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OUTDOOR PANELS FROM NORWAY SPRUCE – THE EFFECT OF COATING COLOUR ON THE TEMPERATURE

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ABSTRACT: Wood used outdoors is often surface treated with a paint to protect the wood from moisture and deterioration. If coated with a dark colour, the albedo value is lowered. A lower surface albedo generates greater amounts of energy absorption and makes the surface, and subsequently the wood, warmer and dryer. This study was carried out to increase knowledge of how different coating colours impact the temperature of the underlaying wood, and the effect this has on the moisture content (MC). The study was performed by exposing panels of Norway spruce [*Picea abies* (L.) H. Karst.] painted with three different colours (white, red, and black) to natural sunlight over a month during summer. Each panel fitted with a dry-bulb humidity sensor inside. The results showed a greater variation in calculated equilibrium moisture content (EMC) in the darker panels, since the temperature reached higher levels than the white panels when exposed to sunlight. The maximum recorded temperature was around 50 °C for the dark panels while the maximum for white was around 40 °C. Furthermore, it was shown that the temperature inside the panel reaches its maximum around the same time as the outside air, while the maximum values for EMC were recorded approximately 8-9 hours apart between the panels and the outside air.

KEY WORDS: Coated wood, Coating colour, Moisture content, Natural exposure

1 INTRODUCTION

Wood is a bio-based material which decomposes under unfavourable conditions. When used as a façade material, the wood is exposed to water in the form of precipitation which increases the moisture content in the wood. After long exposure, in situations where the wood cannot dry out, it can lead to discolouration or rot by wood-decay fungi. Both cause a decrease of the service life of the façade. To be able to fully implement wood as a construction material, research within the field is necessary.

Wood used for facades is often surface treated with a coating to protect it from moisture. This coating can have different colours which are affected differently through their surface albedo. The surface albedo causes dark surfaces to reflect less solar radiation than light surfaces, in turn making them warmer than a light surface subjected to the same amount of solar radiation [1]. This means that a façade panel coated with light paint should also be less warm than one painted with a darker paint.

All NCS-colours provide a number regarding the blackness, chromaticness, and hue. Since the blackness and chromaticness of the colour should be the factors theoretically most important regarding the effect of albedo, these will be studied closer in this study. The risk for fungal development and decay is closely related to the temperature [2-4]. A greater variation in temperature also leads to a greater variation of the equilibrium moisture content (EMC) in the wood [5]. Relative humidity is the factor that affects EMC the most [6]. The EMC is the point where the moisture content in a material is constant, and will not change as long as the RH and the temperature around is also constant [7]. A façade panel with different colours should in theory reach the same temperature during night-time without sunlight, causing darker panels to be subjected to a greater variation in temperature during a 24-hour span.

The increase in temperature of darker coloured paints has also been shown to create a more rapid moisture diffusion [8]. A greater variation in moisture content causes cracks in the wood as well as the paint layer at an earlier stage than for a constant MC [9,10]. Sources suggest that the risk for cracks in the wood occurs already when the EMC of the surrounding environment and the MC of the wood deviate with 2%, the risk increases the higher the difference [11].

Only few studies that investigate the effect of a specific coating colour on the moisture content and the temperature in a material have been carried out. Furthermore, most of the studies carried out measure the moisture content in the material either by weighing the entire test piece [8,12-15] or with electrical resistance [13,16].

This work aims to study the temperature and calculated EMC just below the coating. By collecting the data for the given exposure, it will increase the understanding of how

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moisture and temperature in the wood fluxes under similar conditions. As this in turn is related to both microbial activity and crack formation, this will increase the understanding of the most suitable coating colour for a given situation, with regards to moisture and temperature related issues.

2 MATERIALS AND METHOD

A total of nine test pieces (panels) were made of Norway spruce [*P. Abies* (L.) H. Karst.], with dimensions 300x105x45 mm. The panels consisted of two boards of 22 mm thickness glued together with a silicone adhesive, creating a single panel with a thickness of 45 mm (Figure 1). The panel behind was added to prevent moisture from entering from the backside of the panel as the adhesive film between the two parts creates a vapor barrier (Figure 1).

