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Abstract: The radiometric properties of metallic roofing materials and their effects on the surface temperature were evaluated. Nine metallic smooth materials used for livestock buildings were tested: 4 were made of aluminium and the other 5 of steel and they were characterised by different colours. Solar reflectivity and long wave infrared emissivity were evaluated by means of laboratory tests; the influence of the radiometric properties on the surface temperature was evaluated in the field by using an experimental structure. The solar reflectivity coefficient ranged from 7.1% for the brown aluminium to 40.1% for the red steel; significant differences of the temperatures were recorded when the solar radiation hitting the metallic surface was higher than 600 Wm-2, a difference of 27.9 % of the solar reflectivity coefficient between the brown steel and the red steel resulted in a difference of the surface temperature up to 4.67 °C. The value of the convection coefficient hc was calculated by means of the data measured in the field, the mean value of hc was equal to 12.2 Wm-2K-1.

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To the Editor
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Dear Editor,

I would like to submit the research paper entitled "Radiometric properties and their influence on the surface temperature of roofing materials for livestock buildings", authors Giuliano Vox, Angela Maneta, Evelia Schettini, for publication in Biosystems Engineering.

Best regards
Evelia Schettini

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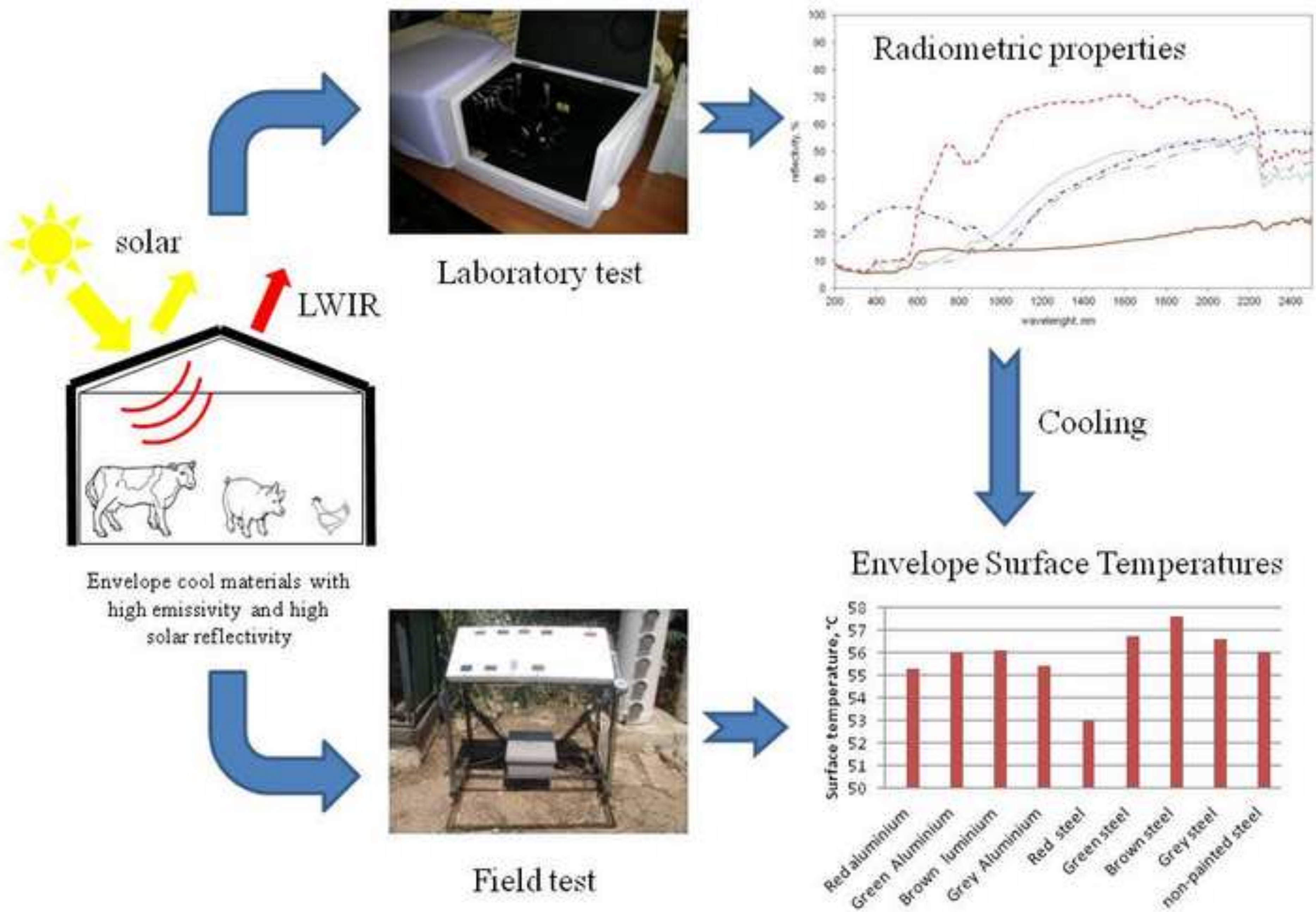
Graphical Abstract (for review)



***Highlights (for review)**

HIGHLIGHTS

- Influence of envelope materials on livestock buildings microclimate
- External surfaces able to reduce solar heat gain
- Red steel with the highest solar reflectivity and the lowest surface temperatures
- The mean value of the convection coefficient was equal to 12.2 W m^{-2} K^{-1}

Evaluation of the radiometric properties of roofing materials for livestock buildings and their effect on the surface temperature

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ABSTRACT

The radiometric properties of metallic roofing materials and their effects on the surface temperature were evaluated. Nine metallic smooth materials used for livestock buildings were tested: 4 were made of aluminium and the other 5 of steel and they were characterised by different colours. Solar reflectivity and long wave infrared emissivity were evaluated by means of laboratory tests; the influence of the radiometric properties on the surface temperature was evaluated in the field by using an experimental structure. The solar reflectivity coefficient ranged from 7.1% for the brown aluminium to 40.1% for the red steel; significant differences of the temperatures were recorded when the solar radiation hitting the metallic surface was higher than 600 Wm^{-2}, a difference of 27.9 % of the solar reflectivity coefficient between the brown steel and the red steel resulted in a difference of the surface temperature up to 4.67 °C. The value of the convection coefficient h_c was calculated by means of the data measured in the field, the mean value of h_c was equal to 12.2 $Wm^{-2}K^{-1}$.

Keywords: steel, aluminium, reflectivity, emissivity, convection coefficient, solar radiation

1. Introduction

Indoor microclimate of livestock buildings plays an important role for animal comfort, health, welfare, growth and productivity (Caroprese, 2008; Jeppsson & Gustafsson, 2001). The indoor air temperature depends on a combination of several different parameters related to the climate of the region, the building itself and its use, and also to the animals. The main parameters influencing the microclimate are: external air temperature and relative humidity, incident solar radiation, long wave radiation exchange between the structure and its surroundings, incidence and speed of the wind, air exchanges, physical and thermal properties of the building's envelope materials, design variables such as building dimensions and orientation, presence of artificial light, electrical equipment and also heat produced by the animals (Simpson & McPherson, 1997; Jo *et al.*, 2010).

