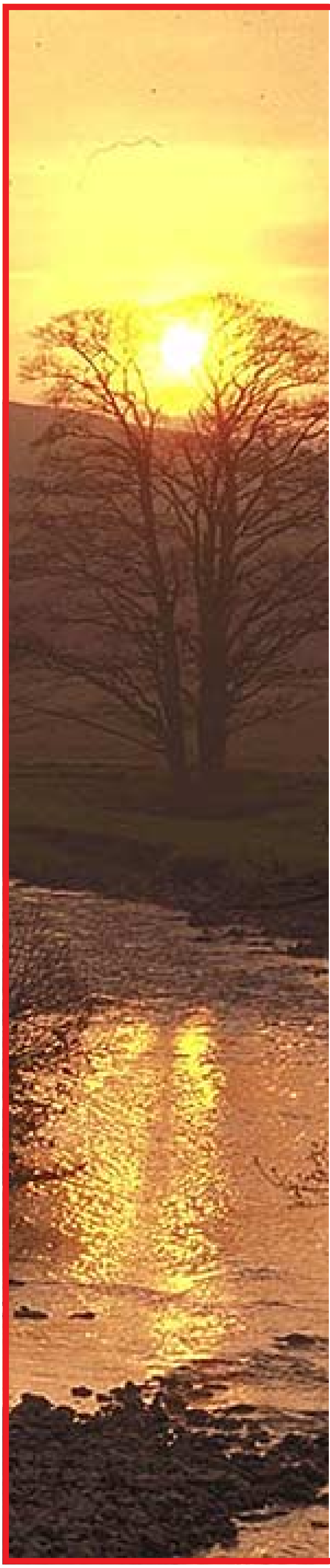


Renewable Energy Information Office

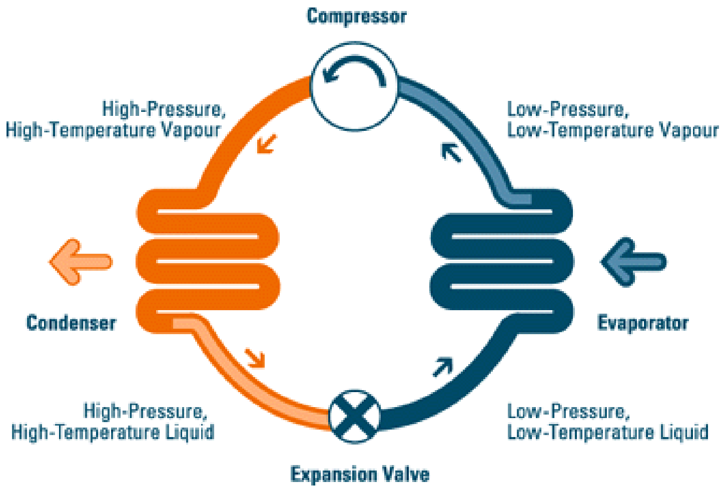
Renewable Heat Pumps

A guide for the technically minded

How do heat pumps work ?

A heat pump is an environmental energy technology that extracts heat from low temperature sources (air, water, ground), upgrades it to a higher temperature and releases it where it is required for space and water heating. Heat pumps can also be operated in a reverse mode for cooling purposes.

The heat pumping cycle can be divided in three steps:



Step 1. A fluid with a boiling point lower than the heat source temperature serves as a medium for heat transport. It is called the working fluid or refrigerant. As the working fluid extracts the heat from the source through a heat exchanger, its temperature rises and it evaporates.

Step 2. Then a compressor compresses the evaporated fluid. Consequently, the pressure and the temperature of the vapour increase. When pumping up a bicycle tyre, you can also observe this phenomenon. The lower side of the pump – where the pressure is highest – is getting very hot.

Step 3. Finally, heat is being transferred from the evaporated fluid to the heat distribution fluid (water or air) in the condenser. As it releases its heat, the working fluid temperature decreases to such a degree that it condenses. After passing through the expansion valve, the fluid regains its initial liquid, low-temperature and low-pressure state. It then flows back to the evaporator where the process starts all over again.

Applications

In the residential sector

A heat pump does not look very different and can perform the same functions as a conventional gas or oil boiler i.e. space heating and sanitary hot water production.
But it does it much more efficiently, using most of its heating energy from free renewable sources. Renewable heat pumps for space heating are best suited in new houses where high levels of insulation and low temperature heating systems result in low heating demand. In retrofit situations, the heat pump should be installed in parallel with the existing heating system to provide a large proportion of the annual heating needs at reduced operating temperatures.

