Climate-related Risk at the Building Level

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Abstract

Climate-event related failures at the building level are closely connected to electrical supply failure. Shut-down of electro-mechanical systems will leave buildings without heating, cooling, elevators, and those five stories and taller without water (for drinking, washing, sanitation, fire-protection), except in so far as emergency generators serve these loads. Biomass fuel sources may be important in upstate New York for mitigating residential sector impacts of winter electrical failure. Disaster management planning and preparation is an important step in mitigating the risks from these building service failures. Building operations can also play a significant role in mitigating overload and failure at the electric grid level.

Introduction

Human experience of the environment is strongly mediated by the built environment, in particular by the buildings in which people live and work. Climate-related events will be felt through their impacts on buildings. Therefore, a systematic review of how buildings and building systems may fail under specific circumstances is a basic element in the risk assessment of climate-related events.

Other parts of this research describe the probabilities of climate-change and the kinds of climate-related events that can be expected to occur with increasing frequency in the future. Extreme climate events such as heat waves and cold waves, ice storms, flooding, and drought are predicted to become more severe and more frequent. Our goal here is to understand how such events might play out in buildings. Our buildings are designed for service within a band of conditions and with the assumption of various infrastructural services. Outside of these conditions, buildings can become uninhabitable. We consider how such failures may occur in general and under three sets of climate-event scenarios:

- **Heat Wave**. Extended heat waves have occurred in the recent past and are projected with greater frequency and severity. We will examine the impact of such conditions on office buildings in New York City.
- **Ice Storm**. Climate extremes also include extremes of cold and precipitation. In northern climates severe ice storms periodically occur with devastating impacts. We will consider the impact of such an event in upper New York State.
- **Flooding.** Although not below sea level, because of its harbor configuration, New York City is understood to be exposed to a Katrina-like storm event with massive flooding. How would buildings be impacted?

Our findings will provide the basis for recommendations for mitigation of climate-related disaster-risk at the building level. We also consider how buildings, as the end-use points in the energy system, can play a significant role in supporting the reliability of the electric system.

Buildings and the Energy System

Buildings are intimately connected to the energy system, as its end-use points. If the energy system is failing, building functions will, to one degree or another, fail. The primary, although not the only, cause of failure in building services is failure of the electric system.

Conversely, because building services are a major end-use of the electric system, the way energy is used can have important impacts on the reliability of the system. Increasing peak demands, especially associated with hot weather and air-conditioning, de-stabilize the system in a positive feedback loop that can lead to system overloads, stresses in distribution, and localized or generalized black-outs.[1] Reducing peak demands can reduce stress on the system, help stabilize it, and avoid black-out crises. Three kinds of energy action at the building level must be considered.

- **Energy efficiency.** Energy efficiency in buildings usually affects the building's base loads and lowers most or all of the building's daily load profile. Some efficiency measures, however, are effective over much of the time but not at peak demands. Chilled water temperature resets, variable speed fan and pump controls, and economizer cycles, for example, are highly effective at improving part-load efficiencies but will not be effective at times of peak loads and peak demands.

- **Demand Response (DR)**. While efficiency measures operate much of the time, Demand Response measures are called into play only for relatively short durations, aimed at reducing peak demands when the wider electrical system so requires. Demand-response is called into play by conditions at the utility system level, rather than at the building level as in the older strategy of demand-limiting, in which the goal is to limit the building's peak demand to reduce monthly demand-charges. In so far as DR actions are manual or supervised by the building operator, this is a good example of an area where operator training can be especially valuable.

    - **Peak-demand limiting** focuses on the building's peak demand which may or may not be coincident with the grid's peak. For example, residential buildings typically have summer peaks late in the evening, after the grid's peak established by commercial buildings. Limiting this demand could be economically attractive for a master-metered building but would not help manage the grid's peak. For winter-peaking utilities (as is typical of several in upstate New York), office building peaks set by lighting and hvac fans may not be coincident with system-wide peaks set by night-time residential heating requirements.

- **Real-time Pricing (RTP).** A further evolution beyond DR is RTP. Under RTP the dynamic utility system situation is reflected in prices. Some automated systems for price recognition and response have entered the market. Mechanisms presently involve a mix of automated responses, with building automation systems programmed to respond based on prices, and behavioral response on the part of price-informed end-users.

