



## Research paper

# Fabrication of low emissivity paint for thermal/NIR radiation insulation for domestic applications

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## ABSTRACT

Recently, low-emissivity paint has gained more importance than commercial paints. Low emissivity (Low-E) Paint also termed as a coating for radiation control, in which the emissivity of radiations of longer waves are reduced dramatically (i.e., the emissivity of commercially available paint is 0.9) by imparting low emissivity particles in the base paint but not suitable to reduce near-infrared radiation. Commercially available paints as of today have minimum of 0.7 emissivity and it does not give any significant energy saving. The low emissivity property of paint makes it particularly suitable for reducing the radiative heat exchange in many domestic applications i.e., home electronics, building construction components, roof surfaces, heat storage tanks, and pipes, etc in result, low power required to heat or cool the building in respective whether conditions. In this work, different samples of white paint were prepared in the lab by using a low shear mixer (mechanical stirrer) under very controlled conditions and studied the results of dry paint films to reduce the thermal emissivity then commercially available paint. Then we investigate the drying time of the wet paint films and analyze thermal heat into visible light through thermal imaging camera, Crosshatch, and IR transmission. We also studied the emissivity through ET-100 and aging stability through a weather-o-meter instrument, which investigated that emissivity value achieved in the range of 0.4–0.6 than commercial paints. The results showed that paint exhibits an acceptable aesthetic emissivity value of ~0.60. It was calculated theoretically that by the use of this novel Low-E paint, annually about 20%–25% less energy will be consumed in building for cooling or heating.

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## 1. Introduction

Energy consumption is quickly increasing as a result of population increase and urbanization. Climate, house style, and development level all influence residential energy demand. Construction operations use 38 percent of the world's energy each year. Building energy usage and its potential environmental consequences are causing increasing concern. These are issues that all construction professions face around the world (Lam et al., 2008; Zang, 2011). Buildings absorb energy at various levels and for various purposes during their entire cycle. In the functioning phase of

construction with at least 50 year duration, electricity required for material fabrication, transportation, and construction is “at least five times” what is necessary in the quantity of energy used and operational phases. Heating, air conditioning, ventilation, and artificial lighting use a significant amount of energy (35%–60%) at this stage. If you reside in a building for more than 50 years, you will notice that it has energy-efficient features which can dramatically cut energy use. It is vital, even if it is merely to focus on the usage and operation phase (Saber, 2012). In many countries, passive methods are used which mostly include green roofs, plaster of Paris in the roofs and walls, self-shading, and fiber-reinforced composites (Shi and Zhang, 2011). Air-conditions are widely used for maintaining the appropriate room temperature; however, they consume too much energy (Rezaei et al., 2017). Therefore, the development of energy-saving technology for all countries of the world has become an urgent requirement

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(Goudarzi and Mostafaepour, 2017). In hot atmospheric regions, reflecting all radiation from buildings surfaces is important to keep cooling requirements inside the building without increasing the use of air conditions (Ding and Clavero, 2017). Many studies report that buildings are insulated to fulfill cooling requirements in the summer season and heating requirements in the winter season using different materials by different techniques and methods (Yuan et al., 2016), but these types of materials are not effective in blocking all types of Infrared radiations and thermal insulation (Afilipoaei and Teodorescu-Draghicescu, 2020). Due to high solar reflectance materials reflect all radiation from the walls and keep the cool inside of rooms. The use of heat radiative materials lowers the cooling requirements in warm areas and lowers heating in colder areas to keep the heat from radiating to outside (Shakir et al., 2020). For the development of these types of building structures, use a passive method which is low-emissivity (Low-E) materials of large interest (Lapinsky and Easty, 2006). However, another factor considered with low emissivity materials is geographical climatic conditions (Grynning et al., 2013).

Low-E materials or coatings are used in buildings especially in windows manufactured with metal oxides as well as thermally insulated buildings with other radiant barriers (Simpson et al., 2019). But it has been suggested that these low-emissivity windows cause damage to their surroundings, and also damage to the sides of homes and automobiles (Kamalisarvestani et al., 2020). That is why low emissivity paints are manufactured with metal oxides (without using any types of pigments) which can enhance its durability effect, weather ability effect, lifetime performance in domestic purposes for both opaque and transparent areas without disturbing communication systems and cell phone signals (Shakir et al., 2022; Zhu et al., 2020).

With the development of technology, high-temperature emission of infrared radiation also increases (Trevisan et al., 2021). To reduce this low emissivity materials are used by different researchers in the form of paints/coatings, polymer, composite, and film by different techniques (Guo et al., 2012). As we know that Low-E materials have great importance in buildings, industries, and aircraft to reduce the effect of absorption from thermal infrared radiations (Shakir et al., 2019). From the last few years, different methods for the manufacturing of Low-E paints were used in which Ni-based materials, and single layer oxides were used. Single-layer of oxides going to diffusion which effect on paints durability (Ibrahim et al., 2018). That is why multilayer deposition of different materials with Ni-based. Al/N/Cr multilayer formed with dielectric effect (Pt., Zn, etc.) which not only protects chemically or mechanically but also acts as a diffusion barrier (Li and Yang, 2019). Simple and colored pigmented paints tend to absorb near-infrared radiation. That is why paints and coatings technologies used resins and solvents to reduce pigmented effect for emission control and reduce surface temperature produced due to thermal radiations (Bao et al., 2017). Different theories, designs, and fabrication methods are used to manufacture optics and spectrally selective coatings for building applications.

At high temperatures, gold foil, copper foil, aluminum foil, nickel foil, molybdenum foil, and stoneware are materials used as a thermal radiation reflector in a multilayer insulation material (Furong et al., 2018). These metal sheets are oxidized easily and lose the effect of reflection and heat insulation in an oxidizing environment. The external building area is subject to solar radiation and can be divided into three parts: the ultraviolet region (200–400 nm); the visible region (400–750 nm), & NIR region (750–2500 nm) (Gao et al., 2020). The visible area of light and the infrared region of light occupy 95% of energy from solar radiation to the surface of the Earth. Many studies are based on near-infrared reflective insulated cooling materials but these are not suitable for high temperature (Cinali and Coşkun, 2021).

Emissivity may be viewed as the radiative heat efficiency factor released from the surface of an object. The Planck law indicates the emission of a “black body” object, whose emissivity is 1, therefore the emissivity value below from this figure of all the real objects (ärvinen\* et al., 2003). Emissivity is defined as the ratio of emitted/absorbed radiations from the surface of materials by the radiations emitted/absorbed by the blackbody within the same temperature and wavelength (Gustavsen et al., 2011). Low emissivity materials or coatings are mainly used to protect indoor and outdoor surfaces from NIR radiations applicable for both opaque and transparent surfaces. These materials are applicable for many applications e.g. domestic level, a defense area, and industries (Montero et al., 2015).