In the Mediterranean region the main problem is to control solar heat gain penetrating through the building's surfaces during the hot season. Solar heat is transferred to the internal air through the envelope by the heat transfer mechanisms as conduction, convection and radiation. The increasing of the indoor air temperature is influenced by the solar radiation incident on the external surfaces of the buildings and as well as by the heat exchange processes between the building and the external environment. Of the total solar radiation incident on the outer surface of the building, a part of it is reflected to the environment, a part is absorbed by the surface and the remaining part is conducted into the envelope. The part that is transmitted by conduction into the building envelope is characterized by a damping and phase shift heat thermal wave; afterwards this energy is transferred by convection with delay from the internal surface of the building to the indoor air. The external building surface exchanges energy by convection with the external air, by conduction with the internal layers of the surface, by radiation through the daytime absorption of the solar radiation and the long wave infrared radiation coming from atmosphere, and by radiation through the emission of infrared radiation towards the external area connected with the surface temperature (Cooper *et al*., 1998; Jeppsson & Gustafsson, 2001) .

Exterior surface temperature is a key parameter that is influenced by the physical properties of the surface, such as the solar reflectance, infrared emittance and the convection coefficient (Berdahl & Bretz, 1997); the latter can be modified using architectural features, such as screens, that can influence air flow near the roof surface. In order to control surface temperature, the materials must be characterized by adequate radiometric properties, such as high solar reflectance or albedo, which expresses the ability of a material surface to reflect the incident solar radiation, and high infrared emissivity, defined as the ability of a surface to release away the absorbed heat by radiation (Bretz & Akbari, 1997; Gentle *et al.*, 2011; Joudi *et al.*, 2013; Karlessi *et al.*, 2011; Synnefa *et al.*, 2006; Zinzi *et al.*, 2012). These materials, known as cool materials, can be used on external surfaces of the livestock buildings remaining cool under the sun at day-time and radiating away the stored heat during night-time. Moreover low-emissivity materials applied to the internal surface of the building can decrease the amount of long-wave thermal energy radiated to the interior of the buildings (Uemoto *et al.*, 2010; Bretz *et al.*, 1998).

Lower surface temperatures reduce building heat gain decreasing the cooling loads in case of air conditioning, or creating more comfortable thermal conditions inside non-air-conditioned buildings (Berdahl & Bretz, 1997; Bretz & Akbari, 1997; Bretz *et al.*, 1998; Gentle *et al.*, 2011). Improvements that limit solar heat gain will result in energy cost savings reducing also building's overall environmental impact thus increasing the sustainability of the productions in the rural land (Bretz *et al.*, 1998; Jo *et al.*, 2010; Picuno, 2014; Picuno *et al.*, 2012; Briassoulis *et al.*, 2013; Castellano *et al.*, 2008) .

Commercially available cool materials to be used for roofs and walls include cool roof coatings (elastomeric, acrylic, etc), cool single ply membranes, reflective tiles and metal roofs (Synnefa *et al.*, 2006). Non-metallic inorganic materials such as fiber cement tiles are greatly emissive (Uemoto *et al.*, 2010). Low-emissivity materials include many aluminum coatings and unpainted metal shingles or panels (Bretz *et al.*, 1998).

External surface temperature of building's envelope is also affected by the convection heat transfer coefficient (h_c) of the surface; the higher h_c, the lower surface temperature. Convection heat transfer coefficient depends on wind velocity, surface orientation and roughness and difference of temperature between surface and air temperature. Numerous reserches have been carried out to define convection coefficients, obtaining several mathematical laws and a large spectrum of results (Defraeye *et al.*, 2011; Hagishima & Tanimoto, 2003; Kindelan, 1980; Liu & Harris, 2007; Loveday & Taki, 1996; Jayamaha *et al.*, 1996; Zhang *et al.*, 2004).

Aim of this paper is to compare the radiometric properties of different metallic constructive materials used for the outer surfaces of livestock buildings as simple or as sheet layers in an insulated sandwich panel type. The radiometric properties of 9 different aluminum and steel materials were tested, their surface temperature, when exposed to solar radiation, was measured and evaluated in relation with the radiometric properties. A heat balance equation was defined for the surface and it was used to calculate the value of the effective convection heat transfer coefficient.

2. Radiometric properties of envelope surfaces

Knowledge of the surface radiometric characteristics of construction materials is important when assessing the potential benefit on building microclimate of different materials under similar environmental conditions (Bretz & Akbari, 1997; Prado & Ferreira, 2005).

The solar reflectivity ρ_λ of a surface at a wavelength λ is the ratio of the reflected solar radiation to the incident solar radiation at the surface at the same wavelength λ ; it includes specular and diffuse reflection. Specular reflection occurs when the beam of incident solar radiation is reflected from a smooth surface with the angle of incidence equal to the angle of reflection respect to the surface normal. Diffuse reflection occurs when a rough or opaque surface reflects the beam of incident solar radiation at many angles, i.e. breaking up and scattering it into different directions. Specular reflection increases with the increasing of the angle of incidence and a specularly reflecting surface absorbs less solar radiation in comparison than a diffusive surface made of the same materials.

Solar radiation that reaches the Earth's surface is an electromagnetic radiation in the wavelength range from 280 to 2500 nm. Thus, the capacity of a construction material to reflect solar radiation is defined by its capacity to reflect in this range of wavelengths (Prado & Ferreira, 2005; Duffie & Beckman, 1991). The ability of a surface to reflect and, afterwards, to absorb the solar radiation is evalauted by means of a coefficient of reflectivity that is obtained as the weighted average of the spectral reflectivity using as weighting function the spectral distribution of the solar radiation incident on the terrestrial surface (Fig. 1).

The solar reflectivity coefficient is measured on a scale from 0 to 100 %: a value equal to 0 means no reflecting power of a perfectly black surface (none reflected, all absorbed), a value of 100% means perfect reflection of a perfectly white surface (all reflected) (Li *et al.*, 2013). The solar reflectivity of a surface depends upon material properties such as colour, and surface roughness, and presence of impurities (Berdahl & Bretz, 1997).

In addition to solar reflectivity, the emissivity of a surface also affects surface temperature; infrared emission plays an important role in the energy exchange at the outer surface of a building (Monteith & Unsworth, 1990; Siegel & Howell, 1972). The emissivity ε_λ of a surface at a wavelength λ is the measure of the ability of a surface at ambient temperature to emit energy in the form of thermal radiation in the Long Wave Infrared Radiation (LWIR) range, for wavelength values higher than 3000 nm. All objects continuously emit infrared radiation and at the same time absorb some of the infrared radiation emitted by the other surrounding objects. Moreover, the external surfaces of a building receive also infrared radiation emitted from the atmosphere toward the ground (Chou *et al.*, 1991; Ineichen *et al.*, 1984; Sherwood & Jackson, 1969; Swinbank, 1963). In fact, the water vapor and the carbon dioxide contained in the atmosphere emit radiation in the LWIR wavelength range. The amount of direct radiation towards the ground is a function of the weather conditions of the location and of the time of the year, such as air temperature, air relative humidity and pressure, as well as the presence of clouds (Rasmussen *et al.*, 1998).

