Economic assessment of a two-stage heat pump with heat exchanger to exploit low-temperature geothermal energy

SVEN H. DE CLEYN
Faculty of Applied Economics
University of Antwerp
Prinsstraat 13, BE-2000 Antwerp
BELGIUM
Sven.decleyn@ua.ac.be http://www.ua.ac.be/sven.decleyn

AMARYLLIS AUDENAERT
Department of Applied Engineering: construction
Artesis Hogeschool Antwerpen
Paardenmarkt 92, BE-2000 Antwerp
BELGIUM
Amaryllis.audenaert@artesis.be
&
University of Antwerp
Prinsstraat 13, BE-2000 Antwerp
BELGIUM
Amaryllis.audenaert@ua.ac.be http://www.ua.ac.be/amaryllis.audenaert

Abstract: - Within the context of sustainable housing, considerable research attention has been on different devices and techniques to lower energy consumption and alternative, environmental-friendly alternatives to generate energy. Recently, scholars engage increasingly in the economic aspects of these devices and techniques. This study elaborates on the study of Kulcar et al. [1], which have investigated the economy of exploiting a two-stage heat pump with heat exchanger using low-temperature geothermal sources for building heating purposes.
The results of the analysis suggest that under the circumstances defined in [1], the system is an interesting investment from a financial viewpoint. However, the results turn out to be strongly dependent on the evolution of the electricity and heat prices. It turns out that the net present value of the investment is more sensitive to changes in heat prices than it is to variations in electricity prices.

Key-Words: Economic analysis; Payback time; Geothermal energy; Heat pump

Nomenclature

a_n	Annual instalment factor
C_E	Price of electricity (EUR/kWh)
C_{INV}	Investment costs (EUR/year)
C_P	Incoming cash flow from the extracted heat (EUR/year)
C_{PS}	Electricity costs for running the compressor (EUR/year)
C_T	Price of heat (EUR/kWh)
C_S	Expenses (EUR/year)
C_{TC}	Total price of a heat pump (EUR)
C_t	Total yearly incoming or outgoing cash flow (EUR/year)
C_0	Investor's own resources (EUR)
k	Required rate of return (%)
n	Lifespan of a heat pump (years)
IRR	Internal Rate of Return (%)
NPV	Net Present Value (EUR)
P	Power used by a compressor (kW)
Q_k	Heat flow of a condenser (kW)
r	Discount rate
r_a	Discount rate of annual instalments
r_j	Inflation rate
t_1	Operational time of heat pump (h/day)
t_2	Operational time of heat pump (days/year)

1 Introduction

Considerable research has been and is currently being spent on investigating the effects of human activities on the emission of greenhouse gases and the subsequent climate changes. The actual debate on global warming then cranks up the search for environmental-friendly alternatives to maintain our current living standards and level of activity. Reduction of energy use and environmental-friendly alternatives to generate energy are two pathways that have to be walked simultaneously. For both alternatives, environmental impact should be assessed together with the economic viability [2], which is however not yet common practice. Some of the scarce studies relates to sustainable housing [3, 4]. One of the many alternative energy sources currently being exploited on a larger scale is geothermal energy [5, 6]. Geothermal energy gradually becomes an interesting energy source from an economic point of view.

As the energy demand used for space heating accounts for 78% of EU15 household delivered energy consumption [7], significant reductions in energy demand can be achieved by promoting sustainable housing and environmental-friendly alternatives [8]. In Japan, 24.5% of total electricity consumption of households is used for space heating [9]. There is thus a currently largely untapped potential that offers significant opportunities to reach the Kyoto objectives [10].

Within this framework of sustainable housing, Kulcar et al. [1] have investigated the economic implications of a two-stage heat pump using low-temperature geothermal energy for high-temperature heating of buildings in the Slovenian context. The potential of this green technology has been illustrated by e.g. Gillet [11], stating that he never encountered a situation where fossil fuel-based technologies cannot be replaced by a cleaner technology at a lower total cost. Heat pump technology thus has a significant potential in reducing energy needs, amongst other for space heating purposes [12, 13]. This article will elaborate on the economic aspects of their findings, using identical technical specifications of the heat pump. Therefore, the technical section of this article will be reduced to its utmost minimum, as more details can be found in [1]. The remainder is structured as follows. Firstly, the technical specifications of the two-stage heat pump under consideration will be highlighted. Afterwards, the economic analysis will simulate different scenarios, especially considering the impact of energy and heat prices and their effects on the feasibility of exploiting low-temperature geothermal energy for high-temperature building heating.

