Leaks and Lives: How Better Building Envelopes Make Blackouts Less Dangerous

Richard Leigh, Jamie Kleinberg, Cecil Scheib, and Russell Unger, Urban Green Council
Nico Kienzl, Michael Esposito, Emilie Hagen, and Michael Tillou, Atelier Ten

ABSTRACT

Superstorm Sandy left thousands of New Yorkers in the dark and without running water for up to five days. Fortunately, the hurricane struck at a time of moderate outdoor temperatures. Would an extended blackout in a cold week in January or a hot week in July leave many of our residents in physical danger? Typical New York City buildings exhibit poor thermal performance, while the sheer number of residents makes evacuation impractical and ensures that shelters cannot hold the population, leaving many at home.

To assess the danger, building simulation models representative of six existing NYC building types were prepared and run using historical weather data. Two scenarios were analyzed over weeklong periods: a February blackout including the loss of heat and a July blackout including the loss of cooling. By technical standards of habitability, all six structures pose some risks to health after one to three days without power or heat, although the results varied with building type. To determine how improvements to the building envelopes could improve habitability, the models for each building type were modified to comply with energy codes in effect in New York City from 2010 to 2013, and also to a more stringent high-performance building standard. In most cases, a building meeting the requirements of energy code showed substantially improved performance, while in some cases the "high performance" building was so improved that it was merely uncomfortable, rather than dangerous. Clearly, better envelope performance brings with it a dramatic improvement in building resilience.

Introduction

Over one million New Yorkers were plunged into darkness after Superstorm Sandy, and hundreds of thousands were without power for days or weeks (NYC 2013). But it could have been worse. During the blackout, temperatures were above freezing at night and in the 40s and 50s during the day. What if the power outage had occurred during a winter cold spell or summer heat wave?

Our study, initiated for the Building Resiliency Task Force (UGC 2013b), found that during an extended winter blackout the space temperature inside a typical single-family house is likely to fall to 35°F after three days. A typical high-rise apartment would drop to 45°F after three days, and then keep falling. More thermally massive current buildings, row houses, and low-rise apartment buildings, would still be above 50°F after three days, but only the row house would remain above 40°F after seven days.

Buildings constructed in compliance with the energy code in effect in 2010-2013 would fare better, with the single-family house at 47°F (rather than 35°F) after three days, and the row house staying above 55°F for seven days. A high performance building, with better windows, fewer air leaks, and more insulation, would do even better. After three days without power, a high performance single-family house would stay above 60°F, and a high performance row house would stay above 65°F for more than a week. For the case of a high-rise masonry apartment building, the temperature changes over a week without power are shown in Figure 1 for an existing building and for the two buildings with improved envelopes.