The energy balance of an external surface in the LWIR range depends on the energy that this surface receives and emittes. When a surface is hitted by intense solar radiation as during summertime, the emitted energy, proportional to the fourth power of the absolute temperature (Siegel & Howell, 1972), is greater than the energy received from the sky and from the other surrounding bodies. Thus, a coating material characterised by a high value of emissivity is desirable to reduce temperatures that occur inside.

The emissivity coefficient can have a value from 0 (shiny mirror) to 100% (blackbody). In literature emissivity values higher to 80 % are reported for fiber cement or wood. Low-emissivity materials include many aluminium coatings and unpainted metal shingles or panels (Bretz *et al.*, 1998). A low emissivity material maintains a higher surface temperature in the sun than a high emissivity material with the same solar-reflectance.

3. Materials and methods

Laboratory and field tests were performed in order to compare different roofing metallic materials; laboratory tests were performed in order to evaluate the radiometric properties of the materials, field tests were carried out in order to evaluate the surface temperature of the materials exposed to solar radiation.

3.1. Roofing materials

Nine metallic smooth samples were tested: 4 were made of aluminium and the other 5 of steel; the materials, produced by Tegomont (Arsago Seprio, Varese, Italy), are commercially used as simple or as sheet layers in an insulated sandwich panel type, applied as building's envelope materials. The steel and aluminium plates, coated with a polyester paint having a thickness of 25 μm, were characterised by different colors: red, brown, green and grey (Fig. 2); one sample of non-painted galvanized steel was also tested.

3.2. Radiometric tests and calculation methodology

The radiometric tests were carried out at the DISAAT Department of the University of Bari (Italy); the reflectivity of the materials was measured in the solar range (200-2500 nm) and in the LWIR range (2500-25000 nm). The measurements in the solar wavelength band from 200 to 2500 nm were carried out by means of a double beam UV-VIS-NIR spectrophotometer (Lambda 950, Perkin Elmer Instruments, Norwalk, CT, USA), in steps of 10 nm using radiation with a direct perpendicular incidence. An integrating sphere (diameter 60 mm) was used as receiver of the spectrophotometer, with a double beam comparative method (Wendlandt & Hecht, 1966), , to measure the fraction of diffuse radiation reflected from the sample examined. Tests in the LWIR range, between 2500 and 25000 nm, were carried out by a FT-IR spectrophotometer (1760 X, Perkin Elmer Instruments, Norwalk, CT, USA) in steps of 4 cm^{-1}; near normal reflectivity was measured, i.e. with a radius of incidence on the sample forming an angle of 10 ° with the normal to the same.

The emissivity was calculated from the reflectivity by the law of Kirchhoff (Siegel & Howell, 1972):

$$\varepsilon_\lambda = 1 - \rho_\lambda \tag{1}$$

where ρ_λ and ε_λ are the spectral reflectivity and the spectral emissivity at wavelength λ, respectively.

The radiometric coefficients of the materials were calculated as average values of the spectral values over different wavelength bands: the solar wavelength range (200-2500 nm) and the long wave infrared radiation (LWIR) range (7500-12500 nm).

The reflectivity coefficient in the solar range (R_{sol}) was calculated as the weighted average value of the spectral reflectivity using the spectral distribution of the solar radiation at the ground level as weighting function (Duffie & Beckman, 1991; Papadakis *et al.*, 2000; Vox *et al.*, 2005). The R_{sol} coefficient was calculated with:

$$R_{sol} = \frac{\sum_{i=1}^{N} S_{\lambda i} \rho_{\lambda i} \Delta\lambda}{\sum_{i=1}^{N} S_{\lambda i} \Delta\lambda} \qquad (2)$$

where λ_i is the wavelength that assumes discrete values ranging between 350 and 2500 nm; $\rho_{\lambda i}$ is the spectral reflectivity measured in the range of wavelength $\Delta\lambda$ around the wavelength $\lambda_{i;}$ $S_{\lambda i}$ is the weighting function that takes into account the spectral distribution of the solar radiation incident on the Earth's surface in the same range of wavelength (ISO 9050, 1990; Papadakis *et al.*, 2000).

The emissivity coefficients in the LWIR range were calculated as average values of the spectral emissivity in the wavelength range from 7500 to 12500 nm (Scarascia Mugnozza *et al.*, 1994; Vox *et al.*, 2010). This interval was chosen because it corresponds to the range of wavelength where the emission of the bodies at room temperature is maximum, being an index of the ability of the material to emit radiation and to disperse heat.

3.3. The experimental field test

The experimental set-up consisted of an isolating polystyrene foam board, mounted on a iron bearing construction, having a slope of 10° (Fig. 3) that is a typical slope of roofs. The samples were spaced one from another so as not to interfere each other; rectangular metallic samples having a size of 9 cm x 5 cm and a thickness of 0.65 mm were tested in the field.

The experimental apparatus was placed in open air from July to September 2013 at the University of Bari in Bari (Italy), latitude 41°08′ N and longitude 16°51′ E.

The following variables were continuously measured during the testing period: external air temperature with a Hygroclip-S3 sensor (Rotronic, Zurich, Switzerland); metallic sample surface temperature by means of contact thermistors (Tecno.el s.r.l. Formello, Rome, Italy); solar radiation in the wavelength range 0.3-3.0 μm, by means of a pyranometer model 8104 (Schenk, Wien, Austria); wind speed by the Young Wind Sentry anemometer (Young Company, Traverse City, Michigan, U.S.A). The data, measured with a frequency of 60 s, were averaged every 5 minutes and stored in a data logger (CR10X, Campbell, Logan, USA). The sensors used to measure the surface temperature were attached on the back side of the plates. The pyranometer was situated over the iron bearing construction, keeping the same slope in order to measure the amount of solar radiation received by the materials.

The averages temperatures of the surfaces, of the air and of the radiation were calculated over 8 time samples recorded every 300 s. Statistical analyses were carried out with the CoStat software (CoHort Software, Monterey, CA, USA); analysis of variance (ANOVA) at 95 percent probability level was carried out in order to compare temperature mean values; correlations were evaluated by means of the Pearson product moment correlation coefficient.