Water heating is often provided in addition to space heating. The heat pump can provide indirect heating in the domestic hot water cylinder via an internal or external heat exchanger. Because of the high output temperature required, (minimum 55 °C) the efficiency for water heating may be reduced. A desuper-heater can also be installed between the compressor and the reversing valve of a space conditioning heat pump. It is a refrigerant hot gas-to-water heat exchanger which is sized to remove the superheat from the compressor discharge gas prior to entry into the refrigerant condenser.

Some heat pumps allow for a reversing of their cycle to provide cooling (air-conditioning). However air-conditioning is expensive and energy intensive. It is absolutely unnecessary in Irish houses as natural ventilation is more than sufficient to reduce excessive temperature during the summer.

In the commercial sector

A heat pump is really a three-in-one HVAC system. It combines heating, cooling and air-conditioning in an economical and eco-friendly machine. They are particularly suited for buildings with a high demand for space heating and sanitary hot water production, extensive work-in times and a simultaneous need for cooling.

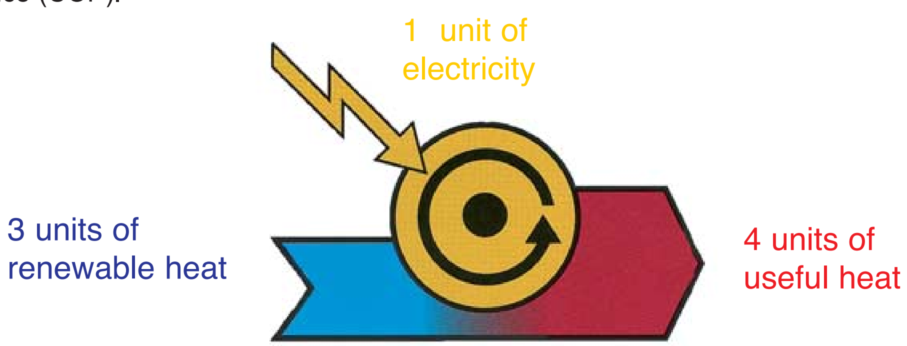
In large buildings, several individual heat pumps can be placed in different zones and each can be sized to meet the needs of the space it conditions. Some zones of the building may need heating at the same time as other zones need cooling. When properly integrated, a heat pump system can recover excess heat in one zone (sunny side, computer rooms, etc.) and transfer it via a water pipe loop to areas of the building requiring heating. It is therefore possible to achieve a balance between heating and cooling needs during a good part of the year (40 to 60%).

When the demand for heat exceeds the energy reclaimed, a central heat pump can supply the distribution loop with heat from a renewable source, generally the ground. In reverse, the same heat pump can extract excess heat from the loop and dispose of it in the ground to replenish the heat source for further demand.

As for the residential sector, a demand for cooling can be avoided by careful design of the building and taking advantage of natural ventilation. However, a ground/water source heat pump can be used for direct cooling, at low energy cost, by bypassing the evaporator and circulating fluid from the ground/water coil through a water-to-water or water-to-air heat exchanger.

How is their performance measured?

Energy is needed to activate the heat pump cycle and to compress the vapour for the production of useful heat. The efficiency of this process is expressed by the ratio between the useful heat delivered by the condenser and the driving energy used by the compressor. This ratio is called the Coefficient of Performance (COP).



As environmental heat is free and available in very large quantities, it is not included in the COP. That is why the COP is bigger than 1. The COP of the current generation of heat pumps varies from 2.5 to 5. Since the COP shows performance at a steady state only, a second parameter is usually used to show the performance of the heat pump over an entire year. It is called the seasonal performance factor (SPF), which is the ratio of annually delivered useful heat over annually used driving energy. When calculating the SPF, it is common to include the annual electricity requirements of auxiliary equipment, such as circulation pumps, fans, etc.

The performance of a heat pump system is affected by several factors, which include:
* The climate (annual heating and cooling demand and peak loads);
* The temperature of the heat source and the heating distribution system;
* The auxiliary energy consumption;
* The heat pump control.

