Best Environmental Management Practice in THE TOURISM SECTOR

Efficient applications of heat pumps and geothermal heating/cooling

This best practice is an extract from the report Best Environmental Management Practice in the Tourism Sector.

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7.4 Efficient applications of heat pumps and geothermal heating/cooling

Description

Heat pumps harness RE, but require significant amounts of electricity to operate, and often involve the use of refrigerants with a high GWP. Therefore, they are considered an option to reduce energy demand, and described in this section separately from section 7.6 where RE options are described. Geothermal cooling is a renewable cooling source that requires small amounts of electricity to operate, but owing to its operational similarity with heat pump applications, it is described in this section.

Ecolabel criteria for heat pumps, such as those contained in Commission Decision 2007/742/EC for the award of the EU Ecolabel to heat pump devices, provide useful guidance on characteristics of well performing heat pumps. Selection of equipment awarded the EU Ecolabel (or alternative efficiency labels such as Energy Star) can make an important contribution towards best practice. Reverse heat pumps represent basic air conditioning technology commonly used in accommodation buildings, and in themselves do not represent best practice (although selection of efficient air conditioning units, for example based on the aforementioned labels, represents good practice). Best practice measures for this technique are summarised in Table 7.17, and elaborated using relevant case studies.

### Table 7.17: Main heat pump and geothermal energy applications

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
<th>Applicability</th>
<th>Best practice example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal or ground-source heat pumps</td>
<td>Groundwater, or water circulating in buried pipes, is passed through a heat exchanger, then heat upgraded with a heat pump is exchanged to the building HVAC and DHW systems</td>
<td>Winter months, all climates. Sufficient outdoor or suitable geology</td>
<td>Hotel Victoria (retrofit); Crowne Plaza Copenhagen Towers (new)</td>
</tr>
<tr>
<td>Geothermal cooling</td>
<td>Cool water pumped from underground is circulated within building HVAC systems in summer</td>
<td>Summer months, moderate and warm climates. Sufficient outdoor or suitable geology</td>
<td>Hotel Victoria (retrofit); Crowne Plaza Copenhagen Towers (water, new)</td>
</tr>
<tr>
<td>Use of low GWP coolants</td>
<td>Commission Decision 2007/742/EC for award of the EU Ecolabel to heat pumps prohibits use of coolants with a GWP &gt;1000. Natural refrigerants such as CO₂ and ammonia are increasingly being used, with GWPs 0 – 3 (see section 8.4)</td>
<td>May be specified for any new system</td>
<td>Scandic Copenhagen</td>
</tr>
<tr>
<td>Efficient air source heat pumps</td>
<td>Use of efficient air-source heat pumps for HVAC heating and/or cooling, and for DHW. Equipment certified according to, or complying with, Commission Decision 2007/742/EC</td>
<td>Winter months, excluding coldest climates</td>
<td>Where water-source heat pumps impractical or too expensive.</td>
</tr>
</tbody>
</table>

**Heat pumps**

Heat pumps extract and upgrade low grade renewable heat stored in surrounding air, water, ground, etc., so that it can be circulated within HVAC systems to provide space and water heating. They also
work in reverse to extract heat from building HVAC systems and expel it to the surrounding environment. Heat pumps function according to thermodynamic principles underpinning the basic refrigeration cycle (Figure 7.22). The external energy required by heat pumps to transport and upgrade heat from a heat source to the point of heating, and vice versa for cooling, is lower than the amount of heating or cooling energy provided by the heat pump, potentially resulting in significant energy savings compared with conventional heating or cooling systems.  

![Figure 7.22: Basic heat pump refrigeration cycle used to provide indoor cooling](source: Derived from Wikipedia (2012)).

The efficiency of heat pumps, expressed as a coefficient of performance (COP) for heating or Energy Efficiency Ratio (EER) for cooling, depends on the following critical factors:

- heat exchange media
- heat differential between source and destination
- system design and installation.

Heat exchange media may be: (i) ambient air (air-source heat pumps); (ii) water, including groundwater (water-source heat pumps); (iii) the ground, close to the surface or at depth (ground-source heat pump). Ground-source heat pumps typically use a heat medium such as brine or a water-glycol mixture, which may either be circulated down through a deep borehole or horizontally through piping installed at shallow depth (1 – 2 m), to exchange heat with the ground. As a rule of thumb the outdoor area required for the latter system is twice the area that requires heating, restricting applicability to smaller accommodation premises.

