Life Cycle Assessment (LCA) of Buildings
Concrete Sustainability Hub
Massachusetts Institute of Technology
Interim Report, December 2010

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Buildings are the largest greenhouse gas emission sector in the United States, representing 39% of nationwide CO_2 emissions, and the construction industry is a major contributor to economic activity. Because of the enormous environmental and economic impact of the building sector, there is a need to better understand the life cycle performance of residential and commercial buildings and to investigate methods for reducing their global warming potential (GWP). It is essential to consider the full life-cycle environmental performance of buildings, including the energy and resources required to construct, operate, and dispose of buildings over time.

We have undertaken a series of projects to quantify the full life cycle carbon emissions of buildings from manufacturing to disposal. Unlike the majority of previous life cycle assessment (LCA) studies on buildings, our work includes a detailed analysis of the operating, or use, phase of the life cycle. These ground-breaking LCA studies provide a better understanding of the full life cycle environmental impacts of commercial and residential buildings. In particular, this work demonstrates that there are measureable differences between existing materials and that concrete structures can provide potential greenhouse gas emission reductions compared to other construction materials over a typical life cycle of 75 years. To compare regional and climatic differences, all LCAs were carried out for two different cities in the United States: Chicago, representing a cold climate, and Phoenix, representing a hot, dry climate.

Conducting life cycle assessment of buildings requires a number of key steps. Firstly, data must be collected for the life cycle impacts of all of the materials involved, including resource extraction, processing, transportation, and construction. Secondly, an inventory of the quantity of the materials is used to estimate the total tonnage of construction materials required per functional unit. Next, the operating energy of the system must be calculated through energy simulations, and the impacts of the fuel consumed must be accounted for depending on the fuel mix and the geographical region. Finally, the material flows together with the operating use are assembled into an LCA model to determine the impacts throughout the life cycle.

Over the past year, we have conducted LCA studies of large commercial buildings, single-family residential buildings, and multi-family residential buildings. To maintain a common metric throughout, all LCA studies use Global Warming Potential (GWP) in which greenhouse gas emissions are represented as carbon dioxide equivalence, or CO_2e. This provides an essential starting point for both policy discussions as well as design discussions, and the results are of interest to a range of audiences. This research provides a new level of clarity for carbon accounting, which will help to develop more quantitative approaches to green construction in the future.

A selected review of research highlights is given below.

LCA of Residential Buildings

Principal Investigators: Les Norford and John Ochsendorf
Research Assistants: Dorothy Brown, Hannah Durschlag, Lori Ferriss, Kasia Fydrych, Omar Swei, Jason Tapia, Amanda Webb, Margaret Wildnauer

Focus: To investigate the potential energy savings in homes constructed with insulated concrete forms (ICF), we compare single-family and multi-family residential buildings in concrete with traditional wood frame construction. The goal is to demonstrate the potential energy savings due to the benefits of thermal mass, effective insulation, and reduced air infiltration, which are inherent to ICF construction.

Approach: For single family homes, we analyzed a 2,400 ft^2, two-story house and for multi-family homes we analyzed an L-shaped four-story structure with a typical floor plate area of 2,900 ft^2. Both the ICF and wood-framed single-family homes were designed according to ASHRAE 90.2-2007 "Energy Efficient Design of Low -Rise Residential Buildings." The air tightness of homes can have a major impact on the HVAC operating energy, and therefore we collected new data to give higher confidence in the air-infiltration values. New blower-door tests of ICF homes across the United States have demonstrated a tight construction system with corresponding advantages in reduced operating energy. We use these results in EnergyPlus simulations to accurately reflect the energy performance of ICF homes. The life cycle assessment of each building includes the embodied energy of the structural systems and building envelope, as well as the operating energy and end-of-life disposal for each building type.

Result Highlights: Over the past year, we have discovered the following:

> The advantages of higher R-value and lower thermal bridging enable ICF homes to deliver energy savings in heating, cooling, and ventilation compared to conventional wood-framed construction.
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> For residential buildings, insulated concrete form (ICF) construction can offer operational energy savings of 20% or more compared to code compliant wood-framed buildings in a cold climate such as Chicago. Because use-phase emissions are much larger than pre-use and end-of-life emissions, this same percentage is a reasonable estimate of life-time savings in carbon emissions associated with the use of ICFs. The energy savings can compensate for the initial carbon emissions of the concrete within a few years of operation.
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> More than 90% of the life cycle carbon emissions are due to the operation phase, with construction and end-of-life disposal accounting for less than 10% of the total emissions.
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> New blower-door testing has demonstrated that ICF homes achieve tight construction with minimal air infiltration, which improves the energy performance of residential construction.

