

Transcript Lesson 4a. Heat delivery

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Welcome to Module 4a, Heat Delivery, part of the course Renewable Energy Integration in the Energy System, developed by The Hague University of Applied Sciences.

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In this module, we will explore the main systems used to deliver heat.

Before discussing how these systems work, and comparing their advantages and disadvantages, we will first review some basic concepts. These include thermal energy, temperature, and heat transfer. Understanding these ideas will help us better understand how heat delivery systems operate.

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Thermal energy is the internal energy of an object that results from the motion of its particles. The faster the particles move, the more thermal energy the object contains.

The thermal energy of an object can be estimated from three main factors: the mass of the object, the specific heat capacity of the material, and the temperature difference between the object and its surroundings.

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Temperature is a measure of the average kinetic energy of the particles in a substance.

Several temperature scales are commonly used. These include Kelvin, which is the unit used in the International System of Units; Celsius, which is widely used around the world; and Fahrenheit, which is mainly used in the United States.

The lowest possible temperature is zero Kelvin, also called absolute zero. At this temperature, particle motion theoretically stops.

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Specific heat is the amount of thermal energy required to raise the temperature of one unit of mass of a substance by one degree Celsius or one Kelvin.

The value of specific heat can vary greatly depending on the substance. For example, water has a relatively high-specific heat capacity. This means that water can store a large amount of thermal energy compared with many other materials.

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Substances can exist in different phases, also called states of matter. The phase mainly depends on temperature and thermal energy.

The three most common phases are solid, liquid, and gas.

When thermal energy increases, the motion of particles increases and the temperature rises. However, when the phase-change temperature is reached, the temperature remains constant while the substance changes phase.

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Latent heat is the energy absorbed or released by a substance during a phase change at constant temperature.

During this process, the temperature does not change. Instead, the energy is used to modify the molecular bonds between particles. For this reason, phase changes require relatively large amounts of energy per unit of mass.

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Heat is the transfer of thermal energy between systems that have different temperatures.

Thermal energy always flows from the hotter system to the colder system until thermal equilibrium is reached.

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Heat transfer occurs through three main mechanisms.

The first mechanism is conduction. This is the transfer of heat through direct molecular contact, and it usually occurs in solids.

The second mechanism is convection. This is the transfer of heat through the movement of fluids such as liquids or gases.

The third mechanism is radiation. Radiation transfers heat through electromagnetic waves and does not require a physical medium.

In many real situations, these three mechanisms occur at the same time.

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In Lesson 1 we introduced the concept of energy efficiency in energy conversion or energy transfer systems.

Energy efficiency is defined as the ratio between useful energy output and energy input. Its value can never be greater than one.

For thermal energy transfer systems, another concept is often used. This is called the coefficient of performance, or COP.

The COP relates the useful thermal energy delivered by the system to the electrical energy used to move or transfer the heat.

For example, electricity may be used by water pumps in geothermal systems, or by the compressor in heat pumps.

The COP can be greater than one because the system is transferring heat rather than creating energy.

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Geothermal energy is thermal energy extracted from the Earth's crust.

This heat originates from the formation of the Earth and from the radioactive decay of minerals inside the planet.

Geothermal energy can be used directly as a source of heat and, in some cases, it can also be used to produce electricity.

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In countries such as the Netherlands, underground water reservoirs with temperatures above eighty degrees Celsius can be found at depths greater than two kilometers.

These reservoirs can be used as a heat source.

A typical geothermal installation consists of two boreholes and a heat exchanger.

One borehole extracts hot underground water. The water passes through a heat exchanger, where its heat is transferred to a secondary water circuit. This secondary circuit supplies heating to buildings, greenhouses, or industrial processes.

After the heat is transferred, the cooled underground water is reinjected back into the underground reservoir.

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During the operational phase, the surface area required for a geothermal installation is relatively small, roughly half a football field.

However, during the drilling phase, the required surface area can be closer to one full football field.

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In some regions of the world, underground water with very high temperature and pressure can be found at relatively shallow depths.

In these cases, geothermal heat can be used to produce steam. This steam drives a turbine connected to a generator, allowing the production of electricity.

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Examples of geothermal power plants that produce electricity can be found in places such as Iceland, where geothermal resources are abundant.

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Geothermal energy offers several advantages.

