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Theoretical thermal performance of the air-source heat pumps in Trabzon, Turkey

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Abstract
A heat pump raises heat from its surroundings such as air, solar collector, ground water, or waste process heat from a lower temperature level to a higher. A crucial factor in the planning and selection of a heat pump system is the type of intended application. If requirements change from heating to cooling in accordance with the seasons a reversible heat pump can supplement the conventional heating system in winter, or can even replace it. During the summer, the hydraulic system of a heat pump is reversed to supply cooling instead of heat energy. One of the benefits of electric heat pumps is that they can take advantage of the anticipated growth in renewable energy production and provide low-carbon heat generation in the residential and commercial sectors, while also offering potential flexibility on the demand side. In this study, thermal performance of the air-source heat pumps in Trabzon, Turkey was investigated by theoretical with using the SOLSIM simulation program. In this model, an electrically driven air-source heat pump was used for heating a single family building with a floor area of 100 m^2. In simulation model, third-order polynomials relating the heat pump's COP to the outdoor air temperature. Also, economic comparison was made of the heat pump's performance with Ground source heat pump, oil and natural gas furnace heating systems, using payback-time economic method.

Keywords: air-source heat pump, building heating, thermal performance, simulation method.

1. Introduction

Heat pumps are a quite effective means to look forward to the enhancement of energy efficiency and savings. It is a very broad subject, and therefore, it is almost impossible to include all the related features in a unique volume. Far from being exhaustive, this volume is aimed at providing a detailed overview of the main topics that any professional needs to know, before either employing such machines in his designs or evaluating their energy performances [1-3].

After a general description of the world market, the thermodynamic basic principles of heat pumps are recalled, emphasizing the effects of the internal and external irreversibilities on the heat pumps' performances. The main components are analyzed, also concerning their reciprocal interactions and those with the thermal environment they are in contact with. In fact, heat pumps are complex systems which, in turn, interact with other complex systems constituted, on the one hand, by the indoor environment (internal source) and, on the other, by the outdoor environment (external source) [4-8].

Heat pumps are an effective means of energy production in several fields of modern technology.

To have an idea of the present situation we can refer to [1]. It reports a European market increase of 3.5% in 2014 with respect to 2013. Even if some countries recorded a decrease of the sold units, it was largely compensated by the top 10 markets led by France, Spain and Finland. In particular France (leading country) followed by Italy and Sweden reached more than hundred thousand units sold per year, while Finland, Germany, Norway and Spain exceeded fifty thousand of annual sold units [9-14].

A fast increase of using heat pumps for sanitary water production is taking place both as stand-alone units (heat pump and water storage tank in the same casing) or as heat pumps with separate tanks. Air has been and is the most diffused heat source so far, while larger heat pumps are increasingly employed for industrial and commercial uses, and for district heating. Air is still used, but also geothermal and hydrothermal sources are often employed. In some cases heat is provided by waste waters. To have a short insight on the more general state of the art in the world we can refer to [2].

In order to investigate the energy performance of air-

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to-air heat pumps for residential heating in the Black Sea region of Turkey, an experimental set-up was constructed. An electrically driven air-to-air heat pump was used for heating a laboratory building with a floor of 75 m^2. The experimental results were obtained for December, January, February, March, April and May of the 1991–1992 heating season. The experimentally obtained results are used to calculate the heat pump's coefficient of performance (COP). Actual experimental performance data were used to generate third-order polynomials relating the heat pump's COP to the outdoor air temperature. Also, economic comparisons were made of the heat pump's performance with electrical resistance, oil, gas and coal-fired heating systems, using an annualised life-cycle costing method. This showed that the heat pump offers economic advantages over the oil and coal-fired boiler systems, but is not an economic alternative to the gas-fired heating system. Because the unit price of the gas is 3·84 times less than that for electricity, to become competitive with a gas-fired boiler, either the capital cost of the heat pump must be substantially reduced or its seasonal COP increased by about 60%: it should also be driven by a gas engine rather than an electric engine.