The performance of electrical heat pumps should be balanced by the fact that the efficiency of electricity generation in Ireland is less than 40%. That means that for every unit of electricity used, more than 2.5 units of primary energy (mix of oil, gas, peat, etc.) have been burned. Therefore, a heat pump with a COP of 4 driven by electricity generated by a thermal power plant has a primary energy efficiency of 160%.

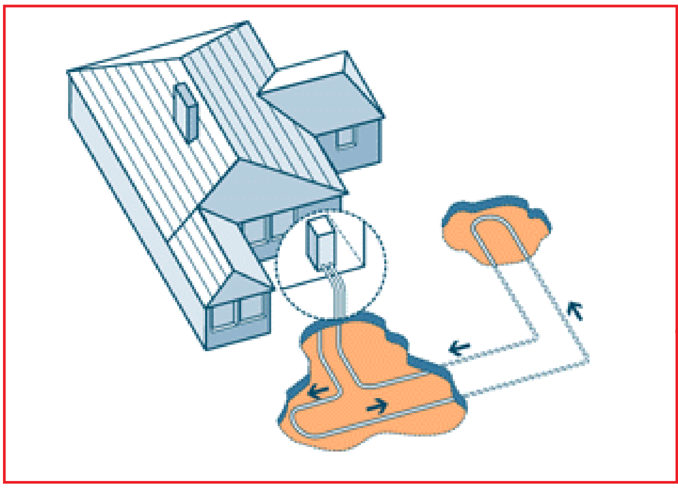
That is already better than the 100% achieved by a modern gas condensing boiler operating at low temperature for example. But you can increase the primary energy efficiency of your heat pump, and therefore its environmental benefit, by 3 times by driving it with green electricity. It is now possible to switch easily to a green electricity supplier at no extra cost (see the REIO fact sheet on green electricity).

Renewable heat sources

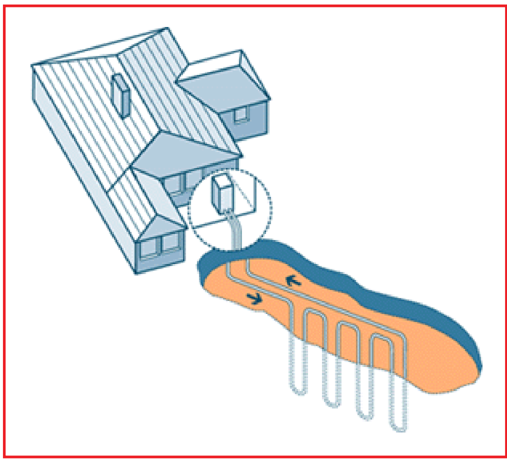
The choice of the heat source is of vital importance for the heat pump, as it will directly influence its application, efficiency (COP & SPF) and initial and operating costs. Renewable heat sources that can be used by heat pumps are air, water and ground.
The main factors that will affect this choice are:
* its availability: quantity, location relative to need and coincidence with need;
* its cost: installation, operation and maintenance;
* its temperature: level (the higher the better) and variation.

Ambient air, the most common heat source for heat pumps, is free and widely available. However air-source heat pumps achieve on average 10-30% lower seasonal SPF than ground-source or water-source heat pumps. This is mainly due to the rapid fall in capacity and performance with decreasing outdoor temperatures.

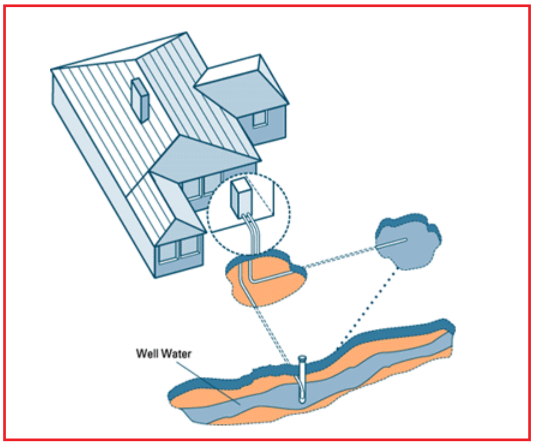
A ground-source heat pump uses the earth or ground water or both as sources of renewable heat. The temperature of the ground doesn't vary very much over the year and is generally higher than 5 °C. This ensures a relatively stable supply of heat for the heat pump and higher performances than air-source ones. Heat is removed from the ground through a collector and transferred to the heat pump via a liquid (water or antifreeze solution). The pictures below show the three main types of ground collectors:



Closed-Loop, Single Layer Horizontal Configuration

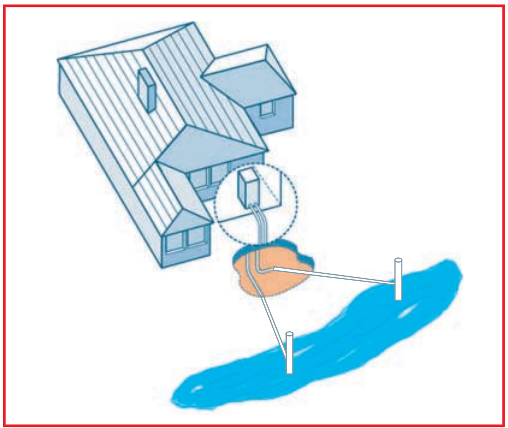


Closed-Loop, Single U-bend Vertical Configuration

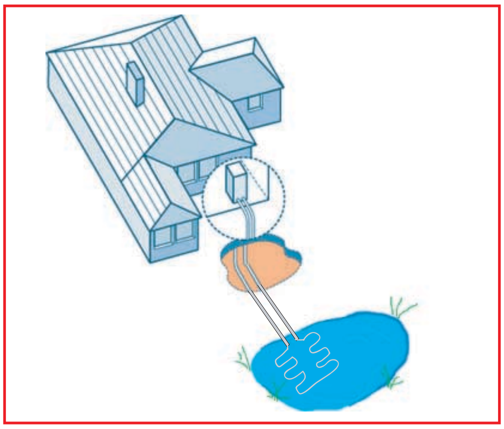


Open System Using Ground Water from a Well as a Heat Source

Open water can be also used as a low temperature heat source. Rivers, streams and lakes, when available, are ideal sources of energy. They have the advantage of needing much less collector surface area than for a ground-source heat pump.



Closed-Loop Pond or River Collector



Open System Using Open Water from a Pond or River as a Heat Source

The table below presents the advantages and disadvantages of the most common heat sources:

Heat Source	Examples	Advantages	Disadvantages	Remarks
Outside Air	Ambient air (10 to 15˚C)	*Unlimited availability *Low Investment	*Low Temp. in winter lower COP *Additional heating required * No storage effect, no 'free' cooling in summer * Noise pollution	*Suitable source for gas absorption heat pump as small source capacity required
Ground	Shallow ground (0 to 10˚C) Horizontal Collectors Vertical Collectors	* Potentially unlimited availability * Constant temperature (10 - 15˚C) higher COP * Possibility 'free' cooling in summer Needs only a small amount of ground area	* Relatively high investments due to ground collector * Output dependent on thermal properties of the soil and collector area * Available ground area for horizontal collectors can be limitative * cost of well drilling prohibitive * Might need permission from authorities	* The ground collector is generally close-looped and can be horizontal or vertical * The heat reserve of the ground can be regenerated by solar collectors or by heat disposal during summer.
Surface Water	Pond & Rivers (0 to 10˚C0, sea (3 to 8˚C), Wastewater(>10)	* Usable temperature for circulating or flowing water * Unlimited availability if source in the vicinity	* Low temperature with dead water in winter * Permission of the water board may be required * Water needs to be filtered	

Low Temperature heating Systems

As mentioned before, heat pumps work best when the temperature of the heat released is low. Floor, wall and low temperature radiator heating systems are therefore particularly suited for heat pumps. Floor and wall systems are more and more popular for reasons of comfort and health, as well as aesthetic reasons (no pipes and radiators).

Convection radiators create higher temperatures in the ceiling and cooler temperature at floor level. This will cause convection drafts and air circulation which have a cooling effect on the occupants and carry dust particles. This can result in respiratory problems and dirt on walls and furniture. With underfloor heating, floor to ceiling temperature and humidity levels remain more constant, producing a more comfortable environment for occupants.

In retrofit situations, underfloor heating might not be possible. Different options can then be considered:

- modern radiators can be used to distribute heat at a low temperature. They are larger than conventional radiators to allow for lower heating temperatures with larger convection areas;

- hydronic convectors assisted with a fan can be operated at low water temperature with a heat pump. They are typically 20% to 40% the size of an equivalent output radiator, and are equipped with advanced control;

- existing radiators can be operated at lower temperature than usual to provide a base heating load with the heat pump. The heat pump is backed-up by the existing boiler or an immersion heater when higher temperatures are required.

