If you put water in the freezer, you'll end up with ice. If you leave ice on your countertop, you'll end up with liquid water. You've almost certainly seen these phase changes in your everyday experience. But there's more to freezing and melting than meets the eye, and we can use these seemingly simple phenomena to make buildings significantly more energy efficient.

In this video, we'll explain the concept of "latent heat" and see how it can dramatically reduce heating and cooling costs in homes and skyscrapers alike.

This video is part of the Conservation video series.

In order to analyze or modify a system, it is important to understand how the laws of conservation place constraints on that system.

Hi. My name is Stephen Ray and I am a graduate student in the Department of Mechanical Engineering at MIT. My research in the Building Technology Lab under the guidance of Professor Leon Glicksman focuses on energy efficient buildings.

In order to understand the topic of this video, you should be familiar with the Law of Conservation of Energy. You should also be familiar with the effects of intermolecular forces on phase transitions.

After watching this video, you should be able to describe the energy transformations that occur during a phase change and apply the law of conservation of energy to phase changes.

Let's start with a demonstration.

Here we have a container of water to which we are adding table salt.

Quite a bit of table salt, actually.

Let's stir that up.

Next, we are going to crush up some ice to add to the salt water.

Our goal is to lower the temperature of the ice bath.

Let's add some more salt.

Freezing point depression, yeah!

Alright, minus 8 degrees Celcius. That's pretty good.

Let's place a smaller container of liquid water into this ice bath. We've added green food coloring to the water so that it is easier for you to see.

After a few minutes, we'll insert a thermometer and watch the temperature drop as the water is cooled by the ice bath.

The temperature reads about -5 degrees Celsius. The green water is still a liquid even though the temperature is below the normal freezing point of water. This is called supercooling.

In the next step of this demo, we are going to add a couple of small pieces of ice to the green water. The supercooled water will crystallize rapidly with the addition of the ice.

When this happens, what do you predict will happen to the temperature on the thermometer?

Will it increase, decrease, or stay the same?

What reasoning supports your prediction? Pause the video here to discuss your ideas with the person beside you, then continue playing the video to see what happens.

Okay, ready to see what happens? Be sure to keep your eye on the digital display.

Now we'll drop a couple of small pieces of ice into the container of green water.

Watch what's happening.

The green water froze. There is still a little bit of liquid, but we can turn the container upside down and you can see that the ice remains inside.

So, when the liquid froze, what happened to the temperature?

The temperature went up! Is this what you predicted? How can we explain what happened?

Well, let's think about what happens at a molecular level when water changes phase from a liquid to a solid. In the liquid state, water molecules are moving around a lot. As it gets colder, the water molecules slow down.

Generally speaking, as the water cools and solidifies, there is an increase in hydrogen bonding, the dominant intermolecular force amongst the water molecules.

With this hint, can you now explain why we observed a temperature increase when the water froze? Pause the video, take a moment to think about it on your own and then discuss your idea with a classmate. Then, continue playing the video for an explanation.

As we said before, when water transitions from liquid to solid, there is an increase in the number of hydrogen bonds that are formed between water molecules. Does bond formation release energy or require energy?

Bond formation releases energy.

So then, is the process of ice forming exothermic or endothermic?

Ice formation is exothermic.

If we were to do an energy balance on the system and the surroundings, we would see that the energy that was released by the water freezing is equivalent to the thermal energy that caused the temperature to increase. This is the Law of Conservation of Energy.

Generally speaking, when a substance transitions between phases, intermolecular forces between neighboring molecules are either formed or broken. When a substance transitions from a liquid to a solid, intermolecular forces, or bonds, are formed and energy is released to the surroundings. This is called the latent heat of fusion.

Going in the other direction, when a substance transitions from a solid to a liquid, energy is required to overcome intermolecular forces, so this is an endothermic process. Energy is absorbed from the surroundings. This is called the latent heat of melting.

The latent heat of melting is equivalent in magnitude to the latent heat of fusion, but opposite in sign.

This phenomenon of latent heat is used in a variety of ways to heat and cool buildings.

Using melting ice to absorb thermal energy from the surroundings saves some buildings thousands of dollars a year in cooling costs.

Consider a large office building during the middle of a hot summer day. In order to keep the building comfortable, the air conditioning is running at full power, requiring a lot of electricity from the utility company. The utility companies can't easily shut down their power plants, so nearly the same amount of electricity is produced during the night as is during the day. However, nighttime demand for electricity is very low, so utility companies sell this electricity at a lower price. This is common practice by utility companies across the U.S.

