Green Energy and Technology

David Borge-Diez
Enrique Rosales-Asensio *Editors*

Geothermal Heat Pump Systems

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Contents

Geoespatial Distribution of the Efficiency and Sustainability of Different Energy Sources for Geothermal Heat Pumps in Europe

Ignacio Martín Nieto, David Borge-Diez, Cristina Sáez Blázquez, Arturo Farfán Martín, and Diego González-Aguilera

Abstract This research work aims at the multinational study, in Europe, of the emissions and energy costs generated by the operation of low enthalpy geothermal systems, with heat pumps fed by different energy sources. From the economic point of view, gas natural and biogas prizes are, usually, lower than electricity ones. So, it may be advantageous to use these energy sources to feed the heat pumps instead of electricity. From the environmental point of view, it's intended to highlight the fact that under certain conditions of electricity production (electricity mix.), more CO_2 emissions are produced by electricity consumption than using other a priori less "clean" energy sources such as natural gas. In order to establish the countries where each of the different heat pumps may be more cost-efficient and environmentally friendly, multi-source data have been collected and analyzed. The results show that in the whole majority of cases, the electric heat pump is the most recommendable solution. However, there are some countries (such as Poland and Estonia), where the gas engine heat pump may be a better alternative.

Keywords Electric heat pumps · Gas driven heat pumps · Electricity mix · Economic and environmental analysis

Nomenclature and Formulae

HP	Heat pump
COP	Coefficient of performance
SPF	Seasonal performance factor
GSHP	Ground source heat pump geothermal system
EHP	Electric heat pumps

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GEHP	Gas engine heat pump
LPG	Liquefied petrol gas
W	Mechanical energy from the compressor (MWh)
Q_c	Thermal energy from the condenser (MWh)
Q_e	Thermal energy from the evaporator (MWh)
C_1	Coefficient of performance of the electric motor or the gas engine motor of the HP
C_2	Average performance of the thermoelectric transformation of the primary energy into electricity.
HCV	Higher calorific value
IDEA	Institute for the diversification and energy saving
EUROSTAT	Statistical office of the European Union
EP	Electricity prices (€/kWh)
EEC	Emissions (CO_2) by electricity consumption (g CO_2/kWh)
NGP	Natural gas prices (€/kWh)
ENGC	Emissions (CO_2) by natural gas consumption (g CO_2/kWh)

1 Introduction

Many European countries are heavily committed in developing a sustainable and decarbonized energy system [1]. This may be due, in large part, to the lack of oil and natural gas resources in most of the countries of Europe. In the challenge to reduce the CO_2 emissions, the building stock plays a very important role because it is responsible for the 36% of emissions in the E.U.

Heating and cooling systems powered by electricity instead of fossil fuels may become more and more important in the future due to the upcoming policies of CO_2 emissions control [2]. In this environment, the low enthalpy geothermal systems may emerge as one of the best solutions available due to the wide locations where is possible to install these systems and the high efficiency of them [3].

The above-mentioned systems do not depend on great geothermal anomalies; they can be installed in many other places where a certain heat conductivity of the ground and some initial temperature conditions can be found [4]. In exchange for this wide availability, these systems are not able to use geothermal energy in a direct way; they need to include a heat pump in their core.

These heat pumps may work with electricity or with natural gas or even biogas. The first group may be the most environmentally friendly, however, under certain circumstances, the natural gas and biogas driven heat pumps can be more efficient in terms of CO_2 emissions and annual costs.

The idea of the present work is to make a comparison between heat pumps belonging to low enthalpy geothermal systems, working under different conditions (technical, economic and energetic), in many different European countries.

Heat pumps (HPs) constitute a very important part of the aforementioned installations [5] so one of the main concerns about using them in low enthalpy geothermal systems is associated with their primary energy consumption. The performance of an HP is commonly characterized by the Coefficient of Performance (COP) and the Seasonal Performance Factor (SPF). Both are performance coefficients, defined by the ratio between the heat obtained through the HP and the primary energy consumed by it (most of it goes to the activation and operation of the compressor's power unit). The COP is obtained using instantaneous values, while in the SPF are considered annual behaviors [6, 7]. For the present work, we have used the COP of the chosen HPs to make the comparisons due to data availability; nevertheless, we think that using the SPF instead wouldn't change the results in a significant way.

The general workflow followed in this study is shown in the next diagram (Fig. 1).

We must also remember that the COP of a HP conditions the design of the well field associated to the geothermal system. A higher COP means that the field must supply much more energy to the system so a much larger well field is needed. In the HPs driven by natural gas and biogas, the COPs are much lower; this reduces the drilling length of the well field. so the initial investment is smaller [8].

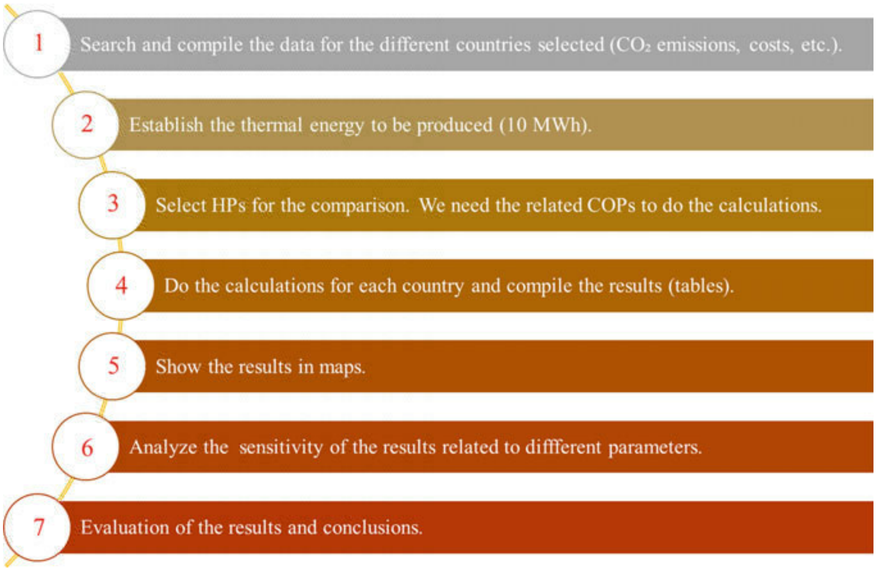

Fig. 1 Description of the workflow followed in the present research

2 Heat Pumps Technology

Ground source heat pumps geothermal systems (GSHPs) use the ground as a heat source or sink depending on seasonal working conditions. In heating mode (winter), heat is extracted from the ground by the set of boreholes, the energy taken from the ground is then lifted by the heat pump up into the building/s. For cooling applications (summer), this process can be reversed, injecting the heat extracted from the building into the ground.

