PUMP-UP

Open Educational Resources

Learning Unit 3

System design & costing

Upskilling HVAC technicians on heat pump technologies for green energy transition

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Contents

1 INTRODUCTION

1.1 Lesson 1. Dimensions of heat emitters, pipework & materials.

When integrating heat pump technologies into building heating systems, careful consideration must be given to the dimensions and types of heat emitters, as well as the associated pipework and materials. Radiators, while common and easy to install, are less efficient with heat pumps due to their design for higher temperature operation typical of gas or oil boilers. To compensate for the lower water temperatures supplied by heat pumps (typically 35–55°C), radiators must be significantly larger—often three to seven times the size of traditional units—or replaced with advanced designs such as aluminium models that offer greater heat output per area. In contrast, underfloor heating systems, though more costly and complex to install, are inherently more compatible with heat pumps. Their large surface area enables efficient heat emission at lower temperatures, resulting in better comfort and reduced operational costs for occupants. The placement and accessibility of underfloor heating manifolds are also key to optimal system performance.

The efficiency of a heat pump system is further influenced by the design and material selection of the pipework. Hydronic systems use a network of feed and return pipes, typically running in parallel, to distribute hot water from the central heat source to the emitters and back. Pipe sizing is critical: main feeds are usually 28–35mm in diameter, with smaller branches and final connections, although microbore systems require careful control of temperature differentials and flow rates. Copper pipes are valued for their durability but are more expensive, while flexible plastic alternatives like PEX and PERT are increasingly used in retrofits for their ease of installation and lower heat loss. Accommodating thermal expansion with bellows or loops is essential for both materials. Ultimately, optimizing pipe routing, sizing, and emitter placement—while referencing manufacturer data for specific output and pressure-drop requirements—ensures the system operates efficiently and reliably, maximizing the benefits of heat pump technology.

1.2 Lesson 2. Selection of control options (space heating/cooling, hot water)

Effective control strategies for heat pump systems are essential for optimizing both space heating/cooling and hot water production. For space heating and cooling, a range of control options exists, including time controls (intermittent, continuous, and combined set-back modes), temperature controls, weather compensation, and optimized controls. Time controls allow systems to operate only during periods of occupancy, thereby conserving energy, while set-back programming enables different temperature set points throughout the day for further efficiency. Temperature controls, such as thermostatic radiator valves (TRVs) for radiators and room thermostats for underfloor heating or fan coil units, provide localized comfort and prevent overheating. Weather compensation adjusts the heat pump’s output based on outdoor temperatures, improving efficiency during milder conditions, and optimized controls use learning algorithms to anticipate heating needs and adjust start times accordingly. The combination of these controls ensures that the system operates only when necessary and at the most efficient settings, balancing comfort and energy savings.

For hot water production, it is crucial to ensure that hot water is available when needed while minimizing energy consumption. Controls should be set to deliver the appropriate flow temperature for hot water generation, which is typically higher than that required for space heating, especially if weather compensation is used for the latter. Maintaining hot water temperatures at or above 55°C is important for both user comfort and health, as it prevents the growth of harmful bacteria such as Legionella. Periodic pasteurization of the hot water storage cylinder—by raising the temperature to at least 60°C—is recommended to ensure safety, usually on a weekly basis. The overall efficiency and safety of the heat pump system can be maximized by managing the separation of flow temperatures for space heating and hot water, and implementing appropriate time and temperature controls.

1.3 Lesson 3. Cost assessment

The European heat pump market has experienced significant fluctuations in recent years, largely influenced by energy prices, government support, and broader economic conditions. The energy crisis of 2022 triggered a surge in heat pump sales, with top markets growing by around 40% as high energy prices and a narrowing electricity-to-gas price gap made heat pumps more attractive to consumers. However, this momentum slowed in 2023–2024, with sales declining by about 20% due to stabilizing energy prices, government price caps, reduced subsidies, and a slowdown in new building projects. Despite this temporary downturn, the outlook remains positive: by 2026–2027, the market is expected to recover as energy prices decline further, subsidy programs are relaunched, and several countries implement bans on fossil-fuel heating in new buildings. These factors are projected to stabilize and then boost heat pump sales across Europe, with annual growth rates of 10–15% anticipated after 2027.

The costs associated with heat pump systems vary widely across Europe and are shaped by factors such as national regulations, building characteristics, labor costs, and system complexity. Initial installation costs for air-to-water heat pumps in a standard home can range from €12,000–€18,000 in Central and Northern Europe, with higher costs in countries like Germany due to stricter standards and technical requirements. In Southern Europe, such as Spain, Italy, and Greece, costs are generally lower, often between €3,000 and €10,000. Ground or water-source heat pumps are typically more expensive, often exceeding €20,000–€30,000 due to the need for drilling and groundwork. Operating expenses are primarily driven by electricity consumption, maintenance, and occasional repairs, with efficiency (measured by SCOP/COP), local energy prices, climate, and user behavior all playing significant roles. Lower electricity prices relative to gas, as seen in Norway and Sweden, make heat pumps more economically attractive and drive higher adoption rates.

Policy support and financial incentives are critical to the continued expansion of the heat pump market. The European Union's Social Climate Fund (SCF), operational from 2026, will allocate up to €86.7 billion to support vulnerable households and micro-enterprises in adopting clean heating solutions, funded through revenues from the new Emissions Trading System (ETS2). These subsidies, combined with national programs offering rebates, tax credits, and grants, help reduce upfront costs and make heat pumps accessible to a broader segment of the population. The effectiveness of these incentives varies by country, with higher-income nations often needing to supplement EU funds with additional national measures. As the EU aligns financial support with decarbonization targets and carbon pricing mechanisms, the SCF and related policies are expected to play a pivotal role in accelerating the equitable and widespread adoption of heat pump technologies across Europe.

