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Ruey-Sen Chiu
Institute of Technology Management, Chung Hua University, Hsinchu, Taiwan., rdesignchiu@yahoo.com.tw

Shao-Tsai Cheng
Department of Construction Management, Chung Hua University, Hsinchu, Taiwan.

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THE IMPROVEMENT OF HEAT INSULATION FOR ROOF STEEL PLATES BY TRIZ APPLICATION

Ruey-Sen Chiu[1] and Shao-Tsai Cheng[2]

Key words: TRIZ, plate paint, heat insulation.

ABSTRACT

More and more colored plates have been used on roofs in the steel buildings in Taiwan, such as roofs of high-technology factories and offices of large-scale construction sites. Facing the impacts of global economic crisis as well as the exhaustion of natural resources, we should seriously look at the issue of energy saving and try every possible method to save energy in daily life. In architecture industry, architects have devoted themselves to green buildings. However, there should be an inventive way to upgrade heat insulation of external building structures. The studies on this topic in Taiwan mainly focus on the heat insulation of air flow and use the compound-heat-proof materials to decrease the heat load of buildings. There were a few researches done on the invention of heat-proof paint on roof plates.

This paper applies TRIZ, the Russian acronym for theory of inventive problem solving, to develop a new heat-proof paint used on the colored roof plates. After conducting and analyzing several heat resistant tests, this study has successfully developed a new paint that upgrades the solar reflectance and heat insulation of the plate paint, which saves over 24% of electricity and thus achieves the goal of saving energy.

I. INTRODUCTION

Nowadays, the number of colored steel deck roofs used in steel-plate buildings in Taiwan has been increasing, such as high technology factories and huge construction firms. Architects have been trying to decrease the heat inside buildings and to upgrade heat insulation as well as visor designs of architectures. During summer noon, horizontal solar radiation is over 1000 W/m^2 in Taiwan [1]. The solar radiation leads to high room temperature, causing unnecessary waste of electricity in air conditioning.

Paper submitted 04/16/10; revised 06/18/10; accepted 07/02/10. Author for correspondence: Ruey-Sen Chiu (e-mail: rdesignchiu@yahoo.com.tw).
[1] Institute of Technology Management, Chung Hua University, Hsinchu, Taiwan.
[2] Department of Construction Management, Chung Hua University, Hsinchu, Taiwan.

The number of buildings in steel deck plates has been increasing, so more steel deck plates with sprayed coating have also been used on roofs. However, Taiwan is a small island with earthquakes and tropical weather. The plates on roofs are exposed to the hot-humid weather so the surfaces of plates get rusted and have stains due to acid rain, which causes poor outlooks of buildings. This paper aims at the application of TRIZ, the Russian acronym for theory of inventive problem solving, to develop colored steel plates with new heat-proof paint by conducting several heat resistance tests. The test results prove that this new developed paint advances solar reflectance as well as heat insulation of the plates and achieves the goal of saving energy [1].

II. METHODOLOGY

1. TRIZ Inventive Principles

TRIZ is a Russian acronym of Teoriya Resheniya Izobreatatelskikh Zadatch, meaning Theory of Inventive Problem Solving. The new inventive principles of TRIZ are professional theory generated by professional analysts from studying over 200 thousands of updated research results and patents of different fields. This experience has significant reference values in instructing invention of new products in various industries. On the base of analyzing all patents around the world, Altshuller has proposed 39 engineering parameters (EPs), which is a breakthrough to traditional technologies, and he has further categorized them into 40 inventive principles (IPs) [2, 7]. To improve invention systems and solve problems through TRIZ, first of all, is to use 2 of 39 EPs to represent two internal potentially conflicting requirements and then to search for the inventive principles that solve problems from the contradiction matrix. After 50 years of development, TRIZ has become one of problem-solving methodologies for technology and invention. This method has successfully overcome difficulties in developing new products throughout U.S.S.R., U.S.A., Europe, Japan⋯etc. Dr. Savransky, an internationally well-known TRIZ expert, has given a TRIZ definition–TRIZ is the methodology based on common knowledge, human-orientation and problem-solving system [9].

2. Inventive Problem Solving Procedures in TRIZ

To solve inventive problems through TRIZ is first to identify and specify problems, then to convert problems to similar

Table 1. The contradiction matrix chart (partially extracted) [5].

Parameters to be improved \ Deteriorated parameters	01. weight of moving object	02. weight of stationary object	…	18. brightness	…	39. productivity
01. weight of moving object		-	…	19,01 32	…	35,03 24,37
02. weight of stationary object	-		…	19,32 35	…	01,28 15,35
⋮	⋮	⋮		⋮		⋮
17. temperature	36,22 06,38	22,35 32	…	32,30 21,16	…	15,28 35
⋮	⋮	⋮		⋮		⋮
35. adoptibility	01,06 15,08	19,15 29,16	…	06,22 26,01	…	35,28 06,37
⋮	⋮	⋮		⋮		⋮
39. productivity	35,26 24,37	28,27 15,03	…	26,17 19,01	…	

Note: The numbers in Table 1 stand for the category numbers listed in the 40 inventive principles.

