

# Thermal Energy



Before you leave for the day, what is the first thing you think about with regard to the weather? If you said temperature, don't be surprised. The temperature of the air around us dictates greatly what we will do. If the day is too hot, we will dress in lightweight clothes, and schedule our outdoor activities for the morning or evening to avoid overheating. If the day is too cold, we will bundle up with scarves, hats, gloves, heavy coats, and sometimes insulated pants and boots in order to stay warm. We wear very warm clothing in the winter so we don't freeze to death, but we also wear the types of clothing we do each season to stay comfortable.

Keeping the interior of our homes comfortable is important, too. You may not think about it much, but the temperature indoors helps keep you healthy. If you're comfortable, you don't think at all about the heating system. However, if that heating system stops working properly and your house gets cold, you will probably think about it all the time.

The same can be said for schools. How difficult is it to concentrate on school work when your hands are cold? How easily can you stay awake if the room is too warm? The temperature of the room dictates our comfort level, and our comfort level greatly influences our ability to concentrate and be productive.

In Lesson 1, you read that most energy transformations also involve some "wasted" energy that is thrown off as thermal energy, and that energy is not typically useful. However, when it comes to keeping us comfortable, thermal energy is the most important form of energy.

## Thermal Energy Science

Thermal energy is the energy that allows atoms and molecules to move. As you can imagine, solids have less thermal energy than gases; liquids fall somewhere in between. As long as you are comparing the solid, liquid, and gaseous state of the same substance, it is safe to say solids have the least amount of thermal energy and gases have the most. However, because different substances have the ability to retain different amounts of thermal energy, it is not always the case. For example, a gram of ice will have more thermal energy than a gram of oxygen gas. The amount of thermal energy a substance can retain is called its **specific heat capacity**, and it is different for each element or compound. Substances with a high specific heat capacity require a lot of thermal energy to increase in temperature, but they also can hold that energy for a longer time. Glass, water, and ceramics have high specific heat capacities. A substance with a lower specific heat capacity will heat up quickly and cool down quickly. Specific heat capacity factors into whether a substance is used to transfer thermal energy to heat a space.

Thermal energy is transferred via three mechanisms: **conduction**, **convection**, and **radiation**. Conduction occurs when thermal energy is transferred from one object in direct contact with another object. In order for conduction to be feasible, the substance being used to transfer the energy must be a good conductor. In general, metals are good thermal conductors and non-metals are not. That is why cookware is often made of metals like copper, iron, and stainless

steel. Metals typically have low specific heat capacities, which is a desired quality in this case because the purpose is not to heat the cooking pot, but to transfer the heat from the burner to the food inside the pot.

Convection transfers thermal energy by heating a fluid, then circulating that fluid. The fluid must have a specific heat capacity large enough to make convection a worthwhile way to heat a space. Water has a very high specific heat capacity, and makes an excellent fluid for convection. The water is heated in a boiler, then circulated through pipes or tubes, releasing some of its energy and returning to the boiler at a lower temperature. Air does not have as high a specific heat capacity as water, but because it is easy to circulate air with fans, it is used in forced-air heating systems.

Radiation is the third mechanism for transferring thermal energy, and it does not require the assistance of a substance like steel or water. Rather, the thermal energy is emitted from the hot object in waves. You have experienced radiation if you've ever sat around a fire on a cool evening, toasting marshmallows or warming your hands. The thermal energy source is the combustion of the wood and paper on the fire, and you can feel the thermal energy radiating outward from the fire.

When it comes to transferring thermal energy to a specific object, conduction is the most efficient means to do so. However, conduction is not very efficient when it comes to heating entire rooms and it is impractical to have large metallic pieces radiating from a heat source into the rooms of a building. Therefore, convection and radiation are how spaces are usually heated. Small electric or kerosene space heaters use radiation. Forced-air furnaces use convection. Boiler systems with radiators use both convection and radiation.

## School Heating Systems

The first schools were one small room, and had a wood stove in them that kept the room warm. The seats closest to the wood stove were quite warm, and those students seated farthest away from the stove might get cold. They relied on radiation to warm the school.

A century ago, schools were built with a large boiler that was fueled by coal. The boiler heated water, which was circulated through the school through radiators. The heat was either on all the time, or shut down entirely, and there was no control of the temperature from one room to the next. As a result, rooms on the upper floor of the school were often quite warm, while rooms on the lower floor or in the basement could be too cool to be comfortable.

