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RESEARCH NOTE

Multi Objective Optimization on Insulated Residential Roof with Solar Water Heating System Using Grey Relation Analysis

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A B S T R A C T

In this work, a multi-objective optimization on novel insulated roof with solar water heating system at low material cost has been carried out through Taguchi based grey relational analysis technique. The novel roofs have concrete, insulating polyurethane, and a channel of water in a metallic pipe tunneling the chromium block. Chromium block is used to conduct more heat to raise the water to relatively high temperature. On the other hand, roof with such high conductive material gains more indoor heat and this can be reduced by providing insulation material at the bottom of the roof. Performance of such a novel roof on water heating and heat insulation have been studied and provided for the months of December and May. In this multi-objective optimization study, chromium block thickness, polyurethane layer thickness, pipe material and pipe diameter are considered as control parameters and varied for three levels. Taguchi's L9 orthogonal array has been employed and the performance of novel roof patterns is studied through numerical simulation. The optimized novel roof raises the water temperature by 44°C in December and maintains the room temperature at 28°C in the month of May which is 3°C less than the conventional roof. Finally, ANOVA is employed to identify the contribution of each control parameter on overall multiple objective function.

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1. INTRODUCTION

Hot water earns a lot of importance and water heater finds many applications for the fulfilment of various domestic as well as industrial requirements. Many types of water heaters are available in the market and most popular are electric, gas and solar type. Electric water heaters are more common as they are having good advantages like faster controlled heating, robustness, and reliability. However, it consumes more electrical energy; electric energy which indicates the fossil fuel consumption. Randi H. Brazeau et al. [1] studied the demand for hot water and stated that about 14% of electric energy was consumed for water heating in almost all the countries. Gas geysers are developed as an alternative to eletrical water heater. But the high operation cost, installation cost, requirment of more space and non-conventional energy consumption leads to a limited use of gas geysers[1]. Later, solar water heaters have become more popular as they reduce the dependence on fossil fuels by utilizing free and abundantly available solar radiation energy. Many researchers have worked on development of solar water heaters. Goudarzi et al. [2] made an advancement in the solar water heater with helical copper instead of collector tube and absorbent coating. But, higher upfront costs and long payback time restricts their usage and some solar heaters require expensive collectors and overheating resistive devices to operate more efficiently[2]. Hence, there is the need for a novel heater that would probably overcome all the cons of existing heaters. In this context, roof integrated with direct water heating system is believed to be more advantageous than other systems, since it needs less maintenance. With all these information in hand, present study is focused on designing a solar water heater attached to the roof, and the new design is expected to deliver hot water with a maximum temperature rise at less cost. In this design, higher thermal conductivity material, chromium

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block is used as the radiation collector. However, transfer of heat into the building is undesirable. In this aspect, many research works has been carried out to reduce the indoor heat gain. Pasupathy and Velraj [3] made an extensive study to maintain the indoor temperature with the aid of PCM material along with concrete. Alicia Oliver [4] studied the thermal behavior of gypsum board with 45% by weight of PCM and found that 1.5cm thick board of gypsum with PCM stores 5 times the thermal energy of a laminated gypsum board. Chengbin Zhang et al. [5] also studied the effect of filling amount of PCM material on the thermal response of brick wall. Ana Vaz Sa et al. [6] developed a new composite construction material embedded as a micro encapsulated PCM with plastering mortar for thermal management. Also, some cool roofs are available that is having a high ability to reflect the sun's radiation and emits the absorbed thermal energy back to the sky [7, 8] and often remains at a lower temperature than traditional roofing materials, up to 28-33 °C cooler, which can lead to energy saving[4]. Zwanzig et al. [9] conducted numerical study to investigate the characteristics of PCMs in building applications as they are promising materials in reducing the energy requirement for maintaining thermal comfort, downsizing the AC/heating equipment, and shifting the time of the peak load on the electrical grid. Alawadhi et al. [10] reduced the heat flux at indoor space by 39% using a roof with cone frustrum holes containing PCM. Arumugam et al. [11] optimized the roof insulations for a roof with high albedo coating. Vijaykumar et al. [12] studied the transient heat transmissions across various types of roof structures and recommended hallow clay tiles over weathering coarse to lay on the roof as it delivers a net energy saving of about 38-63%. Wei Yu et al. [13] discussed the status and shortcomings of domestic energy consumption models and proposed the establishment of a residential building energy consumption demand model approach based on a BP neural network model. However, all these works are having one common objective as to reduce heat gain into the room through roof. Hence, insulating the roof is a best way to reduce the heat gain due to the high absorption of solar radiation by chromium.