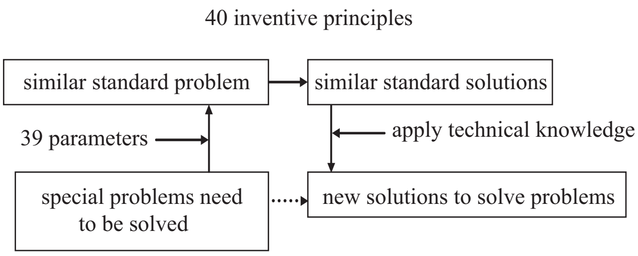
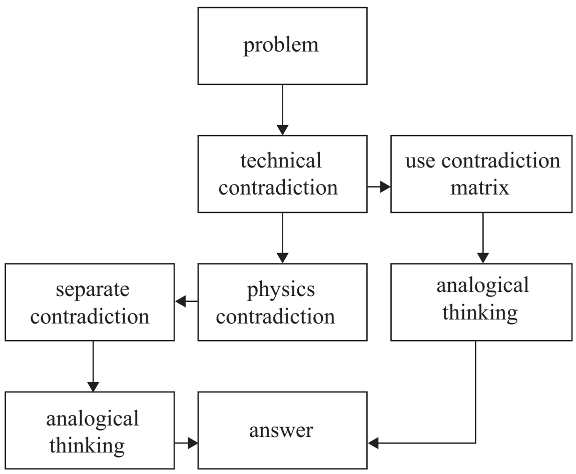


Fig. 1. Inventive problem-solving procedures in TRIZ [9].

standard ones according to the methodology provided by TRIZ. Thus, a standard solution is formed by summing up and categorizing similar standard problems, finally, applying this standard solution to solve problems. The whole process is shown as Fig. 1 [9].

3. TRIZ-The Contradiction Matrix Chart

When designers face a problem in invention and try to improve a feature of products, most of time, the situation turns out that another feature gets worse. The traditional way is to compromise but TRIZ uses elimination instead. According to Altshuller's analysis, there are totally 39 EPs in technical contradictions and Altshuller has organized these patterns of problem-solving in matrix, which is the most well-known contradiction matrix in TRIZ. The horizontal axis in matrix refers to the negative effects that occur when attempting to get positive effects, while the lateral is the positive effects planned to be improved. Assuming when designers intend to improve feature A but cause to deteriorate feature B, designers can get solutions from inventive principles and TRIZ contradiction matrix efficiently. The contradiction matrix consists of 39 rows and columns, totally 1521 elements [5]. Table 1 is the chart of contradiction matrix. Fig. 2 is the flow chart of problem solving in TRIZ.



Note: Then counter point of the horizontal axis (deteriorating parameters) and lateral axis (parameters needed to be improved) is the principle suggested to solve problems.

Fig. 2. The flow chart of contradiction solving in TRIZ [5].

4. TRIZ Application to Development of Heat-Proof Paint on Steel Plates

When designers face an inventive problem in developing new heat-proof paint and try to improve a product or a feature, the situation turns out that another product or feature gets worse. The traditional way is to compromise but TRIZ uses elimination instead. The idealization = useful function/harmful function. The purpose is to maximize the useful function while minimizing the harmful result [5].

This paper is to improve solar reflectance of heat-proof paint, such as to upgrade the reflectance of physical property by applying TRIZ contradiction matrix and 40 principles [1].

The brief elaboration is as below. Traditionally to improve reflectance of materials is to thicken heat-proof materials with

Table 2 . The contradiction Matrix chart.

Deteriorated parameters / Parameters to be improved	13. stability of objects	18. brightness	35. adaptability
17. temperature	1,35,32	32,30,21,16	2,18,27
30. harmful factors acting on objects	35,24,30,18	1,19,32,13	35,11,22,31
35. adaptability	35,30,14	6,22,26,1	

Note: The top four IPs most frequently used are IP35, IP1, IP32 and IP30.
(IP35) Transformation of the physical and chemical states of an object.
(IP1) Segmentation.
(IP32) Changing the color.
(IP30) Flexible membranes or thin film.

two or three compound materials. However, in this study, we follow the traditional way to thicken the new paint on the backside of roof plates, but it causes small air bubbles between layers of paint, which makes the paint peeling off and leads to poor outlooks of plates and, worse, a construction failure.

