15

Building Green

Chris Benedict

Photo taken by Benjamin T. Erwin

Key Concepts
from Previous Chapters

- 7 Systems
- 11 Loads
- 11 Construction Materials—Characteristics

Winters get very cold in New York City. But, obviously, that doesn't keep people from living here. Technology allows people to live in some pretty extreme climates. Our structures protect us from the harsh conditions. We've developed climate-control systems for our structures that keep us warm in the winter and cool in the summer. The problem is that many climate-control systems require a lot of energy.

I'm Chris Benedict. I design buildings that are energy efficient, which means that I focus on ways to design buildings that use less energy to keep their occupants comfortable. Architects like me have been nicknamed "green" architects because we design buildings that have fewer negative impacts on the environment.

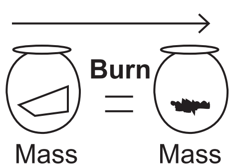
Being an architect takes a lot of study, preparation, and hard work. I studied architecture at The Cooper Union for the Advancement of Science and Art, a private college in New York City that specializes in art, architecture, and engineering. Like most new architects, I worked in several different architecture offices after I graduated. When I started my own architecture business, I knew that I wanted to introduce green concepts into every new design. Green buildings, when designed well, come alive because they respond to their environment. I love how elegant and creative green design can be.

Even though I'm no longer in school or an apprentice, my learning hasn't stopped. Far from it! I'm always attending conferences, reading about energy-efficient design, and learning from my previous experiences. I'm also always trying to spread the word to others in the building industry and the general public about the importance of green architecture. I do this by sharing my experiences and giving tours of building sites. That's one reason why I'm happy to have the opportunity to describe my work to you.

What Is Energy?

In my line of work, people talk a lot about saving or conserving energy, but just what do we mean by "energy"? Even though it's a term you've probably heard and used many times, it's not so easy to get a handle on what it is. We all have direct experience with energy. We feel like we have more energy after eating a chocolate bar or drinking a glass of orange juice. We're "out of energy" at the end of a long day. We know that we need energy to run our electronic devices. Energy is also needed to move things such as cars, bicycles, or paddle wheels. And energy is necessary to raise the temperature of bathwater or to heat up a home.

What's tricky about energy is that it's not a substance. You can't pick up a handful of energy. But energy acts like a substance in many ways. Like matter, energy cannot be created or destroyed. I know it seems like matter can be destroyed. If you burn a piece of paper, it seems to disappear, right? But the matter that made up the paper is not gone. The paper has been converted to ashes and smoke. If you were to burn the piece of paper in a jar that trapped all of the smoke and ash and then use a scale to find the mass of the substance in the jar, you'd find that it has the exact same mass as the piece of paper.



Physicists refer to this as the ***Law of Conservation of Mass.*** The law basically states that the mass of the inputs to a system will always be the same as the mass of the outputs from a system, regardless of the processes involved. So if you ripped the paper into little shreds instead of burning it, you would still have the same amount of matter.

The same is true for energy. The energy inputs of a system will always equal the energy outputs, regardless of the processes. This is referred to as the ***Law of Conservation of Energy.*** While energy cannot be created or destroyed, it can be stored or transferred from place to place. A fuel such as wood, gasoline, or oil stores energy. When these fuels are burned, they transfer their stored energy to the objects in their environment.

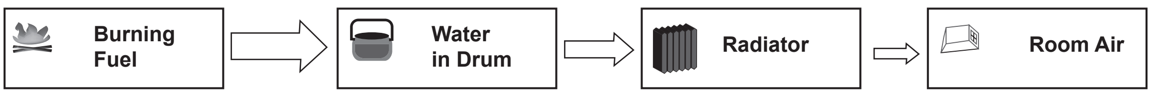
As a green architect, I'm interested in finding the best ways to heat homes and keep them warm. In a standard home heating system, a machine called a ***boiler*** burns natural gas or oil. Most of the energy released from the burning fuel is transferred to a drum of water inside the boiler. The hot fluid is then pumped to radiators in the rooms of the building. The radiators then get hot and transfer energy to the air in the room. After water in the radiators transfer its energy to the air in the room, it flows back into the boiler to be heated again.