Given the evolving potential for both efficiency gains (baseline reductions) and demand-responsiveness, building designs and retrofits should be seen as a major element in reducing the risk of electric grid stress and failure. NYS' programmatic efforts over recent years[2] to inform and educate the building industry about the import of its decisions to electrical-grid risk mitigation should be continued and expanded.

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[1] Hammer and Parshall

[2] Reference ISO, PSC, NYSERDA programs

Electricity-based Building Failure

The absence of electric service will cause numerous building systems to cease operation. Lighting will fail, except lighting necessary for emergency egress which will be provided for by emergency power via generator or battery-pack fixtures. Motor-driven equipment will cease operation, again, with the exception of those services on emergency circuits where emergency generators are in place. Failure of pumped and fan-driven systems will be discussed further below.

Electric Grid Failure A review of the history of electric grid failures shows that they can occur at various scales and from various causes. Failures may occur solely due to equipment failure. But utility equipment failure is often precipitated by environmental factors that place equipment under poor operating conditions and/or significant stress; such environmental factors can be expected to occur with greater severity and frequency due to global climate change.

- **Ice storms.** Heavy precipitation in extreme cold can cause ice storms that bring down power lines due to the weight of accumulated snow and ice over extensive areas. This occurred in 2005 in Quebec. With the physical downing of lines, the event's aftermath stage can be quite extended with power outage persisting over weeks while restoration work proceeds. Upper New York State, like Quebec, has much of its residential sector dependent on electric heating, posing extreme health risk for isolated households. However, the availability of biomass resources could be a mitigating factor if households are equipped with appliances capable of burning biomass.

- **Heat Wave.** Extended heat wave stresses the electric system in various ways. Over-capacity demand can crash an entire network; operators watch vigilantly for such situations and will use voltage regulation ("brown-outs") and rolling black-outs to prevent total blackout failure. This was the approach taken in California's state-wide electrical shortage in 2000.[3] However, extended heat stress can cause other types of failure that are harder to mitigate. Local network transformers, relays, cable or cable connections may overheat and fail, causing a local distribution network to blackout. This occurred, for example, **in New York City's upper Manhattan (Washington Heights) blackout of 1999 and again in Long Island City and neighboring parts of Queens in 2006.** Restoration took almost two weeks. Utilities generally know which parts of their local distribution system are most stressed and at risk and may be able to take special mitigating steps.[4]

  In overhead electric distribution systems ground faults are common occurrences that usually only create short-duration effects in local networks. [5] The causes of ground faults are generally well understood and controlled by protective relaying. Occasionally,

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[3] Timney, Mary M. Short Circuit: Federal-State Relations in the California Energy Crisis. Publius, Jan 2002; 32: 109-122
Graham, Stephen and Nigel Thrift. Out of Order: Understanding Repair and Maintenance. Theory Culture Society, May 2007; 24: 1 - 25.

[4] Con Edison's alledged failure to do so throughout its system after the 1999 incident was part of the assessment of the 2003 incident. OAG report reference http://nysl.nysed.gov/uhtbin/cgisirsi/20100302190412/SIRSI/0/518/0/43923289/Content/1?new_gateway_db=HYPERION&user_id=CATALOG

[5] Reference to LBNL study about major import of short duration events – particular one in mind? http://eetd.lbl.gov/ea/EMP/reports/47043.pdf or http://eetd.lbl.gov/EA/emp/reports/52048.pdf

however, such relay action can "cascade" into progressively wider grid networks, causing regional blackout. This is what occurred in the NYC power failure of 1969 and, again, affecting the entire northeast in August 2003. Physical damage to the system utility system is minimal but the aftermath stage can be extended over days as the "black-start" restoration of the system must be done gradually and with care or the system can collapse again due to imbalance between generators and loads.

