Non-Potable water in the Gas Network to support electrically-driven heat pumping (GAS-NET-NEW)

Ice Source Heat Pumps

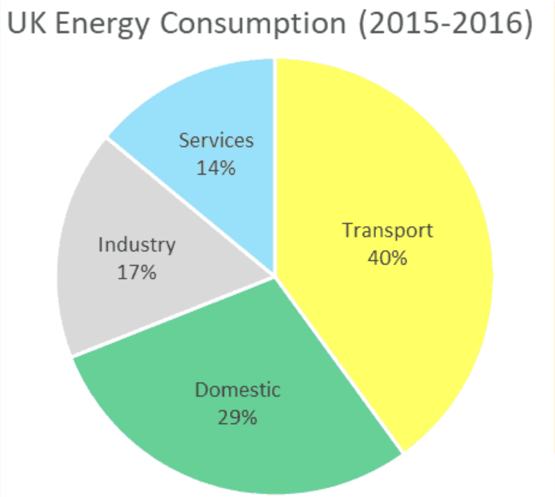
R.Mehdipour, S.Garvey, B.Cárdenas , Z. Baniamerian

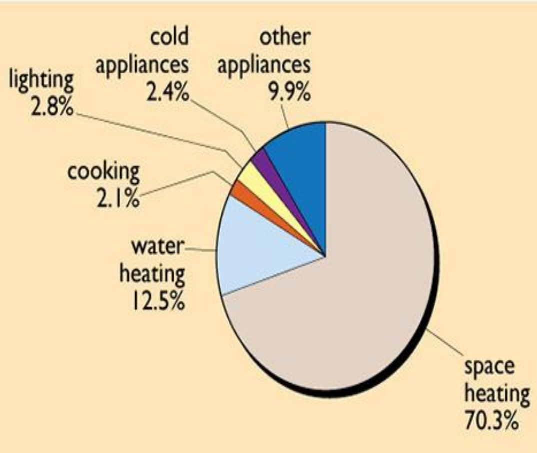
Decarbonising UK domestic heating: Disruptive approaches

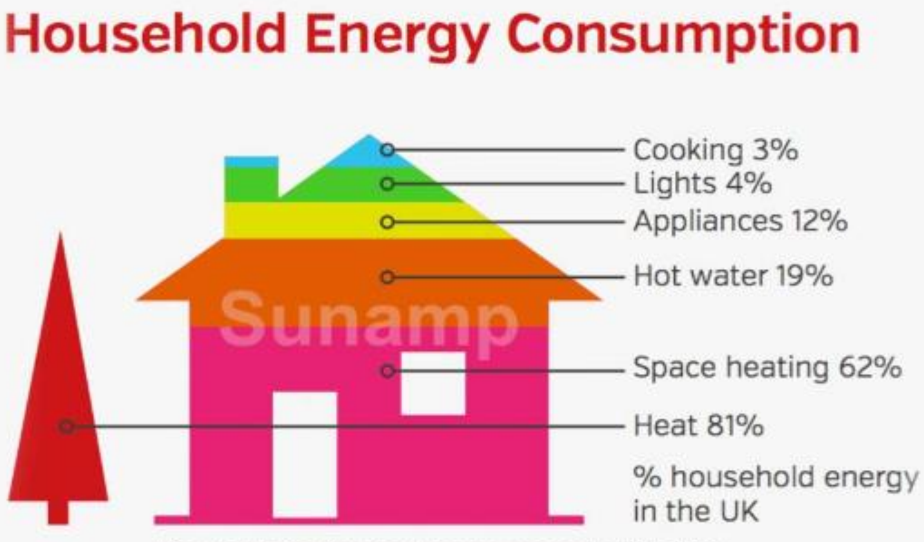
6th of November, 2024. IMechE, London

The Importance of Phasing Out Natural Gas for Heating

- Reduction of **greenhouse gas emissions and CO2 production** is a top global and UK priority.
- Set goals for **zero greenhouse gas emissions by 2030 and 2050**, prompting a re-evaluation of fuel choices.
- Current Challenges in the UK for Heating:
  - ❑ Heating and hot water account for around 80% of household energy use, with over 24 million UK homes relying on natural gas boilers, contributing to approximately 30% of the nation's carbon emissions.
  - ❑ Significant emission reductions in this area are essential to achieving national climate goals.
  - ❑ While comprehensive policies exist for carbon neutrality in transportation, similar success is lacking for energy consumption in industries and homes.







*Source: United Kingdom housing energy fact file 2012

Alternative solutions for natural gas-fired heating systems

Electrification

Direct Use of Clean Electricity for Heating

Heat Pumps

These systems efficiently transfer renewable heat from sources like air, water, and the ground.

Alternative Fuels Technologies

Hydrogen-Based Heating
Hydrogen presents a promising low-carbon option, though its widespread adoption will require infrastructure upgrades, policy support, and advancements in green hydrogen production.

Biomass Heating Systems
Biomass offers a renewable option by using organic materials, but it requires sustainable sourcing and infrastructure development to ensure minimal environmental impact.

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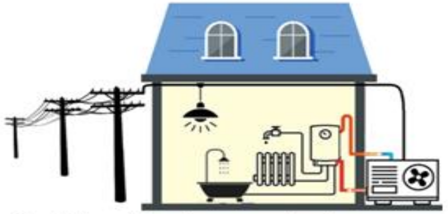
District heating

Energy supply by electricity and gas

Provision of heating energy by electricity

Provision of heating energy by water-source heat pump



Provision of heating energy by air-source heat pump

Heat Pump Solutions

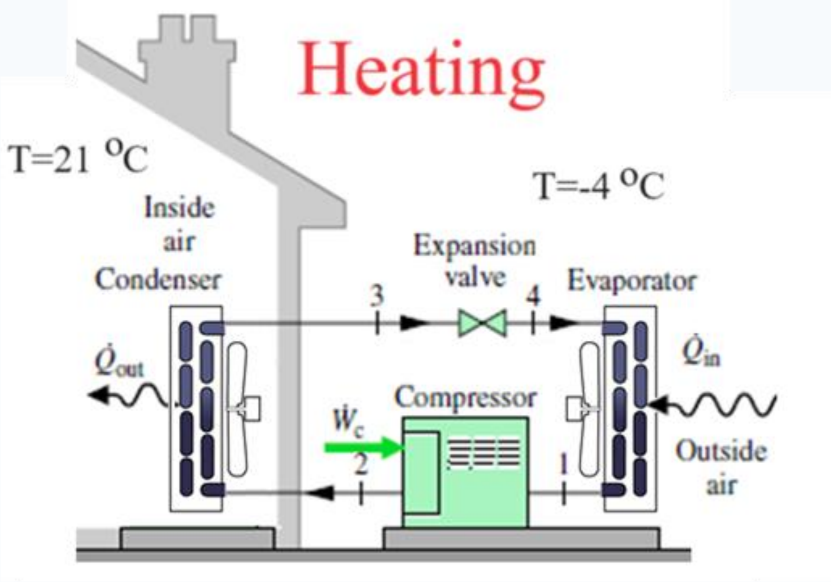
- Heat pumps are efficient systems that transfer heat from natural sources such as air, water, or the ground into buildings.

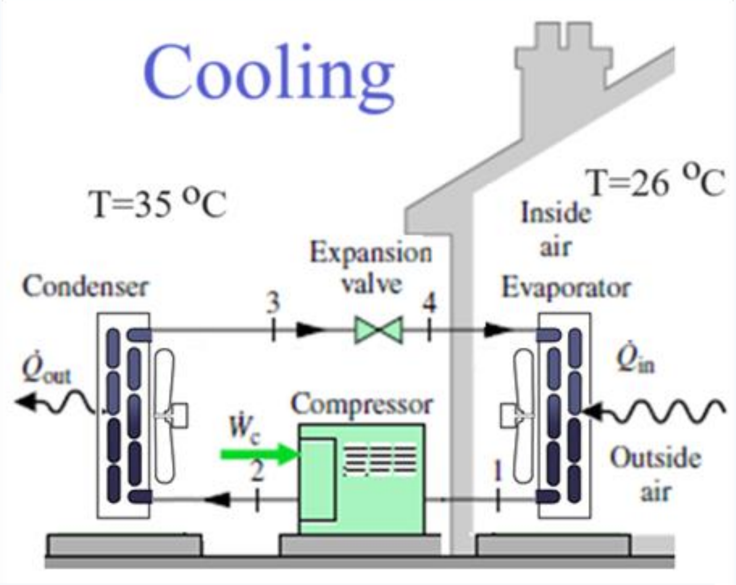
- Heat pumps can derive a significant portion of their heating energy from low-temperature thermal sources, reducing the reliance on electrical energy.

Heat pumps can utilize a variety of heat sources:

- Air
- Water(Lakes, Rivers, Rainwater, Black water (wastewater)
- Ground-source heat pumps(extracting heat from the earth)

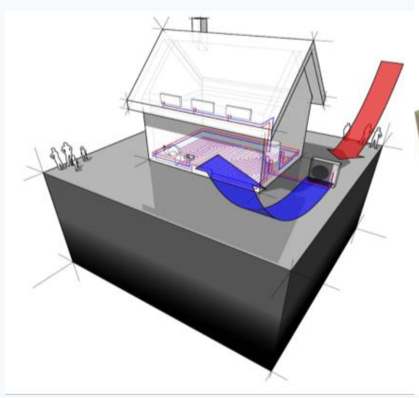
It is the most important clean energy solution for heating.

