Olin College of Engineering
Sustainable Design Lab

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A Thermal Design Strategy for Net-Zero High-Glazing Buildings in Temperate Climates

Architecture accounts for a large percentage of our energy footprint, with commercial and residential buildings consuming 40% of the total energy United States in 2013. In particular, heating and cooling accounts for one of the largest energy loads in most buildings. Green building design has the potential to address this challenge and green building standards have started to appear that are effective at promoting its use. Popular standards include the Living Building Challenge (LBC) certification program, the Passivhaus energy standard, and the Leadership in Energy and Environmental Design (LEED) rating system. This research focuses on identifying a low cost heating and cooling strategy to meet these standards for buildings with higher glazing percentages in temperate climates.

What is the Living Lab?

The Living Lab will be a 1,200 square foot self-sufficient and beautiful building with dedicated greenhouse and project space, and demonstrating true sustainability as defined by the Living Building Challenge.

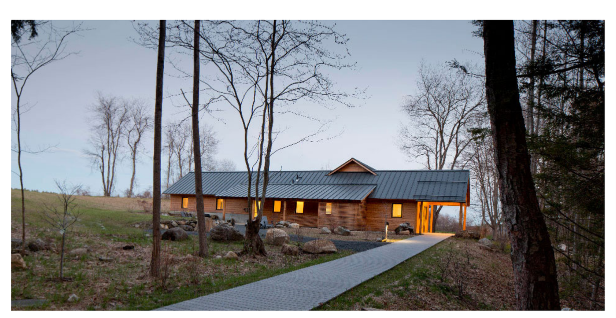
Why?

We seek to redefine engineering education to incorporate sustainability in an integral way. Olin is committed to developing new approaches and serving as a model for others to promote change.

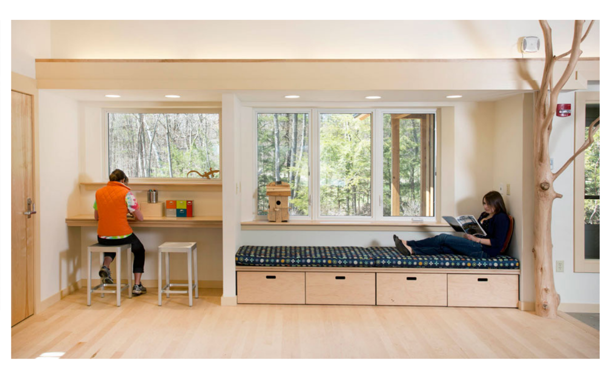
The Living Lab project will incorporate deep environmental and sustainability practice into engineering curricula, and help Olin to gain experience with a small, net-zero pilot building to prepare for a more substantial green building on campus.

LBC Certification

The Living Building Challenge is a rigorous green building certification process that requires a project to meet all set criteria, and certification is based upon 1-year occupancy performance data and not anticipated or modeled results. There are seven petals and a total of 20 imperatives associated with these petals.

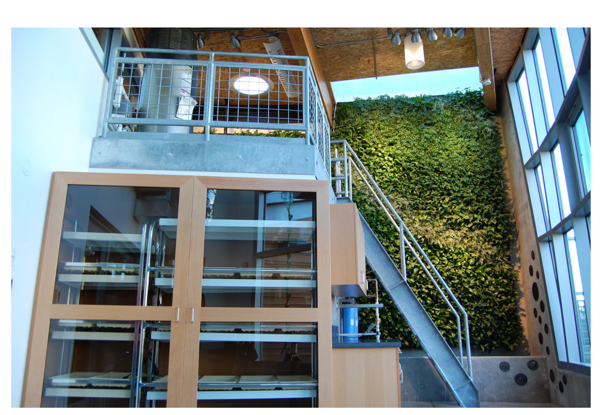


The Smith Bechtel Environmental Classroom serves as proof of concept for the Living Lab at Olin.



The interior of the Smith building is filled with warm woods and elements brought in from outside.

The Betschi School created a very educational space within their LBC buidling



The Bertschi building uses a bio wall to treat the site's gray water.

Hawaii Prep Academy takes advantage of the region's sun with their solar panel system

The Energy Lab serves as an educational facility, giving high school students the opportunity to explore renewable energy.

