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Variables Associated with Thermal Emittance of Wall Mural Art in Richmond, Virginia

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ABSTRACT

The objectives of this research are to determine the factors associated with the minimum, maximum, and average thermal emittance temperatures of wall murals in Richmond, Virginia, and make recommendations for color and location of wall murals. Data for 17 parameters were collected for 64 art murals in downtown Richmond, VA from 28 June 2018 – 19 July 2018. Date, time, solar exposure duration, solar elevation, latitude, longitude, air temperature (C), lux, color, solar cardinal minutes, cardinal direction, minimum, maximum, and average surface thermal emittance temperatures of mural face were recorded for each mural. We reject the hypothesis that minimum, maximum, and average thermal emittance temperatures of wall murals do not vary significantly with temporal, spatial, physical changes, and solar factors. Maximum, minimum, and average emittance temperatures of wall mural art varied significantly with the number of minutes that solar energy directly illuminating mural art for each cardinal direction, lux, solar elevation, total diurnal exposure, maximum mural color, and percent dark colors on murals. Minimum mural wall art temperatures (30.0-37.0 C) occurred on surfaces facing East, North, Northwest, and Northeast which also had the lowest lux values (8,867-14,231); highest temperatures (44.8-49.9 C) were recorded on walls facing South, Southeast, and West, which had the highest lux values (42,517-46,000). Based on results of this study and those investigating mitigation of the urban heat island effect with building materials and coatings on walls and roofs, we recommend a study that uses a systematic approach to locating wall mural art based on specific colors, paint composition, and wall materials to guide local building authorities owners, and artists to maximize albedo. Additionally, we recommend, where possible, mural art should be painted on vertical surfaces facing North, Northeast, and Northwest where

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lux values and thermal gain are the lowest of all possible cardinal directions. Such locations could accommodate the use of dark colors without significantly increasing the heat load in urban communities. And finally, where mural art is being considered for building walls facing South, Southeast, Southwest and West, we recommend that artists use a palette of primarily light colors with high reflective properties to maximize albedo, and minimize use of dark colors.

INTRODUCTION

Hundreds of metropolitan areas around the world experience warmer temperatures compared to surrounding rural lands (Fox et al., 2018). Rapid urbanization has caused these warmer microclimates to develop through a phenomenon known as the Urban Heat Island effect (UHI), which is particularly acute during warmer months (Nuruzzaman, 2015). Urban Heat Islands are a result of human modification of land surfaces (e.g. asphalt roads, parking lots, non-reflective roofs) related to urban sprawl (Fox et al., 2918). Vegetation and open spaces are replaced by buildings and pavements which absorb and retain solar energy more than green environments, increasing the ambient air temperature of an urban area. UHI effects have been demonstrated to exacerbate livability and human health during the summer months resulting in increased heat-related illnesses, such as dehydration, heat exhaustion, heat cramps, heat syncope, and heat strokes (Lugo-Amador et al., 2004), as well as increased cooling costs (Pisello, 2017).

External surface temperature of buildings is a key factor in UHI because solar energy absorbed by buildings is radiated back into the atmosphere, and intensifies the heat within cities (Fox et al., 2018). Therefore, finding effective and innovative ways to increase solar reflectance of surfaces or albedo has become a major concern in metropolitan areas. Many studies have been conducted to mitigate the effects of UHI by increasing albedo. 'Cool' materials such as cool roofs, paints, and pavements have recently gained interest due to their high reflectivity and cost-effectiveness to mitigate UHI. For example, in thermal performance tests of 10 prototypes, containing near-infrared reflective color pigments, Synnefa et al. (2011) determined that cool colored coatings had solar reflectance values higher than conventional colored coatings, which resulted in maintaining a lower surface temperature. Zinzi (2016) found that near-infrared reflective paints have been proven to be effective on building facade application by reducing cooling energy uses from 10-20%, reducing peak operative temperatures by 0.5 to 1.6 °C for buildings in free floating conditions, and by reducing external surface temperatures up to 6°C. Akbari et al. (2009) and Akbari et al. (2012) discovered that by installing cool roofs and pavements (highly reflective surfaces) globally, can lead to an offset of 44 Gt CO_2. Akbari et al. (2012) continued their studies in CO_2 offsets and determined that increasing the albedo of metropolitan areas resulted in global cooling occurred from 0.01 to 0.07 K, corresponding to 25 to 150 billion tonne reduction in CO_2 emission. Additionally, Sproul et al. (2014) found that by replacing black tops with white tops on residential buildings, there was a 50-year net saving in energy costs of $25/m^2 relative to the black tops due to increased solar reflectance.