Low emissivity Paints available in the market are not very effective in blocking thermal radiation and heat insulation. Mostly metal pigments are used in the paint to achieve low emissivity. Lead etc. are very toxic and health-hazardous materials. Currently available low emissivity paint has very less weather and wear resistance. The present study aims to replace pure metal pigment paints with metal oxides with low emissivity paints/coatings to improve environmental impact, enhance wear and weather resistance properties, and lower the radiation effect at the domestic level. These paints are used in inner and outer surfaces for the hot and cold climatic region to develop thermally insulated buildings from infrared radiation. To fulfill these goals different concentrations of metal oxides were characterized, both individually mixed like paint which has high thermal stability, heat, and corrosion resistance and also play role in reflectivity in the NIR region.

## 2. Experimental section

### 2.1. Materials

Materials included Aluminum Oxide ( $\text{Al}_2\text{O}_3$ ,  $\geq 99.9\%$  Sigma Aldrich), Magnesium Oxide ( $\text{MgO}$ ,  $\geq 99.9\%$  Sigma Aldrich), Bismuth Oxide ( $\text{Bi}_2\text{O}_3$ ,  $\geq 99.9\%$  Sigma Aldrich), Zinc Oxide ( $\text{ZnO}$ ,  $\geq 99.9\%$  Sigma Aldrich) as filler, Enamel paint of (Primax Company) as a polymer, mild steel plates (50 mm  $\times$  50 mm). (See Table 1.)

### 2.2. Fabrication of low emissivity paint

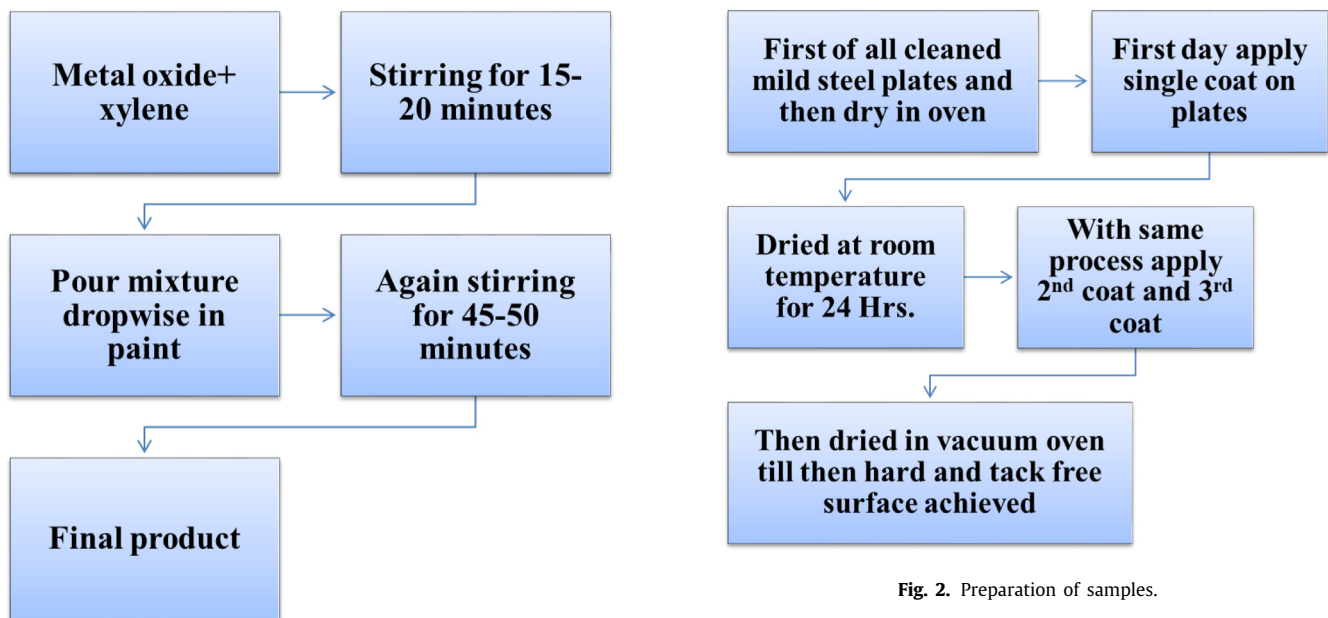
The first stage of the project was to fabricate low emissivity paint by varying material concentration, for this purpose, mechanical stirrer was used. First of all, evaluate solid content in the enamel paint labeled on the box which has 70% solid content and 30% liquid content. According to the solid content of paint prepared, samples of 100% and 200% concentration. In the first step prepare 2 different concentrations of material, for the first sample added xylene in 50%  $\text{Al}_2\text{O}_3$  nano-particle and stir for 15–20 min through a mechanical stirrer or also sonicate the material in a sonication bath for proper homogenization. Then 50% paint was measured in a beaker and the prepared solution was added dropwise then stirred for 40–45 min continuously. Now prepared 66% concentration of  $\text{Al}_2\text{O}_3$  in which also added xylene and stirred for 15–20 min and then added this solution dropwise in 33% paint with vigorous stirring. Through this process homogenized low emissivity paint was prepared. Other samples were prepared by the same method (see Fig. 1).

### 2.3. Preparation of samples

Mild steel plates with a thickness of 1.2 mm were cleaned by scrubbing with P240 sandpaper and then soaked plates for 10 min in a 33% aqueous solution of nitric acid and rinsed with tap water.

**Table 1**  
Design of an experiment to perform further experimentation and testing.

Sr. #	Sample No.	Paint (wt. %)	Thickness	Al <sub>2</sub> O <sub>3</sub> (wt. %)	MgO (wt. %)	BiO (wt. %)	ZnO (wt. %)
1	Paint	100	150 μm	0	0	0	0
2	Paint	100	450 μm	0	0	0	0
3	Sample 1	50	150 μm	50	0	0	0
4	Sample 2	50	450 μm	50	0	0	0
5	Sample 3	33	150 μm	66	0	0	0
6	Sample 4	33	450 μm	66	0	0	0
7	Sample 5	50	150 μm	0	50	0	0
8	Sample 6	50	450 μm	0	50	0	0
9	Sample 7	33	150 μm	0	66	0	0
10	Sample 8	33	450 μm	0	66	0	0
11	Sample 9	50	150 μm	0	0	50	0
12	Sample 10	50	450 μm	0	0	50	0
13	Sample 11	33	150 μm	0	0	66	0
14	Sample 12	33	450 μm	0	0	66	0
15	Sample 13	50	150 μm	0	0	0	50
16	Sample 14	50	450 μm	0	0	0	50
17	Sample 15	33	150 μm	0	0	0	66
18	Sample 16	33	450 μm	0	0	0	66



**Fig. 1.** Fabrication of paint.

This process was repeated until a clean surface was obtained and then placed in the oven for drying.