- **Flooding.** Flooding scenarios can develop in various ways. Here we consider the possibility of a Katrina-like event impacting New York City. Flood lines under rising sea level and storm severity projections have been extensively mapped and can be found in other parts of this research. New York City's electrical grid is largely underground. It has proven highly reliable even under high precipitation conditions. Its failure risk under hurricane-induced flooding is a topic for further research. In-city power plants are located on the city's waterways and nearby out-of-city plants are located on the banks of the Hudson River. Whether a severe, hurricane-induced flooding event could affect the operation of these plants is another topic worthy of consideration but beyond the scope of this paper.

Building-level Electric Failure. Severe flooding may also cause ***electrical failure at the building level.*** In NYC, building electrical service enters at the basement level through transformer vaults beneath sidewalks. Building switchgear is normally at the basement level. Basement storm drainage has historically performed well so that electrical service is not threatened. However, should the municipal drainage system be overwhelmed by flood conditions, building basements would not drain. Undrained, water levels rising to 2-3 feet in a basement could cause outage of an individual building's electric service or specific pieces of electrically-driven equipment. Pumps used for a building's water pressurization, for example, are typically set not much above the basement floor.

Building Failure Modes: What Happens to Buildings with Failed Electric Service.

We will briefly summarize what happens in various types of buildings with failed electric service. These descriptions apply to services that are not on emergency circuits. It should be noted that even where emergency generators are in place, they supply only a limited number of designated emergency circuits and loads. Emergency systems are also designed with fuel supply only for a limited period of time, usually not more than 1-2 days.

Temperature. Our temperature control systems are, with certain exceptions, dependent upon electricity. Air-conditioning compressors are usually driven by electric motors; even when they are not, necessary auxiliary devices require electricity. Boilers and furnaces burn fossil fuel but depend on electrically driven fans, pumps and ignition systems to do so. In larger buildings, electrically driven fans and pumps are necessary to circulate heating or chilled water. Thus, without electricity, it may be impossible to maintain interior temperatures within habitable range.

Building construction will affect the severity of the condition. Poorly insulated buildings will react more dramatically than well insulated ones. Sealed buildings (without operable windows), as in some high-rise curtain wall designs, will quickly overheat in the absence of fan system operation. Over the course of several days, building without heating or cooling will approach the temperature of the outdoor environment.

Ventilation. Ventilation, both for breathing and for its cooling effect, can usually be obtained by opening windows. But some high rise curtain wall designs are sealed – for other design reasons -

without operable panels, and ventilation is provided solely through the fan-driven HVAC system. In such buildings, loss of electricity means loss of ventilation. The building will quickly become uninhabitable and will need to be evacuated.

Water. It is essential to recognize that water must be pumped for delivery to large parts of New York City -- all those areas above about 60 feet (or six stories) high. ***Without pumping, the higher regions of buildings will quickly be without water for drinking or sanitary purposes and with limited water for fire protection.***

The city's water is delivered by gravity from the upstate reservoir system and under normal conditions reaches most buildings with about 40 psi (pound per square inch) pressure at the basement level. Depending upon piping system conditions, this is sufficient to raise a column of water 60 – 80 feet. In a six story building the top floor would receive water with little or no pressure. Consequently, the roof tank is a familiar feature of the NYC roof-scape, providing water pressurization for buildings six stories and taller. Water is pumped up to this tank by a pump located in the basement, controlled by a float valve in the tank. This pump is typically set on a concrete "housekeeping" pad, 6-8 inches thick on the basement floor or on a concrete pedestal 2-3 feet above the basement floor.

In newer buildings, the roof tank may be replaced by a pump-set that maintains pressure in the piped system. This pump-set, too, would be located in the basement, with the pumps and associated electric motors at the floor level.

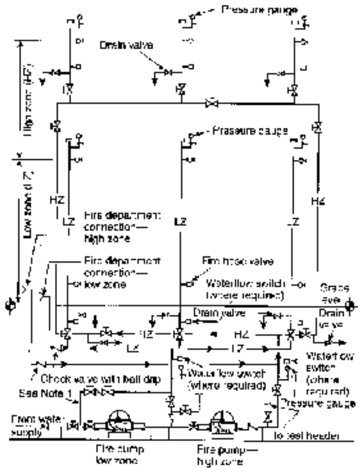
There are similar, parallel arrangements for the water system dedicated for fire protection purposes, called the stand-pipe system.

