HOURS OF SAFETY IN COLD WEATHER:
A FRAMEWORK FOR CONSIDERING RESILIENCE IN BUILDING ENVELOPE DESIGN AND CONSTRUCTION

insight brief

February 2020

Sneha Ayyagari
sayyagari@rmi.org

Michael Gartman
mgartman@rmi.org

Jacob Corvidae
jcorvidae@rmi.org

HIGHLIGHTS

- Hours of safety is a framework that can be developed to understand how long a home can maintain thresholds of comfort and safety before reaching unsafe indoor temperature levels. This is especially important in considering the health and safety of vulnerable populations as extreme weather events increase in frequency.
- In a simulated power outage during a cold snap, indoor temperatures within homes constructed before 1950 dropped to below 40 degrees Fahrenheit within eight hours; whereas 2009 code-compliant buildings dropped to below 40 degrees after 45 hours. Weatherization efforts such as air sealing, increasing insulation, and installing storm windows can help extend the amount of time a building maintains safe indoor temperatures—helping reduce the risk of hypothermia and keeping vulnerable populations safe.
- Homes with Passive House standard building envelopes and net-zero energy buildings maintained safe indoor temperatures for significantly longer than even code-compliant new buildings, lasting over six days before indoor temperatures fell below 40°F.
- While this research simulated a power outage during a cold weather event, hours of safety is relevant to heat waves as well.
- The research outlined in this insight brief highlights the opportunity to factor building envelope efficiency into local and state resilience planning and home valuation.

INTRODUCTION

Winter storms are increasing in severity because of climate change. Warmer ocean temperatures can lead to heavier snowfall, and extreme cold temperatures can travel further south because of the **warmer and weaker arctic air jet streams**. When winter storms are in full blast, millions of people take refuge inside to stay warm. But what happens to indoor temperatures if there is a power outage or if a furnace stops working?

Homes vary widely in their ability to maintain comfort during these events. High-performance homes with more insulation, better airtightness, and better windows can outlast the cold, making it possible for people to comfortably "shelter in place" until power is returned. Improving our homes to withstand extreme weather events is an essential strategy for climate change adaptation (while providing lower utility bills and other benefits)—but to this point, we haven't had a way to tangibly quantify the resilience benefit yielded by these improvements or to compare the extreme weather performance between homes.

This insight brief is intended to address this knowledge gap by outlining the concept of hours of safety. The concept attempts to define the duration of time that homes can be expected to provide safe temperatures when the power goes out based on key building characteristics (e.g., insulation levels). This metric can be used to quantify the amount of time people are exposed to extremely hot or cold temperatures indoors, information that can be used to effectively guide weatherization efforts, emergency response measures, and more.

This study modeled the interior conditions for five representative buildings during a simulated power outage in extreme cold conditions in Duluth, Minnesota. These five buildings represent the range of conditions seen in our current building stock: a typical home built in the 1950s, a typical home built in the 1980s, a home that meets the 2009 IECC Code, a net-zero energy ready (NZER) home, and a house that meets Passive House (PH) standards. This research characterizes how well each building typology retained safe indoor temperatures once power was lost.

INSIGHT 1: THE DANGERS OF EXTREME COLD ARE SIGNIFICANT BUT DIFFICULT TO QUANTIFY

The risks of extreme cold and their contributing factors are influenced by age, physical health, clothing, duration of event, humidity and other climactic factors, and more. This variability makes it challenging to quantify a single threshold for cold weather safety that applies to all people and all situations, which in turn makes it difficult to provide actionable information about building resilience in extreme cold events. We developed a cold stress scale based on a literature review, but more modeling and work with healthcare professionals is needed to define a widely applicable single threshold for safety from cold exposure. This section summarizes the impacts of cold stress and describes the scale that was used in this analysis.

Cold stress can cause a wide range of health challenges

Cold stress, as defined by the **US Navy Environmental Health Center**, is when the net heat balance at a given activity level with typical clothing results in heat loss unless the body compensates by thermoregulatory mechanisms. But the health impacts from cold weather can either be acute and happen in minutes (falling into cold water) or chronic and happen in weeks or months (commuting to work every day in cold weather).

Acute exposure can result in **serious health conditions** that can potentially be life-threatening such as hypothermia, when the core body temperature drops below its usual temperature; frostbite, when a body part becomes injured by the cold; and chilblains, ulcers formed by damaged small blood vessels in the skin. **Other health risks** include pneumonia, flu, cardiac arrhythmias, cerebral insults, ischemic stroke, amnesia, and breathing difficulties.

