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ARTICLE

Using the Taguchi Method and Grey Relational Analysis to Optimize the Performance of a Solar Air Heater

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ABSTRACT

Solar energy is regarded as one of the promising renewable energy sources in the world.The main aim of this study is to use the Taguchi-Grey relational grade analysis to optimize the performance of two Solar Air Heaters (SAHs). A typical Grey–Taguchi method was applied. The Orthogonal Array, Signal-to-Noise ratio, Grey Relational Grade, and Analysis of Variance were employed to investigate the performance characteristics of SAH. Experimental observations were made in agreement with Jordanian climate 32°00′ N latitude and 36°00′ E longitude with a solar intensity of 500 W\m^2. The operating factors selected for optimization are the tilt angle (T) with three levels (0°, 22°, 45°), inlet velocity (V) with two levels (1.2, 1.8 m/s), and absorber plate material (M) with two levels (Aluminum, wood). In this study, the Grey–Taguchi approach is validated by performing 12 individual experiments. The results show that the process factors sequence required for a maximum SAH efficiency (SAH μ) is V > T > M. Using this approach, we combined the Orthogonal Array design with Grey Relational Analysis. As a result of that, the level of each operating conditions which optimizes both process responses (Temperature difference, ΔT and Solar air heater efficiency, SAH μ) can be specified with a minimum number of tests compared with classic Grey Relational Analysis. The optimal operating conditions of a SAH for multiple performance characteristics are determined as T2, M2, and V2, respectively, which are in congruence with the experimental results.

KEYWORDS

Solar air heater; collector efficiency; thermal efficiency; grey-taguchi method; robust design

Nomenclature

ΔT:	Temperature difference (°C)
yj(k):	Value of process response *k* at replication$_j$
Xj(k):	Normalized value of each process response
$\xi_i(k)$:	Grey relational coefficient
$\Delta_{oj}(k)$:	Absolute value difference between $x_o(k)$ and xj(k)
$x_o(k)$:	Reference value
m:	Mass flow rate of air (kg/s)

Abbreviations

SAH:	Solar Air Heater
CFD:	Computational Fluid Dynamics
THC-VGs:	Truncated Half Conical Vortex Generators
GRA:	Grey Relational Analysis
Re:	Reynolds number
p/e:	Pitch ratio
Nu:	Nusselt number
TEF:	Thermal Enhancement Factor
FEF:	Friction Factor Enhancement Factor
THPP:	Thermohydraulic performance parameter
DOE:	Design of Experiment science
f:	Friction factor
OA:	Orthogonal Array
S/N:	Signal-to-Noise ratio
SAHμ:	Solar Air Heater efficiency (%)
T:	Tilt angle (o)
M:	Material of solar plate
V:	The Inlet air velocity (m/s)
DOF:	Degree of Freedom
N:	Number of replications in each experiment
Cp:	Specific heat of air at constant pressure (kJ/kg.K)
A:	Surface area of the SAH (m^2)
I:	Irradiance (W/m^2)
Ac:	Constant cross section area of air outlet (m^2)

Greek Symbols

α:	Angle of attack (o)
Ψ:	Distinguishing coefficient in the range $0 \leq \psi \leq 1$
γ_{j}:	Grey rational grade of experiment j
ρ:	Air density (kg/m^3)

1 Introduction

Solar Air Heater (SAH) performance depends on many factors such as; collector orientation, thickness of cover materials, wind velocity, collector length, collector depth, and type of the used absorber material, etc. [1]. A wide range of research have been devoted to improving the SAHs' performance. Some studies like [2,3] have attempted to improve the heat transfer rate by incorporating fins on absorbers plate. Several researchers [4] tried to provide roughness on the absorbing plate. Furthermore, many novel techniques such as; heat storage [5], jet impingement [6], and use of Nanofluids have been employed to improve heat transfer in different devices, including SAH [7,8].

