resident population, expected building performance during a given hazard scenario, and budget (Findlan et al. 2014; Linnean Solutions 2013; Multihazard Mitigation Council 2005; Urban Green Council 2013; Wright, Koo, and Belden 2015). In this paper, we lay out our concept for a multifamily resiliency audit protocol by which property owners and operators can evaluate the relative priority and costs of the suite of climate change hazard mitigation measures available.

Extensive literature exists describing the natural disaster hazards faced by multifamily housing and mitigation measures available (Findlan et al. 2014; Furman Center 2013; Mullendore et al. 2015; Schoeman 2015). This literature has proliferated since the disproportionate impact on low-income multifamily housing of Hurricane Sandy's landfall in New York and New Jersey became clear, in addition to the lingering impacts from Hurricanes Katrina and Irene (Brayton and Munroe 2012; Furman Center 2013; Kelly and Tracey 2014; Schoeman 2015). Much of the literature has, therefore, focused on coastal flooding risk. Fortunately, the most recent studies and guidelines for multifamily housing resiliency have included several additional hazards and mitigation measures, further rounding out this important discussion.

In our practice, the two most frequent questions we encounter are, "My property is not in a flood zone, so resiliency is not a concern, right?" and, "I see all of the hazard mitigation measures available, but which ones are right for me?" These questions have driven us to create a streamlined protocol for evaluating climate change hazards to multifamily buildings that can translate into a set of recommendations, incorporating the research and findings of the existing body of literature.

Methodology

To produce the audit protocol we assembled a matrix of primary and secondary hazards affecting building systems and created a list of mitigation measures for each hazard-system combination. We then created a questionnaire to complement our energy audit protocol, divided by building system and each hazard and mitigation measure. In this way we tailor the questionnaire to the group of primary and secondary hazards for a given building and location, and quickly identify which measures may improve resiliency.

Primary and Secondary Hazards

Primary climate change hazards to multifamily buildings were collected from the existing literature (AIANY 2015; Madsen and Wilcox 2012; MunichRE 2014; National Ocean Services 2014; U.S. Global Change Research Program). Primary hazards were those we identified as having a direct impact on building mechanical systems, envelope and architecture, or on the health and safety of residents. Priority was given to the health and safety of vulnerable residents, such as elderly individuals, the very young, and low-income populations whose ability to avoid or recover from disaster is limited by nature of their age, health, or access to resources.

We then identified secondary hazards which are those having an indirect impact on buildings and residents either in time or in space. Secondary hazards may either be a result of primary hazards, or may be independent in time or space from the primary hazards. Secondary hazards may be additional delayed impacts of primary hazards or the result of failures in complex, interdependent systems. Such systems include the infrastructure providing transportation, access, electricity, gas, water, sewer, emergency response, communications, and other services to buildings.

An example of a primary hazard for individuals is extreme heat or a heatwave. During an extended power outage, a heat wave may compound the risk of heat stroke or death for individuals with existing cardiovascular or pulmonary conditions, the elderly, or the very young. An example of a secondary hazard affecting buildings and resulting from extreme heat is increased electrical demand for cooling, and the resulting potential for power grid brown outs.

A power grid failure might also occur by other means, such as by a flood at a power plant. The flood is a primary hazard for the power plant, and the resulting power outage is a secondary hazard for a multifamily building 10 miles away, which might not be flooded itself.

Below we describe the primary and secondary hazards mostly likely to impact a particular location, in this case Okemos, Michigan. Two groups of hazards are considered, heat and precipitation:

Primary Hazards, Okemos, Michigan

- **Heat waves.** In addition to higher average annual temperatures, the Upper Midwest can anticipate an increasing number of days over 95°F.
- **Extreme precipitation.** Climate change is expected to drive fewer and larger extreme rain and snowfall events in the Upper Midwest, leading to local flooding in river and stream floodways and in the FEMA flood zone.
- **Less consistent precipitation.** Less consistent precipitation could lead to isolated instances of drought.

