A GREEN BUILDING MODEL KIT FOR ENGINEERING DESIGN

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Precollege engineering education is increasingly recognized as an indispensable part of STEM education. The National Research Council's conceptual framework for new science education standards has concluded that engineering should be incorporated into American science education [1]. For years to come, thousands of science teachers will be charged with teaching engineering—a subject that could be new to many. At the center of this challenge is the question of how to teach engineering design.

Design is as important to engineering education as inquiry to science education. It is through the iterative cycle of designing and improving a system that students become engaged in engineering practices and learn engineering principles. A classroom engineering project without a design challenge for students to make a product is incomplete at best.

The variety of engineering systems precollege students can realistically design, build, and test in classrooms is, however, limited by the constraints of time, resources, and student preparedness. At present, robotics and computer programming are perhaps the most frequently adopted student projects. More options will be needed to cover a wider spectrum of science in order to allow for broader and deeper infusion of engineering. Situated in the context of sustainability and centered on the concept of energy, our *Green Building Model Kit* adds a new member to the family of engineering design projects.

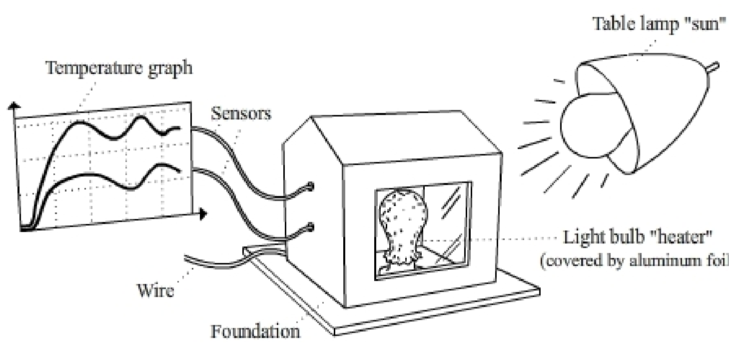

Figure 1. The Green Building Model Kit at work: A simple model house can be heated by a light bulb inside and an adjustable table lamp outside, simulating a furnace and the sun, respectively; Temperature sensors can be used to monitor and investigate the temperature distribution inside the house and heat flow across the building envelope.

Tools and materials

- *Computer*
- *Logger Lite*
- *Vernier temperature sensors*
- *Ruler and protractor*
- *Pencils*
- *Scissors*
- *Utility cutter*
- *Cardstock*
- *Transparency film*
- *Foamcore board*
- *Clear tape*
- *Aluminum foil*
- *40 W light bulb in a socket with an inline switch as the "heater"*
- *300 W light bulb in a gooseneck fixture as the "sun"*
- *Electric fan to create wind*
- *Energy3D (CAD tool)*
- *Energy2D (CFD tool)*

An Engineering Kit for Building "Green" Model Houses

The *Green Building Model Kit* was developed to support our *Engineering Energy Efficiency* (EEE) curriculum for high school engineering. The EEE curriculum bridges science and engineering by combining scientific inquiry and engineering design in a hands-on, project-based, and technology-enhanced learning process lasting 10-16 class periods. Through laboratory experiments and computer simulations, students will be guided to learn the science behind energy flow and usage in houses. Having acquired with the basic knowledge and skills necessary to undertake more sophisticated tasks, they then team up to design, construct, test, and improve a model house step by step using the kit, with the goal of maximizing its energy efficiency. The EEE curriculum has been designed, tested, and improved through several rounds of field tests involving more than 300 high school students in Massachusetts. The majority of students responded in surveys that it was easy to create a model house and measure its energy performance using the kit.