In this study, thermal performance of the air-source heat pumps and their role in a clean energy system was study by theoretically. The SOLSIM simulation program was used to calculate coefficient of performance (COP) for air-source heat pump for mild climate condition such Trabzon, Turkey. Also an economic comparison was made of the heat pump’s performance with Ground source heat pump, oil and natural gas furnace heating systems, using payback-time economic method.

2. Heat pumps for highly efficient technology

2.1. Overview

Heat pump is a highly efficient technology for heating residential and commercial buildings. They use electricity to transfer heat from the outside air, or the ground, to the interior, in contrast to more widespread technologies such as warm-air furnaces and variable air volume systems, which typically burn oil or natural gas to heat buildings. Electrification of space heating can help decarbonize the heating sector by using renewable electricity generation from wind, solar, and hydropower. There is no technology that can currently rival heat pumps in efficiently delivering space heating for the residential and commercial sectors [1].

Heat pumps are generally classified into two main categories based on the source of heat: air-source heat pumps (ASHPs) and ground-source heat pumps (GSHPs). As the name implies, an ASHP (Fig. 1) transfers heat from the cold outdoor air. While this may seem counterintuitive, energy in the form of heat is always present at any temperature above absolute zero. An ASHP simply absorbs some of that heat and transfers the absorbed heat into the interior space. Similarly, ground-source heat pumps extract heat from the ground. They are more expensive but also more efficient than ASHPs due to the nearly constant 4.4-15.5°C temperature of the ground throughout the year [2].

Figure 1. A photograph for air-source heat pump. Source: Wikipedia Commons.

2.2. Operating principle

Heat naturally travels from warmer to colder places. In a heat pump, electrical energy is used to move heat in the opposite direction against a temperature gradient. The amount of input energy needed is generally much less than the amount of energy transferred as heat, resulting in the heat pump's high efficiency. Similar to refrigerators and air conditioners, most heat pumps operate on the principle of the vapor-compression cycle, which exploits the physical properties of a volatile evaporating and condensing fluid and the heat stored or released during its phase changes. The main components of a heat pump are a compressor, an expansion valve, and two heat exchangers called the evaporator and the condenser (Fig. 2) [3]. When refrigerant vapor enters the compressor, it is compressed to high pressure and temperature. The superheated vapor then travels to the condenser, where it condenses into a saturated liquid and gives off heat.

The temperature (and pressure) of the warm fluid is then further lowered when it expands through an expansion valve. The now-cold liquid (colder than the outside air) enters the evaporator, where it absorbs heat from the surrounding outside air (or ground) and boils again to vapor. On the other hand, in a reversible heat pump, the whole process can be inverted to cool the building by employing a reversing valve. In cooling mode (AC), the outdoor coil becomes the condenser and the lower temperature indoor coil becomes the evaporator.

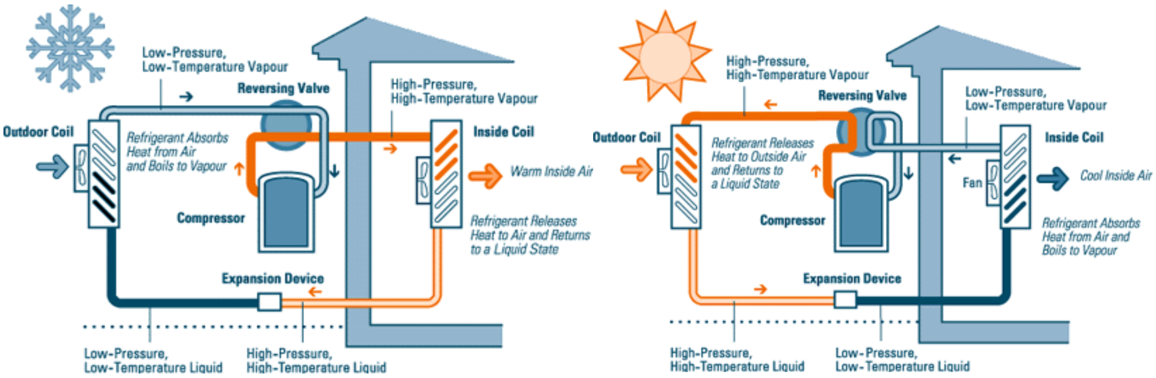

Figure 2. The components and operation of heating and cooling cycle [3].