2 LECTURE NOTES

2.1 Lesson 1. Dimensions of heat emitters, pipework & materials.

The dimensions of heat emitters, pipework, and the materials used are critical factors in the design and performance of heat pump systems. For radiators, sizing is particularly important because their heat output at the lower flow temperatures typical of heat pumps (e.g., 40–50°C) is significantly reduced compared to operation with traditional boilers. As a result, radiators often need to be oversized—sometimes by a factor of three or more—to meet the heat demand of a room when used with a heat pump. For example, a standard double panel radiator (700mm high, 1000mm wide) that delivers 1,961 watts at 70°C with a boiler may only provide around 1,010 watts at 50°C with a heat pump, and even less at lower temperatures. Fan-assisted radiators or advanced designs can help achieve the necessary output without excessively increasing the physical size of the unit. Underfloor heating systems, due to their large surface area, are particularly well-suited to low-temperature operation and can achieve higher efficiency and comfort in heat pump applications.

Pipework must be carefully sized to match the flow requirements of the heat emitters and the heat pump. Contrary to the common misconception that all heat pump systems require 28mm pipes, the correct pipe diameter depends on the total heat load, the temperature differential (ΔT) between flow and return, and the maximum allowable flow velocity (typically 1 m/s). Undersized pipes can cause excessive noise, vibration, and reduced efficiency, while oversized pipes can increase costs and lead to poor heat transfer. Material selection is also crucial: copper pipes offer superior durability and heat resistance but are more expensive, while PEX and PPR pipes are more cost-effective and easier to install, though they are better suited to lower temperature systems. Ultimately, optimal system performance relies on accurately matching the dimensions and materials of both emitters and pipework to the specific requirements of the building and the heat pump system.

2.1.1 Heat Emitters

A heat emitter is a crucial component in any heating system, responsible for transferring heat from the system into the building space to maintain comfortable indoor temperatures. Heat emitters come in various forms, with radiators and underfloor heating systems being the most prevalent in residential and commercial settings. Radiators, typically mounted on walls, use convection and radiation to distribute warmth throughout a room and are favored for their ease of installation and compatibility with both new and existing buildings. Underfloor heating systems, on the other hand, provide even heat distribution across large surface areas, enhancing comfort and energy efficiency—especially when paired with low-temperature heat sources like heat pumps. Other types of heat emitters include fan coil units, convectors, and trench heaters, each offering unique benefits depending on the specific heating requirements and building design. The selection and sizing of heat emitters are critical to ensuring optimal system performance, energy efficiency, and occupant comfort.

2.1.1.1 Radiators

Radiators have long been a staple in residential and commercial heating systems due to their affordability, widespread availability, and straightforward installation process. Their ubiquity is partly a result of their ability to be easily integrated into existing buildings, making them a practical choice for both new constructions and retrofits. Traditionally, radiators are positioned in the coldest parts of a room—most commonly beneath windows—to counteract drafts and maximize their heating effect. However, despite these advantages, radiators tend to be less efficient than other types of heat emitters, such as underfloor heating or fan convectors, particularly in terms of operational costs. This inefficiency arises because radiators are less effective at distributing heat evenly throughout a space, often resulting in higher energy consumption to achieve the desired comfort levels.

The compatibility of radiators with modern heat pump systems presents additional challenges. Conventional radiators are designed to operate with high water temperatures, typically around 70°C, which aligns well with the output of traditional gas or oil boilers. Heat pumps, on the other hand, function most efficiently when circulating water at much lower temperatures, generally between 35°C and 55°C. At these reduced temperatures, standard radiators often lack the necessary surface area to adequately heat a room, necessitating the installation of significantly larger units or supplementary radiators. This requirement can also extend to the pipework, which may need to be upsized to accommodate the increased volume of water needed to deliver the same amount of heat at lower temperatures. Consequently, retrofitting a building with a heat pump system often involves substantial modifications to the existing radiator network to maintain thermal comfort.

To address these limitations, modern low-temperature radiator designs have been developed, with aluminium radiators emerging as a preferred option due to their superior thermal conductivity and higher heat output per unit area. The dimensions of radiators used with heat pumps typically need to be three to seven times larger than those designed for traditional boilers, compensating for the lower flow temperatures. This increased output is achieved through various means, such as extending the length or height of the radiator, incorporating additional panels, or adding convector fins to enhance heat transfer. By adopting these advanced designs, it is possible to achieve efficient space heating even at lower water temperatures, thereby optimizing the performance of heat pump systems while maintaining occupant comfort.

Figure 1. Heat Emitters (Radiator, left; Underfloor, right)

2.1.1.2 Underfloor heating

Underfloor heating is a modern and efficient method of space heating that involves circulating warm water or electric heating elements beneath the floor surface to provide radiant heat throughout a room. Unlike traditional radiators, which heat the air locally and rely on convection currents, underfloor heating distributes warmth evenly across the entire floor area, resulting in a more consistent and comfortable indoor environment. This system is particularly effective in reducing cold spots and drafts, and it allows for greater flexibility in interior design since there are no bulky radiators taking up wall space. The installation process, however, is more complex and typically involves embedding pipes or cables within the floor structure, making it more suitable for new builds or major renovations.

One of the main advantages of underfloor heating is its compatibility with low-temperature heat sources, such as heat pumps, which operate most efficiently when delivering heat at lower flow temperatures. The large surface area of the floor enables effective heat transfer even at these lower temperatures, enhancing the system's overall energy efficiency and reducing operational costs. Manifolds, which control the distribution of heated water to different zones, are usually placed centrally for optimal performance and must be accessible for maintenance. While the initial investment for underfloor heating is higher compared to traditional systems, the long-term benefits in comfort, efficiency, and energy savings make it an increasingly popular choice for modern, sustainable homes.