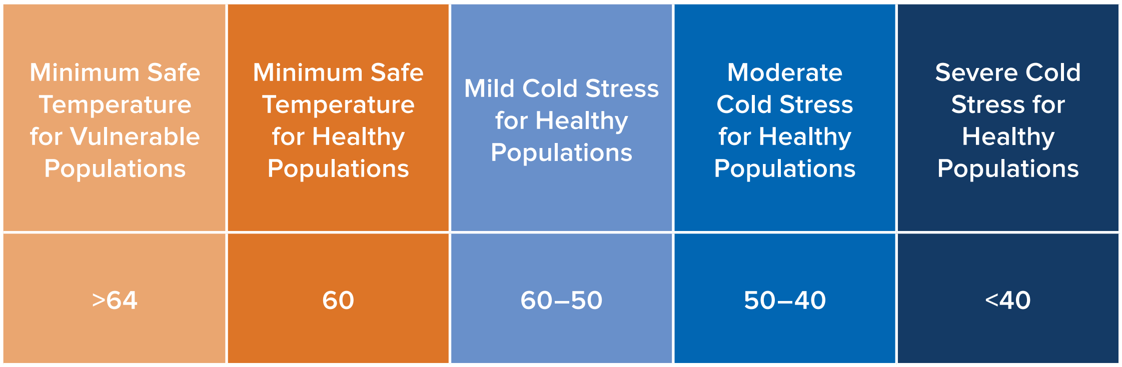
The impacts of cold exposure increase for vulnerable populations. As we age, we lose the ability to effectively thermoregulate. For example, at the age of 80, metabolic heat production is about 20 percent less than that at age 20, so people in their eighties may prefer temperatures about **3°F warmer than people in their twenties**. In addition to age, people with certain diseases like diabetes and people acclimated to living in warmer environments can be **more susceptible to extreme cold**.

Providing a starting point for a cold safety threshold

Because windspeed is not a consideration in indoor environments, hours of safety for cold weather events should be largely defined by temperature and metabolic rate. While more work needs to be done to effectively correlate the dangers of cold stress to these factors, available research can provide a starting point. The temperature ranges shown in Exhibit 1 were selected to roughly categorize cold stress based on a review of over a dozen data points from **ASHRAE**, the World Health Organization, the National Institutes of Health, and more.

EXHIBIT 1

Cold Stress Scale



Minimum Safe Temperature for Vulnerable Populations	Minimum Safe Temperature for Healthy Populations	Mild Cold Stress for Healthy Populations	Moderate Cold Stress for Healthy Populations	Severe Cold Stress for Healthy Populations
>64	60	60–50	50–40	<40

INSIGHT 2: HOMES WITH POORLY BUILT WALL SYSTEMS PRESENT THE MOST RISK

In an extreme cold event, a community's most poorly built (and often oldest) homes can become dangerously cold within the first 12 hours of a power outage. Exhibit 2 shows how each type of building performed during a power outage.

As seen in Exhibit 3, it took between 8 and 152 hours for the indoor air temperature to fall below 40°F in each representative home. During the first day, residents of the modeled Passive House would experience some discomfort as temperatures drop to 64°F. However, they fared much better than those occupying the most poorly insulated and older homes, where the indoor temperature drops below freezing within 12 hours. Even 2009 code-compliant homes drop to 56°F on the first day, a temperature where residents, especially vulnerable populations, may start to experience health issues. During the second day, 1980s homes and code-compliant 2009 homes drop below 40°F, while Passive House residents experience just a 5°F degree temperature change throughout the day.

The fact that older buildings quickly drop to unsafe temperatures compared with newer and more efficient housing is an equity concern—low-income residents or seniors may be more likely to live in older housing, which can expose them to life-threatening conditions in winter storm-triggered outages.