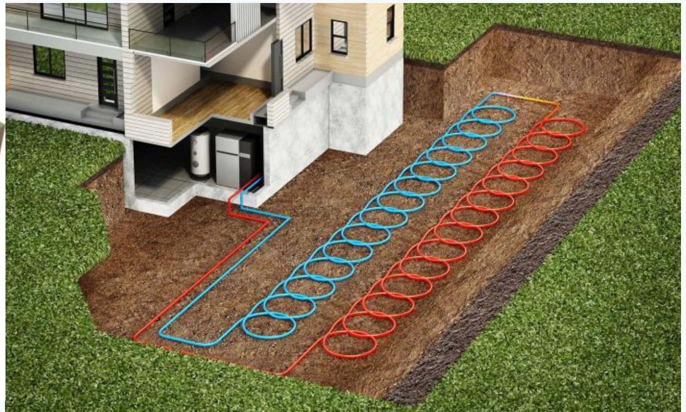




Comparison of Heat Pumps

Heat Pump Type	Advantages	Disadvantages
Air Source Heat Pumps	- Relatively low installation costs	- Reduced efficiency in cold temperatures
	- Easy to install and retrofit into existing buildings	- Performance can drop significantly during peak cold periods
	- Can provide cooling in addition to heating	- Requires backup heating in extremely cold climates
Water Source Heat Pumps	- High efficiency due to stable water temperatures	- High water consumption and potential ecological impact
	- Ability to draw heat from multiple sources (lakes, rivers, etc.)	- Dependence on proximity to water sources
	- Generally requires less energy compared to air-source systems	- May require permits and regulations related to water usage
Ground Source Heat Pumps (Geothermal)	- Consistent performance year-round due to stable underground temperatures	- High installation costs and complexity
	- Very low operating costs once installed	- Requires significant land area for horizontal systems
	- Environmentally friendly with minimal emissions	- Longer payback period compared to other heat pump types





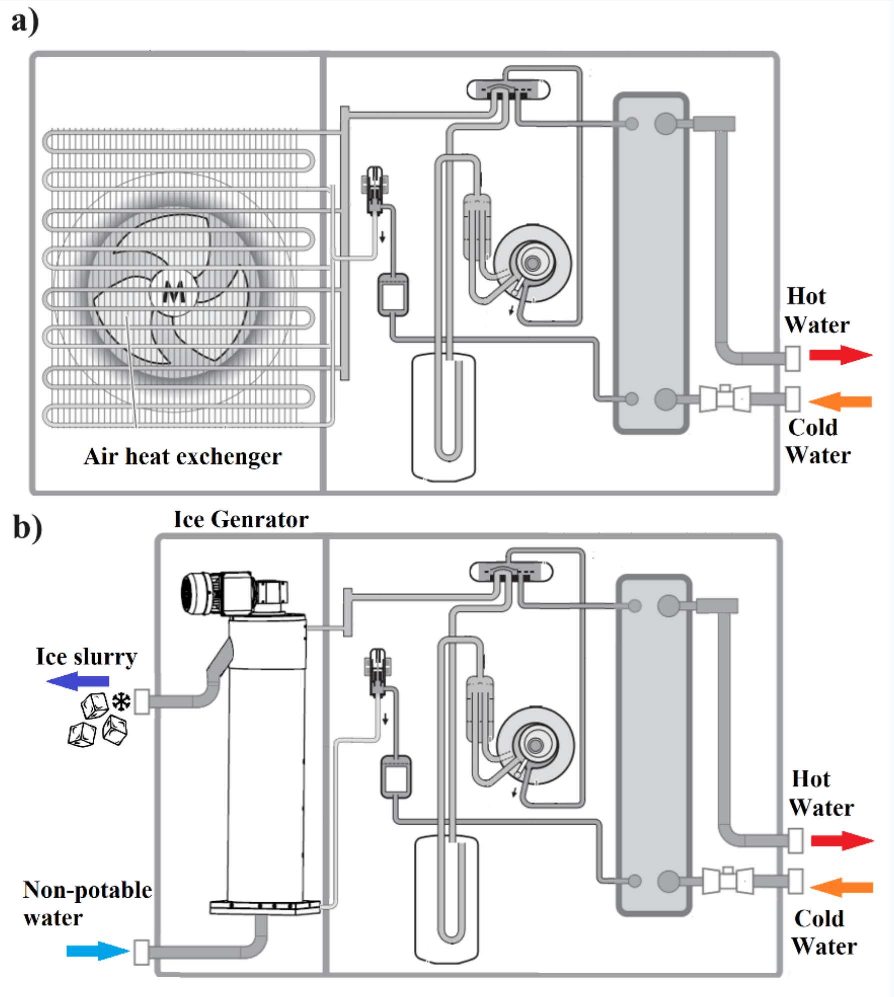
The coefficient of performance of heat pumps with different heat sources.

	COP(min)	COP(max)
Heating by air	4.32	5.85
Heating by lake and river water	4.77	6.33
Heating by Ground	4.77	6.24
Heating by pipe water (winter)	4.77	5.13
Heating by pipe water (autum)	4.77	6.21
Heating by waste water (grey water)	4.77	9.37
Heating by ice	4.77	4.77

Ice-Source Heat Pumps

An Ice Source Heat Pump is a thermal system that utilizes heat transfer from an ice source to water. This system uses the latent heat generated during the phase transition from liquid to ice to transfer heat.

By employing phase change technologies like ice production, these systems can transfer heat to the environment while minimizing water consumption.



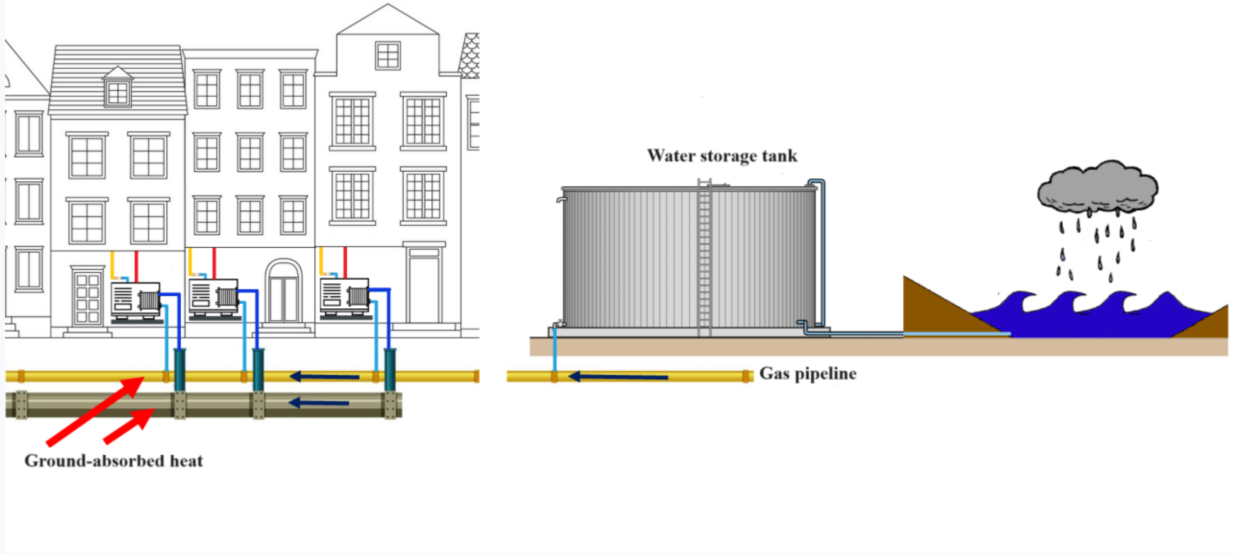
Highlighted Data:

The dimensionless energy ratio, comparing the energy required to freeze one kilogram of water (334 kJ) with the energy needed to raise the temperature of the same amount of water by 1 degree Celsius (4.18 kJ), is approximately **80**.

Implementation of the Central Ice Heat Pump

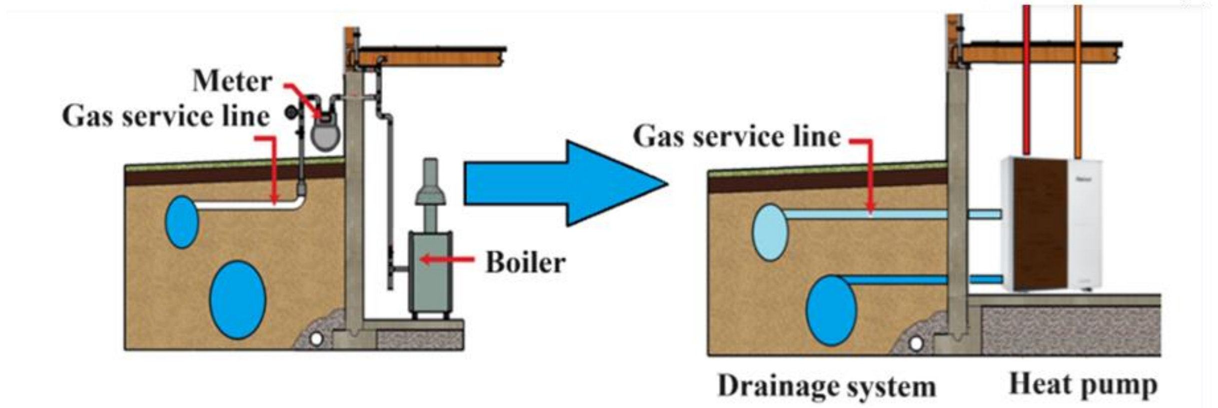
Non-potable water in the gas network

- In the proposed system, an ice-source heat pump is used as the heating system, and gas pipes are utilized to supply and transfer water for this system. The heat pump extracts the energy from the water to heat the residential unit, converting the water into ice, which is then discharged into the drainage system.



Infrastructure Benefits:

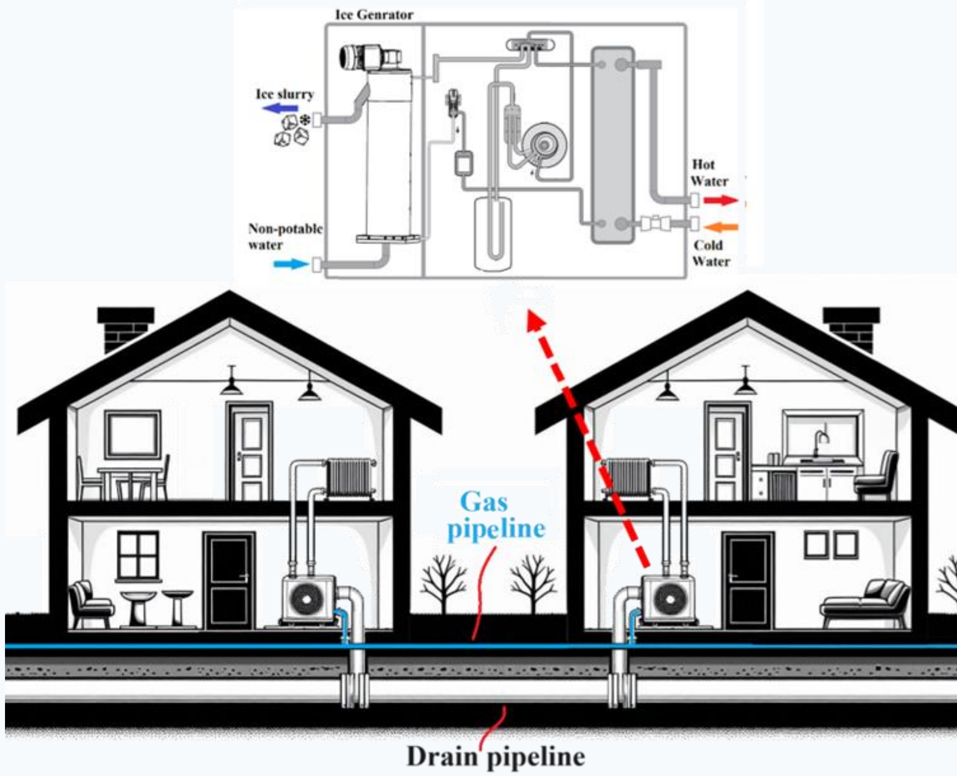
- This approach integrates with existing pipelines, requires no additional piping, and offers a centralized, compact solution.
- Furthermore, the system's use of stable ground temperatures aligns with the principles of geothermal heat pumps.