3.4. Evaluation of the convection heat transfer coefficient

Surface temperatures measured in the field were used to evaluate the effective convection heat transfer coefficient h_c ($Wm^{-2}K^{-1}$), which was calculated by the following equation obtained modifying the equation used by Prado and Ferreira (2005):

$$(1-\alpha)R = \varepsilon\sigma\left(T_s^4 - F_{sky-s}T_{sky}^4\right) + h_c(T_s - T_a) \qquad (3)$$

where R (Wm^{-2}) is the solar radiation, α is the solar reflectivity coefficient of the surface, $F_{sky—s}$ is the view factor between the emitter (sky) and the receiver (surface) (Sparrow, 1963; Vox *et al.*, 1996), T_s (K) is the temperature of the surface, T_a (K) is the air temperature, T_{sky} (K) is the sky temperature calculated by:

$$T_{sky} = 0.0552T_a^{\frac{3}{2}} \qquad \text{for clear skies} \qquad (4)$$

$$T_{sky} = T_a \qquad \text{for overcast skies} \qquad (5)$$

The sky temperature (T_{sky}) takes into account the downward flux of the atmospheric radiation at the earth's surface emitted in the long wave infrared range by the atmospheric gases, mainly water vapour and carbon dioxide (Kindelan, 1980; Monteith & Unsworth, 1980) .

4. Results and discussion

4.1. Radiometric characteristics of the materials

The curves of the spectral reflectivity of the aluminium materials in the solar range show that the highest reflectivity was recorded for the red aluminium (Fig. 4), which was also characterized by the highest value of the reflectivity coefficient, equal to 22.1 %, while the same coefficient was equal to 10.5% for the grey aluminium, 8.7% for the green aluminium and 7.1% for the brown aluminium (Table 1). Prado and Ferreira (2005) found for the red aluminium a total solar reflectance equal to 45.7%.

Among the steel materials, the spectral reflectivity curves (Fig. 5) show a different behaviour between the red steel and the other steel materials, in fact the red steel was characterized by a reflectivity coefficient equal to 40.1%, higher than the values evaluated for the green, grey and brown steel materials (Table 1). The red steel was characterised by a higher reflectivity also in comparison with the non-painted steel, the value of which was equal to 27.4%. Prado and Ferreira (2005) recorded a reflectivity coefficient equal to 37.6 % for the red steel, 21.7 % for the green steel and 72.6 % for the uncoated steel.

For red painted metal coverings Kültür and Türkeri (2012) summarized values of total solar reflectance ranging from 25 % to 45 % and for non-painted metal coverings from 20 % to 60 %; a total solar reflectance equal to 65 % was recorded for a silver aluminium sheet.

In the LWIR range from 3000 nm to 25000 nm all the materials, with the exception of the non-painted steel, were characterised by high values of emissivity (Fig. 6 and 7).

Emissivity coefficients in the LWIR band ranged from 98.2% (green) to 98.9% (brown) for the aluminum materials (Table 1). Concerning the steel materials, significant differences were recorded between the painted steel and the non-painted material (Fig. 7, Table 1); the emissivity coefficient ranged from 91.1% for the grey steel to 98.7% for the green steel while the non-painted steel showed a coefficient of emissivity equal to 5.7%.

Prado and Ferreira(2005) recorded emissivity coefficients of about 90 % for the red and green steel, while for the steel without coating recorded a lower value, equal to 25%.

Berdahl and Bretz (1997) found for the galvanized non-coated steel an emissivity coefficient equal to 10 %. Kültür and Türkeri (2012) recorded for red painted metal coverings an emissivity coefficient ranging from 80 % to 90 % and for non-painted metal coverings emissivity coefficients ranging from 5 % to 35 %.

4.2. Surface temperatures of the materials

The measured temperatures of the metallic plates were evaluated during three days (18-20/7/2013) for 4 different ranges of solar radiation (R): between 500 and 600 Wm^{-2} (Table 2), between 600 and 700 Wm^{-2} (Table 3), between 700 and 800 Wm^{-2} (Table 4) and for values of radiation higher than 800 Wm^{-2} (Table 5). The average radiation and the average temperature of the metallic surfaces and of the air were calculated in correspondence of the same time intervals.

Measurements of temperature were carried out at the beginning and at the end of the field tests, keeping the sensors in the same temperature conditions, in order to obtain values useful to compensate the systematic error of the sensors.

In the solar radiation range 500-600 Wm^{-2}, the surfaces temperatures did not show significant differences between the materials (Table 2).

Concerning the other higher radiation ranges ($R > 600$ Wm^{-2}) the different metallic surfaces showed significant differences of the temperatures that were influenced by the radiometric properties. Among the steel and aluminium materials, the red steel was always characterized by the lowest surface temperatures while the brown steel was characterized by the highest temperatures (Tables 3-5). The brown steel recorded the highest value of surface temperature, equal to 58.37 °C (R=838 Wm^{-2}, Table 5), the red steel the lowest value equal to 44.85 °C (R= 654 Wm^{-2}, Table 3). The difference between the temperature recorded for the brown steel and the red steel ranged from 4.33 °C (R=834 Wm^{-2}) to 4.67 °C (R=650 Wm^{-2}). Synnefa *et al*. (2006) recorded in Athens (Greece) a maximum surface temperature of 56.85 °C with a solar radiation of about 800 Wm^{-2} for an aluminium coating with a solar reflectivity coefficient of about 40 % and an emissivity coefficient of 71 %.

The behaviour of the materials tested in the present research was compatible with their radiometric properties (Table 1): the red steel was characterized by the highest reflectivity coefficient in the solar range, equal to 40.1%, while the brown steel by a low reflectivity coefficient, equal to 12.2%; the higher LWIR emissivity coefficient of the brown steel did not compensate the difference of the solar reflectivity coefficient.

The grey steel and the green steel behaved statistically in a similar way (Tables 2-5) due to their similar reflectivity coefficients in the solar range (Table 1), while the effect on the surface temperature of the difference between the LWIR emissivity coefficients (7.6 %) was not significant.

Temperature of the non-painted steel was often higher than the temperature of materials with lower solar reflectivity coefficient; temperature of the non-painted steel was affected by the opposite effects of the high solar reflectivity coefficient (27.4 %), able to cool the surface, and of the low LWIR emissivity coefficient (5.7%), which allowed a low heat dissipation, thus reducing the cooling effect of the low solar reflectivity.

The aluminium materials were characterized by LWIR emissivity coefficients very similar, such value ranging between 98.2 % (green aluminium) and 98.9 % (brown aluminium), thus temperature differences were determined by the solar reflectivity; the red aluminium showed the lowest values of its surface temperature due to its higher reflectivity coefficient in the solar range, equal to 22.1% .

4.3. The convection heat transfer coefficient

The values of the effective convection heat transfer coefficient h_c were calculated by the equation (3), where the data measured in the field were used for T_s and T_a , while $F_{sky—s}$ was set to 0.7 in relation with the surfaces orientation (Sparrow, 1963; Vox *et al.*, 1996). The results showed that the mean value of h_c was equal to 12.2 $Wm^{-2}K^{-1}$.

Prado and Ferreira (2005) used for aluminium and steel surfaces a convection heat transfer coefficient equal to 12 W m^{-2} K^{-1}, while Berdahl and Bretz (1997) obtained, from their outdoor measurements at Berkeley Laboratory, an approximate convection coefficient ranging between 18 W m^{-2} K^{-1} and 25 W m^{-2} K^{-1} for different kinds of materials.