EXHIBIT 2

Building Performance in Simulated Power Outage (begins 12/24)

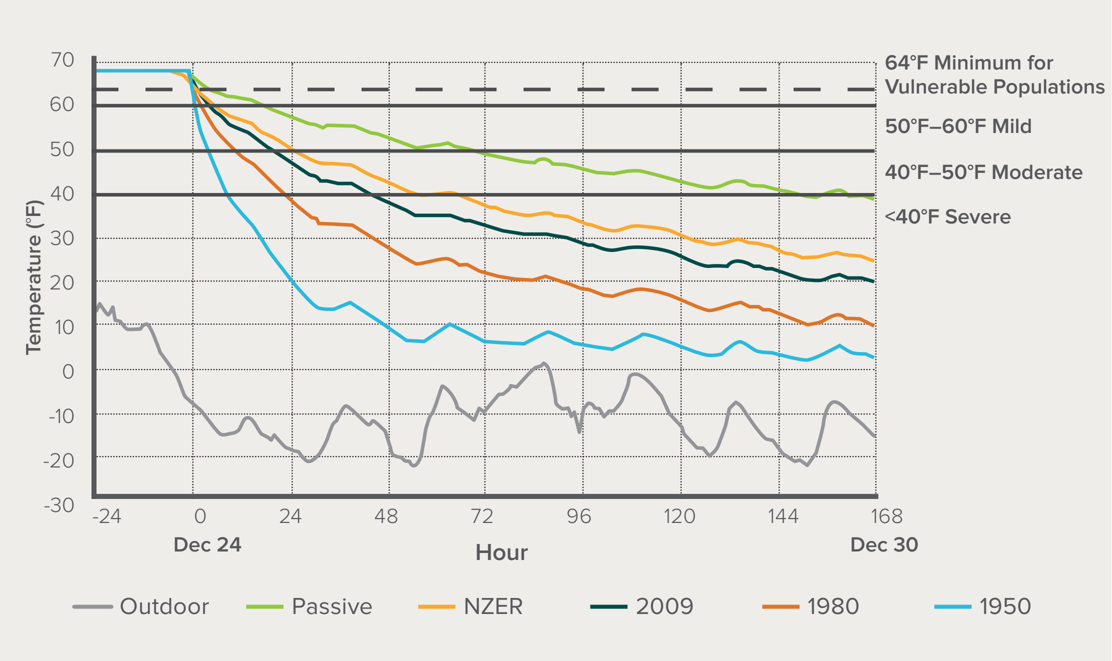


EXHIBIT 3

Time to Fall Below 40°F in a Power Outage

House model	Number of hours
Typical 1950s home	8
Typical 1980s home	23
Code-compliant 2009 home	45
Net-zero energy ready home	61
Passive House	152

City and state governments can use hours of safety as a metric to overcome these equity and safety concerns:

- **Retrofits:** Weatherization programs such as California's Low-Income Weatherization Program and New York's Retrofit New York can use hours of safety to more comprehensively define the value proposition of energy efficiency in building envelope upgrades. This metric can help support incentives offered by state energy agencies and utility companies and potentially from other sources interested in health, safety, and resilience.

- **City and state emergency response plans:** Hours of safety can be used as a metric to help identify neighborhoods or buildings that are particularly vulnerable to extreme weather, and to identify priorities for support or evacuation. It can also be used to identify safe places to "shelter in place." Eventually this metric could be incorporated into geospatial models of cities to identify where government agencies should prioritize retrofit programs and can inform program design, evaluation, and metrics.

Homeowners can also use hours of safety to justify purchasing decisions. Today, many homeowners in cold climates purchase gas or diesel backup generators to survive grid outages, but these generators are costly, inefficient, and can fail without notice. Providing clear and actionable insight on the resilience benefit of envelope improvements could help many homeowners avoid the cost of that generator by instead investing in efficiency measures such as increased insulation and improved windows that provide additional cost savings and comfort benefits.

INSIGHT 3: PASSIVE HOUSE PERFORMANCE ADDS VALUE

As expected, the Passive House building was able to buffer the cold temperatures for the longest period during the outage. As shown in Exhibit 4, there was a 90 percent reduction in severe cold stress hours between the 1950s model and the Passive House model. Exhibit 5 shows that Passive House buildings performed over 7 percent better than the next most efficient building type, the net-zero energy ready building. Thus, the more we improve the insulation, thermal bridging, and air sealing of homes, the more hours of safety the home will provide, with dramatic differences from current code up to Passive House standards.

Considering hours of safety improves the value proposition for Passive House buildings and other super-efficient buildings by quantifying the resilience benefit of greater investments in high-performance building envelopes, particularly in areas prone to extreme weather events.