A waterborne alkyd primer was used before applying the top coating according to the instructions from the manufacturer (Becker). All panels were top coated with waterborne acrylic paint in the three different colours: white (NCS S 0502-Y50R), red (NCS S 5040-Y80R) and black (NCS S 9000-N). Three panels were coated with each colour. By using the NCS atlas [17], the luminous reflectance factor (LRF) can be found. This value is based on both the blackness and chromaticness of the colour to represent the percentage of reflection of the colour when shone with a light. The values for white (NCS S 0502-Y50R) and black (NCS S 9000-N) were given as 87% and 4.0% respectively. The value for red (NCS S 5040-Y80R) was interpolated to be approximately 8.5%. These values were then used when studying the temperature increase found in the samples during sunlight.

Each of the nine panels were equipped with a dry-bulb relative humidity sensor (Sensirion SHT35-DIS-F), which also measured temperature. The sensors were placed within a pre-drilled hole and fixed 8 mm from the coated surface (Figure 1). The holes were then sealed with silicone to prevent moisture from entering from the back of the panel. The sensors were connected to a data acquisition system that logs the parameters in 5 min intervals and their respective time stamps to a .txt-file, see [18] for a general description of the system.

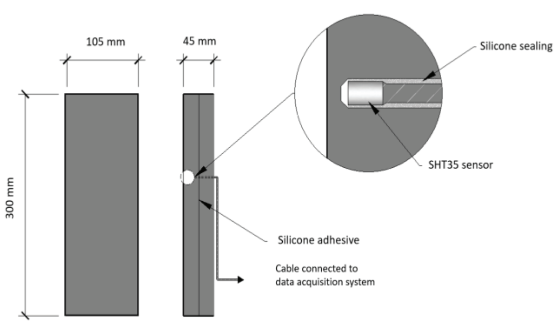

Figure 1: *Dimensions of the panels and placement of sensor*

The panels were placed outdoors in Växjö, Sweden, on a rack facing south, with an angle of 45° to the ground. Apart from the sensors in the boards, a separate sensor was placed freely without direct sunlight, which measured temperature and RH in the surrounding air.

The measured values for temperature and relative humidity were used to calculate the EMC using Equation 1 by Simpson [19]. The EMC indicates the MC once it has been stabilized and not the actual MC at a given time.

$$EMC(\%) = \frac{1800}{W}\left(\frac{K\,h}{1-K\,h} + \frac{(K_1\,K\,h + 2\,K_1\,K_2\,K^2\,h^2)}{(1+K_1\,K\,h + K_1\,K_2\,K^2 h^2)}\right) \quad (1)$$

Where:

h = relative humidity in decimal form

$W = 349 + 1.29\,T + 0.0135\,T^2$

$K = 0.805 + 0.000736T - 0.00000273\,T^2$

$K_1 = 6.27 + 0.00938\,T - 0.000303\,T^2$

$K_2 = 1.91 + 0.0407\,T - 0.000293\,T^2$

T = temperature in °Celsius

The density of the panels was measured after the exposure by the simple displacement method. The mean value of the oven-dry density was 495.6 kg/m^3 (Table 1).

Table 1: *Saturated density and oven-dry density in the samples*

Sample	Saturated density (kg/m^3)		Oven-dry density (kg/m^3)	
	Mean	Std. deviation	Mean	Std. deviation
White	716.3	35.1	501.5	31.1
Red	743.4	11.8	505.5	15.3
Black	721.9	17.8	479.7	5.2
Overall	727.2	29.0	495.6	21.2

3 RESULTS AND ANALYSIS

The following weather data is collected from observations in Växjö, Sweden, by the Swedish Meteorology and Hydrological Institute (SMHI) during the month of July 2021 [20]. The total precipitation was 98 mm distributed over 16 days, where each day must have at least 0.1 mm of precipitation to be included. A total of 243 hours of sunlight was recorded, which is slightly higher than the average of 234 hours. The total global radiation during the month was 162.6 kWh/m^2.

All data presented is calculated as a mean value between all three panels of the same colour, the maximum and minimum values are therefore not extreme values for the individual panels but a calculated mean of all panels of the same colour at a given time. The only exceptions to this are found in Figure 6, where the values are instead shown individually for all samples.

3.1 TEMPERATURE ANALYSIS

The measured temperature for all values recorded during the month of July can be seen in Table 2.

Table 2: *Internal temperature for the different coating colours and the outside air during the entire month of July*

Sample	Temperature (°C)			
	Mean	Max	Min	Std. deviation
White	21.3	41.0	11.0	6.3
Red	23.3	49.7	11.0	8.5
Black	23.6	51.3	11.0	8.9
Outdoor	21.0	37.8	11.5	5.2

The results in Table 3 are based on measured values between 6:00 AM-6:00 PM from the whole measurement period. This interval lies safely between the average times of sunrise-sundown during July in Sweden. The table contains the mean, maximum, minimum, and standard deviation of temperature during all days of the month.