From the literature, the demand of people to enjoy the hot water facility and also the importance of reducing the heat gain into the building through the roof are noticed. In many of the research works, the focus is limited either to raise the water temperature or to reduce the heat gain into the building and the cost for the construction is not considered. However, the present work is aimed to develop a new roof structure that yields water at higher temperature with minimized ceiling temperature in a cost effective construction through multi objective optimization technique- grey relation analysis (GRA).

[3] http://www.coolroofs.org/index.html

2. INSULATED ROOF INTEGRATED WITH SOLAR WATER HEATER-A NOVEL DESIGN

The conventional pattern of roof is made of concrete of 15 cm and weathering coarse of 2 cm in thickness. The developed novel roof structure consists of concrete, polyurethane foam, water channel in a pipe tunneling the chromium block having more thermal conductivity which directly receives the solar rays and raises the water temperature. Further transfer of heat into the building is arrested by polyurethane foam laid below the chromium block. The schematic arrangement of the roof structure is shown in Figure 1. This novel roof is optimized for maximum rise in water temperature, minimum ceiling temperature and minimum cost through optimization technique.

3. OPTIMIZATION OF NOVEL ROOF – TAGUCHI BASED GREY RELATION ANALYSIS

Grey relational analysis was developed by Geng in 1989 and it is widely used by the researchers for multi-objective optimization. The grey theory is based on the random uncertainty of small samples which developed into an evaluation technique to solve certain problems of system that are complex and having incomplete information. This method overcomes the limitations of traditional mathematical statistics methods such as the necessity for overlarge samples, a great deal of calculation, and the disaccord between quantitative and qualitative analysis results [14]. The grey systems have a level of information between black and white, where the black represents having no information and white represents having all information. Grey relation analysis along with Taguchi's technique is an effective method to analyze the relationship between sequences with less data and can analyze many factors that can overcome the disadvantage of statistical methods. Tosun [15] used Grey Relation Analysis to optimize the drilling process parameters for the workpiece surface roughness and the burr height considering various parameters such as feed rate, cutting speed, drill and point angles of drill.

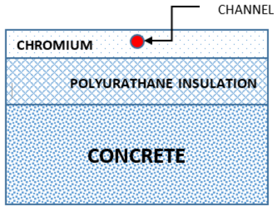

Figure 1. Insulated roof with solar water heater

Chang et al. [16] showed the significance of utilizing Grey relational analysis by providing a numerical example for athletic scores ranking in a typical decathlon competition. Prakash et al. [17] carried out a multi-objective optimization on roof layer thickness through Taguchi based Grey Relational Analysis technique. Abhishek Kumbhar et al. [18] investigated the optimization of CNC end milling operation parameters for stainless steel 304 using Taguchi methodology and Grey Relational Analysis approach. Surface Roughness (Ra), Material Removal Rate (MRR) were selected as the quality, productivity target respectively. Farhad Kolahan et al. [19] presented an approach implemented on turning process of St 50.2 steel that combines grey relational analysis and regression modelling to convert the values of multi responses obtained from Taguchi method design of experiments into a multi objective model.

In the present paper, grey relation method is employed to optimize the multiple objectives (1) Maximizing the water temperature (2) Minimizing the heat transfer into the building and (3) minimizing the cost. The control factors included in this optimization study and its levels of variations are given in Table 1.

Taguchi's L9 orthogonal array is used to design the experiments with the different combinations of control parameters and is shown in Table 2. The nine experiments are tested through numerical simulation method and detailed methodology is given in the next section.

3. 1. Numerical Simulation of Heat Transfer

During the last two decades, numerical simulation method has become more popular in simulating the heat transfer across any building envelope. The rapid increase in computing power, advancements in numerical analysis and modelling makes the technique as a most successful one.