Download links:

- *Engineering Energy Efficiency Student Workbook*: http://energy.concord.org/EEE-Workbook.pdf
- *Energy3D*: http://energy.concord.org/energy3d
- *Energy2D*: http://energy.concord.org/energy2d

The *Green Building Model Kit* uses inexpensive tools and materials (see the list), making it widely implementable. Several other considerations have contributed to its educational applicability. For example, for an experiment to be interactive and useful in the classroom, students must be able to conduct multiple runs in a limited time. We found a 40W light bulb is a good simulator of a furnace—it has low heat capacity and can reach a high temperature rapidly, which allows it to warm up a model house in a short time. Wrapped with aluminum foil that has low emissivity, the light energy it radiates heats the foil and the air around it, mimicking the heat transfer through air circulation from a furnace. We have also developed two free software tools for enhancing the kit. *Energy3D* is an educational computer-aided design (CAD) tool that can be easily used to sketch up buildings and print them out for scale-up and assembly using constructional materials such as cardstock and foam board. *Energy2D* is an educational computational fluid dynamics (CFD) tool that provides interactive simulations for studying basic concepts in thermodynamics and heat transfer such as heat capacity, conduction, convection, and radiation.

"I would have to say the part of the Engineering Energy Efficiency Project I enjoyed the most was seeing the drastic change in temperature after minor modifications were made."

---Student, Arlington High School

The *Green Building Model Kit* supports two design phases. In the first phase, students design and build their own model houses using cardstock. In the second phase, they design and add energy-efficiency measures to their model houses. The kit has considerable flexibility that allows for different implementations in the classroom. For example, if phase one takes longer than time would permit, teachers may choose to skip it by giving students a cardstock cutout for making a "standard" model house (see the model house in Figure 1). In this case, students will be immediately focused on “green designs” with a clear goal of improving the energy efficiency of the “standard” model house, which provides an exact same starting point and constraints for every team. The “green” design tasks include insulation, air tightness, and passive solar units. Each of these tasks is an application of one or more concepts in power, energy, and heat transfer. For example, insulation reduces energy loss through heat conduction. In designing insulation for a model house, students will add foam boards as the insulation materials to the cardstock house and determine how many layers are cost-effective based on measuring heat conduction rate across different layers of insulation. Unlike insulation and air sealing that achieve energy efficiency by cutting heat loss, passive solar units save energy cost by harnessing energy from the sun. The next section will show how to design passive solar units for a model house.

ENRICHING ENGINEERING DESIGN

“Insulation is sexy” is President Obama’s words to convince the green building industry that insulation is the cheapest way to save energy [2]. He was responding to an opinion held by some industry folks that insulation was not “glamorous” enough. Part of that opinion, however, is not entirely untrue when it comes to education, because insulation seems to lack the breadth and depth for student explorations. For many students, insulation is an intuitive idea, just like putting on more clothes in a chilly day. The same may be true for air sealing. Well-designed educational goals and learning progression necessitate that students insulate and seal their model houses and confirm their effects on saving energy, but a good engineering project should be more challenging. The richness of design is the key to successful engineering projects, as the vast success of robotics and programming have demonstrated.