Installation of the heat pump into the gas and wastewater pipeline system.

Advantages of this system:

- **Space Efficiency:** Suitable for densely populated areas by using existing gas pipelines, avoiding new installations.
- **Compact and Quiet Design:** Smaller, quieter heat pump without air components, suitable for enclosed spaces.
- **Cost-Effective Centralization:** Lower costs through centralized heating/cooling for multiple units using existing infrastructure.
- **Reduced Electricity Use:** Consumes less electricity compared to air-source heat pumps.
- **No New Piping Needed:** Avoids additional piping installations near buildings.
- **Water Supply for Additonal Use:** Provides non-potable water for gardening and sanitary purposes.
- **Optimized Subsidies:** Facilitates targeted government subsidies for energy projects.

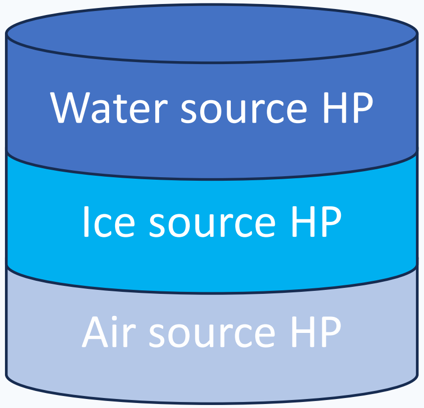


Performance Evaluation of the Heating System

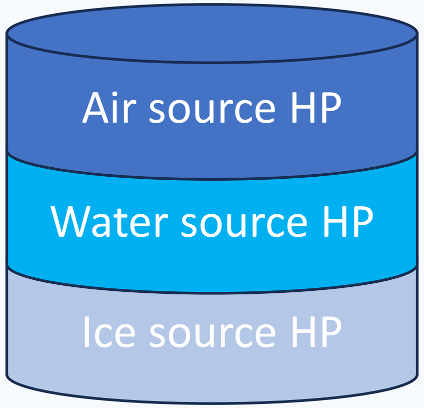
A residential unit was modelled with different heating system configurations (gas boiler, air source heat pump, water source heat pump, ground source heat pump, and ice source heat pump).

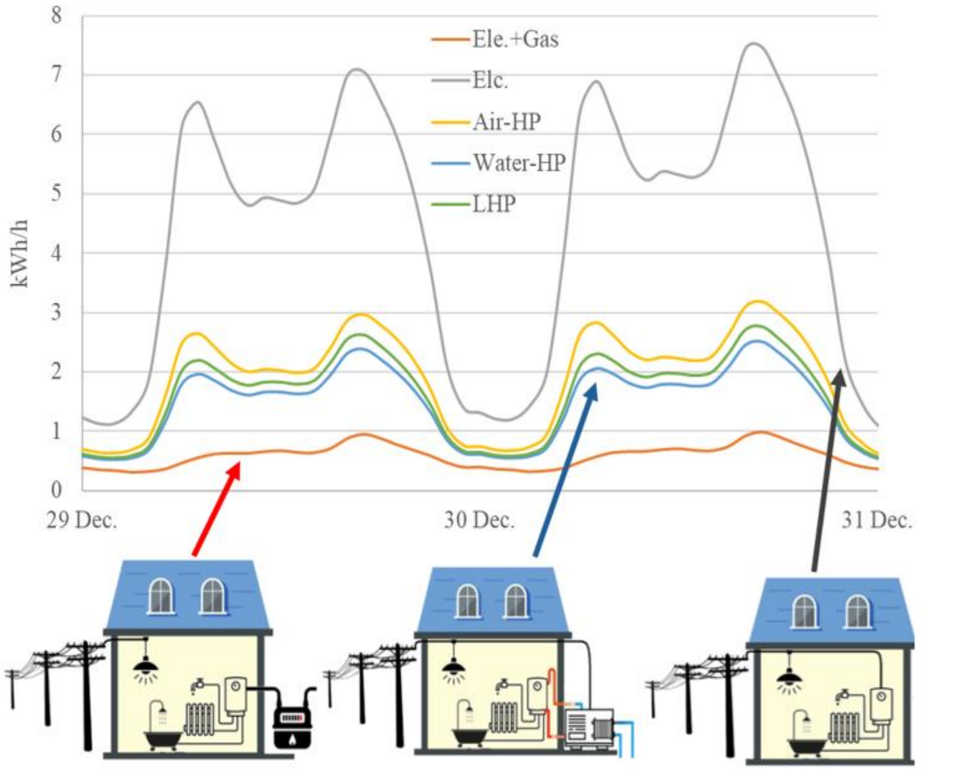
The peak electricity consumption has increased by 3.2 times for an air-source heat pump, 2.5 times for a water-source or ground-source heat pump, and 2.75 times for a Latent heat pump.

Cold peak



Autumn and Spring



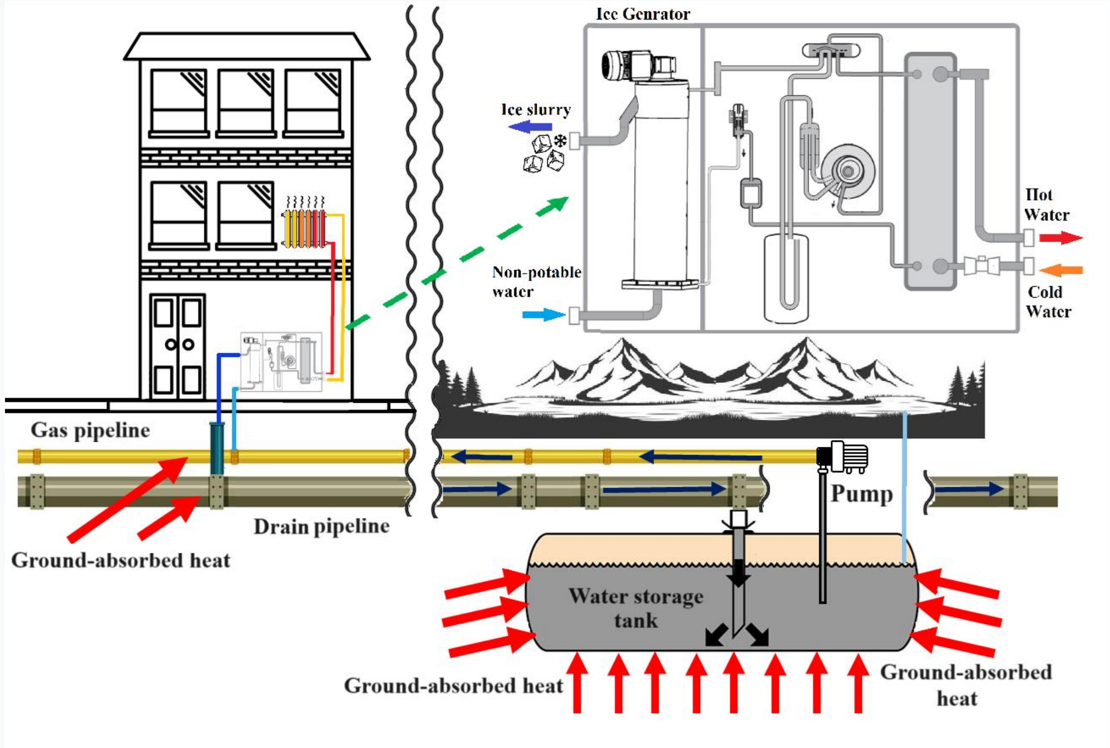


electricity consumption per residential unit in three heating scenarios: gas heating, electric heating, and heat pump heating.

However, the performance of air source heat pumps declines significantly during peak cold periods, which may reduce their efficiency to that of a simple heater, leading to a sevenfold increase in peak electricity consumption.

Important question

The summary shows that the proposed system performs comparably to a geothermal heat pump, but offers easier implementation and greater simplicity than an air-source heat pump.



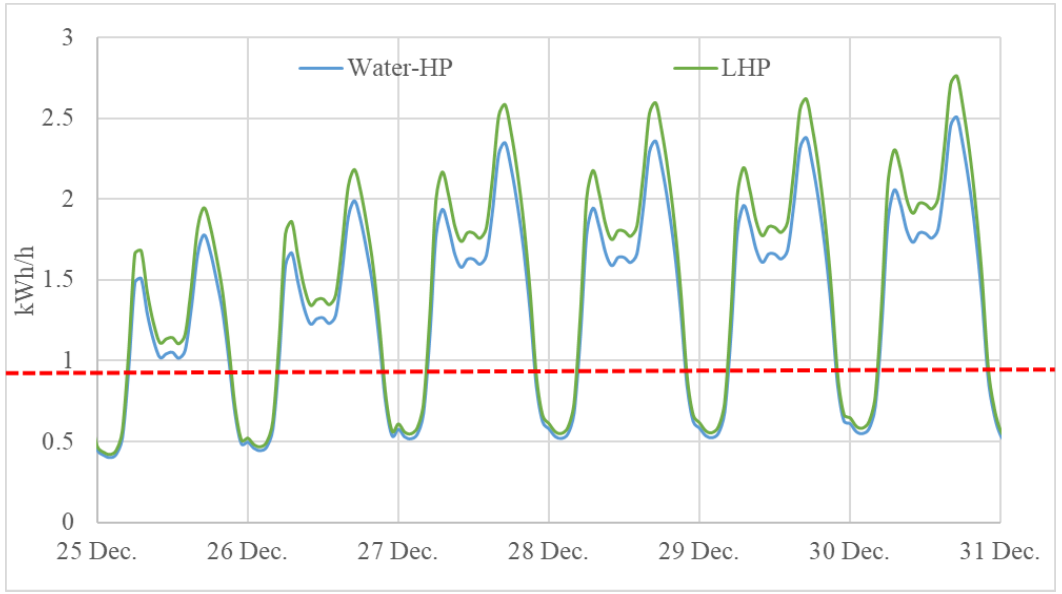
- Is a water-source heat pump or an ice-source heat pump suitable for this system?
- What is the volume of piping required to transfer water for this system?
- Does the existing gas piping infrastructure have the capacity to accommodate water transport?