Moreover, thickening heat-resistant materials causes more weights on roof structure and thus plate structures need to be strengthened, which increases construction cost and unnecessary capital burden. Through applying the contradiction matrix procedure, a solution is suggested that is to convert the physical property of materials to chemical property, which is to add suitable amount of thixotropy resin in the mixture of material Polypropylene resin (A-type) [4]. While mixing these materials, the air within the mixture dries the material, forming mini bubbles in the mixture. After this compound material dries, it gets lighter and has better heat insulation. This new method improves the physical property of the paint and also advances the stability of the material. To upgrade the physical property of heat-proof paint, this study applies TRIZ contradiction matrix and 40 inventive principles to conduct this revision. The parameters which need to be improved and the deteriorated ones are listed as following: temperature (EP17), harmful elements on objects (EP30), adaptability (EP35), stability of objects (EP13) and brightness (EP18), the five parameters in the contradiction matrix. To solve these five contradictions, four inventive principles are singled out in TRIZ as shown in Table 2.

5. Introduction of Heat-Proof Paint on Plate

As the study of Hideki Takebayashi & Masakazu Moriyama indicates [3], the Table 2 in the study mentions solar reflectance (Albedo) of highly reflective white paint is 0.74, which is better than that of other colors. Thus, white color is selected as heat-proof paint for roof plates in this study. This study uses 2 kinds of heat-proof paint materials on roofing steel plates. The material A, Polypropylene resin, is mainly used in adhesives, water-proof materials, protective materials, concrete addictives and so on. Material B is mixture of two different heat-insulation materials which are SxOy-Al type and SixOy-Al type couplier agent, mainly used in water-proof materials, fire-proof materials, concrete additives, retarders and so on [11]. The mixture of these two materials in suitable proportion is a heat-proof material for roof steel plates. This mixture gets solid after it dries due to the two reasons stated below. 1. This mixture in resin breaks surface tension, which allows water to vaporize and speeds up hardening without causing cracks. 2. The mixture has vacant spaces itself which stop thermal conductivity, thermal current and solar radiation [1].

Only two materials are used in this new developed heat-resistant paint. Polypropylene resin, material A, is easier to control in production cost and manufacturing process. Furthermore, this type of resin is more stable, which secures the stability of the resin, ensuring the reliability of analysis results. Polypropylene resin, material A, is the common name for Butyl Acrylate, Methyl Methacrylate and Methacrylic acid. It is weak acid. Besides, the mixture of two heat-insulation materials (material B) is the mixture of SxOy-Al type and SixOy-Al type couplier agent， aluminosilicate salty, silice, and titanium dioxide. It is alkalescent. The goal of this new developed product is to fit and satisfy customers' needs in green buildings. Through the design of Taguchi Quality Engineering, the best combinations of manufacture parameters are formed, thus providing high-quality production conditions. Before a new product is developed, customers' demands and expectations need to be settled and converted to a requirement in every aspect of production so as to achieve the goal of satisfying customers [1].

6. The Definition of Thermal Conductivity Rate (U_i Rate) and MRT

(1) Thermal conductivity rate also known as U_i rate refers to the thermal conductivity rate of exterior buildings when the temperature difference between indoors and outdoors is 1K. The formula is U_i [W/(m^2 · K)].
(2) MRT, Mean Radiant Temperature, refers to the average radiation temperature of walls. The formula is shown as follows.

$$\text{MRT} = \frac{\Sigma(A_i \times t_i)}{\Sigma A_i} \tag{1}$$

A_i refers to the size of walls and t_i is the radiation temperature of walls.

MRT = $t_g + 0.237\ v^{0.5}(t_g - t)$ v: wind speed (m/s); t_g: temperature taken by globe thermometers; t: the indoors temperature.

7. The Calculation of Average Radiation Heat Inside the Boxes and Temperature Taken by Globe Thermometers

(1) Indoors heat radiation is usually indicated as average radiation temperature (T_{mrt}) [10]. The average radiation refers to the average rate of surface temperature that influences exchange of radiation heat in people.

(2) It is difficult to have a precise calculation of average indoors radiation temperature. The formula commonly used in engineering is $T_{\mathrm{mrt}} = (T_1A_1 + T_2A_2 + \ldots + T_nA_n)/(A_1 + A_2 + \ldots + A_n)$. This formula indicates T_{mrt} is average indoors radiation temperature (K), T_1, T_2, …, and T_n are indoors surface temperatures and A_1, A_2, …, and A_n are measurements of the indoors surface (m^2).

(3) The average radiation temperature can be also acquired from the temperature taken by globe thermometers which are the black globe thermometers in this experiment (T_g). Belding's formula can be used to transfer the temperature of average radiation to that of black globe thermometers. The formula is $T_{\mathrm{mrt}} = T_g + 2.4v^{0.5}\ (T_g\text{-}T_a)$.

(4) The interior test box is a closed space so the indoors wind speed v is nearly equal to zero. In the preceding paragraph of formula T_{mrt} is nearly equal to T_g.

(5) T_{mrt} and MRT refer to the same definition. They both mean average radiation temperature.

