**POLİTEKNİK DERGİSİ**

***JOURNAL of POLYTECHNIC***

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)

URL: http://dergipark.gov.tr/politeknik

# Optimization of process parameters of ground source heat pumps for space heating applications with taguchi method

***Yazar(lar) (Author(s))**: Mustafa Bahadır ÖZDEMİR*

*ORCID: 0000-0001-7801-9367*

**Bu makaleye şu şekilde atıfta bulunabilirsiniz(To cite to this article):** Özdemir M. B. "Optimization of process parameters of ground source heat pumps for space heating applications with taguchi method", ***Politeknik Dergisi***, 21(4): 991-998, (2018).

**Erişim linki (To link to this article):** http://dergipark.gov.tr/politeknik/archive

**DOI:** 10.2339/politeknik.473411

# Optimization of Process Parameters of Ground Source Heat Pumps for Space Heating Applications with Taguchi Method

***Araştırma Makalesi / Research Article***

**Mustafa Bahadır ÖZDEMİR***

Energy Systems Engineering Department, Technology Faculty, Gazi University, Ankara, Turkey

(Geliş/Received : 02.10.2016 ; Kabul/Accepted : 26.08.2017)

## ABSTRACT

In this paper, optimization of the influence of the process parameters of ground source heat pump (GSHP) with the double U tube heat exchanger for space heating applications was performed. The coefficient of performance ($COP_{sys}$) in GSHP system was investigated during experimental measurements with various process parameters; space air inlet/outlet temperatures ($T_{i,sa}$ and $T_{o,sa}$) and soil inlet/outlet temperatures ($T_{i,wa}$ and $T_{o,wa}$). Taguchi method performed for obtained the optimum process conditions on the $COP_{sys}$ in GSHP system. Taguchi experimental design considered as L16 orthogonal array. The most influence of process parameter on the $COP_{sys}$ in GSHP system was evaluated by using analysis of variance (ANOVA) and signal/noise (S/N) ratio. The optimum process parameter was determined as A4B1C1D1 for $COP_{sys}$ in GSHP with ANOVA analysis. The optimum levels were computed as $T_{i,sa}$ at Level 1 (32 °C), the $T_{o,sa}$ at Level 2 (17°C), the $T_{i,wa}$ at Level 2 (6°C) and and the $T_{o,wa}$ at Level 1 (9°C). The most significant parameter on the COPsys for space heating applications of GSHP system were found as $T_{i,sa}$ and $T_{o,sa}$ with 48.4 %..

**Keywords: Taguchi method, ANOVA, ground source heat pump, $COP_{sys}$, heating applications absorbent, refrigeration.**

## 1. INTRODUCTION

Ground source heat pump (GSHP) systems of the space heating and cooling applications were one of the promising technologies as regards evaluations ground energy [1-3]. GSHP system was drawn energy stored under the ground during winter months for space heating applications. The absorbed ground temperature was higher than the ambient temperature. Therefore, coefficient of performance ($COP_{SYS}$) of GSHP obtained higher than the system performance [4-5]. Also, ground heat exchangers (GHX) provided connection between the heat pump and the ground and affected of the efficiency of GSHP. GSHP systems was the most important for space heating systems in winter months, as the systems reduced significant electric consumption in the place. GSHP system with these advantages can be evaluated parametrically and the efficiency can be increased. In previous studies, the optimal utilization of the space cooling and heating of the GSHP systems were evaluated with some optimization techniques. The various process parameters of vertical ground coupled heat pump (VGCHP) system were performed by Esen and Turgut [6]. The process parameters in VGCHP for varying depth of boreholes and temperatures of condenser and evaporator were optimized by using Taguchi method. The author computed COP with helping ANOVA and S/N ratio. Ramniwas et al. [7] investigated effect of the process operation of a ground coupled heat pumps (GCHP) system with Taguchi method for space heating applications. The author was determined the most important parameter of the value COP of a GCHP system as the condenser outlet temperature. The optimization of ground heat exchanger parameters of GSHP for space heating applications with Taguchi method was evaluated by Sivasakthivelet. al., [4]. The GSHP systems to utilize ground energy for space heating and cooling applications was set up and performed by Pandey et. al., [8]. Also, the author performed by using Taguchi method to determine optimum length of GHX for heating and cooling applications. Sivasakthivel et al. [9] presented the optimum process parameters of a GSHP system for both heating and cooling operations. The author obtained the best COP for the case of heating and cooling situations during experimental measurements. The influence of the parameters a solar assisted GCHP system was performed with Taguchi method for heating application by Verma and Murugesan [10]. Also, the optimum solar collector area and ground heat exchanger length for COP in GSHP systems was determined. Özdemir and Özkaya designed vertical ground source heat pump system with the single tube heat exchanger for Ankara conditions. They reported that R407c and water+antifreezewere used as working fluids for heat pump system and single U-tube heat exchanger, respectively. According to the experimental results, they found out the performance of the system as 3.12 for the heating season [10]. Hu et al., conducted energy and exergy analyzes under different control strategies to improve the performance of a ground source heat pump system for a building in Wuhan, China. According to their analysis, the use of flow control and variable flow pump has shown to improve the performance of the system [11]. Xia et al., experimentally investigated a vertical and horizontal type ground source heat pump and made an optimization for control. Experimental results suggest that the energy