Typical water-source heat pumps achieve COPs of 4 to 5, compared with COPs of 2 to 3 for typical air-source heat pumps, although performance varies widely from less to more efficient designs and according to operating conditions. The lower the heat differential between the source and destination, the higher the efficiency, and the efficiency of air-source heat pumps decreases dramatically when outdoor temperatures drop below 0 °C. Seasonal temperature variations are further below ground and in water bodies, making water- or ground-source heat pumps more efficient throughout the year.
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Thus, one important aspect of best practice is to utilise ground- or water-source heat pumps where feasible according to space, geological and economic considerations (more expensive than air-source heat pumps). Another important aspect of best practice with respect to heat pump application is installation of a low temperature distribution (HVAC) system, which in turn is most effective where relatively low heat demands have been achieved through a good quality building envelope. Thus, optimised heat pump applications depend on an integrated approach to building design that incorporates a high-quality building envelope (section 7.2) with an HVAC system designed to optimise the efficiency of the heating and cooling source (section 7.3).

Geothermal cooling
Deep groundwater maintains a relatively constant temperature of 4 – 10 °C throughout the year (IEA, 2012), and provides a useful source of cooling for building HVAC systems. Geothermal cooling is simple to implement, comprising a borehole sufficiently deep to extract cool groundwater, a pumping system and a heat exchanger, as represented in Figure 7.23. Extraction of cool water during summer is sufficient to provide 100% of cooling demand, and the return of warmed water through a sink well results in localised warming of the groundwater during the summer. This slightly warmer water may then be pumped up in winter to provide heat to the HVAC system via a heat-pump. Examples of this system include the Hotel Victoria in Freiburg, Germany, and the Crowne Plaza Copenhagen Towers hotel in Denmark. In the latter hotel, the system returns four kWh of heating per kWh of electricity consumed to drive the system in heating mode, and eight kWh of cooling per kWh of electricity used to drive the system in cooling mode. Geothermal cooling may also be used to cool water supplied to accommodation via district cooling systems, especially in northern and eastern Europe where such systems are more common.
Ground cooling tubes are an alternative approach for summer cooling that may be suitable in some circumstances, for low-rise premises with sufficient outdoor space and where the earth is easy to excavate. Tubes typically 15 – 50 cm in diameter and tens of metres in length are buried approximately two metres below the ground. Incoming air, or recirculating indoor air in closed loop systems, passes through these tubes, dissipating heat to the surrounding ground (usually a few degrees cooler than the air during summer months, on average). One example of the use of such tubes is the Alma Verde holiday villas in Portugal, where the Coolhouse project (Faber Maunsell, 2004) measured cooling-energy savings of over 95% for a ground cooling tube system compared with use of conventional air conditioning units (although indoor air temperatures were slightly higher). The main benefit of such systems is a significant reduction in peak daytime indoor temperature, potentially avoiding the need for air-conditioning, but applicability is restricted to specific conditions and such systems are not practical for large buildings.
Low GWP refrigerants
Heat pump systems traditionally incorporated refrigerants such as hydrofluorocarbons and other inert compounds with high GWPs many thousands of times higher than CO$_2$ on a mass basis, and in some cases also high potential to destroy stratospheric ozone. In recent years, various low GWP refrigerants such as the hydrocarbons R1270, R290, R600A, or the natural refrigerants CO$_2$ and NH$_3$, have begun to replace traditional refrigerants. These new refrigerants do not damage the ozone layer and have much lower GWPs. A detailed overview of the use of hydrocarbon and natural refrigerants is presented in the EMAS technical report for the retail trade sector (EC, 2011), with respect to retail refrigeration systems.

Achieved environmental benefit
The main environmental benefit of heat pumps and groundwater cooling is a significant reduction in primary energy demand. The extent of this reduction is heavily dependent upon the reference system compared (Figure 7.24), and is determined by the system efficiency (e.g. heat pump COP) and by the primary energy factor of the energy carrier (e.g. 2.7 for electricity: Table 7.4 in section 7.1). The primary energy saving potential of heat pumps and groundwater cooling range from 0.2 to 2.0 kWh per kWh heating or cooling delivered. Despite the high COP of groundwater cooling, the primary energy savings are higher for heat-pump heating owing to the lower efficiency of conventional heating systems.