Law of Conservation of Mass

The mass of the inputs to a system will always be the same as the mass of the outputs to a system, regardless of the processes involved. $m_{in} = m_{out}$

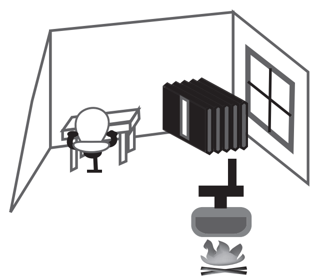
Law of Conservation of Energy

The energy inputs of a system will always equal the energy outputs to a system, regardless of the processes. $e_{in} = e_{out}$

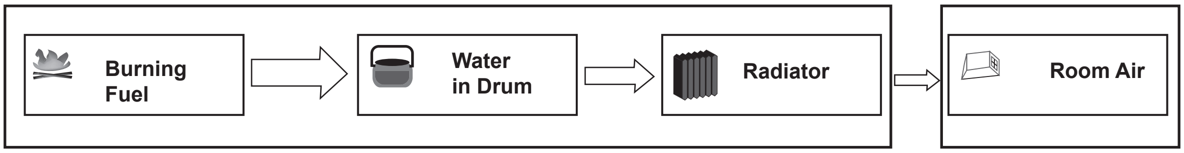


In order to keep track of how energy moves through a system, it's useful for engineers to identify the different objects in the system. In the above example, one might define the system as consisting of four objects: the fuel, the water in the drum, the radiator, and the room air. The arrows indicate energy transfer from one object to the next within the system.

The purpose of the system is to heat up the air in the room. It makes sense to consider the room air as an object outside of the heating system. The darker lines in the diagram on the next page indicate system boundaries. How we define the systems is really up to us—it's arbitrary. Engineers define systems in ways that help them keep track of how the energy moves through and beyond the system.

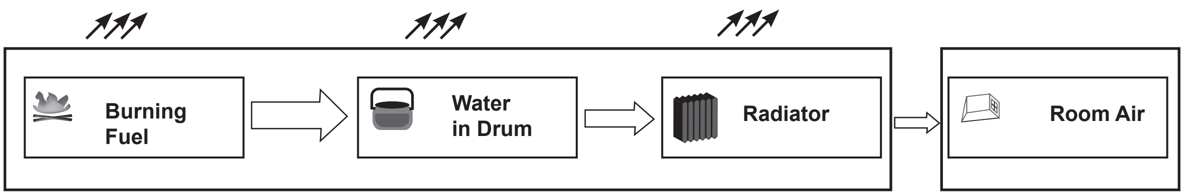


In this diagram, energy crosses a system boundary when it is transferred from the radiator to the room air. When energy crosses a system boundary and causes the objects outside of the system boundary to get hot, we call this ***heating.*** The energy transferred is called ***thermal energy.***



Heating
is when energy crosses a system boundary and causes the objects outside of the system boundary to get hotter.

In our daily language, we often talk about "heat" as if it is an object. We might say to a friend, "This radiator is giving off a lot of heat." Scientists and engineers think of heat a little differently. To us, heat is not an object. Rather, it's a process by which energy is transferred across a boundary. The room air is not the only object outside of the heating system that is getting hotter. The air around the boiler, the pipes, the air around the pipes, and many other objects also may get hotter. If you stood close to the boiler, you would get hotter too. The goal of the heating system is to transfer energy to the room air, but some of the energy is heating other objects. Engineers often refer to this energy as "lost." Of course, it's not lost. We know where it is. It's just not in a place that is useful to us. A more precise diagram that accounts for "lost" energy looks like this:



A major engineering challenge is to reduce these losses, so that the room is heated at maximum efficiency. To meet this challenge, engineers need to understand the relationship between thermal energy and temperature.

What Is Temperature?

Temperature
is the measure of how hot something is.