Engineers have thought of a way to buy the electricity during the night when it is very cheap, but use it during the day when they need to run the air conditioning. This strategy is called peak load shifting. Think about what you have learned so far. There are a variety of ways this can be done. How do you think they do this? Pause the video here, take a moment to think about it, and discuss your idea with the person next to you. Continue playing the video to hear about one way they do this.

One way we can decrease the amount of electricity needed in the daytime to cool a building is to use the energy storage capacity of ice, or its latent heat of melting.

Large tanks, such as these in the basement of the Bank of America Tower in New York, store water that is frozen over night using cheap electricity. During the day, the ice melts and absorbs energy from the cooling fluid running through the building's air conditioning system. Each of the tanks in the Bank of America building holds approximately 1600 gallons of water which translates to roughly 570 kilowatt hours of cooling capacity. Bank of America reports that these ice tanks supply 25% of their cooling energy annually.

The desire to harness latent heat has led to the development of a class of materials called phase change materials. These materials have been specifically designed to change phase at desirable temperatures so that they can store and release energy in a way that is useful to consumers. This slide shows some examples of these materials. The materials on this slide fall into three classes of phase change materials: inorganic salt hydrates, paraffinic hydrocarbons, and organic fatty acids.

Some ordinary building materials such as concrete, dry wall, or insulation have been specially engineered over the past 50 years to contain microscopic pellets of phase change materials.

Cellulose insulation, shown here, is commonly used to insulate attics and walls. Researchers at the Oak Ridge National Laboratories in the United States have impregnated small paraffin pellets in this common type of insulation to increase its performance.

Because these pellets are microscopic, the phase change insulation looks exactly like the ordinary insulation to our naked eye. However, under a Scanning Electron Microscopic, the clusters of paraffinic pellets are easy to spot.

Now lets look at the measured performance of a similar type of phase change insulation that is installed in a typical residential roof. The chart here shows the heat transfer into a house on the vertical axis and time on the horizontal axis. The two large black peaks, which occur during two consecutive summer days, correspond to the large amount of heat transfer into a home that a conventional roof allows. The smaller green peaks show how changing the roof surface material and venting the attic significantly help lower the heat transfer into a home by approximately 70%. This reduction in heat transfer leads to less energy required for cooling the home. The purple curve shows that if phase change insulation is used in addition to these roof modifications, we can reduce the required cooling energy by 90%!

How does phase change insulation help save energy? Pause the video, take a moment to think about it, and share your thoughts with a classmate.

Consider two homes with and without PCM roof insulation. Both homes are exposed to the same amount of solar energy from the sun. Although not all of that energy enters the home without PCM insulation, a significant portion is transferred through the roof into the house. The house with PCM insulation reduces this amount because some of the energy that would otherwise enter the house is used to melt the phase change material in the roof.

In order for this effect to occur each day, the phase change material must solidify every night before it can melt again the next day.

Let's take a look at this chart of example phase change materials again. What phase change material would you use in a home or building in Singapore? Why? What additional information might you need to know to help make your decision? Pause the video here and discuss your choice with the person beside you.

On average, year-round temperatures in Singapore hover between 23 and 32 degrees Celcius. This is important when making our decision. Some of you may have selected the calcium chloride hydrate as a candidate phase change material because its melting temperature falls within the range of daytime high temperatures in Singapore. You may have selected octadecane for a similar reason. If you eliminated paraffin wax and palmitic acid, it was probably because their melting points are so much higher than the highest outdoor temperatures reached in the day. However, these phase change materials could be used on a conventional dark-colored roof where temperatures can exceed 70 C because of all the energy absorbed from the sun. Caprylic acid, on the other hand, has such a low melting temperature, that few, if any, building components would ever drop below this temperature.

So, let's go back to calcium chloride hydrate and octadecane. Both would melt and solidify within the temperature range of the environment, but octadecane has a higher heat of fusion, which leads to greater potential energy savings. While it is beyond the scope of this video, we also need to think about the heat transfer properties of the other building materials used in the roof and the cost and stability of the phase change materials.

Today, you learned about the concept of latent heat and how the energy transformations that occur during a phase change are a consequence of the law of conservation of energy. You also saw how engineers have used the concept of latent heat to design phase change materials that can allow us to cool and heat homes more efficiently. The incorporation of phase change materials in building materials is still an active area of research. There are still engineering challenges to address, perhaps by you, in order to make these technologies cost-effective and more widely used.