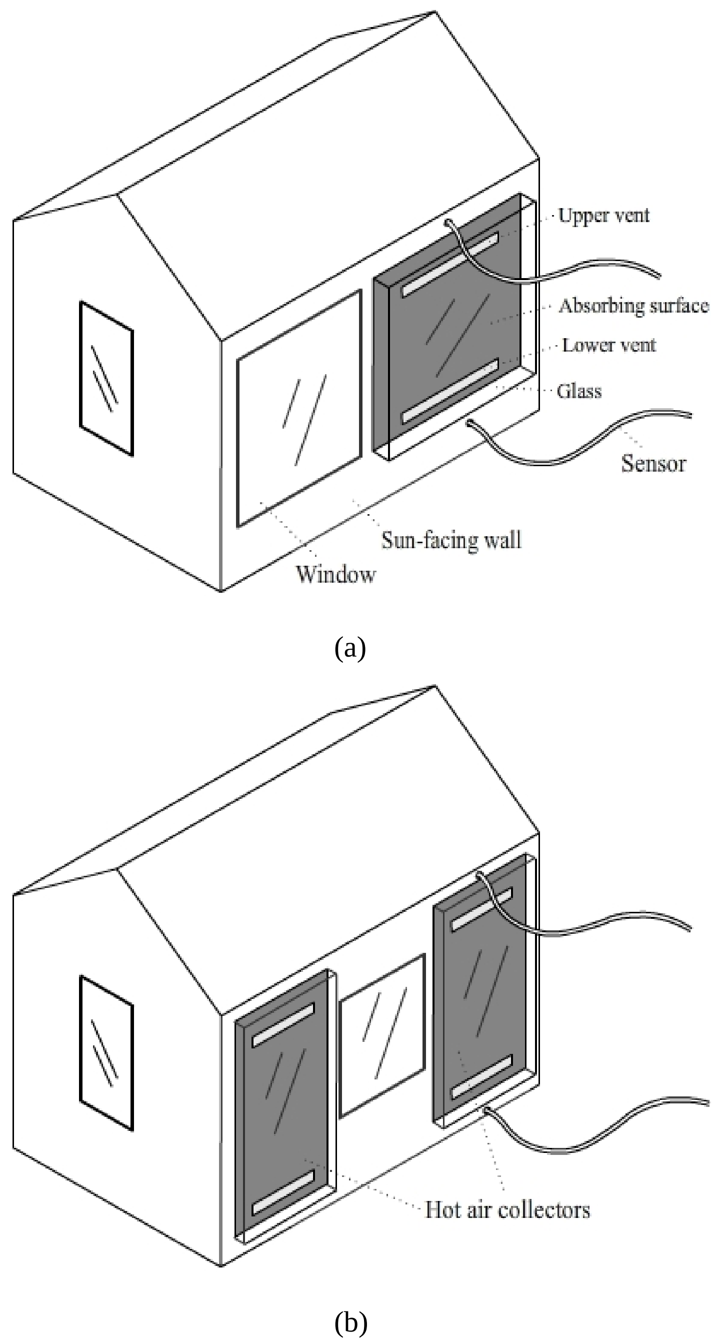

Figure 2. (a) A side-by-side layout of an HAC and a window. (b) An alternative layout of two HACs and a window, with the window in the middle. In both designs, the idea is to maximize the use of the sun-facing wall for collecting solar energy.

Passive solar design with our *Green Building Model Kit* offers a proactive approach for harvesting solar energy that would be novel to many students. This engineering design task allows students to create many structures of different shapes that may or may not have an effect of supplemental heating. Passive solar architecture studies the interactions between a building and solar radiation, with the goal to find an optimal way to collect as much solar energy as possible for heating the building in winter. These interactions can be well modeled using our kit. In the following, we will use the design of a hot air collector as an example to show this.

A hot air collector (HAC) consists of a light-absorbing dark surface, an air space enclosed by glass, and two vents (Figure 2a). Sunlight shines through the glass and heats up the dark surface. An HAC can give the absorbed heat to the house in two ways. First, the heat conducts into the wall behind the surface and is then radiated into the house. Second, the heat warms up the air near the surface. The hot air rises and enters the house through the upper vent, which creates an updraft force that draws the cooler air at the bottom of the house into the air space through the lower vent. The air in the house can, therefore, circulate through the HAC and get heated. This circulation effect is sometimes called thermosiphon.

HAC units are usually mounted to the sun-facing wall, which also has windows to let light in. If you think of this design challenge as a task to "capture the energy from the sun as much as possible for the house," it is really a problem about the optimal use of the sun-facing wall surface. A house has only this much of precious surface area exposed to the sun, so what is the best way of using it?