---

**Sorumlu Yazar (Corresponding Author)*
*e-posta : mbozdemir@gazi.edu.tr*

consumption of the system increases with the use of a variable speed pump and the energy consumption decreases by about 8% during the heating and cooling season [12]. Verma and Murugesan in the performance of solar assisted ground source heat pump a different mass flow rates were determined for the Indian winter conditions. 0.23, 0.28, and 0.33 kg / s mass flow rate throughout the day in experiments have determined that the COP value reaches the maximum value at low flow rates [13]. Sivasakthivel et al. investigated the soil heat exchanger in a ground source heat pump system as single and double U-tube. The thermal performance analysis of single and double U-tube heat exchangers has been discussed in this paper by focusing on its effectiveness, ground temperatures, heat extraction-injection rate and its effects on surrounding ground formations. The calculations according to the experimental results show that the average efficiency of the single U-tube heat exchanger in the heating and cooling modes is 0.34 and 0.40 respectively, 0.46 and 0.57 for the double U-tube, respectively [14].

In this work, optimization of the process parameters was performed in GSHP systems with the double U tube heat exchanger for space heating applications using Taguchi experimental design method. The obtained results were analyzed using a signal-to-noise (S/N) ratio and ANOVA method to determine the percentage contribution of each parameter on $COP_{SYS}$ in GSHP systems. The main objective of the present study was to optimize the process parameters in the GSHP systems using Taguchi experimental design method.

## 2. MATERIALS AND METHOD

### 2.1 System Descriptions

The main objective of this work is to heat a space by means of the GSHP sytems. A schematic view of the GSHP system is shown in Figs. 1 and 2.