2.1.2 Pipework

In hydronic heating systems, hot water is distributed from a central heat source to individual heating elements via a network of pipes, which is typically divided into two main subsystems: feed pipes and return pipes. The feed pipes are responsible for transporting heated water from the source to the heat emitters located throughout the building, while the return pipes channel the cooled water back to the heat source for reheating. These feed and return pipes are generally installed in parallel configurations, which not only simplifies the installation process but also allows for more efficient routing. Efficient routing is crucial, as it minimizes the use of materials and reduces both heat loss and friction loss within the pipe network.

Regarding pipe sizing, main feed pipes typically have diameters ranging from 28mm to 35mm, while branch pipes are preferably sized at 22mm, with 15mm pipes reserved for final connections to individual emitters. In some cases, microbore pipes with diameters between 8mm and 12mm may be used; however, these require a higher temperature difference (ΔT) between the flow and return to maintain adequate heat transfer at reduced flow rates. The system is designed to operate at lower flow velocities, with a maximum recommended velocity of 1 m/s, and a higher ΔT of up to 20°C. These design choices help to minimize noise and vibration in the system while enhancing overall efficiency.

2.1.3 Materials

Copper pipes remain the industry standard in hydronic heating systems due to their proven durability and long service life, despite their relatively higher cost. In contrast, plastic piping materials such as PEX and PERT have gained popularity, particularly in retrofit applications, because of their flexibility, ease of installation, and reduced heat loss. The bore diameter of plastic pipes can vary depending on the manufacturer, necessitating careful selection to ensure compatibility with system requirements. Managing thermal expansion is an important consideration in both copper and plastic piping systems; this is typically achieved by incorporating bellows or expansion loops to accommodate changes in pipe length due to temperature fluctuations.

Key design considerations for hydronic systems include the suitability of existing pipework and the optimization of heat distribution. While existing 22mm or 15mm pipes may be adequate for some retrofit projects, upgrading to 28mm main feeds is often recommended to reduce flow resistance and maintain system efficiency. Larger diameter pipes generally facilitate lower flow resistance, whereas microbore systems—employing smaller pipes—require meticulous control of temperature differentials (ΔT) and precise pump sizing to ensure effective heat delivery. The placement of heat emitters, such as wall-mounted or trench radiators, should be optimized for low-temperature operation to maximize efficiency. For project-specific design, it is essential to consult manufacturer data regarding radiator outputs at low ΔT and to reference pressure-drop charts for accurate pipe sizing.

2.2 Lesson 2. Selection of control options (space heating/cooling, hot water).

2.2.1 Space Heating/Cooling Controls

2.2.1.1 Time Controls

There are different opinions amongst specialists about whether heat pump systems should be run intermittently (time clock controlled) or continuously. Local Building Regulations will likely require some form of time clock / programmer control but may not stipulate the settings. The designer of the system must take overall responsibility for the control regime after discussion with the system owner but should not default to 24/7 operation as a 'safety' factor.

Intermittent

Intermittent heating is where the plant is switched off at the end of a period of predicted building occupancy and turned on again prior to the next period of predicated occupancy in order to return the building to design conditions. With this type of heating control system some margin in the output of the heat source and heat emitter should be allowed for in order to ensure an ability to reach an acceptable room temperature within a reasonable time, particularly at or near design temperatures (external).

Continuous

As its name suggests these systems have no actual time clock control. The system is 'on' all the time, usually depending on a manually adjustable thermostat or temperature sensor. Continuous does not mean the unit will run continuously but that it is 'enabled' to run continuously. As noted previously this practice is questionable as to whether it complies with common Building Regulations.

Combined Intermittent and Continuous (Set Back)

This refers to programmers which enable different temperature set points to be scheduled at different times. For example, overnight a lower temperature is acceptable enabling the system to turn off for a while. However, the same may be true if the dwelling is largely unoccupied during the working day.

In a sense, the system is continuous in that it is enabled all the time, but the temperature settings vary during the day and hence are effectively intermittent and determine if the system is actually running or not.

This could also be used where different forms of heat emitter are used, such as radiators and UFH. The UFH may have its set back temperature enabled and returned to occupancy levels much earlier than the radiator heat emitter circuit depending on the reaction time.

2.2.1.2 Temperature Controls

Room Sensors/Set Point Controllers

It is essential that any user interface controls are simple to use and well explained to the end user. Ideally, some form of temperature control should be available in all rooms either by thermostatic radiator valves (TRVs) in the case of radiators or zone control valves for UFH.

Radiators

Typically, individual radiators will have trimming control of the room temperature via TRVs. These are a relatively low cost, passive methods of providing user comfort control, whilst also conserving energy by reducing the risk of overheating the space.

Underfloor Heating

Typically, individual rooms will be controlled via a thermostat in each room with balancing flow regulation valves for each loop of pipe.

Fan Coil Units

Typically, individual units will be controlled via a controller located in the unit or a separate room thermostat. Fan coil emitters have a heater matrix with a fan to aid heat transfer from the matrix to the air and to aid circulation within the heated space.

2.2.1.3 Weather Compensation

Weather compensation (more accurately described as Ambient Air Temperature Load Correction) endeavours to improve the efficiency of the heat pump during seasonal operation by recognising that the output of most heat emitters does not need to be set at maximum during low load conditions. This means that the flow temperature can be reduced, which in turn will ordinarily increase the efficiency of the unit.