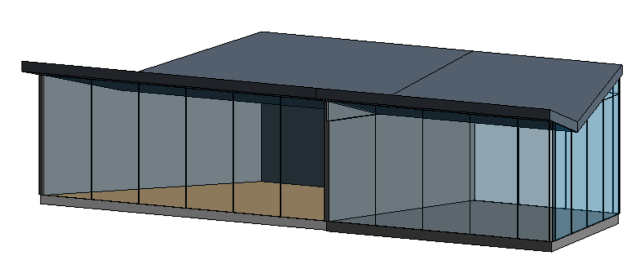
Introduction | Background

Large heating and cooling loads can be addressed through seasonal thermal energy storage (STES) of solar energy or with the use of a geothermal heat pump (GHP). The choice between the two systems may be determined by the particular site conditions, occupancy needs, and local costs. The total cost of either system (STES or GHP) can easily climb without careful consideration of the overall system requirements and design options. For example, a cost reduction may be possible by sizing the main system for base load and using a subsystem for peak loads. Similarly, the space may be divided zonally to match a more limited capacity system to occupants needs, if a spatial configuration of needs can be arranged. The objective of this research is to investigate how high glazing levels in net zero energy homes influence design choices and total cost.

Monthly Heating Load

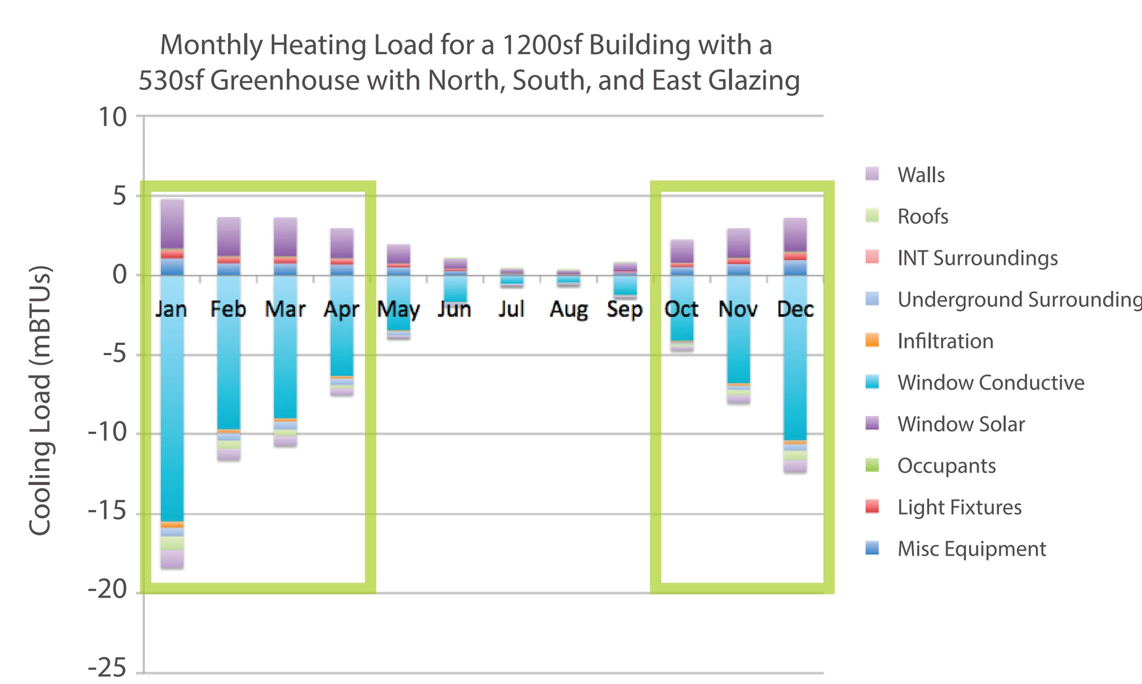
Several Revit building configurations were created with different greenhouse to project space ratios and greenhouse glazing percentages. These were analyzed for peak and monthly heating and cooling loads for the purpose of designing heating and cooling systems for this space. For our climate, we decided it was reasonable to assume a building configuration with a moderately-sized greenhouse that contains north, south, and east glazing (shown below). Below are the monthly average heating and cooling loads for this configuration.

Configuration



44% greenhouse, Full South, North, and East Greenhouse Glazing

Monthly Average Heating Load



Cumulative Winter Months Heating Load

Assuming the building needs to be heated in October-April, the winter months heating load is ~40 MMBtus. This energy load informs the size of the storage system for the HVAC design modeling.

Calculating the Size of the Storage System

Using basic heat transfer equations, we were able to use our heating load of 40 million BTUs and specifications from a Mitsubishi Mr. Slim P-Series H2i air to air heat pump data sheet to determine the volume of heat storage we would need. We calculated that we would need 2600 m^3 of soil in order to store enough heat to heat our building in the winter.