Different optimization techniques have been used to pinpoint the proper geometric configuration for enhancing the performance factors that affect heat transfer [9,10]. Jawad et al. [11] carried out research with the goal of enhancing the performance of a SAH by adding tubes from aluminum chips, paraffin wax, and nano-SiC which have been fixed on the absorption plate of the SAH. This study was conducted according to the weather conditions of Baghdad in winter. It was found that the new composite material's thermal conductivity increased by 18.2% when 3 wt.% of nano-Sic was added. Also, the heat capacity of the new composite decreased by 4.5% although the effect on the SAH performance did not change. The sustainability of the proposed SAH was proven by improving the performance and accelerating the heating rate. The tested SAH hit high heating degrees and went on to operate for not less than 3 h after sunset. Bensaci et al. [12] had developed a numerical and experimental study to improve the thermal and hydraulic performance of SAH by changing the baffle position inside the air channel. The numerical study investigated four cases corresponding to the different placement of baffles, regulating devices, with Reynolds numbers extending from 2370–8340. It was found that the right placement of baffles pointedly increases the thermo-hydraulic functioning of SAHs. The optimum value was obtained when the baffles were fixed in the first part of the air channel which occupies 50% of the SAH. Zhu et al. [13] carried out numerical optimization research on micro-heat pipe arrays based SAH.A3D computational fluid dynamics modeling (CFD) based on the physical heat transfer process in the SAH was introduced in this study. Airflow, how thick the air is, ambient temperature, air duct aspect ratio, and fins geometrical parameters were the process factors that were used in the optimizing the efficiency of the system and the thermal-hydraulic performance of airflow. This model was verified experimentally. It was found that the optimal operating conditions of the air heater are: an inlet velocity of the air heater with 3.3 m/s, the air layer thickness of 25 mm. The results also showed that the values investigated in the paper, including the optimal aspect ratio, the height of the fin, and the spacing of the fin are 0.25, 12, and 6 mm, respectively. Bezbaruah et al. [14] came up with a numerical study based on enhancing the thermohydraulic functioning of a SAH by adding truncated Half Conical Vortex Generators (THC-VGs) on the absorber plate. Grey Relational analysis (GRA) was used to specify the optimal configuration for the applicable range of Reynolds numbers (Re 3500–16000). The THC-VGs were adjusted at different relative pitch ratio (p/e) ranging from 2.67–6.67 while the angle of attack (α) lies between 0°–90°. Results were examined by calculating different process parameters such as; Nusselt number (Nu), Thermal Enhancement Factor (TEF), Friction factor (f), Friction Factor Enhancement Factor (FEF), and Thermohydraulic performance parameter (THPP). The results revealed a better thermal impact when VGs are placed at a 60° angle of attack. Also, it was noted that the highest percentage betterment was 187% in Nu for $\alpha = 60°$. Jeffrey et al. [15] had applied the Taguchi method, GRA, and analysis of variance (ANOVA) to optimize the performance of a flat-plate collector. The process factors which were considered in this work include the material of the collector tube, endothermic plate material, the diameter of the tube, the number of collector tubes, and the type of the absorption film. Heat dissipation factor and efficiency coefficient were the response variables that were measured in this paper. The findings divulge that the mean values of heat dissipation and the efficiency coefficient dropped within a 95% confidence interval. Also, it was noticed that the absorber film type has a remarkable effect on the process responses.

The key goal of the current work is to use the Taguchi-Grey relational grade analysis to optimize the performance of two SAHs that were experimentally tested by Al Khalil et al. [16]. In the current study, we use the Taguchi–Grey method to detect the maximum setup to perform a strong statistical analysis of a SAH concerning the Jordanian climate. The operating factors selected for optimization include tilt angle with three levels (0°, 22°, 45°), inlet velocity with two levels (1.2, 1.8 m/s), and two different absorber plate (Aluminum, wood). The absorber plate of the first SAH was made of black painted wood, whereas the second one was made of the black painted Aluminum sheet.