2.2.1.4 Optimised Control

Optimised controls compare how close the system gets to the set point conditions in the controlled space at the time the temperature is required. These controllers ‘learn’ how the building reacts to heat-up periods and adjusts the start time depending on room temperature and outside temperature. These controls are becoming much more widely available, and many manufacturers now build these functions into their controllers.

2.2.2 Hot Water Controls

It is important that the production of hot water is addressed to ensure hot water is available as and when required (i.e. time control). In order to minimise running costs the heat pump controls should be set up to deliver the flow temperature appropriate to the function, i.e. hot water generation will likely require a higher flow temperature from the heat pump than when providing heat for space heating, especially if the latter has weather compensation flow temperature adjustment. Complete separation of flow temperatures for space heating and hot water (when provided by the same heat pump) will optimise the efficiency of the heat pump particularly in space heating mode.

Ideally heat pump flow temperatures for hot water generation should be 55oC or greater. This temperature will assist in reducing the multiplication of potentially harmful bacteria such as legionella pneumophila which can result in a pneumonia type infection known as 'Legionnaires Disease'. Legionella bacteria stop multiplying at temperatures above 50oC and are 'killed' by temperatures > 60oC. Occasionally stored water should be heated to 60oC in order to pasteurise the cylinder. Typically, this is carried out weekly but can be required more or less frequently, and further advice should be sought.

2.3 Lesson 3. Cost assessment.

The energy crisis in 2022 triggered a significant increment in heat pump sales, with the top 10 markets experiencing approximately 40% growth-from 1.8 million units sold in 2021 to 2.5 million units in 2022. This dramatic increase was primarily driven by increasing energy prices and a narrowing gap between electricity and gas costs, making heat pumps an attractive and viable option for homeowners seeking to lower their energy expenses.

However, in 2024, the heat pump market slowed down – heat pumps sales declined by approximately 20% in 2023–2024. One key factor was the decrease in energy prices, as wholesale prices stabilized, and governments introduced price caps or reduced taxes for retail energy prices. In addition, some countries faced uncertainty or reduction of government support in the context of elections or termination of subsidies programs. The broader macroeconomic context also played a role, driving a slowdown in new building projects (e.g., ~20% decline in building permits in 2023) that substantially affect heat pumps installations as new builds account for 30–60% of heat pump sales.

While 2025 is expected to be a transitional year, by 2026–2027, the heat pump market is forecasted to return to its pre-energy crisis growth trajectory. Energy prices are predicted to decline – futures prices dropping by 30–40% between 2024 and 2026/2027. Additionally, government subsidy schemes are being relaunched as governments focus on meeting their energy and environmental targets. The construction market is also expected to recover with the improvement in the macroeconomic context. In addition, several countries, including Austria and Germany, are set to introduce bans on fossil-fuel heating systems in new buildings. This will provide an additional tailwind for the heat pump market. As a result, heat pump sales in Europe are expected to stabilize by 2027 and grow by 10–15% in the years following.

Heat pumps are central to Europe's decarbonization strategy, but their adoption hinges on upfront costs, operating expenses, and policy support. Understanding the cost breakdown and financial considerations is important since it varies across Europe.

2.3.1 Initial Costs

The installation costs vary significantly by country and system type:

2.3.1.1 Air-to-Water Heat Pumps:

For a standard 3-bedroom home in Central and Northern Europe, installation costs typically range from €12,000 to €18,000.

In Germany, the cost for an 8 kW air-to-water heat pump is about €28,000, while in the UK, the same system costs around €14,000. This significant difference is due to stricter technical requirements, more complex installations, and higher efficiency and sound insulation standards in Germany.

Regarding Mediterranean countries, installation costs in Spain typically range from €3,000 to €10,000 depending on system size and property requirements. Similar cost ranges are reported in Italy and Greece, with most residential ASHP systems falling between €3,000 and €10,000 before subsidies.

Premium systems (e.g., 12 kW output) can cost €27,000 to €40,000 before subsidies, with some brands quoting €32,500 for a 12 kW system. After subsidies (up to 55%), the net cost can drop to €21,000.

2.3.1.2 Ground/Water Source Heat Pumps:

These systems generally cost more than air-source heat pumps, often exceeding €20,000–€30,000 for installation, depending on the complexity and local conditions.

Spain: Installation costs are higher, typically €10,000 to €20,000 due to drilling and groundwork requirements.

Italy & Greece: Comparable ranges, with some projects exceeding €20,000 depending on soil conditions and system complexity.

2.3.2 Operating expenses

The operating cost of a heat pump system primarily refers to the ongoing expenses required to run the system, excluding the initial purchase and installation costs. These costs are mostly determined by electricity consumption, which depends on the system's efficiency, local electricity rates, climate, and the specific heating or cooling demand of the property.

Key Components of Operating Costs

- Electricity Consumption: The main recurring cost, as heat pumps run on electricity.
- Maintenance: Regular servicing, typically ranging from $100 to $300 per year for residential systems.
- Repairs: Occasional repair costs, which can vary depending on system age and complexity.

2.3.2.1 Electricity Consumption

Electricity consumption represents the largest portion of a heat pump system’s operating expenses. Heat pumps work by transferring heat rather than generating it directly, making them significantly more energy-efficient than traditional electric resistance heaters. However, they still require a substantial amount of electrical energy to power their compressors, fans, and controls. The actual electricity usage depends on several factors, including the system’s efficiency (measured by the Coefficient of Performance or Seasonal Coefficient of Performance), the size of the space being heated or cooled, the local climate, and the user's temperature preferences. In colder climates, the heat pump may need to work harder, especially if it has to rely on supplemental electric resistance heating during extremely low temperatures, which can increase electricity consumption and, consequently, operating costs. Monitoring and understanding your system's energy usage is essential for managing and potentially reducing these costs.