2.3. Efficiency

When measuring the technical performance of heat pumps, it is best to avoid the term "efficiency," which has a very specific thermodynamic meaning. Instead, a commonly used measure is the Coefficient of Performance (COP), defined as the heat delivered QHP divided by the electrical input energy W_{HP} :

$$COP = \frac{Q_{HP}}{W_{HP}} \qquad (1)$$

Because heat pumps move heat as opposed to creating it, the heat energy transferred from the outside can be several times larger than the input electrical energy. A typical ASHP has a COP of 3.2 – 4.5, while a GSHP has a COP in the range of 4.2 – 5.2 [4]. By comparison, an electrical resistance heater can have a maximum COP of only 1 because all the produced heat is created from the input electrical energy. The COP of a heat pump can also be expressed as:

$$COP \approx \eta \frac{T_{hot}}{T_{hot} - T_{cold}} \qquad (2)$$

where all losses and deviations from the ideal cycle are represented by η [4]. This shows that the performance of a heat pump is inversely proportional to the temperature difference between the external source of heat (T_{cold}) and the output heat (T_{hot}). To maximize the COP, the difference between inside and outside temperatures (the so-called "lift") needs to be as small as possible. For this reason, heat pumps are more efficient as space heaters than as domestic water heaters (T_{hot} ~32°C for air compared to 54°C for water), and ground-source pumps have higher seasonal efficiency than air-source pumps because ground temperatures fluctuate around an annual average of $T_{cold} \sim 10°C$, whereas ambient air temperatures in the winter can fall to below $T_{cold} = -17°C$ depending on the geographic location. To account for the seasonal variations in the COP, a seasonally averaged COP (SCOP) is often used, as well as another rating called the Heating Seasonal Performance Factor (HSPF) [1-6].

2.4. Cost, payback times, and maintenance

The upfront capital costs for heat pumps are normally higher than for conventional heating systems. In addition, the installation price tag for GSHPs is much greater compared to ASHPs due to the additional labor required for underground piping. Despite the high capital expenditures, heat pumps have passed the break-even point required to save money in the long run due to their high efficiency and minimal operational and maintenance costs [2]. Because electricity tends to be three to four times more expensive than natural gas per unit energy, the payback periods for replacing gas for heating buildings can be close to 30 years [2,5]. By contrast, when replacing oil or electrical heating systems, the payback time falls to between 5 and 15 years [2] and can be as low as 3 to 4 years in some geographic locations. Heat pumps require minimal maintenance compared to conventional furnaces as there is no risk of explosion or natural gas leakage.

One disadvantage of ASHPs in cold and damp climates is the freezing of the outdoor heat exchanger during colder spells and the need for defrost cycles. This reduces the efficiency of ASHPs and makes them less suitable than GSHPs for climates with extreme winters [2]. Newer “cold-climate” ASHPs, however, use more efficient compressors and advanced refrigerants that boil at lower temperatures, improvements that make ASHPs economical even in relatively cold climates such as upstate New York [7-14].

3. Role in demand-side management and smart grids

As the share of electricity generation from renewable energy resources increases, the power grid will gradually advance towards a system where electricity demand is continuously adjusted to accommodate variable electricity generation from renewables like wind and solar. Heat pumps are viewed as an enabling technology on the flexible demand side that can be actively managed to support the realization of a smart grid [6].

At the same time, a key issue is the effect of heat pumps on peak electricity demand in areas with cold winters. In such climates, electricity demand tends to peak in the coldest months and the use of heat pumps can exacerbate this effect [1]. Solar energy production is correlated with air temperature and therefore anti-correlated with space heating demand, which adds to the challenge. Development of scalable smart controls for large numbers of heat pumps and expansion of the grid to interconnect broad geographic areas can help alleviate these problems [4-14].