Ajay and Kundan analyzed the performance of nanofluid based parabolic solar collector using computational fluid dynamics technique [20]. Similarly many researchers have used this technique in analyzing the heat transfer across the roof.

TABLE 1. Control parameter and levels of variation

S.No	Factors	Level 1	Level 2	Level 3
1	Pipe Diameter (D) cm	1	1.5	2
2	Pipe Material (PM)	Copper (Cu)	Aluminium(Al)	Steel (Si)
3	Chromium Block Thicknessv (Ct)	2d	2.5d	3d
4	Insulation Thickness (It)	3	5	7

TABLE 2. Taguchi's L9 orthogonal array

Exp No.	Pipe Diameter (cm)	Pipe Material	Chromium Block Thickness (cm)	Insulation Thickness (cm)
1	1	Copper	2d	3
2	1	Aluminium	2.5d	5
3	1	Steel	3d	7
4	1.5	Copper	2.5d	7
5	1.5	Aluminium	3d	3
6	1.5	Steel	2d	5
7	2	Copper	3d	5
8	2	Aluminium	2d	7
9	2	Steel	2.5d	3

Hence, in this study the numerical simulation technique is employed and the roof model is created in the GAMBIT software as a two dimensional surface module, as well. The thermal behaviour of the roof structure is analyzed under transient mode with the aid of FLUENT software. The thermal properties of the roof materials are given in Table 3.

3. 1. 1. Assumptions

The heat conduction in the composite roof is one dimensional and the end effects are neglected.

1. The thermal conductivity of roof materials is considered as constant and not varying with respect to temperature.
2. The Polyurethane is homogeneous and isotropic.
3. The interfacial resistances are negligible

3. 1. 2. Boundary Conditions

Roof Top: Solar radiation data for the months of December and May at Chennai are specified at the roof top. This solar radiation value is converted into T_{solair} through the Equation (1). The variation of solar radiation and the calculated T_{solair} for the months of December and May at Chennai are shown in Figure 2.

TABLE 3. Thermal properties [21]

S.No	Material	Density (kg/m ^{3})	Specific Heat (J/kg-k)	Thermal Conductivity (W/m-K)
1	Copper	8978	381	387.6
2	Aluminium	2719	871	202.4
3	Steel	8030	502.48	16.27
4	Concrete	2300	1130	1.279
5	Chromium	200	840	11.28
6	Polyurethane	32	1590	0.022
7	Water	998.2	4182	0.6

This solar radiation value is converted into T_{solair} through the Equation (1). The variation of solar radiation and the calculated T_{solair} for the months of December and May at Chennai are shown in Figure 2.

$$T_{solair} = T_a + (\alpha q / h_o) \quad (1)$$

where T_a is the ambient temperature, α - absorvity, q- solar radiation and h_o -convective heat transfer coefficient at the outer surface.
Roof bottom surface: Constant Temperature is specified as 298K with a convective heat transfer coefficient of 10W/m^{2}K.

3. 1. 3. Solution Methodology The model is meshed with quadrilateral/triangular elements. Initially, the model is meshed with four patterns of mesh, namely pattern A: Concrete layer with 0.01m and other layers with a size of 0.003, pattern B: Concrete layer with 0.005m and other layers with a size of 0.002m, pattern C: concrete layer of 0.005m and other layers with a size of 0.001m and pattern D: concrete layer of 0.005m and other layers with a size of 0.0005m. The exit water temperature (Tw) and ceiling temperature (Tc) for the above patterns of mesh are predicted and shown in Figure 3.