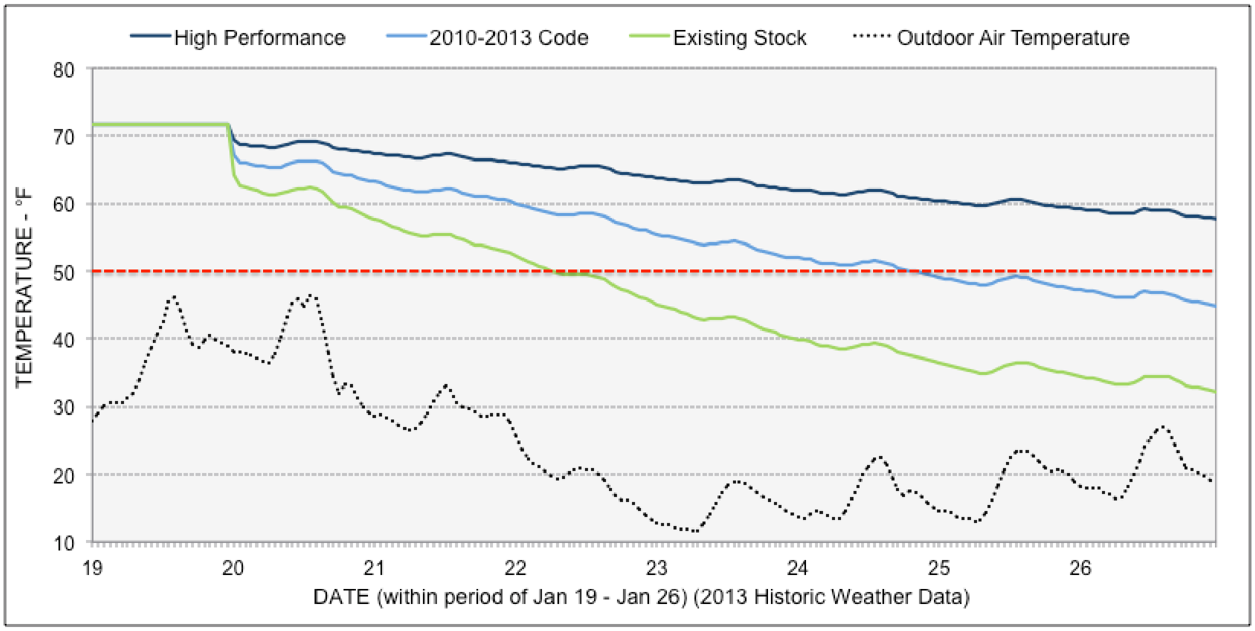

Figure 1. Temperature drift in early high-rise masonry residence, existing and improved envelopes.

In a summer blackout, the reverse would occur. Temperatures in a south-facing apartment in a typical window wall building would jump to almost 90°F on the first day, eventually rising above 100°F. Even a window wall building compliant with recent code would have temperatures above 95°F by the fourth day. A previous study has shown that poor building characteristics can add to the danger for apartment dwellers during events such as the Chicago heat wave of July 1995 (Huang 1996). But better buildings are possible, and a high performance brick high-rise building similar to the window wall building would keep interior temperatures below 85°F for a week or more.

History shows that many people remain in their homes during extended blackouts. Without electricity, buildings are dependent on whatever protection is provided by their walls, windows, and roof. In today's buildings, that protection is modest at best. If it wore clothing, the typical New York City building would have a light jacket on – not what you'd wear outside in winter, and certainly not performance wear.

The risk of dangerous, citywide, indoor environments is a modern problem. Two hundred years ago, leaky houses heated by fireplaces and Franklin stoves were much cooler than today's dwellings, and people managed to survive and prosper by dressing accordingly. One hundred years ago, coal fired steam heating systems warmed homes. However, these systems did not depend on an electric grid, and since wood and coal are normally stockpiled with a week to a month of fuel supply, the issue of widespread, simultaneous heating failures did not arise. Similarly, for heat waves, residential buildings were designed for cross ventilation, and people occasionally slept on fire escapes. The threat of an epidemic of hypo- or hyperthermia is a product of the way modern building envelopes and space-conditioning systems have evolved in the era of inexpensive energy.

In the near future, heat waves will last longer and bring higher temperatures more often. But climate change does not mean that winter will go away, as January of 2014 has shown the eastern half of the country. There will continue to be power failures affecting large swaths of the city, and these failures may occur during severely hot or cold weather. Currently, only a few of our existing buildings are constructed well enough to maintain habitable indoor temperatures without power. To provide truly resilient housing, these high performance buildings must become the new normal.

Habitability

An extended blackout disables almost all heating systems. But how cold is dangerous? Conversely, in summer, how hot is dangerous?

Indoor temperatures considered comfortable range from 67 to 79°F in winter, and from 75 to 83°F in summer, based on the assumption that people wear warmer clothing in winter and lighter clothing in the summer (ASHRAE 2013). But this only recognizes people's perception of discomfort. Low temperatures also carry significant health risks and the danger to a person's well-being can be realized very quickly. At 61°F, resistance to respiratory diseases is weakened. More than two hours at a temperature of 54°F raises blood pressure and increases the risk of heart attack and stroke. At greater stress levels, an indoor environment at or below 41°F leads to a significant risk of hypothermia (Baker 2013).

People can respond to low temperatures to some extent by adding layers of clothing. However, the population of New York City is accustomed to very well heated interiors and may not have adequate warm clothing to respond to an extended period of lower indoor temperatures. Even winter coats will not be adequate for the low activity levels common indoors. The data cited above indicate that interior space temperatures below 50°F over an extended period pose a significant threat to health.