Schools today often have boiler systems that circulate hot water or steam, but they are usually fueled by natural gas, and the water circulates into a device that blows air over the hot water piping system to heat the room. Some systems even have individual thermostats in each room that can open and close valves to control the temperature.

# Preventing Thermal Energy Transfer

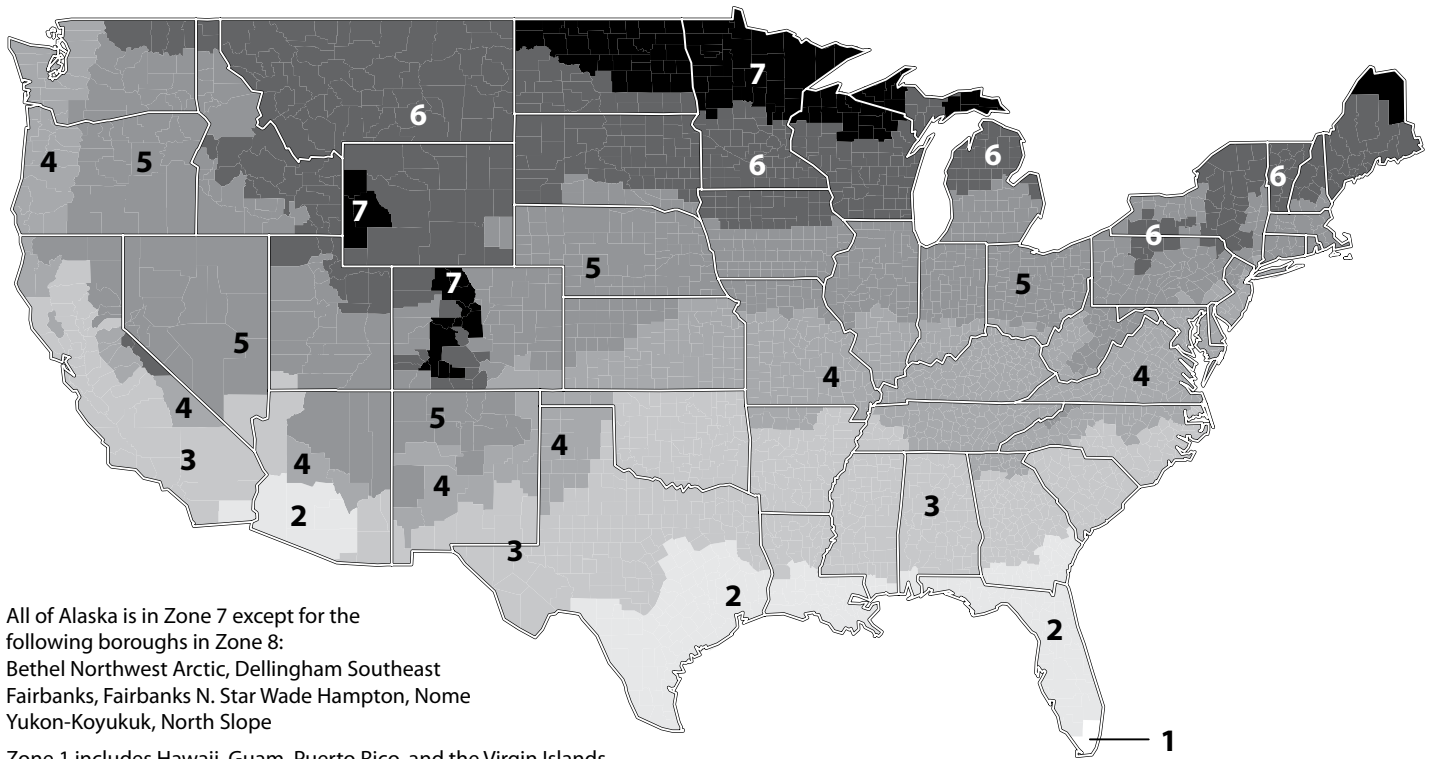
Buildings are designed to keep the indoor air separated from the outdoor air. Otherwise, the heating and cooling system is trying to heat or cool the air outside the building as well. That would be terribly inefficient. Buildings are constructed out of materials that **insulate**, or block thermal energy transfer. Insulating materials do not conduct thermal energy well.