The wind velocity ranged from 1.1 ms^{-1} to 1.4 ms^{-1} during the measurements; the evaluation of the Pearson product moment correlation coefficient showed no significant correlation between h_c and wind speed, due to the very low variation of the wind speed.

The difference (ΔT) between T_s and T_a showed high variations during the measurements. Given that the h_c coefficient can be expressed as a function of the ΔT value (Defraeye *et al.*, 2011) the dependence of h_c on ΔT was investigated. The Pearson product moment correlation coefficient showed no significant correlation between h_c and ΔT.

5. Conclusions

The research showed that the radiometric properties influenced the surface temperature of the metallic sheets; significant differences of the temperatures were pointed out when the solar radiation hitting the metallic surface was higher than 600 Wm^{-2}. The higher was the solar reflectivity coefficient, the lower the surface temperature; a difference of 27.9 % of the solar reflectivity coefficient between the brown steel and the red steel resulted in a difference of the surface temperature ranging from 4.33 °C to 4.67 °C . The results showed that values of the solar reflectivity coefficient higher that 40% and of the emissivity coefficient higher than 90 % are able to reduce significantly the surface temperature of the metallic surface. Future research should be addressed in order to increase the solar reflectivity values of the materials especially in the wavelength range 400-800 nm where the solar radiation has its emission spectral peaks.

The value of the convection coefficient h_c, calculated by means of the data measured in the field, is a useful contribution to the scientific literature, by adding information on the value of the coefficient with reference to the slope of the surface, the wind velocity and the difference of temperature between the surface and the air.

The use of cool materials, with improved radiometric properties, is a must and not an option in the design of eco-buildings in regions characterized by hot summer climates.

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Figure Captions

Figure 1. Spectral distribution of the solar radiation incident on the earth's surface; measurements carried out in Bari (Italy), latitude. 41 ° 05' N, at 12 am on 5 June 2009

Figure 2. Painted steel (bottom) and aluminium (top) plates.

Figure 3. The experimental apparatus

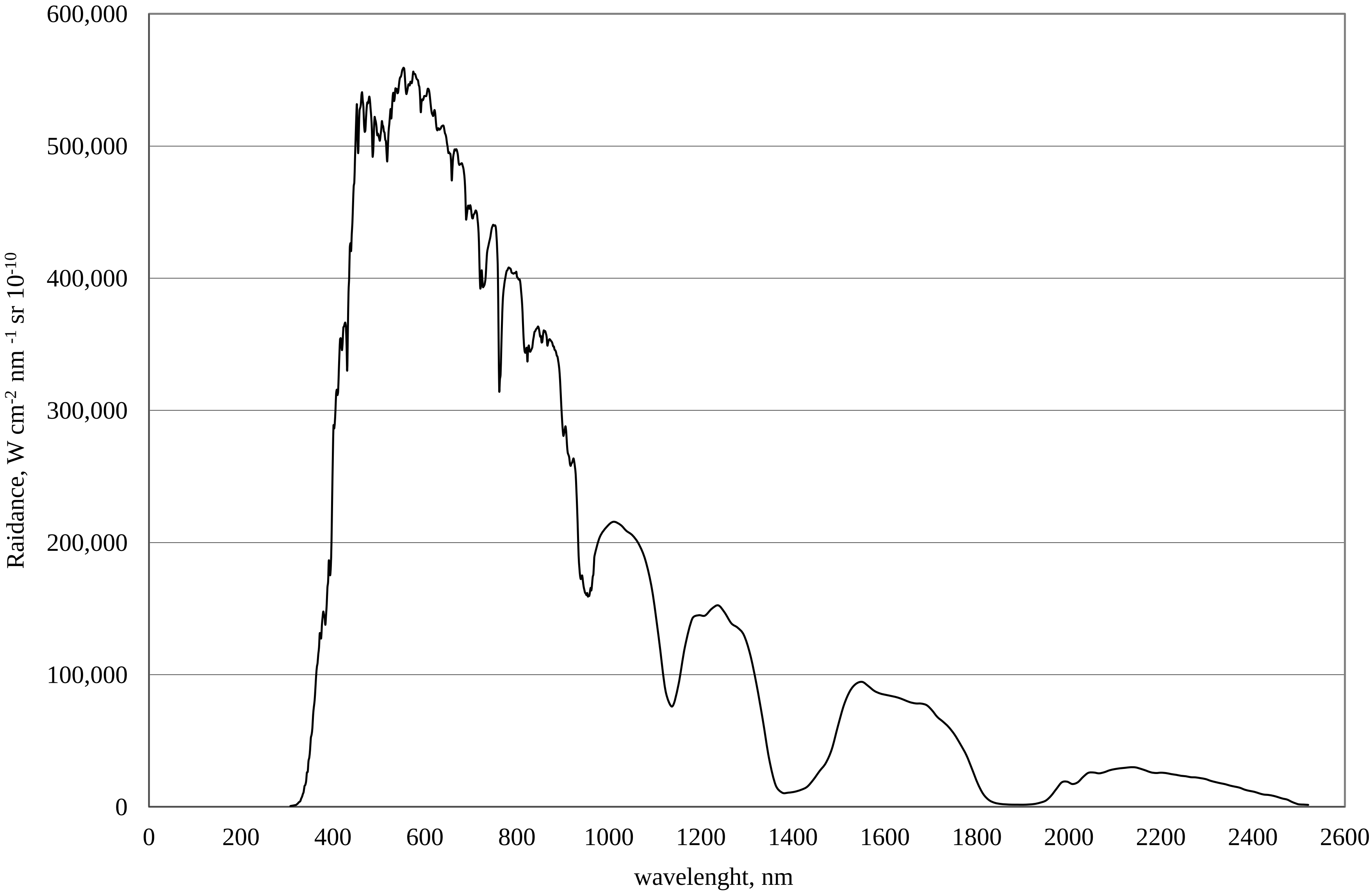
Figure 4. Spectral reflectivity of the red, grey, green and brown aluminium in the solar wavelength range (200-2500 nm).

Figure 5. Spectral reflectivity of the red, grey, green, brown and non-painted steel in the solar wavelength range (200-2500 nm).

Figure 6. Long wave infrared (LWIR) spectral emissivity of the red, grey, green and brown aluminium in the wavelength range 3000-25000 nm.

Figure 7. Long wave infrared (LWIR) spectral emissivity of the red, grey, green, brown and non-painted steel in the wavelength range 3000-25000 nm.

