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A Race for the Sun

Lauren Stencel

Photo taken by Donald Foster

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Every few years, college teams from around the world meet at the National Mall, which stretches from the White House to the National Monument in Washington, D.C., to compete in a 21-day decathlon. But this is not a usual decathlon. In the National Solar Decathlon, each team builds a home that must function independently—not connected to electricity, water, or waste lines—for eleven whole days.

My name is Lauren Stencel, and I am a solar decathlete. My team is from the University of Massachusetts, Dartmouth, where I study chemistry. Last year, I read about an opportunity to join the school's solar decathlon team and I couldn't pass it up. I've always cared about the environment. When I was growing up, my mom was a big environmentalist and taught me about the importance of recycling and conservation.

Our team plans to donate our home to Habitat for Humanity, an organization that provides homes at much-reduced prices to people who need them.

This project is a lot of work. We're raising all of the money to pay for the costs of building the home ourselves—about $95,000. And, of course, we're doing most of the design and construction as well. The team members take classes in energy-efficient technology and architecture, but we also devote plenty of time to building the house. We're constructing a small-scale test home on campus. In my first day building the house, I hit my thumb with a hammer, got a massive splinter in my arm, and I went home with blisters on both hands. But I don't mind the hard work or the splinters. I believe that what we're doing is important. Not only are we providing a home for someone who needs it, but we're also learning about technologies that can help solve some of the serious problems we face today. When I was in high school, I never imagined that, as a college student, I could work on projects that had such a positive impact.


Courtesy of Stefano Paltera/Solar Decathlon

As we design our home, we have two different sets of criteria: Not only does our house have to function on the National Mall, it also must eventually function as a family's home. For this reason, we are planning to build the house on my college campus. Then we'll move the house to the competition site on a big flatbed truck. After the competition is over, we'll take the home to its permanent location in a Washington, D.C., neighborhood and get it ready for the family to move in.

The Comfort Zone

All systems of a house are important, but a reliable climate-control system is absolutely critical for getting through a cold winter or a hot summer. The primary function of a house, after all, is to shelter inhabitants from the elements. In Washington, D.C., the winters can be well below freezing, and the summers run hot and humid.

Fortunately, there are many ways to design a house to take advantage of the sun for heating and cooling. Ideally, an architect should put large windows on the home, positioned to face due south. That way the sun can shine through the windows and warm up the air inside the house. Of course, if the home is located in the southern hemisphere, the windows must be oriented to face north to collect the most sunlight.

The sun can also warm the thermal mass of the home—concrete or flagstone floors or walls. Then, at night when it's chilly, the floors or walls will release stored energy to the home, providing warmth. This is called ***passive solar heating.***

In the summer, the windows have overhangs so that they block the midday sunlight, when the sun is highest in the sky. This solar shielding helps to keep the air inside the home comfortably cool. The house also relies on good insulation to keep hot air out. Remember that an insulator is a material that resists the flow of energy. When it's warm outdoors, the insulation keeps energy outside the home from creeping in.

We're building our home out of a very effective insulator. It's basically a thick slab of polystyrene—the material used in disposable coffee cups—sandwiched between two pieces of ply board. A company in Michigan makes the boards in 24 × 8–foot panels. We're having the panels cut to meet the dimensions of the house. The panels will hold up the ceiling of the one-story home. We're using the panels to make the walls, the ceilings, and the floors. Polystyrene has a very high R-value, which is a measure of how well a material resists the flow of energy, so it will keep the energy outside of the home in the summer and inside in the winter.

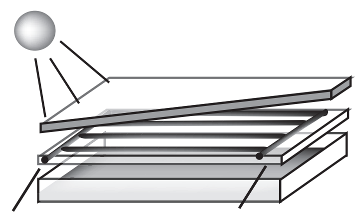
Our home will face due south in its permanent location. It will include large windows on the front of the home to collect the most sunlight. But we're installing another heating system that will work regardless of how the house is positioned. This ***active solar heating*** system uses pumps to circulate a "working fluid"—usually water or antifreeze—through collectors and into storage tanks. The collectors, which are located on the roof, use energy from the sun to warm up the fluid, and the storage tanks hold the fluid until it is used to warm up the home.

A common type of solar collector is a flat, rectangular box that is about one meter by two meters long with a dark surface that absorbs energy from the sunlight and becomes very hot. The energy is transferred to pipes that coil through the collector. The pipes then transfer energy to a fluid flowing through them. The hot fluid flows to a highly insulated tank, which stores the hot fluid until it is used to heat the home. Insulation prevents the heat from escaping from the collector.

Passive solar heating refers to designing a home to take advantage of sunlight for heating.

In a passive solar heating system, sunlight shines through large south-facing windows onto a concrete or ceramic floor, heating it up.

Active solar heating systems use pumps to circulate a fluid that has been heated by the sun.



The collector has a clear window over the top, which allows the sun's rays to reach the collector but prevents the wind from cooling it. The plate and pipes in the collector are usually made of copper because copper has high thermal conductivity, which means that it transmits energy well.