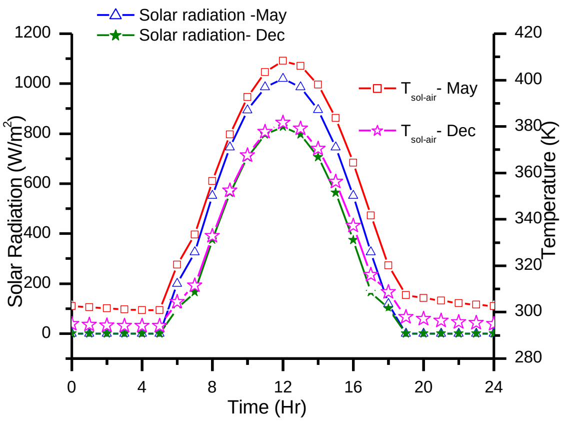

Figure 2. Solar radiation data at Chennai

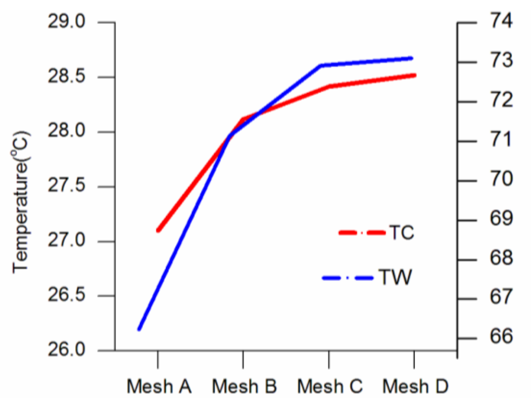

Figure 3. Grid independence test

From this figure, mesh size of 0.005 m for the concrete layer and 0.001m for all the remaining entities is identified to produce a grid independent result. The roof domain is initially analyzed using FLUENT software under steady state with double precision segregated solver.

Later it is solved under transient state for one complete cycle of 24 hours with second order implicit method. All the cases are iterated up to the convergence level of 10^{-6}.

Figure 4 shows the temperature distribution of the roof model for the month of May and December. It is observed that for both months the behaviour of the temperature variation with respect to time is same but with different magnitude of values. From the simulation, the water outlet temperature and ceiling temperature are predicted for all the 9 cases and are given in Table 4.

The obtained values of the water temperature range from 72.48 to 74.55ºC and those of the ceiling from 27.60 to 28.42ºC for all the 9 different experiments.

3. 2. Grey Relation Analysis

3. 2. 1. Data Pre Processing In the data pre-processing stage, the various output responses (experimental results) shown in Table 4 are normalized between zero and one. This is the process of transferring the original sequence to a complete sequence. Normalizing the output response is based on its quality objectives like maximization, minimization and definite target. The mathematical equations used to normalize the responses are given from Equations (2-4) [22].
For the quality objective maximization: The larger the better:

$$x_i^* = \frac{x_i^0(k) - min x_i^0(k)}{max x_i^0(k) - min x_i^0(k)} \quad (2)$$

For the quality objective minimization: The smaller the better:

$$x_i^* = \frac{max x_i^0(k) - x_i^0(k)}{max x_i^0(k) - min x_i^0(k)} \quad (3)$$

TABLE 4. Outcomes of experiments

S.No	D (cm)	PM	Ct	It	Tw (°C)	Cost (₹)	Tc (°C)
1	1	Cu	2d	3	72.91	46234	28.42
2	1	Al	2.5d	5	74.07	45694	27.82
3	1	Si	3d	7	74.55	58712	27.60
4	1.5	Cu	2.5d	7	74.42	83736	27.60
5	1.5	Al	3d	3	72.69	69540	28.43
6	1.5	Si	2d	5	73.95	55984	27.87
7	2	Cu	3d	5	73.52	116263	28.87
8	2	Al	2d	7	74.25	71387	27.60
9	2	Si	2.5d	3	72.48	80804	28.42

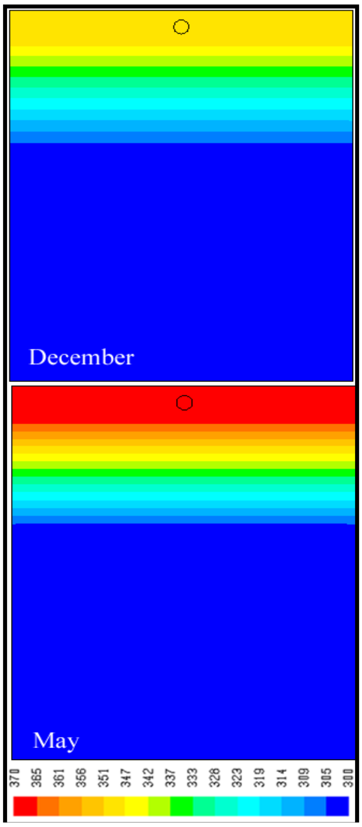

Figure 4. Temperature distribution at 12 PM

For the quality objective definite target: The smaller the better:

$$x_i^* = \frac{x_i^0(k)}{x_i^0(1)} \quad (4)$$

Where x_i^0 is the value after the grey relation generation, $max x_i^0(k)$ is the largest value of $x_i^0(k)$, $min x_i^0(k)$ the smallest value of $x_i^0(k)$ and x^0 the desired value. The subscript i =1,2,….,m and k= 1,2,….,n, where m is the number of experiments and n the total number of observations of data. For this study, the output responses- temperature of ceiling bottom in May, cost of the model should be minimized and hence “the –smaller-the-better” is selected and water temperature rise for December month should be maximized and hence "the -larger -the-better" is selected. Table 5 shows the normalized data for the output responses.

3. 2. 2. Grey Relational Coefficient And Grey Relational Grade From the normalized values, the deviation sequence, $\Delta_{0i}(k)$ from the reference sequence of pre-processed data $x_i^*(k)$ and the comparability sequence $x_i^*(k)$ are calculated. Later, the grey relational coefficient is calculated from the deviation sequence using the Equation (5) to express the relationship between the ideal and actual normalized experimental results.

TABLE 5. Normalized and deviation values

Ex No	Normalized value			Deviation values		
	Tw	Tc	Cost	Tw	Tc	Cost
1	0.2084	0	0.9923	0.7915	1	0.0076
2	0.7686	0.6752	1	0.2313	0.3247	0
3	1	0.9996	0.8155	0	0.0003	0.1844
4	0.9398	0.9998	0.4609	0.0601	0.0001	0.5390
5	0.1017	0.0021	0.6620	0.8982	0.9978	0.3379
6	0.7126	0.6747	0.8541	0.2873	0.3252	0.1458
7	0.5036	0.6773	0	0.4963	0.3226	1
8	0.8594	1	0.6359	0.1405	0	0.3640
9	0	0.0015	0.5024	1	0.9984	0.4975

$$\xi_i(k) = \frac{\Delta_{\min} + \xi \cdot \Delta_{\max}}{\Delta_{0i}(k) + \xi \cdot \Delta_{\max}} \quad (5)$$

where, $\Delta_{0i}(k)$ is the deviation sequence of the reference sequence $x_0^*(k)$, x_i^* is the comparability sequence and ξ is the distinguishing or identification coefficient. The deviation sequences are calculated through the Equations (6 – 8) [22]:

$$\Delta_{0i}(k) = \| x_0^*(k) - x_i^*(k) \| \quad (6)$$

$$\Delta_{max} = \max_{\forall j \in i} \max_{\forall k} \| x_0^*(k) - x_j^*(k) \| \quad (7)$$

$$\Delta_{min} = \min_{\forall j \in i} \min_{\forall k} \| x_0^*(k) - x_j^*(k) \| \quad (8)$$

From the grey relation coefficients (GRC), grey relation grade (GRG) is calculated from Equation (9) [22].

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \quad (9)$$

The grey relation grades are used to show the relationship among the sequences and are given in Table 6.

TABLE 6. Grey relation co-efficient and Grey relation Grades

Exp. No.	GRC of Tw	GRC of Tc	GRC of Cost	GRG	Rank
1	0.3871	0.3334	0.9849	0.5684	6
2	0.6836	0.6062	1	0.7633	4
3	1	0.9992	0.7304	0.9099	1
4	0.8925	0.9997	0.4811	0.7911	2
5	0.3576	0.3338	0.5967	0.4293	8
6	0.6350	0.6059	0.7742	0.6717	5
7	0.5018	0.6077	0.3334	0.4809	7
8	0.7806	1	0.5786	0.7864	3
9	0.3334	0.3336	0.5012	0.3894	9

The respond table of Taguchi method was employed to calculate the average grey relational grade for each factor level.

The procedure is to group the relational grades firstly by factor level for each column in the orthogonal array and then to average them. For example, the grey relation grades for the factor pipe diameter(d) can be calculated as follows:

$\gamma_{wc1} = \frac{1}{3}(0.5684 + 0.7633 + 0.9099) = 0.7472$

Similar method was adopted for each factor under all levels of variations and the response table is generated as shown in Table 7.