III. EXPERIMENT FACILITIES

1. Experiment Designs of the 3 Boxes in the Test

The design of boxes in this experiment is based on Fig. 2 (The components of a test cell) in the study [8]. This study simulates the mould and builds up the boxes for heat resistance tests. They are conducted on 3 various paints with different paint thickness. The designs of the test boxes, facilities used and assembling process are stated in Table 3.

1.1 The location of facilities in test boxes: to have two stages of heat resistance tests on plate paint, several facilities are installed in each test box as Fig. 3 shows.

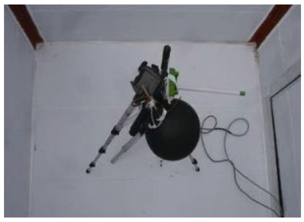
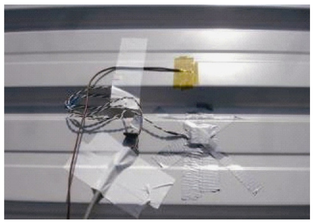
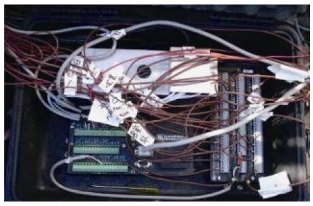
1.2 The plate paint of each box in each group:

There are 2 stages in heat resistance tests that aim to compare and prove the heat insulation of the new paint. In each stage, there are 3 groups in this heat resistance test, one control group, Plate B and two experiment groups, Plate A & C, which is as Table 4 shows.

2. First stage of heat resistance comparison test on the 3 boxes

The experiment was conducted during 10 a.m. to 2 p.m. from Feb. 8th to 23rd in 2010. The size and measurement of paint for each plate in the 3 boxes are indicated from Tables 5~7.

Table 3. The installation of facilities in test boxes.

Test boxes (left side)	Test boxes (right side)
	
Facilities installed inside the box-1	Facilities installed inside the box-2
	
Pyrheliometer and outdoors thermometer	Auto data recorder (CR-10) and one-inch heat flow
	

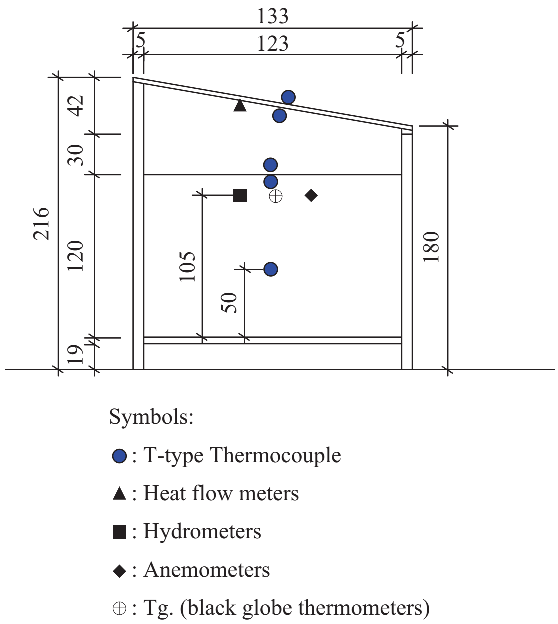


Fig. 3. The location of facilities in test box.

Table 4. The introduction of each group in heat resistance test.

Group	Experiment group-plate A	Control group-plate B	Experiment group-plate C
A: white SixOy-Al type paint B: plate with original colored paint C: white SxOy-Al type paint			

Table 5. The introduction of plate paint and tests in 1st stage.

Date / Test	Group	Experiment group-plate A	Control group-plate B	Experiment group-plate C
2010/2/8	paint	3 layers of SixOy-Al type	light green plate	3 layers of SxOy-Al type paint
1st test	Thickness of paint	0.65 mm (including the loss during spraying)	Overlooked	0.65 mm (including the loss during spraying)
2010/2/10	paint	4 layers of SixOy-Al type	light green plate	4 layers of SxOy-Al type paint
2nd test	Thickness of paint	0.8 mm (including the loss during spraying)	Overlooked	0.8 mm (including the loss during spraying)
2010/2/23	paint	5 layers of SixOy-Al type	light green plate	5 layers of SxOy-Al type paint
3rd test	Thickness of paint	0.95 mm (including the loss during spraying)	Overlooked	0.95 mm (including the loss during spraying)

Table 6. Outdoors weather condition.

Date	Wind speed	Humidity	Solar radiation	Outdoors temperature
2010-02-08	1.24 m/s.	67%	657.25 W/m^2	23.82°C
2010-02-10	1.17 m/s.	57%	676.57 W/m^2	26.31°C
2010-02-23	1.40 m/s.	62%	746.48 W/m^2	22.27°C

Table 7. The heat resistance test results of 3 boxes.