2 Performed Experimental Research

Two SAHs were constructed of 1.0 m^2 of black painted aluminum sheet and wood absorber plate. These two configurations were covered with a glass plate of 5 mm thickness. The components of each SAH are shown in Fig. 1:

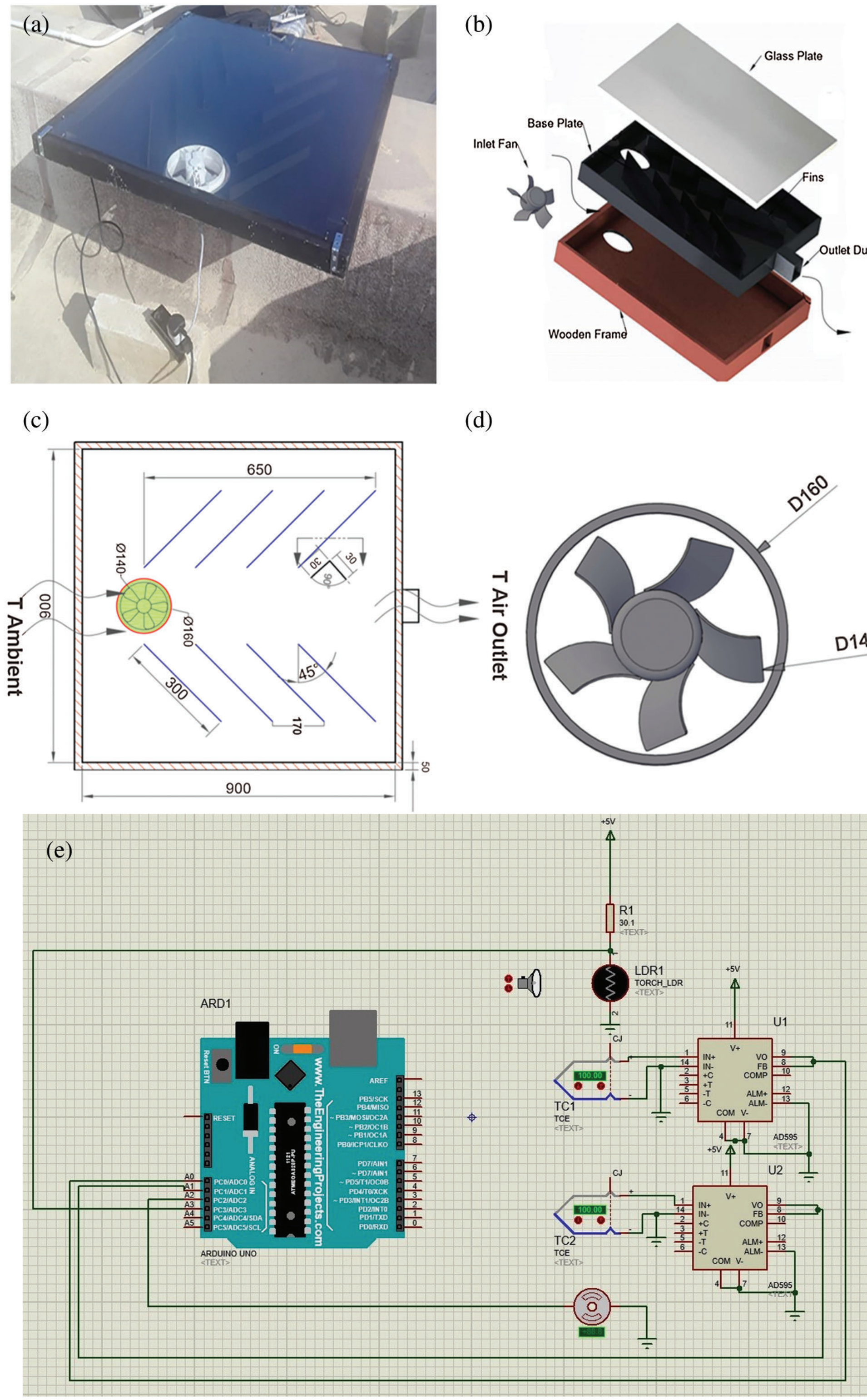

Figure 1: a) Experimental setup components, b) Solar collector components, c) Schematic illustration of SAH, d) Inlet fan cover, and e) Arduino controller

a) SAH which is used to heat the atmospheric air which is introduced and flows inside the heater, and it is to leave the heater at a higher temperature.
b) Variable speed fan is used to introduce the atmospheric air into the heater at variable velocity; hence, there is a variable mass flow rate.
c) Arduino Controller from which the digital values of air velocity within each heater are obtained.
d) The inlet and outlet air temperature is measured by copper constantan thermocouples.