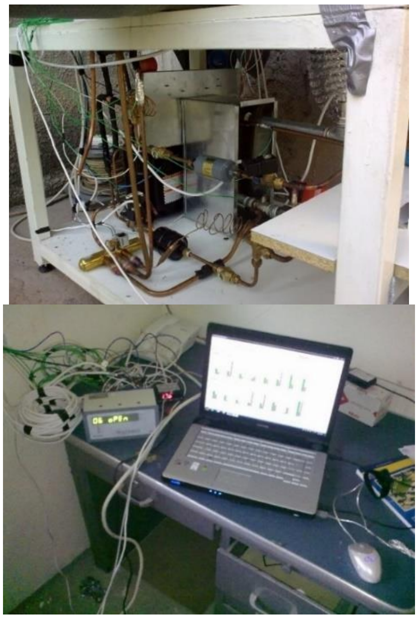

**Figure 2.** General view of the experimental setup used for space heating applications in GSHP

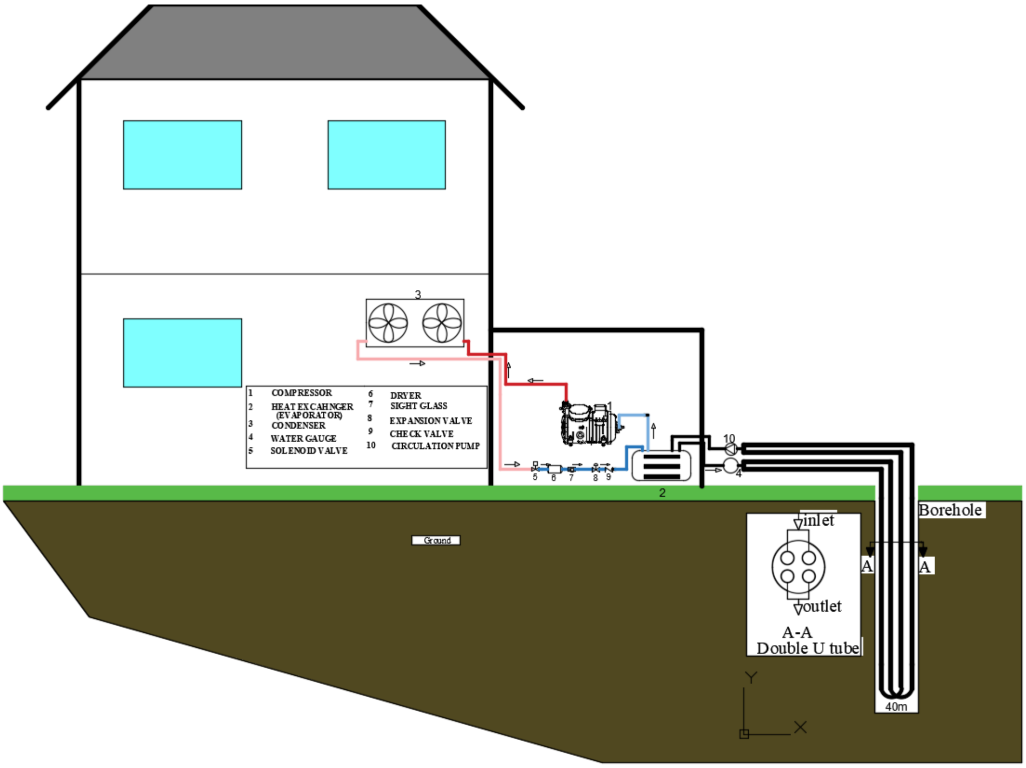

**Figure 1.** Schematic diagram of GSHP for space heating applications

The working fluid was water-antifreeze mixture. In the heating cycle, the water-antifreeze mixture circulated in the soil transfers heat from the soil to the evaporator, after the refrigerant vaporizes in the evaporator. It is compressed by the compressor into the condenser and the refrigerant circulated through the condenser enters the expansion valve after condensing due to heat transfer. After the pressure of the refrigerant is reduced at the expansion valve, the cycle is completed when the refrigerant returns to the evaporator. The air that contacts with the condenser and is blown into the room with the help of a fan, heats the room. The main components of the system and characteristic information are given in Table 1. The air flow rate was determined via a TESTO 435 air speed meter.

**Table 1. Main components and characteristics in GSHP**

| Place: Ankara, Turkey (Latitude 39.56 ºK; Longitude 32.14 ºD | |
|---|---|
| ***Annual average weather information:*** | |
| Average outside temperature | 287.5K |
| Average soil temperature (1 m) | 288.6K |
| ***Cooling ambient information:*** | |
| Volume | 21 m$^3$ |
| Comfort temperature | 293 K |
| ***Heat pump information:*** | |
| Capacity | 1.85 kW |
| Compressor type / power | Hermetic/ 1 HP, 0.736 kW |
| Evaporator type | HS 10; Kontherm |
| Condenser type | AC30-30EQ Plate heat exchanger |
| Condenser fan | 1046 m$^3$/h |
| Refrigerant | R407c |
| ***Soil heat exchanger information:*** | |
| Heat exchanger type | Vertical |
| Double U-tube material | Polythene, SDR-11 |
| Borehole length | 40 m |
| Double U-tube diameter | 32 mm |
| Borehole diameter | 180 mm |
| ***Circulation pump information:*** | |
| Type | Rio-C25-70 |
| Powers | 40,62, 83 W |

## 2.2 Thermodynamic Analysis

The COP$_{sys}$ of the GSHP system for heating applications is calculated by the following equation [11-12]:

$$COP_{sys} = \frac{\dot{Q}_c}{\dot{W}_c + \dot{W}_{ef} + \dot{W}_{cp}} \tag{1}$$

The $\dot{Q}_C$ of the GSHP system is calculated by the following equation:

$$\dot{Q}_C = \dot{m}_a \, c_{p,a} \, (T_{i,sa} - T_{o,sa}) \tag{2}$$

where $\dot{Q}_C$ is an amount of heat transferred from the condenser to the space depending on the air flow rate passing through the fan on the condenser and the inlet and outlet temperatures of the air to the condenser. The amount of heat transferred to the soil by the mixture of water and antifreeze circulated in the soil heat exchanger is calculated by Eq. 3 [11-12].