2 Technical characteristics

A heat pump is a device which extracts heat from its environment and emits it into a heating system at a higher temperature level. The characteristics of a heat pump depend on various design choices: the coefficient of performance (gained heat flow in the compressor divided by the compressor's energy use), the heat flows of the condenser and evaporator, the energy consumption of the compressor and the pressure ratio of the compressor. For more information on these technical characteristics, we refer to the work of Kara and Yuksel [14], Kulcar et al. [1], Ozgener and Hepbasli [15] and Ozgener et al. [16].

As building heating requires high-temperature heating, a two-stage heat pump is necessary [1]. Therefore, this article exclusively considers a two stage heat pump with heat exchanger, which is schematically presented in Figure 1. The heat pump is made up of three components: two single stage heat pumps connected by a heat exchanger. The main advantage of such configuration is that according to the physical–chemical characteristics different refrigerants can be used at each stage [1]. The heat exchanger between the two stages represents a condenser for the first stage and an evaporator for the second [1].

Geothermal water (T_{gl} = 62°C) serves as input for the heat exchanger, of which the output (T_{gm} = 42°C) in turn serves as input for the heat pumps. The principle of exploiting heat from geothermal water in an individual facility is shown in Figure 1. With such a system it would be possible to exploit the heat of geothermal water to the temperature of 10°C [17].

The best results are obtained when combining refrigerant R407c in the first stage and refrigerant R600a in the second [1]. The choice of the refrigerants has been inspired by the physical–chemical characteristics, ecological acceptability, and the trend of using refrigerants of well-known heat pump manufacturers. Refrigerant R407c is a mixture of the following refrigerants: 23% R32, 25% R125 and 52% R134a [1, 17]. The main characteristics of the refrigerants are presented in Table 1.

Fig. 1. Heating system using a two stage heat pump with heat exchanger [1].

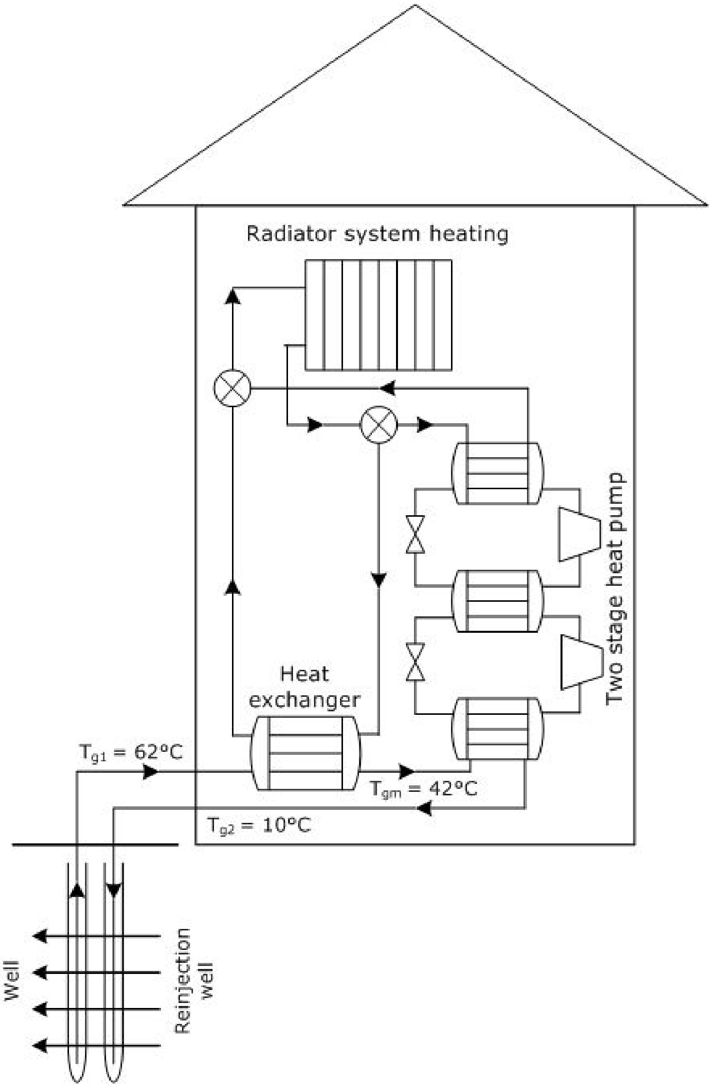


Table 1. Characteristics of refrigerants [1].