In order to perform the thermal delivery from the ground to the building, the heat pump performs a cyclic process with the following phases (in the heating cycle, for the cooling cycle is the same in reversed order):

1. Liquid refrigerant inside the heat pump, absorbs heat in the evaporator from the ground loop, turning into gas.
2. The refrigerant is put through a compressor, which raises the pressure of the gas, increasing its temperature.
3. The hot gas flows through condenser coils inside the building to be heated, and since it is at a higher temperature than this space, it transfers heat to the room and condenses back into a liquid.
4. The liquid finally flows back through a valve (expansion valve), which reduces its pressure in order to cool it down so it can repeat the cycle.

In step 2 (Fig. 1) we have a compressor, the way of powering the compressor shaft will condition the type of heat pump (HP) we may choose. Although the cycle described above is the same in all HPs, depending on the primal energy, there are some differences between HPs which are worth commenting on.

Heat pumps are usually categorized as electric heat pumps (EHPs) or gas engine heat pumps (GEHPs) [9]. Most of the current heat pump models in the market are driven by electric motors. Regarding gas engine heat pumps, this equipment is recently used as an alternative to the conventional electric heat pumps. They use natural gas, liquefied petrol gas (LPG) or biogas and are able to recover the waste heat released by the engine to enhance the total heating capacity (this characteristic makes it possible to significantly reduce the drilling length of the well field) [10].

For an EHP operating in heating mode we can establish energy efficiency as follows. We may start quite intuitively, thinking about the balance between the energy we introduce and the heat we are going to get. Thus, a COP (Coefficient of performance) which is the most widespread coefficient to compare performances of heat pumps (European Standard EN-14825–2016 of good practices in the calculation of HPs performance), can be defined, as follows (Eq. 1).

$$COP = \frac{Q_C}{W} = \frac{Q_c}{Q_c - Q_e} = \frac{1}{1 - \frac{Q_e}{Q_c}} \tag{1}$$

The concept of performance of our system can be extended to the electrical supply and performance of our compressor (electric), defining what is known as global coefficient of performance (Eq. 2):

$$COP_{global} = C_1 * C_2 * COP \quad (2)$$

The coefficient of performance of the electric motors (C_1) of heat pumps in the domestic regime is around 90%. C_2 depends on the electric mix of the situation where the HP is operating [11].

Data from the EHP selected for this study are presented, in order to be able to implement the comparison in a table (Tables 1 and 2) later on, the typical COP of these heat pumps is around 4–4.5 [12].

There are heat pumps on the market (GEHPs) which perform the thermodynamic heat exchange cycle described above driven by a compressor which in turn is driven

Table 1 General features of electric heat pumps versus gas engine heat pumps

	EHP	GEHP
Energy consumption	Electric consumption	Natural gas, biogas consumption
Compressor shaft's engine performance	Around 90% and up	Around 30–35%
COP	1.5–1.7	4–4.5
Refrigeration circuit	Not required	Required (heat recovery systems)
Equipment cost	High	Very high
Operation costs	Electricity price	Gas or biogas price
Weight of the equipment	Normal	Very high
CO_2 emissions	Electricity mix of the area	Natural gas 252 g/kWh; biogas 0 g/kWh

Table 2 Characteristics of the heat pumps used for the comparative

EHP		GEHP	
Waterkotte GmbH Basic Line Ai1 Geo		AISIN (Toyota group) GHP 8hp	
COP EN14511 B0/W35[a]	4.6	COP[b]	1.57
Refrigerant	R410A[c]	Refrigerant	R410A
Power consumption output	5.7 kW	Power consumption	8hp (5.96 kW)
Electrical engine performance	92%	Gas engine	3 cylinder, 4-stroke
		Gas engine performance	32%
		Engine displacement	952 cm^3
		Water cooling engine, heat recovery systems	

[a] *A device using brine as heat source and water as heat transfer for example is called a brine/water heat pump. In the case of brine/water heat pumps, the nominal standard conditions at low temperature are for brine at 0 °C (B0, B = brine, a mixture of anti-freeze and water) and a heating water temperature of 35 °C (W35, W = water). This boundary condition is abbreviated to B0W35*

[b] *No brine temperature is given, due to the pre-heating cycle previous to the evaporator inlet*

[c] *Mixture of difluoromethane (CH_2F_2, called R-32) and pentafluoroethane (CHF_2CF_3, called R-125), patented by Allied Signal (now Honeywell International Inc.) in 1991*

by an internal combustion engine (most commonly fueled by natural gas or biogas). In this case, Eq. (2) turns into Eq. (3).

$$COP_{global} = C_1 * COP \tag{3}$$

The thermodynamic performance obtained from that Otto cycle engine, C_1 from Eq. (3) here is usually around 30–35% [13]. This reduces the COP of the heat pump thinking in terms of the energy provided (from the natural gas) and the energy obtained from the land to be transferred to the building. The COP from GEHPs is usually around 1.5–1.7 (more detailed data about the GEHP selected for this study can be found in Table 2).

The effect of the lower performance of the Otto cycle engine, from the GEHPs, compared to the electric one of the EHPs electric heat pumps, may induce GSHP designers to think that the EHP is a better choice in any case, however, we must take into account some considerations:

- The price per kWh of natural gas and biogas is much cheaper than the price per kWh of electricity in general in most countries of Europe.
- The sizing of the geothermal well field is reduced more or less by a half (depending on the thermal conductivity of the project's site). This means a very significant lowering of the initial investment in the installation. Recall that the initial investment is one of the main drawbacks when considering a geothermal system instead the other alternatives [14].
- The heat produced in the internal combustion engine driving the compressor's shaft, excess heat that cannot be used as mechanical energy, is usually used to heat the geothermal fluid from the wells before being introduced in the evaporator intercooling system of the heat pump. This increases significantly the performance of the internal heat pump process. It can be used also to feed the domestic hot water circuit of the installation.

So the heat pumps selected for this study are described in Table 1. All the characteristics are from a real heat pump which can be purchased and included in a geothermal system.

