

REIES – Lesson 4a: Heat Delivery

Exercise Sheet

Complete the exercises below to practise the concepts from Lesson 4a. Show all working for calculation questions.

Section A – Knowledge Questions

Exercise 1

Knowledge

The lesson introduces four heat delivery technologies: geothermal energy systems, combustion boilers, solar thermal collectors, and heat pumps. Each has specific advantages and disadvantages.

- For each of the four technologies, state the primary energy source it uses and indicate whether it delivers heat only or can also produce electricity.

Technology	Primary energy source	Delivers heat only / also electricity?
Geothermal system		
Combustion boiler		
Solar thermal collector		
Heat pump		

- Of the four technologies, which is the only one that can have a Coefficient of Performance (COP) greater than 1 while operating without any heat source beyond the fuel it burns? Explain why the others can or cannot exceed $COP = 1$.

Exercise 2

Knowledge

The lesson explains the difference between energy efficiency (η) and the Coefficient of Performance (COP).

- Write the formula for efficiency (η) and the formula for COP. What is the key difference between them?

- A combustion boiler has an efficiency of 92 %. Can its COP ever exceed 1? Explain.
- A heat pump delivers 5 kWh of heat using 1 kWh of electricity. What is its COP? Why is this value greater than 1, and where does the 'extra' energy come from?
- Geothermal systems can reach a COP of up to 20. Explain physically why such a high value is possible.

Exercise 3

Knowledge

The lesson covers three mechanisms of heat transfer: conduction, convection, and radiation.

- Define each mechanism in one or two sentences and give one example from everyday life.
- In a geothermal installation, underground hot water is pumped to a heat exchanger. Identify which heat transfer mechanism is primarily responsible for: (a) moving the thermal energy underground, (b) transferring it to the secondary circuit in the heat exchanger.
- In a solar thermal flat-plate collector, which mechanisms are involved in (a) the sun delivering energy to the absorber plate, and (b) the absorber plate heating the water in the tubes?

Exercise 4

Knowledge

Each of the four heat delivery technologies has a list of advantages and disadvantages given in the lesson.

- The lesson lists 'location-specific' as a disadvantage for both geothermal energy and solar thermal collectors, but for different reasons. Explain the location constraint for each.
- Combustion boilers and solar thermal collectors can both supply heat to a building. Give two reasons why a building owner in a northern European country might still choose a combustion boiler over solar thermal collectors despite the environmental advantages of solar.
- Heat pumps are described as 'multifunctional'. What does this mean in practice? Give two different services the same heat pump device can provide.
- The lesson notes that cogeneration (CHP) can significantly increase overall energy efficiency. Explain in your own words why a CHP unit uses less primary energy than a separate boiler and separate power plant delivering the same amounts of heat and electricity.

Section B – Calculation Questions

Exercise 5

Calculation

Thermal energy stored in a water tank. A hot water storage tank contains 300 litres of water. The specific heat of water is $c_p = 4\,180 \text{ J/(kg}\cdot\text{K)}$ and the density of water is 1 kg/litre.

1. The water is heated from 15°C (cold supply) to 65°C . Calculate the thermal energy stored (in Joules and in kWh). Use: $Q = m \cdot c_p \cdot \Delta T$
2. A family uses 100 litres of hot water per day. How many full tanks are needed per day, and how many kWh does heating this water require?
3. If a solar thermal collector with area 4 m^2 and efficiency 65 % receives an average solar irradiance of 500 W/m^2 , what is the collector's useful output power (W) and daily energy output (kWh, assuming 6 hours of effective sunshine)? Is this enough to supply the daily hot water demand calculated above?

Exercise 6

Calculation

Latent heat and phase change. An ice-storage system uses 500 kg of ice to provide cooling. The latent heat of fusion of water is $L_f = 334\,000 \text{ J/kg}$.

1. How much thermal energy (in MJ and kWh) is absorbed when all the ice melts at 0°C ?
2. After the ice has melted, the resulting water warms from 0°C to 20°C . How much additional sensible heat is absorbed? Use $c_p = 4\,180 \text{ J/(kg}\cdot\text{K)}$.
3. What percentage of the total heat absorbed (melting + warming) is due to the phase change alone? What does this tell you about the energy density advantage of latent heat storage?