Paint samples were prepared to have different fillers (MgO, Al<sub>2</sub>O<sub>3</sub>, ZnO, BiO) and each filler has two different concentrations (50% and 66%). Each sample has only one filler with one concentration. A total of 16 samples were prepared. Samples were applied over the smooth mild steel surface with two film thicknesses 150 μm and 450 μm individually. All paint samples were dried at room temperature for 24 h to remove all the solvent. The final paint samples were hard and tack-free (see Fig. 2).

### 3. Characterization

To evaluate the results of the following prepared samples, different techniques were used:

#### 3.1. Thermal images

Thermal visual images cameras have now developed into compact, digital camera-like systems. They are easy to use and produce crisp, high-resolution images in real-time. The construction

industry is one of the sectors which quickly found that thermal imaging might provide valuable data with which no other tool can be captured (Robinson, 2016). Thermal imaging cameras have been developed from an adventurous technology into a widely used tool used by many building inspectors around the globe. A thermal camera is a special tool for mapping the building's energy dissipation. This process is rapid and the camera's thermal images are a conclusive and accurate assumption (Fantucci et al., 2017). To determine the radiation emissions on the human body, IR thermal images of various concentration samples were taken. It is a modern technique for receiving and converting electromagnetic radiation into electrical signals. The signals are then shown in or color combinations which show the value of temperature, minimum and maximum temperature absorption (AB, 2011).

#### 3.2. Emissivity testing

At two incidence angles of 20° and 60°, the ET-100 measures directional reflectance in the thermal infrared spectral region at six bands. The total hemispheric emissivity and directional emissivity are calculated using these values. The ET-100 is operated by a battery and it is a handy tool used for heat radiative transfer applications. Here is a specular gold coupon placed on the sample



surface and then pressed the trigger to record results which takes almost 7 s (Ingenierie, 2021).

### 3.3. Weather-o-meter

A weather-o-meter is a lab device that simulates high temperatures from outside high-powered light sources and water. Ultraviolet light can cause long-term damage to paints, plastics, and concrete finishes, as a wavelength of solar radiation is not visible. Ultraviolet, indoor or other luminous frequencies can be created by weather-o-meter to test products under controlled environments and also include water spray to investigate further environmental impacts. In testing Weather-o-meter ASTM G155, (cycle 9) was used for further investigation. In this exposure cycle, used daylight filter, 180 W/m<sup>2</sup> Irradiance, 300–400 nm wavelength, 102 min light at 63 °C black panel temperature, and 18 min light and water spray at a controlled temperature (Weathering, n.d.).

### 3.4. Crosshatch adhesion

For the evaluation of adhesion performance of the paint/coatings, around edges knife with eight cutting blades was used and draws the cross line on the painted mild steel plates at the angle of 90°. Pulled off the painted samples and evaluate that the paint is still with the substrate and there were no empty spaces on the plate's panels.

### 3.5. T & H chamber

Temperature and relative humidity chambers (whether known as climatic change chambers) approximate impacts on products or materials, such as communications equipment or solar energy exposed to outdoor temperatures and moisture, as well as temperature and moisture conditions. The effects are simulated. They apply in industries that are so various as food technology, electronic components, and the guarantee of military quality or coatings. For testing model 123H temperature and humidity temperature were used with −73 °C–190 °C temperature range and 100% humidity also recognized for controlled environmental conditions. The test was performed in incubating chamber for 2 weeks at 50 °C with 100% humidity. The suitable parameters such as color change, blisters, loss of adhesion, softening are observed (Llc et al., 2014)

## 4. Results and discussion

### 4.1. Thermal images

Minimum and maximum temperature absorption values are shown in Fig. 3. The first step of performing this test is to place all coated samples with an uncoated sample in the oven for 25–30 min at 60 °C. To check that all samples reached at 60 °C, a thermocouple probe is used. Then one by one took images through a thermal imaging camera. In images without a coat was on the right side and the coated sample was on the left. The figure shows that uncoated samples are white and shows a high temperature of the sample surface which means body is losing heat in form of IR radiation. Coated samples show the minimum surface temperature in the range of 30–31 °C and uncoated samples show the maximum surface temperature range of 45–47 °C. Thermal imaging results of sample 1 & 2 showed maximum temperature at 45 °C of uncoated sample and minimum temperature in the range of 30 °C of coated sample which confirms that the sample with low e-coats blocks IR radiation as compared to the uncoated sample. Samples 3–6 showed maximum temperature at 45 °C & minimum temperature at 30.14 °C. Samples 7–16 showed maximum temperatures at 46–47 °C & minimum temperature at 30.23–30.2 °C.