The table below shows how the COP of a water/brine-to-water heat pump varies with the temperature of the distribution system:

Heat distribution system	supply/return temperature	COP[1]
Conventional radiators	60/50 °C	2.5
Floor or wall heating	35/30 °C	4.0
Modern radiators	45/35 °C	3.5
Hydronic convectors	48/38 °C	3.5

[1] Heat source 5 °C

Air heating may also be used with heat pumps in modern houses in which the heating requirement is limited. It has the advantage of working at a low temperature and of being able to react quickly to temperature fluctuations in the house. An air-heating appliance can also be used to purify and refresh the air to create an optimum indoor climate.

Storage systems

Conventional heating systems (gas or oil boilers) are generally sized to meet peak demands (only a few days if not hours per year). Heat pumps are not suitable for such an approach as the investment required would be too high. To fit this economically, we therefore aim at a system with a heat pump as small as possible, working for as many hours as possible. A certain amount of heat or cold can be stored in a buffer at a certain time to meet peaks in demand later on.

Temporary storage can take place in the mass of the building. Heat produced by the heat pump can be stored at night in the mass of the floor slab through an underfloor heating system and released slowly during the day. The mass of walls insulated externally, or partition walls, can be used similarly. This principle can be applied to avail of the low cost electricity at night to store most of the heat (60%) that will be used during the next day.

Long-term storage (for a period of several months) can take place in the ground (aquifer). When operating as a cooling unit, the heat extracted from the building by the ground-source heat pump is stored in the ground. This heat can then be pumped back in the building during the heating season. Inter-seasonal storage is generally only feasible in commercial buildings which have a cooling requirement.

Sizing the heat pump system correctly

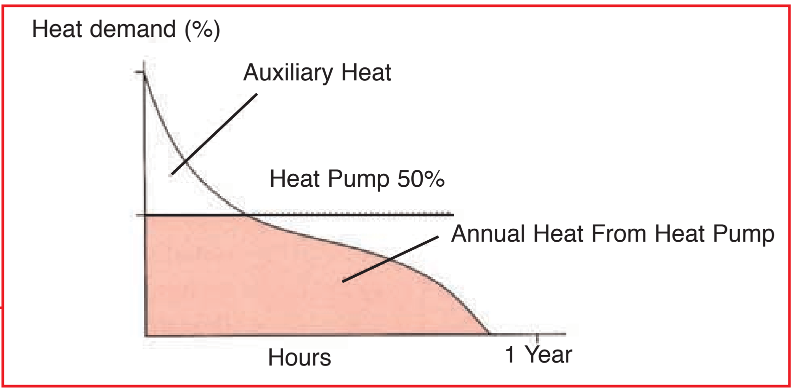
Sizing the heat pump

The capacity (power) of a heating system is defined according to the maximum heat demand of a given building. The maximum heat demand, also called the heat load, is calculated for the building according to specific weather conditions and indoor air temperature.

In Ireland, the capacity of the heat pump should be designed according to the heat load, in priority to the cooling load when there is demand for cooling. It is essential that the design and sizing of the heat pump system are done carefully and should be carried out by an expert. In a new building, the architect is best placed to calculate the heat load according to the characteristics of the building (insulation, area, occupancy, etc.) and local climate conditions.

As mentioned earlier on, heat pumps should be sized in order to have the lowest initial cost and to be working as many hours as possible. The optimum economic size of the heat pump design capacity is normally in the range of 30 to 60% of the maximum heat load of the building. Such a heat pump can cover between 60 and 90% of the annual heat demand. The figure below shows schematically the relationship between the heat pump capacity and the building requirements.

Heat Pump capacity and building heat requirements in a heat duration diagram. the heat requirements of the building do not include domestic hot water



As can be seen from the figure above, an auxiliary heater is used to supplement the heat pump during the colder part of the year. This combination, in which the heat pump is referred as bivalent, is particularly interesting in retrofit situations where the existing heating system can be kept to meet peak demand periods.

In new buildings with a high level of insulation and using a low temperature heat distribution system, heat pumps can meet the whole heat load and heating requirement. For safety, a powerful immersion heater can be installed at the inlet of the heat distribution system.