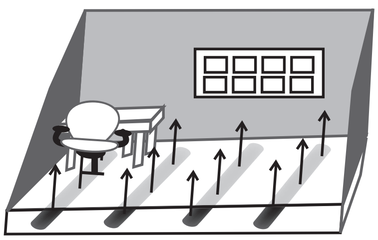
After we have all this hot water in the storage tanks, we need to transfer the energy it contains into the living space of our home. Most homes have radiators through which hot water from the furnace circulates. The radiators become hot and, in turn, they transfer energy to the room air, heating up the room.

We could use this approach, and some solar homes do, but in our house, we're planning to embed radiator pipes in the floor. The pipes will weave back and forth in order to cover the entire floor, just under the surface. When hot water circulates through these pipes, energy is transferred to the floor. The floor then transfers energy to the air above it.

This combination of passive and active solar systems will keep the home at a comfortable temperature during the fall competition, when temperatures will be dropping. But the heating system will also work very well all year long, once the home has reached its final destination. Not only will the system keep the home warm in the winter and cool in the summer, it will also provide hot water for showers, laundry, and dishes.

Measuring Energy

How can we be sure that our solar collectors can transfer enough energy to the home to keep it warm enough in the winter? To answer that question, I need to explain how energy is measured.



In the metric system, the unit for energy is the Joule. It takes 4.186 Joules to raise the temperature of one gram of water by one degree Celsius. The British and the Americans have their own unit for energy, the British Thermal Unit, or BTU. A BTU is the amount of energy required to raise the temperature of one pound of water by one degree Fahrenheit (°F). Of course, it's possible to convert between Joules and BTUs. One BTU is equal to 1,055 Joules. Most American engineers use BTUs when talking about heating systems.

As you know, fuels such as coal, oil, and natural gas store energy. These fuels release the stored energy when burned. In the table below, you can see the different energy content in BTUs for some common heating fuels.

Fuel Source	**Energy Content (BTUs)**
Heating Oil	140,000/gallon
Gasoline	124,000/gallon
Wood (air-dried)	8,000/pound
Coal	24,000,000/ton

When these fuels are burned, they release the stored energy. This energy is transferred by the heating system to the room air. Of course, heating systems are not perfectly efficient. You've probably heard and even used the word "efficiency" before, but what does it really mean? ***Efficiency*** is the comparison of energy inputs with respect to the useful outputs of a system. In an ideal system that is 100 percent efficient, the useful outputs are equal to the inputs.

But no system is 100 percent efficient. Not all of the energy contained in one gallon of heating oil—140,000 BTUs—is transferred to the room air. A certain amount of energy released from the heating oil will be transferred to places where it's not useful, such as the air around the boiler, the air around the pipes, the pipes, and the pumps. And it's possible that not all of the oil will burn completely.

To calculate the percent efficiency of this system, you need to determine the ratio of the useful output to the ideal output (which is equal to the input) and then multiply by 100. In a typical heating system, about 112,000 BTUs make it to the room air when a gallon of oil is burned.

Efficiency
is the comparison of energy input with respect to useful energy output of a system.

↑ vs. ↓

In an ideal system that is 100 percent efficient, the useful output are equal to the input.

↑ = ↓

No system is 100 percent efficient!

$$\textbf{\textit{Efficiency}}\ (\eta) = \frac{useful\ output}{inputs}$$

Useful output: 112,000 BTUs
Input: 140,000 BTUs

$$\%\textbf{\textit{Efficiency}}\ (\eta) = \frac{useful\ output}{inputs} \times 100$$

$$\%\textbf{\textit{Efficiency}}\ (\eta) = \frac{112,000\ BTUs}{140,000\ BTUs} \times 100$$

$$\%\textbf{\textit{Efficiency}}\ (\eta) = 80$$

So a typical oil heating system is 80 percent efficient.

Is Solar Enough?

Will our "solar" systems keep our house warm enough? On a typical winter day, when temperatures hover around 30 degrees Fahrenheit, we may want the home to be about 40 degrees warmer than the outside temperature. Based on the volume of our home, we can calculate the amount of energy it will take to raise the temperature of that volume of air by 40 degrees. We estimate that it will take between 200,000 and 300,000 BTUs to do that.

Of course, we won't have to pump this many BTUs into the home each and every day. Most days we'll just have to make up for any energy that escapes the building through the walls, ceiling, or open doors and windows. Based on the insulation we've chosen and how air tight the house is, we estimate that we'll need to add about 45,000–50,000 BTUs of energy to the house every day to maintain a temperature that is 40 degrees higher than the outside air.

Our solar heating system can supply that amount of energy with no problem. On a sunny day, our solar collectors can heat water circulating through the system from 80 to 200 degrees Fahrenheit, a 120-degree difference. The piping-hot water is stored in the insulated 150-gallon tank. The fluid in the tank weighs about 2,500 pounds. Now, we know that when the temperature of one pound of water is increased by one degree F, the water has stored one BTU. After all, that's the definition of a BTU! When every pound of water in the tank has been heated 120 degrees, that gives us a total of 300,000 BTUs stored in the tank.