Although there are multiple studies on how cool materials and pavements are able to mitigate the effects of UHI, there is little to no research in how street art and building murals affect external surface heat absorption. With many urban areas concerned about the aesthetics of the city, street murals have become an essential part of city design and life (Weber et al., 2008). Yet street murals have not been investigated in terms of heat absorption mainly because the research focus has been on solar radiation impacts on horizontal surfaces rather than vertical surfaces. Other than a newspaper report by Thompson and Byrne (2017) suggesting that street art decreases indoor temperatures of buildings across the street, there is no published research on the factors associated with mural wall art temperatures on vertical surfaces of buildings in urban areas. The objectives of this research are to determine the factors associated with the minimum, maximum, and average temperatures of wall murals in Richmond, Virginia, and make recommendations for color and location of wall murals. The hypothesis is that minimum, maximum, and average thermal emittance temperatures of wall murals do not vary significantly with changes in date, time, location, solar exposure and elevation, air temperature, cardinal direction, lux, and light and dark surfaces of murals.

MATERIALS AND METHODS

Data for 17 parameters were collected for 64 art murals in downtown Richmond, VA on cloudless to near cloudless days (okta[1] range 0-1) from 28 June 2018 – 19 July 2018. Date, time, solar exposure duration (total daylight minutes/day), solar elevation (degrees), latitude, longitude, air temperature (C), solar cardinal minutes (number of minutes striking a vertical wall facing each cardinal direction, Fig. 1), and cardinal direction of mural face (degrees) were recorded for each mural. ArcGIS was used to verify cardinal directions and solar cardinal minutes of each mural initially generated from Google Street View. Solar exposure and elevation were derived from the NOAA Solar Position Calculator of the Earth System Research Laboratory, Global Monitoring System at the Department of Commerce. Air temperature was obtained for Richmond, VA from historical temperature data archives from the National Weather Service Forecast Office in Wakefield, VA. Distributions of minimum, maximum, and average surface thermal emittance temperatures (C) of each wall mural were recorded using a thermal imaging camera (Flir One Gen 3 Pro camera for android phones) with an error range of approximately +/- 3° C. Wall thermal emittances were recorded *in situ* from 12 pm to 4 pm. Lux (luminous flux/area) striking the surface of each mural was recorded using an AEMC Model1110 Light Meter Data Logger. Light and dark colors on each mural were assigned a value from 1-10 (1=white, 10=black) and used to calculate percent dark color and color preference (scale 0-1), where:

$$\text{Color preference} = \frac{(\text{dark value} - \text{light value})}{(\text{dark value} + \text{light value})}$$

A fixed grid in the Flir® Tools and Report Studio software was used to calculate the total number of dark and light color areas on murals and generate a dark color percentage for each mural.

[1] Unit of measurement describing cloud coverage. Okta ranges from 0 (clear sky) to 8 (complete cloud coverage)

Correlation analyses (SAS 2018) calculated Pearson correlation coefficients to determine significant relationships among all parameters (p=0.05). A General Linear Model followed by Duncan's Multiple Range Test (SAS 2018) was used to determine significant differences for each parameter (p=0.05) by cardinal direction. Rotated factor patterns derived from factor analyses (SAS 2018) were used to determine the groups of parameters accounting for signification variation for each of the minimum, maximum, and average thermal emittance temperatures of wall murals.

RESULTS

South-facing murals receive sunlight for the entirety of the day, absorbing the most solar radiation, whereas North-facing murals are not in the sun's path except early in the morning and late in the evening in the summer and receive the least amount of solar radiation.

Minimum, maximum, and average temperatures of murals were significantly positively correlated with each other at $p<0.001$, and with solar cardinal direction ($p<0.001$), air temperature (p=0.009, 0.05, and 0.02, respectively), and lux (p=0.06, <0.001, and 0.001, respectively; Table 1). Lux was significantly correlated with solar exposure (p=0.001) and solar cardinal direction ($p<0.001$; Table 1).

Average maximum temperatures (44.7-50.0 C) of murals facing South, Southeast, Southwest, and West were significantly higher than those (30.6-42.6 C) painted on walls facing North, Northeast, and Northwest (Table 2; Fig. 2, 3 and 4). Average minimum temperatures (33.0-37.3 C) of murals facing West, Southwest, Southeast, East, and South were significantly higher than those (26.3-30.8 C) facing North (Table 3; Fig. 2, 3 and 4). Average temperature of murals facing North was significantly lower than those facing Southwest, East, West, Southeast, and South (Table 4; Fig. 2, 3 and 4). Average lux values (45,600-46,000) measured at mural surfaces facing West and South were significantly higher than those (8,867-21,839) facing Southeast,, Northeast, Northwest, North, and East ((Table 5; Fig. 5). Average solar exposure (882 min) at mural surfaces facing East were significantly greater than those facing West (875.6 min) (Table 6).