Acknowledgments

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References

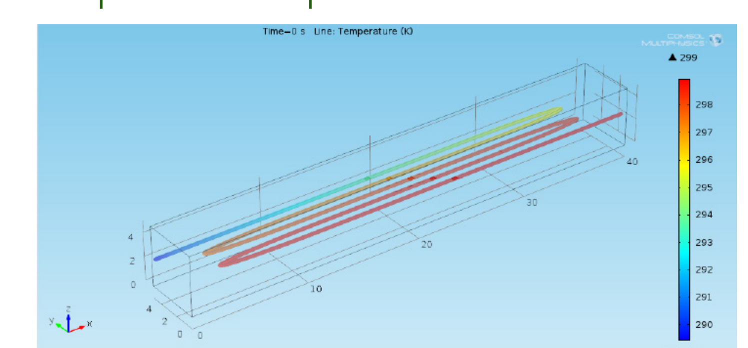
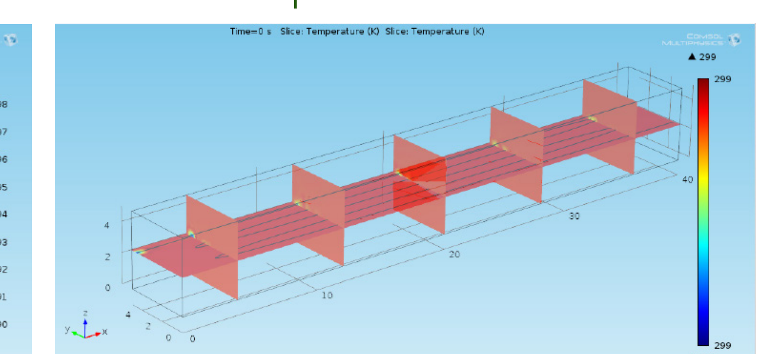
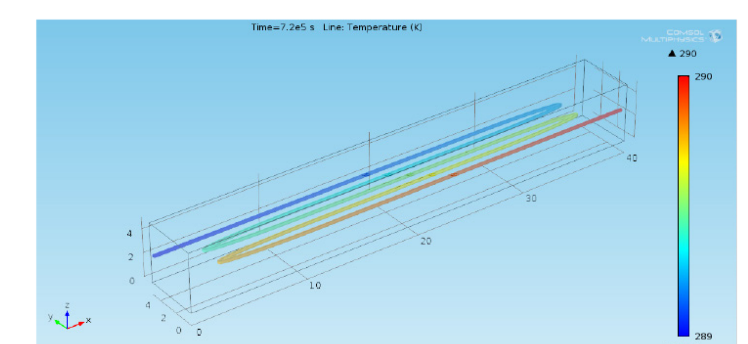
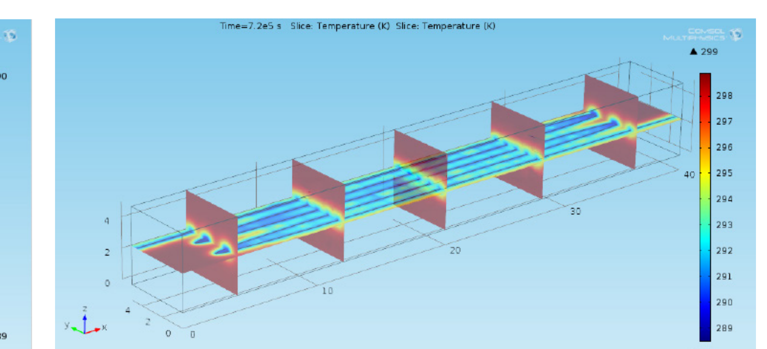
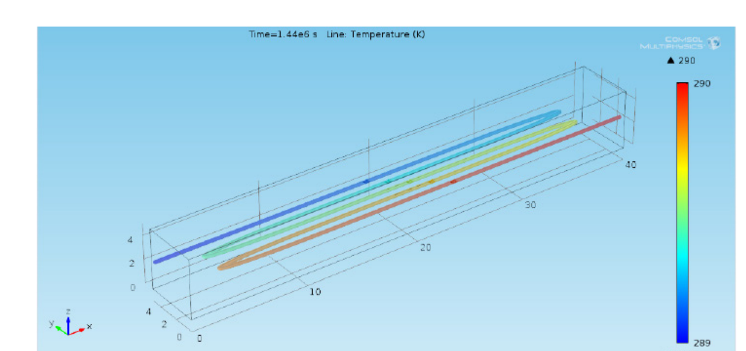
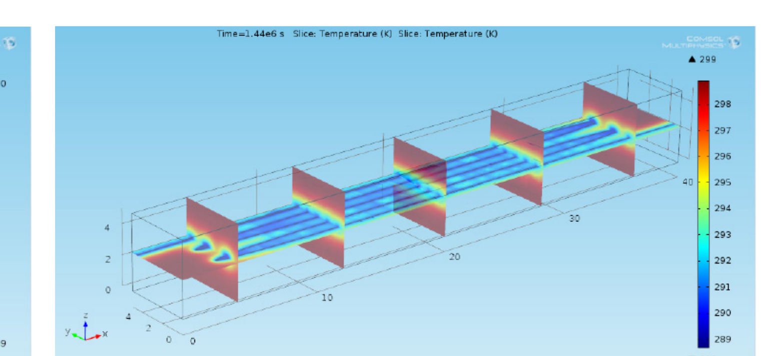
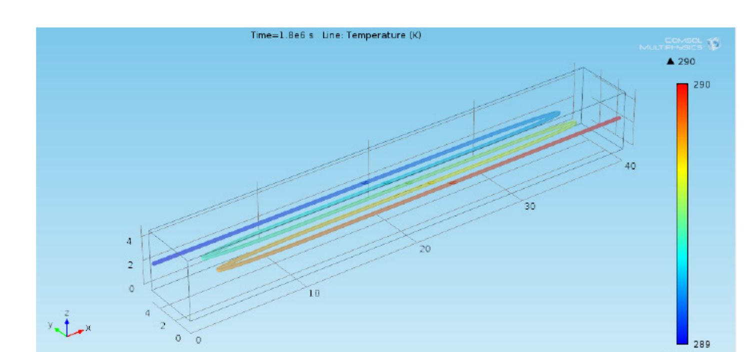
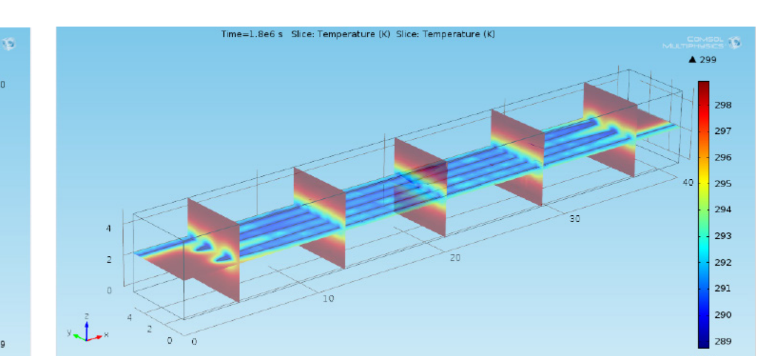
[1] Advanced Products Division, HVAC. "Mitsubishi Hyper-Heating Inverter." Mitsubishi. Mitsubishi, 2008. Web. Oct. 2014.
Faninger, Gerhard. "Thermal Energy Storage." (n.d.): n. pag. Web. Oct. 2014.
"Living Building Challenge." The Living Building Challenge. The Living Future, n.d. Web. Oct. 2014.