$$\dot{Q}_{SHE} = \dot{m}_{wa} \, c_{p,wa} \, (T_{o,wa} - T_{i,wa}) \tag{3}$$

Table 2. **Uncertainty of measurement devices in GSHP**

| Uncertainty types (W) | Uncertainty of measurement and calculation |
|---|---|
| Mass flow ($\dot{m}_a$) | ±2x10$^{-5}$ kg s$^{-1}$ |
| Space air outlet temperatures ($T_{o,sa}$) | ±0.1 °C |
| Space air inlet temperatures ($T_{i,sa}$) | ±0.1 °C |
| Specific heat ($c_{p,a}$) | ±0.01 kJ kg$^{-1}$°C$^{-1}$ |
| Total energy consumption ($W_T$) | ±0.01 kW |
| The performance of system ($COP_{SYS}$) | ±2.146 % kW |

### 2.3. Uncertainty Analysis

In experimental studies, the accuracy of measurement data is as important as experimental results. The measurement devices used in the experiments have measurement sensitivities. During measurement, the uncertainties due to the measurement sensitivities of the devices must be calculated. In this study, sensitivity and uncertainty of measurement devices uncertainties were given Table 2. The uncertainty was performed using the following equation [13-14]:

$$W = \left[(x_1)^2 + (x_2)^2 + .......... + (x_n)^2\right]^{1/2} \qquad (4)$$

## 3. EXPERIMENTAL DESIGN AND OPTIMIZATION

In this paper, the effects of the air inlet/outlet temperatures and soil inlet/outlet temperatures of $COP_{sys}$ in GSHP systems were performed. The full factorial experimental test was designed for the four factors and levels with as L16 orthogonal array as shown in Table 3 and Table 4. The control factors and their corresponding levels were given as shown in Table 3.

**Table 3.** Assignment of the levels to the factors in GSHP

| Symbol | Process Parameter | Levels | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| A | $T_{i, sa}$ | 26 | 28 | 30 | 32 |
| B | $T_{o, sa}$ | 17 | 19 | 21 | 23 |
| C | $T_{o, wa}$ | 9 | 9.5 | 10 | 10.5 |
| D | $T_{i, wa}$ | 6 | 6.5 | 7 | 7.5 |

**Table 4.** Experimental design using L16 orthogonal array in GSHP

| Experiment no. | A | B | C | D |
|---|---|---|---|---|
| **1** | 1 | 1 | 1 | 1 |
| **2** | 1 | 2 | 2 | 2 |
| **3** | 1 | 3 | 3 | 3 |
| **4** | 1 | 4 | 4 | 4 |
| **5** | 2 | 1 | 2 | 3 |
| **6** | 2 | 2 | 1 | 4 |
| **7** | 2 | 3 | 4 | 1 |
| **8** | 2 | 4 | 3 | 2 |
| **9** | 3 | 1 | 3 | 4 |
| **10** | 3 | 2 | 4 | 3 |
| **11** | 3 | 3 | 1 | 2 |
| **12** | 3 | 4 | 2 | 1 |
| **13** | 4 | 1 | 4 | 2 |
| **14** | 4 | 2 | 3 | 1 |
| **15** | 4 | 3 | 2 | 4 |
| **16** | 4 | 4 | 1 | 3 |

The factor and levels for $COP_{sys}$ for heating applications in GSHP systems were considered as $T_{i,sa}$, $T_{o,sa}$, $T_{i,wa}$ and $T_{o,wa}$. The main of the optimization was decreased test time and cost. Therefore, Taguchi design proposed and performed to investigate the full parameter with a small number of experimental tests in order to decrease the experimental tests. The Taguchi method provided a simple, efficient and systematic approach to specifying the optimum process in GSHP systems. The experimental design can determined the effect of the control factor in GSHP systems. The design can be provided of determining the optimal process conditions of highest $COP_{sys}$ in GSHP systems for heating system [15-21]. The test results were evaluated with a signal-to-noise (S/N) ratio to evaluate of quality characteristics with desired values. The quality characteristics in S/N ratio were debated with three categories, i.e. the lower the better, the higher the better, and the nominal the better. This study aimed to optimize the best $COP_{sys}$ in GSHP systems. Therefore, a higher- the-better has been performed to measure the S/N ratio. The-higher-the-better quality formula used for calculating S/N ratio was given below [16, 17-20]:

$$\eta = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \qquad (5)$$

where $\eta$ is the S/N ratio for the higher-the-better case (unit: dB), and yi represents the COP in GSHP systems obtained from the experimental results and n the number of repetitions in a trial [16, 17-21]. The S/N ratios were presented in Table 5.