Primary energy savings for heat pumps and groundwater cooling are reduced owing to their dependence on electricity, which has a high primary energy factor. However, the primary energy factor of electricity varies considerably depending on generating sources, so that primary energy savings arising from heat pumps and groundwater cooling can be close to 100% if renewable electricity is used to drive the systems.

![Figure 7.24: Primary energy requirements for 1 kWh heating or cooling delivered by air- and water-source heat pumps (A-HP and W-HP) and groundwater cooling (GW-C), and savings compared with conventional heating and cooling sources](image-url)
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Application of groundwater heating and cooling, with COP and EER values of 4 and 8, respectively, is claimed to result in total final energy consumption of less than 43 kWh per m² per year for the Crowne Plaza Copenhagen Towers hotel (CP Copenhagen, 2012).

Appropriate environmental indicator

Currently, there remains a lack of standardisation with regard to measuring the overall system efficiency of heat pump applications at the building level. The project ‘SEasonal PErformance factor and Monitoring for heat pump systems in the building sector (SEPEMO-Build)’ is intended to develop a common methodology for field measurement of heat pump systems and calculation of SPF in the building sector. However, the efficiency of heat pump units can be measured with respect to energy inputs and outputs.

Heat pump energy efficiency

Heat pump efficiency is calculated as the ratio between the total heat output and the primary energy input. A standardised methodology to calculate heat pump efficiency is provided by EN14511: 2004. The most common way to express the heating efficiency of a heat pump is the COP:

\[
\text{COP} = \frac{Q_H}{W}
\]

- \(Q_H\) is the delivered heating energy, expressed in kWh;
- \(W\) is the work energy used to drive the system (usually electricity), expressed in kWh, and including all circulating pumps.

The same equation applies for calculating cooling EER, replacing \(Q_H\) with \(Q_C\).

Heat pumps and geothermal cooling usually rely on electricity, with high upstream energy consumption and loss. For comparison with alternative direct heating sources, such as on-site gas boilers, primary energy efficiency (PPE) is a useful indicator. Primary energy efficiency can be calculated accordingly:

\[
\text{PEE} = \frac{Q_H}{Q_P}
\]

- \(Q_H\) is the delivered heating energy, kWh;
- \(Q_P\) is the primary energy consumption, in kWh, calculated by multiplying the final energy consumption by the primary energy factor for the relevant energy carrier (see Table 7.4).

COP and EER values may also be expressed as Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER), respectively, specifically representing operational performance averaged over a heating or cooling season.

System global warming potential

Refrigerant leakage makes a significant contribution to the environmental impact of heat pump systems owing to the high global warming potential (GWP) of traditional CHFC refrigerant gases (see Figure 8.27 in section 8.4). Leakage (top-up) rates of refrigerants can be multiplied by their GWP, and added to the carbon footprint of electricity consumed by the heat pump where these data are available, to calculate the annual carbon footprint of the cooling or heating system.
Building energy performance
Ultimately, the efficiency of the heating and cooling system is reflected in the indicators for building total energy consumption, and more specifically where available heating and cooling energy consumption (sections 7.2 and 7.3), expressed as kWh per m² heated and cooled area per year.

Benchmark of excellence
German DENA standards define a heat pump to be 'efficient' if it has a HSPF above 3.0 and 'very efficient' if it is above 3.5. A more detailed breakdown of reference performance COP, EER and PER values for different types of heat pumps is provided in the EU Ecolabel criteria for heat pumps (Table 7.18 and Table 7.19). These values are proposed as benchmarks of excellence for specific heat pump types under specified conditions, according to the methodology of EN14511: 2004.

In relation to an EER benchmark for geothermal cooling, in the absence of detailed information, a value of 8 is initially proposed.

In addition, best practice in this technique is to install water-source heat pumps and/or geothermal cooling systems wherever feasible, and to optimise their operation through an HVAC system design that minimises the heat differential between the heat/cool source and delivery temperature (see section 7.3).