This example is fascinating because it involves the synthesis of the knowledge about all three mechanisms of heat transfer and it is not difficult for students to make an HAC unit and add it to a model house. And there are a variety of designs that they can try, test, and invent. Figure 2 shows two possible layouts of HACs and windows. Note that students should always test how well their designs work in order to make improvements. The *Green Building Model Kit* includes temperature sensors for verifying if heat flows in the anticipated courses as designed. For the design shown in Figure 2a, students can compare the energy gains and losses through a window and a HAC. Figure 2b shows an alternative design with two HAC units when the window

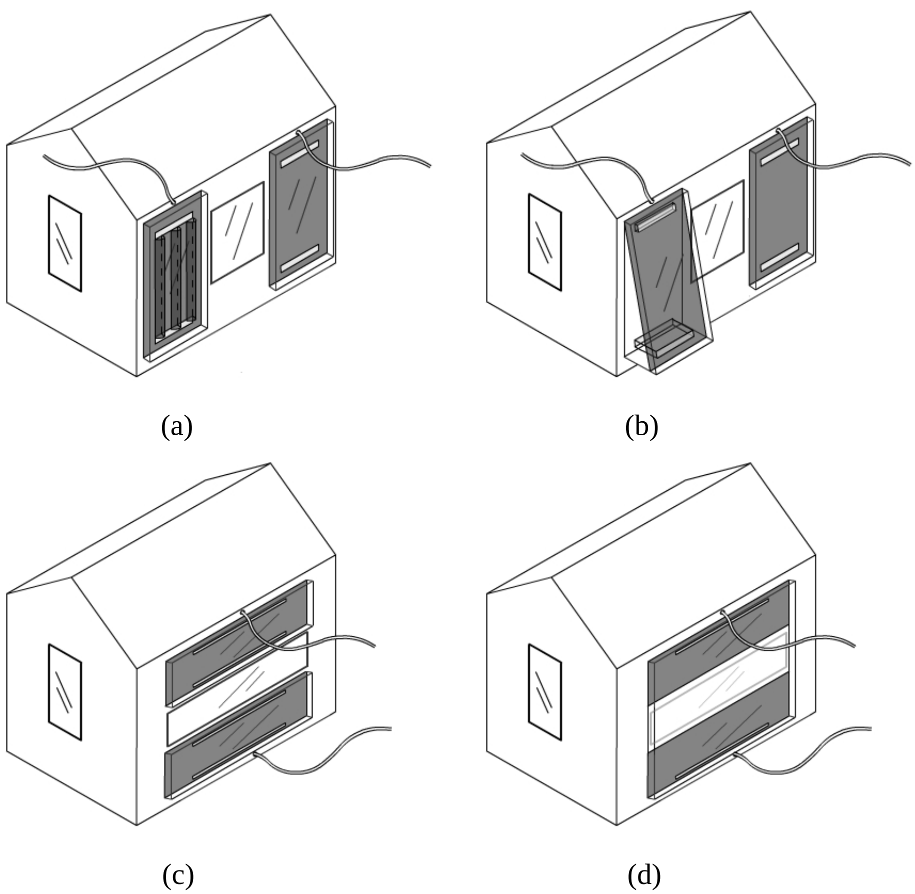

Figure 3. Four design variations of HAC units.

has to be in the middle of the wall.

Figure 3 shows four more variations. Figure 3a illustrates an idea of corrugating the absorbing surface to enlarge the interface for heat exchange between the air and the surface. But the design does not increase solar input. Figure 3b shows a design in which the absorbing surface slants to receive more sunlight, similar to a solar hot water collector. As an improvement of the design shown in Figure3c that aligns two HACs and a window vertically, Figure 3d combines the benefits of windows and HACs. It is basically a large HAC unit with the middle part replaced by a window. Sunlight still can shine into the house through the window. As the HAC unit is tall, the convective heat flow into the house will be more significant.

These examples about HACs demonstrate the ability of the *Green Building Model Kit* to support creative and inventive engineering design. In addition, the kit allows students to design many variations of sunspaces such as sunrooms, solariums, and greenhouses. Some of these capabilities will be added to our design software *Energy3D* to enable the exploration and evaluation of various designs before making real products. All these design capacities are critically important to engineering education, as they hold the promise of reducing the tendency of “cookbook” design in the classroom. By empowering students to think and design in many different ways, engineering education will blossom.

REFERENCES:

[1] National Research Council, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington DC: The National Academies, 2011.

[2] L. A. Times, "Obama calls insulation 'sexy'," in *The Los Angeles Times* Los Angeles, 2009.