Secondary Hazards

- **Cooling demand increase.** Warmer average temperatures drive additional space cooling.
- **Lower efficiency electric plants.** As water body temperatures rise, water-cooled electricity plants will lose efficiency at the same time as electricity demand rises, leading to brownouts and additional plant operation and air pollution.
- **Pest range expansion.** Higher temperatures and shorter frost seasons will lead to Northward expansion of pests, such as termites.
- **Air quality decline.** Warmer air will lead to higher ground-level ozone and higher smog formation, compounded by high fossil fuel electricity generation regionally.
- **Combined sewer overflows.** Combined sewer overflows in cities with combined sanitary and stormwater sewer systems could cause drinking water contamination.

Impacted Building Systems and Mitigation Measures

Building systems and operations impacted by climate change hazards were identified from the outside in; that is from the region, to the locality, to the site, to the interior of the building, to the individual mechanical, electrical, and plumbing systems. The divisions are: landscape and civil engineering, architecture and space planning, structure, envelope, HVACR-MEP, and operations and maintenance inclusive of emergency response preparedness.

Mitigation measures were collected from the existing literature and classified into the building system to which they pertained (Findlan et al. 2014; Linnean Solutions 2013; Mullendore et al. 2015; NYC Planning 2013; Pearson 2016; Schoeman 2015; Wilson, 2014; Wright, Koo, and Belden 2015). Mitigation measures were also matched with hazards, as in the generic example below from Okemos, MI, Table 1.

Table 1. Mitigation Measures, Okemos, MI

Hazard	Mitigation measures
Extreme heat	• Air sealing and envelope insulation • Considered glazing strategy • Building orientation and shading • Model building drift temperatures • Natural and mechanical ventilation strategy • Heat island remediation
Water outage or contamination	• Maximize water conservation • Avoid lawns and irrigation • Install a gravity flow or hand-pump emergency potable water source • Storage of potable water containers • Rainwater harvesting for grey water uses
Power outage	• Operable windows • Backup power source with or without backup power storage and a dedicated critical load electric panel to include egress lighting, egress elevators, food storage, medical equipment, and medication storage
Air quality	• Low/no-emitting materials indoors • Mechanical ventilation filtration
Flooding	• Elevated mechanicals • Sump pumps • Drain backflow preventers • Ample stormwater conveyance, infiltration, or storage
Pest range expansion	• Pest-resistant building materials, screens, and barriers

Audit Protocol

As described above, the audit protocol is in a questionnaire format with approximately 225 questions depending on which hazards and building systems are present.[2] Questions are categorized by building systems and operations including landscape and civil engineering, architecture and space planning, structure, envelope, HVACR-MEP, and operations and maintenance. The questionnaire is designed to take between 1 and 8 hours to complete by an experienced audit professional depending on building size and type. The form is completed through a combination of online database information gathering, on-site inspection, and through conversation with property management staff and/or the building owner. With the primary and

[2] Given the size of the audit questionnaire, it is not reproduced here, but excerpts are to be shared in the presentation accompanying this paper.

secondary hazards identified, mitigation measures appropriate to the building type and location are then selected. We prioritize mitigation measures according to risk and vulnerability.[3] Risk is the combination of hazard likelihood and consequence. Vulnerability is the combination of sensitivity and adaptive capacity. Measures mitigating high risk events are prioritized over measures mitigating lower risk events. Table 2 gives an example ranking of two mitigation measures for a hypothetical multifamily building located in the Northeast in a flood zone.

Table 2. Mitigation Measure Ranking Example, Northeast Multifamily Building in Flood Zone

Hazard	Likelihood	Consequence	Sensitivity	Adaptive Capacity	Mitigation Measure	Measure Cost	Measure Rank
Flood	Moderate	High	High	Low	Elevate mechanicals	$200,000	High
Earthquake	Extremely low	Extremely high	Moderate	Extremely low	Seismic retrofit	$10,000,000+	Very Low

Below we describe hypothetical case studies in which we have applied the audit protocol to two different building typologies. Many of the details in these case studies are based on accumulated experience from past energy audits in similar buildings.[4]

Case Studies

Case Study 1: Three Story, Three Unit, Wood-Framed Multifamily Building

Building and historical overview. Case Study 1 is a three story walk-up, multifamily building with three residential units. The owner does not live at the property.