2.3.2.2 Maintenance

Routine maintenance is crucial for ensuring the efficient and reliable operation of a heat pump system. Maintenance tasks typically include cleaning or replacing air filters, checking and cleaning coils, inspecting ductwork for leaks, verifying refrigerant levels, and ensuring that the thermostat and controls are functioning correctly. Regular servicing helps prevent minor issues from developing into major problems, maintains the system's efficiency, and can extend the lifespan of the equipment. For residential systems, annual maintenance costs generally range from $100 to $300, depending on the complexity of the system and local service rates. While some basic maintenance tasks can be performed by homeowners, professional servicing is recommended to ensure all components are thoroughly inspected and serviced.

2.3.2.3 Repairs

Despite regular maintenance, heat pump systems may occasionally require repairs due to component wear and tear, electrical issues, or mechanical failures. The frequency and cost of repairs can vary widely based on the system's age, usage patterns, and overall quality. Common repairs might involve fixing or replacing compressors, fans, thermostats, or refrigerant lines. Newer systems under warranty may incur minimal repair costs, while older systems or those exposed to harsh operating conditions might experience more frequent and costly breakdowns. Repair expenses can range from minor fixes costing under $100 to major component replacements that may exceed $1,000. Planning for occasional repair costs is important for budgeting the total operating expenses of a heat pump system.

2.3.3 Incentives and Subsidies

The European Union is taking significant steps to accelerate the adoption of heat pumps and promote energy-efficient retrofits through the Social Climate Fund (SCF), which will become operational in 2026. The SCF is set to allocate up to €86.7 billion, with a particular focus on supporting vulnerable households and micro-enterprises by providing subsidies for the installation of fossil-free heating systems and other energy-saving measures. This ambitious initiative is partly financed by revenues generated from the new Emissions Trading System (ETS2), which will introduce carbon pricing for heating and transport fuels beginning in 2027. By channeling ETS2 revenues into the SCF, the EU aims to offset the anticipated rise in energy costs associated with carbon pricing, thereby reducing the upfront financial barriers to clean heating technologies such as heat pumps. Additionally, these funds will supplement national incentive programs, ensuring a sustained and coordinated approach to heat pump deployment across member states. The design of the SCF reflects a commitment to social equity, as it prioritizes low-income groups and integrates mechanisms to make renewable heating solutions more accessible. By aligning financial support with the EU's broader decarbonization targets and leveraging carbon pricing to drive market transformation, the SCF represents a comprehensive strategy to foster the widespread and equitable adoption of renewable heating technologies throughout Europe.

Country-Specific Incentives:

Other countries have similar direct rebates, tax credits, or grants, often requiring certified installers and high-efficiency models.

Country/Region	Air-to-Water Heat Pump (8–12 kW)	Ground/Water Source Heat Pump	Subsidy Impact
Germany	€28,000–€32,500	€30,000+	Up to 40% rebates via the BEG program, with extra bonuses for replacing oil heating systems. [1]
UK	€14,000	€20,000+	£7,500 grants[1]
Central/Northern EU	€12,000–€18,000	€20,000–€30,000+	[1]
France	€12,000–€18,000	€20,000–€30,000	MaPrimeRenov' program offers €2,000–€5,000 refunds, depending on income and system type [1]
Spain	€3,000 to €10,000	€10,000 to €20,000	[1]
Italy	€3,000 to €10,000	Over €20,000 depending on soil conditions	[1] The Conto Termico scheme reimburses up to 65% of installation costs within two months of approval.
Greece	€3,000 to €10,000	Over €20,000 depending on soil conditions	[1]
Norway	€8,000–€12,000	€15,000–€25,000	[1]
After Subsidies	20–55% lower	20–65% lower	[1]

Table 1: Heat pump cost across Europe

2.3.4 Factors Affecting Cost

Heat pump system costs in Europe exhibit substantial regional disparities, driven by regulatory frameworks, building specifications, and market dynamics. Germany consistently ranks among the most expensive markets due to stringent efficiency standards, sound insulation mandates, and requirements for reinforced foundations and advanced indoor units. These technical demands, coupled with higher labor costs and supply chain complexities, contribute to installation expenses that can reach €8,000–€12,000 for air-to-water systems-four to six times the cost of a gas boiler. In contrast, markets with fewer regulatory burdens, such as parts of Eastern Europe, often report lower upfront costs, though subsidies and energy prices play a critical role in overall affordability.

Key Cost Determinants

- Country-specific regulations: Germany's strict technical standards necessitate specialized components and labour, while France and Italy prioritize energy efficiency through localized incentive structures.
- Building characteristics: Older homes with poor insulation frequently require supplementary upgrades (e.g., radiator replacements, underfloor heating) and higher-capacity systems, increasing total costs by 15–30%.
- Labor and market conditions: Installation expenses vary regionally, with labour rates in high-demand areas like Scandinavia and Western Europe exceeding those in less competitive markets.
- System size and complexity: Larger homes or those in colder climates often require ground-source heat pumps, which cost €15,000–€25,000 due to excavation and piping needs.

Operating Cost Drivers

Operating expenses for heat pump systems are fundamentally influenced by the ratio of electricity to gas prices, making this relationship a pivotal factor in the overall economics of heat pump adoption. In countries where electricity is relatively inexpensive compared to gas, such as Norway and Sweden, the market penetration of heat pumps is notably high; for example, Norway boasts a 98% market share for heat pumps in new heating system installations. This trend underscores the importance of favorable electricity pricing in driving the adoption of heat pump technology, as lower operational costs make these systems more attractive to consumers. Conversely, in regions where electricity prices are high relative to gas, the economic advantage of heat pumps diminishes, potentially slowing their uptake.