The parts of the building that separate indoors from outdoors construct the **building envelope**. The walls, floor, roof, doors, and windows are parts of the building envelope **system**. Their purpose is to keep the interior of the building a comfortable, healthy place to work or learn while allowing access into and out of the building.

The space above the ceiling, below the floor, and within walls is filled with insulation, which prevents thermal energy transfer. Insulation is graded by its **R-value**, which is an abbreviation for its resistance to conduction. Different materials have different R-values, and the

amount of insulation needed in total R-value varies according to the climate in which you live. Industry professionals calculate the R-value per inch thickness of different materials and builders install the appropriate thickness of locally-available materials to provide the proper amount of insulation. The materials used in buildings in your area depend on what is easily available and how many people are trained in their installation.

## Recommended R-Values for New Wood-framed Homes



All of Alaska is in Zone 7 except for the following boroughs in Zone 8:  
Bethel Northwest Arctic, Dellingham Southeast  
Fairbanks, Fairbanks N. Star Wade Hampton, Nome  
Yukon-Koyukuk, North Slope

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands.

ZONE	ATTIC	CATHEDRAL CEILING	WALL INSULATION		FLOOR
			CAVITY	INSULATION SHEATHING	
1	R30 to R49	R22 to R38	R13 to R15	None	R13
2	R30 to R60	R22 to R38	R13 to R15	None	R13, R19 to R25
3	R30 to R60	R22 to R38	R13 to R15	R2.5 to R5	R25
4	R38 to R60	R30 to R38	R13 to R15	R2.5 to R6	R25 to R30
5	R38 to R60	R30 to R60	R13 to R21	R2.5 to R6	R25 to R30
6	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 to R30
7	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 to R30
8	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 to R30

Data: U.S. Department of Energy

## Air Infiltration

In order for the building envelope to do its job, air must not be allowed to flow into or out of the building. The most obvious way to avoid air infiltration is to keep doors and windows closed when the heating or cooling system is running. However, there are other ways air can find its way into or out of a building that are just as important to control. Doors and windows that leave gaps even when closed need a strip of weatherstripping to seal those spaces. The space between doors or windows and the walls that contain them also need to be sealed. Immediately after a building is completed, the doors and windows fit snug in their respective spaces. Over time, however, the building expands and contracts slightly as it heats and cools with the seasons, and the doors and windows may not be as tight a fit as they once were. Therefore it is important to inspect these junctions annually and fill any gaps with weathertight caulking.

Attic spaces are also frequent culprits in air infiltration. Any ventilation piping systems that exit the building, such as a flue from a boiler or a vent pipe for plumbing, have the potential to allow air to enter or exit the building. Because hot air is less dense than cold air, it rises, and can escape through the roof of a building if the attic is not well sealed.

## Windows and Doors

Windows made of metallic frames were often used in schools built in the 1950s and 1960s. The aluminum in the frames is an excellent thermal conductor and will conduct the energy right through to the other side. As you can well imagine, this is not a great material for constructing window frames. Most windows today are made of vinyl, wood, or composite materials that are better insulators.

The number of panes of glass in a window is important, too. Single-pane windows are not well insulated; double- or triple-pane glass has an insulating space between the glass that allows light in but keeps thermal energy from transferring across the window.

Most schools have two sets of doors at each entry point. This prevents large amounts of air from rushing in or out of the building as people enter and exit. To work properly, both sets of doors need to be kept closed when not being used.

## Moisture

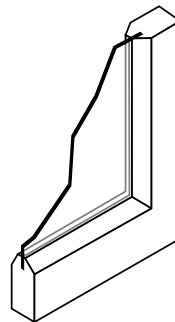
Up until this point we have been considering heating or cooling indoor spaces under the assumption that moisture levels remain constant. The amount of water in air varies from day to day, according to climate, weather, and temperature, and is measured according to its **relative humidity**.

Think of air as a moisture sponge. Warm air can hold more moisture because the atoms and molecules are moving faster and are more spread out. Warm air is like a bigger sponge. Cool air holds less moisture because the particles are spaced closer together. Cool air is like a smaller sponge. Imagine the sponge can increase or decrease in size as the temperature changes. If you add 100 mL of water to a small sponge, it might be completely saturated – it is holding all of the moisture it can hold. If that sponge expands, but no more moisture is added, it is no longer saturated, and is now holding a fraction of the water that it could potentially hold.