3.1. Carbon emissions

Bioma In most cases, CO_2 emissions from heat pumps are necessarily linked to the carbon intensity of the electricity they use. Thus, the marginal carbon intensity of the grid at a given point in time and a given location can greatly influence the attractiveness of heat pumps for the heating sector. Studies have shown that CO_2 emissions from domestic heating are reduced by approximately 50% on average when heat pumps displace solid fuel, oil, or electric heating, and by 10% to 35% when they displace natural gas heating. One concern regarding the carbon footprint of heat pumps is their use of refrigerants with very high global warming potential. While there is no impact on climate during heat pump operation, refrigerant leakage is a serious concern and needs to be minimized over the life span of the heat pump [2, 7, 8, 9].

4. Case study in Trabzon

4.1. Climate

The Trabzon climate is normal in the summer and warm in the winter. The average temperature of the summer months is around + 32 °C. In the coldest days of winter, the temperature drops down to - 6.0 °C. Spring months are usually rainy and foggy. Autumn is quite beautiful. Trabzon has a humid climate, and the humidity is sometimes up to 98%. The average annual rainfall is 800-850 kg/m^2. As the interior reaches the interior, the rainfall increases. The least raining months are July and August and the most snow falls in February. The coldest months are January and February. With these features, it can be said that Trabzon's climate is mild and soft. As the beach goes inward, the air is better and the water is cleaner. The lowest value is 6.0 °C in March. Table 1 gives the climatic conditions for Trabzon, Turkey [16-22].

Table 1. Climatic conditions for Trabzon over year.

	Jan.	Feb.	March	April	May	Nov.	Dec.
Average outdoor temperature (ºC)	7.2	7.3	8.4	11.9	15.6	12.6	9.5
Minimum outdoor temperature (ºC)	3.9	4.0	5.0	8.4	12.4	9.2	6.1
Maximum outdoor Temper. (ºC)	10.6	10.7	11.8	15.4	18.8	16.3	13.1
Minimum water temper. (ºC)	9.4	8.4	8.6	9.5	13.4	14.7	11.4
Average water Temper. (ºC)	10.2	8.9	9.1	11	16	16.5	12.9
Maximum water temper. (ºC)	11.3	9.4	9.5	13	19	18.4	14.4
Average Relative Humidity (%)	66.7	67.2	65.2	71.9	81.4	76.4	68.6
Average wind velocity (m/s)	2.3	2.1	2.1	2.3	1.9	2.4	2.4
Average solar Rad. ($MJ/m^2.d$)	5.42	7.18	11.74	14.32	14.52	5.80	4.40
Degree days	297	305	313	246	158	125	283
Rainfall (mm)	90	66	58	56	58	109	93
Soil temp. for 1.0 m depth (ºC)	9.2	8.1	10.2	12.1	15.2	15.6	11.2

4.2. Method of theoretical analysis

The complexity of the thermal analysis of air-source heat-pump system makes the use of computer simulations the only feasible method for determining the system dynamics and performance. These simulations were performed with the simulation program SOLSIM [15]. This was modified to include the heat-pump system performance behavior. So, this computer program contains some subroutines, which model the behaviors of individual pieces of hardware (i.e. outdoor air temperature, soil temperature, heat pumps, building heating load), and an executive routine which links these component models and solves the resulting system of equations. The simulation calculations are performed with a 30 min computational time step to allow consideration of the transient effects and short-term interactions of components.

The heat-pump model used in these simulations is quasi steady-state in nature. The heat pump has only one heat source for the evaporator such as air source. The actual performance data obtained from experimental results are used to generate third-order polynomials relating the heat pump's COP to the source temperature [18-20]. For the air-source heat pump, one different sets of polynomials are used, one set relating to the air-source given as:

For the air-source heat pump:

$$COP = -27.86 + 0.121T_a + 1.601x10^{-4}T_a^2 – 7.035x10^{-7}T_a^3 \quad (3)$$

$$Q_{con} = 18.45 - 0.101T_a + 6.508 \text{ x } 10\text{-}5T_a^2 - 5.044 \text{ x}10^{-7}T_a^3 \quad (4)$$

The building used in the simulation is the single family house, whose structural properties are given in Table 2. The building has 100 m^2 floor area and was not well insulated. Table 3 also shows the air-source heat pump parameters.