High temperatures also present considerable risks to health, especially for people with medical conditions. The condition is called "hyperthermia", and it is when the body's internal temperature rises to a dangerous level, usually taken as above about 100°F (38°C), although it can range up to 104°F (Tintinalli 2004). Hyperthermia is different from a fever: a fever is created by the body as a defense against infection; hyperthermia is a failure of the body's temperature control mechanisms, normally as a result of excessive external temperature.

The risk of hyperthermia is correlated with the "heat index," a measure that takes into account both actual temperature and the relative humidity, since high humidity makes it difficult for the body to lose heat by sweating. Generally, a heat index of 105°F or higher is regarded as "dangerous" (NOAA 2014), and even at 40% relative humidity, this will occur when the dry-bulb temperature exceeds 98°F. Under these criteria, both dangerously low and dangerously high temperatures will occur in ordinary residential buildings under the conditions represented in our models. These conditions represent a cold period in winter and a hot period in summer, but are far from record-breaking extremes.

Winter Danger in Existing Buildings

New York City has had building codes for at least a century, but they were originally concerned with structural integrity and direct threats to health and safety. In the 1980s the New York State Energy Efficiency Construction Code appeared, but it was lax by today's standards and only weakly enforced. As a consequence, the bulk of today's buildings have poor thermal envelopes and require substantial heating and cooling systems to maintain habitable conditions in their interiors.

These systems depend on electric power to operate, and nighttime images after Sandy show that the vast majority of buildings have no functioning backup generators on site. To determine likely indoor temperatures in the event of an extended outage during the winter, we created computer models of residential apartments located in six different building types:

- Single-family house
- Row house
- Masonry low-rise
- Early masonry high-rise
- New masonry high-rise
- Window wall high-rise

The thermal integrity of the envelopes was adjusted to match today's buildings, using building characteristics derived in a previous Urban Green Council study (UGC 2013a, Wright 2014). The building parameters are listed in Appendix A, and were selected in that earlier study to describe buildings that, when scaled up to citywide building areas, use the same fuel and generate the same greenhouse gas emissions as does New York City.

For those six buildings, the parameters describe envelopes representing an average over buildings of all vintages, essentially from the 1880s to today. However, the window wall structure has only become common in the residential sector recently, with large numbers being built since 2000. To provide a meaningful comparison, we examined the performance of a more recent masonry high-rise building, with an envelope conforming to the requirements of ASHRAE 90.1-2004. Results for that building are included in charts labeled "New Masonry High-Rise."

Simulation models of the buildings were then prepared using the Energy Plus building simulation software package (DOE-EP 2013), and were run using historical weather data for the period of January 19th to 26th, 2013, an unusually cold period. Figure 2 presents the outdoor temperature (in red) and the interior temperatures in each of our model buildings.

The variation in building performance is striking. The low mass, wood-frame single-family house is freezing inside by the fourth day, while the masonry-walled row house, protected on two sides by other buildings, still has temperatures in the forties after seven days. Both the single-family house and the row house have both north and south exposures, and the heat gain from solar energy during the day is clear in the traces of their temperatures.

For the other three building types, the models represent north-facing apartments, and only very small solar gain from scattered global skylight insolation interrupt the steady downhill slide of the temperatures. The typical masonry high rise and the contemporary window wall building are comparable, taking about four days to reach 40°F. In contrast, the newer masonry high rise (built to the 2004 energy code) takes six days to reach the same temperature.