It is a renewable energy source. It produces very low carbon dioxide emissions during operation. It can provide a reliable and constant energy supply, and it requires a relatively small land area during operation. Operating costs are also relatively low.

In addition, geothermal systems can have a very high coefficient of performance. In some cases, the COP can be around twenty, because large amounts of heat are delivered while only a small amount of electricity is used for pumping.

However, geothermal energy also has some disadvantages.

The initial investment is high, mainly because of the drilling costs. The technology is also location dependent, since suitable underground reservoirs must exist.

If heat extraction exceeds the natural regeneration of the reservoir, resource depletion may occur. There is also a small risk of induced seismic activity.

In some cases, the extracted water may contain natural gas or oil. These substances must be properly managed to prevent equipment damage or atmospheric release.

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Nuclear energy is the energy stored in the nucleus of an atom.

This energy can be released through certain nuclear reactions.

In a nuclear power plant, these reactions produce heat inside the reactor vessel. This heat is used to warm water to a very high temperature.

Because the water is kept under high pressure, it does not boil.

The hot pressurized water flows through pipes in a steam generator. There, it transfers heat to a second water circuit. The second circuit produces steam, which drives turbines connected to generators that produce electricity.

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A fission reactor works by splitting the nuclei of heavy atoms, usually uranium-235.

When a neutron hits a uranium-235 nucleus, the nucleus becomes unstable and splits into two smaller nuclei. This process is called fission.

During fission three main things are released: heat energy, two or three neutrons, and radiation.

The released neutrons can trigger additional fission reactions, creating what is known as a chain reaction.

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To control the chain reaction, nuclear reactors use control rods and moderators.

Control rods are made of materials that absorb neutrons, such as boron, cadmium, or hafnium.

By inserting or removing the control rods, operators can regulate the number of fission reactions taking place.

Water inside the reactor also acts as a moderator. It slows down the neutrons so they are more likely to cause additional fission reactions in uranium-235.

These mechanisms ensure that the reaction remains stable and controlled, producing a steady amount of heat.

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Nuclear power plants are large installations composed of multiple buildings and technical systems.

Often, a single nuclear power plant contains more than one reactor, which increases the total electricity generation capacity.

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Nuclear energy has several advantages.

It produces very low greenhouse gas emissions during operation. It has a very high energy density, meaning that a small amount of fuel can produce a large amount of energy. It can also provide reliable and continuous power generation, which makes it suitable for base-load electricity supply.

Fuel costs during operation are relatively low.

However, nuclear energy also has several disadvantages.

Uranium is not a renewable resource, so fuel availability is limited. Nuclear power also produces radioactive waste that requires long-term storage.

There is also a risk of severe accidents, although such events are rare.

Nuclear power plants involve very high construction costs and long decommissioning processes.

In addition, nuclear energy often faces strong public concern and political resistance in many countries.

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Another common system used to deliver heat is the combustion boiler.

In this system, chemical energy stored in fuels is converted into thermal energy through combustion.

The heat generated during combustion is transferred to water, producing hot water or steam. This heat can be used for heating buildings, industrial processes, or electricity generation.

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Combustion boilers used in residential applications can operate with different types of fuels.

Common fuels include natural gas, fuel oil, liquefied petroleum gas, also called LPG, and biomass such as wood pellets or wood chips.

The choice of fuel often depends on availability, cost, and environmental considerations.

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In industrial applications, combustion boilers are frequently used to produce steam.

This steam can be used directly in industrial processes or it can drive a steam turbine connected to a generator to produce electricity.

Many conventional thermal power plants operate using this principle.

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In some installations, heat and electricity are produced at the same time.

This approach is known as cogeneration, or combined heat and power, often abbreviated as CHP.

Cogeneration increases overall energy efficiency because the waste heat from electricity production is captured and used for heating.

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Combustion boilers offer several advantages.

They provide high heat output and reliable operation. The technology is mature and well known. Boilers can operate with different types of fuels, and they can respond quickly to changes in heat demand. They are also capable of producing very high temperatures, which are necessary for many industrial processes.

However, combustion boilers also have disadvantages.

They can produce high carbon dioxide emissions, especially when fossil fuels are used. They also generate air pollutants such as nitrogen oxides and particulate matter.

Their overall efficiency can be lower than that of some modern heat transfer systems. They depend on a continuous fuel supply and require maintenance and safety systems related to combustion processes.