Date	temperature difference between front/back side of plate A	temperature difference between front/back side of plate B	temperature difference between front/back side of plate C
2010-02-08	4.10°C	1.41°C	3.77°C
2010-02-10	3.51°C	1.46°C	3.89°C
2010-02-23	4.14°C	0.71°C	3.68°C

2.1 There are 3 tests in the first stage of heat resistance comparison test on plate paint. Taking the weather conditions (as Table 6 shown) into consideration, the test results of 3 tests are shown in Fig. 4 and Fig. 9.

2.2 The test results of heat resistance: Comparison tests of 3 experiments in 1st stage are analyzed shown as Tables 7~9 show.

2.3 In the 3 tests of 1st stage, the analysis of the heat resistance comparison tests indicates Box A in 1st group has the better performance in the test. The temperature difference between front/back side of plate in Box A is 4.14°C, temperature taken by globe thermometer in the box is 27.84°C and its estimated

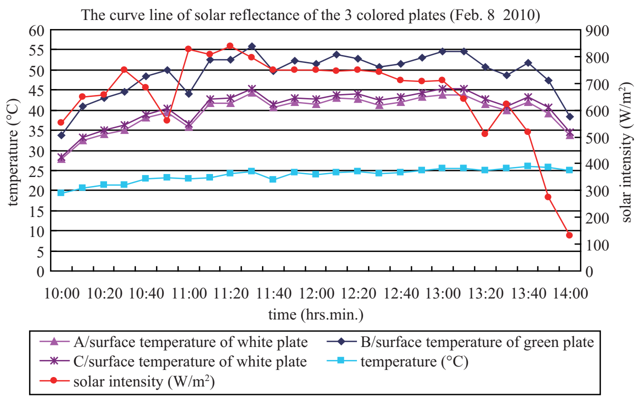


Fig. 4. The curve line of solar reflectance of the 3 colored plates.

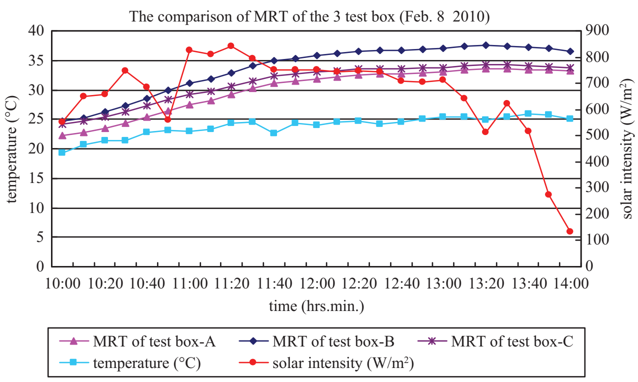


Fig. 5. The comparison of MRT of the 3 test boxes.

U_i rate is 3.68, which are all better than the parameters in Boxes B and C. Therefore, in these 3 tests with totally 9 boxes, Box A with white SixOy-Al type paint has the best perform-

Table 8. The test results of temperature taken by globe thermometers in 3 boxes.

Date	Temperature taken by globe thermometer in Box A	Temperature taken by globe thermometer in Box B	Temperature taken by globe thermometer in Box C
2010-02-08	30.01°C	33.63°C	31.23°C
2010-02-10	32.07°C	36.07°C	33.38°C
2010-02-23	27.84°C	31.80°C	29.20°C

Table 9. The estimated U_i rate in the 3 boxes.

Date	A-the estimated U_i rate	B-the estimated U_i rate	C-the estimated U_i rate
2010-02-08	3.50	5.90	3.72
2010-02-10	3.66	5.89	3.52
2010-02-23	3.68	5.59	3.92

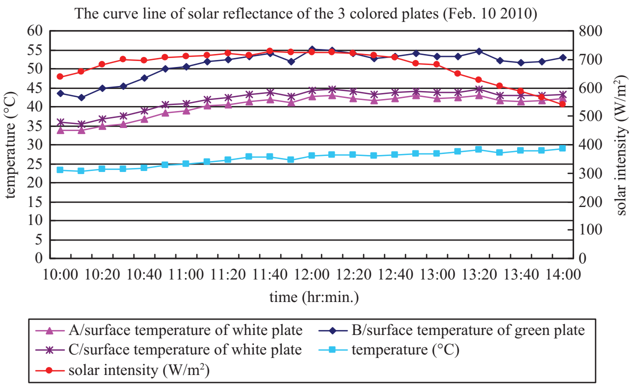


Fig. 6. The curve line of solar reflectance of the 3 colored plates.