Refrige-rant	Chemi-cal formula	Molecular weight (g/mol)	Temperature condition (°C)	Enthalpy of evaporation (kJ/kg)
R125	C2HF5	120.00	-48.9	159.7
R32	CH2F2	52.02	-52.0	382.5
R134a	C2H2F4	102.00	-26.4	216.1
R600a	i-C4H10	58.10	-12.3	355.4

3 Economic assessment

The economic assessment of the heat pump will consist of two major sub-parts. In the first place, the period of time in which the investment returns itself will be computed. The most common investment analysis ratio, the Net Present Value (NPV) will guide this analysis. Within this analysis, attention will be paid to possible variations in the financing of the investment. A wide range of options, varying from entirely financing the heat pump with own resources to borrowing the entire investment will be investigated. As the results will prove, the influence of this choice on the NPV of the project is very limited (under identical circumstances as in [1]). Afterwards, a sensitivity analysis will reveal the most crucial parameters in this computation. More precisely, the influence of the electricity price and heat price on the investment's NPV will be computed.

3. 1 Net Present Value

When considering the Net Present Value, future cash flows (both incoming and outgoing) are balanced, taking the devaluation of money into account. The NPV then indicates how much value an investment project creates for a company or an individual, as it reflects the monetary value of future cash flows, taking the a priori required return and inflation rate into account. The basic formula for the NPV is:

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+k)^t} \tag{1}$$

As Kulcar et al. [1] pertinently remark, an investment can be covered by own funds, (bank) loans or a combination of both. The analysis from the investor's viewpoint then differs depending on the combination opted for. The present value of the investment cost C_{INV} is then:

$$C_{INV} = C_0 + \sum_{j=0}^{n} \frac{a_n C_{TC}}{(1+r)^j} \tag{2}$$

The annual installment factor is then determined as:

$$a_n = \frac{r_a (1+r_a)^n}{(1+r_a)^n - 1} \tag{3}$$

The yearly maintenance costs C_S are estimated at 2% of the initial purchase price of € 24,000, i.e. € 480. Unless in situations where inflation is higher than the discount rate (which is irrational), the discounted maintenance costs will not exceed € 480 (which is in contradiction to the figures in [1]). Therefore, our results will differ from the results obtained by Kulcar et al. [1]. The net present value of the maintenance costs is determined with following equation:

$$C_S = \sum_{j=0}^{N} \frac{0.02 C_{TC} (1+r_j)^j}{(1+r_j+r)^j} \tag{4}$$

To operate the heat pumps and the compressor, a certain amount of electricity is consumed. The net present value of this electricity costs C_{PS} is determined with the equation:

$$C_{PS} = \sum_{j=0}^{N} \frac{C_E P t_1 t_2 (1+r_j)^j}{(1+r_j+r)^j} \tag{5}$$

Operating the heat pumps had the advantage of extracting heat, which provides an income for the owner of the system. The NPV of the income from the extracted heat C_P is determined with following equation:

$$C_P = \sum_{j=0}^{N} \frac{Q_k C_T t_1 t_2 (1+r_j)^j}{(1+r_j+r)^j} \tag{6}$$

(1)

3.2 Influence of financing mechanism

A project's NPV – from the owner's point of view – is partially dependent on the origin of the financial means. If the required investment is entirely financed with own resources, the investment falls entirely at the start of the project. However, if the needed resources are (partially) borrowed, the investment from the owner's viewpoint is spread in (2) time. The disadvantage of this spread lies in the fact that borrowed money carries some additional costs in the form of interests on the capital. To which side the balance tips, depends on the required interest rates on the borrowed capital, the inflation rate and the required rate of return on the investment.

Table 2. Main figures for the economic analysis.

Variable	Symbol	Value	Units
Price of a heat pump system	C_{TC}	24,000	EUR
Operational life time of the heat pump		20	Years
Duration of the loan		10	Years
Discount rate	r	0.07	
Discount rate of annual instalments	r_a	0.07	
Inflation rate	r_j	0.012	
Power used by the compressor	P	51.79	kW
Heat flow of the condenser	Q_k	187.3	kW
Price of electricity	C_E	0.07	EUR/kWh
Price of heat	C_T	0.0325	EUR/kWh
Maintenance costs	C_S	$0.02C_{TC}$	EUR/year
Operational time of the heat pump per day	t_1	18	h/day
Operational time of the heat pump per year	t_2	120	days/year

Within the context of this study, the basic premises of [1] have initially been adopted. The inflation rate rj has been fixed on 1.2% (which reflects an average scenario compared to the past period of high inflation followed by the period of low inflation or even deflation recently), while the discount rate r amounts 7%. With an electricity price of 0.07 €/kWh and a heat price of 0.0325 €/kWh, the influence of the financing mix on the project's NPV from the owner's perspective has been investigated. The financing mix varies between 100% of own and 100% of borrowed resources. In case of borrowed resources, it has been assumed that the loan period amounted 10 years with yearly terms. Additionally, the operational life of the heat pump is assumed to be 20 years. Table 2 summarises the main figure used throughout the economic analyses, unless otherwise indicated.