**BM: water-source heat pumps and/or geothermal heating/cooling is used in preference to conventional heating and cooling systems wherever feasible, and heat pumps comply with EU Ecolabel criteria.**

<table>
<thead>
<tr>
<th>Heat pump type</th>
<th>Min. COP (elec.)</th>
<th>Min. COP (gas)</th>
<th>Min. PER</th>
<th>Outdoor unit (temp., ºC)</th>
<th>Indoor unit (temp, ºC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air/air</td>
<td>2.9</td>
<td>1.27</td>
<td>1.16</td>
<td>Inlet DB: 2</td>
<td>Inlet DB: 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Inlet WB: 1</td>
<td>Inlet WB: 15</td>
</tr>
<tr>
<td>Air/water</td>
<td>3.1</td>
<td>1.36</td>
<td>1.24</td>
<td>Inlet DB: 2</td>
<td>Inlet DB: 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Inlet WB: 1</td>
<td>Inlet WB: 35</td>
</tr>
<tr>
<td>Brine/air</td>
<td>3.4</td>
<td>1.49</td>
<td>1.36</td>
<td>Inlet: 0</td>
<td>Inlet DB: 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Outlet: –3</td>
<td>Inlet WB: 15</td>
</tr>
<tr>
<td>Brine/water</td>
<td>4.3</td>
<td>1.89</td>
<td>1.72</td>
<td>Inlet: 0</td>
<td>Inlet DB: 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Outlet: –3</td>
<td>Inlet WB: 35</td>
</tr>
<tr>
<td>Water/water</td>
<td>5.1</td>
<td>2.24</td>
<td>2.04</td>
<td>Inlet: 10</td>
<td>Inlet DB: 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Outlet: 7</td>
<td>Inlet WB: 35</td>
</tr>
<tr>
<td>Water/air</td>
<td>4.7</td>
<td>2.07</td>
<td>1.88</td>
<td>Inlet: 15</td>
<td>Inlet DB: 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Outlet: 12</td>
<td>Inlet WB: 15</td>
</tr>
</tbody>
</table>

NB: Additional lower COP and PER values are indicated in EU Ecolabel criteria based on higher output temperatures.
DB = dry bulb thermometer, WB = wet bulb thermometer.

*Source: EC (2007).*
The benchmarks of excellence proposed for HVAC and total final energy consumption in sections 7.2 and 7.3 in relation to overall building energy performance for existing hotels are based on data for hotels that mostly do not use heat pumps for heating or cooling. Therefore, application of efficient heat pumps and geothermal cooling should enable enterprises to perform considerably better than those benchmarks.

**Cross-media effects**

Operation of heat pumps containing hydrofluorocarbon refrigerants contributes to global warming via refrigerant leakage which can somewhat offset GHG emission savings attributable to lower energy consumption. The EU Ecolabel for heat pumps requires use of refrigerants with a GWP of ≤2000, and allows a 15% reduction in minimum COP, EER and PER values for heat pumps using refrigerants with a GWP of less than 150. Air-source heat pumps also generate some noise.

**Operational data**

Basic good practice in heat pump system design is provided in EU standard EN 15450 ‘Heating systems in buildings – Design of heat pump heating systems’.

**Efficient heat pump system design**

The decision to install a heat pump, the selection of the preferred type of heat pump, and the specific application of the heat pump will depend largely on local factors and the alternative heating and cooling options available. As referred to under ‘Applicability’, climate is a critical factor when deciding whether to install air-source heat pumps, but can affect all types of heat pump through its influence on the heating and cooling demand. The key questions that follow are relevant.

- What are the heating and the cooling demands (see section 7.3)?
- What alternative heating and cooling options are available?
- What supply temperatures are required for the existing or planned distribution system (section 7.3)?
- What is the seasonal capacity and temperature of available heat sources/sinks?
Heating and cooling demand should be determined in accordance with relevant national standards, based on modelled data for new or newly renovated buildings or recent data for existing buildings. The concurrency between heating and cooling demands and heat source/sink is an important factor that should be ascertained by using an expert based on a site survey, considering yearly and daily variations that can have a large effect on the exploitability of a heat source/sink. Concurrency is important in relation to the selection of heat source and distribution system, and the installation of a buffer system. Buffer systems can be more easily integrated into water- and ground-source heat pumps operating with water-based distribution systems. Buffer systems enable loads to be balanced and the operating cycles length to be extended.

Calculation of theoretical and estimated actual (e.g. approximately half theoretical) efficiencies for different heat pump types using different heat sources or sinks locally available at specific temperature ranges (see below) can be used to indicate the relative energy and economic performance of different types of heat pump. When comparing alternative heating and cooling options, key aspects include energy consumption and costs as well as lifetime of the existing system (if an existing system is being replaced). The availability of alternative heating and cooling options is a critical and highly site-specific factor. For example, accommodation may be located in an area where district heating and/or district cooling is available, which could significantly reduce the energy and cost benefits of heat pump systems. Table 7.20 lists advantages and disadvantages associated with different types of heat pump.