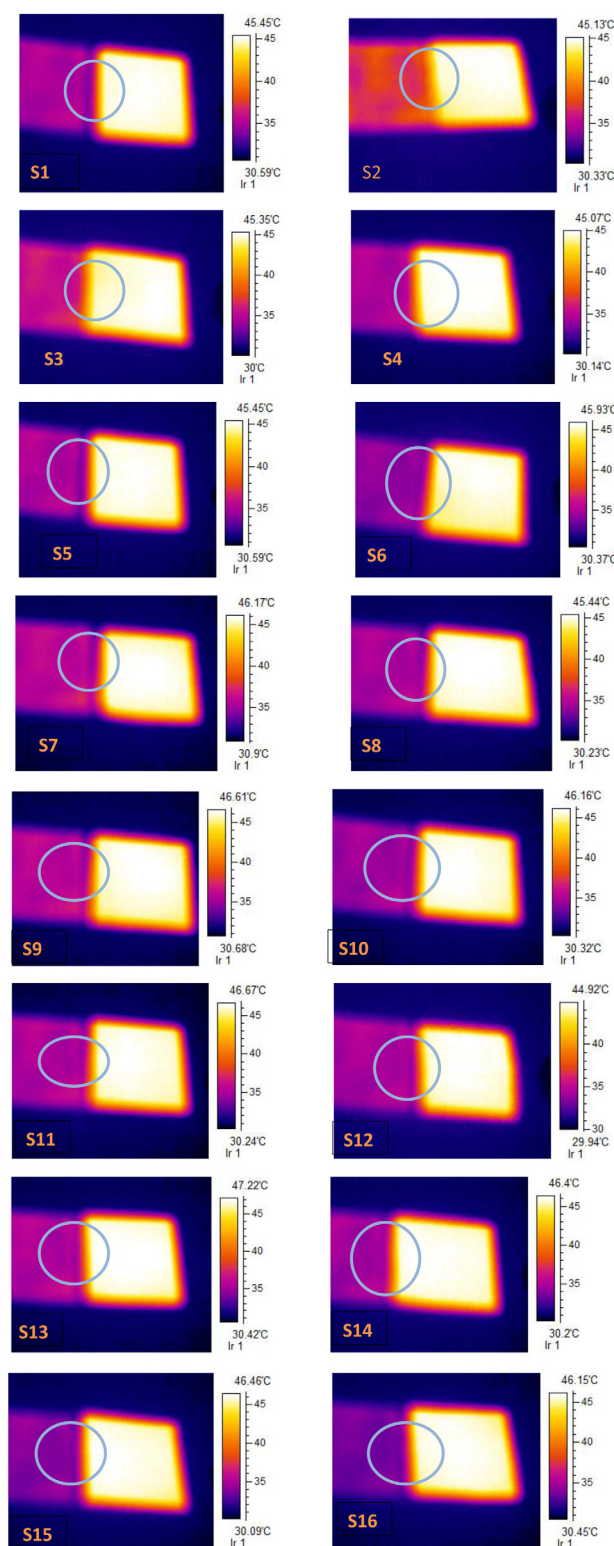


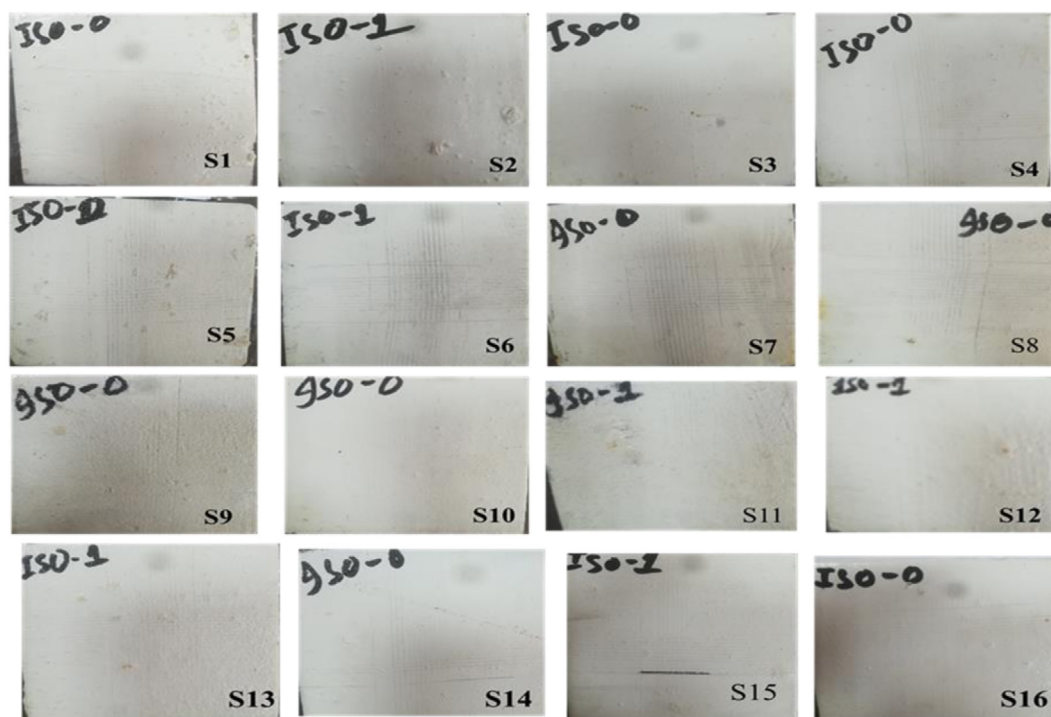
Fig. 3. Thermal images of coatings for samples 1–16.

### 4.2. Crosshatch adhesion

We performed the cross-hatch test in primax paint Faisalabad all our results show that the adhesion of all our samples was excellent. Crosshatch adhesion is classified according to ASTM/ISO standards. Class0 means samples fall in 5B and class1 in 4B

**Table 2**  
Results of cross-hatch according to ASTM/ISO class.

Sr. #	Sample Name	ASTM/ISO Class	Results
1	Sample 1	5B/0	Cuts are completely smooth.
2	Sample 2	4B/1	Cuts are about 5% is affected.
3	Sample 3	5B/0	The cuts are completely smooth.
4	Sample 4	5B/0	The cuts are completely smooth.
5	Sample 5	5B/0	The cuts are completely smooth.
6	Sample 6	4B/1	Cuts are about 5% is affected.
7	Sample 7	5B/0	The cuts are completely smooth.
8	Sample 8	5B/0	The cuts are completely smooth.
9	Sample 9	5B/0	The cuts are completely smooth.
10	Sample 10	5B/0	The cuts are completely smooth.
11	Sample 11	4B/1	Cuts are about 5% is affected.
12	Sample 12	4B/1	Cuts are about 5% is affected.
13	Sample 13	4B/1	Cuts are about 5% is affected.
14	Sample 14	5B/0	The cuts are completely smooth.
15	Sample 15	4B/1	Cuts are about 5% is affected.
16	Sample 16	5B/0	The cuts are completely smooth.



**Fig. 4.** Results after cross-hatch test.

category. All samples fell in the 5B/class0 and 4B/class1 category according to ASTM/ISO class. Sample 1, 3, 4, 5, 7, 8, 9, 10, 14, and 16 fall in ASTM/ISO class 5B/class 0 which shows excellent adhesion, the edges of the cuts are completely smooth whereas, Sample 2, 6, 11, 12, 13, and 15 falls in 4B category which shows that not greater than 5% are affected and good adhesion (see Fig. 4). (See Table 2.)

#### 4.3. Emissivity testing

The figure shows the results of emissivity for four different paint-coated samples (1–16) at 20 and 60 °C in the range of 0–1 NIR region (700–2500 nm) with two different concentrations and thicknesses. Sample (1–16) shows 0.2–0.4 emissivity values at 20 °C and 0.1–0.4 emissivity at 60 °C. From the emissivity test results, it is concluded that the required emissivity of samples lies in the range of 0.3–0.6 where percentage emission is 40% to 60% which is correlated to the reduction in the IR Transmission. In graph (a)  $\text{Al}_2\text{O}_3$  showed that with the addition of 66% additive emissivity decreases as compared to 50% concentration. In graph

(b)  $\text{MgO}$  showed that with the addition of 66% additive emissivity increases as compared to 50% concentration. In graph (c) with the addition of 66% additive emissivity increases as compared to 50% concentration. In graph (d)  $\text{ZnO}$  showed that with the addition of 66% additive emissivity decreases as compared to 50% concentration. According to these results,  $\text{Al}_2\text{O}_3$  and  $\text{ZnO}$  showed low emissivity at high temperatures as compared to  $\text{MgO}$  and  $\text{BiO}$  (see Fig. 6).