The same characteristics for the GEHP and the biogas HP are assumed, although there are some differences between the two energy sources explained in the next section. These differences may require specific design of the devices in the biogas HPs which are not yet available in the market.

3 Analysis Description

The objective of this study, as presented in the introduction, is to compare the economic and environmental performances of different HPs in different European countries. This will be done by considering a certain quantity of thermal energy (equal for all cases) in order to describe how this thermal energy is delivered by each one of the different heat pumps in each case and then reveal the economic and environmental costs of the process. The annual energy demand in Europe of a single-family home strongly depends on the climate area where this is located [10, 15]. In the cited article [10], there are described the thermal needs of the same building located in the three different climate areas stablished by the European Directive 2009/28/CE [16]. The annual thermal needs in these three equal buildings are: 39.088, 71.742 and 88.882 MWh per year. As can be seen, the usual thermal needs in Europe for a regular home are in the order of magnitude of some tens of MW per year. So, 10 MWh of thermal energy has been stablished as the reference energy to be produced in this comparison by the different systems.

3.1 Heat Pump Selection

For this study, two types of domestic heat pumps have been selected in order to perform the analysis on a real basis, in Table 2 are the characteristics of both devices.

The GEHP will be asked also to work with Biogas for the shake of this study, although this technology is not fully developed, it could be one of the best solutions from the economic and the environmental points of view. To be able to work with biogas some considerations about the system must be assumed. First of all, at the moment there aren't any HPs in the market ready to be fed with biogas yet, so for this study the data from the GEHP selected in Table 2 will be used as if were possible to feed that HP with biogas. Secondly, the consumption of the GEHP fed with biogas will be greater than with natural gas to get the same amount of energy, this is because the biogas higher calorific value (HCV) is lower than the natural gas HCV. According to the Institute for the Diversification and Energy Saving "IDAE" [10] the biogas HCV is 46.21% lower than the natural gas HCV, so the volumetric gas consumption will be 46.21% higher in this case. However, the COP of the biogas GEHP will remain the same because it only depends on the energy balance of the thermodynamic process, and here the thermal energy supplied by the natural gas and the biogas are the same.

3.2 Input Energies

A brief look at the energies used in the operation of the correspondent HPs. Main characteristics and sources are given, in order to stablish the framework for the economic and environmental calculations in the next section.

3.2.1 Natural Gas

An equal natural gas composition is stablished for all countries, consisting of 99% methane and 1% of other components, mainly CO_2 [17].

Energy data, comes from the IDAE, in its report on calorific powers of fuels, where it quotes sources from EUROSTAT and the International Energy Agency (IEA). HCV of natural gas is set to 9667 kcal/Nm^3 (11.23 kWh/Nm^3).

Regarding the emissions, data from IDAE, in its guide of CO_2 emissions for each energy source [18], has been considered. Then 0.252 kg CO_2/kWh of final energy will be the used in further calculations. These energy and CO_2 emissions data can be extended to all countries, since we have set equal natural gas conditions.

3.2.2 Biogas

The IDAE data for calorific powers of fuels mentioned in Sect. 3.2.1 has been used as a reference here also. HCV of 5200 kcal/Nm^3 (6.04 kWh/Nm^3) for biogas is set, from that same source.

The biogas type composition is 53.5% Methane and 46.5% CO_2. The energetic consequence of this chemical composition, stablished as standard for all countries, is clear if we compare the calorific values of the natural gas and biogas. This is also mentioned in previous sections.

3.2.3 Electricity

In order to calculate CO_2 emissions by electric energy use, data from the International Energy Agency have been used. The fraction of the CO_2 emissions that should come from electricity production only have been proportionally separated, taking into account the amounts of generation that come from renewable energies and those that do not (data in I.A.E. Statistics by country).

The process of obtaining the CO_2 emissions factor by electricity production in each country, has started from the separation of total emissions by electricity and large-scale heating. Here it has been taken into account that the data on the production of electricity from fossil fuels (those that contribute to these emissions), is given to us in the form of electrical energy, a performance factor in that transformation of 0.4 have been considered in order to evaluate the thermal energy used, and to be able to establish a proportion which determines the electrical contribution to the total emissions of the data.

4 Costs and Emissions Comparative

In Table 3 the countries selected and the CO_2 emissions and household prices for the three types of energies considered to feed the different HPs are presented.

Emissions and costs in the three cases of primal energy feed to the HPs in different countries selected can be found in Table 4. Emissions from biogas combustion are usually considered to be zero, because of the neutral cycle contemplated during its production. For the costs and emissions in EHP and GEHP fed by natural gas, the associated calculations have been performed as follows.

For the EHP, Eqs. (4) and (5):

$$\text{Costs (€/10 MWh)} = \frac{EP\ (\text{€/kWh}) * 1000\ \left(\frac{kWh}{MWh}\right) * 10}{COP} \quad (4)$$

$$Emissions\ (kgCO_2/10\,\text{MWh}) = \frac{EEC\left(\frac{gCO_2}{kWh}\right) * 10}{COP} \quad (5)$$

For the GEHP, Eq. (6):

$$Costs\ (\text{€}/10\ MWh) = \frac{NGP\ (\text{€}/kWh) * 1000\ \left(\frac{kWh}{MWh}\right) * 10}{COP} \quad (6)$$

$$Emissions\ (kgCO_2/10\,\text{MWh}) = \frac{ENGC\left(\frac{gCO_2}{kWh}\right) * 10}{COP} \quad (7)$$

Biogas prizes are an estimation based on prizes offered in Spain by some biogas producers extended to all the other countries by keeping the ratio of the prize with the natural gas (this seems to fit in the countries with biogas prizes available to compare).

As shown, while biogas prices are related to the natural gas prices or taken directly from suppliers, biogas emissions are considered zero.

With all the data from Table 3 and the formulas referred above, we can introduce Table 4.

There are some remarkable results in Table 4. Regarding the economic aspect, biogas costs are, by far, the cheapest of all the three options. EHPs prices to get 10 MWh are commonly higher than the ones from GEHPs except for three countries: The Netherlands, Sweden and Czech Republic (Figs. 3 and 4).

From the emissions point of view, Table 4 shows that there are two countries (Poland and Estonia), where EHPs CO_2 emissions are higher than GEHPs emissions as suggested in previous sections. We can see also that there are some countries where both emissions are quite similar (Fig. 4).