Since the grey relational grades represented the level of correlation between the reference and the comparability sequences, the larger grey relational grade means the comparability sequence exhibits a stronger correlation with the reference sequence. Therefore, the comparability sequence has a larger value of grey relational grade for the thickness of chromium block and polyurethane layer, pipe diameter and pipe material are identified. Based on this, this article selects the level 1,2,1 and 3 for the parameters pipe diameter, material, chromium block thickness and polyurethane thickness respectively as an optimum condition appreciating larger the better model for water temperature rise (noted for Dec. only) and smaller the better for the ceiling temperature (noted for May. only) and for the cost. Out of all the possible space of combinations, the best combination that optimizes all the objectives effectively is found to be:

1. Pipe metal: Aluminium
2. Pipe Diameter: 1 cm
3. Chromium block thickness: 2 cm (2d)
4. Polyurethane thickness: 7 cm

Heat transfer simulation for this configuration of solar water heating roof yields water at average temperature of 347.764 k in December and 300.76K as average temperature of the ceiling in May at the final cost of 43,000 INR(approx.).

4. COMPARISON WITH TAGUCHI'S DESIGN OF EXPERIMENTS TECHNIQUE

The optimization by Grey relation method is compared with the Taguchi's Design of Experiments method.

In the Taguchi's DOE technique, signal to noise ratios are calculated for the responses water temperature (Tw), Cost and ceiling temperature (Ct). The signal to noise ratio is calculated from Equations (10- 11) [23]:

Smaller is the better (Minimization)

$$\frac{S}{N} = -10log\left(\frac{1}{n}\sum_{i-1}^{n} y_i^2\right) \quad (10)$$

Larger is the better (Maximization):

$$\frac{S}{N} = -10log\left(\frac{1}{n}\sum_{i-1}^{n} \frac{1}{y_i^2}\right) \quad (11)$$

In this study, Larger is the better function is used for maximizing the water temperature and smaller is the better function is used for cost and ceiling temperature. Weighted S/N ratios are determined based on the importance of output quality characteristics. For this optimization, equal weight is given to all the output responses. Finally, the average S/N ratios are calculated and given in Table 8. The response calculation is also made based on the Taguchi's DOE technique and shown in Table 9.

Based on the Taguchi's DOE technique, the best values for the control parameters are identified as follows:

1. Pipe metal: Aluminium
2. Pipe Diameter: 1 cm
3. Chromium block thickness: 2 cm(2d)
4. Polyurethane thickness: 7 cm

It is found that both the methods yields the same values for the control parameters for the identified quality objective function.

TABLE 7. Response table based on Grey relation method

Particulars	Level 1	Level 2	Level 3
Avg. GRG of Pipe Diameter (D)	**0.7472**	0.6307(2)	0.5522(3)
Avg. GRG of Pipe material	0.6135(3)	**0.6597**	0.6570(2)
Avg. GRG of Chromium Block Thickness	**0.6755**	0.6479(2)	0.6067(3)
Avg. GRG of Insulation Thickness	0.4624(3)	0.6386(2)	**0.8291**

TABLE 8. S/N ratio for L9 based on Taguchi's DOE technique

S. No	S/N ratios			Average S/N ratio
	Tw	Cost	Tc	
1	37.256	-93.299	-29.072	-28.372
2	37.393	-93.197	-28.887	-28.230
3	37.449	-95.375	-28.818	-28.915
4	37.434	-98.458	-28.818	-29.948
5	37.229	-96.845	-29.076	-29.564
6	37.379	-94.961	-28.903	-28.828
7	37.328	-101.309	-29.209	-31.063
8	37.414	-97.072	-28.818	-29.492
9	37.204	-98.149	-29.072	-30.006

TABLE 9. Response table based on Taguchi's DOE technique

Factors	Level 1	Level 2	Level 3
Pipe Diameter cm	**-28.5057**	-29.4465	-30.187
Pipe Material	-29.7943	**-29.0954**	-29.2495
Chromium Block Thickness	**-28.8975**	-29.3945	-29.8471
Insulation Thickness	-29.4514	-29.374	**-29.3137**

5. ANALYSIS OF VARIANCE(ANOVA)

ANOVA is a collection of statistical models used to analyze the differences among group means and their associated procedures (such as "variation" among and between groups), developed by statistician and evolutionary biologist Ronald Fisher. The ANOVA is used to find the most influential parameters to the process factor-level response [24]. In this study, ANOVA is performed on the outcomes to know which parameter affects the results the most even with smaller variation. Table 10 shows the results of ANOVA.