A metrological station was used to measure the metrological data (solar intensity and ambient temperature). For each stated air velocity at the inner space of the collector and after steady-state is reached (that is indicated for a constant air inlet and outlet air temperatures). The tilt angle was modified at different steps ranging from 15°–50° with 5° interval. This was repeated several times to determine the optimum tilt angle that gives the maximum increase in air temperature inside the collector. This procedure was repeated several times with different air velocities. Additional experiments were conducted to determine the optimal tilt angle during summer (22°) and winter (45°). Also, in order to a void shading effect, it was recommended to use 0° tilt angle.

3 Results and Discussion

3.1 Optimization Using Grey–Taguchi

In the present study, the Taguchi technique and the GRA are employed to maximize the performance of a SAH. The Taguchi method is an analytical technique that belongs to Design of Experiment science (DOE). Taguchi method is used to reduce the number of tests that are necessary to measure the effects of different levels for certain control factors on a specified process response individually. Each test consists of one level of each control factor being used. The experimental design proposed by Taguchi involves an Orthogonal Array (OA) that organizes different parameters known to affect the process response and the levels at which they should be varied. The effect on process response is obtained by performing each experiment several times, followed by converting the results to Signal to Noise (S/N). According to this approach, experiments with the maximum S/N values represent the best levels of control factors [17,18]. Tab. 1 shows the control factors with the specified levels which are tested to optimize the performance of a SAH.

Table 1: The levels of control factors tested in designing a SAH

Control factors	Number of levels	Levels	
Inlet air velocity	2	1.2 m/s 1.8 m/s	(V1)
			(V2)
Absorber plate material	2	Aluminum wood	(M1)
			(M2)
Tilt angle	3	0°	(T1)
		22°	(T2)
		45°	(T3)

The temperature difference (ΔT) and Solar Air Heater efficiency (SAHμ) are the two process responses that are considered in the current study. As it is stated in the Taguchi method, one degree of freedom (DOF) is regarded for each of the two control factors with two levels (Inlet air velocity, Absorber Plate Material respectively) and two DOFs are considered for the control factor with three levels (Tilt angle). The total DOF for the Taguchi method is (1 + 1 + 2) + 1 = 5. Therefore, the Taguchi design of a SAH must have at least 5 rows. Taguchi OA with L_{12} is employed in the experimental layout Tab. 2. The notation for this mixed OA is L_{12} ($2^2 \times 3^1$). All tests were performed by the following same environmental conditions, and each test was repeated 5 times. The average of each process response collected values (SAH μ, ΔT) was computed and listed in Tab. 3. For each experiment, Eq. (1) is employed to find the S/N ratio for the larger, the better process response is [19].

$$(S/N)L = -10\log\frac{1}{n}\sum_{j=1}^{n}\frac{1}{\left[y_j(k)\right]^2} \tag{1}$$

where n is the number of experimental measurements and yj(k) is the average measured value of process response k at replication j.

Table 2: Control factors and their combination in the L_{12} OA

Experiment	Factor level		
1	T1	M2	V1
2	T2	M2	V2
3	T3	M2	V1
4	T2	M1	V1
5	T1	M2	V2
6	T2	M1	V2
7	T1	M1	V1
8	T3	M1	V1
9	T1	M1	V2
10	T3	M2	V2
11	T3	M1	V2
12	T2	M2	V1

In this study of the SAH, the number of replications in all tests was set to be 1. Tab. 3 shows the average value of the response variables and the corresponding S/N ratios for all 12 experiments being carried out randomly. After that, the marginal average of ratios for each level of the control factors belonging to each process response values was found and listed in Tab. 4.