Table 2. Construction properties of the single family building.

Window area (single glass, *U* = 4.8 $W/m^2.^oC$)	**100 m^2**
Wall area (single brick, U = 1.6 $W/m^2.^oC$)	80 m^2
Floor area (concrete, U = 2.5 $W/m^2.^oC$)	100 m^2
Ceiling area (concrete & flat metal, U = 2.0 $W/m^2.^oC$	100 m^2
Effective *UA* (kWh/ºC)	0.800
Comfort temperature (ºC)	22.0
Average degree days for heating season for Trabzon	1180
Average total heating load of the building for heating season (kJ)	$7.64x10^7$
Dimension of the building (m)	4 m x 10 m x 10 m
Volume of the building (m^3)	400 m^3

Table 3. Air-source heat pump parameters.

Heat pump information	
Capacity	5820 W
Compressor type	Hermetic
Evaporator type	Water-cooled shell and tube
Condenser type	Air-cooled copper tube
Evaporating temperature	7.2 ºC
Condensing temperature	54.4 ºC
Air mass flow rate in condenser	2420 m^3/h

4.3. Estimated CO_2 emissions reduction and payback times

The 2030 target for greenhouse gas (GHG) emissions reductions in Turkey is 40% below 1990 levels. In order to reach this goal, it is essential to achieve substantial reductions in the use of fossil fuels in the residential heating sector. Space heating is the largest single residential energy end-use in Trabzon province, accounting for 56% of the residential energy consumption. Space conditioning and water heating account for more CO_2 emissions than the entire electricity sector of Trabzon province combined. The residential sector itself is responsible for over 60% of the emissions associated with space conditioning and water heating and the vast majority of those emissions come from residential space heating.

Table 4 summarizes the estimated installation costs, annual energy use, annual energy costs, cumulative CO_2 emissions over 15 years, and payback times for cold-climate ASHPs and GSHPs compared to natural gas and oil heating systems. Natural gas and heating oil are by far the most common heating fuels in Trabzon province, accounting for 60% and 20% of all residential heating systems respectively. The residential buildings considered here are single unit structures with 80 to 120 m^2 of heating area, assuming the retrofit takes place at a time when the oil or natural gas furnace needs replacement.

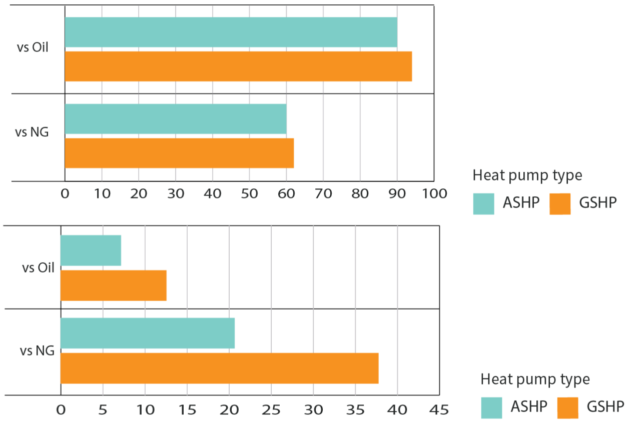

Figure 3(a). Cumulative CO2 emissions reduction over 15 years as a metric tons of CO_2 versus oil and natural gas, (b) Payback times as a year versus oil and natural gas.

Table 4. Costs, CO_2 emissions and payback times for different heating option in Trabzon, Turkey.