There were no significant differences among average values of air temperature (avg. range=32.0-33.3 C), solar elevation (avg. range=64.7-70.7), percent dark areas on murals (avg. range=36.7-58.3), minimum colors of murals (avg. range=1.0-1.7) maximum colors of murals (avg. range=9.7-10.0), and preference of dark to light areas on wall murals (Table 7) among all cardinal directions and wall murals.

Factor analysis indicated that the first three factors accounted for 80.9 percent of the variation in the maximum temperature of wall mural art (Table 8). Factor 1 (maximum temperature, solar cardinal minutes striking mural art, and lux) contributed 32.8 % of the variation in maximum wall mural art temperature; Factor 2 (maximum color of mural, solar elevation) contributing 26.5 % of the variation in the maximum wall mural art temperature; and Factor 3 (total diurnal exposure, and percent dark colors on murals) contributed 21.5% of the variation in maximum wall art temperature (Table 8).

For minimum temperatures of wall mural art, factor analysis indicated that the first three factors accounted for 80.1 percent of the variation in minimum temperatures (Table 9). Factor 1 (maximum temperature, solar cardinal minutes striking mural art, and lux) contributed 28.7 % of the variation in maximum wall mural art temperature; Factor 2 (maximum color of mural, solar elevation) contributing 27.2 % of the variation in the maximum wall mural art temperature; and Factor 3 (total diurnal exposure, and percent dark colors on murals) contributed 24.2% of the variation in maximum wall art temperature (Table 9).

Factor analysis results for average temperatures of wall mural art indicated the same three Factors as in those for maximum and minimum temperatures of wall mural art accounted for 80.7 percent of the variation in average temperatures of wall mural art (Table 10). Factor 1 accounted for 31.6% of the variation in average wall temperature; Factor 2 contributed 26.6 %, and Factor 3 contributed 22.5 % (Table 10).

DISCUSSION

We reject the hypothesis that minimum, maximum, and average thermal emittance temperatures of wall murals do not vary significantly with changes temporal, spatial, physical, and solar factors. Maximum, minimum, and average emittance temperatures of wall mural art varied significantly with the number of minutes that solar energy directly illuminating mural art for each cardinal direction, lux, solar elevation, total diurnal exposure, maximum mural color, and percent dark colors on murals (Table 1). Minimum mural wall art temperatures (30.0-37.0 C) occurred on surfaces facing East, North, Northwest, and Northeast which also had the lowest lux values (8,867-14,231) (Figs. 4 and 5); highest temperatures (44.8-49.9 C) were recorded on walls facing South, Southeast, and West, which had the highest lux values (42,517-46,000) **(**Figs. 4 and 5**).**

Although average solar elevation angle (64.7-70.7), dark mural color rank (9.7-10), and percent dark mural color (36.7-58.3) did not vary significantly with cardinal direction, they did contribute to the variation in data in factor analyses (Tables 8-10). The amount of solar energy per unit area striking surfaces has been demonstrated to vary with solar elevation (Ruelas, 2017). Solar elevation angle is one of the most important factors for parameterizing surface albedo (Zheng et al., 2017). In a study of white, green, and black flat roofs, Sproul et al. (2014) indicated that white and "green" (vegetated) roofs have begun replacing conventional black (dark-colored) roofs to mitigate the adverse effects of dark impervious urban surfaces.

Likewise, air temperature was a significant factor accounting for the variation in wall mural art temperatures (32.0-33.3 C) albeit it did not vary significantly with cardinal direction (Tables 8-10). Thermal lag time between solar flux and ambient air temperature, longwave radiation energy, and heat storage of vertical walls may account for the higher temperatures of wall mural art facing South, Southeast, and West. Banyal et al. (2013) determined that peaks of solar flux and ambient temperature are shifted by two hours due to thermal time lag. Longwave radiation energy (heat emitted from ground surfaces surrounding the vertical faces of buildings) (Engineering Reference, 2018) and climatic conditions (e.g. summer air temperatures), used in calculations of thermal insulation and heat storage of exterior building materials (Long and Ye, 2016) are factors that impact air temperature, and may have affected the maximum temperature of wall murals.

Numerous studies have focused on the effects of building facades and materials (including those of historic buildings), cool coatings, high albedo colors, and reflective materials to mitigate urban heat island effects (Becherini et al., 2018; Fox et al, 2018; Mauri et al, 2018; Pisello, 2017; Zinzi, 2016; Rossi et al., 2015; and Hernandez-Perez et al., 2014). This includes the question of heat dispersion when light is reflected off of a high-albedo surface. (Dupuis 2013, Ibrahim 2013, Jacobson 2012). Although Jacobson 2012 found that installation of white roofs increased overall global temperatures, there are little to no literature on vertical surfaces increasing global temperatures, in part due to the complexities and variability of irradiation of vertical and titled surfaces (Maxwell et al., 1986). Algorithms for measuring vertical surface irradiation can also be highly inaccurate (Maxwell et al., 1986). However, there are studies and examples that show vertical surfaces having an impact on the surrounding, local air temperatures (Price, 2015, Zinzi 2016, Fox et al. 2018, Thompson, J. & C. Byrne. 2017).