Since we have more than one process response (ΔT, μ), the Taguchi approach cannot figure out the overall optimum conditions, so GRA is employed to select the best level of each control factor. By using the GRA, the observations of process response are combined into a single value called the GRG. After applying this concept, the experiment with the uppermost GRG has the best levels of the control factors. In this research, the OA which was used for the Taguchi design is applied in GRA to reduce the number of tests compared with classic GRA. The grey relation grades, which we got by the QA, were computed depending on the designated tests. After that, the GRGs were converted to S/N ratios. The technique of the Grey–Taguchi is illustrated in the following steps:

Table 3: S/N values and the process response for the Taguchi design of the SAH

Exp. No.	Factor level			ΔT			SAH efficiency μ		
	T	M	V	Response1	Avg.	S/N	Response 2	Avg.	S/N
1	T1	M2	V1	22	23.52	27.429	49.6	53.08	34.499
				22.5			50.8		
				23.1			52.2		
				24.3			54.8		
				25.7			58		
2	T2	M2	V2	24.1	26.12	28.339	80	88.04	38.894
				25			84.6		
				26			88		
				27.5			93		
				28			94.6		
3	T3	M2	V1	26.6	28.68	29.152	60	65.34	36.304
				27.7			62.4		
				29.3			66.1		
				29.8			67.2		
				30			71		
4	T2	M1	V1	23.1	25.12	28.000	43	49.08	33.818
				24			45.8		
				25			47.4		
				26.5			51.8		
				27			57.4		
5	T1	M2	V2	22	23.52	27.429	75	79.4	37.997
				22.5			76		
				23.1			78		
				24.3			82		
				25.7			86		
6	T2	M1	V2	23.1	25.12	28.000	73	81.04	38.174
				24			77.6		
				25			81		
				26.5			86		
				27			87.6		
7	T1	M1	V1	21	22.52	27.051	41.2	44.84	33.033
				21.5			44.2		
				22.1			44.6		
				23.3			45.6		
				24.7			48.6		

(Continued)

Table 3 (continued)

Exp. No.	Factor level			ΔT			SAH efficiency μ		
	T	M	V	Response1	Avg.	S/N	Response 2	Avg.	S/N
8	T3	M1	V1	25.6	27.68	28.843	46.2	56.96	35.111
				26.7			50.2		
				28.3			55.6		
				28.8			63.4		
				29			69.4		
9	T1	M1	V2	21	22.52	27.051	70	74.4	37.431
				21.5			71		
				22.1			73		
				23.3			77		
				24.7			81		
10	T3	M2	V2	26.6	28.68	29.152	63	68.46	36.709
				27.7			66		
				29.3			70		
				29.8			71		
				30			72.3		
11	T3	M1	V2	25.6	27.68	28.843	56	61.46	35.772
				26.7			59		
				28.3			63		
				28.8			64		
				29			65.3		
12	T2	M2	V1	24.1	26.12	28.339	54.4	58.92	35.405
				25			56.4		
				26			58.6		
				27.5			62		
				28			63.2		

Table 4: Average of the S/N ratios for each level of the control factors of each process response

Process response	Factor level			Max-Min	
	1	2	3		
ΔT	T	27.24	28.17	28.998	1.758
	M	27.965	28.307	-	0.342
	V	28.136	28.136	-	0
SAH μ	T	34.695	36.573	35.974	1.878
	M	35.557	35.938	-	0.381
	V	34.695	36.8	-	2.105

a) The value of each process response is linearly normalized in the range between zero and unity using Eq. (2).

$$X_i(k) = \frac{y_i(k) - min_j\{y_j(k)\}}{max_j\{y_j(k)\} - min_j\{y_j(k)\}} \tag{2}$$

∀j, k|k ∈ (the larger, the better the process responses).

b) For each response factor, the Grey relational coefficient $\xi_j(k)$ is calculated by Eq. (3).

$$\xi_j(k) = \frac{\Delta min + \Psi\Delta \max}{\Delta_{oj}k + \Psi\Delta \max}\forall_j, k, \tag{3}$$

where $\Delta_{oj}(k)$ is the deviation sequence = difference of the absolute value between $x_o(k)$ and Xj(k), the $x_o(k)$ is a reference value, it can be defined as the best-normalized value of process response k among all its experiments signifying that $x_o(k)$ = maxj{xj(k)}, and Δmin and Δmaxl are calculated as minj mink{Δ_oj} and maxj maxk{Δ_oj}, respectively. While ψ is a distinguishing coefficient which is defined in the range of 0 ≤ ψ ≤ 1, this value may be attuned depending on the application. In this work, the value ψ is = 0.5.

c) GRG of each experiment is found by Eq. (4).

$$\gamma i_j = \frac{1}{n}\sum_{k=1}^{n} \xi_j(k)\forall_j \tag{4}$$

where γj is the grey rational grade of experiment j.