The difference in NPV between the two extreme situations of the financial mix (the entire investment borrowed or financed with own resources) is zero. The annual installments have been discounted without accounting for inflation (as a bank loan with fixed interest rate has been opted for).

The results indicate that, under the basic circumstances assumed in [1] (C_E = 0.07 €/kWh and C_T = 0.0325 €/kWh), investing in a two stage heat pump with heat exchanger using low-temperature geothermal sources for building heating purposes is financially interesting. All financial mixes give a significantly positive NPV of € 27,584.16. The total investment cost of € 24,000 is easily recovered by the gains through heat production. The Internal Rate of Return (IRR), which indicates the rate of return that the owner receives for his investment, amounts almost 20%. This is much higher than the required 7% (indicated by the discount rate). Thus, under the given circumstances, investing in the heat pump is financially very attractive. This result is in line with the findings of Poberžnik et al. [5].

Under the assumptions of [1], where € 8,000 is invested from own resources, the NPV is € 27,584.16. After a period of 3.64 years, the investment returns itself. This result is considerably different (+14%) from the result obtained in [1]. As indicated earlier, this is due to a difference in maintenance costs. However, under the given circumstances, the investment remains attractive.

3.3 Influence of electricity and heat price

Besides the financing mix, other variables can exert significant influence on the financial attractiveness of the investment. In this section, it is assumed the entire investment is covered with borrowed resources (own capital = € 0). As discussed earlier, the financial mix has no influence on the results. The NPV of the project might be influenced by the evolution of the electricity price (needed to operate the compressors) and the heat price (income received from the heat extracted by the condenser). Especially in view of the sharply increasing energy prices of the first half of 2008, this analysis could reveal the sensitivity of the results to the electricity and heat prices.

Fig. 2. Electricity prices for medium size households in Belgium, Slovenia and EU-15 (EUR/kWh)

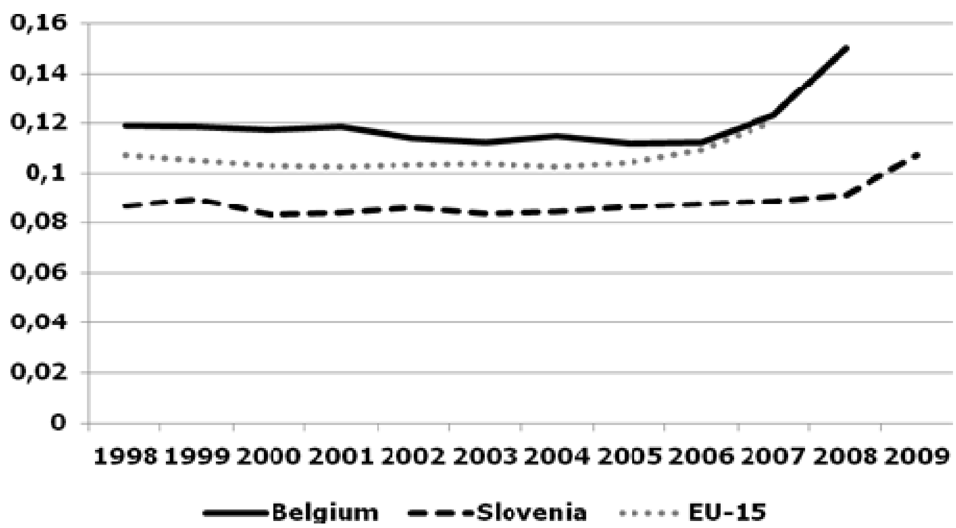
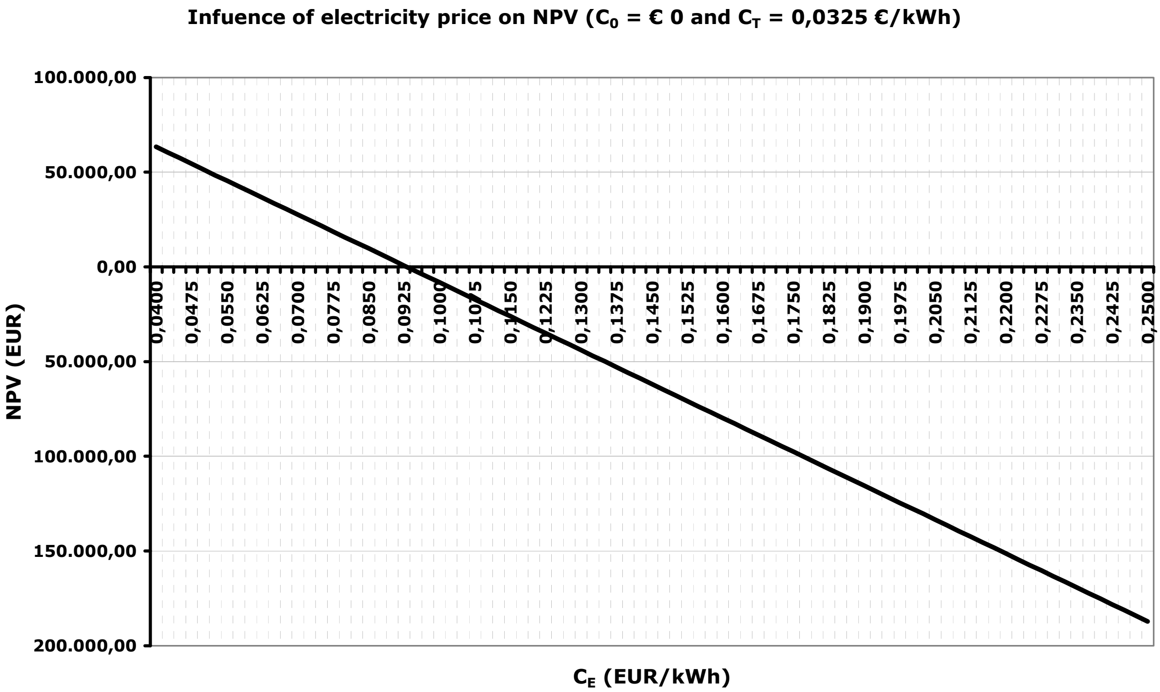