Figure 1



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Raidance, W cm-2 nm -1 sr 10-10
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2200
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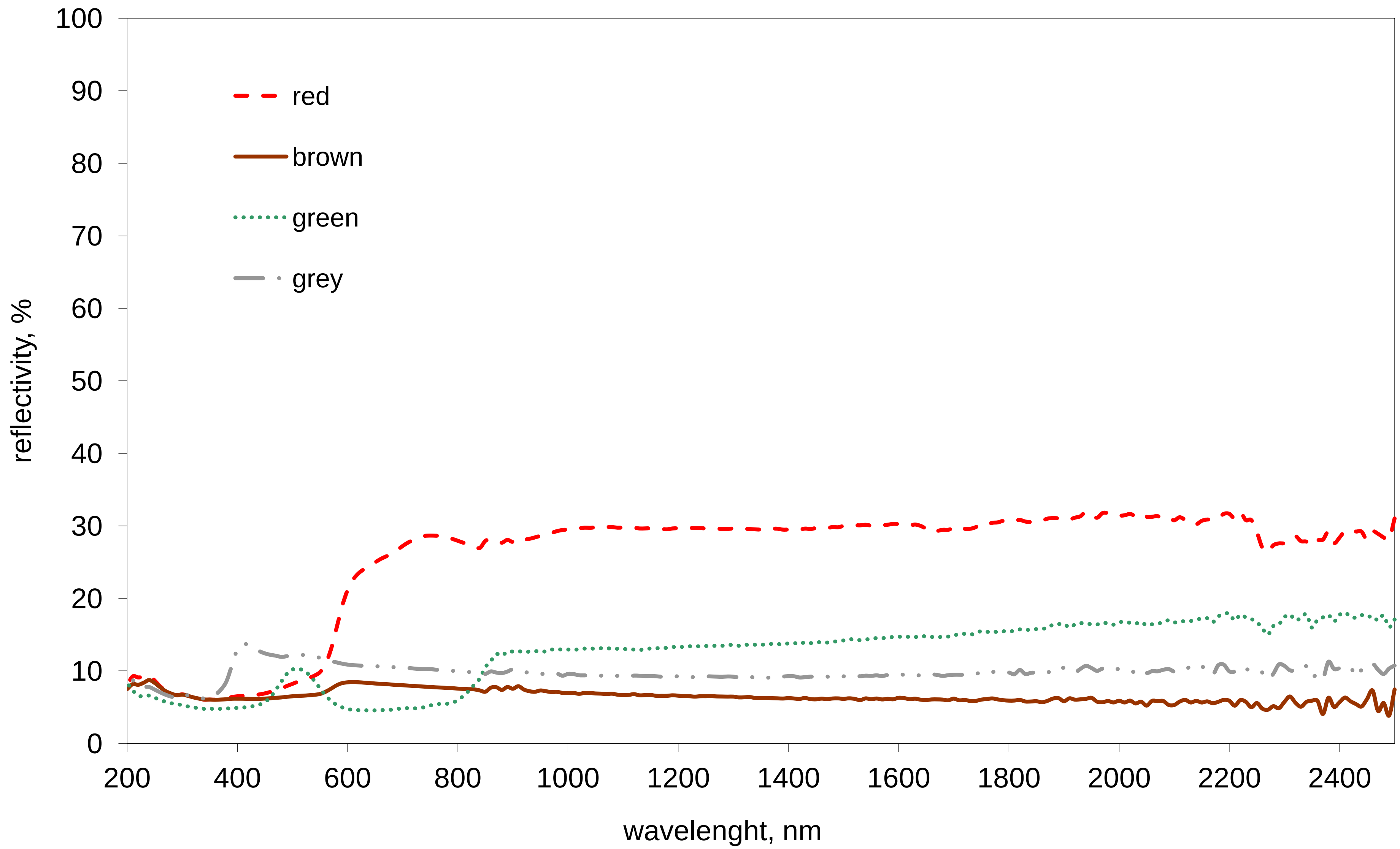
2600
wavelenght, nm

Figure 2
Click here to download high resolution image

Figure 3
Click here to download high resolution image

Figure 4



red
brown
green
grey
reflectivity, %
100
90
80
70
60
50
40
30
20
10
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600
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1000
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1400
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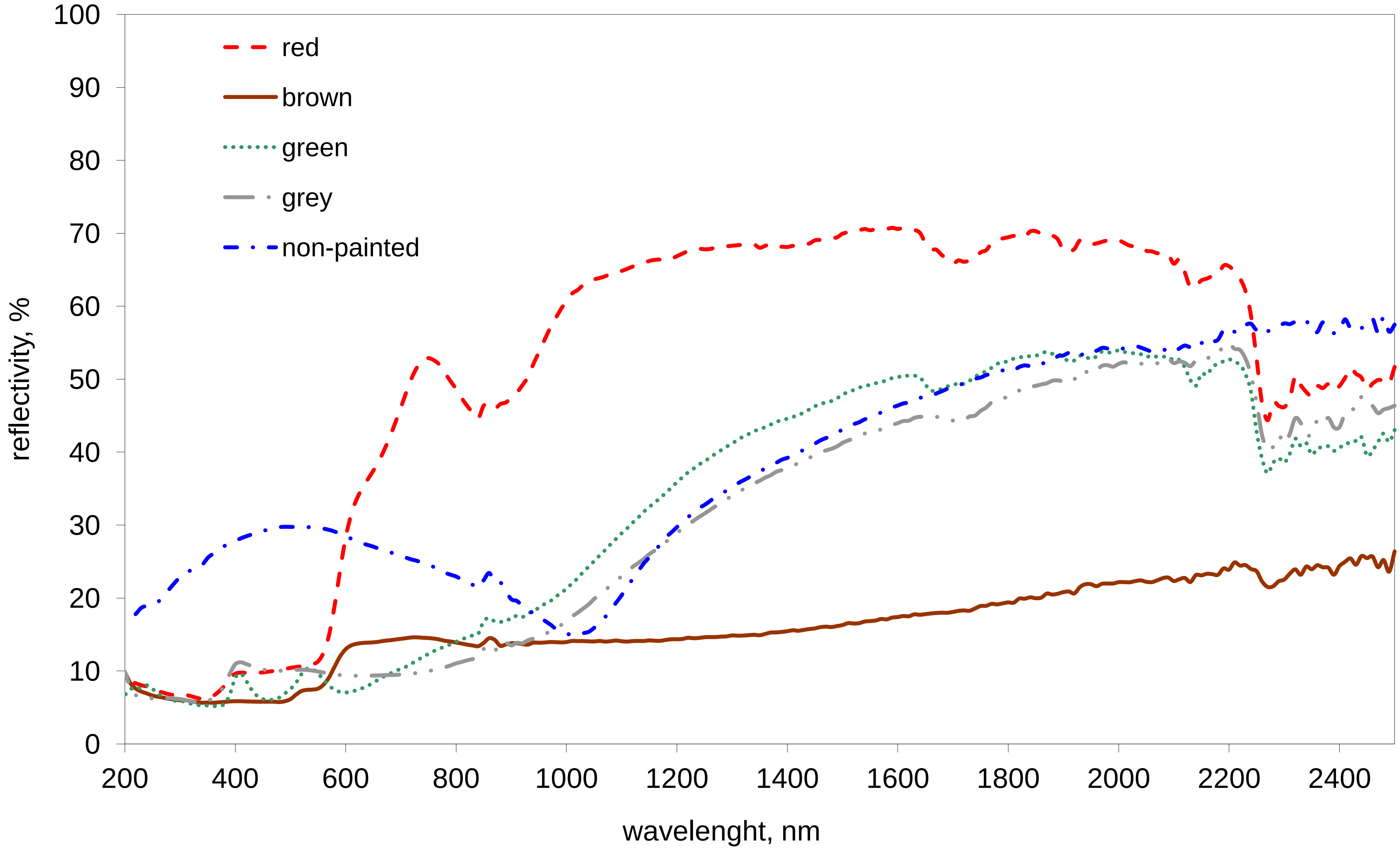
1800
2000
2200
2400
wavelenght, nm