For every test, the S/N ratio is computed from its GRG using the same equation (Eq. (1)) which is used for the Taguchi method. Thus, the average S/N ratio for all the levels of controlling factors or from S/N ratios of the grey relation grade is calculated. All the findings for the Grey–Taguchi design of the SAH, which were obtained from Steps (a)–(d), are listed in Tab. 5. Also, the marginal average of S/N ratios for the different levels of each control factor is shown in Tab. 6.

Table 5: The GRGs for the SAH

Exp. No.	Factor level			ΔT				Efficiency μ				γ_j	S/N
	T	M	V	$y_j(k)$	$X_j(k)$	$\Delta_{0j}(k)$	ξ_j (k)	$y_j(k)$	$y_j(k)$	$\Delta_{0j}(k)$	$\xi_j(k)$		
1	T1	M2	V1	23.52	0.162	0.838	0.374	53.08	0.191	0.809	0.382	0.378	−8.454
2	T2	M2	V2	26.12	0.584	0.416	0.546	88.04	1.000	0.000	1.000	0.773	−2.236
3	T3	M2	V1	28.68	1.000	0.000	1.000	65.34	0.475	0.525	0.488	0.744	−2.571
4	T2	M1	V1	25.12	0.422	0.578	0.464	49.08	0.098	0.902	0.357	0.410	−7.739
5	T1	M2	V2	23.52	0.162	0.838	0.374	79.4	0.800	0.200	0.714	0.544	−5.287
6	T2	M1	V2	25.12	0.422	0.578	0.464	81.04	0.838	0.162	0.755	0.610	−4.300
7	T1	M1	V1	22.52	0.000	1.000	0.333	44.84	0.000	1.000	0.333	0.333	−9.542
8	T3	M1	V1	27.68	0.838	0.162	0.755	56.96	0.281	0.719	0.410	0.582	−4.695
9	T1	M1	V2	22.52	0.000	1.000	0.333	74.4	0.684	0.316	0.613	0.473	−6.500
10	T3	M2	V2	28.68	1.000	0.000	1.000	68.46	0.547	0.453	0.525	0.762	−2.358
11	T3	M1	V2	27.68	0.838	0.162	0.755	61.46	0.385	0.615	0.448	0.602	−4.414
12	T2	M2	V1	26.12	0.584	0.416	0.546	58.92	0.326	0.674	0.426	0.486	−6.268

Table 6: Average of the S/N ratios for each level of the control factors for the GRG

Process response		Factor level			Max-Min
		1	2	3	
Grey rational grade	T	−7.446	−5.136	−3.509	3.937
	M	−6.198	−4.529	–	1.669
	V	−6.545	−4.183	–	2.362

3.2 Analysis of Results

To optimize the performance of a SAH, the results in Tabs. 1–6 were analyzed to get the most effective control factor and the best level of each control factor. This analysis was performed for each process response (ΔT, SAH μ, and GRG). The GRG, a combination of ΔT and SAH μ.S/N ratios, were analyzed by using two different methods to specify the most effective factor.

The first method, the dissimilarity between the highest and lowest marginal means of the levels of each factor was calculated and listed in Tab. 4 (concerning ΔT and SAH μ). A similar way was also used for the GRG and results which are listed in Tab. 6. The most effective factor in designing a SAH is considered when the difference between max and min is the highest value. Based on the above-mentioned sentence and based on the obtained results of both ΔT and SAHμ together (as shown below), the most effective factor is the tilt angle (T):

- Based upon the ΔT control factor, the most effective factor is the tilt angle (T).
- Based upon SAH μ, the most effective factor is the Inlet air velocity (V).

