Sustainable, Resilient Buildings

Buildings both contribute to and are vulnerable to climate change. In the U.S., the heating, cooling, and operation of buildings and homes account for more than 40% of carbon dioxide emissions each year—more emissions than are produced by either transportation or industry. Meanwhile, the damage to property by the increasing number and intensity of hurricanes, tornadoes, and typhoons endangers lives and costs billions.

Any strategy for mitigating the effects of climate change must decrease energy usage and emissions from the building sector, as well as make structures more hazard-resistant. These measures will have substantial environmental, financial, and safety benefits for companies and individuals.

Research at the MIT Concrete Sustainability Hub (CSHub) supports the development of sustainable and resilient buildings by quantifying their energy use and hazard resistance. The CSHub is developing streamlined methods for quantifying the environmental and economic impacts of different material and construction systems.

BETTER TOOLS FOR ASSESSING THE LIFE CYCLE OF BUILDINGS

In focus groups and surveys with decision-makers in the building industry, CSHub researchers found that existing life-cycle assessment (LCA) and life-cycle cost analysis (LCCA) tools have several shortcomings. As a result, the environmental impact, cost, and performance of a structure over its entire lifespan may be inaccurately predicted, if they are predicted at all.

The CSHub is developing and refining tools that address the gaps in LCAs/LCCAs. The goal is to enable designers, developers, owners, and other decision-makers to understand the costs and benefits of hazard-resistant and energy-efficient structures early in the design process—when building materials are typically selected and decisions can have the biggest impact.

- Researchers developed a streamlined LCA methodology that may be used early in the design process to identify key drivers of environmental impact and reduce the quantity and specificity of information required to conduct an LCA. The streamlined approach allows practitioners to focus on the parameters that matter most and leave the rest underspecified.
    - A 2018 update to the CSHub's streamlined methodology incorporated a **genetic optimization algorithm** inspired by natural selection. The algorithm quickly and efficiently analyzes thousands of possible design scenarios by making pairings based on desired outcomes and refining pairings with each generation before settling on a near-optimum design.
- Researchers have also developed a method for integrating hazard resistance into LCCA by incorporating costs due to energy use, construction, maintenance, and damage from hazards. This enables calculation of a payback period for more hazard resistant design.

CSHub researchers have conducted energy-related analyses in order to improve the application of energy-efficiency strategies in building design and LCA tools.

- Researchers mapped thermal mass benefits (the ability of wall materials to help regulate the temperature in a building) of residential structures across the U.S., and showed climate to be a key determinant of the range of benefits from thermal mass.
- Researchers also analyzed data from blower door tests for wood frame and ICF (insulated concrete form) homes in the U.S., which revealed no significant difference between the construction systems.

IMPACTS OF BUILDINGS IN URBAN ENVIRONMENTS

Increasing urbanization means that policies enacted in cities are critical to mitigating the effects of climate change, urban heat island (UHI) effects, and natural or man-made disasters. CSHub research analyzes the economic, environmental, and hazard resistance impacts of building configuration and design in urban environments.

- One study conducted in Cambridge, Mass., demonstrated how retrofitting a small, targeted percentage of buildings in the city would have big impact on carbon emissions.
  - By comparing gas bill information with city-provided data on the size and volume of the buildings, along with weather data collected during the study period, the team was able make detailed predictions about which buildings would benefit most from retrofits.
  - The analysis could make it possible for cities to adopt highly targeted strategies for reducing energy used for heating and cooling.
- Researchers are studying the urban heat island (UHI) effect, a phenomenon where a city is significantly warmer than its surrounding rural areas, and have developed an innovative approach inspired by theories from statistical physics applied at the molecular scale to study the horizontal movement of heat in urban areas and characterizing cities by their surface geometry. The work has demonstrated a strong correlation between urban structure and the significance of the UHI effect.
- Researchers are working to better understand the impacts of albedo (a measure of the solar energy reflected by the earth's surface) and the impact that material choices for buildings and hardscapes in urban areas have on UHI climate change. The team recently determined that city texture, the arrangement of streets and buildings, makes a big difference in how heat builds up – a finding that could provide city planners and officials with new ways to influence UHI effects.
- Researchers have also introduced methods which make it possible to identify specific buildings within cityscapes that are most vulnerable to failure as a result of intensified wind loads, making it possible to make those buildings much more resistant to hurricane damage through already well-known hurricane-proof retrofitting techniques.