There will be some losses when that energy is transferred from the water through the floor pipes and into the room air. If we tried to transfer all of the energy in the water to the room air, only about 85 percent—or 255,000 BTUs—would actually make it. But that's still a lot more than we would need on a typical winter day. The tank can keep any unused water hot for a long time. So if we have a long stretch of gray days, we should still have plenty of energy to heat the home.

Powering Up

Our home will need electric power so that its users can run their appliances, turn on lights, and plug in a computer or a stereo. During the day, large south-facing windows and skylights will maximize daylight so that the inhabitants will not need to turn on as many lights. But, of course, they'll need electric power if they want to see at night.

To solve this problem, we're equipping our home with photovoltaic (PV) panels. PV panels use the energy of the sun to generate electricity. The panels will be located on the roof next to the solar collectors. The PV panels should provide all of the power that the home's residents will need. During the day, the panels will generate more than enough electrical energy. The extra electricity will be stored in a battery. At night, the battery will be used to power the home.

Courtesy of Stefano Paltera/Solar Decathlon

Photovoltaic panels on a rooftop use energy from the sun to generate electricity.

Down the Pipes

As soon as our home is in its final location, we'll connect it to the local municipality's water and sewerage system. But for the competition we must find another way to get clean water to the home and remove dirty water, or "gray water," as it's often called.

We will provide a 300-gallon tank of purified water that will act like a "water tower," pushing clean water to the home's taps. The tank will be on the ground floor, so we can't take advantage of gravity, which most reservoirs and water towers use to supply water to cities and towns. Instead, our tank will be pressurized. An electric pump, powered by the PV panels, will add air to the tank, which will compress the air space above the water and push the water through the pipes of the home.

We're connecting our home's drains, toilet, and laundry machine to another 300-gallon tank. This tank will be used to hold gray water. We don't plan to use toilets in the home during the competition. The people who empty the gray water tanks at the end of each day wouldn't appreciate that very much. But we do have to prove that our toilets are operational. We also have to be able to use the sinks, the washing machine, and then show that the wastewater drains out of our home. As soon as the competition is finished and our home is in its permanent position, we'll only need to hook up the sewerage, tap water, and electric connections.

Courtesy of Stefano Paltera/Solar Decathlon

Solar house built during the Solar Decathlon

Look and Feel

How our house will look and feel is every bit as important as how it will function. No matter how energy-efficient our home is, its residents won't like living there if it isn't attractive and comfortable. While we've identified designs for our heating system, our electrical power system, and our water systems, we're only in the initial stages of developing the floor plan of the home.

Courtesy of Stefano Paltera/Solar Decathlon

That's why we're using a professional architecture firm called Clearwater Architects to provide advice as we design the house. The team has split into groups and brainstormed the most important features for a comfortable and attractive home. We've come up with a list of features that we'd like to incorporate in our ideal design. Our ideas include an eat-in kitchen, hardwood flooring in all rooms except the kitchen and bathroom, plenty of natural light (important for day lighting), and a nice, open layout. Of course, we may not be able to include all of these features in our design. This depends on cost and available materials.

Communicating Our Solution

Last but not least, as part of the competition we will be judged on how well we communicate our solution. We've already built a website, which describes our process and what we've learned in more detail. We've written articles for our campus newspaper, contacted the media about our design, and shared our story with you through this textbook. We're also planning to give tours of the house on the National Mall. Communicating our solution is ongoing work. I'm constantly talking with classmates, friends, professors, and parents about what we're doing in hopes of raising public awareness of energy-efficient building design.

The "winner" of the solar decathlon gets a trophy for the best overall design. But, to be honest, I don't think anyone on the team really cares whether we win the trophy or not. We are all much more focused on using energy-efficient technologies to build a high-quality home for someone who needs it. In the meantime, we're all learning a tremendous amount about what it takes to build a home. Everyone who hears about our work, like you, is learning from our experience. So we all win. Now, that's the kind of competition I like!

What's the Story?

1. What are the two different sets of constraints that Lauren's team must consider when designing the house?

2. What is a passive solar heating system? Why is it called "passive"?

3. How does the team plan to communicate their solution?

Designing with Math and Science

4. Draw an energy diagram of the active solar heating system that includes the following: collector, pipes, sun, fluid, floor, and room air.

5. What's a BTU?

Connecting the Dots

6. Where should a thermal mass of a structure be located in order for passive solar heating to work well?

What Do You Think?

7. You've been hired by an architecture firm as an energy efficiency specialist. As a first assignment, the firm has asked you to make a presentation in which you describe the attributes of an energy-efficient building. List the attributes having to do with the location, the architectural design, the construction material, and the heating system of the building.

8. Look at the table of common fuel sources shown in Lauren's story. Do you think these are equivalent quantities? How does this affect how someone might support using one type of fuel versus another? Work with a partner to calculate how many pounds of wood would need to be burned to equal the energy content in a ton of coal or a gallon of heating oil.