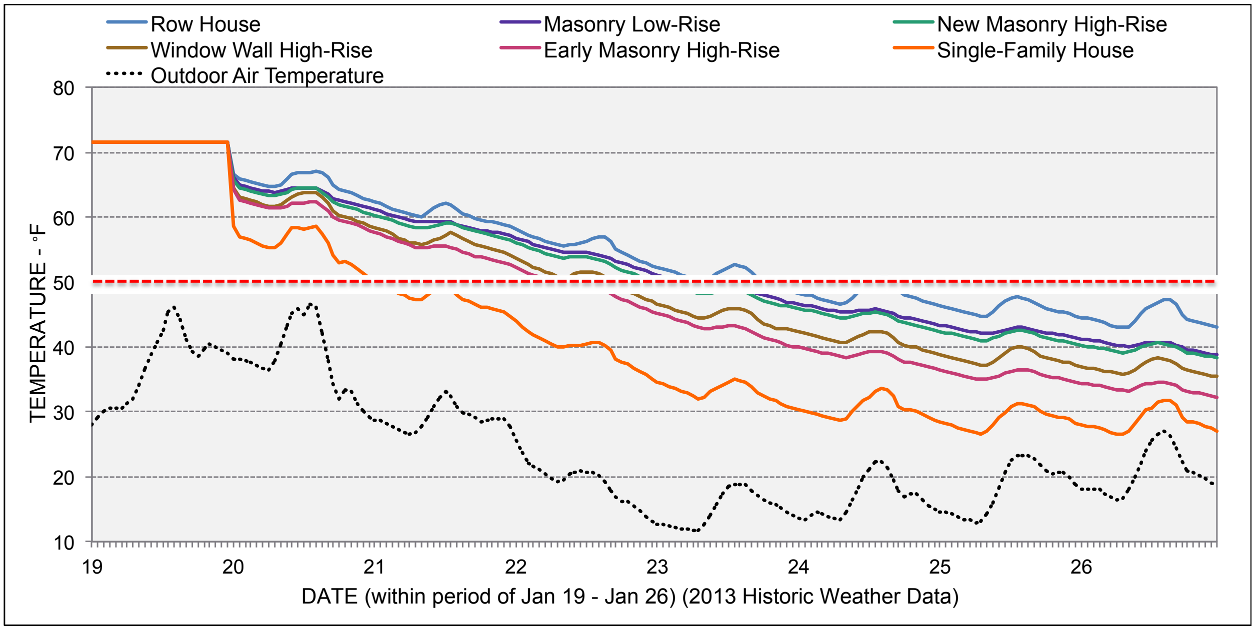

Figure 2. Interior temperatures for all existing buildings during winter blackout.

By our standard of habitability, at temperature of 50°F or less, all six structures pose risks to health after one to three days without power or heat. Of course the risks are greater for the infirm, but extended exposure to temperatures in the 40s will certainly lead to widespread misery, even if only a fraction of the populace is literally sickened.

Of course a window wall apartment facing south would enjoy significant solar gain. Our results for this case (not shown here) indicate that temperatures in the 60s would be maintained during the day all week, dipping to a final minimum of 47°F at night on the seventh day. However, we will see that occupants of the same (south-facing) apartment will experience considerable discomfort if the blackout occurs in summer.

The models were run with no internal sources of heat other than the occupants. If gas were available, it's likely that some stoves would be used and temperatures elevated somewhat above those shown. (Modern gas stoves require electricity to start the oven.) Because the extent to which gas could or would be used is unpredictable, these charts indicate conditions that will occur if gas is unavailable, or if people are reluctant to use it.

Resilient Safety behind Better Envelopes

The steady declines in interior temperatures found in the previous section occur because the envelopes allow substantial amounts of heat to escape whenever the outdoor temperature is lower than the indoor temperature. However, far better envelopes are possible: standard improvements include better air sealing, better insulation, and improved windows. Also, glass conducts heat much better than even a poorly insulated wall section, so more glazing increases thermal losses in winter as it admits more solar radiation on east, south, and west walls.

We examined two cases of buildings with envelopes improved over those typical of today's existing buildings. In the first case, shown in Figure 3 for the single-family house, the levels of insulation, infiltration, and window performance were adjusted to be compliant with the building energy codes in effect from 2010 to 2013, essentially ASHRAE 90.1-2007 and the

IECC 2009. The actual parameters used in the simulation are listed in Appendix B. Although the temperature still drops below 40°F toward the end of the week, this "code-compliant" wood-frame building clearly maintains about a 10°F advantage over the typical existing building of the same type.