A critical factor involved in ensuring that the heat pump systems are operating efficiently at high capacity is to install a centralised heat pump system, rather than a decentral system. The highest overall system efficiencies are achieved by installing a heat pump with a capacity slightly below the peak load, combined with a buffer system to regulate peaks and troughs in demand. This is easier to achieve with water-based, rather than air-based, distribution systems given the high heat capacity of water.

Table 7.20: Main advantages and disadvantages of different heat sources

<table>
<thead>
<tr>
<th>Heat Source</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>– Readily available and easy to establish&lt;br&gt;– Decentralised systems&lt;br&gt;– Relatively low establishment cost&lt;br&gt;– An auxiliary heating system may function as a backup heating system</td>
<td>– May require auxiliary heating system in winter&lt;br&gt;– High temperature variations and low temperatures in winter&lt;br&gt;– Lower HSPF due to temperature conditions&lt;br&gt;– May require defrosting of evaporation coils&lt;br&gt;– Potential noise emissions (decentralised systems)</td>
</tr>
<tr>
<td>Water</td>
<td>– Stable and relatively high temperature&lt;br&gt;– Relatively low temperature difference between source and sink over the year&lt;br&gt;– Higher HSPF due to the temperature conditions</td>
<td>– For groundwater systems: risks of water quality issues, water table issues, risk of polluting or deteriorating the water source&lt;br&gt;– Corrosion due to salts/saline sea water&lt;br&gt;– Relatively high establishment costs&lt;br&gt;– Freezing of evaporation coils (mainly for surface waters or low saline sea water)&lt;br&gt;– Less accessible as heat source, especially in urban areas</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Heat Source</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground and soil</td>
<td>– Stable and relatively high temperature</td>
<td>– Large outdoor space requirements for horizontal systems + reestablishment of outdoor areas, e.g. gardens</td>
</tr>
<tr>
<td></td>
<td>– Relatively low temperature difference between source and sink over the year</td>
<td>– Relatively high establishment costs and high costs of vertical systems (but low as percentage of Life-Cycle Costs)</td>
</tr>
<tr>
<td></td>
<td>– Higher HSPF due to the temperature conditions</td>
<td>– Unknown geological structures or soil thermal properties</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Risk of leakage from evaporation coils and soil pollution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Lowering of soil temperature during heating season and prolonged lowering of temperature at the end of the heating season</td>
</tr>
</tbody>
</table>


Temperature differential

The heat pump cycle follows a Carnot Cycle and the theoretical COP<sub>max</sub> can therefore be calculated by using the temperature difference between the heat source (evaporator) and the heat output (condenser). Thus, the theoretical system efficiency can be calculated based on the input temperature and the output temperature, as presented below for a heating system.

\[
\text{COP}_{\text{max}} = \frac{T}{\Delta T}
\]

\( T \) is the temperature of the heat sink (condenser temperature) in degrees Kelvin; \( \Delta T \) is the temperature difference between the warm and the cool side (evaporator and condenser) in degrees Kelvin.

From the formula it is clear that \( \text{COP}_{\text{max}} \) is inversely proportional to the temperature difference between the heat source/sink and the HVAC supply system operating temperature.

To illustrate the calculation of the \( \text{COP}_{\text{max}} \) we can take two examples where the heat source is groundwater at 10 °C (283 K), the heat distribution system is either a low temperature underfloor heating system requiring supply water at 35 °C (308 K) or a high temperature radiator system requiring supply water at 70 °C (343 K).

Table 7.21: Examples of theoretical \( \text{COP}_{\text{max}} \) values for a low and high temperature distribution system

<table>
<thead>
<tr>
<th>Low temperature underfloor heating</th>
<th>High temperature radiators</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta T = 308 – 283 )</td>
<td>( \Delta T = 343 – 283 )</td>
</tr>
<tr>
<td>= 25 K</td>
<td>= 60 K</td>
</tr>
<tr>
<td>( \text{COP}_{\text{max}} = \frac{308}{25} )</td>
<td>( \text{COP}_{\text{max}} = \frac{343}{60} )</td>
</tr>
<tr>
<td>= 12.3</td>
<td>= 5.7</td>
</tr>
</tbody>
</table>

The \( \text{COP}_{\text{max}} \) as calculated above is a theoretical value for an ideal process. In reality thermal, mechanical, and electrical losses will impact the COP. The achieved COP can, as a rule of thumb, be taken as half of the Carnot Efficiency.
For DHW heating in summer, the COP is likely to be lower than for HVAC heating in winter because of the higher temperatures required for hot water. Studies of selected heat pumps across Germany showed average HSPFs of just above 3.0 for the summer and around 4.0 between October and March (EC, 2012).