Based on results of this study and those investigating mitigation of the Urban Heat Island effect with building materials and coatings on walls and roofs, we recommend a study that uses a systematic approach to locating wall mural art based on specific colors, paint composition, and wall materials to guide local building authorities owners, and artists to maximize albedo. Additionally, we recommend, where possible, mural art should be painted on vertical surfaces facing North, Northeast, and Northwest where lux values and thermal gain are the lowest of all possible cardinal directions. Such locations could accommodate the use of dark colors without significantly increasing the heat load in urban communities. And finally, where mural art is being considered for building walls facing South, Southeast, Southwest and West, we recommend that artists use a palette of primarily light colors with high reflective properties to maximize albedo, and minimal use of dark colors. Our recommendations are consistent with the findings of Becherini et al. (2018); Fox et al. (2018); Mauri et al. (2018), Pisello (2017); Zinzi (2016); Rossi et al. (2015); Hernandez-Perez et al. (2014), and Synnefa et al. (2011) who determined that cool colored coatings on vertical surfaces of buildings have solar reflectance values higher than conventional colored coatings, resulting in lower surface temperatures. Zinzi (2016) and Revel et al. (2014) both show that cool materials on vertical surfaces can have a significant impact on lowering energy use due to reduced thermal absorption. Although cool colored paints have gained attention over the years, artists are probably unlikely to use cool colored paints due to their higher cost and limited availability. However, conventional paints may also have unexpected benefits and consequences that affect the amount of heat being absorbed into the city. For example, Tukiran et al. (2015) found that cool-colored asphalt and concrete pavements all had lower surface temperature compared to conventional or uncoated pavements, even though the paints did not have near-infrared reflective pigments.

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TABLES

TABLE 1. (See Table 1 data as a separate file) Results of Pearson correlation analyses among 17 factors collected for wall art murals in Richmond, Virginia during June - July, 2018.

TABLE 2. Results of Duncan's Multiple Range Test for maximum mural thermal emittance temperature (C) based on a general linear model analysis of variance. Underscored means do not differ significantly at p=0.05.

Cardinal	North	Northwest	Northeast	East	West	Southwest	Southeast	South
N	2	12	8	3	2	12	22	3
Mean	30.56	36.16	37.04	42.61	44.80	45.18	45.53	49.98

TABLE 3. Results of Duncan's Multiple Range Test for minimum mural thermal emittance temperature (C) based on a general linear model analysis of variance. Underscored means do not differ significantly at p=0.05.

Cardinal	North	Northeast	Northwest	West	Southwest	Southeast	East	South
N	2	8	12	2	12	22	3	3
Mean	26.33	30.57	30.83	32.97	33.69	35.29	36.07	99.17

TABLE 4. Results of Duncan's Multiple Range Test for average mural thermal emittance temperature (C) based on a general linear model analysis of variance. Underscored means do not differ significantly at p=0.05.

Cardinal	North	Northwest	Northeast	Southwest	East	West	Southeast	South
N	2	12	8	12	3	2	22	3
Mean	28.53	33.55	34.01	38.91	39.63	40.22	40.45	44.50

TABLE 5. Results of Duncan's Multiple Range Test for lux based on a general linear model analysis of variance. Means underscored by the same line do not differ significantly at p=0.05.

Cardinal	East	North	Northwest	Northeast	Southeast	Southwest	South	West
N	3	2	12	8	22	12	3	2
Mean	8,867	9,400	10,845	14,231	21,839	42,517	45,600	46,000

TABLE 6. Results of Duncan's Multiple Range Test for solar exposure duration (minutes) based on a general linear model analysis of variance. Underscored means do not differ significantly at p=0.05.

Cardinal	West	North	South	Southwest	Southeast	Northwest	Northeast	East
N	2	2	3	12	22	12	8	3
Mean	875.6	875.6	875.9	878.3	879.7	14.66252	880.6	882.0

TABLE 7. Non-significant results derived from Duncan's Multiple Range Test for air temperature (C), solar elevation, % dark, minimum light, and maximum dark colors of murals, and color preference index values based on a general linear model analysis of variance. Means do not differ significantly at p=0.05.

Parameter	n	Average range	F	Pr>F
Air temperature	63	32.0 - 33.3	1.09	0.3832
Solar elevation	63	64.7 - 70.7	1.78	0.1103
% dark mural color	63	36.7 - 58.3	0.77	0.6142
Minimum light color	63	1.0 - 1.68	0.39	0.9030
Maximum dark color	63	9.7 - 10.0	0.24	0.9738
Color preference index	63	0.71 - 0.82	0.41	0.8911

TABLE 8. Rotated factor pattern results of factor analysis for maximum thermal emittance temperature of 64 wall murals in Richmond, VA from 28 June 2018–19 July 2018. Factor analysis grouped parameters into factors from observed variables. Factor 1 indicates the strongest correlation. Factors 1-3 accounts for 81% of the variation in the data.