The building is located within the FEMA Zone X (outside the 0.2% annual flood risk) flood zone and was constructed in 1915 as a single family home. The property does not have flood insurance. Major renovations occurred in 1972 dividing the top three floors into two units and adding the second kitchen. The basement studio was added in 1988 and was initially occupied by the current owner. The building has sustained relatively little damage over 100 years of exposure to rain, snow, and hurricane force winds. The major historical risks have been damage from falling tree limbs during hurricanes and stormwater flooding from heavy rainfall events.

Major damage occurred to the roof in 1967 when a large branch from a tree on the adjacent property fell on the roof, causing extensive damage at the ridgeline, part of the brick chimney, and severing the power and other utility cables. The tree has since been removed.

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[3] Risk is described per ISO 31000 and ISO 31010 as the potential consequences and likelihood of a given event, and consequences may be quantified in terms of cost, health and safety, or other metrics. In general, we use cost as a standard metric to quantify consequences, however there are morally unacceptable consequences, such the death of a resident, which elevate a risk to the highest level in this analysis. Vulnerability is defined per ISO 31000 as sensitivity to a given event and adaptive capacity to respond to that event.

[4] We will soon be applying the audit protocol in one Northeastern neighborhood experiencing climate change vulnerability and subject to frequent stormwater flooding and sewer backups during extreme rain events.

A build-up of ice at the eaves formed during two previous winters with heavy, persistent snows, and visible water damage occurred at the eaves in the upper unit. Eaves were insulated with closed-cell spray foam and only minimal ice dams have occurred since.

Heavy rainfall events often lead to basement flooding, the main sources of which are infiltration through the masonry basement walls, inflow through the basement access hatch at the front of the building from a backed-up stormwater drain in front of the building, and sewage infiltration from the floor drains in the basement mechanical room and shower. The most recent incident of basement flooding occurred in 2011.

Building systems and operations are described in Table 3, below.

Table 3. Case Study 1 Building Systems and Operations

System	Description
Civil Engineering	• Underground gas (3 utility meters, 1 serving DHW line, 1 each for upper units) and water (1 utility meter) connections not vulnerable to flooding • Electric connection from street pole (4 meters, 1 for common load, 1 each for units), meters are vulnerable to flooding
Landscape	• No loose furniture or equipment stored outside that could be disturbed by wind or floodwaters aside from trash and recycling toters • Narrow driveway to one side of building, used by basement resident • Flooding from street will enter via driveway first
Architecture and Envelope	• Stone foundation, concrete slab poured in mid-1960s, extremely porous • Access to mechanical room through hatch at front of building, potential flood entry point • Smell of mold in mechanical room and basement apartment • Walls cavities are uninsulated, and interior is vulnerable to extreme heat and cold • Exterior is vinal siding over ½” sheet insulation over asbestos shingles, with lathe and plaster interior finish, and adding insulation would be cumbersome and require asbestos mitigation • Windows are original single pan, double hung, wood-framed, except newer vinyl windows at grade in basement unit, and have poor thermal performance
HVAC-MEP	• Gas-fired steam boilers serve upper units, basement unit has electric resistance heat mounted on exterior wall at ceiling, systems are only moderately vulnerable to flooding, but will not operate during a power outage • Window AC units are used for cooling, limited due to electric service, building is not habitable during extreme heat and a power outage • Sump pit with submersible pump in mechanical room, not operable during power outage • No backflow preventers on sewer lines

	• No backup power sources
Operations and Maintenance	• Building materials, paints, and cleaning chemicals stored in mechanical room can spill and contaminate flood waters

Recommendations. The above table describes a selection of the building-specific systems and operations assessed to determine risk from and vulnerability to a wide range of potential hazards, the most significant being flooding, extreme heat and cold, and extended water outage. NEI concludes that several relatively low cost measures will moderately improve the building's resilience. Our recommendations, in order of priority, are shown in Table 4, below.

Table 4. Case Study 1 Recommendations

Hazard	Hazard Rank	Mitigation measures
Stormwater Flooding	1	• Install backflow preventers • Move and elevate electrical panels • Upgrade sump pump with automatic controls • Remove hazardous materials stored in basement • Remove basement apartment[5]
Extreme Heat, Extreme Cold, Extended Electric Outage	2	• Insulate and air seal • Replace gas ranges with electric ranges[6]
Extended Water Outage	3	• Purchase 30 gallon drinking water container

Additional measures such as elevating HVAC equipment in the basement, replacing windows and doors, and providing backup battery and/or solar power would be costly and while they address long-term resiliency, they do not address the immediate stormwater and sewer flooding concern. Some, such as solar PV, improving insulation and air sealing, and replacement windows, may be evaluated on their own environmental merits or along with other capital improvement projects, and others, such as elevating and replacing the existing HVAC equipment, should be considered at the end of useful life for the equipment.