**Applicability**

**Building ownership**
As with building envelope improvement and HVAC optimisation, the installation of heat pump and geothermal systems may not be under direct control of accommodation management owing to the ownership structure of accommodation buildings, in particular for hotel chains. In such cases, this technique may be more applicable to building owners and management companies who decide on heating system installations, although accommodation managers may use information here as a guide for selection of appropriate premises, and to encourage building owners to upgrade the heating and cooling systems.

**Air-source heat pumps**
Air-source heat pumps are applicable in most conditions, but the heating efficiency of such systems may be limited and require backup when outdoor air temperatures fall significantly below freezing. Thus, applicability may be limited in very cold and sub-arctic climate zones, as displayed in Figure 7.20 (section 7.3).

**Ground- and water-source heat pumps**
Ground-source heat pumps require either: (i) sufficient outdoor area where extensive digging is possible adjacent to the premises; (ii) appropriate geology below the premises to enable economic drilling of boreholes.

Geothermal cooling with groundwater depends on the presence of suitable hydrogeology (groundwater must be present at an accessible depth) and geology directly below the premises.

**Ground cooling tubes**
The applicability of ground cooling tubes is limited by a number of factors, including the availability of outdoor space and easy-to-excavate ground. The average daily ground temperature must also be at least a few degrees cooler than the average daily air temperature during summer months, and the system may not work well with very warm humid air that requires dehumidification.

**Economics**

**Installation costs**
The costs of installing heat pump systems vary significantly with the type of heat pump, the location, and the selected collection and distribution system, but are typically around twice those of installing conventional heating systems (Geosystems, 2012). Consulted HVAC specialists have provided approximate installation costs of EUR 150 – 300 per kW capacity for the heat pump, and EUR 200 per kW installed capacity for the collection and distribution system (GMCB, 2010).

As an example, for a 5 300 m² 100-room hotel, installing a heat-pump heating system may involve total costs of EUR 106 000, assuming a cost of EUR 400 per kW installed (including distribution system) and installation of 50 W per m² (Ochsner, 2008).

Even for more expensive heat pump applications, installation costs represent 10 – 20 % of lifecycle costs. For example, the comprehensive geothermal heating and cooling systems installed at the Crowne Plaza Copenhagen Towers (described below) are estimated to pay back within 6 years.

Government energy efficiency schemes may provide economic incentives for installing heat pumps. Equipment for which purchase costs may be offset against tax under the UK Enhanced Capital Allowance scheme includes heat pumps for space heating.
Operating cost savings

As for previous sections, country- and contract-specific energy prices determine the cost competitiveness and payback times for heat pump applications. Figure 7.25 shows energy costs per kWh of heating and cooling delivered for different systems, and shows the cost advantages of heat pump systems compared with conventional electric resistance, gas and oil heating systems (apart from air-source heat pumps compared with gas when the electricity price is EUR 0.20 per kWh).

![Energy costs for every kWh of heating and cooling delivered by different systems](image)

NB: Based on efficiency assumptions applied in Figure 7.24, and energy costs of EUR 0.1 – 0.2 per kWh for electricity, EUR 0.06 per kWh for natural gas, and EUR 0.09 per kWh for oil.

Figure 7.25: Energy costs for every kWh of heating and cooling delivered by different systems

The relative differences in energy costs for one kWh of heating or cooling across the different systems are summarised in Table 7.22 and Table 7.23, respectively. Water-sourced heat pumps (i.e. using ground or groundwater) offer the lowest heating cost per kWh, and reduce heating energy costs by 63 % compared with gas and 75 % compared with electric resistance and oil heating (Table 7.22).