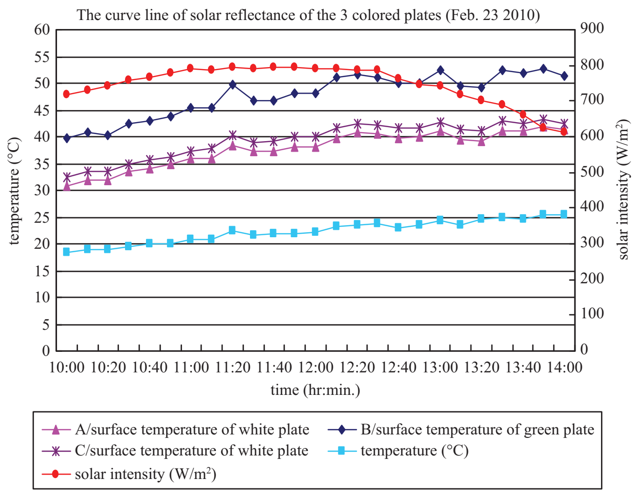


Fig. 8. The curve line of solar reflectance of the 3 colored plates.

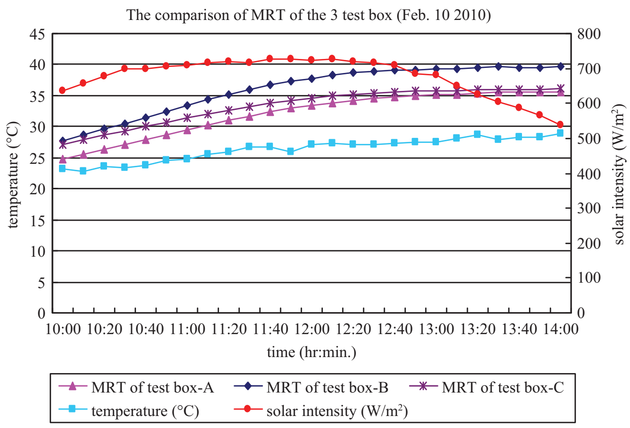


Fig. 7. The comparison of MRT of the 3 test boxes.

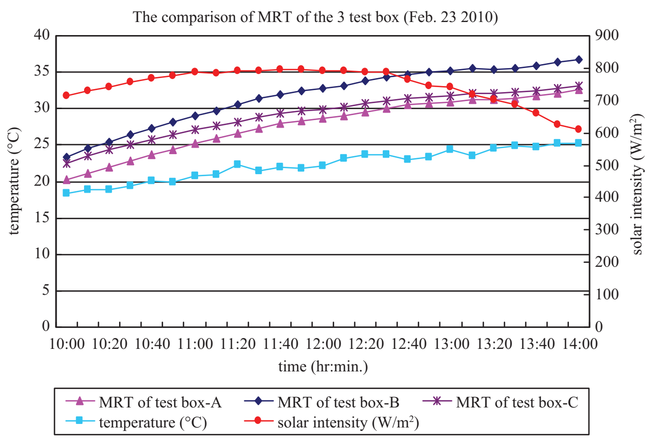


Fig. 9. The comparison of MRT of the 3 test boxes.

ance in the test and the plate with 5 layers of white SixOy-Al type paint is the second ranked.

3. Summary: The test results of 1st stage prove that Box A with white SixOy-Al type paint has the best performance in the test and the plate with 5 layers of white SixOy-Al type paint is the second ranked. In the 2nd stage of the heat resistance test, we conduct another test to reconfirm the finding we get in the first stage. The experiment was conducted from 10 a.m to 2 p.m on Feb. 24th to 28th of 2010. The paint, size and measurement of each plate in the 3 boxes of 2nd stage are introduced in Table 10 as following:

3.1 There are 3 tests in the first stage of heat resistance test on plate paint (the weather conditions in Table 11 are taken into consideration.) The test results of 3 boxes in 2nd stage are shown as Fig. 10 and Fig. 11 show.

3.2 The test results of 3 boxes in 2nd stage prove 3 important heat resistance standards. The test results are analyzed in Table 12.

3.3 In the test of 2nd stage (totally 3 boxes), the analysis of the heat resistance tests proves that Box A in 1st group has the best

Table 10. Introduction of plate paint and size of the 3 tests in 2nd stage.

Date / Test	Group	Experiment group-plate A	Control group- plate B	Experiment group- plate C
2010/2/24	paint	5 layers of SixOy-Al type paint	Light green plate	5 layers of SxOy-Al type paint
Test 1	Thickness of paint	0.95 mm (including the loss during spraying)	Overlooked	0.95 mm (including the loss during spraying)

Table 11. Outdoors weather condition.

Date	Wind speed	Humidity	Solar radiation	Outdoors temperature
2010-02-24	1.26 m/s.	45%	751.97 W/m^2	24.99°C

Table 12. The test results of 3 boxes in 2nd stage.