Also, ANOVA analysis was performed to determine of the effect the design process on quality characteristic [16, 18-21]. The ANOVA analysis can be determined the most significant factors in GSHP system. The COPsys values for space heating applications were evaluated by ANOVA analysis. The percent contribution ratios (PCR) were compute by ANOVA analysis. The PCR for COP values for space heating applications can be indicated the degree of influence of the process parameter in GSHP system. The PCR formula was given below [16-20]:

$$PCR = \left(\frac{SS_A - (V_e).(\upsilon_A)}{SS_T}\right)\times 100 \qquad (6)$$

where $SS_A$ is the sum of squares for parameter A, $V_e$ is the variance of error, $\upsilon_A$ is the degrees of freedom of parameter A, and $SS_T$ is the total sum of squares [16-22].

**Table 5.** Experimental results and S/N ratio, (η), for COP$_{SYS}$ of space heating system in GSHP

| **Experiment no.** | **A (ºC )** | **B (ºC)** | **C (ºC )** | **D (ºC)** | **COP$_{sys}$ Measured** | **COP$_{sys}$ S/N (dB)** |
|---|---|---|---|---|---|---|
| **1** | 26 | 17 | 9 | 6 | 2,95306 | 9,4054 |
| **2** | 26 | 19 | 9,5 | 6,5 | 2,34127 | 7,3890 |
| **3** | 26 | 21 | 10 | 7 | 1,72948 | 4,7583 |
| **4** | 26 | 23 | 10,5 | 7,5 | 1,31769 | 2,3962 |
| **5** | 28 | 17 | 9,5 | 7 | 3,56485 | 11,0408 |
| **6** | 28 | 19 | 9 | 7,5 | 2,95306 | 9,4054 |
| **7** | 28 | 21 | 10,5 | 6 | 2,34127 | 7,3890 |
| **8** | 28 | 23 | 10 | 6,5 | 1,72948 | 4,7583 |
| **9** | 30 | 17 | 10 | 7,5 | 4,17664 | 12,4165 |
| **10** | 30 | 19 | 10,5 | 7 | 3,56485 | 11,0408 |
| **11** | 30 | 21 | 9 | 6,5 | 2,95306 | 9,4054 |
| **12** | 30 | 23 | 9,5 | 6 | 2,34127 | 7,3890 |
| **13** | 32 | 17 | 10,5 | 6,5 | 4,58844 | 13,2333 |
| **14** | 32 | 19 | 10 | 6 | 4,17664 | 12,4165 |
| **15** | 32 | 21 | 9,5 | 7,5 | 3,56485 | 11,0408 |
| **16** | 32 | 23 | 9 | 7 | 2,95306 | 9,4054 |

## 4. RESULTS AND DISCUSSION

### 4.1. Experimental Results

In this study, the characteristics properties of GSHP located in Ankara, Turkey were investigated. The tests for space heating applications in GSHP were conducted between January and February of 2016 winter season. To determine of the COP$_{sys}$ in GSHP, the T$_{i,sa}$, T$_{o,sa}$, T$_{i,wa}$ and T$_{o,wa}$ values were continuously obtained during experimental periods of the ambient conditions. The obtained temperature values of GSHP were presented in Fig. 3.

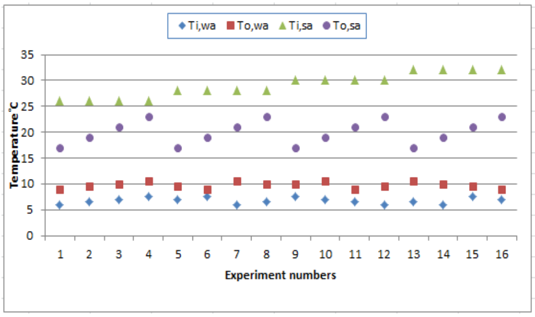

Figure 3. The temperature variations corresponding experimental measurements in GSHP

The most important parameter in GSHP system was found as average of $T_{i,wa}$ and $T_{o,wa}$ temperatures. The average of $T_{i,wa}$ and $T_{o,wa}$ temperatures were measured as 6.75 °C and 9.75 °C respectively. On the other hand, the average of $T_{i,sa}$ and $T_{o,sa}$ was obtained as 29 °C and 20 °C for space heating applications in GSHP. The best COP$_{sys}$ value in GSHP system was obtained that the $T_{i,sa}$ and $T_{o,sa}$ temperatures were 17 ºC and 32 º C. The COP$_{SYS}$, soil temperature T$_{s,40m}$, and ambient air temperature T$_e$ change obtained from experimental tests were given as shown in Fig. 4.