EXHIBIT 4

Percent Reduction in Severe Cold Stress Hours from 1950s Model to Passive House

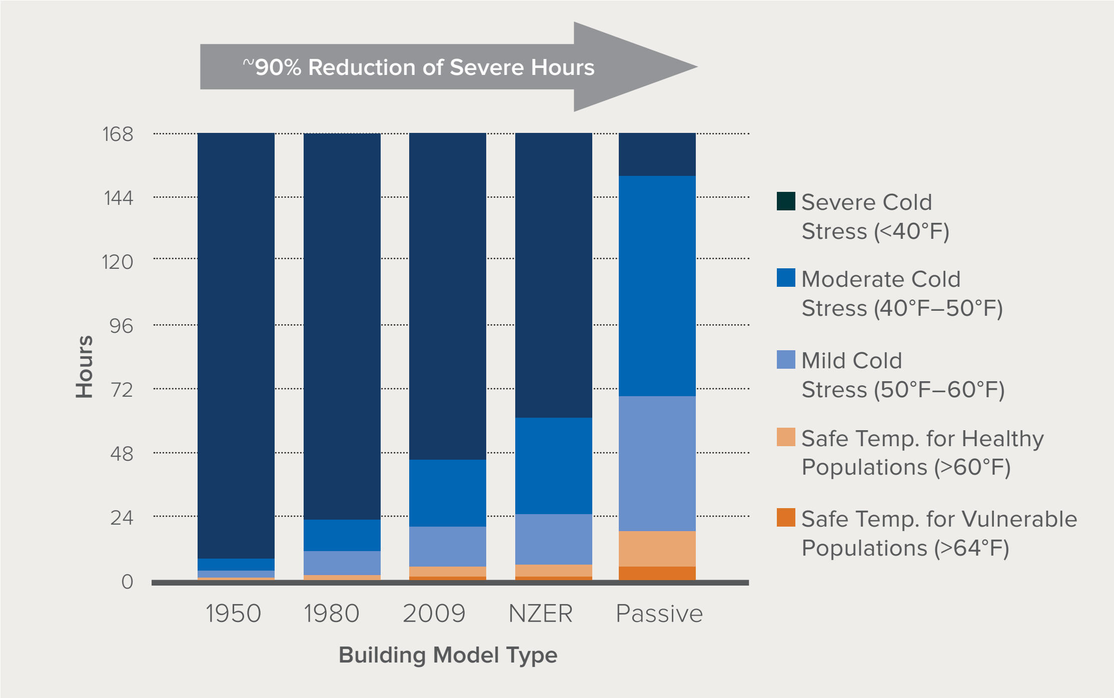
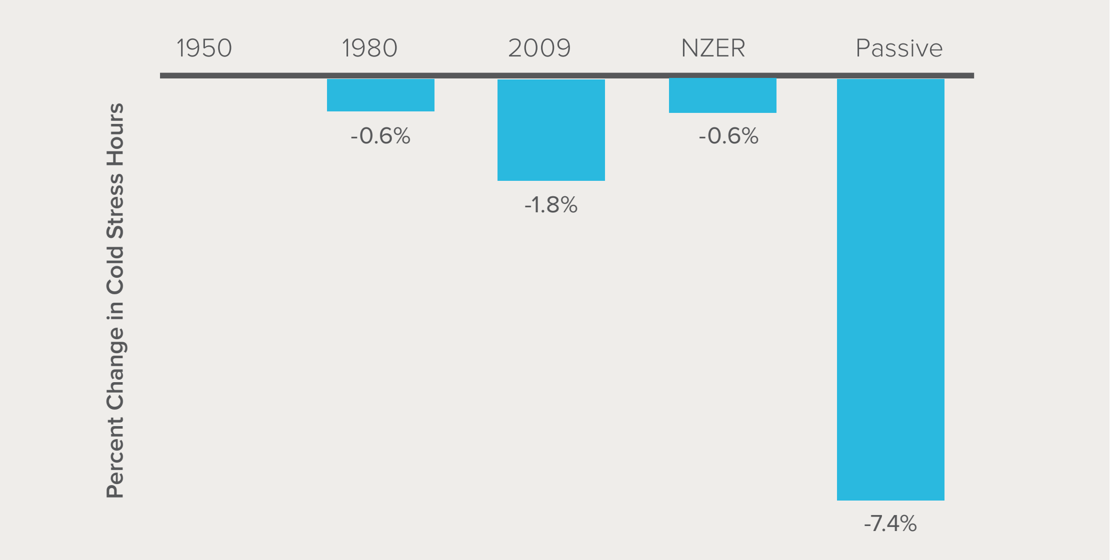


EXHIBIT 5

Percent Change in Mild, Moderate, and Severe Cold Stress Hours from One Model to the Next



HOURS OF SAFETY CAN PROVIDE CLARITY TO POLICYMAKERS AND INDUSTRY DECISION MAKERS

This research suggests that there is value in further developing an hours-of-safety metric that can be used by home performance contractors, policymakers, and homeowners to make informed decisions about resilience, safety, and comfort. Once defined, the data necessary for quantifying hours of safety could be collected through typical construction inspections, energy auditing, commissioning, and building certification practices.