Combining together cost and emissions, Poland and Estonia showed a lower costs and lower emissions scenario for GEHPs against EHPs. Greece shows lower costs

Table 3 Countries, CO_2 emissions and household prices for electricity, natural gas and biogas

Countries	EEC (g CO_2/kWh)[a]	ENGC (g CO_2/kWh)[b]	EP (€/kWh)[c]	NGP (€/kWh)[c]	Biogas prices (€/kWh)[c]
Belgium	169.6	252.0	0.2824	0.0547	0.0042
Bulgaria	470.2	252.0	0.0979	0.0368	0.0028
Czech Republic	512.7	252.0	0.1573	0.0583	0.0045
Denmark	166.1	252.0	0.3126	0.0583	0.0064
Germany	440.8	252.0	0.2987	0.0661	0.0051
Estonia	818.9	252.0	0.1348	0.0346	0.0027
Ireland	424.9	252.0	0.2369	0.0652	0.0050
Greece	623.0	252.0	0.1672	0.0564	0.0027
Spain	265.4	252.0	0.2383	0.0677	0.0050
France	58.50	252.0	0.1748	0.0650	0.0043
Croatia	210.0	252.0	0.1311	0.0428	0.0052
Italy	256.2	252.0	0.2067	0.0731	0.0050
Latvia	104.9	252.0	0.1531	0.0424	0.0033
Lithuania	18.0	252.0	0.1097	0.0413	0.0032
Luxemburg	219.3	252.0	0.1671	0.0454	0.0035
Hungary	260.4	252.0	0.1123	0.0344	0.0026
Netherlans	505.2	252.0	0.1706	0.0779	0.0060
Austria	85.1	252.0	0.1966	0.069	0.0053
Poland	773.3	252.0	0.1410	0.0392	0.0030
Portugal	324.7	252.0	0.2246	0.0913	0.0070
Romania	306.0	252.0	0.1333	0.0332	0.0026
Slovenia	254.1	252.0	0.1613	0.0599	0.0046
Slovakia	132.3	252.0	0.1566	0.046	0.0035
Finland	112.8	252.0	0.1612	0.0310	0.0024
Sweden	13.3	252.0	0.1891	0.1129	0.0087
U.K.	281.1	252.0	0.1887	0.0553	0.0042

[a] *Source "Data and Statistics by country, CO_2 emissions from electricity and heat by energy source," (2018). International Energy Agency (IEA), 31–35 rue de la Fédération 75,739, Paris, France*
[b] *"Factores de emisión de CO_2 y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector de edificios en España.". Instituto para la Diversificación y Ahorro de la Energía, "IDAE" 2018*
[c] *International Monetary Fund. World Economic Outlook Database, October 2018. Eurostat Database, 2019*

Table 4 Costs and emissions

Countries	Costs (€) [a]			Emissions (kg CO_2) [a]		
	EHP	GEHP	BIO-GEHP	EHP	GEHP	BIO-GEHP
Belgium	706.00	348.41	26.76	424.00	1605.10	0
Bulgaria	244.75	234.39	18.00	1175.50	1605.10	0
Czech Republic	393.25	371.34	28.52	1281.75	1605.10	0
Denmark	781.50	530.57	40.75	415.25	1605.10	0
Germany	746.75	421.02	32.34	1102.00	1605.10	0
Estonia	337.00	220.38	16.93	2047.25	1605.10	0
Ireland	592.25	415.29	31.90	1062.25	1605.10	0
Greece	418.00	359.24	27.59	1557.50	1605.10	0
Spain	595.75	431.21	33.12	663.50	1605.10	0
France	437.00	414.01	31.80	146.25	1605.10	0
Croatia	327.75	272.61	20.94	525.00	1605.10	0
Italy	516.75	465.61	35.76	640.50	1605.10	0
Latvia	382.75	270.06	20.74	262.25	1605.10	0
Lithuania	274.25	263.06	20.21	45.00	1605.10	0
Luxemburg	417.75	289.17	22.21	548.25	1605.10	0
Hungary	280.75	219.11	16.83	651.00	1605.10	0
Netherlands	426.50	496.18	38.11	1263.00	1605.10	0
Austria	491.50	439.49	33.76	212.75	1605.10	0
Poland	352.50	249.68	19.18	1933.25	1605.10	0
Portugal	561.50	581.53	44.67	811.75	1605.10	0
Romania	333.25	211.46	16.24	765.00	1605.10	0
Slovenia	403.25	381.53	29.31	635.25	1605.10	0
Slovakia	391.50	292.99	22.50	330.75	1605.10	0
Finland	403.00	197.45	15.17	282.00	1605.10	0
Sweden	472.75	719.11	55.23	33.25	1605.10	0
U.K.	471.75	352.23	27.05	702.75	1605.10	0

[a] To produce 10 MWh (thermal energy) as explained in Sect. 3

from GEHPs and similar emissions and The Netherlands presents similar emissions but higher costs from GEHPs.

Evolutions expected and extended conclusions are detailed in the next sections.

5 Sensitivity Analysis

This section presents a sensitivity analysis to evaluate how different factors may influence the costs and the emissions of the different HPs considered. We will be proposing changes in the main factors guided by the recent circumstances around them, and also taking into account the political and social environment.

5.1 Sensitivity Related to COP Improvement in EHPs

A 25% improvement in the COP of the EHPs (from 4 to 5 in our case) could be possible in the near future according to the past behavior, so seems interesting to take into account this scenario.

This COP enhancement may come from new and improved designs on this device and also because of the improvements in the design of the geothermal systems where an improvement in the working conditions may affect the COP [19].

With this COP improvement in the EHPs, the map from Figs. 2 and 3 changes a lot (Fig. 4). We have 12 countries now (instead of two) where the cost to get 10 MWh of thermal energy is higher from the GEHPs than from the EHPs.

Regarding the emissions in this scenario, is interesting to compare Fig. 3 with Fig. 5. Whereas in the first case there are two countries with higher emissions from the electricity mix than from the gas engine heat pumps, in the new scenario, there is only one country in this situation, Estonia, and two other countries where emissions are similar (difference is less than 25%), Poland and Greece, The Netherlands have now clearly lower emissions from EHPs.