Heating system	Installation Cost ($)	Annual energy use (kWh)	Annual energy cost ($)	CO_2 emissions for 15 years (metric tons)	Payback time versus oil (Years)	Payback time versus NG (Years)
ASHP	6 000	7 000	800	14	3.2	20.2
GSHP	20 000	5 000	500	10	12.2	34.2
Oil	2 000	25 000	1 400	104	-	-
NG	2 000	26 000	800	74	-	-

ASHP: Air Source Heat Pump ; GSHP: Ground Source Heat Pump ; NG: Natural Gas

These estimates do not include discount rates or projections of future fuel costs due to the high uncertainty in natural gas and oil prices. The societal benefits of reducing carbon emissions, the health benefits of reducing air pollution, and the climate impacts of upstream methane emissions associated with natural gas production and distribution are also not considered in this simple analysis.

Table 4 and Figure 3 above suggest that switching from fossil fuel heating to either an ASHP or a GSHP system can result in significant CO_2 emissions reduction over 15 years. The two heat pump options have a comparable emissions reduction potential with a slight advantage for GSHPs. The numbers also suggest that it is very cost-effective to replace an oil furnace with a heat pump. The lower installation cost of the former leads to significantly higher net benefits over 15 years. With a life span of 10 to 15 years, an ASHP can nearly break even and a GSHP with a life span of 15 to 20 years would be unable to do so. It is important to keep in mind that these estimates can vary substantially depending on the geographic location, the heat pump size, and, most importantly, the fuel and electricity prices. In general, the current low prices of natural gas compared to electricity coupled with the greater upfront costs make ASHPs marginally economical and GSHPs uneconomical as a natural gas heating replacement unless the co-benefits of CO_2 emissions and air pollution reduction are taken into account. An additional benefit of heat pumps is that they can serve as a hedge for volatile fossil fuel prices due to their lower energy consumption and the relatively stable cost of electricity.

We note that the Trabzon City area is expected to be slightly less cost-effective for heat pump adoption compared to Ankara, Erzurum, Bayburt, Kars, Konya, Kayseri due to the lower heating requirements for apartment buildings, the lower cost of natural gas and heating oil, the higher equipment and labor costs, and the higher electricity prices. These higher costs are somewhat offset by the milder climate in Trabzon City area, which improves the seasonal efficiency of air-source heat pumps.
The estimates above suggest that a switch from fossil fuel space heating to efficient electrical heat pump systems specifically ASHPs should be encouraged in Trabzon and the state should prioritize policies to overcome the various market barriers for heat pump adoption. In particular, the state should facilitate the rapid retrofitting of all oil-heated homes with efficient electrical systems. In areas without natural gas infrastructure, Trabzon province residents can affordably switch directly to efficient heat pump systems. In areas with natural gas infrastructure, ASHPs may still be the most beneficial option for new buildings, especially when CO_2 emissions, air pollution, and the volatility of fossil fuel prices are taken into account. Meeting the goal of 40% reduction in CO_2 emissions from the residential heating sector in Trabzon such as other cities in Turkey by 2030 would require replacing all existing oil furnaces and over 20% of existing natural gas furnaces with efficient heat pumps by 2030, assuming the country's target of 60% renewable energy by 2030 is also met.

5. Conclusions

Heat pumps have the potential to effectively replace fossil fuel heating systems, decarbonize the heating sector, and lower heating costs over conventional heating systems. Some challenges remain, including high initial capital costs and added grid complexities in colder climates. To overcome market and behavioral barriers for heat pump adoption policies involving financial incentives, utility programs, minimum energy performance standards, and roadmaps for market expansion need to be adopted.

The seasonal performance of the air-source heat pump has been determined by theoretically with using SOLSIM simulation program for Trabzon during the heating season from December to May. The obtained results are summarized in Table 4. As shown in Table 5, the average percent of heating load supplied by the ASHP is 84% and average actual heating COP is 2.40.

Table 5. Theoretical performance of the air-source heat pump system for heating season in Trabzon.