You can see that temperature has something to do with energy. You know that temperature is a measure of "hotness" and "coldness," and that the room air gets hotter when energy is transferred to it. What is different about a "hot" room or a "cold" room is the concentration of energy in the room. ***Temperature*** can be defined as the concentration of thermal energy in a substance. Temperature changes are one type of evidence that energy transfer is taking place as thermal energy is moving from an area of high concentration to low concentration.

So, What's the Problem?

The heating systems in use today are very effective in keeping our homes, offices, and other building comfortably warm, even on the coldest winter day. But the technologies used in most heating systems rely heavily on fossil fuels—oil, gas, and coal—which contribute to a number of health and environmental problems. Burning these fuels releases pollutants such as carbon monoxide and nitrous oxide into the air, and they are unhealthy to breathe. Many scientists believe these gases also contribute to global climate change. Extracting and transporting fossil fuels poses other serious problems. Because oil, natural, gas, and coal are found deep under the Earth's surface, people must build complex systems of wells, mines, pipelines, and roadways to extract them. This has led to habitat loss and degradation in some beautiful natural places on our planet. And heating homes with fossil fuels can be expensive. In some parts of the United States, many families simply cannot afford to keep their homes warm in the winter.

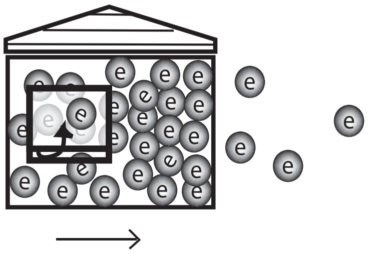
Given all of the problems associated with burning fossil fuels, I feel that we must find ways to use less of them. One way to reduce consumption is to construct buildings with heating systems that require us to burn as little fuel as possible while keeping us comfortably sheltered from the elements.

Keeping Warm while Conserving Energy

Right now, I'm overseeing the construction of several six-story low-income-housing buildings that I designed. When they are done, these buildings will be rented to people, often families, who don't have a lot of money. The rents will stay fixed for a long time, so that the tenants can afford to keep living in them even as housing prices climb year after year. Surprisingly, we are designing a "green" building for the same amount of money that a conventional building costs. In fact, this green building will save money in the long run because the owners and tenants won't spend as much money on heating.

I asked my colleague Henry Gifford to design a more efficient heating system for the building. Henry is a heating systems specialist, an essential team member in the effort to build an energy-efficient building. I met Henry at a green design conference a few years ago, and since then we have collaborated on a number of projects together. He has developed a heating system for the low-income-housing project that includes a thermostat in every room. A ***thermostat*** can measure the temperature of air and turn on the heating system automatically if the temperature drops below a certain temperature. It turns the heating system switch off as soon as the air is warm enough.

A lot of apartments have thermostats, but few have thermostats in every room. Why are more thermostats better? Well, let's say it's mid-January. An apartment has three very warm rooms and one cold room. Unfortunately, the only thermostat in the apartment is located in the cold room. The thermostat keeps the heating system on, making the hot rooms even hotter. When the tenant gets home from work at the end of every day, she has to open windows in the hot rooms in order to make those rooms more comfortable. Think of all that energy going out the window! If every room has its own thermostat, we don't have this problem. In fact, Henry estimates that the additional thermostats reduce the amount of hot water that the boiler has to produce by about 25 percent. This allows us to install a smaller boiler, which saves cost.



The Great Escape

With Henry on my team, I knew we'd find an efficient way to heat the building. But I also knew I needed to find a good way to keep the energy inside the building once it was there. Warm air escapes buildings through even the tiniest openings around doors or windows and at the seals of vents. Thermal energy even passes through walls!

Why does it do this? That's something fundamental to the nature of energy: When there is a difference in temperature in two objects, thermal energy will transfer from the hotter to the cooler object. The transfer will continue until there is no temperature difference.

Energy will always transfer from the hotter to the cooler object. The transfer will continue until the difference disappears.