Fig. 3. Influence of electricity price on NPV.



The results of the analysis are presented in Figures 3 and 4. Both graphs have been obtained through variation of one of both parameters (resp. electricity price and heat price) under the ceteris paribus hypothesis. The results suggest a linear negative relationship between the electricity price and the NPV of the investment. For each increase of the electricity price with 0.0025 €/kWh (under ceteris paribus circumstances), the NPV decreases with € 2,982.00. Under the given circumstances (C_0 = € 0 and C_T = 0.0325 €/kWh), the investment gets a negative NPV if the electricity price surpasses € 0.0925. In many European countries, this price is not unrealistic. For example, the average electricity price for household consumption in Slovenia in January 2007 was 0.1064 €/kWh, while in Belgium this was 0.1581 €/kWh [18]. Since then, electricity prices have been rising unremittingly in almost all European countries, as is illustrated by Figure 2, until the end of 2008. Since then, electricity prices are decreasing a little again. Therefore, the attractiveness of the project should be nuanced within the light of these results. In a further stage, the influence of the electricity price will be evaluated simultaneously with an evolution in the heat price.

Starting from the basic circumstances (C_0 = € 0 and C_T = 0.0325 €/kWh), an increase of the electricity price to 0.075 €/kWh leads to an increase of the payback period from 3.64 to 4.83 years under ceteris paribus hypotheses.

The results of a similar analysis to investigate the influence of the heat price on the NPV are presented in Figure 4. As expected, the relationship is positive. Each increase of the heat price with 0.0025 €/kWh under ceteris paribus circumstances induces an increase of the project's NPV with € 10,784.47. This leads to a NPV of € 0 when the heat prices reaches 0.00261 €/kWh, which is low compared to current prices. The evolution of the heat price can be assumed to have a positive effect on the attractiveness of investing in a heat pump system. The recent favourable climate however largely depends on the evolution of the electricity prices (and inflation), as illustrated previously.

Additional to the sensitivity analysis performed on the individual variables electricity price and heat price, it might be interesting to evaluate simultaneous variances in both prices. It is indeed natural that both prices, although not perfectly related, vary in a similar way at the same time, as it concerns prices of energy goods. The results of this analysis are presented in Figure 5. For the analysis, variations of the electricity price between 0.04 €/kWh and 0.25 €/kWh and of the heat price between 0.01 €/kWh and 0.15 €/kWh have been investigated.

As the results illustrate, an equal increase in absolute terms of the electricity and heat price leads to an amelioration of the NPV. For example, starting from the original situation where C_E equals to 0.07 €/kWh and C_T equals to 0.0325 €/kWh, a rise of both variables with 0.005 €/kWh leads to an increase of the NPV from € 27,584.16 to € 43,189.11.

Similarly, an equal relative rise of both variables leads to an increase in the NPV. For example, an increase with 10%, from 0.07 €/kWh to 0.077 €/kWh for the electricity price and from 0.0325 €/kWh to 0.03575 €/kWh for the heat price, leads to a NPV of € 33,254.39 instead of € 27,584.16. Therefore, it can be argued that the net present value of the investment is more sensitive to changes in heat prices than it is to variations in electricity prices.