Cast Study 2: Nine Story, Ninety-Two Unit, Concrete and Brick Multifamily Building

Building and historical overview. Case Study 2 is a nine story, multifamily high rise building with ninety-two residential units, constructed in 1972. The construction is slab-on-grade pre-cast concrete with a brick façade. Entry to the building is through a main entrance vestibule and primary circulation is by a single elevator. One emergency staircase is located at one end of the building, accessed at the end of the double-loaded corridor. All units are low-income elderly rental units and rent is subsidized by Section 8 Project Based Rental Assistance.

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[5] We recognize the larger legality and affordability issues implied in removing an existing apartment, but they are not addressed within the scope of this paper.

[6] The market forces at play here are in contradiction to this recommendation, but the focus here is health and safety.

The building is not located within the FEMA 100-year flood zone. The terrain is exceedingly flat. The building is constructed on alluvial soils with grade beams and pilings shown in available construction drawings. The property does not have flood insurance.

No major renovations have occurred since the building was constructed. However, two of the three gas-fired heating boilers were replaced in 1995 and both domestic hot water boilers were replaced in 1990. Residential refrigerators and ranges were replaced in 2010 with Recovery Act funds.

The building has sustained relatively little damage over 43 years of exposure to rain, snow, and tornadoes. The major historical risks have been damage from projectiles during high winds and flooding from heavy rainfall events when the two local rivers overtop their banks.

Minor damage occurred to the vestibule in 1998 when a large branch from a street tree fell on the roof. The tree has since been removed.

Heavy rainfall events often lead to riverine flooding when the two rivers bordering the city overtop their banks. The most recent large flood event occurred on June 15, 2010, when both rivers reached record flood levels. Water traveled down the street in front of the site but did not enter the building before receding. Storm and sewer drains backed up in to the building causing some flooding in first floor bathrooms, but no other damage was sustained.

Drainage from the site in general is poor, and large rain events tend to cause water to accumulate in small pools around the perimeter of the ground level, where evidence of persistent moisture is visible in mold growing on the exterior façade on the North and East sides of the building.

Building systems and operations are described in Table 5, below.

Table 5. Case Study 2 Building Systems and Operations

Systems	Description
Civil Engineering	• Above ground gas (1 utility meter at first floor of building exterior) and water (1 utility meter, in first floor mechanical room) connections are vulnerable to flooding • Electrical connection underground up through slab into first floor mechanical room to electrical panels, vulnerable to flooding
Landscape	• All of the site is either concrete hardscape or grass, no other landscaping or drainage buffers are located between the building and the site, floodwaters move across the site quickly • Flooding from the street will enter at the driveway first but will spread across site at 6 inches of water or more
Architecture and Envelope	• Flat EPDM roof ballasted with loose stone, stone can blow off in high winds • Rooftop mechanical room is access from a stair from the 9th floor, most equipment is protected from flooding • Roof drains to six center drains connected to three internal drain stacks, connected to the sanitary sewer before leaving the building, leading to potential combined stormwater and sewer backups • Walls are alternating bands of concrete and single-paned, aluminum-framed, glazing, providing little thermal protection for extreme heat and cold

	• The smell of mold is present in some bathrooms, indicating existing moisture management issues
	• Three atmospheric gas-fired boilers provide heating hot water to Whalen fan coil units (FCUs) in apartments on 10 risers, boilers are 20 years old (2 boilers) and of unknown age (third boiler), heating is not provided during power outages • FCUs are equipped with refrigerant coils for cooling, served by three rooftop condenser units, cooling is not provided during power outages • Two of three windows in each unit are operable, allowing ventilation during power outages • Heating, ventilation, DHW recirculation, and food refrigeration are the main critical electrical loads and no backup power is provided
Operations and Maintenance	• Building materials, paints, and cleaning chemicals are stored in the first floor electrical closet and custodial storage area, and may spill and contaminate flood waters

Recommendations. The above table describes a selection of the building-specific systems and operations assessed to determine risk from and vulnerability to a wide range of potential hazards, the most significant being flooding and stormwater and sewer backup, tornados and high winds, extended water outage, and extreme heat and cold. Based on the results above, NEI concludes that several measures will improve the building's resilience. Our recommendations, in order of priority, are shown in Table 6, below.