You can see this is true in the case of the boiler in the heating system. When the boiler is first turned on, the burning fuel is much hotter than the water in the boiler. The burning fuel transfers energy to the water. The hot water is then pumped to the cool radiators, which get hot. Now, of course the radiators are hotter than the room air. So what happens? The radiators transfer energy to the room air. The transfer continues until the room air is the same temperature as the radiators.

But as soon as the home is heated, the interior of the building has a higher temperature than the air outside. Consequently, thermal energy naturally transfers to the air outside of the home, even through the walls!

One way to keep the energy inside a warm home from escaping is to make sure that the windows and doors are airtight when they are closed, because warm air can escape. To ensure this, we use a blower-door during construction to test for air tightness. A blower-door is a fan with fabric around it. The fabric attaches to the doorway. If any air is moving through the doorway when the door is closed, the fan blades will turn. Based on how much the fan blades turn, we can measure the amount of air escaping through the doorway and determine the best way to make the door more airtight.

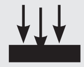
To keep energy from moving through the walls, we put insulation in the walls. A thermal ***insulator*** is a material through which energy does not flow well. An insulator is the opposite of a ***conductor,*** through which energy passes easily.

To describe how effective a material is as an insulator, we give it an "R-value." The R stands for "resistance," and it characterizes the material's ability to resist the flow of energy. A larger R-value means greater resistance. Therefore, a material with a higher R-value is a better insulator. Below is a chart with R-values for some common materials. We use mineral wool insulation because it has a high R-value and does not burn easily.

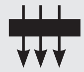
Material	R-value
Wood	0.91
Fiberboard	2.78
Fiberglass	3.90
Styrofoam	3.57
Cellulose Insulation	3.5
Mineral Wool	3.0

The outer walls of the building have three layers: brick on the outside, followed by a layer of mineral wool insulation, and concrete block on the inside. To test how well these walls resist the flow of energy, we take photographs of our building with infrared cameras. The infrared camera images show us where energy was escaping from some of the walls in the building. So we add more insulation in those areas.

An ***insulator*** is a material through which energy does not flow well.



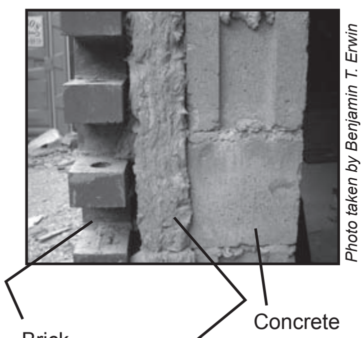
A ***conductor*** is a material through which energy flows well.



A ***thermal mass*** is a component of a building (such as concrete) that absorbs and stores heat or thermal energy during the day and releases it slowly at night.

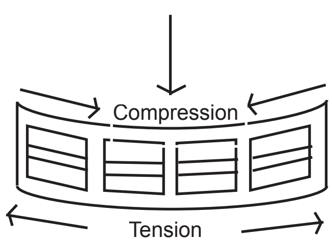
Unlike a typical home that uses plaster or sheetrock on the inside walls, I used concrete block, which acts as a thermal mass. In engineering, the word "thermal" is used to describe systems that transfer energy to raise or lower the temperatures of objects inside or outside of the system. A ***thermal mass*** is a component of a building where materials absorb and store energy. Concrete is often used as a thermal mass because it easily absorbs and stores energy. It is also very slow to change temperature. During winter, the building's heating system transfers energy to the concrete. The mass of the concrete stores the energy and slowly releases it into the apartments. In the summer, the bricks and the insulation protect the concrete from being heated by the summer sun. Instead, the concrete absorbs the energy from the interior of the building, cooling it down.

Cross-section of the outer wall of the building



Carrying the Load

Besides adding thermal stability, the concrete layers also provide critical structural support for each floor. The floors of the building are made of concrete planks, which are essentially a set of concrete blocks connected with steel rods running through them. Concrete alone cannot bear the necessary loads that the floor will experience. That's why the concrete planks are reinforced with steel rods. A floor experiences compression on the upper side and tension on the bottom side. Concrete is very good at withstanding compression forces. That's why it's often used in columns or pillars, which must withstand compression. But concrete does not withstand tension very well. Steel holds up well under both tension and compression. So the two materials work together as a team: The concrete withstands the compression and the steel reinforcing rods run through the concrete withstand the tension.