## Window Glazing Types

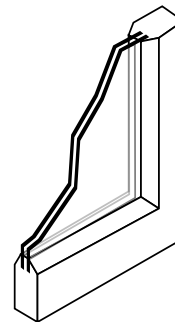
LEAST EFFICIENT

MOST EFFICIENT



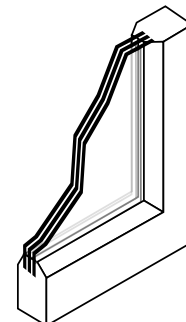
### SINGLE

often has storm window, screen, or combination



### DOUBLE

space between glass may be gas-filled  
glass may be low-E type with coatings



### TRIPLE

space between glass may be gas-filled  
glass may be low-E type with coatings

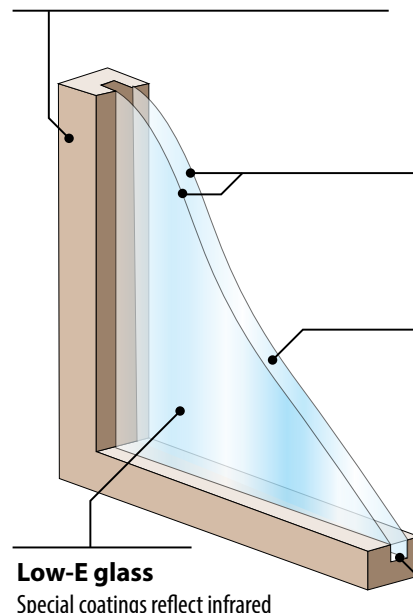
## What Makes a Window Energy Efficient?

### Improved frame materials

Wood composites, vinyl, and fiberglass frames reduce heat transfer and help insulate better.

### Multiple panes

Two panes of glass, with an air- or gas-filled space in the middle, insulate much better than a single piece of glass. Some ENERGY STAR-qualified windows include three or more panes for even greater energy efficiency, increased impact resistance, and sound insulation.



### Gas fills

Some energy efficient windows have argon, krypton, or other gases between their panes. These odorless, colorless, non-toxic gases insulate better than regular air.

### Low-E glass

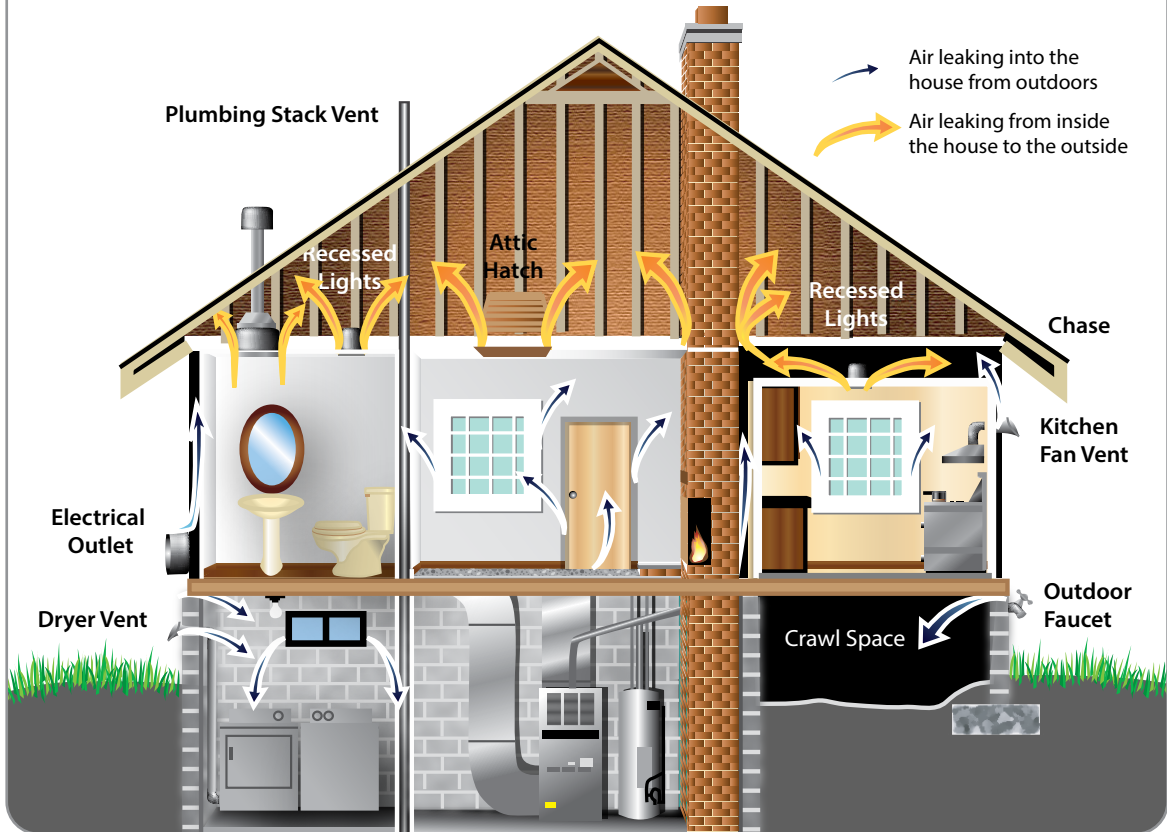
Special coatings reflect infrared light, keeping heat inside in winter and outside in summer. They also reflect damaging ultraviolet light, which helps protect interior furnishings from fading.