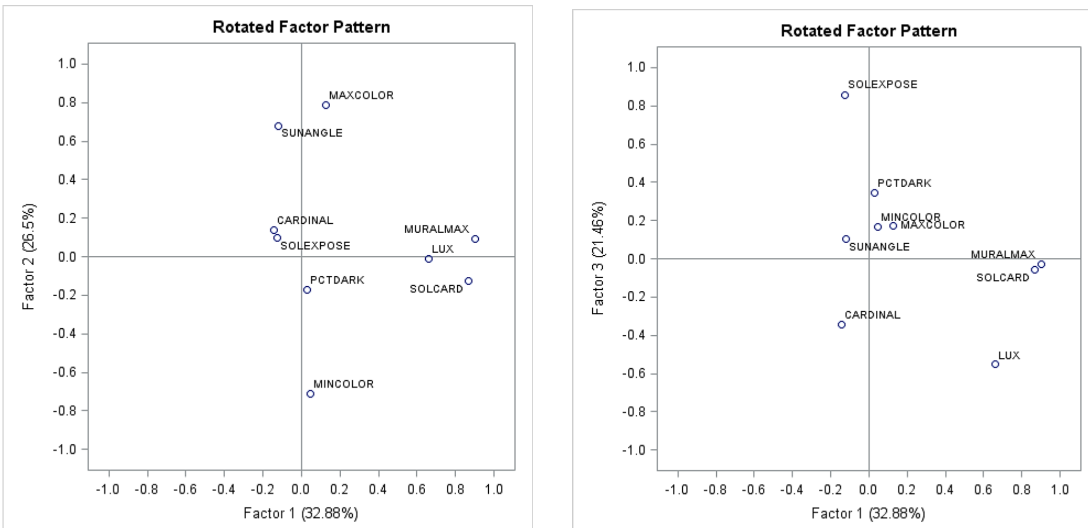
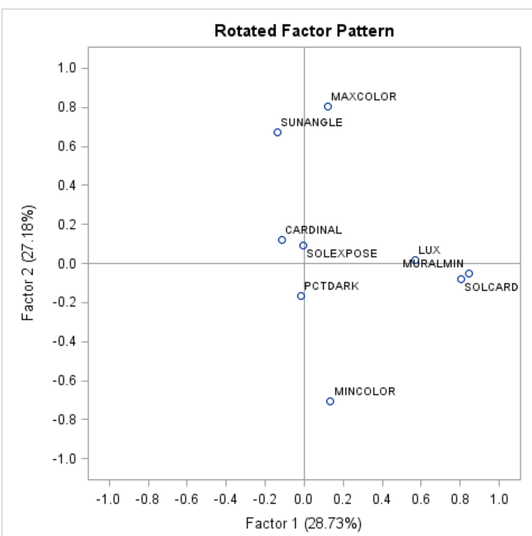


TABLE 9. Rotated factor pattern results of factor analysis for minimum thermal emittance temperature of 64 wall murals in Richmond, VA from 28 June 2018–19 July 2018. Factor analysis grouped parameters into factors from observed variables. Factor 1 indicates the strongest correlation. Factors 1-3 accounts for 81% of the variation in the data.

	Factor1	Factor2	Factor3	Factor4
Mural min. temp	0.84532	-0.05149	0.10702	-0.11827
Solar cardinal	0.80352	-0.07935	-0.20942	-0.05339
Max. color	0.11955	0.80279	0.14463	0.05796
Sun angle	-0.13526	0.67077	0.12866	-0.25069
Min. color	0.13533	-0.70394	0.18083	-0.10138
Solar exposure	-0.00528	0.09002	0.89185	0.06772
Lux	0.56676	0.01839	-0.65251	0.18449
% Dark	-0.01638	-0.16872	0.25812	0.77345
Cardinal	-0.11297	0.12307	-0.23994	0.69101