#### 4.4. IR spectroscopy

IR spectroscopy technique investigates the transmission of IR radiation from the surface of samples in the range of NIR region (700–2500 nm) [33] and results are shown in Fig. 5 pure paint showed almost 70% transmission allowing maximum radiations to transmit whereas samples were prepared by the addition of Nano-particles of oxides showed 0–0.18% transmission which describes that minimum transmission. According to results, S1–S2 showed 0.01–0.15% transmittance whereas S3–S4 showed 0.17%

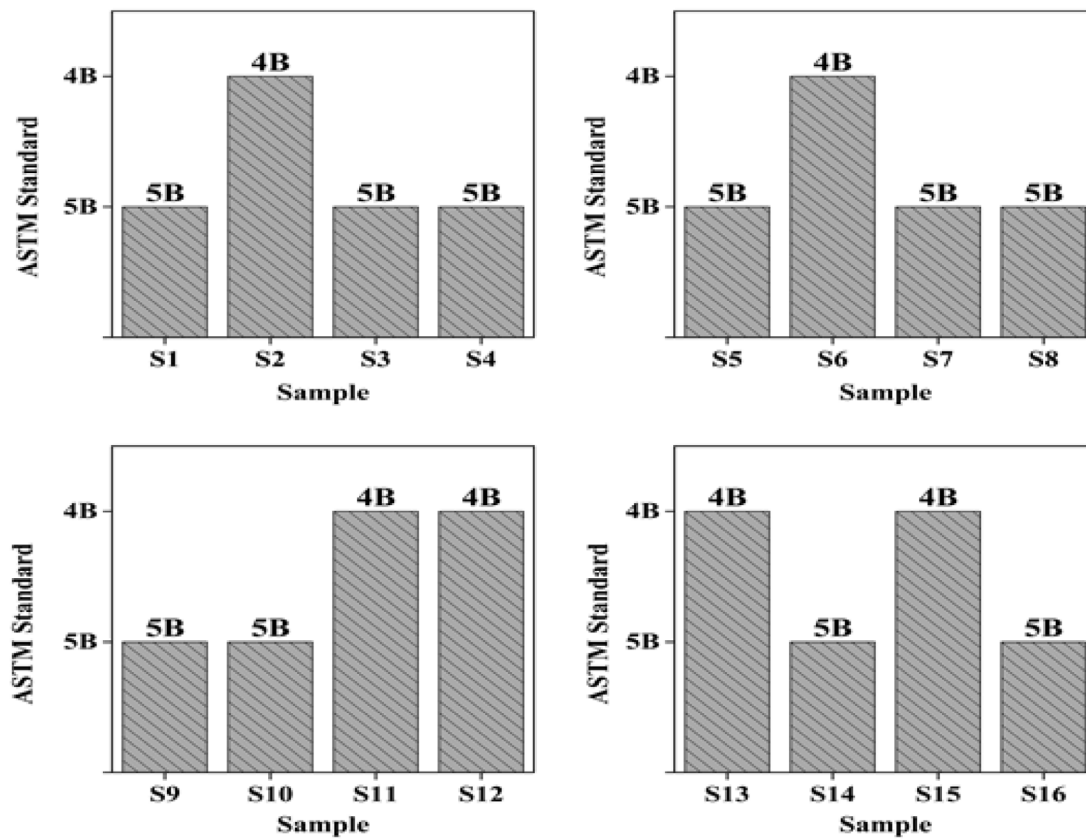


Fig. 5. (a) Crosshatch results of coatings for sample 1–4 with the addition of  $\text{Al}_2\text{O}_3$  nano-particles. (b) Sample 5–8 results with the addition of MgO nano-particles. (c) Sample 9–12 shows results with the addition of BiO nano-particles. (d) Sample 13–16 shows results with the addition of ZnO nanoparticles.

transmittance with the addition of 50 wt% and 66 wt%  $\text{Al}_2\text{O}_3$ , S5–S6 showed 0.12–0.15% transmittance and S7–S8 showed 0.18% transmission with the addition of 50 wt% and 66 wt% MgO, S9–S12 showed 0.12–0.17% transmittance with the addition of 50 wt% and 66 wt% BiO and S13–S16 showed 0.18% transmittance with the addition of 50 wt% and 66 wt% ZnO. So results showed that oxides show minimum transmission from the surface of the sample than pure paint (see Fig. 7).

#### 4.5. Dynamic energy and thermal analysis

During warm season, the thermal inertia of the building is required to stop external temperature and improve internal temperature by using low emissivity paint. General equation of the sol-air temperature  $T_{sa}(t)$  is utilized to model the external thermal excitations (Asan, 2000). This equation combines the effect of the ambient temperature and the absorbed solar energy at the outer face of the roof.

$$T_{sa}(t) = T_{amb} + \frac{\delta}{h_1} I(t) - \frac{\xi \Delta R}{h_1} \quad (1)$$

In Eq. (1):  $T_{sa}(t)$  is denoted as solar air temperature,  $T_{amb}$  denoted for ambient temperature,  $\frac{\xi \Delta R}{h_1}$  is correction factor,  $\delta$  act as solar radiation effect.

The ambient temperature is assumed to show sinusoidal variations during a 24 h period. Ambient temperature is used to calculate surrounding inside and outside temperature of enclosed room or materials. According to ambient temperature evaluate change in temperature within 24 h. For an ambient temperature this equation used: Chihab et al. (2020)

$$T_{amb} = \frac{[T^{max} - T^{min}]}{2} \sin\left(\frac{2\pi t}{P} - \frac{\pi}{2}\right) + \frac{[T^{max} - T^{min}]}{2} + T^{min} \quad (2)$$

The time lag and decrement factor are determined solely by the roof material properties, not the climatological data. According to Eq. (1) sol-air temperature as a periodic sinusoidal function for external thermal excitation calculated by this equation (Yassine et al., 2021)

$$T_{sa}(t) = 29.19 \times \sin\left(\frac{2\pi t}{86400} - \frac{\pi}{2}\right) + 39.77 \quad (3)$$

When the emissivity is lowered, the heat flow  $Q$  at the inner surface is greatly reduced. Low emissivity levels do, in fact, contribute significantly less heat radiation. Overall heat transfer through the roofing is greatly reduced. As a result of the low emissivity coating, the overall thermal load over a 24 hour period is greatly lowered, lowering power network demand and improving building internal thermal comfort. To calculate total thermal load following equation is used:

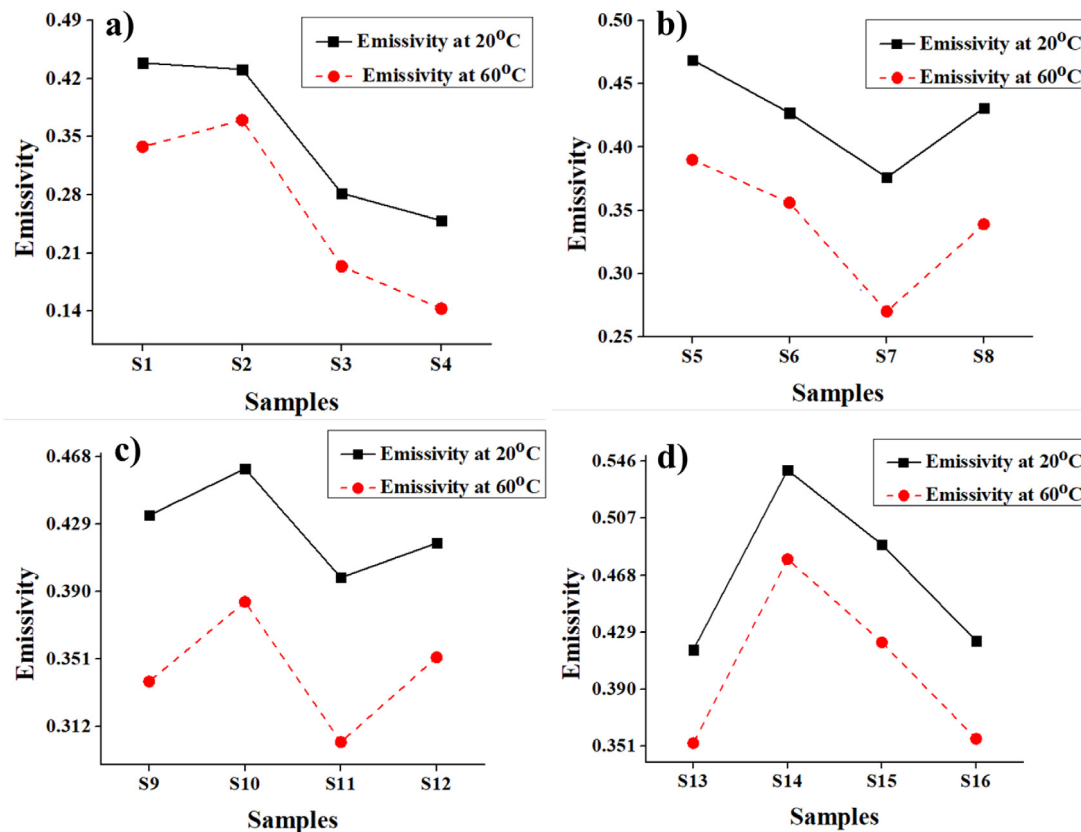
$$Q = \int_0^{t=24h} \left( \lambda \frac{\partial T(y, t)}{\partial y} \Big|_{y=0} \right) \cdot dt \quad (4)$$

In this equation  $Q$  is act as heat flux,  $\int_0^t$  is denoted as integral along time 24 h,  $\lambda$  is wavelength.

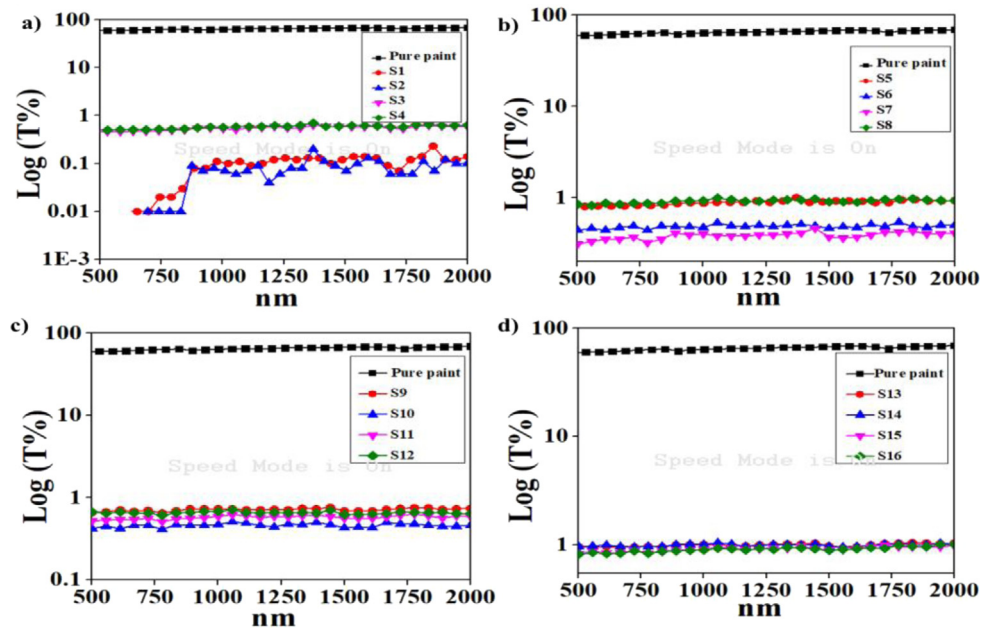
Thermostat is a component that forms part of buildings to control and helping maintain a steady or pre-determined temperature. which is used Moving the thermostat back  $10^\circ$  to  $15^\circ$  for 24 h will save you between 5% to 15% per year on heating costs—a saving of as much as 1% per degree if the setback period is 24 h long. The percentage of savings through setback is higher for structures in warmer climates. In the summer, similar savings can be obtained by keeping the indoor temperature higher when no one is around. (Syngellakis et al., 2005).

In winter season according to Eq. (2) radiative heat losses are decreased when interior surfaces have lower emissivity. In the





**Fig. 6.** (a) Emissivity values of Al<sub>2</sub>O<sub>3</sub> with two concentrations 50 and 66 wt. %. (b) Emissivity values of MgO with two concentrations 50 and 66 wt. %. (c) Emissivity values of BiO with two concentrations 50 and 66 wt. %. (d) Emissivity values of ZnO with two concentrations 50 and 66 wt. %.



**Fig. 7.** (a) IR spectroscopy results of S1–S14 (Al<sub>2</sub>O<sub>3</sub>). (b) IR results of S5–S8 (MgO). (c) IR results of S9–S12 (BiO<sub>2</sub>). (d) IR results of S13–S16 (ZnO).

result of temperature set of the room is decreases to save room energy from 25 °C to 15 °C, with the decrease of emissivity value from 0.9 to 0.1. In warmer areas or summer season significantly more heat released from the surface when emissivity value near that of blackbody. Corresponding Eq. (2) radiative heat loss from 50.5 W for an emissivity 0.1 to 80.5 W for an emissivity 0.9. As a

result the set point temperature increases 4–5 °C, from 20–22 °C, when emissivity increases.