### Warm edge spacers

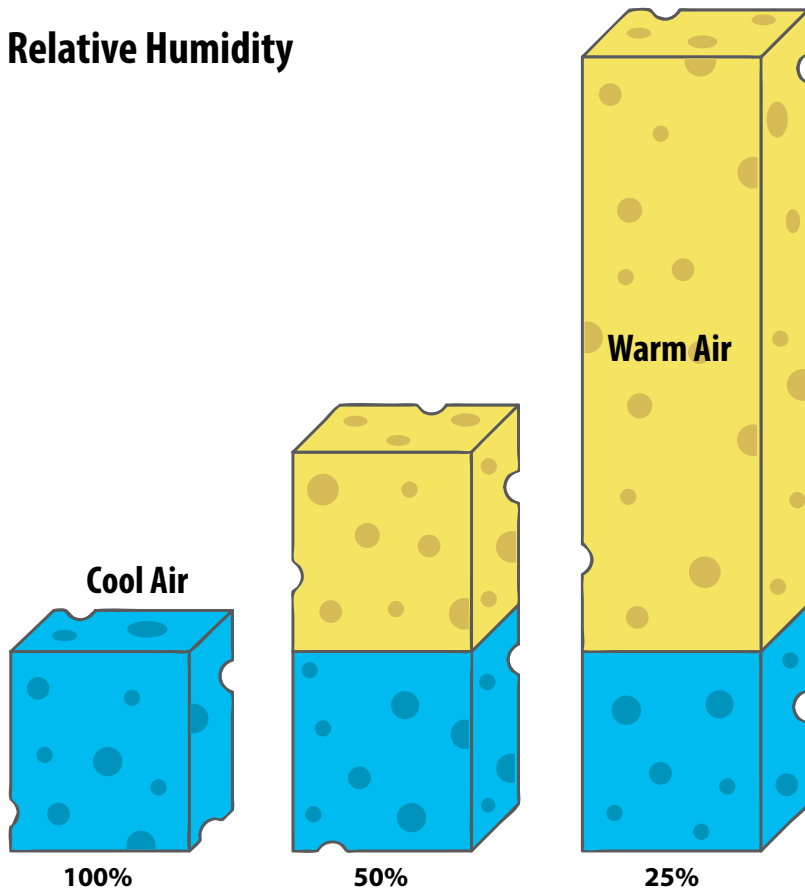
A spacer keeps a window's glass panes the correct distance apart. Today's warm edge spacers—made from steel, foam, fiberglass, or vinyl—reduce heat flow and prevent condensation.

Data: ENERGY STAR®

# House as a System



## Relative Humidity



Cool air is like a small sponge—it holds a small amount of water. Warm air is like a larger sponge—it holds more moisture. Warming the air increases the amount of water it can hold, but the relative humidity decreases because no additional moisture is added.