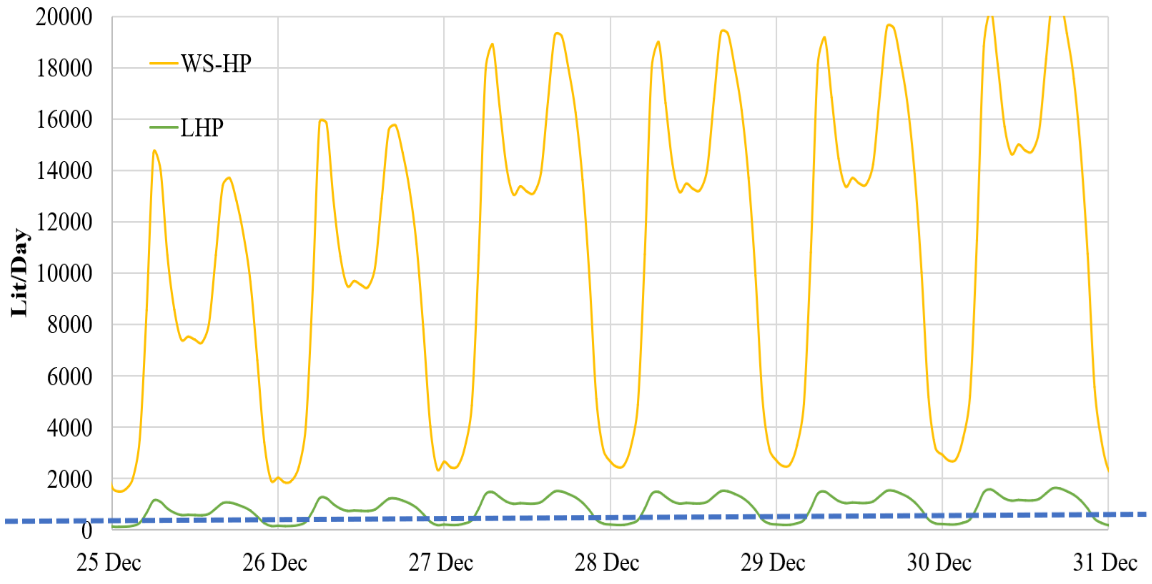
Water source Heat pumps or Ice source Heat pumps

- It is true that water-source heat pumps perform better, but only when there is abundant access to water.

- In areas with limited access to water or geothermal heat pumps, there is little performance distinction between this system and the ice-source heat pump heating system.

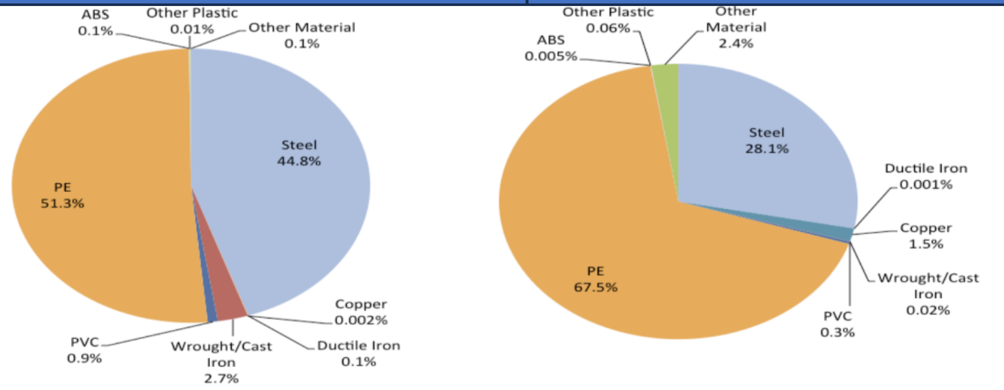
- Ice-source heat pumps use 37.56 times less water than water-source pumps, with slightly lower thermal performance.





Water transfer through gas pipes

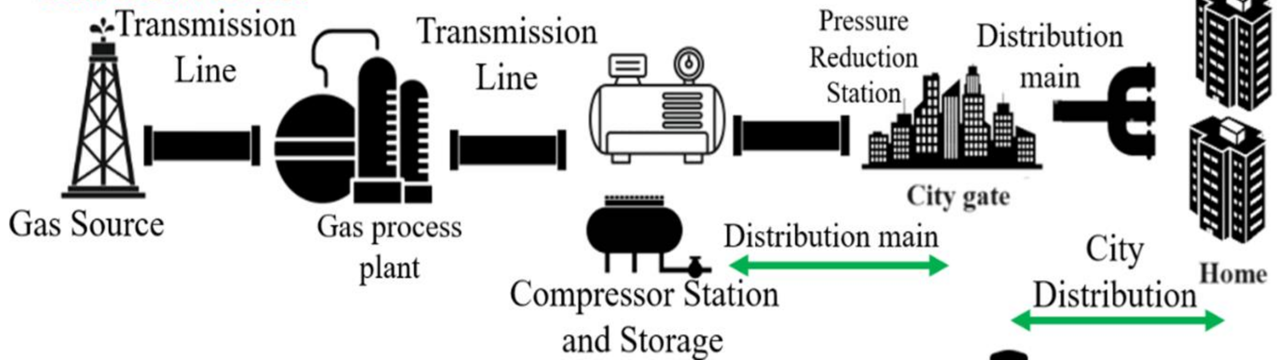
Materials used in piping	
Gas Pipes: Metal Piping, PVC Pipe, Fiberglass Pipe, PE Gas Pipe, Aluminium-Plastic, APCP, Hot Dip Galvanized Steel Pipes, HDPE.	**Water Pipes:** PVC Pipes, Steel Pipes, Copper Pipe



(c) Distribution mains (d) Distribution service lines

Pressure in pipeline	
Gas Source: 6.895 to 103.42 bars. Pressure Boosting Station: 13.79 to 103.42 bars. Inter-City Transmission Lines: 6.895 to 68.95 bars. Pressure Reduction Station: 0.6895 to 13.79 bars. City Distribution Network: 0.2758 to 4.137 bars. Regulators at Residences: 0.2758 to 0.8274 bars.	City Water Pressure: In municipal water distribution networks, water pressure typically falls within the range of 2.8 to 5.5 bar. These values can vary in different areas and networks. Domestic Water Pressure: In domestic plumbing systems inside buildings, water pressure commonly ranges from 1.4 to 4.1 bar.

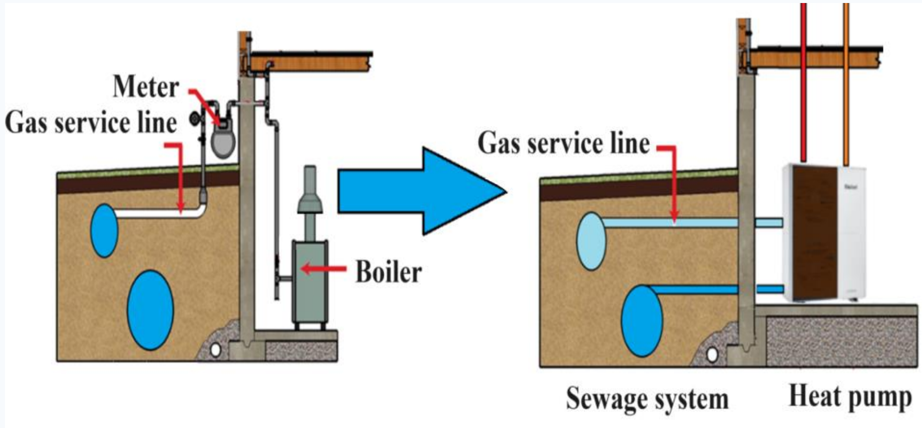
Gas networks:



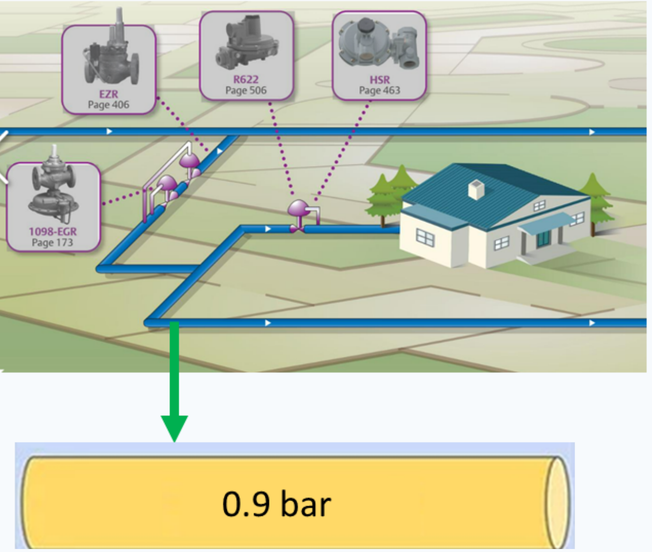
Water networks:

Evaluation of Energy Transfer Capability through Pipes

- If the existing gas pipes are repurposed for transporting water to supply heating in this system, they can provide approximately 39.66% of the previous heating capacity based on the heating value of natural gas.

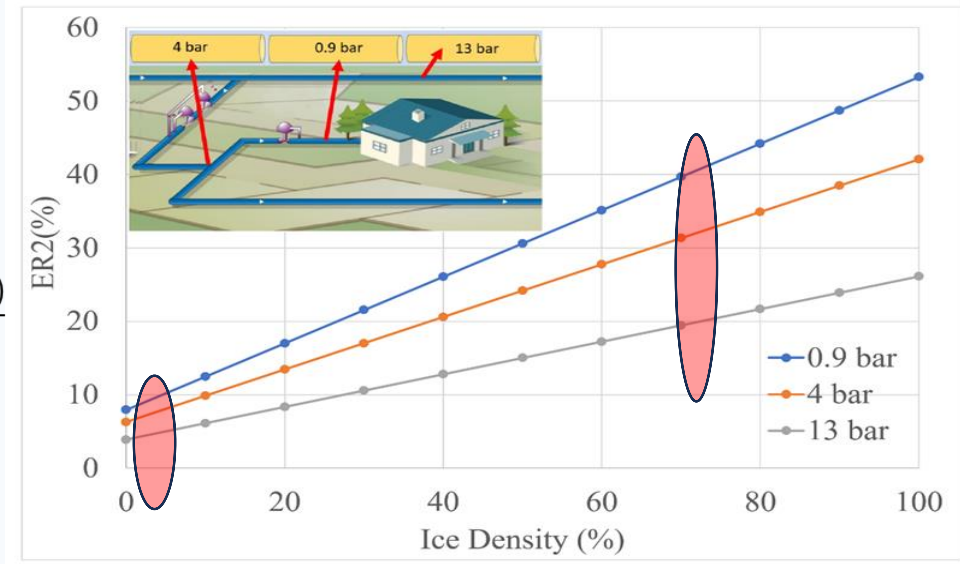


- The modelling showed that the heating system's water consumption is 2.3 times the unit's drinking water usage, rising to 86.5 times with a water-source heat pump.