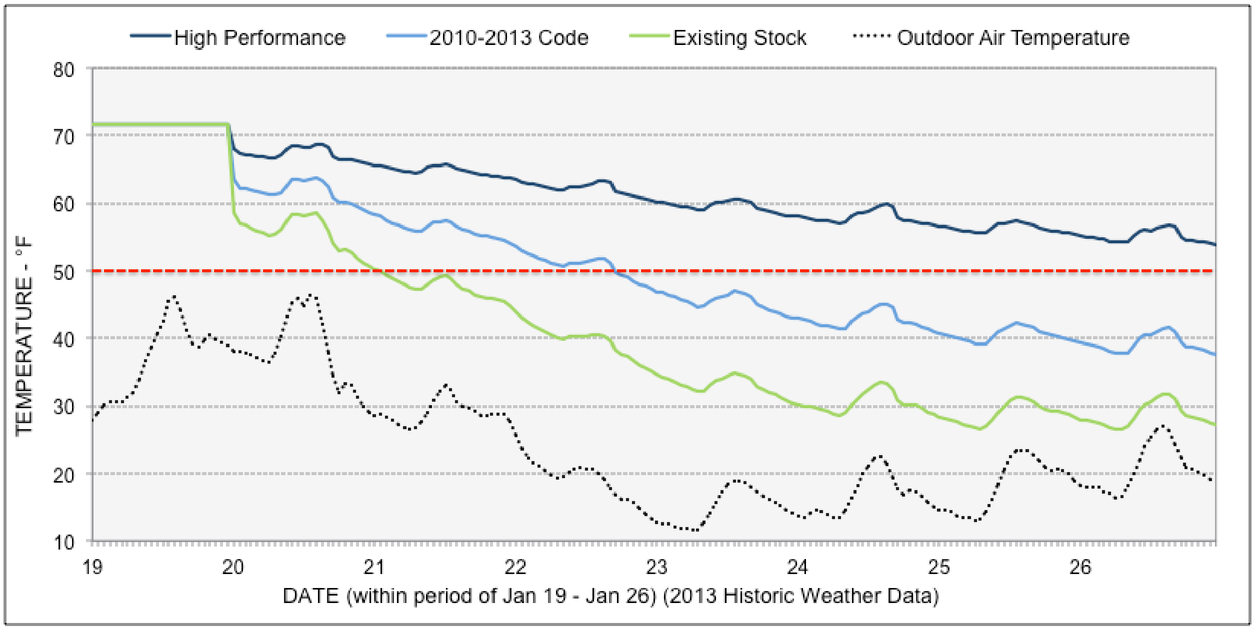

Figure 3. Temperature change in single-family house in winter blackout as envelope is improved.

We also examined buildings compliant with a hypothetical and substantially more rigorous future standard based upon today's best technology for insulation and air sealing. These parameters were developed in an earlier study (UGC 2013a, Wright 2014) that determined building performance levels that, coupled with carbon-free power sources, would permit New York City to lower its greenhouse gas emissions 90 percent below current levels by 2050. These building improvements, corresponding to about a 50 percent reduction in primary energy use, are all available today. They are more stringent than any current or proposed energy code, but are less demanding than the Passive House standard (PHIUS). The measures are cost effective in terms of avoided fuel and electricity expenses at today's prices, but for some, only if quite long payback periods are accepted (UGC 2013a, Wright 2014). Again, the parameters used in the modeling exercise are listed in Appendix B. It is clear from Figure 3 that this "high performance" house will remain almost comfortable despite the blackout, as would the masonry high-rise apartment shown in Figure 1.

This comparison makes our conclusion clear: since many New Yorkers will stay in their apartments during a prolonged electrical outage, the likelihood that they will face significant threats to their health in these circumstances can be dramatically reduced by improving the integrity of building envelopes.

In the Good Old Summertime

A blackout is most likely at the height of summer, since air conditioning loads place the highest demands on the regional and local electrical grids. And a blackout during high temperatures poses health risks to building residents, especially the infirm, since without air conditioning or fans, residents are dependent on the presence of wind for air exchange. In this section we quantify how dangerous today's buildings are in the case of a summer blackout, and how improved envelopes lessen that danger.