Air works the same way. Cool air, like the smaller sponge, holds a certain amount of water. If that air is warmed, but no more moisture is added, the relative humidity goes down because it is only holding a fraction of the water that the warm air could potentially hold. In winter, when the temperature is very cold, air holds little water. For the sake of argument, let's say the cold air outdoors is at 50% relative humidity. That same air is warmed indoors, but no additional moisture is added. The warmer air is now at 18% relative humidity. The amount of moisture hasn't changed, but the percent saturation – relative humidity – has changed because cold air holds less moisture than warm air. The amount of moisture in the air is very important. Air with too little moisture dries out skin, eyes, noses, and mouths and promotes static electricity buildup. Air with too little moisture also will not retain thermal energy as well, and the heating system needs to work harder to maintain a comfortable temperature. Too much moisture will cause the pages of books to curl and promotes the growth of mold and mildew, which are significant health hazards. During cooling season, air with too much moisture feels muggy and uncomfortable, and the cooling system will need to work harder to keep the room comfortable. The optimal relative humidity level for indoor spaces is 30-60%.

## Indoor Air Quality

In schools, what is mixed in the air is a major concern because schools tend to be closed up tight all day, every day. Some classrooms may have an open window here and there, but for the most part, the doors and windows are kept closed.

Because schools have a lot of people in a smaller space than homes do, bringing fresh air in from outside is important. Each person in the building is a living, breathing, thermal energy and carbon dioxide-producing machine. In a sealed building, the carbon dioxide will build up, which creates a health hazard of its own. When carbon dioxide is added to possible mold growth, cleaning product fumes, cooking odors, and the smells of gym class, the need for fresh air becomes readily apparent.

Commercial buildings like schools have HVAC systems – heating, ventilation, and air conditioning. Your home has a heating system and might have an air conditioner, but ventilation is usually accomplished by opening and closing doors and windows. Because you have relatively few people per square foot in your home, adding fresh air is unnecessary. In commercial buildings, it is not only desirable, it is vital to keep the occupants healthy.

Ventilation is measured by the number of air changes per hour. One air change in one hour means enough fresh air is brought into the room such that in one hour all of the air is exchanged. Fresh air exchange is important not only to remove the carbon dioxide produced by the people, but also to keep moisture at a healthy level to prevent mold growth and to remove chemicals from activities like cooking, cleaning, science lab experiments, and art projects.

Different buildings with different uses are required to exchange the air at different rates. Local building codes and regulations also vary. Therefore, what may be sufficient in one school may not meet regulated ventilation requirements in another school. You can check with your school's maintenance supervisor or your local building code enforcement office to find out how many air changes per hour are needed.

## The Struggle Between Comfort and Fresh Air

You may be wondering at this point what a discussion of air quality has to do with thermal energy in a building's energy use picture, especially if you live in a climate where you can have the doors or windows open almost all the time. However, in climate zones where winter temperatures get very cold or summer temperatures are very hot, the balance between fresh air and indoor comfort is difficult to maintain.

On the one hand, the building needs to be kept at a comfortable temperature, either by heating or cooling the air. This is achieved by using a heating or cooling system, and recirculating the air in the building to add or remove thermal energy from it.

On the other hand, the occupants of a building need fresh air to stay alert and healthy. If the air outside is very cold, bringing significant amounts of it into the building will place a heavy burden on the heating system. If the outdoor air is very warm, the cooling system must work hard. Both situations will require more energy. Moisture just adds to the complexity of the situation.

Maintenance supervisors need to maintain a balance in their buildings between what is comfortable and what is necessary for the occupants of the building to get the fresh air they need. A century ago, most people were not very concerned with indoor air quality except in extreme situations. Today, though, indoor air quality is a major factor in selecting the HVAC equipment for a commercial building. Fortunately, computer systems and other guides are available that help building managers keep that balance.

## Vapor Barriers

When constructing a building, a vapor barrier is often placed inside the wall. The purpose of the vapor barrier is to resist moisture diffusing through the wall. Its presence can minimize the amount of moisture that will build up inside the wall, which in turn prevents mold growth. Placing the moisture barrier properly ensures that the insulation does its job, and the inside air is kept separate from the outside air. It also prevents moisture as condensation from accumulating and adversely affecting indoor air quality.

## AIR CONDITIONING SYSTEM