4 Conclusion

The results of our study suggest that the economic viability of exploiting low-temperature geothermal energy for heating of buildings using a two-stage heat pump with heat exchanger is guaranteed under many circumstances. Under the basic assumptions (identical to those in [1]), the investment in the heat pump system returns itself in less than 4 years. However, in view of the recent variations in energy costs, this result should be approached with caution. It turns out that the NPV of the investment is more sensitive to changes in the heat price than it is to changes in electricity price. Anyhow, the investment in the heat pump system remains interesting from an economic point of view under the majority of the circumstances. Our results therefore confirm the results of Kulcar et al. [1]. On the opposite side, the investment should be evaluated carefully, especially in circumstances where heat prices would increase at a slower pace than electricity prices do. The balance could then overturn to result in a negative NPV.

Another interesting result of our study is the influence exerted by the balance between own and borrowed resources to finance the investment. Surprisingly, our results suggest that these variables do not have any impact on the final Net Present Value for the investor, under the circumstances investigated. However, depending on the specific situation (other annual instalment factors, inflation etc.), this result might not hold for any individual.

Fig. 4. Influence of the heat price on the NPV.

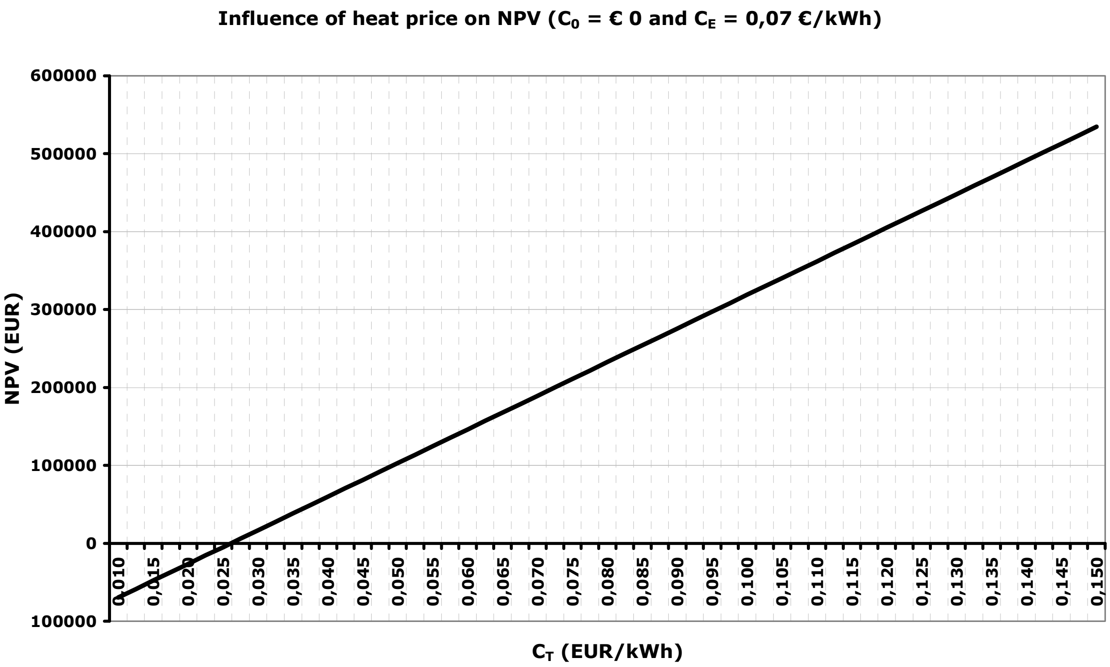
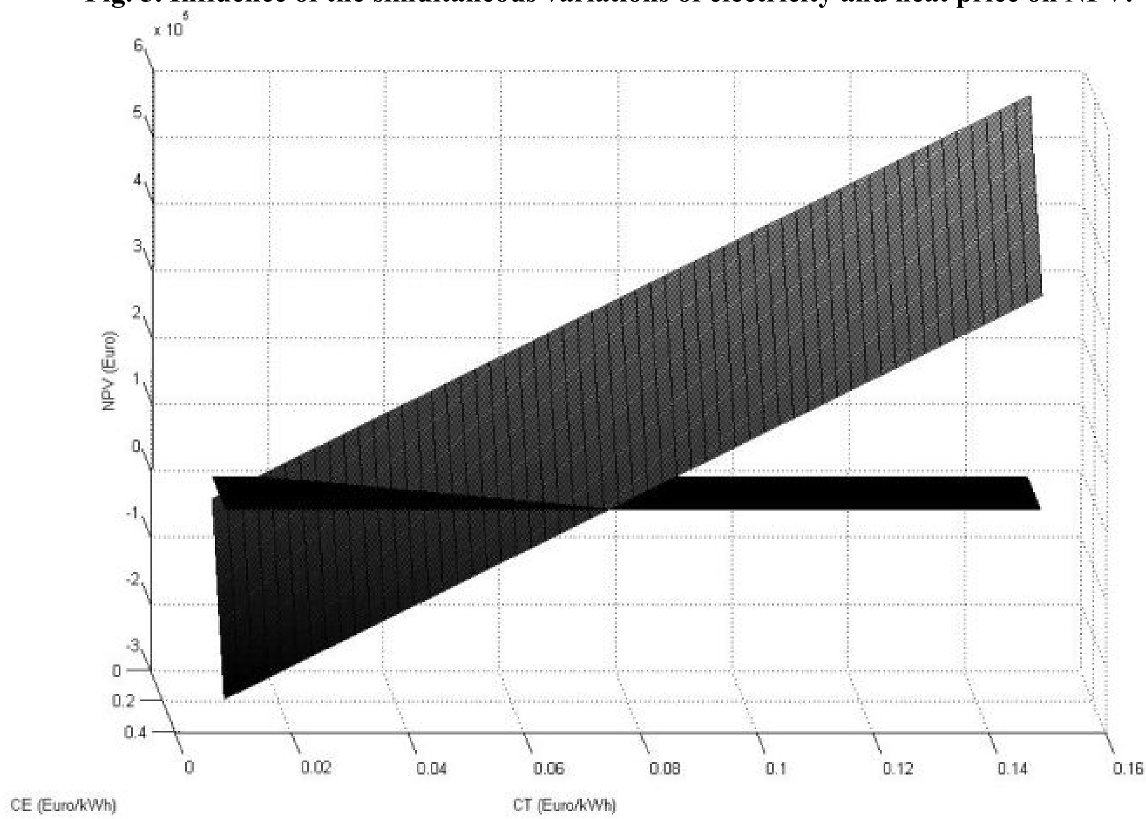