In the event of severe basement flooding, these pumping systems may be inundated and forced out of service. Once thoroughly wetted, it may be days before they can be sufficiently dried out to restore electrical operation or, if circuitry has been damaged, replacement may be necessary. With loss of water pressurization, immediately in the case of a modern pump-set and, in the case of the older roof-tank systems, once the roof tank has been drawn down, water-based building services will be lost:

- **Potable Water.** Loss of water pressure will make drinking water unavailable above five or six stories, except as it is hauled up by hand.

- **Sanitation and Solid Waste.** Water will be unavailable for toilet flushing or cleaning.

- **Fire.** The stand-pipe system provides pressurized water for fire-suppression, if the building has a sprinkler system, and for fighting, via hose connections at the street level and at various floor locations. Most stand-pipe systems have a dedicated tank on the roof or upper building level. The water stored in the tank will be available for fire protection (sprinkler) or fire-fighting purposes but without



Notes

1. Bypass in accordance with NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection.*
2. High zone pump can be arranged to take suction directly from source of supply.

FIGURE A.7.1(b) Typical Two-Zone System.

pumping, the tank will not re-fill. In larger commercial buildings with emergency generators, the stand-pipe pump would be on an emergency circuit. But many apartment buildings may not have an emergency generator.

Vertical Transport. Except in so far as some elevators may be on emergency circuits, elevators will be shut-down. Habitation in high-rises will be difficult with access limited to climbing stairs.

Lighting. Artificial lighting will be unavailable except in stairwells and corridors that are necessary for emergency egress and therefore are on emergency circuits.

Data. Computers and data-storage facilities are severely threatened by all manner of electric events, including interruptions and variations that do not quality as blackouts. Larger business and data centers already protect data carefully with back-up battery (UPS) and generator sources and with data back-up in secondary locations.

Climate, Buildings and Disaster Management

It has been persuasively argued that events become more or less disastrous as a function of how people react and respond to suddenly emergent conditions.[6] Therefore, preparation can be significant in influencing the outcome of such events. Preparation is based on an appreciation of possible events, event sequences, systemic failure modes, and responses to them.

Disaster management is a well-established discipline for mitigating the risk of hazardous events. It is a part of both public and business policy. The best known urban disaster preparation is for fire. Identification, alarming, notifications and safe evacuation procedures are paramount and regulated by law and building code.[7] Analogous disaster management planning has yet to be systematically applied for climate-related events, with the exception of hurricane preparation in southern coastal states. Preparation of the public and of critical responders is an important variable in the impacts and outcomes of events. The European heat wave of 2003 [8] provides a chilling example of what can happen when appropriate plans are not in place and the likely course of events not recognized.

Public sector concerns focus on public safety, using legal and building code requirements. Private sectors plans respond to public mandates for the implementation of public safety procedures and go further to protect business operations and critical data.[9] Public and private entities collaborate, through mandatory implementation of procedures, postings, and widespread training. Recognizing the key role of electricity, emergency power is mandated for critical building systems. These include, for example, lighting for safe egress in high-rise buildings and life-support systems in hospitals. In the wake of Katrina, legal considerations have emerged about the responsibilities and legal liabilities of hospitals during extended-duration emergency conditions.[10] Private industry may extend back-up power to critical data systems. Back-up

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[6] Chiles, James R. Inviting Disaster: Lessons from the Edge of Technology. HarperBusiness; 2001.

[7] ADA Best Practices Tool Kit for State and Local Governments ;
US Fire Administration report Emergency Procedures for Employees with Disabilitiesin Office Occupancies

[8] Hutton, Dave. Putting the Puzzle Together: reducing vulnerability through people-focused planning. Radiat Prot Dosimetry, Jun 2009; 134: 193 - 196.

[9] References to private sector emergency planning and disaster recovery –
FEMA Voluntary Private Sector Preparedness Accreditation and Certification Program

[10] NY Times Magazine DATE

power may be extended to other building systems to maintain functions for longer durations, but at a cost in terms both of equipment size and fuel supply.

Disaster preparation, therefore, comprises a combination of both physical infrastructure and a human dimension that may best be described as societal planning and human response.