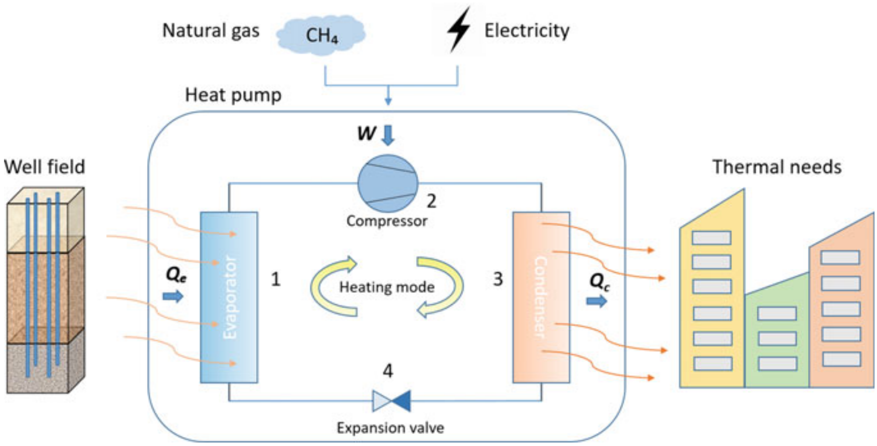

Fig. 2 Phases in the cyclic process inside a heat pump in heating mode (Qe heat exchanged in the evaporator and Qc heat exchanged in the compressor)

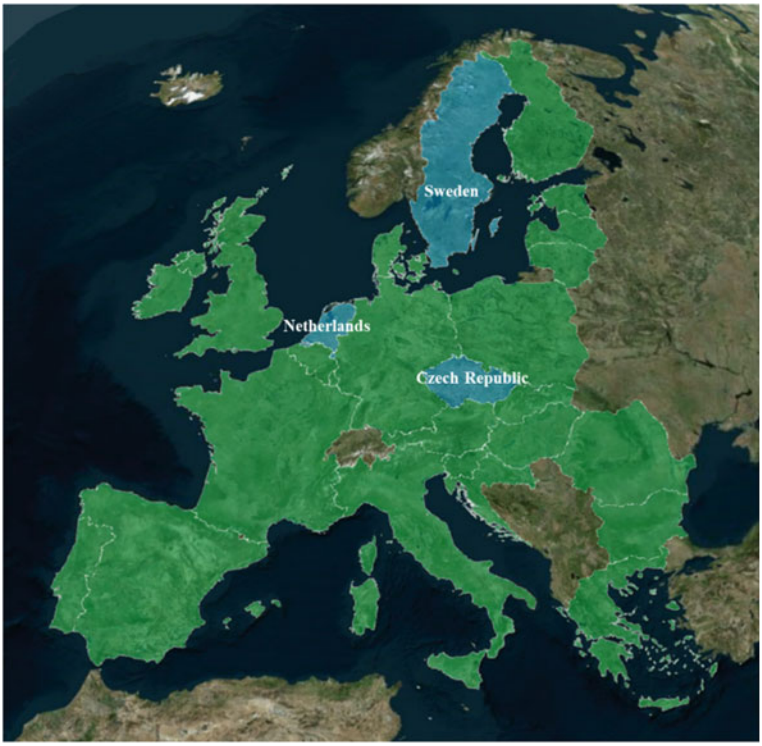

Fig. 3 From Table 4, countries with higher costs from EGP in green. Netherlands, Sweden and Czech Republic, in blue, have higher costs from GEHP (biogas powered HPs has lower costs in all the countries)

5.2 Sensitivity Related to COP Improvement in GEHPs

Due to the low market penetration of these models of HPs, is not realistically expected an improvement in the COP of these systems based on research and development in the factories. In addition to this, the political environment in Europe is not favoring these kinds of devices although the geothermal systems should be considered important in the future plans for the heating & air-conditioning industry.

It is also worth mentioning that an important improvement in the COP of these systems will mean that one of the main advantages of the GEHPs could be compromised. This is the ability to reduce in a considerable way the drilling length of the well field.

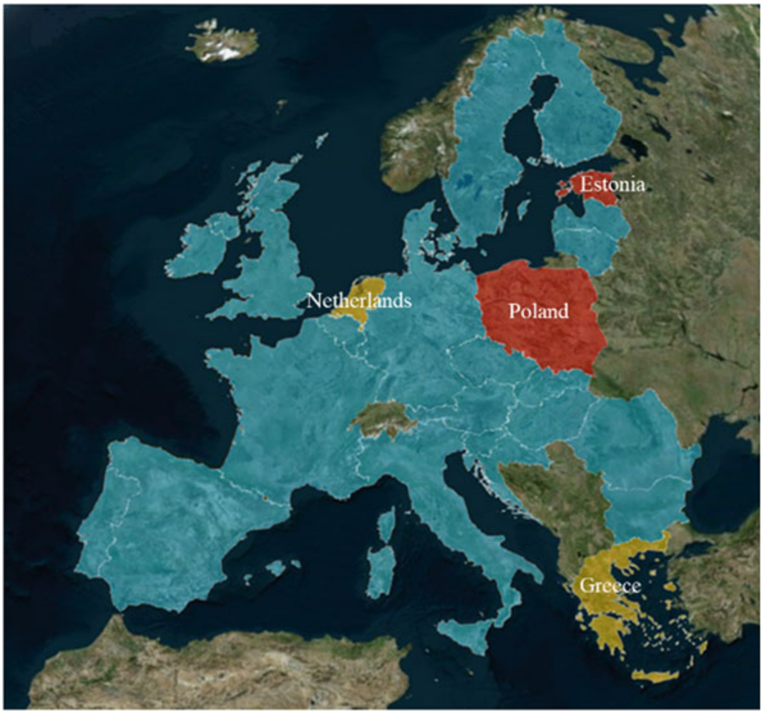

Fig. 4 From Table 4, countries with higher emissions from GEHP in light-blue. Poland and Estonia in red, have higher emissions from EHPs than from GEHPs. Netherlands and Greece, in light-orange, their emissions from EHPs and GEHPs differ less than 20% (biogas powered HPs have, of course, no emissions in all the countries)

5.3 Sensitivity Related to Emissions in Electricity Production

This scenario is especially important for the countries in Fig. 3 where emissions from EHP are higher than the ones from GEHPs, in those cases is where an improvement in the emissions from electricity production can produce a change concerning the solutions with less emissions.

Figure 6 shows the evolution of the CO_2 emissions from electricity production in these four countries.

In two countries, Poland and Estonia, the emissions from GEHPs where less than the ones from EHPs. As Fig. 6 shows in both cases, there isn't any clear decreasing signal in the evolution of the emissions through the last 4–5 years. So, it is unlikely to find a significant change in the near future [20] Fig. 7.