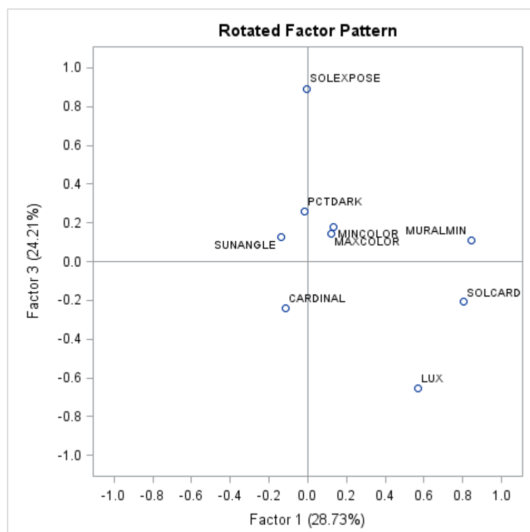
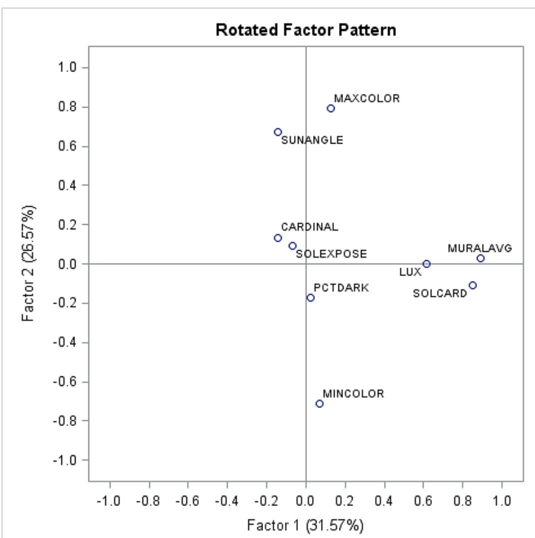
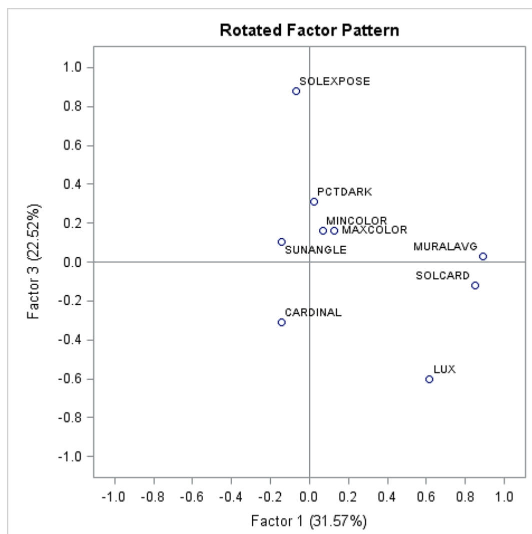


TABLE 10. Rotated factor pattern results of factor analysis for average thermal emittance temperature of 64 wall murals in Richmond, VA from 28 June 2018–19 July 2018. Factor analysis grouped parameters into factors from observed variables. Factor 1 indicates the strongest correlation. Factors 1-3 accounts for 81% of the variation in the data.

	Factor1	Factor2	Factor3	Factor4
Mural avg. temp.	0.89158	0.03080	0.03004	-0.08030
Solar cardinal	0.85102	-0.10626	-0.12065	-0.07783
Lux	0.61703	0.00157	-0.60033	0.17643
Max. color	0.12555	0.79326	0.16114	0.04592
Sun angle	-0.14521	0.67263	0.10534	-0.25302
Min. color	0.06667	-0.71153	0.15901	-0.10753
Solar exposure	-0.07007	0.09199	0.87896	0.05933
% Dark	0.02249	-0.17031	0.31219	0.76819
Cardinal	-0.14497	0.13497	-0.30895	0.69988





FIGURES

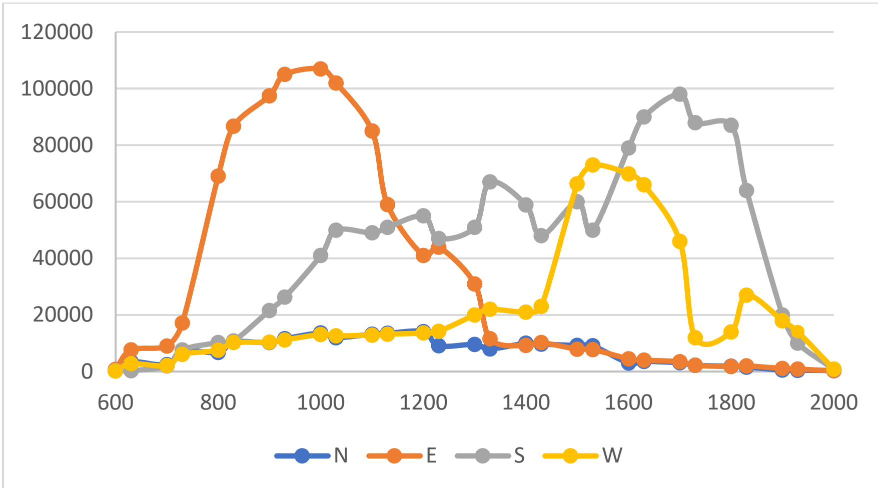


Figure 1. Lux readings of North, East, South, and West Cardinal points taken every 30 minutes in Richmond, Virginia from 6:00 to 20:00 EDT on 18 July 2018. Lux measurements recorded with AEMC model 1110 Light Meter Data Logger.