Design of the heat source collector

When the heat pump is operated with a ground source or a water source, the system harnessing the heat source, called heat collector, must be designed carefully. The heat collector must match the heat requirements of the building with the thermal properties of the source. Undersizing will mean comfort levels are not reached and back up heating/cooling will be required at extra cost. Oversizing results in high initial costs and frequent cycling of the heat pump, reducing the operating efficiency and equipment life. In large multizone buildings, with different heat loads which might not occur at the same time, a detailed energy analysis combined with sophisticated heat exchange models are needed.

In the case of ground-coupled heat pumps, it is necessary to obtain information on the thermal and hydrological properties of the site. Appropriate configuration of the ground coil and installation techniques need to be selected expertly. Surprises in this area can lead to exploding costs.
As an indication, a survey of ground source heat pumps in the USA showed that the length of the vertical heat exchanger varied between 10 and 25 m of borehole per kW of installed capacity, with an average of 14 m per kW. Boreholes are generally 100-150 mm in diameter. Multiple boreholes can be used for larger residential and commercial installations. Vertical exchange loops can also be incorporated into concrete piles where these are needed for supporting the building. These can be very cost-effective as the additional cost of integrating plastic heat exchanger tubes into the piles is small.

Horizontal collectors require a relatively large area free from hard rock or large boulders. They are generally most appropriate for small installations. As a rule of the thumb, the area of collector is more or less equivalent to the floor area of the house. The collector pipe is buried in a trench at a depth of between 0.5 and 1.8 m. As the trenching cost is generally smaller than the piping cost, systems using multiple pipes in one trench will be economical. The energy collected per meter of pipe will be less but the area needed for the collector will be reduced. By placing the coil as spiral horizontally or vertically in the trench, the area of the collector can be reduced further. The advantage of this configuration is that the heat exchange surface is effectively a cylinder with the diameter of the coil.

Economics of heat pumps

Capital costs

The capital costs for a complete heat pump system are made up of the equipment cost of the heat pump unit, the heat source collector, the heat distribution system, and installation. The ground coil and its installation are typical of a ground-source heat pump system and represent 30-50% of the total capital cost.

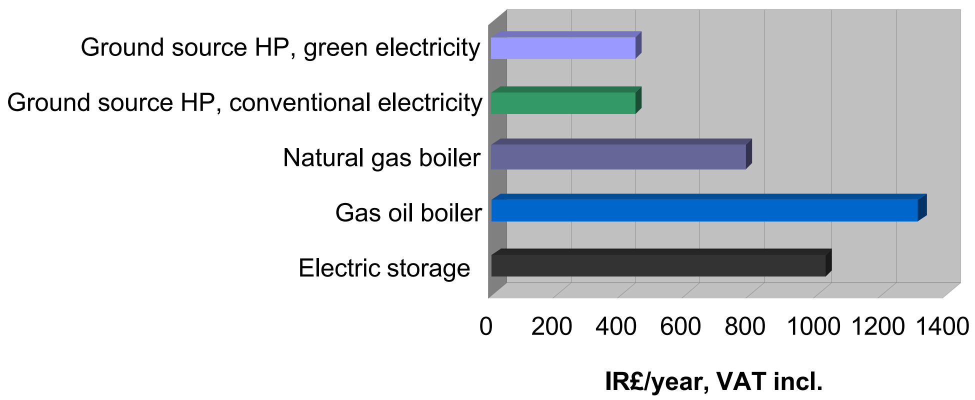
The following table gives an indicative breakdown of the capital costs of a ground-source or water-source heat pump system in a residential building in Ireland:

[1] incl. trenching or digging
[2] Based on US figures, including drilling. According to heat pump suppliers, vertical ground collectors are not economical for small-scale applications in Ireland.