From the above result it is identified that insulation layer thickness dominantly affects the multi-objective optimization by 74.54%, followed by pipe diameter (d), having 21.32%. Pipe material and chromium block thickness are not much influencing the results as they hold a mere 1.47% and 2.65% of the effect, respectively.

6. CONCLUSION

In this work, a novel roof with solar water heater is designed which delivers hot water and provides good thermal insulation to the indoor. The novel roof consists of high thermal conductivity material, chromium and high insulating medium, polyurethane layer. The water is flowing through the pipe tunneling in the chromium block. The roof top is designed for high heat absorbing, conducting capacity and bottom with high insulating capacity.

TABLE 10. ANOVA result

P	Degree of Freedom	Sum of Squares	Mean square	F Value	SS'	Contribution (%)
D	2	0.0577	0.2887	0.2887	0.0577	21.3
PM	2	0.004	0.0020	0.0020	0.0040	1.47
Ct	2	0.0071	0.0035	0.0035	0.0071	2.65
It	2	0.2018	0.1009	0.1009	0.2018	74.5
Error	0	0.00			0.00	0
Total	8					100

The high heat absorbing and conducting capacity helps the water to gain more heat even in the month of December and high insulating material avoids the indoor heat gain in May.

The raise of water temperature and gain of indoor heat are maximized and minimized respectively through multi-objective optimization technique. The cost of the material is minimized as well. Taguchi based grey relation technique is employed and L9 orthogonal array is used in this study. Chromium block thickness, polyurethane layer thickness, pipe material and pipe diameter are considered as control parameters for this optimization. Numerical simulation method is used to predict the performance of novel roof as designed by L9 array. The heat transfer across the roof is carried out for one complete 24 hours for the environmental conditions at Chennai. From this numerical simulation, the delivery water temperature and ceiling temperature are predicted and recorded. These results are used to determine the best value of various control parameters roof through grey relation analysis. The best design of novel roof delivers water at an average temperature of 72°C in the month of December and maintains the ceiling temperature at 28°C in May for the whole day, which is less than 3°C for a conventional roof. ANOVA revealed that insulation layer thickness is having more share in variation of results.

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Multi Objective Optimization on Insulated Residential Roof with Solar Water Heating System Using Grey Relation Analysis

RESEARCH NOTE

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چکیده

در این مقاله بهینه سازی چندهدفه برای هزینه‌ی مواد و عایق‌کاری سیستم جدید آب گرم‌کن خورشیدی سقفی به روش تحلیل منطقی خاکستری تاگوچی انجام شده است. سقف جدید از بتن، عایق پلی اورتان، یک کانال آب مستقر در یک تونل فلزی و بلوک کروم تشکیل شده است. بلوک کروم برای هدایت گرمای بیشتر و در نتیجه بالا بردن آب به دمای نسبتا بالاتر است. از سوی دیگر، سقفی با این مواد رسانای بالا گرمای بیشتری به درون ساختمان وارد می‌کند که می‌تواند با استفاده مواد نارسانا در زیر سقف کاهش یابد. عملکرد این سقف برای تامبن آب گرم در ماه‌های دسامبر و مه و عایق حرارت بررسی شده است. در این بهینه سازی چندهدفه، ضخامت بلوک کروم، ضخامت لایه‌ی پلی اورتان، جنس قطر لوله به عنوان پارامترهای کنترل در سه سطح مختلف در نظر گرفته شده است. شبیه‌سازی عددی با بهره‌گیری از آرایه متعامد تاگوچی L9 انجام شده است. سقف جدید بهینه سازی شده دمای آب در ماه دسامبر را ۴۴ درجه سانتی‌گراد افزایش می-دهد و در ماه مه دمای اتاق را در ۲۸ درجه سانتی‌گراد نگاه می‌دارد که ۳°C کمتر از سقف‌های معمولی است. در نهایت، برای شناسایی سهم هر پارامتر کنترل در تابع چندهدفه به طور کلی از ANOVA استفاده شده است

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