Human responses to evolving circumstances. Disastrous events take people by surprise. They are unexpected both by those who experience them as victims and those who must act in them as trouble-shooters and responders. Disastrous events are unexpected in so far as their occurrence at a specific time is not known. But their likelihood of occurrence can be estimated. The sequence of events following the initial occurrence can be known to a substantial extent. People can be armed with good situational awareness and with planned responses in which they have been trained. After 9-11 the role of emergency "first responders" became the subject of substantial attention, including coordination with building operators and building information systems.[11] While these are more dramatic and sudden events, the same principle applies: behavior in developing crises will vary greatly based on levels of preparation.

Stages in the emergence of disaster. We can examine disasters as they evolve through distinct stages. For purposes of this discussion we identify three stages: unfolding, crisis, and aftermath. The specifics, durations, and dynamics of each stage will vary for different kinds of disaster events but each stage has its own implications for those who have to respond to it.

Recognition of developing emergency conditions is critical. Seismic monitoring and public notification systems are an example of how early warning systems can be used to mitigate the effects of environmental events, although the effectiveness of such systems in the developing world remains largely aspirational, as evidenced by on-going earthquakes and tidal waves with casualties in the hundreds of thousands. Nevertheless, the principle of event-recognition remains pivotal for disaster management and may be more effective in event sequences that are slower to develop.

As has been previously discussed, building level failure is tightly bound to failure in electric service. Thus the stages in stress and failure in the energy system, especially in the power grid, discussed in detail elsewhere in this research, are indicators of incipient building level failure. Monitoring and warning systems need to be integrated from the grid management system to the building level.[12]

Costs at the Building Level

Costs of failure from black-outs are described elsewhere. Analysis is heavily weighted towards costs in the commercial sector due to loss of business production.[13] Utilities may be held liable for damages incurred by customers and rate structures in New York State include provisions for payments to commercial and residential customers.[14]

Commonly recognized costs include damage to utility infrastructure and the costs of restoration of service, loss of business, loss of industrial/commercial production, loss of perishable goods, and damage to electronics and to other personal and commercial property. Other, perhaps less

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[11] NIST-Carnegie Mellon

[12] Reference to blackout literature

[13] LBNL paper, over 90% of electric interruption costs are in commercial and industrial sectors

[14] reference to PSC documents. Most current, LIC-2006, $7,000 per business claim, $350 residential

recognized, costs include security during emergencies, emergency services and re-location of affected populations, remediation of molds, and possibilities of extreme fire losses. Loss of life is certainly recognized as a possible result of extreme climate events – actual recent events make it impossible to ignore – but, nevertheless, is not typically quantified as part of economic risk assessment.

Many of these grid-failure cost-impacts occur at the building level, so electric-grid failure analyses broadly suffice to assess potential damages incurred in buildings. Additional costs could be evaluated for effects not related to failure in the electric grid. As has been discussed here, there are additional failure modes, especially due to flooding, that are not dependent on broader electric-grid failure. These include failure at pumps and building-level electric service and the possibility of post-event mold growth and its costly remediation (or total loss and replacement cost of the affected property). Katrina provides us with the chilling evidence that this kind of event is indeed possible.

For businesses, failures at the building level make it impossible to continue business functions, so economic-loss valuation can be conducted. Widespread building failure in the residential sector causes social displacement as well as directly threatening public safety, health and life. It is more difficult to perform an economic valuation of such public disruption. Yet it lies at the very heart of communities' ability to maintain some semblance of order and function during a crisis period and its aftermath.

Mitigation of Building-level Risk and Some Preliminary Cost Estimating Factors.

From consideration of the building-level failure modes discussed above, we can develop several ideas about mitigation. Mitigation can be achieved both with physical, hardware solutions and/or with behavioral ones that address both our planning practices and also public preparedness, based on awareness of risk.

Emergency Generators. More widespread deployment of emergency generators is an obvious risk-mitigation option, that requires careful analysis of deployment options, costs and benefits. Emergency generators are available at scale appropriate to a commercial building all the way down to units suitable for an individual home (100 – 500 watts). Back-up generator equipment itself is relatively inexpensive but the fuel supply and electrical work may add substantially to costs. A commercial cost of $500 per KW might be achieved on a commercial retrofit basis, higher at the smaller scale of a residential installation. Basic services could be maintained in a residential household with under 1 KW of generator capacity.