Table 3: *Internal temperature for the different coating colours and the outside air during the entire month of July between 6:00 AM-6:00 PM*

Sample	Temperature (°C)			
	Mean	Max	Min	Std. deviation
White	24.9	41.0	12.5	6.2
Red	28.7	49.7	12.9	8.4
Black	29.3	51.3	12.9	8.7
Outdoor	23.9	37.8	13.2	5.0

The table clearly shows the influence of the coating colour on the mean temperature during the month. The differences become even more pronounced when only studying values during a single day (Table 4).

Table 4: *Internal temperature for the different coating colours and the outside air during a single day between 6:00 AM – 6:00 PM*

Sample	Temperature (°C)			
	Mean	Max	Min	Std. deviation
White	25.2	32.8	15.9	5.2
Red	29.8	41.2	16.3	8.0
Black	30.5	42.4	16.3	8.4
Outdoor	23.8	29.9	17.1	4.0

3.2 EMC ANALYSIS

The calculated values of EMC considering all values of RH and temperature recorded during the month of July can be seen in Table 5. The calculated EMC of the surrounding air is included as a reference.

Table 5: *Calculated values of EMC presented for the different colours and the outside air during the entire month*

Sample	EMC (%)			
	Mean	Max	Min	Std. deviation
White	13.9	20.3	11.6	1.5
Red	11.8	26.5	8.4	3.4
Black	11.4	24.5	8.2	3.0
Outdoor	15.9	29.0	5.5	6.6

The results presented in Table 6 contain calculated values of EMC based on values measured between 6:00 AM-6:00 PM from the whole measurement period of July 1 until July 31.

Table 6: *Calculated values of EMC presented for the different colours and the outside air*

Sample	EMC (%)			
	Mean	Max	Min	Std. deviation
White	14.8	20.3	11.8	1.6
Red	13.7	26.5	8.6	3.9
Black	13.2	24.5	8.4	3.4
Outdoor	13.0	29.0	5.5	5.9

The standard deviation is much lower for the white panels than the red and black. Just like for the temperature, the differences are even more apparent when only studying the variation during a single day (Table 7).

Table 7: *Calculated values of EMC for the different coating colours day-time hours of a single day*

Sample	EMC (%)			
	Mean	Max	Min	Std. deviation
White	15.5	18.4	13.0	1.8
Red	16.4	24.6	10.4	5.1
Black	16.2	23.4	10.3	4.5
Outdoor	15.6	29.0	7.6	7.7

The variation in calculated EMC during every single day can be seen in Figure 2, where the y-axis values are the differences in maximum- and minimum EMC calculated from the values extracted during 24-hours for all days of the month.

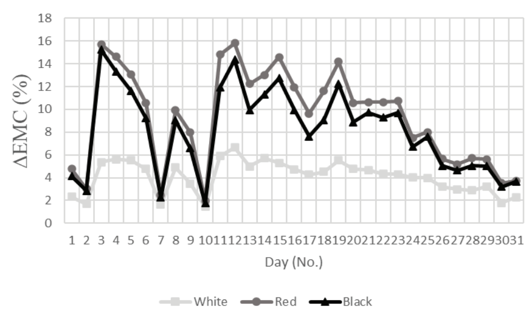

Figure 2: *Maximum daily absolute difference in EMC within the panels for all days of the month of July*

3.3 TEMPERATURE AND EMC IN THE PANELS COMPARED TO OUTSIDE AIR

The temperature in the panels fluctuates in phase with the outside air (Figure 3) while the EMC fluctuates counter-phase (Figure 4). The figures display a typical distribution during a single day with a clear influence of solar radiation.

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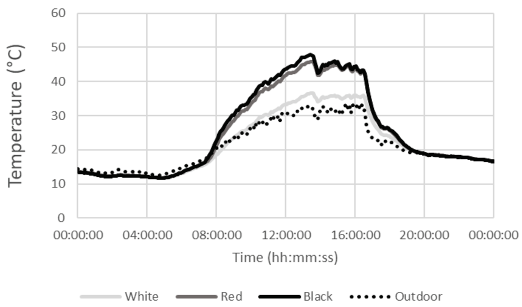

Figure 3: *Temperature distribution in the panels and outside air during 24 hours*