Fig. 5. Influence of the simultaneous variations of electricity and heat price on NPV.



4.1 Implications

Our results hold implications for different parties. In the first place, policy makers could use our results in order to further shape general and subsidy policies towards energy-efficient and environmental-friendly technologies. Our analysis suggests that the economic appeal of certain investments depends on some macro- and meso-economic parameters. In the case of the heat pump exploiting geothermal energy, the outcome is mainly determined by electricity and heat prices on the local market. Under changing market conditions, policy makers might therefore need to review and revise the public policies for the stimulation of green technologies if they wish to obtain large scale introduction. Green technologies will only find their way to the large public if they are affordable – whether intrinsically or after government intervention – and financially interesting. After all, the amount of people willing to make large investments in green technologies out of ideological belief – without financial incentive or positive return – is limited. Thus, policy makers should make an analysis to determine under which circumstances various technologies should be promoted. Our study contributed to this understanding by assessing the economic attractiveness of investing in a two-stage heat pump with heat exchanger to exploit low-temperature geothermal energy in a residential application.

Secondly, for individual investors, this paper gives an overview of the influence of the major impact factors determining the financial result of an investment decision. Although the exact parameter values investigated in this study might not be applicable and relevant for each situation, the methodology and line of reasoning can be adapted to the specific situation of the (potential) investor. For example, investments in specific energy-efficient technologies (including solar energy and heat pumps) for households can in Belgium (partially) be deducted from private taxes, especially if the investor borrows resources to be able to make the investment. Therefore, the aforementioned results indicating that there is no influence of the resource origin are not (entirely) valid in the Belgian context. Other (tax) regimes might imply similar differences.

4.2 Limitations

The tenability of analysis results is rather limited, due to the rapidly changing economic circumstances. In recent years the energy prices have been increasing, although the global economic crisis (temporarily?) slowed down this process. As energy prices have a major impact on this project's NPV, the results should be carefully analysed with respect to the changing circumstances.

A second limitation relates to the influence of inflation on the NPV. This influence has not been investigated in this study. As indicated earlier, inflation has been fluctuating quite substantially in Europe lately (in both directions). Therefore, it might become important to take a closer look at inflation. However, electricity (and heat) prices are a component of inflation. Therefore, it can be argued that variations of energy prices reflect the influence of inflation at least partially.