Box / Date	Box A	Box B	Box C
2010/2/24	Temperature difference between front/back side of plate A	Temperature difference between front/back side of plate B	Temperature difference between front/back side of plate C
	4.13°C	0.44°C	3.76°C
	Temperature taken by globe thermometer in Box A	Temperature taken by globe thermometer in Box B	Temperature taken by globe thermometer in Box C
	32.31°C	37.03°C	33.63°C
	Estimated U_i rate of Box A	Estimated U_i rate of Box B	Estimated U_i rate of Box C
	3.65	5.50	3.86

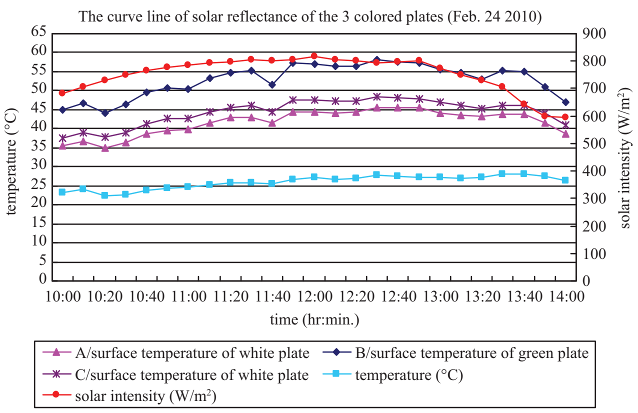


Fig. 10 The curve line of solar reflectance of the 3 colored plates.

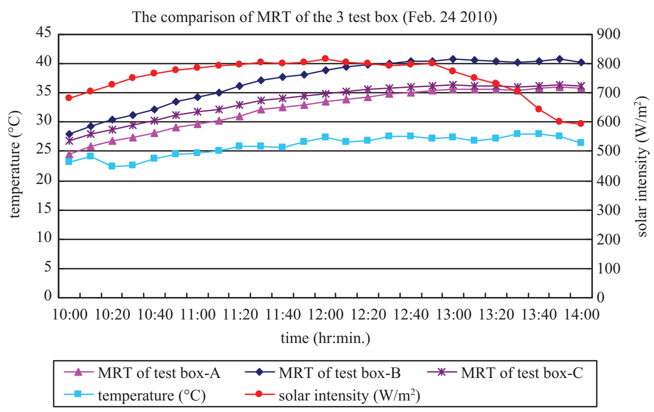


Fig. 11. The comparison of MRT of the 3 test boxes.

performance in the test. The temperature difference between front/back side of plate of Box A is 4.13°C, temperature taken by globe thermometer of the box is 32.31°C and its estimated U_i rate is 3.65, which are all better than Boxes B and C. Therefore, in this test, Box A with white SixOy-Al type paint and the plates with 5 layers of white SixOy-Al type paint have the best performance in the test.

IV. SUMMARY AND DISCUSSION

(1) From the U_i rate calculated based on the test results of the two stages (totally 12 groups), it proves that the heat resistance of Box A and Box C in each group are better than Box B. The change of U_i rate in Boxes A and C in each group is small and the temperature difference between surface temperature of the paint and that below the plate is about 1.95°C~4.14°C, which demonstrates the heat insulation of the paint.

(2) The test results of each group show the surface temperature of plate paint, temperature taken by globe thermometers in boxes and the heat resistance of plate paint. The readings in these two stages are listed in Tables 13~15.

(3) The average thermal conductivity, U_i rate, is acquired as

Table 13. The comparison of surface temperature in the 3 groups of the heat resistance test.

Date	Plate-A (experiment group)	Plate-B (control group)	Plate-C (experiment group)	Temperature difference of the highest and lowest temperature °C
2010-02-08	39.60	49.09	40.70	9.49
2010-02-10	40.22	51.27	41.94	11.05
2010-02-23	37.75	47.73	39.40	9.98
2010-02-24	41.73	52.77	44.35	11.04
Average temperature °C	39.83	50.22	41.60	10.39
Ranking	1	3	2	

Table 14. The heat resistance test results of the 3 groups.

group	plate color	Heat resistance of plate paint (°C)	Solar Radiation heat taken by globe thermometers (°C)	Ranking	Estimated saving of electricity fee (save 6% each decrease of 1°C)
1-A	Light green plate with 3 layers of white SixOy-Al type paint	4.10	30.01	1	21.72%
1-B	Light green plate without spraying	1.41	33.63	3	
1-C	Light green plate with 3 layers of white SxOy-Al type paint	3.77	31.23	2	
2-A	Light green plate with 4 layers of white SixOy-Al type paint	3.51	32.07	1	24.00%
2-B	Light green plate without spraying	1.46	36.07	3	
2-C	Light green plate with 4 layers of white SxOy-Al type paint	3.89	33.38	2	
3-A	Light green plate with 5 layers of white SixOy-Al type paint	4.14	27.84	1	23.76%
3-B	Light green plate without spraying	0.71	31.80	3	
3-C	Light green plate with 5 layers of white SxOy-Al type paint	3.68	29.20	2	
4-A	Light green plate with 5 layers of white SixOy-Al type	4.13	32.31	1	28.32%
4-B	Light green plate without spraying	0.44	37.03	3	
4-C	Light green plate with 5 layers of white SxOy-Al type	3.76	33.63	2	
The heat resistance test result of plate paint; estimated saving of electricity fee			Total average rate		24.45%

Note: (1) The average indoors radiation temperature and temperature taken by globe thermometers are convertible via the Belding's formula by which it estimates the saving of electricity fee. (2) As the announcement of Taiwan Economics department indicates, every 1°C drop in room temperature saves 6% electricity fee.