Months	**Number of working days of the ASHP**	**Real Heat Pump COP**	**Average Outdoor Air temp. (°C)**	**Solar Radiation (MJ/m².day)**	**Average Energy Use (kWh)**	**Percent of heating load supplied by the ASHP (%)**
November	30	2.94	14.4	6.24	800	80
December	30	2.92	10.2	4.74	1150	76
January	30	2.82	6.6	5.12	1450	50
February	28	2.72	5.2	8.06	1300	40
March	30	2.86	7.2	6.94	1100	76
April	30	3.00	11.6	11.84	800	86
May	20	3.21	15.8	16.62	400	92

ASHP: Air-Source Heat Pump

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References

[1] Fawcett, T., Eyre, N., Layberry, R. Heat pumps and global residential heating. In "Proc. of the European Council for an Energy Efficient Economy Summer Study, 2015.

[2] Staffell, I., Brett, D. Brandon, N., Hawkes, A. A review of domestic heat pumps. Energy & Environmental Science 2012; 5(11): 9291–9306.

[3] Lukanov, B. Heat pumps and their role in a clean energy system. Available from www.psehealthyenergy.org/(accessed on December 2019).

[4] Fischer, D., Madani, H. On heat pumps in smart grids: a review. Renewable and Sustainable Energy Reviews 2017; 70: 342–357.

[5] Lund, PD., Lindgren, J., Mikkola, J., Salpakari, J. Review of energy system flexibility measures to enable high levels of variable renewable electricity. Renewable and Sustainable Energy Reviews 2015; 45: 785–807.

[6] Kelly, N., Cockroft, J. Analysis of retrofit air source heat pump performance: results from detailed simulations comparison to field trial data. Energy Buildings 2011; 43: 239–45.

[7] Jenkins, D., Tucker, R., Rawlings, R. Modeling the carbon-saving performance of domestic ground-source heat pumps. Energy and Buildings 2009; 41: 587–595.

[8] Greening, B., Azapagic, A. Domestic heat pumps: Life cycle environmental impacts and potential implications for the UK. Energy 2012; 39: 205–217.

[9] Makhijani, A. Making residential heating and cooling climate-friendly in New York State. Technical Report, New York, 2017.

[10] IEA, International Energy Agency. Energy-efficient buildings: heating and cooling equipment. Technology Roadmap, OECD/IEA, 2011.

[11] Grassi, W. Heat pumps fundamentals and applications. Springer, Switzerland, 2018.

[12] Sauer, HJ. Howell, RH. Heat pump systems, New York: John Wiley and Sons, 1983.

[13] Reay, DA., Macmichael, DBA. Heat pumps. 2th ed. Pergamon Press, UK, 1988.

[14] Elisabeth, K. Solar collectors combined with ground-source heat pumps in dwellings analyses of system performance. Byggnadsfysik LTH, Lunds Tekniska Högskola, 2009.

[15] Howell, JR., Bannerot, RB., Vliet, GC. Solar thermal energy systems. McGraw-Hill, New York, 1982.

[16] Kaygusuz, K. Energy and economic comparisons of air-to-air heat pumps and conventional heating systems for the Turkish climate. Applied Energy 1993; 45: 257-267.

[17] Kaygusuz, K. Performance of an air-to-air heat pump under frosting and defrosting conditions. Applied Energy 1994; 48: 225-241.

[18] Kaygusuz, K. Performance of solar-assisted heat-pump systems Applied Energy 1995; 51: 93–109.

[19] Kaygusuz, K., Ayhan, T. Experimental and theoretical Investigation of Combined solar heat pump system for residential heating. Energy Convers Mgmt 1999; 40: 1377-1396.

[20] Kaygusuz, K. Experimental and Theoretical Investigation of a Solar Heating System with Heat Pump. Renewable Energy 2000; 21: 79-102.

[21] Kaygusuz, K. Performance of solar assisted parallel and series heat pump systems with energy storage for building heating. J. of Eng. Res. Applied Science 2018; 7(1): 759-764.

[22] Kaygusuz, K. Second law of thermodynamics and heat pumps for domestic heating. J. of Engineering Research and Applied Science 2017; 6(2): 668-679.