CASE STUDIES FOR RESIDENTIAL AND COMMERCIAL BUILDINGS

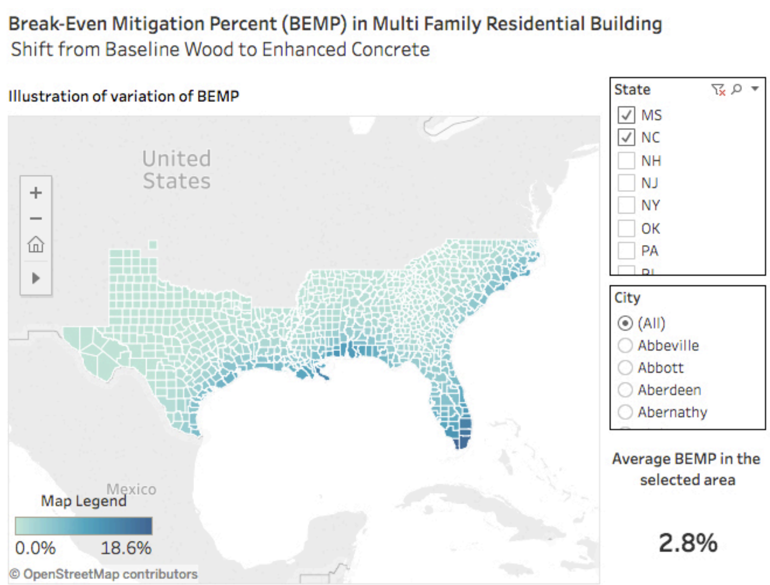
CSHub researchers conducted LCAs/LCCAs for single-family housing, multifamily housing, and commercial buildings in a heating climate (Chicago) and a cooling climate (Phoenix). The scope of the LCCA, specifically, which pertained to single-family residential construction for these cities, focused on understanding the economics of typical ICF versus typical light-frame wood construction, and the associated cost of optimizing the ICF wall. For pairs of residential buildings, they compared wood frame and concrete structures; for the commercial buildings, they compared steel and concrete structures.

- The single and multifamily concrete residences analyzed in the study were shown to produce fewer greenhouse gas (GHG) emissions than wood frame residences over a 60-year service life. The biggest impact occurs in single-family homes, which represent 80% of residential energy consumption in the U.S.
- The concrete homes use 6% to 12% less energy than code-compliant wood frame construction.
- The concrete homes produce 5% to 8% fewer life cycle GHG emissions than wood frame homes and exceed code requirements.
- Increasing fly ash from 10% to 50% in the concrete house reduces impacts by 12% to 14%.
- Reducing the thickness of the concrete wall from 6 inches to 4 inches is cost-effective and reduces emissions over the lifetime of the wall.
- The commercial office building built with concrete produced slightly fewer GHG emissions than a steel structure over a 60-year service life.
- Because of thermal mass, the concrete structural frame results in a 2% energy savings during operation.

BUILDING RESILIENCE

In hazard-prone areas, hazard-induced maintenance costs can be significant over the lifetime of a building, sometimes even exceeding initial construction costs. CSHub researchers have developed a building life cycle cost analysis (LCCA) approach that incorporates operational costs associated with energy consumption and repairs due to damage from hazards.

- The CSHub's *break-even mitigation percent (BEMP)* calculation uses publicly available data about hazards and employs fragility curves to determine the impact of those hazards on a given structure. The BEMP offers building designers a way to evaluate opportunities to mitigate impacts from hazards and make better risk-informed decisions.
- CSHub case studies have demonstrated that investing in more hazard-resistant residential construction in locations that are prone to hazards is very cost-effective.



Researchers are also working to improve on traditional structural mechanics approaches used to evaluate building resilience. Typical approaches fail to account for the contribution of non-structural building elements (such as windows) which clearly impact building integrity. CSHub researchers have introduced a molecular dynamics approach in which the structural and non-structural elements of a building are modeled as a collection of mass points that carry information about the element weight and moving loads.

Additional information may be found at: cshub.mit.edu/buildings