The building characteristics are the same as for the winter simulations, except that orientations are reversed so that apartments now face south in all cases except the single-family house and the row house, since they have both north and south exposures at all times. Clearly there will be less extreme temperature excursions in north-facing apartments, but we are quantifying risk, and that risk will occur in the apartments exposed to summer sun.

Since outdoor temperatures drop at night, the windows can be opened in the late evening and be kept open until morning, when the outdoor temperature again rises. This was modeled in all buildings by increasing the ventilation rates to two air changes per hour from 10:00 PM to 8:00AM, then closing the windows by dropping the infiltration rate to levels corresponding to the infiltration rate of each building under each envelope performance level.

The results are shown in Figure 4 for all six existing buildings. The three masonry buildings are clearly at an advantage, with temperatures generally staying below or well below the outdoor daytime peak. The single-family house suffers substantial temperature increases largely because it can receive direct solar radiation on three sides, while the expanses of south-facing glass in the window wall building cost the residents dearly in comfort and health risks. These two are the only buildings for which the internal temperature stays above the outdoor temperature even at the midday peak. Open windows during the day would mitigate high temperatures in these two structures somewhat, but infiltration already exceeded 2.0 ACH for the single family house. (See App. 1). Thermal mass keeps any of the buildings from dropping to the ambient nighttime lows. In earlier days, this led some to sleep on fire escapes, but this option is not available in modern buildings with internal fire stairs.

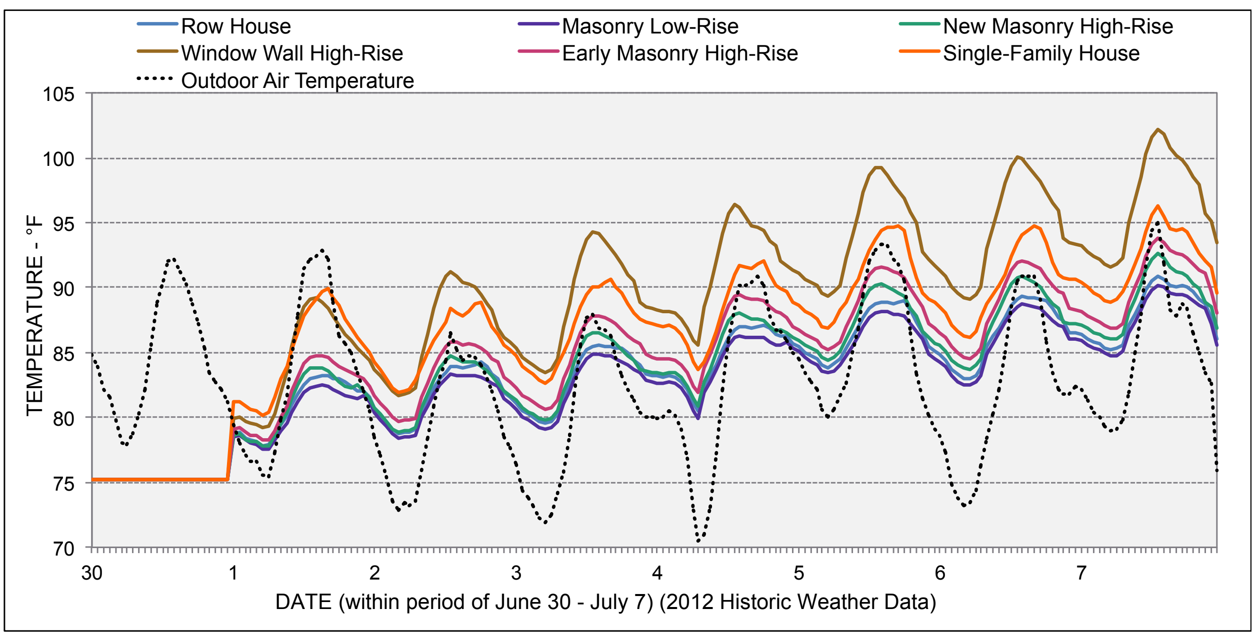

Figure 4. Interior temperatures of all existing buildings during a summer blackout.