Figure 2. South wall art mural (A) and its corresponding thermal emittance image (B) indicating maximum, minimum, and average thermal emittance temperatures at 1305 hours EDT (Lux = 36000) 18 July, 2018. Maximum and minimum readings were taken within a fixed grid to control extraneous factors (e.g. windows, asphalt, skies) that would skew temperature readings.

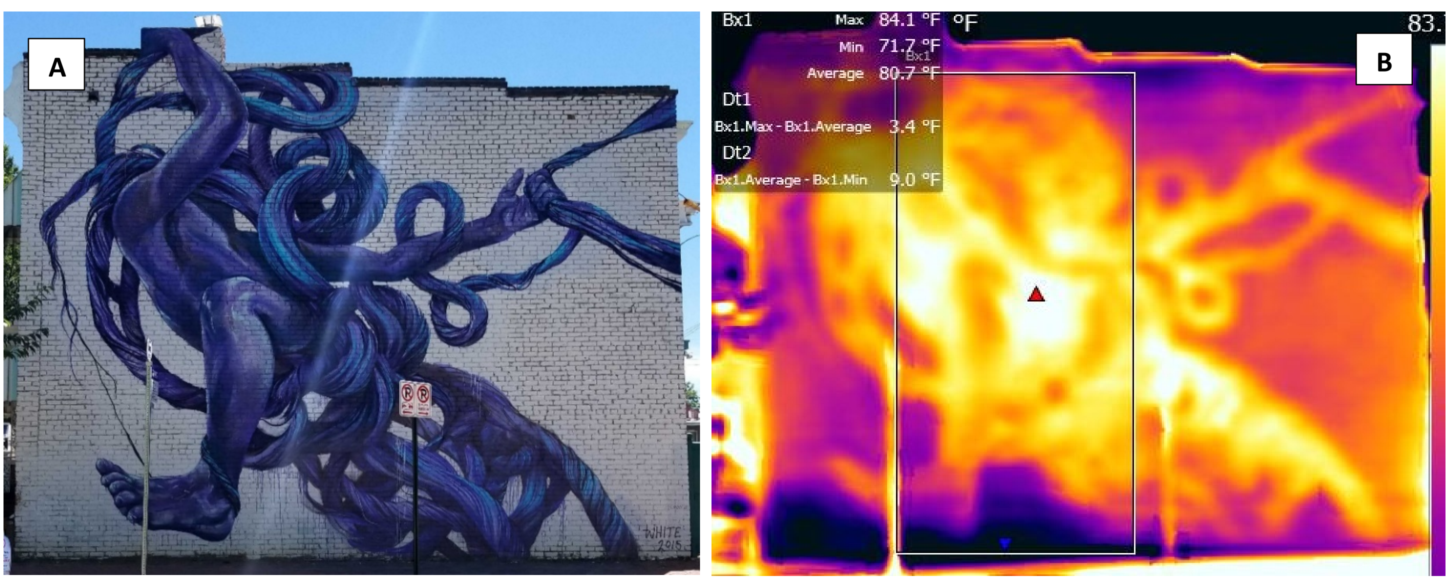


Figure 3. North wall art mural (A) and its corresponding thermal emittance image (B) indicating maximum, minimum, and average thermal emittance temperatures at 1444 hours EDT (Lux = 9000), 09 July, 2018. Maximum and minimum readings were taken within a fixed grid to control extraneous factors (e.g. windows, asphalt, skies) that would skew temperature readings.