Table 15 shows. The formula of U_i rate for heat resistance in each group is according to the R.O.C. regulation of energy-saving for buildings [6]. The formula of thermal conductivity U_i can be shown as follows:

$$U_i = \frac{1}{1/h_o + \Sigma d_x / k_x + r_a + 1/h_i} \tag{2}$$

Comparison and analysis of average U_i rate in each group are shown in Table 15. U_i rate of the light green plate with white SixOy-Al type paint is 3.62, has the best heat insulation performance.

V. CONCLUSION

(1) The two stages of heat resistance tests were conducted from 10 a.m. to 2 p.m. During this period of time, the solar radiation is over 600 W/m^2 which is taken as the base of calculation in this heat resistance test. From the test results, the estimated U_i rate taken is the max. rate on that day, which is more accurate and close to the actual condition.

(2) From the test results of these two stages, we notice that the mixture of two different heat-insulation materials is better than the paint on plate B. Among all the plates, the light green plate with 5 layers of white SixOy-Al type paint has

Table 15. The comparison of U_i rate in 3 groups.

Plate no.	Plate color	Plate thickness (mm)	Paint thickness (mm)	Average thermal conductivity (U_i rage)	Ranking
1-1	Light green plate with 3 layers of white SixOy-Al type paint	0.45	0.65	3.50	1
1-2	Light green plate	0.45	overlooked	5.90	3
1-3	Light green plate with 3 layers of white SxOy-Al type paint	0.45	0.65	3.72	2
2-1	Light green plate with 4 layers of white SixOy-Al type paint	0.45	0.8	3.66	2
2-2	Light green plate	0.45	overlooked	5.89	3
2-3	Light green plate with 4 layers of white SxOy-Al type paint	0.45	0.8	3.52	1
3-1	Light green plate with 5 layers of white SixOy-Al type paint-1	0.45	0.95	3.68	1
3-2	Light green plate-1	0.45	overlooked	5.59	3
3-3	Light green plate with 5 layers of white SxOy-Al type paint-1	0.45	0.95	3.92	2
4-1	Light green plate with 5 layers of white SixOy-Al type paint-2	0.45	0.95	3.65	1
4-2	Light green plate-2	0.45	overlooked	5.50	3
4-3	Light green plate with 5 layers of white SxOy-Al type paint-2	0.45	0.95	3.86	2
Light green plate with white SixOy-Al type paint		Average		3.62	1
Light green plate		Average		5.72	3
Light green plate with white SxOy-Al type paint		Average		3.76	2

the best performance in solar reflectance and heat insulation, which also has the greatest improvement in heat resistance of plate paint.

(3) The box sprayed with several layers of heat-proof paint has the best performance in heat resistance test. The globe thermometers in each box show that the heat resistance of Boxes A and C is better than box B. Based on the calculation that every 1°C drop in room temperature saves 6% of electricity fee, it indicates the improved range is around 22%~28% with the total average rate of 24.45%. This proves that the new developed heat-proof paint in this study has the function of saving energy and this construction method proposed in this paper is effective.

(4) In the future studies about heat-proof paint on roof plates, we suggest the best heat resistance comparison test should be conducted with plates of same materials, thickness, paint layers and thickness of paint. More than two groups are needed in the test so that the temperature readings are more accurate. Moreover, it is recommended to compare the range of high temperature period in curve lines. Therefore, the tests will be performed in a more solid approach, which makes heat resistance test results and the performance of heat-proof paint closer to the actual condition.

NOMENCLATURE

U_i	the thermal conductivity of part i (W/m^2°C)
r_a	the heat insulation of part i in air space (m^2°C/W), if no air space, then $r_a = 0$
h_o	the thermal conductivity of surface (standard rate is 23.0) (W/m^2°C) (Taiwan adopts 3 m/s and the practical thermal conductivity is αo)
h_i	the thermal conductivity of internal surface (standard rate 7.0) (W/m^2°C) (Taiwan adopts horizon with downward heat flow. The practical thermal conductibility is αi)
k_x	the thermal conductivity of layer x inside part i (W/m^2°C)
d_x	the thickness of layer x material inside part i (m)
$R_x = \Sigma d_x/k_x$	the heat insulation of layer x material (m^2°C/W)
T_{mrt}	the average radiation heat [°C]
T_g	the temperature taken by globe thermometer in boxes [°C]
T_a	indoors air temperature
v	indoors wind speed (m/sec.)

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