Potential Impact: Our research on residential buildings provides significantly improved understanding of the performance of ICF homes, and will help to quantify the potential for future low-energy concrete homes in the United States. The findings from this work could lead to the building of prototype low-carbon homes in future housing developments.

Work Plan: We are continuing the research on residential buildings by:

Considering additional climatic zones in the United States;
Investigating the sensitivity of LCA results to uncertainties in the input data;
Exploring the potential energy savings due to passive technology in concrete homes;
Including other concrete construction systems, such as exposed concrete and CMU;
Quantifying the life cycle economic performance of concrete residential construction.

Project Conclusion: August 31, 2011

LCA of Commercial Buildings

Principal Investigators: Professors Leslie Norford and John Ochsendorf
Research Assistants: Libby Hsu and Andrea Love

Focus: To investigate the role of thermal mass in reducing the carbon emissions of large office buildings, we have focused on buildings with higher thermal mass (concrete) and lower thermal mass (steel). The goal is to quantify the inherent energy advantages of concrete due to thermal mass, and to identify potential areas for improvement in the life cycle emissions of commercial buildings.

Approach: We consider a steel building and a concrete building based on the large commercial office building model provided by the Department of Energy (DOE), which is a 12-story, approximately 500,000ft^2 rectangular office building (250ft by 165ft). The DOE Commercial Benchmark Models were developed from data gathered through the DOE Energy Information Agency's Commercial Buildings Energy Consumption Survey (CBECS), which collects data from over 5,500 buildings around the country on a quadrennial basis. To calculate the energy requirements of the two building designs in varying climates, we run simulations for one year of operation using EnergyPlus software. We updated the model to meet the requirements of the current ASHRAE energy standard, code, 90.1-2007. Both building facades consist of 40% glazing and 60% aluminum panels, and the buildings have VAV HVAC systems and concrete slab-on-grade foundations. Particular care was taken to model the thermal characteristics and material requirements of the walls; the former accounts for thermal bridging and the latter is needed for the LCA material estimates. Care was also taken to accurately model air infiltration, on the basis of leakage characteristics of individual components and whole-building leakage data published by the National Institute of Standards and Technology (NIST). Available data do not distinguish façade construction, which was not varied in our simulations. The results of the life cycle assessment are provided in equivalent carbon emissions per square foot for both initial embodied carbon and operating carbon for each year of operation. The sum carbon emissions over the building lifetime are then placed in context, demonstrating the percentage of total carbon emissions due to the choice of construction materials.

Result Highlights: In the first year, we have discovered the following:

Added thermal mass in conventional office buildings due to the use of concrete construction over steel construction provides annual energy savings in heating, cooling, and ventilation (HVAC) of 6% in Phoenix and 5% in Chicago, which can accumulate to provide carbon savings throughout the life cycle.

Based on ongoing laboratory work at MIT, there are even greater opportunities to activate the thermal mass of concrete in buildings, such as radiant floor systems and passive technologies, which can further reduce HVAC energy requirements.

The increased use of concrete envelope systems and the development of low-carbon structural concrete can have a major impact on lowering the life cycle carbon emissions of commercial buildings.

Potential Impact: This project provides improved understanding of the current environmental performance of concrete commercial buildings, and points the way toward dramatically improved buildings in the future. There is growing demand for construction systems which can help to reduce energy costs, and the current project provides much-needed guidance for designers and policy makers. As building design professionals and their clients struggle to meet the demands of high-performance buildings with low carbon emissions, concrete buildings can offer significant advantages over the full life cycle.

Work Plan: We are continuing the research on commercial office buildings by:

Incorporating a range of envelope assemblies;
Identifying building configurations which take advantage of the thermal mass properties of concrete;
Analyzing the impact of passive heating and cooling technologies;
Estimating the impact of heat-island effect on building energy consumption;
Investigating the sensitivity of LCA results to uncertainties in the input data; and
Considering additional climatic zones in the United States.

Project Conclusion: August 31, 2011

Summary

Life cycle assessment is essential for understanding the environmental performance of buildings. It is vital to include all phases of the life cycle of buildings, with a particular focus on the operating energy demands of buildings, in order to quantify the greenhouse gas implications of construction systems. Our work has demonstrated that there are measureable differences between alternative construction systems, and that the thermal mass of concrete can provide energy savings over a life cycle of 75 years. Life cycle assessment provides a rigorous means of testing the relative environmental merits of various design alternatives, and demonstrates that concrete buildings can offer reductions in carbon emissions compared to alternative construction materials.