Thirdly, technological innovations are an important aspect in the industry sectors of renewable energy and sustainable housing. New products, processes or technologies might influence the economics of investments in this sphere. Therefore, the analyses should be performed for every new development to assess its economic attractiveness, besides an environmental and technological evaluation. In this study however, a status quo situation on the technological dimension (compared to [1]) has been investigated and the environmental impact of using low-temperature geothermal energy for heating purposes has not been evaluated.

5 Acknowledgements

The authors gratefully acknowledge the work performed by B. Kulcar, D. Goricanec and J. Krope. Their contribution in Energy and Buildings (Vol. 40, No. 3) initiated our modest contribution to the understanding of economic aspects related to heat pumps. All credits, especially for the technical details and contributions, should be awarded to them. Additionally, the first author wishes to thank the Research Foundation Flanders (FWO Vlaanderen) for financially supporting him as PhD Fellow. Lastly, the authors would like to take the opportunity to thank the reviewers for their useful and constructive comments on earlier versions of our paper.

References:

[1] B. Kulcar, D. Goricanec, J. Krope, Economy of exploiting heat from low-temperature geothermal sources using a heat pump, *Energy and Buildings*, Vol. 40, No. 3, 2008, pp. 323-329.

[2] R. Myskova, The development and use supporting of renewable energy sources in terms of Czech companies, *WSEAS Transactions on Environment and Development*, Vol. 6, No. 3, 2010, pp. 176-185.

[3] A. Audenaert, S. H. De Cleyn, B. Vankerckhove, Economic analysis of passive houses and low-energy houses compared to standard houses, *Energy Policy*, Vol. 26, No. 1, 2008, pp. 47-55.

[4] A. Audenaert, S. De Cleyn, Economic viability of passive houses and low-energy houses, *Proceedings of the 3rd WSEAS International Conference on Urban Rehabilitation and Sustainability (URES'10)*, Faro, 2010, pp. 29-35.

[5] S. Poberžnik, D. Goricanec, J. Krope, Economic Analysis of Geothermal Heat Source for Residential Area Project, *International Journal of Energy*, Vol. 1, No. 1, 2007, pp. 28-32.

[6] G. W. Huttrer, Geothermal heat pumps: An increasingly successful technology, *Renewable Energy*, Vol. 10, 1997, pp. 481-488.

[7] Eurostat, *Energy consumption in households: 1996 survey*, European Commission, 1999.

[8] W. Feist, J. Schnieders, V. Dorer, A. Haas, Re-inventing air heating: Convenient and comfortable within the frame of the Passive House concept, *Energy and Buildings*, Vol. 37, 2005, pp. 1186-1203.

[9] V. R. Tarnawski, W. H. Leong, T. Momose, Y. Hamada, Analysis of ground source heat pumps with horizontal ground heat exchangers for northern Japan, *Renewable Energy*, Vol. 34, 2009, pp. 127-134.

[10] M. Jakob, Marginal costs and co-benefits of energy efficiency investments. The case of the Swiss residential sector, *Energy Policy*, Vol. 34, 2006, pp. 172-187.

[11] A. C. Gillet, The use of heat pumps in solar heating in Belgium, *Renewable Energy*, Vol. 16, 1999, pp. 647-651.

[12] L. Huang, X. Li, X. Fu, The industrialization prospect analysis of water resource heat pump based on scenario planning, *WSEAS Transactions on Environment and Development*, Vol. 5, No. 3, 2009, pp. 240-249.

[13] I. Sarbu, C. Sebarchievici, Heat pumps – Efficient heating and cooling solution for buildings, *WSEAS Transactions on Heat and Mass Transfer*, Vol. 5, No. 2, 2010, pp. 31-40.

[14] Y. A. Kara, B. Yuksel, Evaluation of low temperature geothermal energy through the use

of heat pump, Energy Conversion and Management 42 (2001) 773-781.

[15] O. Ozgener, A. Hepbasli, Modeling and performance evaluation of ground source (geothermal) heat pump systems, *Energy and Buildings*, Vol. 39, 2007, pp. 66–75.

[16] O. Ozgener, A. Hepbasli, L. Ozgener, A parametric study on the exergoeconomic assessment of a vertical ground-coupled (geothermal) heat pump system, *Building and Environment*, Vol. 42, 2007, pp. 1503–1509.

[17] E. Torhac, L.L. Crepinsek, J. Krope, D. Goricanec, A. Saljnikov, R. Stipic, D. Kozic, Profitability evaluation of the heating system using borehole heat exchanger and heat pump, *IASME Transactions*, Vol. 2, No. 8, 2005, pp. 1381–1388.

[18] J. Goerten, E. Clement, Electricity prices for EU households and industrial consumers on 1 January 2007, *Eurostat Statistics in focus, Environment and Energy*, Vol. 80/2007, 2007, pp. 1-8.