This research suggests that there is an opportunity to factor hours of safety into policies and business models in the following ways:

1. **Increased data availability:** Hours of safety is one metric that can be used to provide transparency and data to homeowners, the performance contracting industry, and policymakers interested in resilience planning. This can be driven through local policies such as residential energy disclosure policies, which require sellers or landlords to make home energy performance information available to prospective buyers and/or renters. This type of information enables cities to drive more energy efficiency upgrades, protect consumers and help them make informed decisions, create jobs and invest in local businesses, and reduce energy burdens for low-income households. Increased data availability can also be driven by the private real estate sector in mortgage underwriting algorithms to help insurance agencies mitigate risks.

2. **A tool for resilience education and public health campaigns:** The hours-of-safety concept can help inform a consumer-facing education campaign to highlight the health and safety benefits of energy efficiency in building envelope construction and retrofits. This can help seniors and other vulnerable residents take measures to improve their homes to protect against extreme hot or cold weather events.

3. **A metric to include in future code development and improvements:** Hours of safety can be incorporated into future code cycles to inform new construction and retrofits and help create market incentives for efficiency upgrades. The metric could be particularly useful for jurisdictions adopting energy efficiency standards for rental properties, given that these homes are often the most poorly insulated and renters are less likely to own a backup generator for grid outage events.

NECESSARY FUTURE WORK

Efficient building envelope components provide a significant added value during extreme weather events. Society needs a way to consider that value alongside energy cost savings. The hours-of-safety concept can help value resiliency and further the value proposition for energy efficient building envelopes, helping us understand if our buildings are prepared for the extreme weather events that are unfortunately becoming more frequent.

Future actions for refining this concept include:

1. Refining and updating specifications for a threshold for unsafe temperatures in both extreme heat and cold weather events. The scale used in this analysis was developed from a preliminary review of research on thermal comfort and stress that can be used as a starting point for a more rigorous clinically tested metric.
2. Performing energy modeling for both hot and cold weather scenarios to determine which building characteristics can be used to accurately predict approximate hours of safety in a cost-effective manner. This modeling should consider characteristics such as window-to-wall ratios and infiltration.

3. Creating a standard hours-of-safety metric that the industry can adopt.

4. Crafting guidelines for simplified adoption of the hours-of-safety metric to make it easier to integrate into the industry.

This insight brief provides a starting point that must be built upon in a collaborative effort between policymakers and innovators in the insurance, healthcare, and home performance contracting industries. We must take action to protect the health and safety of vulnerable populations in the face of increasingly frequent extreme weather events. We encourage interested parties to take ownership of these action items, share insights, and call for collaboration among industry peers. Please contact us to learn more.

APPENDIX: MODELING PROCEDURE

Weather Data

To determine a location and weather file for the analysis, we evaluated outdoor temperatures in the Midwest region of the United States to find the location with the coldest temperatures for the year 2017, the latest historical weather year available for download at **Whitebox Technologies**. Current weather files for modeling software are in typical meteorological year format, so they do not represent extreme weather events like heat waves and cold storms. We selected Duluth, Minnesota, as the location for the building simulations. In December, the coldest month that year in Duluth, temperatures started in the 30s and dropped below zero by the end of the month.

Modeling Software

The building modeling software used for the analysis was CBECC-Res. The California Energy Commission developed CBECC-Res for use in demonstrating compliance with the **California Residential Building Energy Efficiency Standards** and the software is open source and free to download. The engine that powers CBECC-Res is called the **California Simulation Engine** (CSE), and is a general purpose building simulation model developed primarily to be used with CBECC-Res. Although the CSE was made to work underneath CBECC-Res, the CSE can be used on its own to run building simulations without the California-specific compliance metrics. For this analysis, the building geometry and other building information was input into CBECC-Res first. CBECC-Res outputs a text file that can be run separately by the CSE. The power outage was simulated by turning off the heating and ventilation equipment in the building model for the month of December. Further work could have been performed to turn off all other end uses in the home, but these were determined to have minimal effect on the heating load so were left on for the time of the simulated power outage for simplicity.