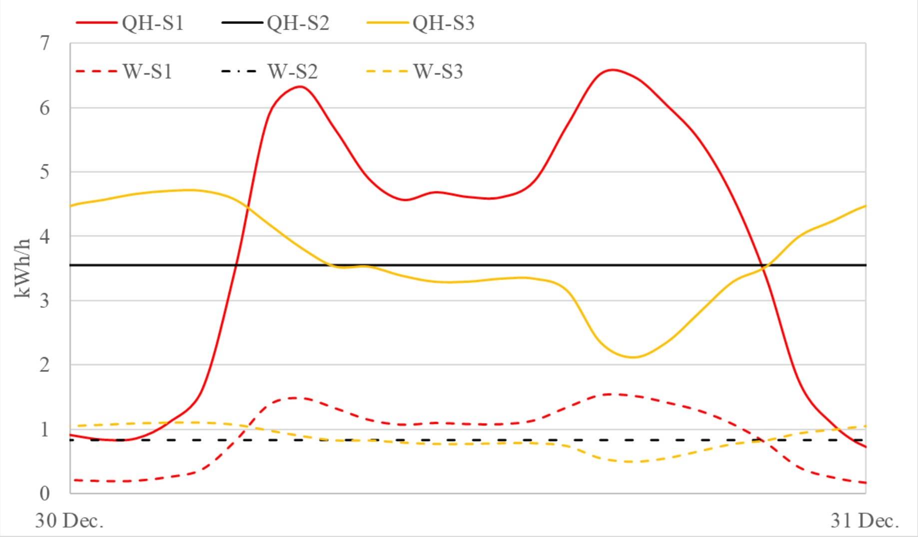
Energy (water) Transport Capability by Gas Pipe

- $ER1 = \frac{\dot{E}_W}{\dot{E}_{NG}} = \frac{\dot{m}_W(c_W T_W + x h_f)}{\dot{m}_h (HV)} = \frac{\rho_W V_{max,W} A_P (c_W T_W + x h_f)}{\rho_{NG} V_{max,NG} A_P (HV)}$
- $ER2 = \frac{\dot{E}_W \frac{COP}{COP-1}}{\dot{E}_{NG}} = \frac{COP}{COP-1} ER1$



Thermal Energy Storage

The study explores the use of phase change material (PCM) energy storage to reduce peak electricity demand, achieving a reduction of 40.75% for ice-source systems. The peak electricity consumption increased by a factor of 2.75 to 1.63 times.



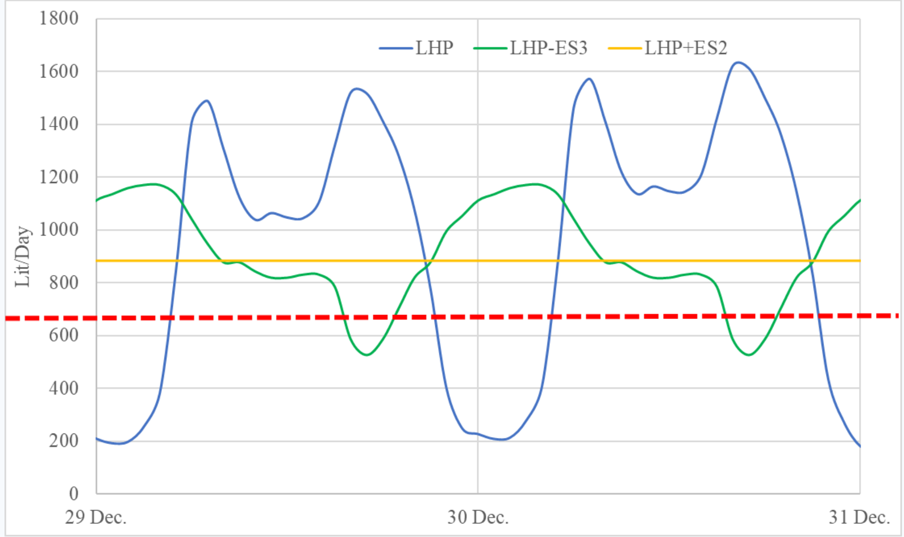
Providing heating to customers through the existing pipelines

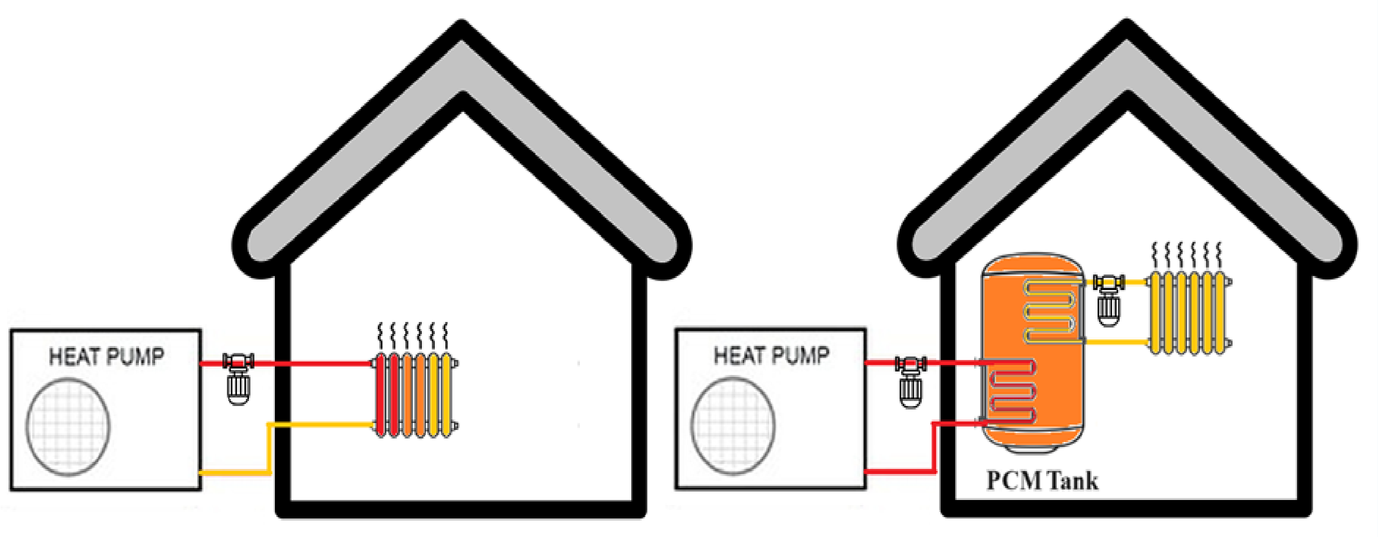
Peak electricity consumption

ER Factor

39.66% → 54.98%

2.75 times → 1.63 times



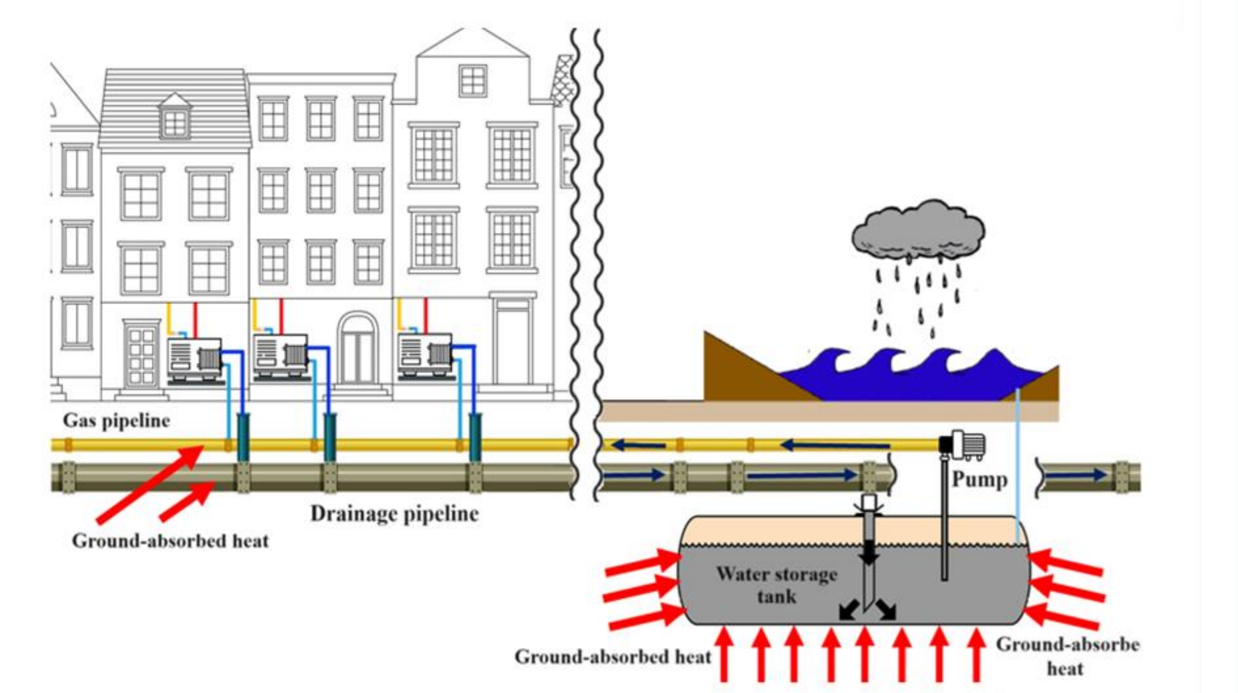


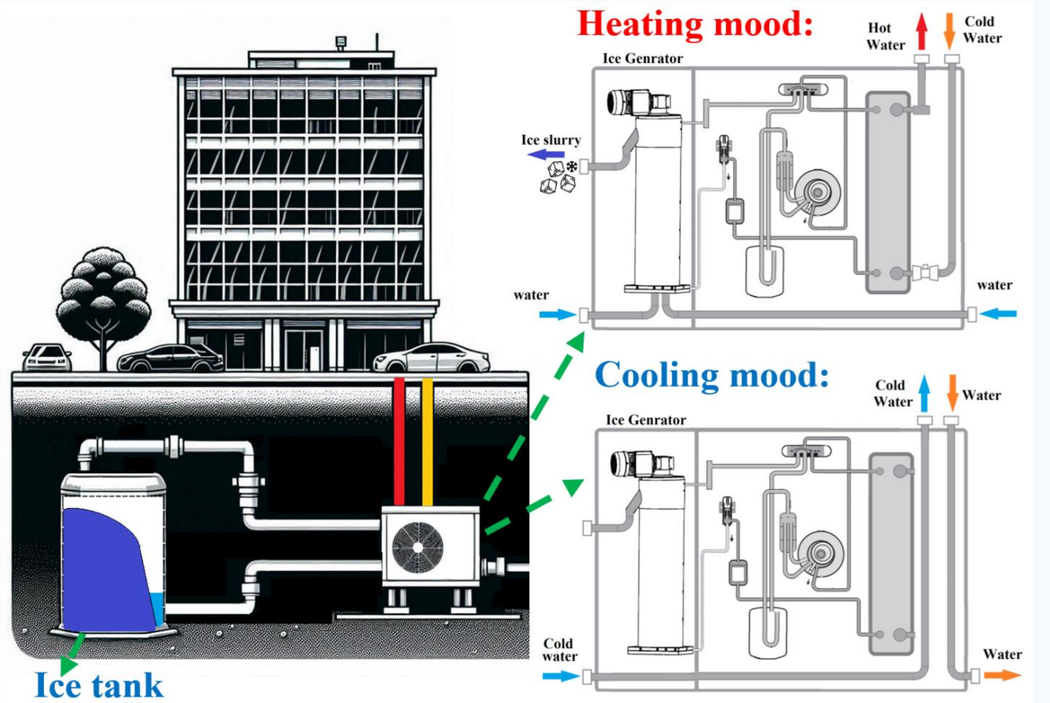
Is this system only suitable for high-rainfall areas?