At a depth of 40 meters (T$_{s,40m}$), the temperature is measured at between 11 ºC and 12 ºC the experimental tests were determined as 2.95, 1.45 and 11.37 ºC, respectively. As investigated in Fig 4., the COP$_{sys}$ value in GSHP system was obtained as between 4.58 and 1.36 values.. The average COP$_{sys}$ value, environmental temperature and temperature of the soil of the GSHP system during

### 4.2.Optimization Results

The results of COP$_{sys}$ for space heating applications in GSHP system of each test were presented in Table 6. The test results were converted into S/N ratio using Eq. (5). The S/N ratio was given in Tables 5 for all responses. The main effect for mean and S/N ratio was illustrated in Figs. 5. The effect of process parameters on COP$_{sys}$ for space heating applications in GSHP system was presented as shown in Table 6 and Fig. 5. It can be seen that the optimum values corresponds to process parameters were given as peak point as shown in Fig. 5.

The optimum process parameters and levels on the $COP_{sys}$ for space heating applications of GSHP system was found to be $A_4B_1C_1D_1$ as shown in Table 6. The optimum process parameters on the $COP_{sys}$ for space heating applications of GSHP system were computed as the $T_{i,sa}$ at Level 1 (32 °C), the $T_{o,sa}$ at Level 2 (17°C), the $T_{i,wa}$at Level 2 (6°C) and and the $T_{o,wa}$at Level 1

(9°C). The improvement in S/Nratio from the initial process parameters to the level of optimal process parameters was 6.6199 dB.

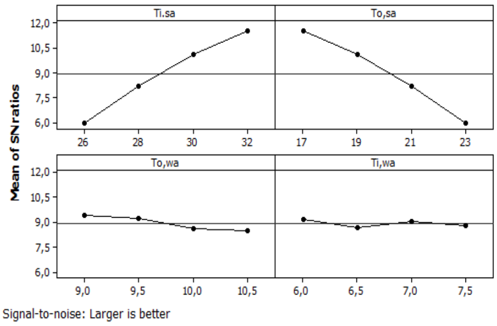

**Figure 5.** Mean S/N ratio graph for $COP_{sys}$ for space heating applications in GSHP

**Table 6.** Results of confirmation tests for $COP_{sys}$ in GSHP

| | Initial process parameters | Optimal process parameters | |
|---|---|---|---|
| | | Prediction | Experimental |
| Level | $A_2B_3C_2D_4$ | $A_4B_1C_1D_1$ | $A_4B_1C_1D_1$ |
| $COP_{sys}$ | 2.14127 | 4.68844 | 4.58843 |
| S/N ratio (dB) | 6.6134 | 14.8115 | 13.2333 |
| Improvement of S/N ratio | 6.6199 dB (100%) | | |
| Prediction error (dB) | 1.5782 | | |
| Improvement of S/N ratio for COP = 6.6199 dB (50.75%). | | | |

The degree of importance of each process parameter was determined using Eq. (6) for $T_{i,sa}$, $T_{o,sa}$, $T_{i,wa}$ and $T_{o,wa}$ corresponding each response. The PCR on the $COP_{sys}$ for space heating applications of GSHP system was given in Tables 8. It can be observed from Table 8 that $T_{i,sa}$ and $T_{o,s\ a}$have the greatest influence on the $COP_{sys}$ for space heating applications of GSHP system followed by $T_{o,wa}$ . The contributions process parameters, PCR, on the $COP_{sys}$ for space heating of GSHP system were computed as Level A (48.40 %), Level B (48.40 %), Levels C (1.31 %) and D (<0.01 %). In addition, the residual error derived from ANOVA results for $COP_{sys}$ for space heating of GSHP system was calculated as 1.88 % as presented in Table 7.