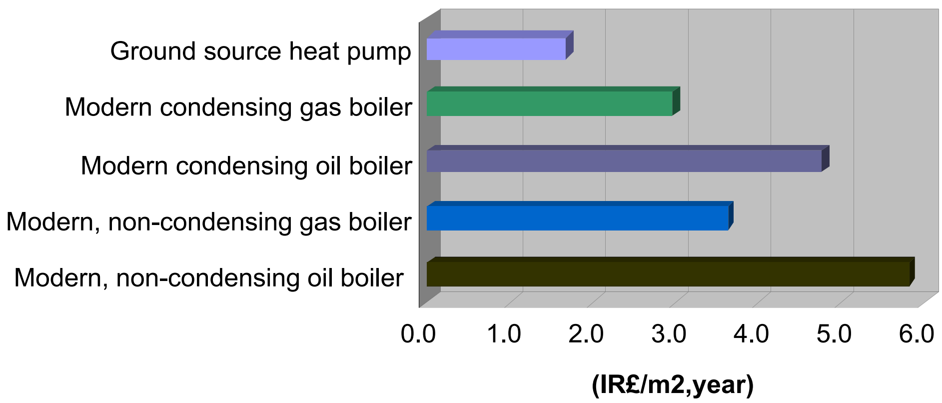
	(excl. VAT)
Heat Source Collector	
Horizontal ground source[1]	€1,905 - 2,539
Vertical Ground source[1,2]	€/m of borehole 32-76
Water Collector	€ 1,905 - 2,539
Heat Pump unit	
Capacity 10 KW	€4,444 - 5,080
Capacity 15 Kw	€5,080 - 5,714
Installation	€1,016 - 1,905
Control Unit Channel & hot water control	€ 381- 635
Hot water heating kit (excl. cylinder)	€ 635
Underfloor heating Incl. material, installation, finish	€/m² 31.74 - 38
Hydronic convectors	
3kW terminal, incl. installation	€/unit 317
6kW terminal, incl. installation	€/unit 356

Operating costs

A heat pump with a seasonal performance factor of 3-3.5 can reduce the energy consumption of a building by 60-75% compared with an efficient oil boiler system for example.
The following graph compares the energy cost to deliver 20,000 kWh of heat per year by different heating system, in a standard 180 m2 Irish house at Spring 2001 energy prices :



The following graph compares the annual energy cost to deliver the heating requirement of a typical office building (110 kWh/m2, without air-conditioning) of different heating systems using Spring 2001 energy prices:



Maintenance costs for a heat pump system are also lower than alternative systems. Heat pumps are relatively robust as they have few moving parts, they operate at low temperature and have no risk of corrosion due to flue gas condensates. There is no need for chimney stack or burner cleaning. In a commercial building maintenance costs have been estimated to be only 20 to 40% of conventional heating and cooling systems.

A cost-effective investment

Heat pumps are generally more expensive to install than conventional heating systems. The extra initial cost for a residential heat pump and its heat source collector (3 to 5,000 EURO) will be rapidly recovered by your energy savings, typically between 3 and 8 years.

In commercial buildings, the initial cost of a heat pump is often competitive with conventional heating and cooling systems (typically boilers, air-conditioning units and cooling towers). When properly designed and integrated in the building, heat pump systems can yield a simple pay-back period of five years or less when compared with conventional systems.

Environmental benefits of renewable heat pumps

Irish households emit nearly 11 million tonnes of CO2 per year due to the combustion of fossil fuels for household heating and hot water production. This represents 30% of total CO2 emissions in Ireland. Commercial and public buildings in Ireland are responsible for the emission of nearly 7 million tonnes of CO2 per year (close to 18% of total CO2 emissions in Ireland) due to their energy consumption. Sixty-five percent of that energy consumption is for space heating, water heating and cooling.
The main environmental benefit of renewable heat pumps is there ability to reduce the primary energy consumption required for space heating, cooling and water heating. However their very high efficiency to produce heat at user's point must be balanced by the power station efficiency at generating the electricity driving a heat pump.
The following table compares the primary energy efficiency and carbon dioxide emissions of different heating systems with a renewable heat pump according to the efficiency of electricity generation:

System	Primary Energy Efficiency (%)	Specific CO2 emissions (kg CO2/kWh heat)
Oil fired boiler	60-65	0.45-0.48
Gas fired boiler	70-80	0.26-0.31
Condensing Gas Boiler + low temperature system	100	0.21
Electric heating (eff. 40%)[1]	36	0.90
Conventional electricity (eff.40%)[1] + GSHP	120[2] (160)[3]	0.27 (0.20)
Green electricity (100% eff.) + GSHP	300 (400)	0.00 (0.00)