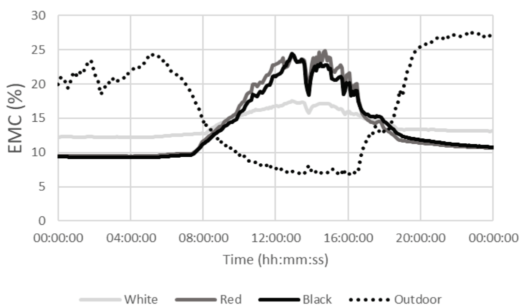

Figure 4: *Distribution of EMC in the panels and outside air during 24 hours*

The difference in time for the panels and outside air to reach its daily peak during the day is presented in Table 8. The results are presented as the average absolute difference between the time stamps at which the daily maximum was recorded for the outside air and within the panels, respectively. The darker panels reach their peak temperatures earlier than the white panels, while the peak temperatures in the outside air were generally recorded later in the day. The EMC shows barely any difference between the different coating colours.

Table 8: *Absolute difference in time of peak values between samples and outside air*

Sample	Difference to outside air (hours)	
	Temperature	EMC
White	0.52	8.60
Red	0.80	8.65
Black	0.90	8.62

The peaks in EMC in the ambient air predominately appeared close to midnight (the coldest period of the day), while the EMC peaks in the panels appeared during the early afternoon (the warmest period of the day). All peak values in temperature within the panels and in the outside air are shown in Figure 5.

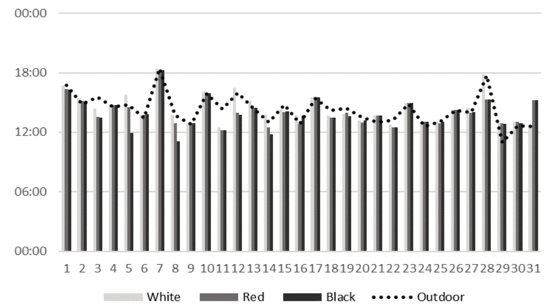

Figure 5: *The time of day when the maximum temperature was recorded in the panels and in the outside air*

3.4 THE INFLUENCE OF COATING LRF ON THE MAXIMUM TEMPERATURE

To isolate the albedo effect, the temperature differences in the panels compared to the outside air temperature at the same time were studied (Figure 6). The figure shows temperature difference when the difference between the outside air temperature and panel temperature was the greatest.

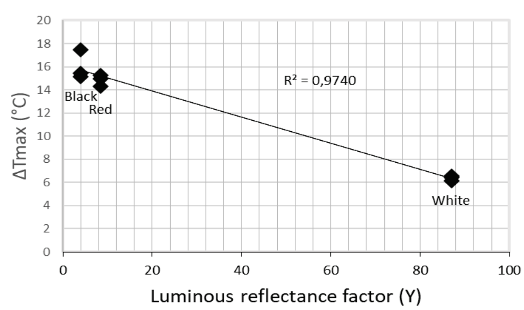

Figure 6: *Maximum temperature difference between the panels and outside air recorded during the month in dependence of the LRF*

The results show a greater variation in maximum temperature in the red and black samples than in the white samples. The LRF naturally has a negative correlation with the temperature increase in the panel compared to the ambient temperature during sunlight.

3.5 THE INFLUENCE OF TEMPERATURE ON THE EMC

Temperature is used to calculate the EMC, albeit weighed less than the RH.

The correlation was best explained with an exponential function for all samples, where T is defined between the minimum and maximum temperature recorded. See Table 9 for the equations used and the R^2-value related to the equations.

Table 9: Data fit equation for the EMC depending on the temperature and their R^2-values

Sample	Equation	R^2
White	$EMC(\%) = 10.483e^{0.0130T}$	0.60
Red	$EMC(\%) = 6.2917e^{0.0256T}$	0.80
Black	$EMC(\%) = 6.4383e^{0.0231T}$	0.81

Where:
EMC = The equilibrium moisture content (%)
T = temperature in °Celsius

The equation for the white samples is close to being linear within the defined range. The maximum value for EMC and temperature within the samples were predominantly recorded less than an hour apart.

The average time between reading of the maximum temperature and maximum EMC for the respective coating colours were, 57 minutes for white, 35 minutes for red, and 29 minutes for black.

4 DISCUSSION

With the temperature being measured within the board, it is likely that the difference in temperature at the surface could be even more pronounced. The temperature measured 8 mm behind the coating could vary between 16.3-42.4 °C in just 12 hours, as seen in the black panels (Table 4). The temperature at the surface is likely even higher than the recorded values.