Exercise 7

Calculation

Geothermal heat exchanger. A geothermal system pumps 20 kg/s of hot underground water from a reservoir. The water enters the heat exchanger at 85°C and leaves at 35°C . Use $c_p = 4\,180 \text{ J/(kg}\cdot\text{K)}$.

1. Calculate the thermal power (in kW and MW) delivered by the underground water to the heat exchanger. Use: $P = \dot{m} \cdot c_p \cdot \Delta T$ (where $\dot{m}$ is mass flow rate in kg/s)

- The water pumps use 50 kW of electrical power. Calculate the COP of the geothermal heat delivery system.
- How many average Dutch homes (each needing approximately 17 000 kWh of heat per year) could this geothermal installation supply? First convert the thermal power to annual energy (assume 8 000 operating hours per year).

Exercise 8

Calculation

Heat pump COP and energy comparison. A ground-source heat pump serves a house that needs 14 000 kWh of heat per year. The heat pump uses the ground (at 10 °C) as its source and delivers heat to a floor heating system at 35 °C. According to the lesson's COP table, this combination gives a COP of 4.8.

- How much electrical energy (kWh/year) does the heat pump consume?
- A natural gas boiler with 92 % efficiency would need how many kWh of gas to supply the same heat? (Note: the energy content figure is the gas input energy.)
- At an electricity price of €0.30/kWh and a gas price of €0.12/kWh, calculate the annual running cost for both systems. Which is cheaper to run in this scenario?
- At what electricity price (€/kWh) would both systems cost the same to run (keeping gas at €0.12/kWh)? Set up and solve the equation.

Exercise 9

Calculation

Temperature conversion and specific heat. A granite rock mass of 2 000 kg is used as a sensible heat storage medium. Granite has $c_p = 790 \text{ J/(kg}\cdot\text{K)}$.

- Convert the following temperatures to the other two scales, completing the table:

Kelvin [K]	Celsius [°C]	Fahrenheit [°F]
	20	
		212
300		
	-10	

- The granite is charged (heated) from 20 °C to 200 °C. How much thermal energy (in MJ and kWh) is stored?

3. Compare this with the energy stored in 300 litres of water heated from 20 °C to 65 °C ($c_{p_water} = 4\,180 \text{ J/(kg}\cdot\text{K)}$). Which stores more energy per kilogram? Which stores more total energy in this scenario?

Exercise 10

Calculation

Nuclear power plant heat balance. A nuclear power plant has a thermal power output from the reactor of 3 000 MW (thermal). The overall efficiency of converting thermal energy to electricity is 33 %.

1. How much electrical power (MW) does the plant generate?
2. How much thermal power (MW) is rejected as waste heat (to cooling water or cooling towers)?
3. If this waste heat could instead be used in a district heating network, how many homes (each needing 10 kW peak heat demand) could it theoretically supply?

Section C – Internet Exploration

Exercise 11

Internet Exploration

Heat pumps are rapidly growing in Europe, driven by the energy crisis and climate targets.

- Visit the European Heat Pump Association website (<https://www.ehpa.org>) or search for 'heat pump market Europe 2024'. Find: (a) how many heat pumps were sold in Europe in the most recent reported year, and (b) which country has the highest sales per capita.
- Look up the IEA page on heat pumps (<https://www.iea.org/energy-system/buildings/heat-pumps>). What share of global heating in buildings is currently supplied by heat pumps, and what share does the IEA Net Zero scenario require by 2030?
- Search for 'heat pump cold climate performance' or visit <https://www.now-gmbh.de> or a similar source. Find: at what outdoor air temperature do air-source heat pumps typically struggle, and what is the COP at -10 °C compared to +7 °C? Write 3–5 sentences summarising your findings.

Section D – Home Experiments

Exercise 12



Home Experiment – Measuring Specific Heat with a Kettle

In this experiment you will measure the specific heat capacity of water using a household kettle and a kitchen thermometer. This connects directly to the thermal energy formula $Q = m \cdot c_p \cdot \Delta T$ from the lesson.