**Table 7.** Results of ANOVA for $COP_{sys}$ in GSHP

| Source | DoF | SS | MS | F-test | P-coefficient | PCR (%) |
|---|---|---|---|---|---|---|
| A | 3 | 69.133 | 23.0443 | 129.51 | 0.001 | 48.40 |
| B | 3 | 69.133 | 23.0443 | 129.51 | 0.001 | 48.40 |
| C | 3 | 2.388 | 0.7959 | 4.47 | 0.125 | 1.31 |
| D | 3 | 0.534 | 0.1779 | 1.00 | 0.500 | 0.00 |
| Residual error | 3 | 0.534 | 0.1779 | | | 1.88 |
| Total | 15 | 141.721 | | | | 100 |

DoF: Degrees of freedom; SS: Sequential sum of squares; MS: Mean sum of squares

## 5. CONCLUSIONS

This paper presented the optimization of process parameters : in GSHP systems with the double U tube heat exchanger for space heating applications with by using the Taguchi method and ANOVA analysis. The main results drawn from this work were as follows

- The $COP_{sys}$ values for space heating applications of GSHP system were as between 4.58 and 1.31 during experimental measurements.
- $T_{i,sa}$ and $T_{o,sa}$has the greatest influence with 48.4 % on the $COP_{sys}$ for space heating applications of GSHP system followed by $T_{o,wa}$ .
- Quality characteristics depend on parameters and levels combination with by using the *S*/*N* ratio was investigated and derived experimental results. The optimum process parameters for $COP_{sys}$s in GSHP systems were determined to be $A_4B_1C_1D_1$.
- $T_{i,sa}$ at Level 1 (32 °C), the$T_{o,sa}$ at Level 2 (17°C), the $T_{i,wa}$at Level 2 (6°C) and the $T_{o,wa}$at Level 1 (9 °C) with ANOVA techniques for $COP_{sys}$s in GSHP systems were determined the best process parameters conditions.
- The improvement in S/Nratio of $COP_{sys}$s in GSHP from the initial process parameters to the level of optimal process parameters was 6.6199 dB.
- Taguchi experimental design methodwas applied to reduce maximum cost and time. This

method was an efficient and effective method for optimization of $COP_{sys}$s in ground source heat pumps.

## SUBSCRIPTS

| | |
|---|---|
| GSHP | - ground source heat pump |
| SHE | - soil heat exchanger |

## REFERENCES

[1] Ochsner K., Geothermal heat pumps: a guide for planning and installing., 1st ed. London, ***Earthscan Publications Ltd.***, (2007).

[2] Sarbu I., Sebarchievici C., Ground Source Heat Pumps, Fundementals, Experiments and applications, 1st Edition, eBook ISBN: 9780128042410, ***Academic Press***, October (2015).

[3] Omer AM. Ground-source heat pumps systems and applications, ***Renewable Sustainable Energy Review***, 12: 344-371, (2008).

[4] Sivasakthivel T, Murugesan K, Sahoo PK., Potential reduction in CO2 emission and saving in electricity by ground source heat pump system for space heating applications-A study on northern part of India, ***Procedia Engineering***, 38: 970-979, (2012).

[5] Kim E, Lee J, Jeong Y, Hwang Y, Lee S, Park N., Performance evaluation under the actual operating condition of a vertical ground source heat pump system in a school building, ***Energy Build***, 50: 1-6, (2012).

[6] Esen H., Turgut E., Optimization of operating parameters of a ground coupled heat pump system by Taguchi method, ***Energy and Building***, 107: 329–334, (2015).

[7] Ramniwas K., Murugesan K., Sahoo P.K., Optimization of operating parameters of ground source heat pump using Taguchi method, in: ***23rd IIRConference***, Prague, Czech Republic, August 21–26, (2011).

[8] Pandey N., Murugesan K., Thomas H.R., Optimization of ground heat exchangers for space heating and cooling applications using Taguchi method and utility concept, ***Applied Energy*** 190: 421–438, (2017).

[9] Sivasakthivel T, Murugesan K, Thomas HR., Optimization of operating parameters of ground source heat pump system for space heating and cooling by Taguchi method and utility concept, ***Applied Energy***, 116: 76-85, (2014).

[10] V. Verma, K. Murugesan, Optimization of solar assisted ground source heat pump system for space heating application by Taguchi method and utilityconcept, ***Energy and Building***, 82: 296–309, (2014).

[11] Özdemir M. Br, Özkaya Musa Galip, Energy and Exergy Analyses of the Vertical Type Ground-Sourced Heat Pump for Ankara Conditions, ***Gazi University Journal of Polytechnic***, 18(4): 269-280, (2015).

[12] Pingfang Hu, Qiushi Hu, Yaolin Lin, Wei Yang, Lu Xing,Energy and exergy analysis of a ground source heat pump system for a public building in Wuhan, China under different control strategies, ***Energy and Buildings***, 152: 301-312, (2017).