Despite having a much lower blackness value than the black samples, the red samples reached temperatures very close to the black ones. This is likely due to the two colours having similar luminous reflectance factors (LRF), and therefore absorbing similar levels of sun light. This indicates that the chromaticness is also an important aspect regarding the increase in temperature of the panel. The black panels could reach temperatures which were more than 17 °C higher than the outside air at the same time, while the red samples were around 15 °C warmer than the outside air at most. Assuming that the back of the panel was closer to the temperature of the ambient air, this could generate significant temperature and hence moisture gradients within the panel. This could generate strains and, subsequently, cracking in the panels.

The results also showed a clear difference in calculated EMC between the samples of different coating colours. However, the EMC is not sufficient in determining the actual moisture content at a given moment in time. It is however useful when analysing the mean values over an entire month, as this is likely close to the actual mean moisture content. Therefore, the variations in EMC over a single day should be treated as indicators of possible variations, rather than actual variation. The variations in EMC in the darker panels could be close to the fibre saturation point and below levels of industrial drying during the same day, which is likely not possible for the actual moisture content. However, the increase in temperature is likely enough to create greater variations in MC in panels of darker colours than light colours, although to an unknown degree. A greater variation in EMC for the darker panels was calculated for all days during the month, not only those with high solar radiation. Surprisingly, the red panels achieved a greater average EMC than the dark panels, even though the LRF was lower, and lower average temperatures were recorded inside the panel.

It is also possible that the high temperatures achieved on the surface of the darker panels are enough to temporarily stop the mould growth, as temperatures around 40 °C can have a negative effect on growth [21].

The correlation between temperature and EMC within the panel is not surprising as an increase in temperature leads to an increase in vapor pressure.

The temperature within the panels and in the outside air fluctuated closely in-phase, while the EMC was affected by the slow water transition between the surrounding and inner relative humidity. The different correlations between EMC and temperature in the different coating colours could be explained by a faster spike in RH due to higher temperatures. The variations in relative humidity were greater in the outside air than in all the panels, while the variation in temperature was greater in the panels than in the outside air.

The white panels never reached the same maximum EMC as the red and black panels. This could have been caused by an increase in water evaporation due to higher temperatures within the darker panels and similar levels of water content. The water would then be concentrated around the area where the relative humidity was measured. However, this is only a hypothesis and should be studied further to increase understanding.

Analysing the minimum values of temperature showed that the minimum daily temperature in the panels never deviated with more than 0.2 °C between the different coating colours. This indicates that high solar absorption in non-reflective colours during the day does not affect the minimum temperature during the full 24 hours of a day. The minimum daily temperature in the panels were on average approximately 0.6 °C colder than the minimum in the outside air.

A similar study [13] also tested moisture conditions and temperature within samples of different colours. It was concluded that the lighter samples kept higher and more constant levels of moisture content than those of darker colour due to a lower absorption of sunlight. This corresponds well with the results acquired in this study. It should however be noted that the authors in [15] measured the MC by use of mass variation and electrical resistance, compared to the use of sensors in this study.

5 CONCLUSIONS

Using darker colours of paint increases both the fluctuation in temperature and moisture content within the panel over the course of a day. The temperature 8 mm below the surface decreased along with the reflectance factor of the colour. This suggests that both the blackness and the chromaticness of the colour are important regarding the solar absorption of a panel, and that the solar absorption of low-reflectance coatings can generate much higher temperatures inside the wood than the ambient temperature.

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The temperature within panels of white coating is close to the outside temperature and barely deviates from the outdoor temperature when considering the monthly average. The calculated mean EMC in the red and black samples were similar, even though the mean temperature was slightly higher in the black samples. To further validate the results, the authors recommend testing common coating colours which have an LRF between the white and red colours used in this test. Furthermore, these values of both temperature and EMC are only applicable for the given geographical location and time of year. Also, the differences between the panels could be different at a different location of exposure. Comparing the results found in this study to a different location and/or time of year would aid in increasing the knowledge of how coating colours affect the wood.

Although this study shows some clear results and trends, the low number of samples decreases validity and further studies should be carried out with a greater sample size. Furthermore, weighing the samples during the exposure to measure the actual moisture content within the panels at a given time could enhance the value of the measurements. Efforts to further understand the temperature and moisture gradients, e.g., by using multiple sensors at different depths, could be helpful when assessing the risk for crack formation within panels of different coating colours.

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