Using CFD model, firstly determined radiative and convective heat exchange. The radiative heat loss from 99.1 W to 72.3 W, when emissivity is decreased from 0.9 to 0.1 matches with the analytical model (Shen et al., 2019). For a closed system the radiative heat flux of the two surfaces can be analytically described:

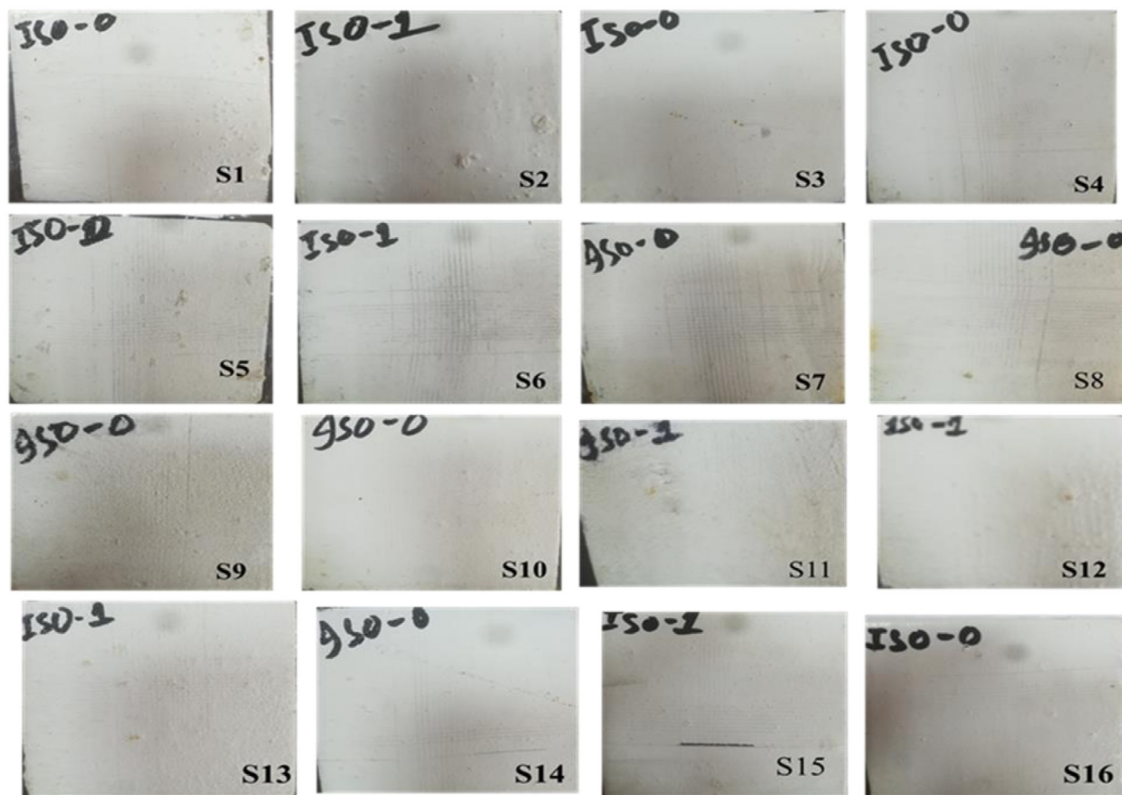


Fig. 8. Weather o meter test of all samples.

$$Q_{1,2} = \frac{(E_{b1} - E_{b2})}{\frac{1-\epsilon_1}{\epsilon_1 A_1} + \frac{1}{x_{1,2} A_1} + \frac{1-\epsilon_2}{\epsilon_2 A_2}} \quad (5)$$

In this equation  $Q_{1,2}$  is heat flux,  $A_1$  is area of hot surface and  $A_2$  is area of cold surface,  $E_{b1}$  and  $E_{b2}$  are blackbody emission from hot and cold surface, where  $E_{b1} = \sigma T_1^4$  and  $E_{b2} = \sigma T_2^4$ ,  $\sigma$  Stefan–Boltzmann constant,  $\epsilon_1$  and  $\epsilon_2$  are the emissivity of hot surfaces (Yu et al., 2019).

According to surface structure equation can be simplified:

$$Q = \frac{A(E_{b1} - E_{b2})}{\frac{1}{\epsilon_1} + \frac{A_1}{A_2} \left( \frac{1}{\epsilon_2} - 1 \right)} \quad (6)$$

In this equation  $Q$  is heat flux,  $A$  is total area,  $E_{b1}$  and  $E_{b2}$  is emissivity of blackbody surfaces of hot and cold area.

By using paint reduction in temperature is almost 5%–10%, but on the other side by using low emissivity paint reduction in temperature was reached almost 15%–20% which is observed by thermal images and also shows better reflection than commercial paint respectively. So, by the comparison of commercial paint observed that inclusion of metal oxide in this paint showed overall heat transfer through the roofs and walls, which is helpful to reduce electricity load and improve internal thermal comfort in the buildings. (See Table 3.)

#### 4.6. Weather o meter and T & H chamber

First of all, samples were placed in a Weather o meter which shows no change in color, loss of adhesion, blisters, and softening. Fig. 8 results show pictures after completion of one cycle of weather o meter test. Fig. 9 showed results of selected samples was stable over the exposure of UV light and salt spray period after the 2nd cycle, whereas selected samples for temperature

and humidity test in Fig. 10 was also stable except sample 8 and 12 shows a change in color. After these tests again cross-hatch test was performed to confirm that adhesion was stable or not after both tests. So, according to the results of cross-hatch same performance was achieved before and after the weather o meter and T & H Chamber test. (See Table 4.)

## 5. Conclusion

This study has focused that metal pigments replaced with metal oxides as a low-E coating to improve energy efficiency and thermal insulation. By the use of metal oxides ( $\text{Al}_2\text{O}_3$ , MgO, BiO, ZnO) as a filler blend with pure paint were synthesized by fabrication method and mixed through mechanical stirrer having a thickness of 150  $\mu\text{m}$  and 450  $\mu\text{m}$  for further process. The different concentrations of low emissivity paint were prepared separately, tested for thermal imaging, emissivity, IR spectroscopy, crosshatch, and aging test. Thermal imaging was first measured that indicated to have very good thermal insulation at high temperature. It was observed to have thermal imaging less than 31 °C from the original temperature at 60 °C. Emissometer and IR spectroscopy were used for the measurement of reflectance and transmission of different paint concentrations in the NIR region. It was observed to have a variation of the emissivity value in the range of 0.4–0.6, depending on the (0–1  $\mu\text{m}$ ) reflectance band and showed almost 0.18% transmissions in the near-infrared region (700–2200 nm). Through crosshatch testing results fall in the 5b and 4b category with excellent and good adhesion. After performing the weather o meter and T & H Chamber test  $\text{Al}_2\text{O}_3$  and ZnO samples showed better results than other oxides and after cross-hatching, the same results records were taken before. This study would be helpful to understand that inclusion of metal oxides especially ( $\text{Al}_2\text{O}_3$  and ZnO) in paint