<table>
<thead>
<tr>
<th></th>
<th>A-HP</th>
<th>W-HP</th>
<th>Electric</th>
<th>Gas</th>
<th>Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-HP</td>
<td>0 %</td>
<td>48 %</td>
<td>-63 %</td>
<td>-44 %</td>
<td>-63 %</td>
</tr>
<tr>
<td>W-HP</td>
<td>-33 %</td>
<td>0 %</td>
<td>-75 %</td>
<td>-63 %</td>
<td>-75 %</td>
</tr>
<tr>
<td>Electric</td>
<td>170 %</td>
<td>300 %</td>
<td>0 %</td>
<td>50 %</td>
<td>0 %</td>
</tr>
<tr>
<td>Gas</td>
<td>80 %</td>
<td>167 %</td>
<td>-33 %</td>
<td>0 %</td>
<td>-33 %</td>
</tr>
<tr>
<td>Oil</td>
<td>170 %</td>
<td>300 %</td>
<td>0 %</td>
<td>50 %</td>
<td>0 %</td>
</tr>
</tbody>
</table>

Groundwater cooling systems offer the lowest cooling costs per kWh, and save between 56 % compared with air-source heat pumps and 69 % compared with chiller systems (Table 7.23).
Best practice 7.4 – Efficient applications of heat pumps and geothermal heating/cooling

Table 7.23: Comparison of input energy costs per unit cooling output for different cooling sources

<table>
<thead>
<tr>
<th></th>
<th>GW</th>
<th>A-HP</th>
<th>Chiller</th>
</tr>
</thead>
<tbody>
<tr>
<td>GW</td>
<td>0 %</td>
<td>-56 %</td>
<td>-69 %</td>
</tr>
<tr>
<td>A-HP</td>
<td>129 %</td>
<td>0 %</td>
<td>-29 %</td>
</tr>
<tr>
<td>Chiller</td>
<td>220 %</td>
<td>40 %</td>
<td>0 %</td>
</tr>
</tbody>
</table>

Payback times
Payback times are highly dependent on the type of system installed, contract energy prices, and the reference system compared, and should therefore be calculated for specific applications. To develop the example of a geothermal heat pump installed in a 5 300 m² 100-room hotel described above, annual heating energy costs could be reduced by between EUR 16 563 and EUR 35 554 compared with gas heating, assuming average and best practice heating demand of 161 and 75 kWh/m²yr, respectively. This compares with an investment cost of EUR 106 000 (see above), of which half may be additional for the geothermal system (Geosystems, 2012), indicating a simple payback period in the region of 1.5 to 3.2 years.

Meanwhile, the same sized hotel in a warm climate with a cooling demand of 75 kWh/m²yr could reduce annual cooling energy costs by EUR 10 931 by installing a groundwater cooling system in place of a chiller. This would be associated with a simple payback of 4.8 years, assuming the geothermal system costs twice as much as the chiller system to install.

In fact, consideration of payback times can be complex for heat pumps, because they can provide both heating and cooling, and may in some cases be considered an upgrade of cooling system heat pumps that would be required anyway. In this context, the application of heat pumps for heating may be most cost effective in the ‘mixed’ and ‘warm’ climate zone of Figure 7.20 (section 7.3) where the heat pumps can also be used in reverse to provide summer cooling, thereby avoiding the costs associated with installing separate heating and cooling systems. In such cases, installation of an efficient air-source heat pump system may pay back immediately, and installation of the most efficient groundwater-based systems may pay back over a number of years before realising large annual energy cost savings.

Online calculation tool
The EU funded project ProHeatPump has developed a basic online calculation tool that can be used to evaluate and compare the following heating options in terms of capital and annual costs:

- ground-source heat pump
- oil boiler
- gas boiler
- direct electric
- electric boiler
- wood boiler
- pellet boiler
- district heat.

Based on information on investment costs, fuel costs, and efficiency the online tool calculates the primary energy demand, annual fuel quantities and costs, annualised capital cost (annuity factor of 0.096 and interest rate of 5 %), and total annual heating cost for the different options. The online tool is available at: http://proheatpump.syneriax.com/calculator.htm?lang=GB
Driving force for implementation

Potentially large reductions in annual energy costs, as described above, represent a major driving force for installing heat pump and geothermal cooling systems. Such systems can also significantly reduce the carbon footprint of accommodation, and facilitate 'carbon neutral' operations as claimed by some accommodation managers in sustainability reporting (e.g. Crowne Plaza, 2011).

With respect to use of low GWP refrigerants, the use of conventional refrigerants with high GWP must be phased out under current regulations.

Case studies

NH Laguna Palace Hotel, Italy

NH Laguna Palace Hotel comprises 384 hotel rooms and a convention centre, and has a total cooling capacity of 3 200 kW provided by decentralised water-to-water compact heat pump units and packaged water-to-air roof-top units (Curano, 2007). These units also provide heating for the hotel, and use river water extracted via a pre-existing underground duct as a stable heat source/sink. The installed system avoids the need for boiler heating of the HVAC system in winter and cooling tower cooling in summer.