1 Primary energy efficiency of electricity generation
2 Value if COP of GSHP is 3
3 Value if COP of GSHP is 4

When replacing your oil boiler with a ground source heat pump, you will reduce your CO2 emissions by at least 40%. That's already a significant contribution towards the fight against climate change. As electricity in Ireland is mainly generated by fossil fuels with a high carbon content (coal, peat, oil, etc.), using 1 kWh of electricity is responsible for a relatively high level of CO2 emissions (0.82 kgCO2/kWh). With the replacement of old power stations using coal or peat with more efficient and cleaner electricity plants, the potential of electric heat pumps to reduce CO2 emissions will increase further.
But the really good news is that Green Electricity produced from renewable energy sources (wind, hydro, biomass) is now commercially available in Ireland at a competitive rate. The generation of Green Electricity is free of CO2 emissions and has a primary energy efficiency of 100%. So by driving your heat pump with Green Electricity, you will heat your house and hot water totally with renewable energy sources and without emitting any CO2. That's a major achievement for the environment.

Other non-financial benefits for the user include:

Low operation noise
Good aesthetics (no chimneys, no cooling towers) and improved room use (no radiators)
No roof penetrations resulting in reduced potential of leakage and ongoing maintenance
Increased safety – no combustion or explosive gases within the building
No local pollution by fuel combustion
Improved indoor air quality and reduced risk of asthma.

The Renewable Energy Information Office

The Renewable Energy Information Office is a service of Sustainable Energy Ireland. Its objective is to support the development of renewable energy in Ireland by providing independent and expert advice as well as information on related financial, environmental and technical issues.

Five ways to contact us:
WRITE: Renewable Energy Information Office
Irish Energy Centre
Shinagh House
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TELEPHONE: our hotline – 023 42193
FAX: 023 41304
EMAIL: renewables@reio.ie
VISIT OUR WEBSITE: www.irish-energy.ie/reio.htm

Sustainable Energy Ireland is a joint initiative of the Department of Public Entreprise and Forbairt.
It is supported by the EU through the Community Support Framework.

I want to know more about renewable heat pumps

Further reading

The Renewable Energy Information Office has a range of publication covering all renewable energy technologies, among which:

Free Factsheets available Directly from Us or Our Web Site:

* Wind Energy
* Bioenergy
  - Biomass
  - Landfill Gas
* Hydropower
* Green Electricity
* Renewable Energy for Buildings & Industry:
  - Passive Solar Design
  - Heat Pumps for Your Home
  - Heat Pumps for Commercial Buildings
  - Heat Pumps for the Health Sector
  - Solar Water Heaters
  - How to Heat with Wood

All these brochures can be downloaded from our website: http://www.irish-energy.ie/reio.htm

The Heat Pump Centre of the International Energy Agency has a very good range of publications on heat pumps, among which:

- Heat Pumps, an opportunity for reducing the greenhouse effect (1992)
- Heat Pumps, a better way of meet heat demand (1996)
- Heat Pumps, better by nature (1993)
- Environmental benefits of heat pumping technologies, analysis report (1999)
- Domestic Hot Water Heat Pumps for Residential and Commercial Buildings (1993)
- Commercial/institutional heat pump systems in cold climates (2000)

The IEA Heat Pump Centre Newsletter is published four times a year and is a very useful source of up-to-date information. Visit the IEA Heat Pump Centre website at:
http://www.heatpumpcentre.org

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has a very good range of practical references for the design and operation of heat pumps:

- Ground source heat pumps – Design of geothermal systems for commercial and institutional buildings (1997)
- Commercial/institutional ground-source heat pump engineering manual (1995)
- Operating experiences with commercial ground-source heat pump (1998)

These publications can be ordered from their website http://www.ashrae.org, by email: orders@ashrae.org or by fax: 00 404/321-5478

Other publications:

Ground source heat pumps, a technology review
R H D Rawlings. The Building Services Research and Information Association,
Technical Note TN 18/99

RETScreenTM International:
RETScreen provides free-of-charge software for renewable energy project analysis, including renewable heat pumps. The software can be downloaded from the Natural Resource Canada's website at
http://retscreen.gc.ca

Interesting websites:

Renewable Energy Information Office, Irish Energy Centre:
http://www.irish-energy.ie/reio.htm

The Heat Pump Centre of the International Energy Agency:
http://www.heatpumpcentre.org

CADDET, Energy Efficiency Information of the International Energy Agency:
http://www.caddet-ee.org (including database with case studies)

The European Heat Pump Network:
http://www.ehpa.org