Better Envelopes Keep It Cooler

As for a loss of heat in the winter, improved envelopes will also make a summer blackout easier to tolerate. Figure 5 shows how improved insulation and glazing in the row house lowers interior temperatures substantially, even after several days without power.

The improvements associated with the 2010-2013 energy code are primarily more insulation and better air sealing, while the jump to the “high performance” case includes exterior shading and advanced coatings on the windows that reject infrared heat radiation while accepting visible light. Because of this, the improvement in performance from the existing stock to the 2010-2013 code level is modest – the improved insulation and lowered infiltration may keep heat from being transmitted in from the outside air, but they also make it harder to get rid of the heat resulting from solar gain. The transition to the “high performance” case lowers solar gain through the external shading and improved window coatings, and the interior temperature rises much more slowly.

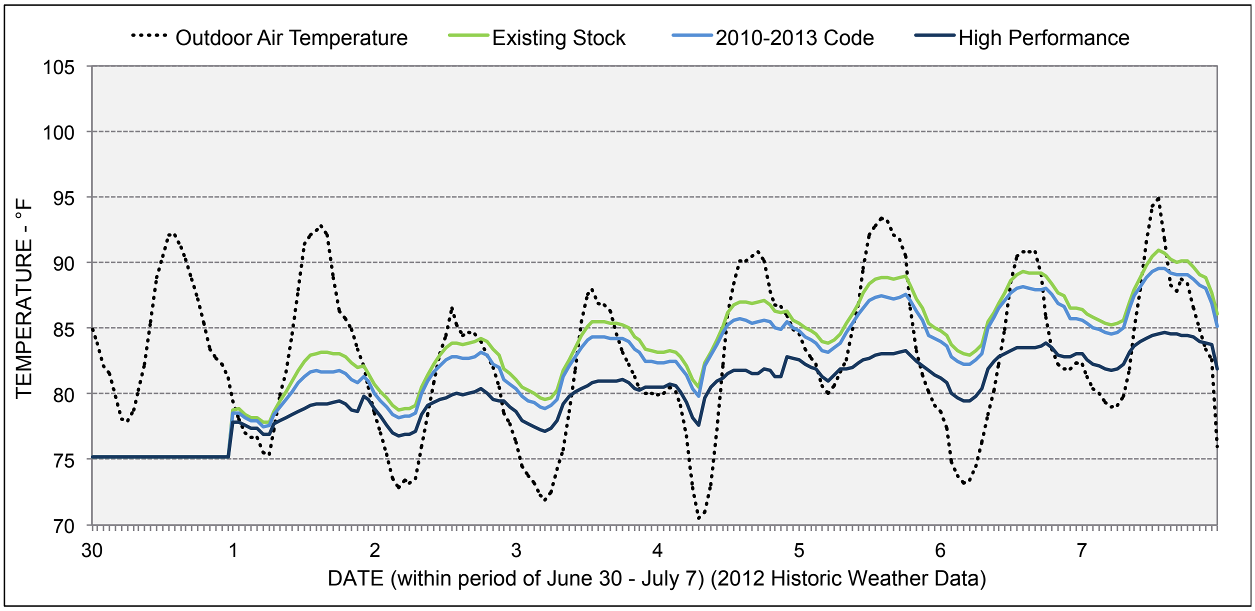

Figure 5. Temperature trends in the row house with envelope improvements during a summer blackout.

Conclusion

Envelope improvements provide well-known benefits such as lowered operating costs, decreased emissions of greenhouse gases and other pollutants, and greater comfort. Indeed, dramatic envelope improvements are central to any future carbon-free energy economy, and are cost-effective from a societal perspective (UGC 2013a, Wright 2014). Here, we have shown that envelope improvements also provide tangible and substantial improvements to the habitability of residences during extended blackouts. While it may be hard to monetize this advantage, it should receive significant attention from policy makers in areas deriving the bulk of their electric power from centralized grid systems.

Appendix A: Characteristics of Existing Buildings

Table 1 shows the overall characteristics of the apartments modeled, and the structure of the buildings in which they are located.

The single-family house and the row house have both northern and southern exposures. For the other building types, the models represent north-facing apartments in winter and south-facing apartments in summer. Apartments facing another direction would experience different indoor temperatures.