High-efficiency water-source heat pumps use refrigeration circuits that include rotary/scroll compressors, 4-way valves, heat exchangers on the demand and source sides (finned coil and plate types), an expansion device (electronic thermostatic valves on larger models), variable flow pumps to reduce energy consumption, electronic controls and automatic safety devices.

A modular decentralised system was chosen because the different zones of the hotel have different needs, in particular the conference centre, rooms and large suites. For example, individual compact water-to-water heat pumps the size of a washing machine are used for each suite. Packaged water-to-air rooftop units supply conditioned air to high attendance zones including the restaurants, meeting rooms and conference centre. The system in this hotel also incorporates aspects of best practice for HVAC optimisation (see section 7.3).

Crowne Plaza Copenhagen Towers, Denmark

Crowne Plaza Copenhagen Towers was built in 2009, has a floor area of 58 000 m², and incorporates 366 rooms, a conference room section, kitchen, restaurant and ancillary office building. Geothermal heat pumps were installed based on the aquifer thermal energy storage (ATES) technique that utilise groundwater as a heat source and heat sink. Cold groundwater is pumped up during the summer and directed to the hotel’s basement where it cools down the water in the internal HVAC system. The groundwater is then returned into the ground, where the water accumulates heat during the summer for use in the winter. During winter, the water which was heated during the summer is pumped up again and heat energy is sent through two heat pumps which raise the temperature to heat the hotel HVAC system. Table 7.24 summarises some technical characteristics of the system. Frequency converters regulate the speed of heat pumps and HVAC system circulation to optimise energy efficiency (Danfoss, 2010; CP Copenhagen, 2012).

Table 7.24: Key characteristics of the geothermal heating and cooling systems in the Crown Plaza Copenhagen Towers

<table>
<thead>
<tr>
<th>Function</th>
<th>Heat pump capacity</th>
<th>Peak demand</th>
<th>COP</th>
<th>Supply temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>1 183 kW</td>
<td>2 900</td>
<td>4.0</td>
<td>30 – 60 °C</td>
</tr>
<tr>
<td>Cooling</td>
<td>1 100 kW</td>
<td>4 100</td>
<td>8.3</td>
<td>12 – 18 °C</td>
</tr>
</tbody>
</table>
The technology realises energy savings of up to 90% compared with mechanical cooling and up to 60% compared with traditional heating, and enables the Crowne Plaza Copenhagen Towers to achieve the Danish Low Energy Class 2 standard, i.e. energy consumption <42.6 kWh per m² per year. The payback time for such systems is typically between 0 and 6 years.

The Zetter Hotel, Clerkenwell, London
The 59-room Zetter Hotel in Clerkenwell, London, installed seven heat recovery air conditioning units that use groundwater from a 130 m borehole sunk below the hotel. The selection of groundwater cooling not only maximised energy efficiency, but avoided losing valuable roof space to conventional air-source air conditioning units, thus enabling the provision of an additional penthouse suite. The main 5-story atrium provides natural ventilation, whilst each of the condensing units can supply simultaneous cooling and heating for up to 16 individual indoor units. Condensing units are interlinked via the building’s water loop, enabling heat recovery from indoor units on the same refrigerant circuit in addition to transferring energy between circuits.

Others
Other examples of geothermal heating and cooling applied in accommodation buildings include:

- Brigittenau Youth Palace, Vienna
- Boutique-hotel Stadhalle, Vienna
- Decoy Country Cottages, Ireland
- Hotel A Quinta da Auga, Spain.

Other best practice examples of heat pump heating in accommodation buildings include:

- Kühlungsborn campsite, Germany (upgrades heat from waste water: section 9.2)
- Krägga Herrgard hotel in Sweden (ground-source heat pumps)
- Alle Ginestre Capri, Italy (air-water heat pump for hot water, and air-air heat pump for HVAC).

References

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Best practice 7.4 – Efficient applications of heat pumps and geothermal heating/cooling

- Geosystems, FAQ about geothermal heating and cooling, webpage accessed January 2012: http://www.gogogeo.com/about-geothermal/faq
- GMCB, personal communication with GMCB HVAC specialists December 2010.
- Hotel Victoria, personal communication October 2011.