Table 6. Case Study 2 Recommendations

Hazard	Hazard Rank	Mitigation measures
Stormwater Flooding and Sewer Backup	1	• Install backflow preventers • Install perimeter drainage around building • Elevate electrical panels in existing electrical closet or relocated to another floor • Remove or elevate hazardous chemicals in electrical closet
Tornado and High Winds	2	• Procure structural wind loading review by structural engineer • Remove and replace ballast stone with alternative, secured roofing • Secure lawn and patio furniture to concrete patio
Extended Water Outage	3	• Purchase inflatable water containers to provide 5-day drinking water supply for each resident
Extreme Heat, Extreme Cold, Extended Electric Outage, Extended Gas Outage	4	• Insulate and air seal at windows and integrated metal panels • Add Southern exposure shading devices

Additional measures such as replacing windows and doors, adding envelope insulation, or providing backup battery power or potable water systems would be costly but would serve to address long-term resiliency. Some measures, such as replacement windows, may be evaluated on their own environmental merits or along with other urgent capital improvement projects such as boiler replacements and ventilation system upgrades.

Lessons Learned

The case studies highlighted above, as well as additional planned pilot audits, are being used to test our audit protocol in a variety of building typologies. By ensuring broad applicability across building types, as well as addressing building-specific resiliency issues, the audit protocol can be applied to several or all of the buildings in a community.

The primary lesson learned through the case studies above is that depending on community context, many resilience issues are highly building-specific. However, further study into prioritization of community-level versus building-level resilience strategies in specific locations needs to be completed to continue to test which mitigation strategies in response to which hazards are the most efficient across a community.

In the two building examples above, both are at risk of flooding from different sources, and the location and type of mechanical and electrical systems, the site features, and the construction type and materiality contributed to different sets of recommendations to mitigate the flood hazard. A community-level approach such as a new levee or improved stormwater infrastructure could also be tested against a survey of building-level needs in the community to prioritize the community- or the building-level strategies.

Conclusion and Recommendations

A resilient building has the potential to not only withstand hazards but also to protect inhabitants, provide long-term human health benefits, reduce operating, replacement, and insurance costs, and to continue critical operations during service outages. Resiliency often intersects with energy efficiency and climate change mitigation. For example, added insulation reduces energy consumption and GHG emissions while providing for a more habitable space during periods of extreme temperatures. While not currently part of our resiliency audit protocol, a side-by-side comparison between resilience and efficiency improvements will readily reveal synergies between the two.

Our application of the audit protocol has also confirmed that hazards affecting a given building will differ tremendously based on location, site, building construction methods, mechanical systems, and a host of other factors. The appropriate hazard mitigation measures will also vary depending on building use and population, projected lifespan, operating and capital budget, and ongoing or planning community-level mitigation measures, amongst other things.

While in most locations, building-level resilience strategies will be most relevant to individual building owners given that owners have direct control over building-level decisions, community resilience planning is also essential for broader mitigation efforts. Understanding existing or planned community-level interventions, such as flood walls, informs building-level hazard mitigation needs across that community. Understanding the most common hazard mitigation requirements and cost-effective mitigation measures in a given community by combining multiple building-level audits with community-level assessments will yield the most comprehensive results.

We recommend a two-pronged approach to resilience, pairing building-level measures with community-level measures such as levees to protect neighborhoods from flooding or microgrids to provide reliable power sources to several buildings during grid outages. Future research should be directed towards implementing building-level resilience audits alongside community-level resilience assessments, planning, and implementation to understand the integrated nature of hazard mitigation measures across a variety of scales.

Here we have presented a building-level audit protocol with broad applicability and rooted in the existing literature and standard risk management methods. We are also currently engaged in efforts to test this audit protocol across several buildings in one community, to evaluate the best means of supporting resilience measures for all property owners in that community by identifying the most common and cost-effective measures to apply in individual buildings in the context of planned community-level improvements.

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