In the winter scenarios, infiltration through leaks in walls, windows, and doors serves as the only supply of fresh air. For all summer scenarios, infiltration was increased to 2.0 air changes per hour from 10:00 PM until 8:00 AM to mimic the opening of windows at night. (The existing single-family home infiltration already exceeded this value.)

Table 1. General assumptions for modeled spaces

Residential Type	Structure	Unit Area	Room Height	Exterior Facades	Façade Area	Glazed Area	Occupancy
		ft^2	ft	#	ft^2	%	persons
Single-Family House	Wood Framed	676	8	6	967	15%	1.6
Row House	Mass Wall	859	8	2	310	30%	2.0
Brick Low-Rise	Mass Wall	610	8	1	160	30%	1.4
Brick High-Rise	Mass Wall	599	8	1	252	30%	1.4
All-Glass High-Rise	Window Wall	686	8	1	274	70%	1.6

Table 2 shows the envelope characteristics assumed when modeling existing New York City buildings. Two existing brick high-rise buildings were modeled. One is typical of construction techniques before 2000. The other is typical of a brick high-rise built after 2000, to provide a meaningful comparison to typical all-glass construction during this era.

Table 2. Envelope properties of existing New York City residential buildings

Residential Type	Opaque Wall Insulation Level	Glazing (double glazed, no coatings)			Infiltration
	R Value*	SHGC*	VLT*	U Value (Assembly)	ACH*
Single-Family House	8	0.7	80%	0.6	2.8
Row House	3.5	0.7	80%	0.6	0.6
Brick Low-Rise	2.6	0.7	80%	0.6	0.4
Pre-2000 Brick High-Rise	2.8	0.7	80%	0.6	0.6
Post-2000 Brick High-Rise	9.5	0.7	80%	0.6	0.6
All-Glass High-Rise	8.1**	0.7	80%	0.6	0.6

* R-value is in hour-ft^2-^{o}F per Btu, SHGC is Solar Heat Gain Coefficient, VLT is Visible Light Transmission, ACH is Air Changes per Hour.
** Includes impact of exposed slab edge

Appendix B: Characteristics of Improved Envelopes

We examined the impact of two levels of improvement in building envelopes, first assuming that the envelope complied with the New York State and New York City energy codes in effect from 2010 through 2013, with the characteristics shown in Table 3. We then modeled envelopes consistent with a substantially more rigorous set of energy criteria, displayed in Table 4. These envelopes are consistent with the improvements modeled in our study of dramatic reductions in New York City's greenhouse gas emissions (UGC 2013a), and are more rigorous than any current code, although less rigorous than Passive House standards (PHIUS).

Table 3. Envelope properties of 2010-13 code-compliant NYC residential buildings

Residential Type	Opaque Wall Insulation Value	Fenestration (double-glazed, low emissivity coatings)			Infiltration
	R Value	SHGC	VLT	U Value (Assembly)	ACH
Single-Family House	11.2	0.4	70%	0.5	0.96
Row House	11.1	0.4	70%	0.5	0.24
Brick Low-Rise	9.6	0.4	70%	0.5	0.18
Brick High-Rise	9.6	0.4	70%	0.5	0.28
All-Glass High-Rise	15.6	0.4	70%	0.5	0.27

Table 4. Envelope properties of high performance NYC residential buildings

Residential Type	Opaque Wall Insulation Value	Fenestration: (triple-glazed, low emissivity, selective coatings, exterior shading on south windows)			Infiltration
	R Value	SHGC	VLT	U Value (Assembly)	ACH
Single-Family House	30	0.3	50%	0.2	0.29
Row House	30	0.3	50%	0.2	0.07
Brick Low-Rise	20	0.3	50%	0.2	0.05
Brick High-Rise	20	0.3	50%	0.2	0.08
All-Glass High-Rise	20	0.3	50%	0.2	0.08

Appendix C: Temperature Swings by Building Type and Season

Temperature curves for all six building types, three levels of envelope performance, and both summer and winter weather conditions can be observed in an interactive format at http://www.urbangreencouncil.org/BabyItsColdInside.

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