The two other countries from Fig. 3, Greece and The Netherlands, are special because their emissions from EHPs are lower but quite near the ones from GEHPs. Here a downward trend in the emissions is observed, especially in The Netherlands. This may affect the selection of GEHPs since the costs are also higher there.

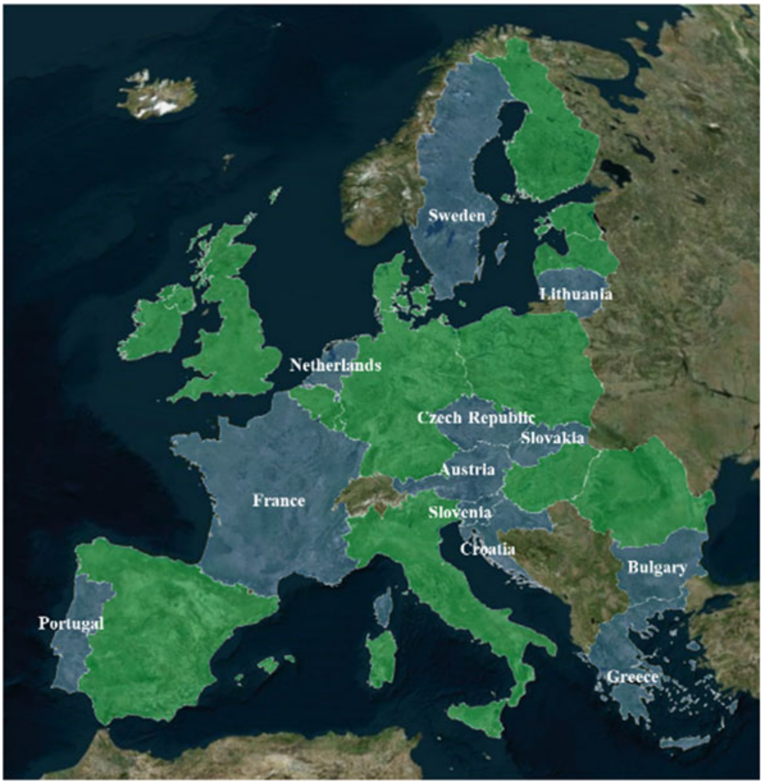

Fig. 5 Green countries represent higher costs from EHPs. Blue countries represent higher costs from GEHPs

6 Conclusions

It is clear from all the data collected and compiled in this work, that the biogas driven HPs are the best solution from the economic and environmental points of view. Development and widespread of these types of GSHP systems would contribute to the low emission policies to be implemented in Europe in the near future [21].

Apart from this, in most countries, EHPs are much more common than GEHPs. The results from this work seem to agree with this selection of most Europeans. However, although emissions are clearly higher from GEHPs, the reduction of the drilling length, with the reduced initial investment derived from this, may be an important factor to consider. Also, the annual costs seem to be lower from gas natural in most countries. Maybe the purchase price of the GEHP is higher but this is fully balanced with the price reduction in the construction of the well field.

In Table 5 we find the four countries where the selection of the type of HP may be not so straight forward.

Fig. 6 Blue countries where CO_2 emissions from EHPs are lower than from GEHPs. Red countries where emissions from GEHPs are lower than from EHPs. Orange countries equal to blue ones except that the difference is less than 25%

It is clear that Poland and Estonia, under the current circumstances (not expecting to change so much in the near future [13]) the GEH P is the ideal selection, from the economic and environmental points of view.

In The Netherlands, the gas price is against the GEHPs, and the emissions are lower from EHPs and going in that direction also in the future The usual selection would be electrical. The Greek case is similar, here even the annual costs are lower for the GEHPs. However, future developments in CO_2 emissions from electricity production and COP improvements in EHPs seem to recommend the electric choice also.

We can conclude that, for some countries, and under certain circumstances, it may be a good idea to recommend the GEHPs in order to reduce the thermal energy costs and the CO_2 emissions at the same time. The cut-out in the initial investment is also an advantage to take into consideration.

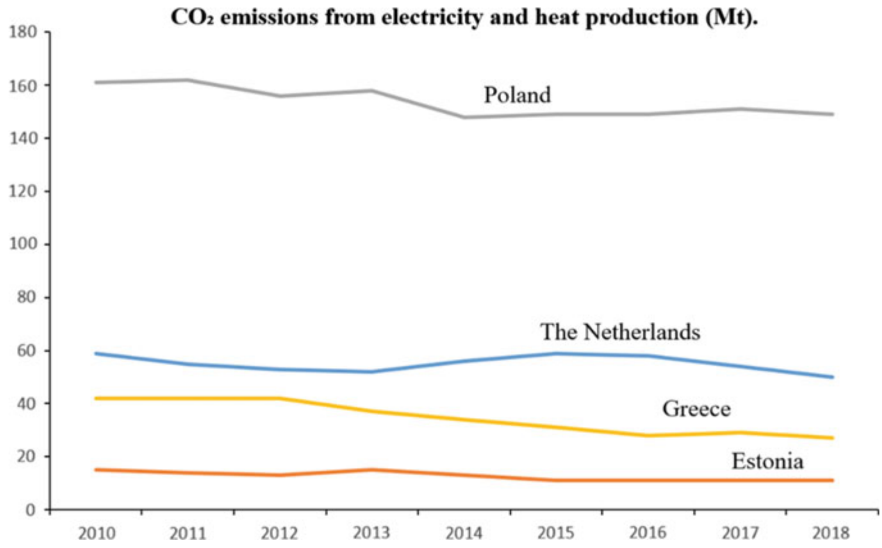

Fig. 7 Evolution of the CO_2 emissions by electricity production in the countries selected. IEA. CO_2 emissions by energy source

Table 5 Countries where GEHPs may be more suitable from the economic and environmental points of view

	10 MWh (thermal energy)			
	Costs (€)		Emissions (kg CO_2)	
Countries	EHP	GEHP	EHP	GEHP
Estonia	337	220.38	2047.25	1605.1
Poland	352.5	249.68	1933.25	1605.1
Greece	418	359.24	1557.5	1605.1
Netherland	426.5	496.18	1263	1605.1

Apart from these exceptional cases, in most countries in Europe an EHP may be a better option (mainly due to the emissions factor), and will be getting even better in the near future.