Closed-loop cycle

Seasonal storage system

The primary advantage of this system, aside from its heating capabilities, is the ability to store and preserve water as ice during the cold season for use and transfer in the warm season.

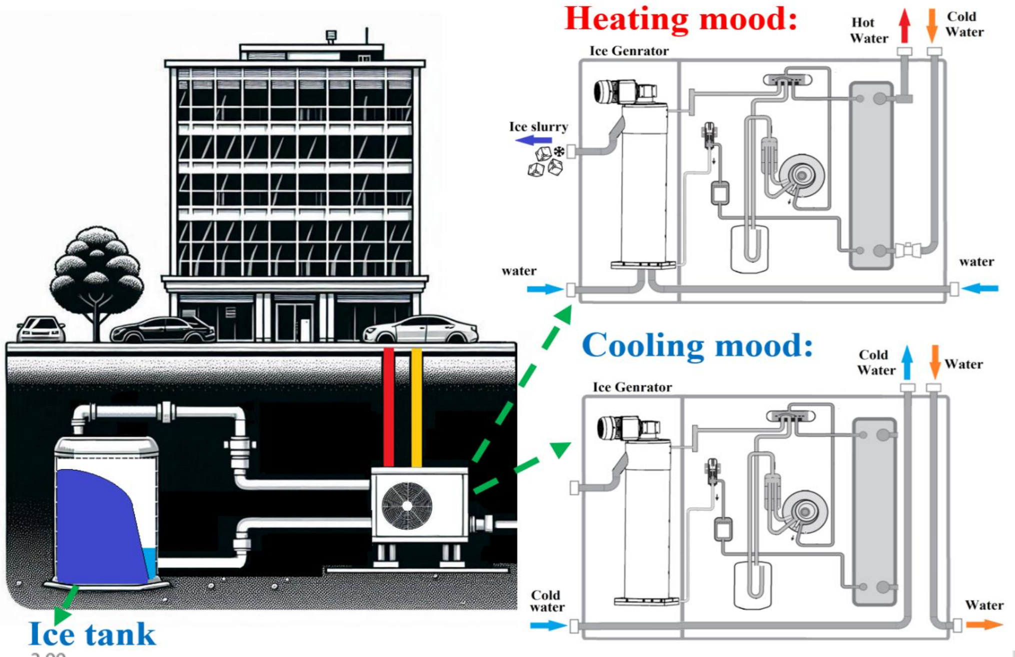


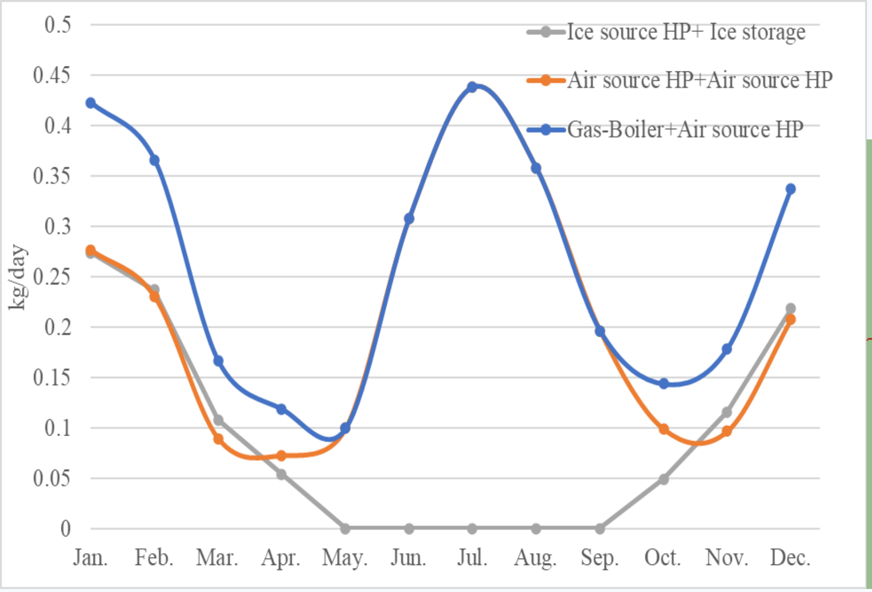


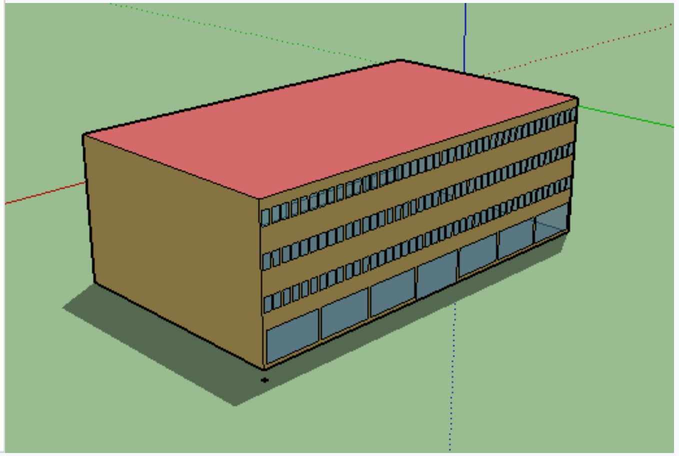
Ice-Source Heat Pump Seasonal storage system

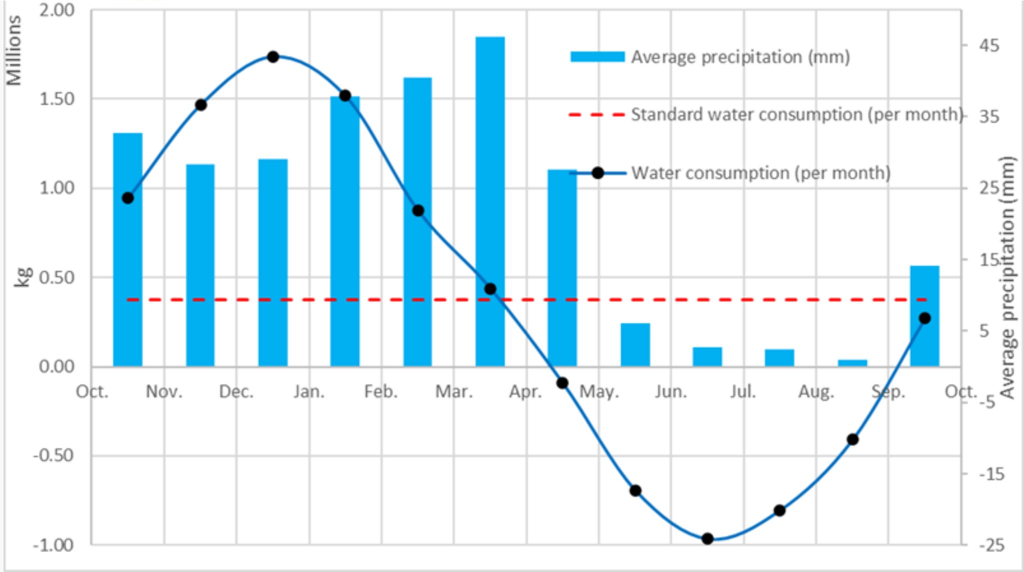
The system performs three functions: winter heating, summer cooling, and water storage

- Approximately 60% reduction in gas consumption throughout the year
- In some areas, a complete reduction in energy consumption for cooling
- Reduced heating energy consumption compared to gas boilers in winter
- Water storage and reduced water loss (similar to natural glaciers)





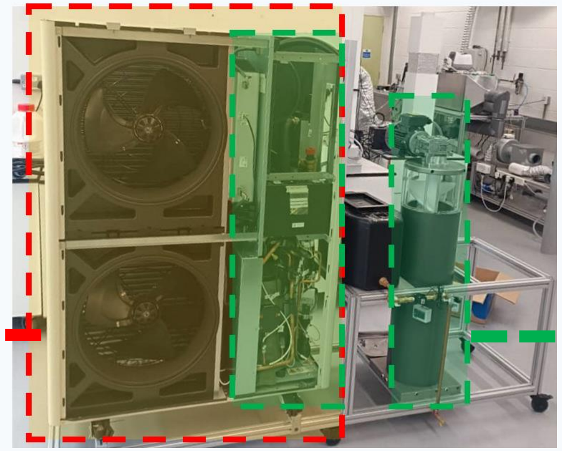




Ice source Heat Pump

The implication of these results is that the use of an ice-source heat pump is essential for the heating solution.

- Hybrid Heat Pump
    - Air Source Heat Pump
    - Water &Ice Source Heat Pump
- 7 kW Heat Pump
- R290 Refrigerant
- Production of ice slurry with a concentration up to 90%.