Beyond energy pricing, the efficiency of the heat pump system—typically measured by the Seasonal Coefficient of Performance (SCOP) or Coefficient of Performance (COP)—plays a significant role in determining annual operating costs. High-performance heat pumps can reduce energy consumption by 20–40% compared to standard or mid-tier models, thereby offering substantial savings over the system's lifetime. Climate is another critical variable: in colder regions, such as Finland, heat pumps must be equipped with frost-resistant components to ensure reliable operation, which can lead to increased maintenance requirements and costs. In contrast, milder climates allow for the use of simpler and less costly air-source heat pumps. Additionally, user behavior—including thermostat settings, daily usage patterns, and seasonal demand—further influences long-term operating expenses, highlighting the multifaceted nature of heat pump economics and the importance of tailoring system selection and operation to specific local conditions.

3 QUESTIONS & ANSWERS

3.1 What are the typical dimensions for heat emitters used in domestic heat pumps?

Typical dimensions for heat emitters—especially radiators—used with domestic heat pumps are significantly larger than those used with conventional gas or oil boilers. This is because heat pumps operate at lower flow temperatures, typically between 35°C and 55°C, compared to the 70–80°C of traditional boilers. As a result, radiators for heat pump systems often need to be 2.5 to 6 times larger in heat output (BTU/kW) and up to 30% bigger in physical size to deliver the same level of comfort. For example, where a standard radiator might measure 600mm high by 1000mm wide for a boiler system, a heat pump system may require radiators that are 600mm high by 1800mm wide or even larger, depending on the room's heat loss and desired temperature. In some cases, the total surface area of the radiator must be three to seven times greater than that of a traditional radiator to compensate for the lower water temperatures.

The exact dimensions required depend on detailed heat loss calculations for each room, factoring in room size, insulation, window type, and local climate. Installers use these calculations to specify radiators that meet the room's heating demand at the lower flow temperatures typical of heat pumps. For underfloor heating, the emitter area is naturally large and well-suited to low-temperature operation, so the focus is on pipe spacing and total coverage rather than physical dimensions. In summary, radiators for domestic heat pumps are typically much larger in both output and size, with specific dimensions tailored to the unique requirements of each space to ensure efficient and comfortable heating.

3.2 How do pipe diameters affect the efficiency of heat pump systems?

Typical dimensions for heat emitters—especially radiators—used with domestic heat pumps are significantly larger than those used with conventional gas or oil boilers. This is because heat pumps operate at lower flow temperatures, typically between 35°C and 55°C, compared to the 70–80°C of traditional boilers. As a result, radiators for heat pump systems often need to be 2.5 to 6 times larger in heat output (BTU/kW) and up to 30% bigger in physical size to deliver the same level of comfort. For example, where a standard radiator might measure 600mm high by 1000mm wide for a boiler system, a heat pump system may require radiators that are 600mm high by 1800mm wide or even larger, depending on the room's heat loss and desired temperature. In some cases, the total surface area of the radiator must be three to seven times greater than that of a traditional radiator to compensate for the lower water temperatures.

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3.3 What materials are most commonly used for heat pump pipework?

The most commonly used materials for heat pump pipework in domestic and residential settings are copper, PEX (cross-linked polyethylene), PPR (polypropylene random copolymer), and, to a lesser extent, stainless steel and carbon steel.

- Copper is favored for its excellent durability, corrosion resistance, and ability to withstand high temperatures and pressures, making it ideal for both high- and low-temperature heat pump systems. It offers a long lifespan (often over 50 years) and low maintenance, though it comes at a higher initial cost and requires professional installation.
- PEX (cross-linked polyethylene) is widely used for its flexibility, ease of installation, and cost-effectiveness, especially in low-temperature systems such as underfloor heating. PEX is less stable at high temperatures compared to copper but is suitable for most residential heat pump applications and is popular for DIY projects.
- PPR (polypropylene random copolymer) pipes provide a mid-range option, balancing cost, ease of installation, and resistance to heat and pressure. They are less durable than copper but still viable for many domestic heat pump systems.
- Stainless steel and carbon steel are also used, particularly in larger or commercial systems, due to their strength and corrosion resistance. Stainless steel is especially valued in environments exposed to moisture or where external corrosion is a concern.
- Plastic multilayer pipes (e.g., PEX-AL-PEX) and specialized plastic pipes are also common, particularly for ground-source and underfloor applications, due to their corrosion resistance and ease of handling. Ultimately, the choice of material depends on system temperature, pressure requirements, installation environment, and budget.

3.4 How does the choice of pipe material impact the lifespan of a heat pump system?

The choice of pipe material has a direct and significant impact on the lifespan and reliability of a heat pump system. Copper pipes are considered the gold standard for longevity, often lasting over 50 years due to their superior corrosion and heat resistance, as well as their natural antibacterial properties. They require professional installation but offer low maintenance and are particularly well-suited for high-temperature systems. In contrast, PEX (cross-linked polyethylene) and PPR (polypropylene random copolymer) pipes are more cost-effective and easier to install, making them popular for low-temperature residential systems. However, these plastic pipes generally have a slightly shorter lifespan—typically around 40–50 years for PEX and somewhat less for PPR—and may require more frequent maintenance, especially if exposed to extreme temperatures or pressures.

Selecting an inappropriate pipe material can lead to serious issues such as leaks, system malfunctions, and increased maintenance needs, all of which can shorten the overall lifespan of the heat pump system. Environmental factors, such as temperature fluctuations and water quality, also play a role in how long different materials last. For example, copper's resistance to corrosion makes it a robust choice even in challenging environments, while plastic pipes are more vulnerable to damage from high temperatures or certain chemicals but are resistant to rust and scale buildup. Ultimately, investing in high-quality, durable pipe materials—matched to the specific demands of the system—can minimize repair costs and system downtime, ensuring the heat pump operates efficiently and reliably for decades.