The second method, ANOVA is utilized to decide the most effective factor in designing a SAH. ANOVA is performed on S/N ratios of the Taguchi and Grey–Taguchi designs for each factor which is mentioned in Tabs. 3 and 5. According to the results listed in Tab. 7 below, the control factor with the highest contribution is chosen as the most effective factor. Based on ANOVA results which consider each control factor, the most contributing control factor is the same as what we have got by the first technique as it is stated above.

Table 7: The ANOVA results calculated based on Tabs. 3 and 5 values

Factor	Degree of freedom (DoF)	Adjusted sum of squares (Adj SS)	Adjusted mean square (Adj MS)	*P*-Value
ΔT				
T	2	6.18448	3.09224	0.000
M	1	0.35089	0.35089	0.000
V	1	0.00000	0.00000	1.000
SAH μ				
T	2	1.475	0.7375	0.558
M	1	3.484	3.4841	0.127
V	1	23.548	23.5480	0.003
GRG				
T	2	31.300	15.650	0.003
M	1	8.360	8.360	0.026
V	1	16.742	16.742	0.005

To determine the perfect level of each controlling factor, the marginal S/N ratios were being calculated for ΔT, SAH μ making use of the GRG. According to these S/N ratio values, the level with the uppermost S/N ratio is the most effective. The marginal S/N ratios were independently represented for all levels of the control factors in Fig. 2 where Fig. 2a presents the marginal S/N ratio for all levels of the factors when ΔT is considered, Fig. 2b presents the marginal S/N ratio for all levels of the factors when SAH μ is regarded, and Fig. 2c illustrates the marginal S/N ratio for all levels of the factors combining both ΔT and SAH μ.

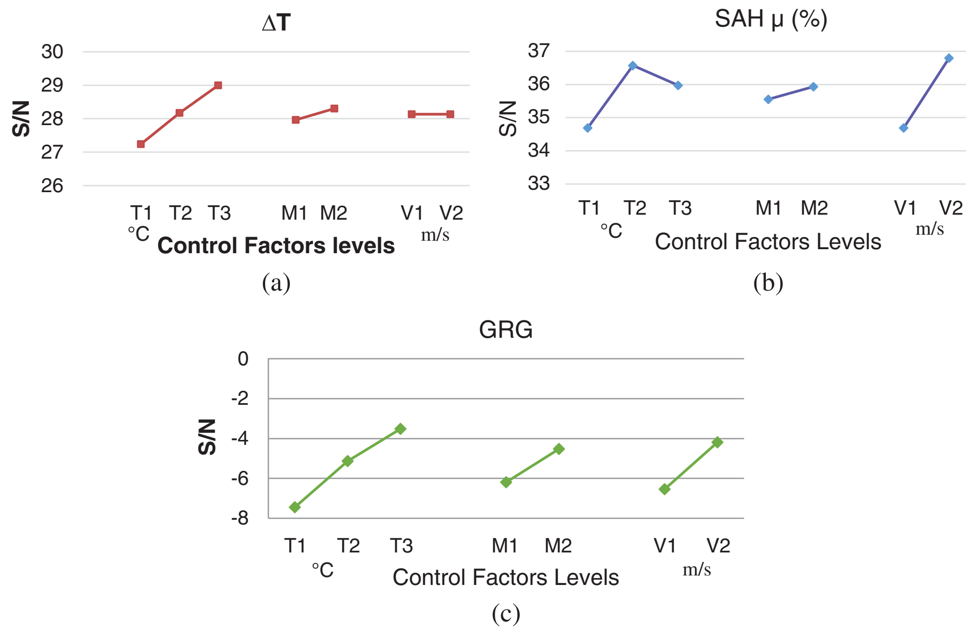

Figure 2: The marginal S/N ratio for all Levels of the factors when (a) ΔT is Considered, (b) SAH μ is Considered, and (c) Combining both ΔT and SAH μ

To summarize the results mentioned earlier, designing optimal SAH based upon each criterion requires selecting the factor level with the optimal S/N ratio. As a final point, the optimal Design based on ΔT, SAH μ, and GRG is individually reported in Tab. 8.