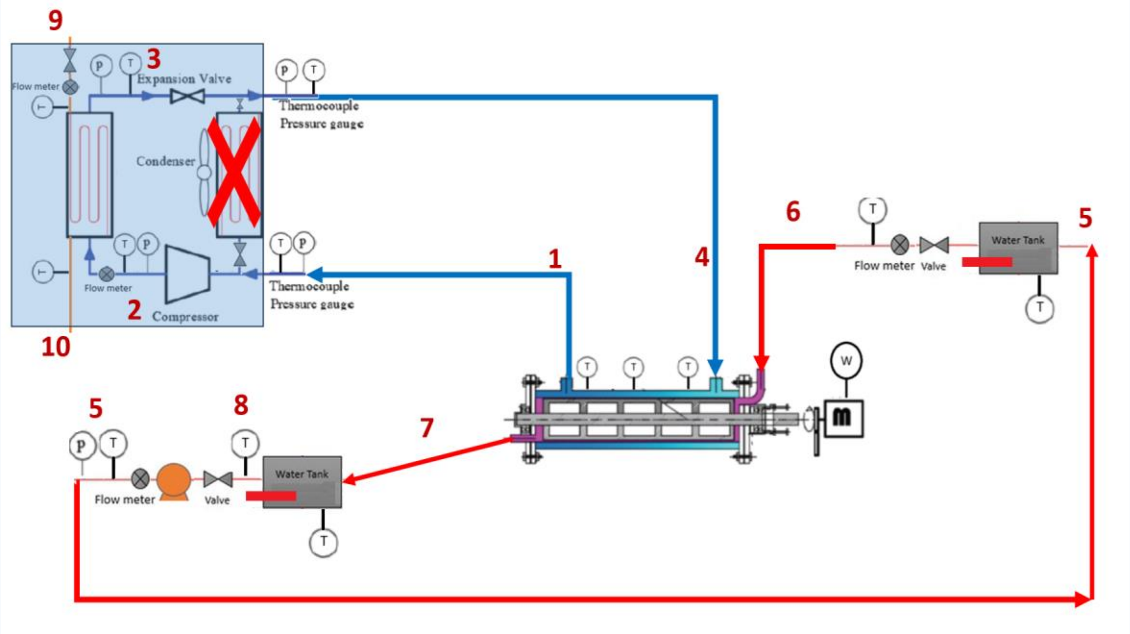


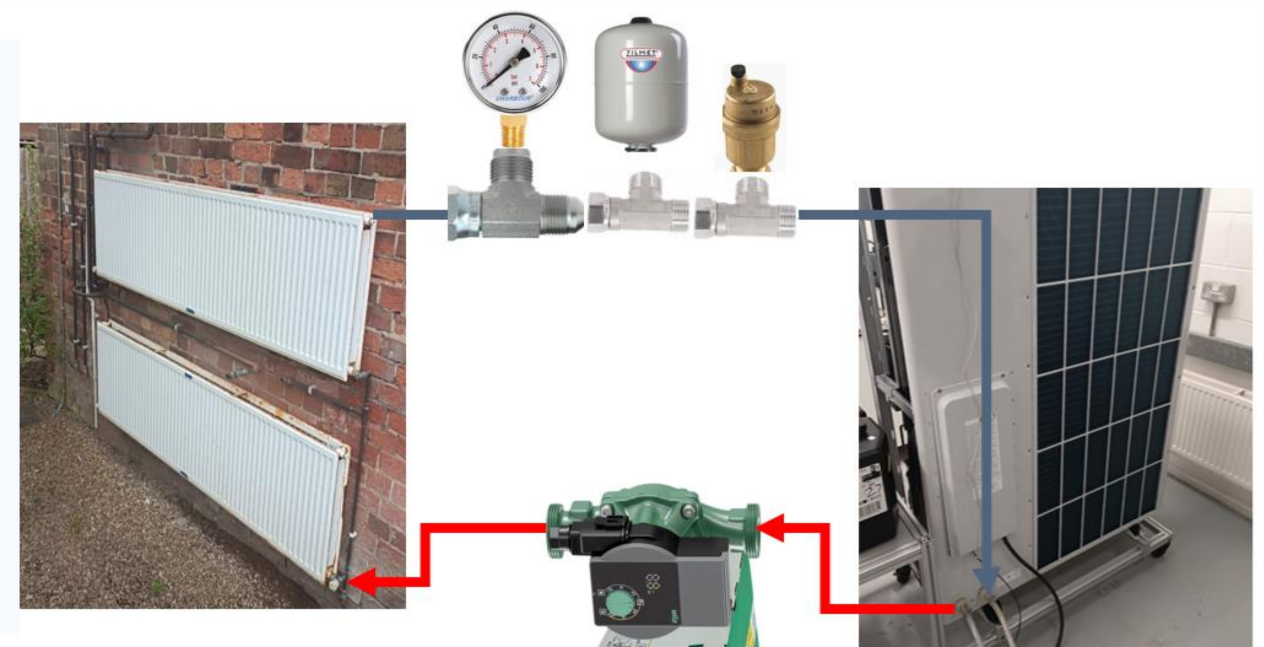
Air source HP

Ice source HP

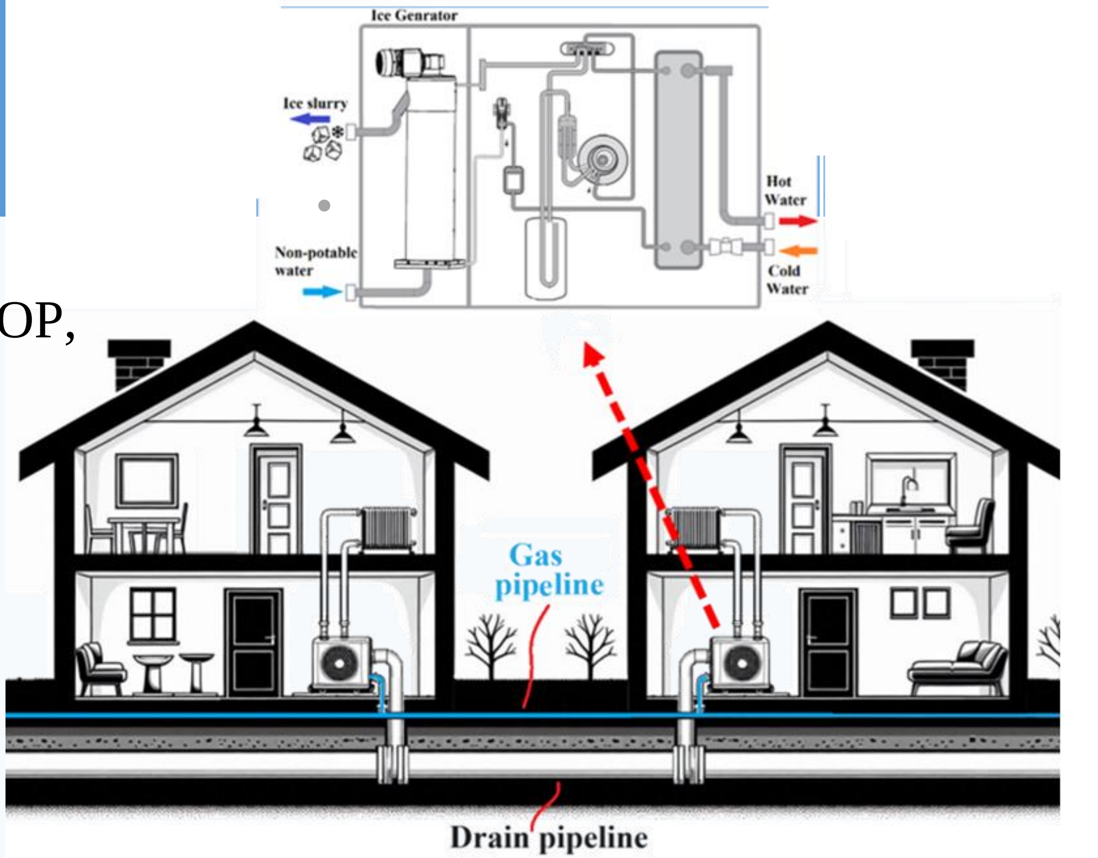
Experimental Test Section

- Performance test
- Comparison ice source heat pump with air-source heat pump,
- Performance improvement for commercialization.





Conclusion



- Examined issues in conventional heat pumps: peak energy use, COP, installation, noise, infrastructure, etc.
- Presented the ice-source heat pump concept
- Introduced a new implementation method
- Evaluated performance of the proposed system
- Assessed feasibility of repurposing existing gas pipelines
- Constructed an ice-source heat pump model and a performance testing device

Concluded that this heat pump offers a unique solution for domestic heating and is a viable alternative to natural gas boilers

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Thank you !

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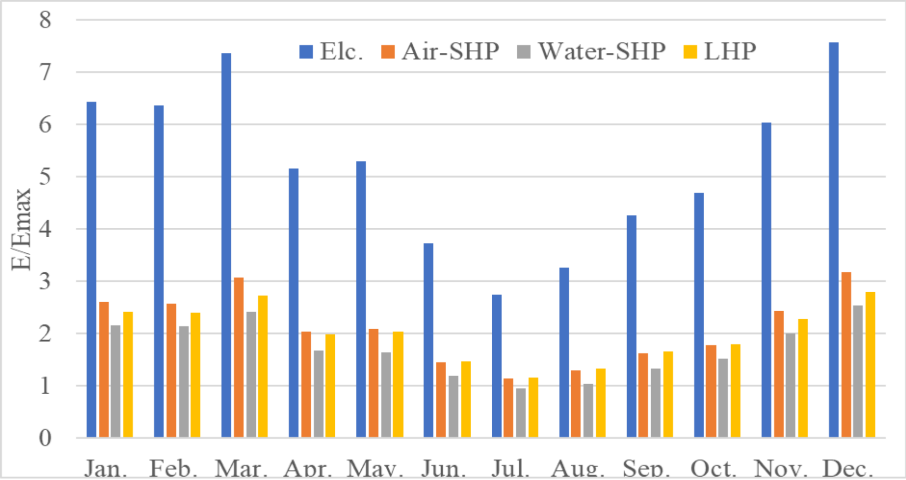
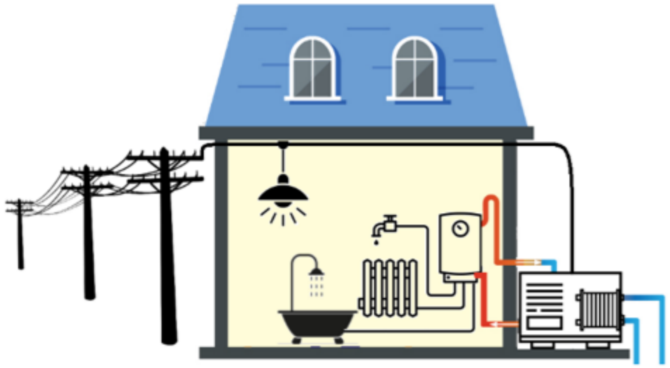
Heat pumps-based heating

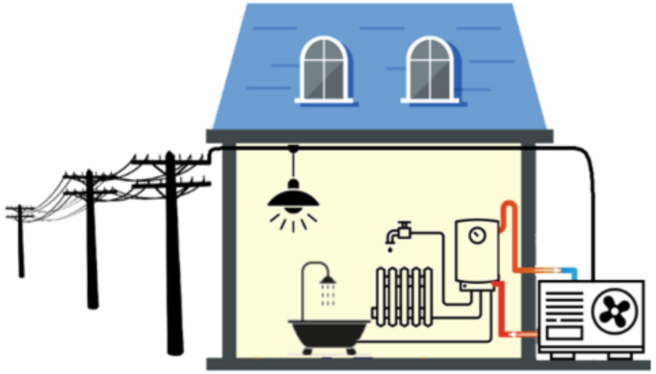


The results indicated that the peak consumption occurred in December. The peak electricity consumption has increased by 3.2 times for an air-source heat pump, 2.5 times for a water-source or ground-source heat pump, and 2.75 times for a Latent heat pump.