3.5 What are the advantages of using copper pipes over PEX pipes in heat pump systems?

Copper pipes offer several key advantages over PEX pipes in heat pump systems, particularly in terms of durability, heat resistance, and long-term reliability. Copper is exceptionally durable, with a typical lifespan of 50–70 years, and is naturally resistant to corrosion and bacterial growth, making it ideal for both hot and cold water applications in demanding environments. Its high heat tolerance allows copper pipes to withstand the temperature fluctuations and higher operating temperatures often found in heat pump systems, ensuring consistent performance and reducing the risk of leaks or failures over time. Additionally, copper's rigidity and larger internal diameter allow for higher flow rates, which can be beneficial for the efficiency of heat pump systems, especially where higher volumes of water must be circulated.

Copper pipes can also be installed outdoors and are unaffected by UV light, unlike PEX, which is limited to indoor or underground installations. They are fireproof, do not release toxic gases in the event of fire, and are fully recyclable, contributing to environmental sustainability. Furthermore, copper's bacteriostatic properties help prevent the growth of harmful microbes inside the pipework, which is particularly important for maintaining water quality. While copper is more expensive and less flexible than PEX, requiring more fittings and skilled installation, its superior longevity, heat transfer capability, and resilience to harsh conditions make it a preferred choice for many heat pump applications where long-term performance and reliability are paramount.

3.6 What are the main types of time controls used in heat pump space heating/cooling systems, and how do they differ?

The main types of time controls are intermittent, continuous, and combined intermittent/continuous (set back). Intermittent controls switch the system off outside predicted occupancy periods, requiring some margin in output to quickly restore temperatures. Continuous controls keep the system enabled at all times, relying on thermostats, but may not comply with building regulations. Set back controls allow different temperature set points at different times, enabling lower temperatures when spaces are unoccupied and higher temperatures during occupancy, thus blending efficiency and comfort.

3.7 Why is it important to have temperature controls in every room, and what are common methods for different heat emitters?

Temperature controls in every room ensure user comfort and energy efficiency by preventing overheating and allowing individual adjustment. For radiators, thermostatic radiator valves (TRVs) are commonly used, while underfloor heating systems typically use room thermostats and balancing valves. Fan coil units are controlled either by built-in controllers or separate room thermostats.

3.8 How does weather compensation improve the efficiency of heat pump systems?

Weather compensation, or Ambient Air Temperature Load Correction, improves efficiency by reducing the flow temperature of the heat pump during periods of low heating demand. This adjustment means the system does not run at maximum output unnecessarily, which increases overall efficiency, particularly during milder weather.

3.9 What is the function of optimised controls in heat pump systems, and how do they operate?

Optimised controls ‘learn’ how a building responds to heating and cooling by monitoring how quickly set point temperatures are reached. They automatically adjust the start times for heating or cooling based on room and outdoor temperatures, ensuring comfort while minimizing energy use. These features are increasingly integrated into modern heat pump controllers.

3.10 What considerations are necessary for hot water controls in heat pump systems to ensure safety and efficiency?

Hot water controls must ensure hot water is available when needed and that the flow temperature is appropriate for the function. For safety, the flow temperature for hot water generation should be at least 55°C to inhibit the growth of legionella bacteria, with periodic heating to 60°C to pasteurize the cylinder. Separating flow temperatures for space heating and hot water optimizes overall system efficiency.

3.11 What caused the significant increase in heat pump sales in Europe during 2022, and why did the market slow down in 2023–2024?

The surge in heat pump sales in 2022 was mainly driven by rising energy prices and a narrowing gap between electricity and gas costs, making heat pumps more attractive to homeowners. However, the market slowed by about 20% in 2023–2024 due to stabilizing energy prices, the introduction of price caps or reduced taxes, uncertainty or reduction in government support, and a decline in new building projects, which are a major driver of heat pump installations.

3.12 How do initial installation costs for air-to-water and ground/water source heat pumps vary across Europe?

Installation costs for air-to-water heat pumps in a standard home range from €12,000 to €18,000 in Central and Northern Europe, but can reach €28,000 in Germany due to stricter requirements. In Mediterranean countries like Spain, Italy, and Greece, costs are lower, typically €3,000 to €10,000. Ground or water-source heat pumps are generally more expensive, often exceeding €20,000–€30,000, especially where drilling and groundwork are needed.

3.13 What are the main components of heat pump operating expenses, and what factors influence them?

The main components of operating expenses are electricity consumption, maintenance, and repairs. These costs are influenced by the system's efficiency, local electricity rates, climate, and the specific heating or cooling demand. In colder climates, higher electricity use may occur due to supplemental heating, while regular maintenance and occasional repairs also contribute to ongoing expenses.

3.14 What role do incentives and subsidies play in the adoption of heat pumps in Europe, and how do they vary by country?

Incentives and subsidies, such as those from the EU's Social Climate Fund (SCF) and national programs, play a crucial role in making heat pumps more affordable by reducing upfront costs. These supports vary by country: Germany offers up to 40% rebates, the UK provides £7,500 grants, France has the MaPrimeRenov' program, and Italy's Conto Termico scheme reimburses up to 65% of installation costs. After subsidies, net costs can be reduced by 20–65% depending on the location and system type.