[13] Lei Xia , Zhenjun Ma, Craig McLauchlan , Shugang Wang, Experimental investigation and control optimization of a ground source heat pump system, ***Applied Thermal Engineering***, 127: 70-80, (2017).

[14] VikasVerma, K. Murugesan, Experimental study of solar assisted ground source heat pump system during space heating operation from morning to evening, ***Journal of Mechanical Science and Technology***, 32(1):, 391-398, (2018),.

[15] T. Sivasakthivel, Mikael Philippe , K. Murugesan , VikasVerma, Pingfang Hu, Experimental thermal performance analysis of ground heat exchangers for space heating and cooling applications, ***Renewable Energy***, 113: 1168-1181, (2017).

[16] Bejan A., Advanced engineering thermodynamics. USA: John Wiley and Sons Inc.; (1988).

[17] Çengel A.Y., and Boles M. A., Thermodynamics: An Engineering Approach, New Media Version***, 6th Edition***, Mc Graw Hill, Inc., (2008).

[18] Holman JP. Experimental methods for engineers. 6th ed. Singapore: McGraw-Hill; (1994).

[19] S.J. Kline, F.A. McClintock, Describing uncertainties in single sample experiments, ***Mech. Eng.*** 75: 3–8, (1953).

[20] Taguchi G., ElSayed E. A., and Hsiang T. C., Quality Engineering in Production Systems, McGraw–Hill, New York, NY, USA, (1989).

[21] Ross P.J., Taguchi Techniques for Quality Engineering, 2nd ed., McGraw-Hill, New York, USA, (1996).

[22] Çakıroğlu R., Acır A., Optimization of cutting parameters on drill bit temperature in drilling by Taguchi method, *Measurement*, 46(9): 3525-3531, (2013).

[23] Yang W.H., and Tarng Y.S., Design optimization of cutting parameters for turning operations based on the Taguchi method, ***Journal of Materials Processing Technology*** 84*:* 122–129, (1998).

[24] Acır A., Canlı M.E., Ata I., Çakıroğlu R., Parametric optimization of energy and exergy analyses of a novel solar air heater with grey relational analysis, ***Applied Thermal Engineering***, *122*: 330-338, (2017).

[25] Çakıroğlu, R., Acır A., Taguchi optimization method of tool chip interface temperature depending on the cutting parameters in drilling operations, ***Makine Teknolojileri Elektronik Dergisi*** 10(2): 73-86 (2013).

[26] Baysal E., Bilginsoy A.K., Acır A., Parametric optimization on exergy analysis of a thermal power plant using Taguchi Method, ***Energy Education Science and Technology Part A-Energy Science and Research***, 29(2): 1313-1326, (2012).

[27] Zhang J. Z. et. al., Surface roughness optimization in an end-milling operation using the Taguchi design method, ***Journal of Materials Processing Technology,*** 184: 233-239, (2007).

## NOMENCLATURE

$COP_{SYS}$ - performance of whole system, [-]

$T_{i,sa}$ - space air inlet temperatures, [°C]

$T_{o,sa}$ - space air outlet temperatures, [°C]
$T_{i,wa}$ - soil inlet temperatures, [°C]
$T_{o,wa}$ - soil outlet temperatures, [°C]
$\dot{Q}_c$ - heat transferred from the condenser to the space, [kW]
$\dot{W}_c$ - power of compressor, [kW]
$\dot{W}_{ef}$ - power of fan, [kW]
$\dot{W}_{cp}$ - power of circulation pump, [kW]
$\dot{W}_T$ - total energy consumption, [kW]
$\dot{m}_a$ -air flow rate, [kg $s^{-1}$]
$\dot{Q}_{SHE}$ -heat transferred from the condenser to the soil, [kW]
$\dot{m}_{wa}$ -flow rate of mixture of water and antifreeze, [kg $s^{-1}$]
$c_{p,a}$ -specific heat of the air, [kj $kg^{-1}$ $°C^{-1}$]
S/N -signal-to-noise, [-]
$\eta$ - S/N ratio, [-]
$c_{p,wa}$ -specific heat of mixture of water and antifreeze, [kj $kg^{-1}$ $°C^{-1}$]

PCR - percent contribution ratio, [-]

$SS_A$ - sum of squares, [-]

$SS_T$ - total sum of squares, [-]

$V_e$ - variance of error, [-]

$\upsilon_A$ is the degrees of freedom, [-]