Resilient Design. An emergent design approach[15] would affect the way we design (rehabilitate or renovate) our buildings to make them more resistant to natural hazards. Resilient Design features are developed based on the specifics of the environment and environmental risk. For example, in San Francisco, resilient design would include features relevant to earthquake. In our NYS case, resilient design might include

- **Location of electrical-mechanical equipment.** Would it make sense to move electro-mechanical equipment out of the basement in so far as possible? It [1]may be a useful consideration for new construction. In existing structures, better flood protection can be a consideration in retrofit and replacement of old equipment. The protection of water supply (pressurization pumping) equipment is especially important. Work involved

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[15] Reference to Alex Wilson in Environmental Design Notes

would be on the order of a few thousand dollars for a residential home, tens of thousands for larger buildings.

- **Mixed-mode Ventilation for large commercial buildings.** Curtain wall designs should at minimum include operable windows or panels so that large buildings do not become almost immediately uninhabitable upon power failure. In many NYS climates, intelligent design for cross and induced ventilation can be very effective. The ability to maintain at least minimal ventilation without central HVAC provides an additional load-shedding opportunity in the face of a severely over-stressed electric supply system.

- **Back-up heating equipment not dependent on electricity or pumped fuels.** Wood stoves, pellet burners, and kerosene heaters are examples of simple heating appliances that can operate without electricity and can therefore be very important during major ice storms. Making sure such appliances, fixed or portable, are on hand can be accomplished at costs under $500 per household.

Resilient Design practices in general and specified measures could be **introduced via building codes and other local regulations and procedures**, such as the State Environmental Quality Review (SEQR) that mandates new developments perform environmental impact and risk assessments. Code provisions apply when major renovations are performed and thus would come into play affecting existing buildings as well as new.

Planning and Preparation. As we have seen, education and training, of both the general public and, more specifically, building operating and emergency personnel, can pay significant dividends. An agenda for public safety and crisis management already exists, so it is a matter of adding awareness of climate-related events to existing practice. While many of the practices and planned responses are common with other emergency preparations, the specific awareness of event-sequences as hazardous needs to be specified as part of the public safety agenda.

Planning and preparation steps may provide the most cost-effective approach to risk. The mechanisms and costs of this approach are well understood and can be incorporated or "piggy-backed" with other on-going programs, in areas such as

- **Civic and municipal planning** for emergencies
- **Public Awareness** promotions, via advertising and public service announcement campaigns
- **Public Education**, via introduction of materials into school curricula at various levels
- **Targeted Training**, of property managers, building operators and emergency personnel

A comprehensive statewide approach could be significantly advanced at a cost of roughly $50 million.

Conclusions

Building-level failure generally follows from the failure of the electric grid. Our current building stock can become uninhabitable under extreme conditions of some duration without electric service. Although variable for any given building type or building, our buildings are at risk for losing the ability to maintain ventilation, habitable temperatures, and water-based services, including potable, sanitary, and fire-protection. Temperature-habitability has been widely considered in connection with summer blackout conditions. We note that several upper New

York State utilities are actually winter-peaking with extensive residential electric heating in their loads. This population must be seen as at risk in winter ice storms.

In addition to building-level failure following electric grid failure, we find that high-rise buildings (defined as above five stories) are at risk of loss of water services from **flooding**. This is a severe public safety condition especially with respect to fire hazard.

We suggest that more strategic use of emergency generators may be important to risk mitigation, especially in the residential sector, where their use is presently more limited than in commercial office buildings and newer residential high-rises. However, widespread deployment of emergency generators would be a large infrastructural investment and various options require study and evaluation. There are other "resilient design" approaches that may more cost-effectively mitigate the risks identified in climate-event scenarios.

We strongly recommend that climate-related events be incorporated into the planning and preparedness framework that exists for a variety of environmental and other emergencies, extending specifically to the level of property managers and building operators. Recognition and response training can be integrated with other training efforts and municipal requirements.

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[1]