Figure 5



100
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reflectivity, %
200
400
600
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1000
1200
1400
1600
1800
2000
2200
2400
wavelenght, nm
red
brown
green
grey
non-painted

Figure 6

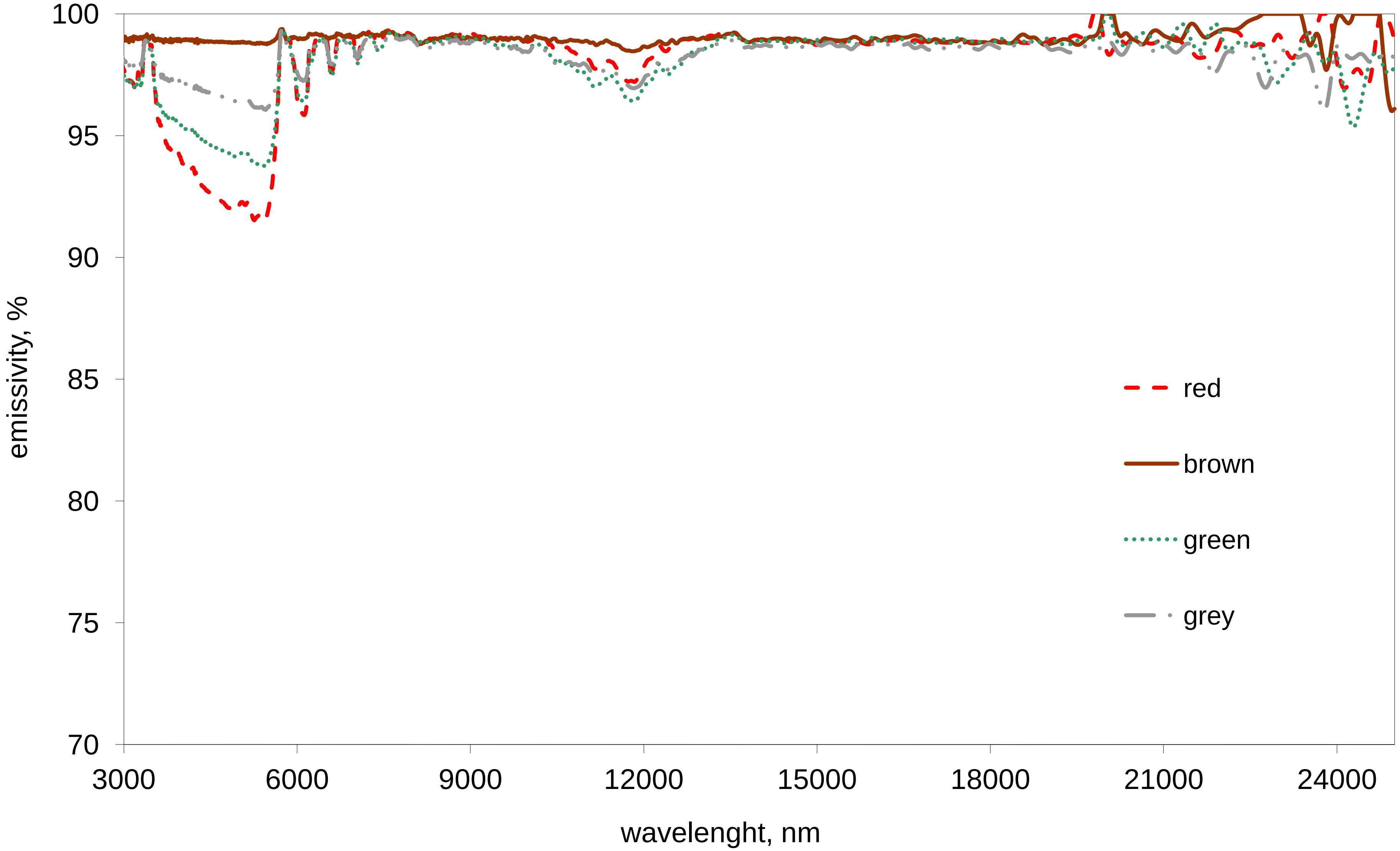
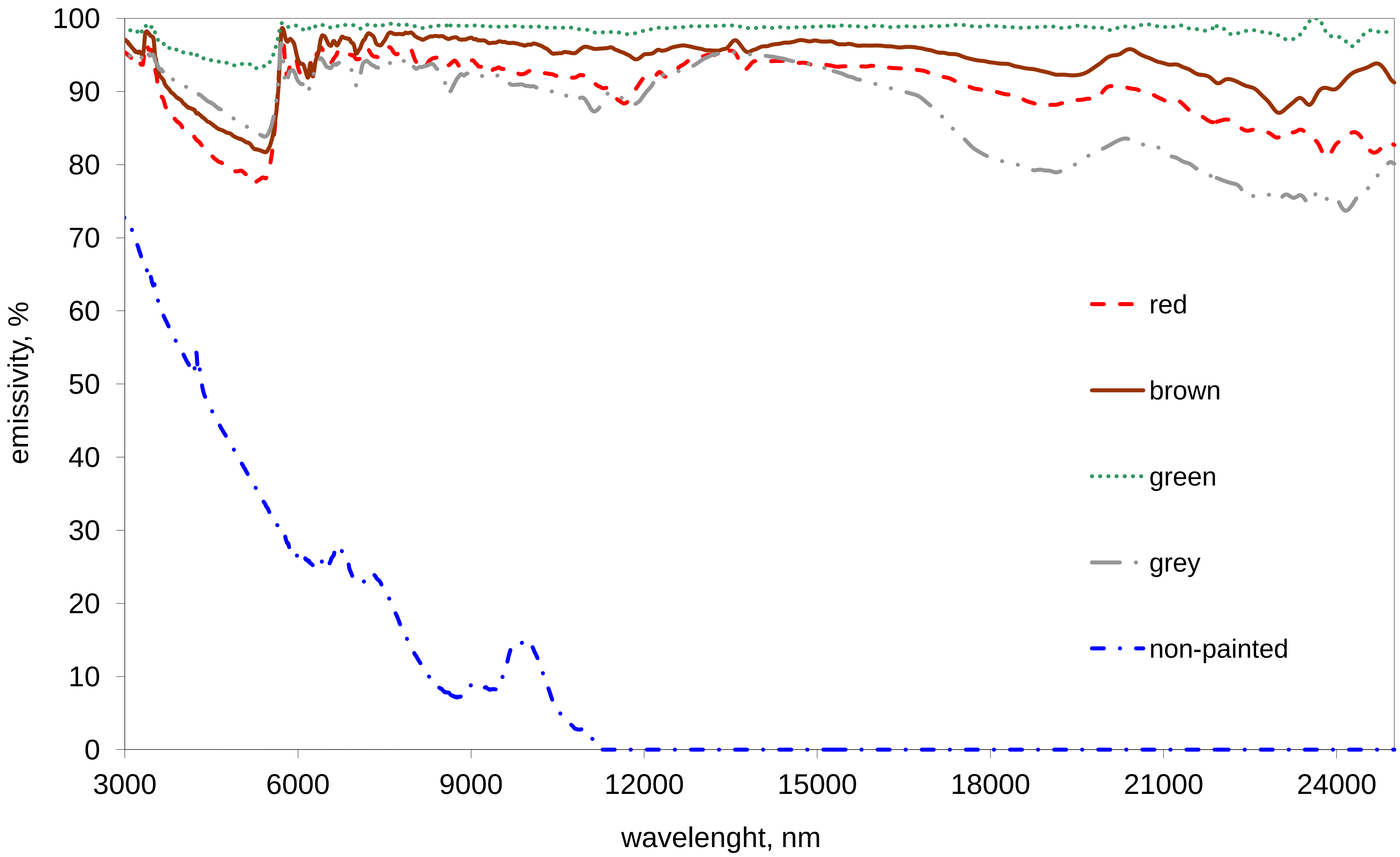