Building Models

We modeled five types of buildings in Duluth, Minnesota. The 2009 IECC Code home as well as the net-zero energy ready home were defined by RMI's report **The Economics of Zero-Energy Homes**. The Passive House building model was based off a case study located in **Northern Minnesota**.

Each home has 2x4 construction, slab foundations, two floors, and two zones. The geometry of the home is the same as the BeOpt model used for RMI's *Economics of Zero-Energy Homes* model (Exhibit A3). Exhibit A2 shows a relative comparison of the envelope measures between each building model. The mechanical systems did vary but will not be discussed in detail because the focus of this study was on the performance of the home without power.

EXHIBIT A1

R-Values for the Various Envelope Components (left axis) and Average R-Value of the Envelope (right axis)

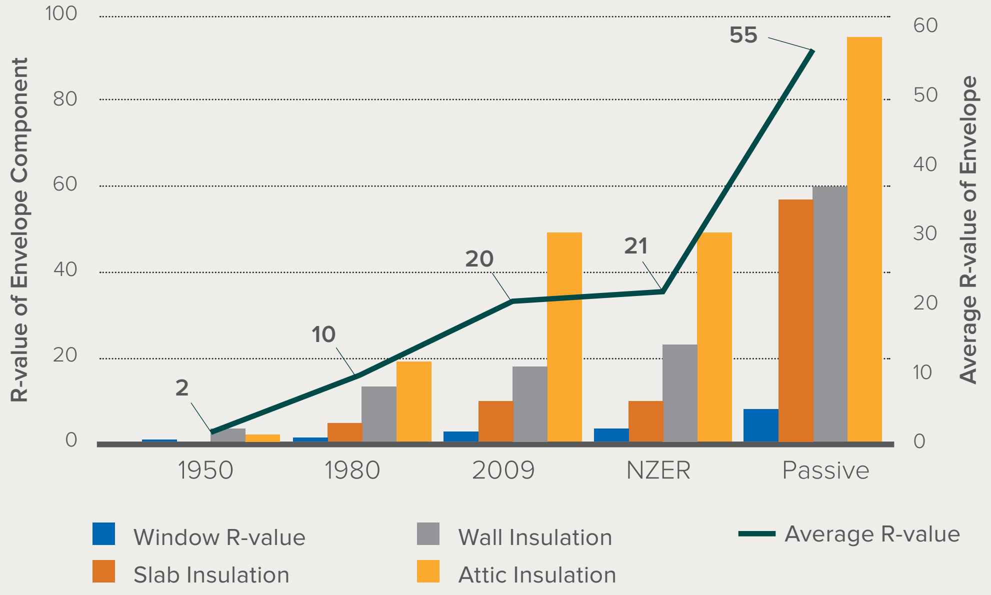


EXHIBIT A2

BeOpt Visualization of the Typical House Model

The geometry was the same as the building used in RMI's ***Economics of Zero-Energy Homes Study***

EXHIBIT A3

Building Parameters Used in the CBECC-Res Building Models

	Unimproved 1950s home	Unimproved 1980s home	2009 IECC compliant	NZER home	Passive House
Walls	No insulation	R13 in-frame insulation	R13 in-frame + R5 continuous insulation	R13 in-frame + R10 continuous insulation	R13 in-frame + R47 continuous insulation
Attic/Roof	No insulation	R19 blown insulation	R13 in-frame + R36 blown insulation	R13 in-frame + R36 blown insulation	R35 in-frame + R60 blown insulation
Slab/ Foundation	No insulation	8 inches, R5 exterior insulation	4 feet, R10 exterior insulation	4 feet, R10 exterior insulation	R57 12 inches EPS foam under and around 9-inch slab
Windows	Single pane 15% window to wall ratio U=1.19, SHGC=0.83	Double pane 15% window to wall ratio U=0.71, SHGC=0.73	Double pane 15% window to wall ratio U=0.35, SHGC=0.44	Double pane 15% window to wall ratio U=0.29, SHGC=0.56	Triple pane 15% window to wall ratio U=0.125, SHGC=0.56
Leakage	15 ACH50	10 ACH50	7 ACH50	3 ACH50	0.6 ACH50
HVAC **DHW** **Appliances** **Lighting**	Active systems were specified per home but had no impact on this study of performance during a grid outage. Assumptions can be provided upon request.				