Table 8: Optimal design of the SAH considering different criteria

Process response	Process factor level
When ΔT is considered	T3 (Tilt angle = 45°)
	M2 (wood)
	V1 OR V2 (1.2 m/s or 1.8 m/s)
When SAH μ is considered	T2 (Tilt angle = 22°)
	M2 (wood)
	V2 (1.8 m/s)
When both ΔT and SAH μ (GRG) is considered	T3 (Tilt angle = 45°)
	M2 (wood)
	V2 (1.8 m/s)

3.3 Uncertainty Analysis

In this study, a weather station was used to measure different values (Tab. 9). Uncertainty in this experimental work comes from temperature, velocity, and irradiance measurements which differ from the true values.

Table 9: Instruments used and their accuracy

Weather station	Accuracy
Pyranometer Sensors	+/−5%
Ambient Air Temperature Sensor	+/−0.3°C
Anemometer	+/−5%

In this experiment the thermal efficiency of SAH (η) is defined as

$$\eta = \frac{\dot{m}C_P\Delta T}{AI} \quad (5)$$

where

$\dot{m}$ is the mass flow rate of air [kg/s]

Cp is the specific heat of air at constant pressure [kJ/kg.K]

$\Delta T$is the temperature difference of air at inlet and at outlet [°C]

A is the surface area of the SAH [m^2].

I is the irradiance [W/m^2].

According to the above Eq. (5) and noting that mass flow rate is defined as

$$\dot{m} = \rho ACV \quad (6)$$

where

ρ is the air density [kg/m^3]

Ac is constant cross section area of air outlet in [m^2]

V is the velocity of the air at the outlet [m/s]

Uncertainty of evaluating η becomes

$$\eta = f(\Delta T, V, I) \quad (7)$$

$$\eta = \sqrt{(\frac{\partial \eta}{\partial \Delta T}\Delta T)^2 + (\frac{\partial \eta}{\partial V}\Delta V)^2 + (\frac{\partial \eta}{\partial I}\Delta I)^2} \quad (8)$$

$$\frac{\partial \eta}{\partial \Delta T} = \frac{V}{I} = \frac{3.6}{500} = 0.0072 \quad (9)$$

$$\frac{\partial \eta}{\partial V} = \frac{\Delta T}{I} = \frac{18}{500} = 0.0.36 \quad (10)$$

$$\frac{\partial \eta}{\partial I} = -\frac{\Delta T}{I^2} = -\frac{18}{500^2} = -0.000072 \tag{11}$$

Hence I is 500 W with ±5%, ΔT = 18°C with ±0.3°C, Accuracy, V = 3.6 with ±5%.

Then the percentage of uncertainty in evaluating thermal efficiency is

$$\Delta\eta = \pm 0.3\%$$

4 Conclusions

This study presents the comprehensive outcomes of the statistical analysis performed to acquire the optimal design of a SAH. The Taguchi method hybridized by the GRA was employed on multi-design variables (V, A, M) to optimize the process responses (ΔT, SAH μ). The Grey–Taguchi method plays a considerable role in decreasing the number of required combinations of process factor levels. The analysis of the results showed that the important order of the process factors according to ΔT is determined as follows: T > M > V. While the process factors sequence, which is important for SAH μ is V > T > M, takes into consideration both process responses (ΔT and SAH μ) and the effective sequence is T > V > M. The ANOVA results proved the same order for both ΔT and SAH μ (GRG), whereas M process factor is more significant than T factor for SAH μ. Furthermore, ANOVA confirmed that T and M factors are at the same level as ΔT process response. The highest and lowest levels of operating conditions of a SAH for multiple performance characteristics are determined as T2, M2, V2 and T1, M1, V1, respectively. Comparing these results with the experimental ones, we can conclude that they follow the same fashion. The experimental results demonstrated that the wood heater has a higher efficiency than that of the metal one. This observation can be ascribed to the fact that the heat loss from the wood heater to the surroundings is considerably less than the thermal losing from the metal heater to the surroundings. Hence, the loss from the wood heater leads to higher efficiency. The maximum efficiency for both the wood and metal-air heater was found to be 94.6 and 87.6, respectively.

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