100
95
90
85
80
75
70
emissivity, %
3000
6000
9000
12000
15000
18000
21000
24000
wavelenght, nm
red
brown
green
grey

Figure 7


100
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emissivity, %
3000
6000
9000
12000
15000
18000
21000
24000
wavelenght, nm
red
brown
green
grey
non-painted

Table 1

Reflectivity coefficients in the solar range (200-2500 nm) and emissivity coefficients in the LWIR range (7500-12500 nm).

Materials	solar(1) reflectivity (%)	LWIR(2) emissivity (%)
Red aluminium	22.1	98.6
Brown aluminium	7.1	98.9
Green aluminium	8.7	98.2
Grey aluminium	10.5	98.3
Red steel	40.1	92.7
Brown steel	12.2	96.4
green steel	17.2	98.7
grey steel	15.7	91.1
non-painted galvanized steel	27.4	5.7

(1)value calculated as weighted average (ISO 9050, 1990)

(2)value calculated as arithmetic average

Table 2

Average temperature of the metallic surfaces at an average value of solar radiation in the range 500-600 Wm^{-2}.

	day	18/7/2013	19/7/2013	20/7/2013
	solar radiation	548 W m^{-2}	550 W m^{-2}	552 W m^{-2}
	air temperature	26.8 °C	27.0 °C	26.3 °C
		surface temperature (°C)		
Red aluminium		40.82^{a}	42.90^{a}	43.15^{a}
Green aluminium		43.20^{a}	44.53^{a}	44.71^{a}
Brown aluminium		42.17^{a}	43.32^{a}	43.42^{a}
Grey aluminium		41.99^{a}	42.87^{a}	43.19^{a}
Red steel		39.27^{a}	40.28^{a}	40.59^{a}
Green steel		42.66^{a}	43.75^{a}	44.19^{a}
Brown steel		43.13^{a}	44.76^{a}	44.58^{a}
Grey steel		42.36^{a}	43.54^{a}	43.73^{a}
non-painted galvanized steel		42.64^{a}	44.38^{a}	44.14^{a}

Table 3

Average temperature of the metallic surfaces at an average value of solar radiation in the range 600 – 700 Wm^{-2}.

	day	18/7/2013	19/7/2013	20/7/2013
	solar radiation	654 W m^{-2}	650 W m^{-2}	657 W m^{-2}
	air temperature	27.1 °C	27.9 °C	27.6 °C
		surface temperature (°C)		
Red aluminium		45.30^{c}	48.41^{c}	48.19^{b}
Green aluminium		48.17^{ab}	49.86^{abc}	49.62^{ab}
Brown aluminium		47.57^{ab}	49.28^{bc}	48.75^{ab}
Grey aluminium		46.84^{b}	48.28^{c}	48.17^{b}
Red steel		44.85^{c}	46.50^{d}	45.90^{c}
Green steel		47.87^{ab}	49.48^{bc}	49.31^{ab}
Brown steel		49.22^{a}	51.17^{a}	50.32^{a}
Grey steel		47.78^{ab}	49.42^{bc}	49.09^{ab}
non-painted galvanized steel		48.10^{ab}	50.07^{ab}	49.32^{ab}

Table 4

Average temperature of the metallic surfaces at an average value of solar radiation in the range 700 – 800 Wm^{-2}.

	day	18/7/2013	19/7/2013	20/7/2013
	solar radiation	771 W m^{-2}	775 W m^{-2}	770 W m^{-2}
	air temperature	27.2 °C	28.3 °C	28.6 °C
		surface temperature (°C)		
Red aluminium		49.66^{d}	53.83^{c}	53.21^{b}
Green aluminium		52.32^{b}	54.79^{b}	54.18^{ab}
Brown aluminium		52.10^{b}	54.44^{b}	53.72^{b}
Grey aluminium		51.36^{c}	53.68^{c}	53.02^{b}
Red steel		49.35^{d}	51.62^{d}	50.91^{c}
Green steel		52.74^{b}	55.02^{b}	54.44^{ab}
Brown steel		53.89^{a}	56.26^{a}	55.45^{a}
Grey steel		52.44^{b}	54.99^{b}	54.32^{ab}
non-painted galvanized steel		52.23^{b}	54.80^{b}	53.91^{b}

Table 5

Average temperature of the metallic surfaces at an average value of solar radiation in the range > 800 Wm^{-2}.

	day	18/7/2013	19/7/2013	20/7/2013
	solar radiation	845 W m^{-2}	834 W m^{-2}	838 W m^{-2}
	air temperature	27.8 °C	28.7 °C	29.3 °C
		surface temperature (°C)		
Red aluminium		55.28^{d}	56.03^{b}	56.07^{d}
Green aluminium		56.02^{c}	56.12^{b}	57.10^{bc}
Brown aluminium		56.09^{c}	56.25^{b}	56.88^{bc}
Grey aluminium		55.42^{d}	55.89^{b}	56.19^{d}
Red steel		52.97^{e}	53.39^{c}	53.71^{e}
Green steel		56.76^{b}	57.28^{a}	57.49^{b}
Brown steel		57.63^{a}	57.72^{a}	58.37^{a}
Grey steel		56.60^{b}	57.13^{a}	57.19^{bc}
non-painted galvanized steel		56.07^{c}	55.86^{b}	56.67^{cd}