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References

1. Bouzarovski S, Tirado Herrero S (2017) The energy divide: Integrating energy transitions, regional inequalities and poverty trends in the European Union. Eur Urban Reg Stud 24(1):69–86
2. DIRECTIVE (EU) 2018/2001 of the European parliament and of the council of 11 December 2018 on the promotion of the use of energy from renewable sources
3. Rybach L (2014) Geothermal power growth 1995–2013—A comparison with other renewables. Energ 7(8):4802–4812
4. Colmenar-Santos A, Palomo-Torrejón E, Rosales-Asensio E, Borge-Diez D (2018) Measures to remove geothermal energy barriers in the European Union. Energ 11(11):3202
5. Neuberger P, Adamovský R (2017) Analysis of the potential of low-temperature heat pump energy sources. Energies 10(11):1922
6. Borge-Diez D, Colmenar-Santos A, Pérez-Molina C, López-Rey Á (2015) Geothermal source heat pumps under energy services companies finance scheme to increase energy efficiency and production in stockbreeding facilities. Energy 88:821–836
7. Fraga C, Hollmuller P, Schneider S, Lachal B (2018) Heat pump systems for multifamily buildings: potential and constraints of several heat sources for diverse building demands. Appl Energy 225:1033–1053
8. Angrisani G, Diglio G, Sasso M, Calise F, d'Accadia MD (2016) Design of a novel geothermal heating and cooling system: Energy and economic analysis. Energy Convers Manage 108:144–159
9. Lian Z, Park SR, Huang W, Baik YJ, Yao Y (2005) Conception of combination of gas-engine-driven heat pump and water-loop heat pump system. Int J Refrig 28(6):810–819
10. Blázquez CS, Borge-Diez D, Nieto IM, Martín AF, González-Aguilera D (2019) Technical optimization of the energy supply in geothermal heat pumps. Geothermics 81:133–142
11. Weisser D (2007) A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies. Energy 32(9):1543–1559
12. Self SJ, Reddy BV, Rosen MA (2013) Geothermal heat pump systems: Status review and comparison with other heating options. Appl Energy 101:341–348
13. Mozurkewich M, Berry RS (1982) Optimal paths for thermodynamic systems: the ideal Otto cycle. J Appl Phys 53(1):34–42
14. Sáez Blázquez C, Farfán Martín A, Nieto IM, González-Aguilera D (2018) Economic and environmental analysis of different district heating systems aided by geothermal energy. Energ 11(5):1265
15. Boyano A, Hernandez P, Wolf O (2013) Energy demands and potential savings in European office buildings: Case studies based on EnergyPlus simulations. Energy Build 65:19–28
16. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC
17. Instituto para la Diversificación y Ahorro de la Energía (2014) IDAE, Factores de emisión de CO_2 y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector edificios en España
18. IDAE (2016) Factores de emisión de CO_2 y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector de edificios en España. Instituto para la Diversificación y Ahorro de la Energía
19. AENOR (2019) UNE-EN 14825:2019. Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling—Testing and rating at part load conditions and calculation of seasonal performance
20. European Environment Agency. Overview of electricity production and use in Europe. Chapter: Is electricity production in Europe becoming less carbon intensive? Published 18 Dec 2018
21. DIRECTIVE (EU) (2018) 2018/844 of The European Parliament and of the Council, amending Directive 2010/31/EU on the energy performance of buildings and directive 2012/27/EU on energy efficiency. Off J Eur Union

Low-Enthalpy Geothermal Applications

Tine Aprianti, Kandadai Srinivasan, and Hui Tong Chua

Abstract This chapter discusses two low-enthalpy geothermal applications in Perth, Western Australia. The first application pertains to using tepid groundwater for the municipal heating of Olympic-size outdoor swimming pools. The second application examines the viability of ground source heat pumps (GSHP) against air source heat pumps (ASHP). In the first application, the objective is to develop an accurate sizing methodology to improve the capital effectiveness for geothermal swimming pools. The predicted pool-water temperature and heating demands are compared against on-site measurements at a Leisure Centre. This model can replicate 71 and 73% of the measured heating capacity data within ±25 kW for the 30-m pool and ±35 kW for the 50-m pool, respectively. In the second application, we assess the feasibility of implementing a GSHP vis-à-vis an ASHP for domestic applications. For the second application, the GSHP has a constant coefficient of performance (COP) of 3.8 ± 6.7%, while that of ASHP ranges from 2.2 to 2.7 ± 6.5%. For cooling, the GSHP has a constant COP of 3.1 ± 13%, while that of ASHP varied between 1.4 and 2.4 ± 11.5%. When a GSHP is considered with a planned installation of a borehole for irrigation, the payback period ranges from near-immediate to four years.

Keywords Electric heat pumps · Heating and cooling · Ground source heat pump · Economic and environmental analysis

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Nomenclature and Formulae

A	Pool surface area (m^2)
C_8	Cloud cover factor (oktas)
$C_{cloud\ effect}$	A scaling parameter to reflect the effect of cloud cover
C_p	Specific heat capacity (kJ/kg K)
D_{AB}	Binary diffusion coefficient for water and air at 1 atm (m^2/s)
E	Irradiance (W/m^2)
F	View factor
g	Gravitational acceleration (m/s^2)
Gr	Grashof number
h	Heat transfer coefficient (W/m^2 K)
h_{fg}	Heat of vaporisation of water (kJ/kg)
h_m	Mass transfer coefficient (m/s)
k	Thermal conductivity (W/m K)
L	Length of the pool (m)
$\dot{m}$	Mass flow rate of water (kg/s)
$\dot{n}$	Mass transfer rate (kg/s)
Nu	Nusselt number
Pr	Prandtl number
p	Pressure (Pa)
Q	Heat transfer (kW)
Ra	Rayleigh number
Re	Reynolds number
Sc	Schmidt number
Sh	Sherwood number
T	Temperature (K)
t	Temperature (°C)
U	Wind speed (m/s)
W	Width of pool (m)

Greek Symbols

α	Absorptivity of the pool
ε	Emissivity
ρ	Density (kg/m^3)
σ	Stefan-Boltzmann constant ($W/m^2\ K^4$)
ϕ	Relative humidity (%)
μ	Viscosity (kg/m s)
θ	Angle of incidence of wind (degrees)
ν	Kinematic viscosity (m^2/s)