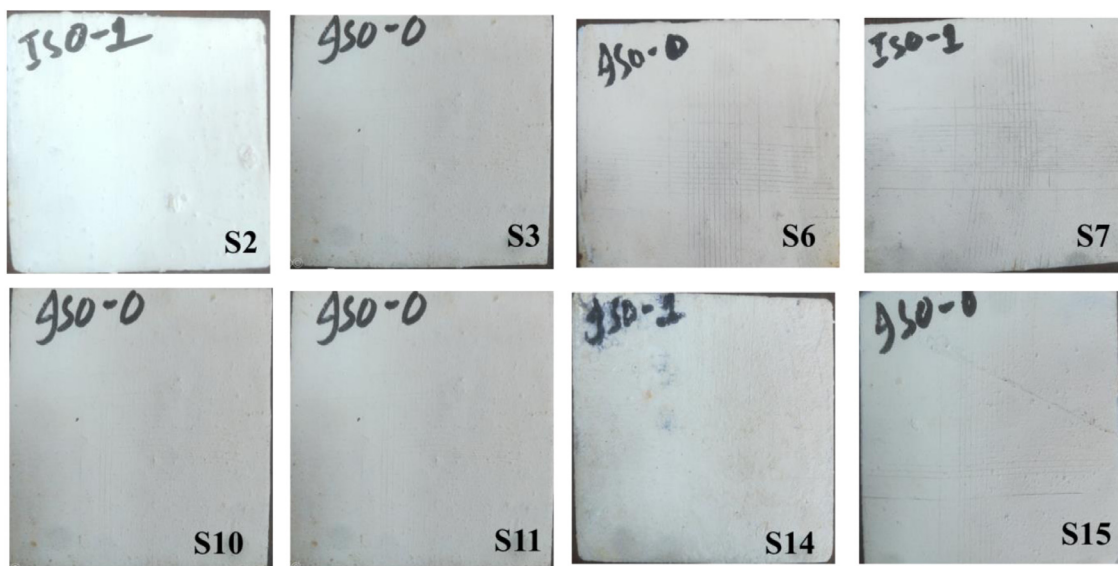


Fig. 9. Results of weather o meter for selected samples.

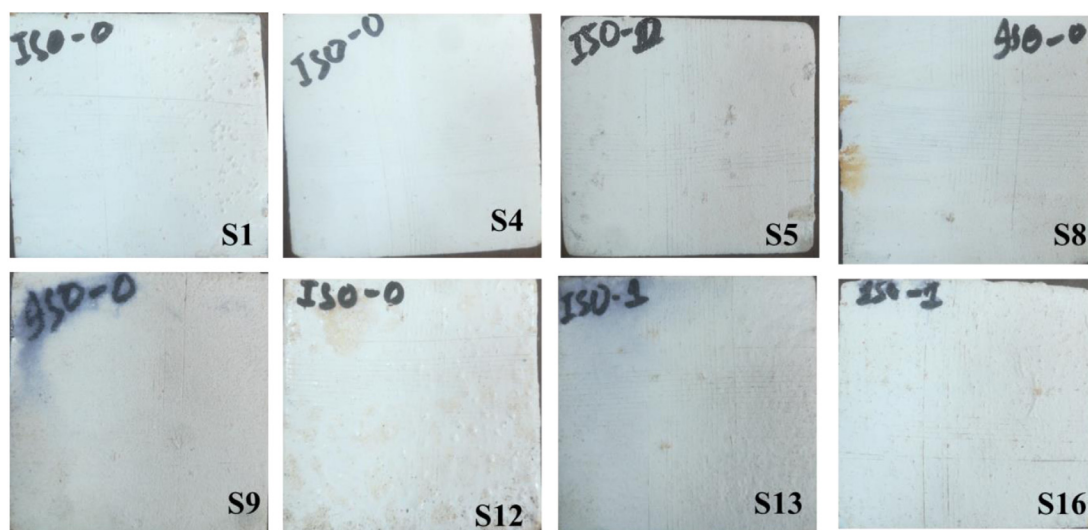


Fig. 10. Results of temperature and humidity chamber test for the selected sample.

**Table 3**  
Literature review of few material, experimental methods and application areas.

Material	Experimental method	Application area	Reference
Tungsten trioxides (WO <sub>3</sub> ), conducting polymers (CPs), vanadium dioxide (VO <sub>2</sub> )	devices based on electrochromism and thermochromism	Infrared camouflage, solar thermal collector, smart energy-saving windows.	Yu et al. (2019)
wall with concrete + cement + white acrylic paint with 30% glass	conventional white acrylic paint	Walls of houses	Yuan et al. (2016)
Tin oxide, silver oxide, or zinc oxide	Sputtered and pyrolytic methods	Internal surface of the windows	Zang (2011)
ZnO and SnO <sub>2</sub> doped with silver	Magnetrons sputtering method	Low-E windows	Zhu et al. (2020)
AlN/Ag low emissivity coatings	Sputtering method	Glass windows	Weathering

**Table 4**

Results of weather o meter and T &amp; H Chamber comparison with before and after cross-hatch results.

Sr. #	Samples	Crosshatch before weather o meter and T & H Chamber	Weather o meter test (one cycle)	Weather o meter test (2nd cycle) Selected samples	T & H Chamber Selected samples	Crosshatch after both test
1	S1	5B/0	No change		No change	5B/0
2	S2	4B/1	No change	No change		4B/1
3	S3	5B/0	No change	No change		5B/0
4	S4	5B/0	No change		No change	5B/0
5	S5	5B/0	No change		No change	5B/0
6	S6	4B/1	No change	No change		4B/1
7	S7	5B/0	No change	No change		5B/0
8	S8	5B/0	No change		Change in color	5B/0
9	S9	5B/0	No change		No change	5B/0
10	S10	5B/0	No change	No change		5B/0
11	S11	4B/1	No change	No change		4B/1
12	S12	4B/1	No change		Change in color	4B/1
13	S13	4B/1	No change		No change	4B/1
14	S14	5B/0	No change	No change		5B/0
15	S15	4B/1	No change	No change		4B/1
16	S16	5B/0	No change		No change	5B/0

showed an acceptable aesthetic emissivity value of  $\sim 0.40$ , 15% reduction in temperature and good adhesion, wear/weather property or good transmission. In future work should be focused to determined actual R-values, improve more reflective insulation in the combination of metal oxides with other insulation materials and climatic conditions. This will help to reduce over heating and cooling equipments.

### CRediT authorship contribution statement

**H.M. Fayzan Shakir:** Formal analysis, Data curation, Visualization, Validation, Writing – original draft. **Aiman Ali:** Investigation, Project administration, Data curation. **Usman Zubair:** Formal analysis, Investigation, Visualization, Data curation. **Ting kai Zhao:** Investigation, Methodology, Software. **Z.A. Rehan:** Conceptualization, Methodology, Software, Writing – review & editing, Supervision. **Imran Shahid:** Funding acquisition, Resources, Supervision.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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