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Another method for delivering heat is through solar thermal collectors.

These systems capture energy from sunlight and convert it directly into thermal energy.

The heat is transferred to a working fluid, which is usually water or a water-based solution.

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There are two main categories of solar thermal collectors.

The first category is non-concentrating collectors. Examples include flat-plate collectors and evacuated tube collectors.

The second category is concentrating collectors. Examples include parabolic collectors and solar power towers.

Concentrating systems are typically used for large-scale power generation, while non-concentrating collectors are commonly used in buildings.

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In residential applications, solar thermal collectors are mainly used to produce hot tap water.

The collected heat is stored in a hot water reservoir.

Because solar collectors usually cannot provide one hundred percent of the hot water demand, the system normally includes a secondary heat source, such as a boiler or a heat pump.

In power plant applications, large thermal storage reservoirs are used. These reservoirs allow the power plant to continue operating for several hours after sunlight is no longer available.

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Solar thermal collectors offer several advantages.

They use sunlight as their energy source, so operational emissions are very low. Once installed, the energy input is essentially free, which results in low operating costs. Most of the remaining costs are related to pumps and maintenance.

Solar thermal collectors are also very efficient at producing heat. They can convert a relatively large fraction of incoming solar radiation directly into thermal energy. This makes them very suitable for applications such as domestic hot water production or low-temperature heating.

Solar thermal technologies can operate across a wide range of temperatures, from residential systems to high-temperature industrial or power generation applications.

Thermal energy storage is also relatively simple, because heat can be stored in materials such as water or molten salts.

However, solar thermal systems also have disadvantages.

Their output is intermittent because it depends on solar radiation, which varies with weather conditions, time of day, and season.

For this reason, most systems require backup heating systems or thermal storage.

Solar thermal installations also require significant roof or land area. Large concentrated solar power plants may involve complex and expensive infrastructure.

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A heat pump is a device that transfers heat from one location to another using electricity.

Unlike a gas boiler or an electric heater, which generate heat, a heat pump moves existing heat from the environment into a building.

Possible heat sources include the air, the ground, or nearby water.

By reversing the cycle, the same system can also remove heat from a building, providing cooling.

A heat pump operates through a continuous cycle using a working fluid called a refrigerant.

The process begins in the evaporator, which is usually located in the outdoor unit.

In the evaporator, the refrigerant is very cold and absorbs heat from the surrounding environment. As it absorbs heat, the refrigerant evaporates and changes from a liquid into a gas.

The gas then flows into the compressor, where it is compressed. Compression increases both the pressure and the temperature of the refrigerant, producing a very hot and high-pressure gas.

The compressor is powered by electricity and is the main component that consumes energy in the system.

Next, the hot refrigerant enters the condenser, which is usually located inside the building.

In the condenser, the refrigerant releases heat to the building's heating system. This heat can warm indoor air or heat water used in radiators or floor heating systems.

As the refrigerant releases heat, it condenses back into a liquid.

Finally, the liquid refrigerant passes through an expansion valve. In this valve the pressure drops rapidly, which causes the temperature of the refrigerant to decrease significantly.

The refrigerant becomes cold again and returns to the evaporator, where the cycle repeats.

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The coefficient of performance of a heat pump mainly depends on the temperature difference between the heat source and the heat sink.

The smaller this temperature difference is, the higher the COP and the more efficient the system becomes.

For residential heating applications, the highest COP values are often achieved when the ground is used as the heat source and heat is delivered through floor heating systems.

Floor heating operates at relatively low temperatures, which reduces the temperature difference and improves the efficiency of the heat pump.

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Heat pumps offer several advantages.

They can achieve high efficiency, especially when the temperature difference between source and sink is small. They produce low direct carbon dioxide emissions and can use renewable heat from the environment.

Many systems are multifunctional and can provide heating, cooling, and domestic hot water.

However, heat pumps also have some disadvantages.

They usually require a relatively high initial investment. Their performance strongly depends on the temperature difference between the heat source and the heat sink.

In buildings with high-temperature heating systems, such as traditional radiators, the efficiency may be lower.

Heat pumps also depend on electricity supply, and some refrigerants may have environmental impacts if not properly managed.

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These are the references used in this lesson. Additional references are included on the individual slides.

Thank you for your attention, and see you in the next module.