Heating and Cooling System Designs using COMSOL Multiphysics

The three main components we wanted to explore were the collector, the storage system, and the working fluid. From this we identified three possible HVAC configurations to model and ultimately determine the feasibility of heating and cooling the building. Air to air heat pumps work by intaking outside air, heating it up, and exhausting air outisde the building. They can be augmented with a ground heat exchanger to raise the coefficient of performance (COP).

The Model

The model below is low temperature system where the storage system is soil, the working fluid is air, and the collector is the output of the air to air heat exchanger. We modeled a loop of pipes in a soil block in COMSOL. As this was a heating scenario, the initial soil temperature was set to 25.7 C (78.26 F), and the temperature of the air flowing through the pipes was set at 16.3 C (61.34 F).

Pipe Temperature	Soil Temperature	
		At time = 0, soil block is set at 25.7 C (78.26 F) and the pipes are the initial temperature of the soil. Cooler air is just beginning to be pumped into the soil, but the exit air is the same temperature as the soil.
		At time = 200 hours , the soil begins to lose heat as it is carried out by the cooler pipe. The exit air is now only 1 C above the entrance air.
		At time = 400 hours, heat continues to be lost by the soil, and the temperature of the pipe is more or less the same as the previous time step.
		At time = 500 hours, the soil continues to lose heat, but the pipes have hit an equilibrium temperature.

Conclusions and Future Work

Greenhouses, and buildings with large attached greenhouse systems, have much higher heating loads than can be expected in well-insulated green buildings. Designing a low-energy HVAC system then becomes a challenge. Given our building configuration, we found a winter-months heating load of 40 MMBtu. Using the heat equation, we sized a 2,600 m^3 insulated soil block to meet this heating load.

Next steps will be to compare soil and water as the storage system, and compare these configurations using COMSOL Multiphysics.