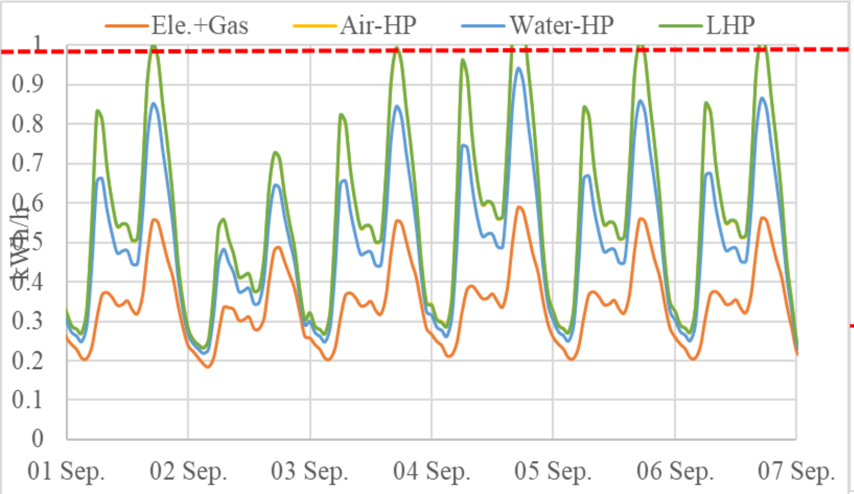
This highlights the effective performance of water-source heat pumps during the cold season and their lower peak consumption.

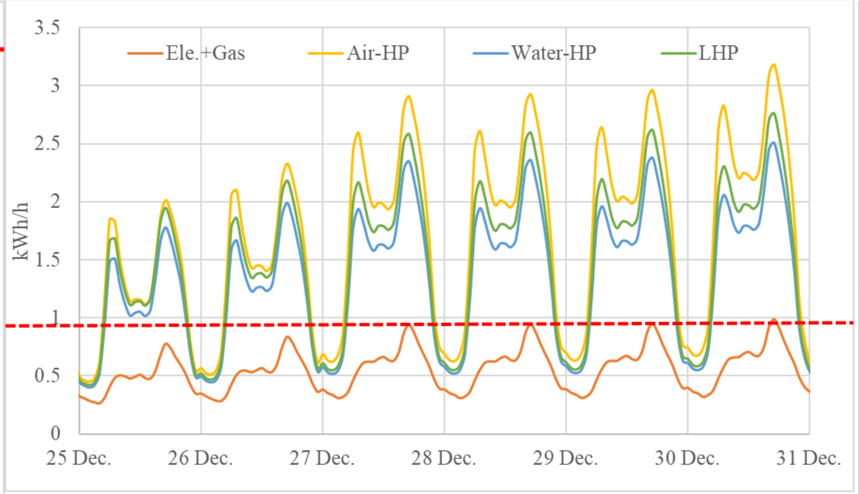


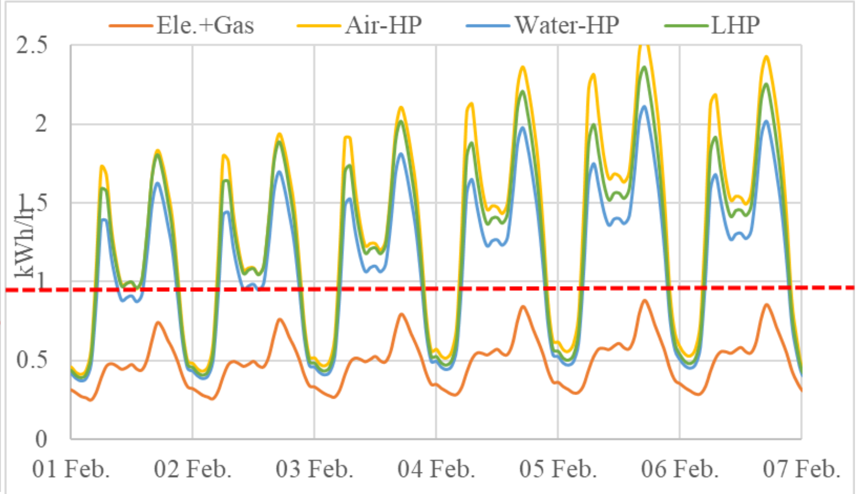
Provision of heating energy by water-source



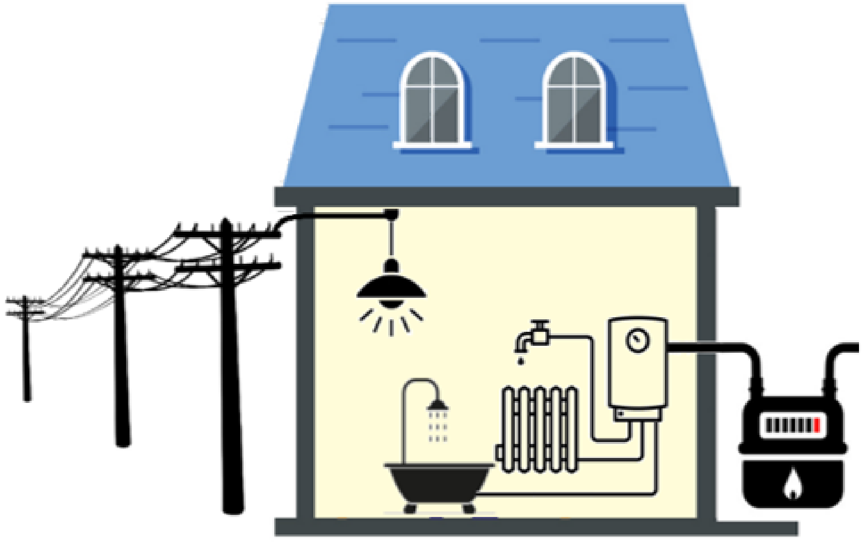
Provision of heating energy by air-source heat pump



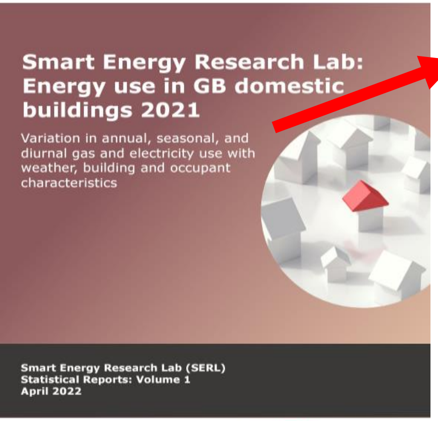




Residential Unit Energy Study

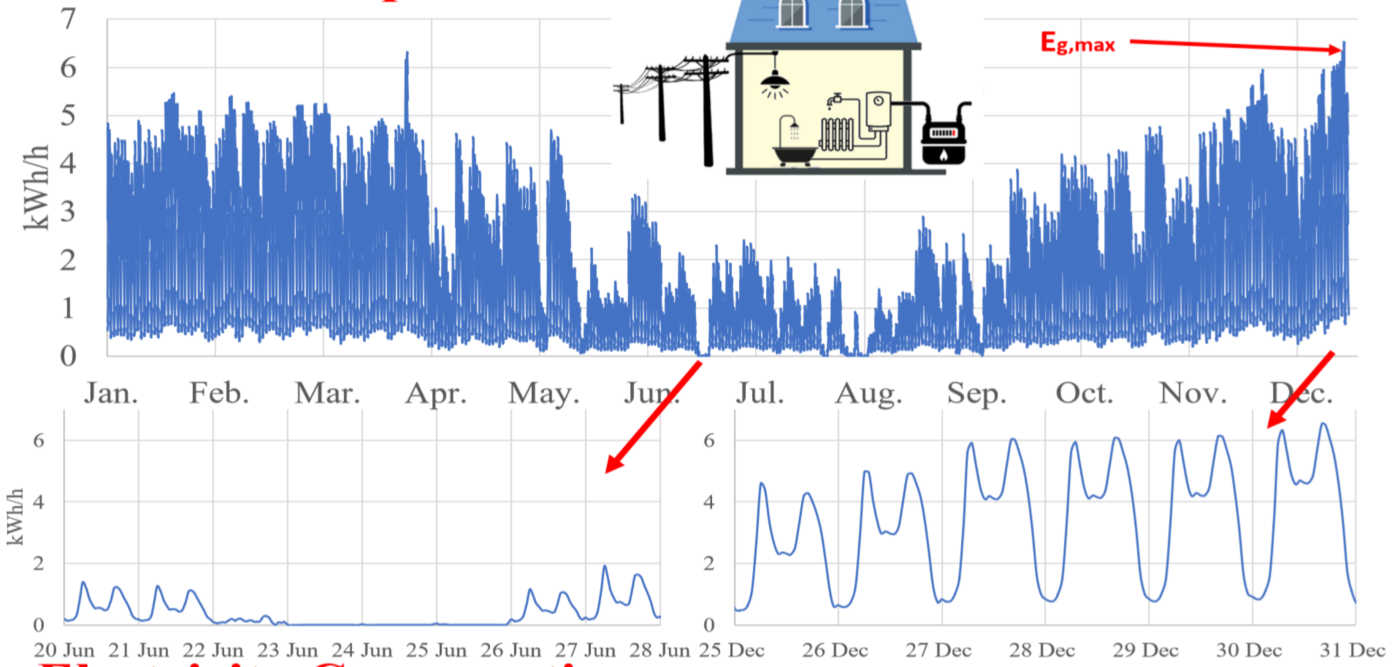


Energy supply by electricity and gas



This report describes domestic gas and electricity energy use in Great Britain in 2021 based on data from the Smart Energy Research Lab (SERL) Observatory, which consists of smart meter and contextual data from approximately **13,000** homes

GAS Consumption



Electricity Consumption