3.15 What are the key factors that determine the total cost and operating economics of a heat pump system in Europe?

Key cost determinants include country-specific regulations, building characteristics (such as insulation and the need for system upgrades), local labor and market conditions, and the size and complexity of the system. Operating economics are influenced by the electricity-to-gas price ratio, system efficiency (SCOP/COP), climate, and user behavior. Favorable electricity pricing and high system efficiency can significantly lower operating costs and increase the attractiveness of heat pumps.

4 PRACTICAL EXERCISES

4.1 Exercise 1. Calculating Heat Pump Operating Costs

Calculating the operating cost of a heat pump system involves estimating its annual electricity usage and multiplying by the local electricity rate. The process can be summarized in a few straightforward steps:

1. Determine Annual Heat Demand

Estimate the total heating (or cooling) demand for your property in kilowatt-hours (kWh) per year. For example, an average household might use 12,000 kWh for heating annually.

2. Identify the System's Efficiency

Heat pump efficiency is measured by its Seasonal Coefficient of Performance (SCOP) or Coefficient of Performance (COP). A SCOP of 4 means the heat pump delivers 4 kWh of heat for every 1 kWh of electricity consumed.

3. Calculate Electricity Consumption

Divide the annual heat demand by the SCOP (or COP):

$$\text{Electricity Consumption (kWh)} = \frac{\text{Annual Heat Demand (kWh)}}{\text{SCOP}}$$

Example: For a 12,000 kWh heat demand and a SCOP of 3.5:

$$\frac{12,000}{3.5} = 3,429\ \text{kWh}$$

4. Multiply by Electricity Cost

Multiply the calculated electricity consumption by the local electricity rate (cost per kWh):

Annual Operating Cost=Electricity Consumption (kWh)×Electricity Rate ($/kWh)

Example: If the electricity rate is $0.15 per kWh:

$$3,429\ \text{kWh} \times \$0.15 = \$514.35\ \text{per year}$$

5. Add Maintenance and Other Costs

Include estimated annual maintenance and any anticipated repair costs for a more complete cost analysis.

As a summary, the generalized equation for calculating the operating cost is:

$$\text{Operating Cost} = \frac{\text{Heat Demand}}{\text{SCOP}} \times \text{Electricity Rate}$$

Furthermore, if you know the power consumption (P, in kW), hours of operation (H), days per month (D), months per year (M), and electricity rate (C):

$$C = P \times H \times D \times M \times C_{\text{rate}}$$

Step	Formula/Action
Estimate heat demand	Use energy bills or building energy model (in kWh/year)
Find SCOP/COP	Check manufacturer specs or energy label
Calculate electricity use	Heat Demand (kWh) / SCOP
Multiply by rate	Electricity Use (kWh) × Local Electricity Rate ($/kWh)
Add maintenance	Include $100–$300 per year (typical)

Table 2: Operating costs steps calculations

4.2 Exercise 2. Operating Cost

Suppose a home needs 16,000 kWh of heat per year, the heat pump has a SCOP of 4, and the electricity rate is 0.15€ per kWh.

What is the cost per year?

Electricity used: 16,000÷4=4,000 kWh

Annual cost: 4,000×0.15€=600€

Add 200€ for maintenance.

Total estimated annual operating cost of 800€ per year.

5 MULTIPLE CHOICE QUESTIONS

5.1 Why do radiators used with heat pumps often need to be larger than those used with traditional boilers?

A) They are less durable

B) Heat pumps operate at lower flow temperatures

C) Radiators are less available

D) Lower installation costs

5.2 What is a key advantage of underfloor heating compared to radiators?

A) Lower installation cost

B) Easier to retrofit

C) Even heat distribution and higher efficiency

D) Requires less floor space

5.3 What is the typical maximum recommended flow velocity for heat pump pipework?

A) 2 m/s

B) 1 m/s

C) 3 m/s

D) 0.5 m/s

5.4 Which material is considered the industry standard for hydronic heating pipework due to its durability?

A) PVC

B) PEX

C) Copper

D) Steel

5.5 What is the main function of a heat emitter in a heating system?

A) Generate electricity

B) Transfer heat into the building space

C) Store hot water

D) Control humidity

5.6 Where are radiators typically positioned in a room for maximum effect?

A) In the ceiling

B) Below windows

C) Behind doors

D) In the center of the room

5.7 What is a common method for controlling the temperature of individual radiators?

A) Manual valves

B) Thermostatic radiator valves (TRVs)

C) Remote controls

D) Timers

5.8 Which pipe diameter is typically reserved for final connections to individual emitters?

A) 28mm

B) 22mm

C) 15mm

D) 35mm

5.9 What is a major benefit of weather compensation controls in heat pump systems?

A) Increases maximum output

B) Reduces flow temperature during low load, increasing efficiency

C) Prevents overheating

D) Reduces installation costs

5.10 What is the primary recurring operating cost for a heat pump system?

A) Water usage

B) Electricity consumption

C) Filter replacement

D) Insurance

5.11 What is the main reason ground/water source heat pumps are more expensive to install than air-source systems?

A) Higher electricity consumption

B) More complex drilling and groundwork

C) Less efficient

D) Require larger radiators

5.12 Which European country offers up to 40% rebates for heat pump installations through the BEG program?

A) UK

B) Spain

C) France

D) Germany

5.13 What is the recommended minimum flow temperature for hot water generation to prevent legionella bacteria?

A) 40°C

B) 45°C

C) 55°C

D) 65°C

5.14 What is the main purpose of the EU Social Climate Fund (SCF)?

A) Reduce electricity prices

B) Provide tax breaks to large corporations

C) Fund fossil fuel infrastructure

D) Support vulnerable households and micro-enterprises in adopting clean heating

5.15 What is a key factor influencing the operating economics of heat pump systems across Europe?

A) The color of the radiators

B) The electricity-to-gas price ratio

C) The age of the building

D) The number of thermostats

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