Materials needed (no purchase required):

- An electric kettle with a known power rating (printed on the label, typically 1 500–2 200 W)
- A kitchen thermometer (probe type) or an instant-read thermometer
- A measuring jug (to measure volume in millilitres)
- A stopwatch or phone timer
- Pen and paper

Procedure:

1. Pour exactly 500 ml of cold tap water into the kettle. Record the starting temperature T_1 (°C).
2. Switch the kettle on and immediately start your timer. Let it heat for exactly 60 seconds, then switch it off before it boils.
3. Stir the water gently and record the final temperature T_2 (°C).
4. Note the kettle's rated power P (W) from the label.
5. Repeat the experiment with 1 000 ml of water and the same 60-second heating time. Record T_1 and T_2 for this run too.

Calculations:

- Energy input by the kettle in 60 seconds: $E = P \times t$ (in Joules, where $t = 60$ s)
- Assuming all electrical energy goes into the water (100 % efficiency assumption): $E = m \cdot c_p \cdot \Delta T$. Rearrange to find c_p : $c_p = E / (m \cdot \Delta T)$. Use mass in kg (500 ml = 0.5 kg).
- Compare your measured c_p to the textbook value of 4 180 J/(kg·K). What is the percentage error?

Reflection questions:

- Why is your measured c_p likely to be higher than the true value of water? (Hint: where does the 'extra' energy go besides the water?)

- When you doubled the water volume, did ΔT halve approximately? What does this tell you about the relationship between mass and temperature change?
- If you repeated this experiment with 500 ml of vegetable oil ($c_p \approx 1\,670\text{ J/(kg}\cdot\text{K)}$, density $\approx 0.92\text{ kg/litre}$), would you expect a larger or smaller temperature rise for the same energy input? Calculate the expected ΔT and compare.

Exercise 13



Home Experiment – Building a Simple Solar Thermal Collector

In this experiment you will build a simple flat-plate solar thermal collector using household materials and test it outdoors (or on a windowsill in sunlight). This directly demonstrates the principle behind the flat-plate solar thermal collectors described in the lesson.

Materials needed (low cost, most may be at home):

- A plastic bottle (500 ml or 1 litre, clear or dark)
- Black paint or black tape (to coat the bottle — black surfaces absorb more radiation)
- A cardboard box slightly larger than the bottle
- Aluminium foil (to line the inside of the box as a reflector)
- Cling film or a transparent plastic bag (to cover the top of the box — acts as the glazing)
- A kitchen thermometer
- A stopwatch or phone

Assembly:

1. Paint the bottle black (or wrap in black tape) and fill it with exactly 200 ml of cold tap water. Record the starting temperature.
2. Line the inside of the cardboard box with aluminium foil (shiny side inward) to act as a reflector.
3. Place the black bottle inside the box, and cover the open top of the box tightly with cling film. This creates a greenhouse effect inside.
4. Place the box in direct sunlight (or as close to a bright south-facing window as possible), angled toward the sun.
5. Record the water temperature every 5 minutes for 30 minutes. Keep a control bottle (plain, uncovered, same water volume) in the shade and record its temperature too.

Record your results:

Time (min)	Temp – collector (°C)	Temp – control (°C)
0		
5		
10		
15		
20		
25		
30		

Reflection questions:

- What is the temperature difference between the collector and the control bottle at 30 minutes? This difference is entirely due to your collector design.
- Estimate the thermal energy gained by the water in your collector over 30 minutes using $Q = m \cdot c_p \cdot \Delta T$ ($m = 0.2 \text{ kg}$, $c_p = 4180 \text{ J/(kg}\cdot\text{K)}$).
- Why does the black surface improve performance? Which of the three heat transfer mechanisms is most relevant here?
- What role does the cling film (glazing) play? Relate your answer to the greenhouse effect and the types of radiation (long-wave vs. short-wave infrared) discussed in the lesson.
- What limitations does your simple collector have compared to a real commercial flat-plate solar thermal collector? List at least two.