Subscripts

a	Air
BOM	Bureau of Meteorology
cs	Clear sky
dew	Dew point
diff	Diffusivity
evap	Evaporation
conv	Convection
f	Film
fc	Forced convection
geo	Geothermal
nc	Natural convection
hx,o	Heat exchanger outlet
m	Mass transfer
MSL	Mean sea level
rad	Radiation
refill	Refill water
s	Interface of pool water and air
w	Water

1 Introduction

Geothermal energy is championed as one of the renewable energy sources along with solar, wind, and wave/tidal. Yet, high enthalpy geothermal energy, from which electricity can be produced using steam or organic Rankine cycles, is available in only very few places which are less inhabited than places where electricity is in demand. However, low enthalpy geothermal energy (at <100 °C) is available more commonly, which can be gainfully used to augment energy conservation though not energy generation. Subterranean aquifers can be judiciously exploited, for example, in the heating and cooling of buildings and heating of large swimming pools. These subterranean sources are available at reasonable depths (up to ca. 1000 m), which do not render drilling and pumping costs prohibitive. By virtue of being subterranean, one can reasonably assume these geothermal reservoirs as constant temperature sources or sinks. Thermodynamically, if source or sink temperatures or both can be maintained constant, the performance of engines or heat pumps will be efficient. Unlike solar, wind, or wave, geothermal has a round-the-clock availability which makes it worth exploring. Comparing the costs a priori, both solar and wind require a large swathe of land area, which may be at a premium economically and environmentally in well-inhabited settlements. On the other hand, geothermal sources require small footprints, but the costs of drilling, maintenance of pipelines, and heat transfer equipment have to be considered. While energy generation with renewable sources will dominate this century, it is also pertinent that the energy is also conserved using renewable energy sources such as low enthalpy geothermal sources.

The objective of this chapter is to present outcomes from several projects where this low enthalpy geothermal energy has been used for supplementing heating inventories of Olympic size swimming pools in winter and is being mulled for substantially reducing electricity bills of cooling and heating at even domestic levels. Although the case studies herein pertain to the Perth Metropolitan Area in Western Australia, the techniques are adoptable all over the globe where near-constant temperature aquifers are present. The chapter is divided into two major sections addressing the aforementioned two distinct applications of low enthalpy geothermal energy.

2 Geothermal Olympic-Size Outdoor Swimming Pools

2.1 Introduction

Due to increasing recognition of the importance of exercise in maintaining good health, ever more Australians are resorting to swimming as an option. This is evidenced by the number of medals won by Australia in swimming events of all international competitions, right from the Olympics to the Commonwealth games. While it used to be a seasonal activity in yesteryears, now it is a year-round activity all over Australia. It is imperative that the pool water temperature be maintained between 26 and 28 °C irrespective of the season. In particular, for competitive swimming, these temperature limits are even more imperative. This is a difficult task for outdoor swimming pools in winters when the ambient temperatures across non-tropical Australia are quite low. Swimming pools maintained by local governments allocate huge budgets for heating them, and gas-fired hot-water boilers are generally used. A collateral liability of the operation of swimming pools is the replenishment of evaporated water. Thus, public swimming pools are confronted with two major environmental issues, namely, greenhouse gas emissions from the boiler and water consumption. While the latter is inevitable, the former can be reduced substantially by using geothermal aquifers.

A study of the distribution of heating energy in 855 swimming pools in Italy indicates that heat lost due to Evaporation accounts for 60% of the total heating requirements, with another 38% being used to replace the water after heating [1]. The conventional methodology adopted to heat the pool water is to use an on-site gas-fired boiler, a heat pump, or solar power. An alternative method of meeting these heating needs sustainability is to use geothermal aquifers [2]. This choice banks on the constancy of groundwater temperature being circa 46.5–48.5 °C when taken from a depth of about 1 km in the Perth Metropolitan Area. Boreholes are drilled for pumping the water up and returning it with adequate spacing to avoid thermal breakthrough [3, 4]. There are several expansive aquifers in and around Perth, Western Australia, and the success of geothermal heating can be seen by its use in at least 14 existing swimming pools in the Perth region alone [2]. Despite the initial capital expense, compared to solar and wind, geothermal systems require a much smaller land area and are immune to weather conditions.

Highly variable environmental conditions ranging from cold nights and clear sky to gales immensely enhance heat loss from swimming pools in Australian winters. In fact, in winters, when heating is mostly required, the availability of solar energy is the least. Further, wind energy cannot be directly used for heating up water. Seasonal fluctuations in the availability of renewable energy sources impel supplementing heating with backup boilers, which may not be powered by clean energy. If renewable energy sources are used, the heating capacity of systems must be pessimistically sized to meet the requirements of the pool in order to reduce the need for backup boilers. In this context, geothermal energy will stand out to be the main renewable energy that can be used in this application. Some heating capacity design methods in vogue are empirical [5–8] and use non-location-specific atmospheric weather conditions, which could lead to either over or underestimating heating inventories. Although the most significant contributor to energy consumption is the heat loss due to Evaporation, there is no standard method of quantifying it and other heat losses in the pool [9]. It is imperative that a model needs to be able to assess all losses accurately so that it can be adapted for pools of all sizes and locations. An attempt in this direction has been made by Lovell et al. [10], who developed a model and benchmarked it against data available from experimental measurements in a 50 m Olympic size swimming pool.

While the Lovell et al. model is an initiation, it is observed that some refinements are necessary to make it more generally applicable. The present model addresses some of the lacunae [6–8, 11] by enhancing the methodology of estimating heat transfer by radiation, solar inputs, cloud, and precipitation conditions. This is to emphasise the importance of radiation from and to the pool under the influence of surrounding structures. These refinements were benchmarked using data from the 50 m pool of Lovell et al. [10] and also another 30 m pool adjacent to that pool. A significant difference between the two is in the surrounding structures. In addition, this section compares results from yet another model developed by Smith et al. [12]. Whatever method of estimating heating inventories is used, it will be preferable to oversize the heating system to avoid the use of boilers. In this context, again, low enthalpy geothermal heating turns out to be the front runner because all that one needs is oversizing the heat exchanger and pump, which have minimal effects on overall costs, provided the heating capacity is designed appropriately. Hereunder has presented a systematic analysis of those heating inventories for two different-sized swimming pools.

2.2 The Beatty Park Leisure Centre Outdoor Swimming Pools

The Beatty Park Leisure Centre is a swimming pool complex in the North Perth suburb of Western Australia. Originally known as the Beatty Park Aquatic Centre,