Steel beams support the portion of the plank under tension. Steel withstands tension well.

Green Architecture Is a Team Effort

My good working relationship with Henry is but one example of the importance of teamwork. For the low-income-housing project, I've worked more closely with engineers and contractors than an architect usually does. Typically, an architect will design a building. This includes the layouts, the colors, the way the building looks, the detailing. She will then hand the plans over to structural engineers. The engineers do the calculations necessary to size the structural beams, heating units, insulation, ventilation fans, water pipes, and more. The architect's plans and the engineers' calculations are given to a contractor, who organizes all of the skilled technicians—the carpenters, plumbers, roofers, bricklayers, and others—who construct the building and all of its systems.

Now that I am a green architect, I see a building as a system made up of interdependent subsystems. The structural elements, the support beams and walls, the heating systems, the electrical systems, the water systems, and the other parts of a building influence each other and must work together. For this reason, the people involved in constructing the building must work closely together as well.

There is another important player when it comes to constructing a building: the building inspector. A ***building inspector*** is a government employee who knows the country, state, and city building code laws, and makes sure that every architect follows them. The building inspector also makes sure that buildings meet health, safety, and energy codes. These codes cover such things as where smoke detectors must be placed, the width of doorways, and the loads the building must withstand. When an architect first comes up with a set of plans, the owner of the building or the contractor will take the plans to the building inspector for approval. After the building inspector approves the plans, the building permit is granted.

Photo taken by Benjamin T. Erwin

Putting a steel-reinforced concrete plank in place

The Total Package

Every aspect of my building must be designed with sustainability in mind. Behind one of the six-story buildings I am working on, we are designing a landscaped backyard area for residents to enjoy. The pavement will be slanted so that rainwater will run off of it into underground pits of sand called ***recharge beds.*** These beds store the rainwater then slowly release it back to the plants over time. This conserves water because, even on dry days, the garden won't need to be watered from the municipal water supply. It will receive plenty of water from the recharge beds. On another building down the street, we are putting in a community garden on the roof. Roof gardens are not only great places to hang out, but they also hold rain water on the roof during strong rainstorms and keep our sewage treatment plants from being overwhelmed with waste water. In New York City, if the sewage treatment plant is overwhelmed, it releases untreated sewage into the rivers.

As you are starting to see, I am involved in every detail of the buildings that I design, and all of the details are critical to the function of the building as a whole. One more problem that I have to contend with in a big city is pigeons. To prevent pigeons from hanging out and nesting above the windows, I designed the concrete ledges to be narrow enough so that the pigeons won't land. I have a bet with Henry as to whether my design will keep pigeons away. Henry thinks they won't work. He says he's seen pigeons cling to razor-thin ledges. Well, we'll see who wins the bet!

What's the Story?

1. What problem do green architects try to solve?
2. What makes the heating system in Chris's green building more efficient than the heating system in "conventional" buildings?
3. Make a list of four materials that Chris will use in her building and briefly explain the function of each material.

Designing with Math and Science

4. Draw an energy diagram of a toaster heating up a slice of bread.
5. What's the difference between an insulator and a conductor? Would an engineer choose a good insulator or a good conductor as a material for a coffee mug? What about a saucepan?
6. Which is a better insulator, wood or cellulose insulation? (Use the R-value chart earlier in the chapter.) How do you know?

Connecting the Dots

7. Many of the engineers in this book discuss the importance of teamwork. Why is teamwork so critical when it comes to designing green buildings? How is this different from the teamwork in "The Making of a New Balance Shoe" and other earlier chapters?

What Do You Think?

8. Look around your school building and list at least three ways the building could be designed to better conserve energy.
9. Chris talks about the role of a building inspector. Why is this an important role? What might result if cities and towns did not employ building inspectors?