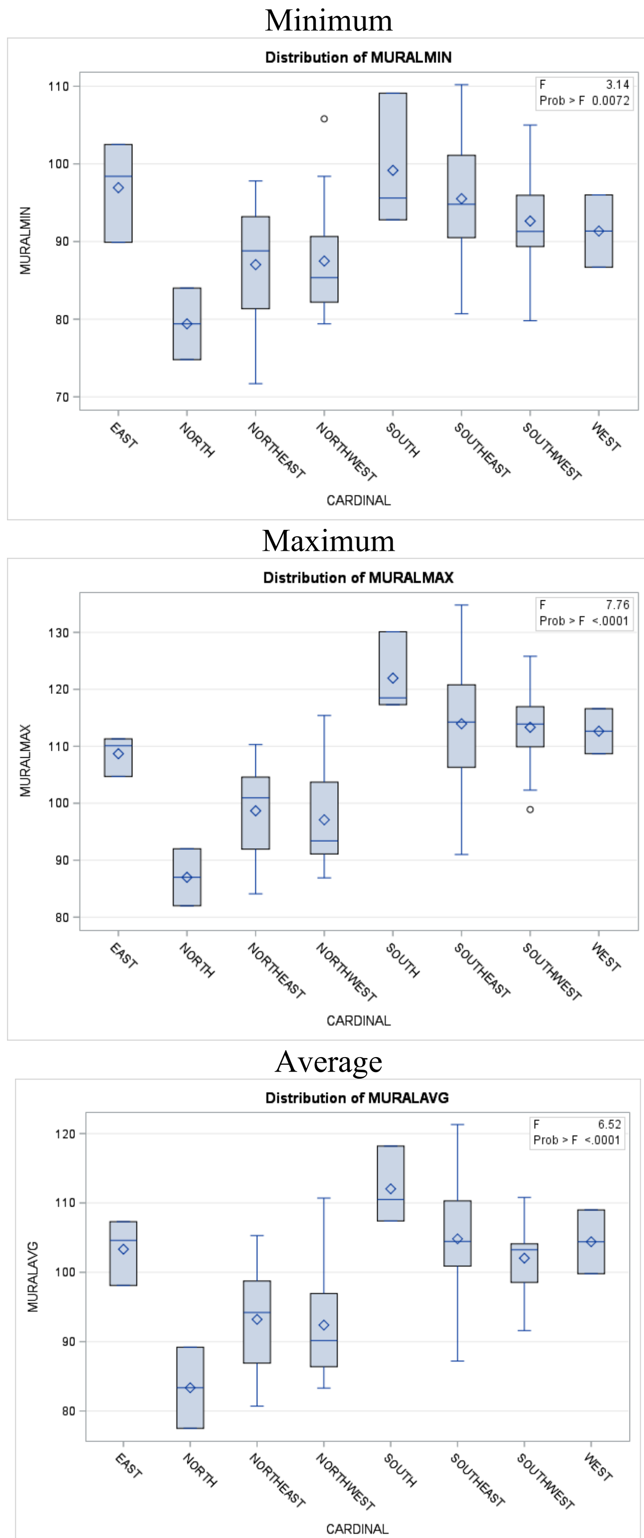


Figure 4. Minimum, maximum, and average thermal emittance (C) of wall murals by cardinal direction in Richmond, Virginia from 28 June 2018–19 July 2018 (n=64).

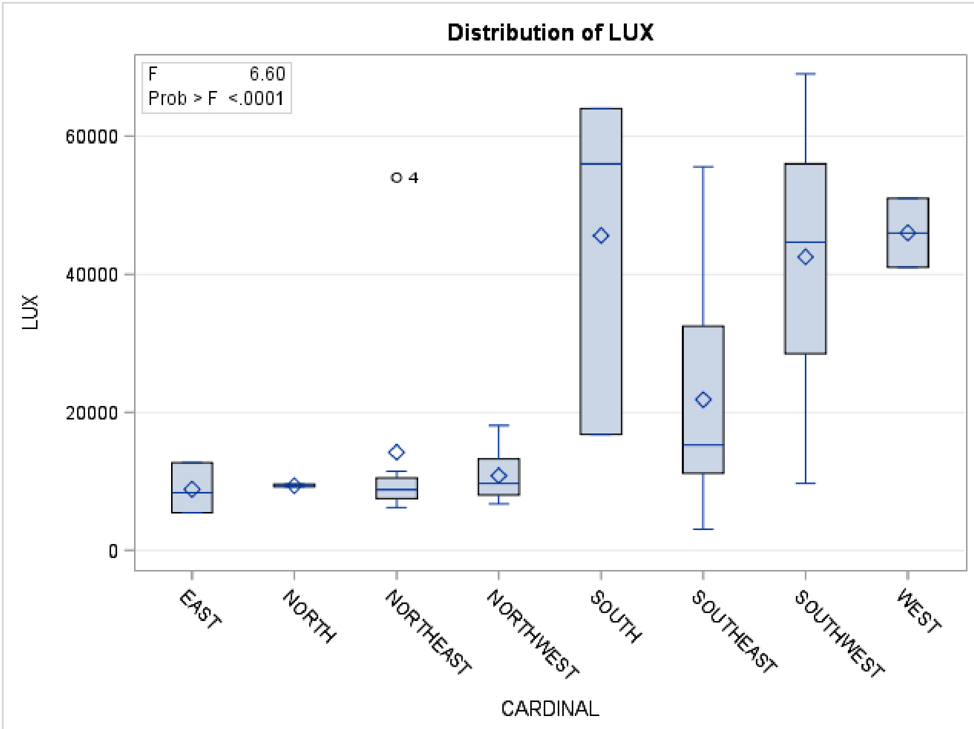


Figure 5. Average lux values of wall murals by cardinal direction in Richmond, Virginia from 28 June 2018 – 19 July 2018 (n=64).

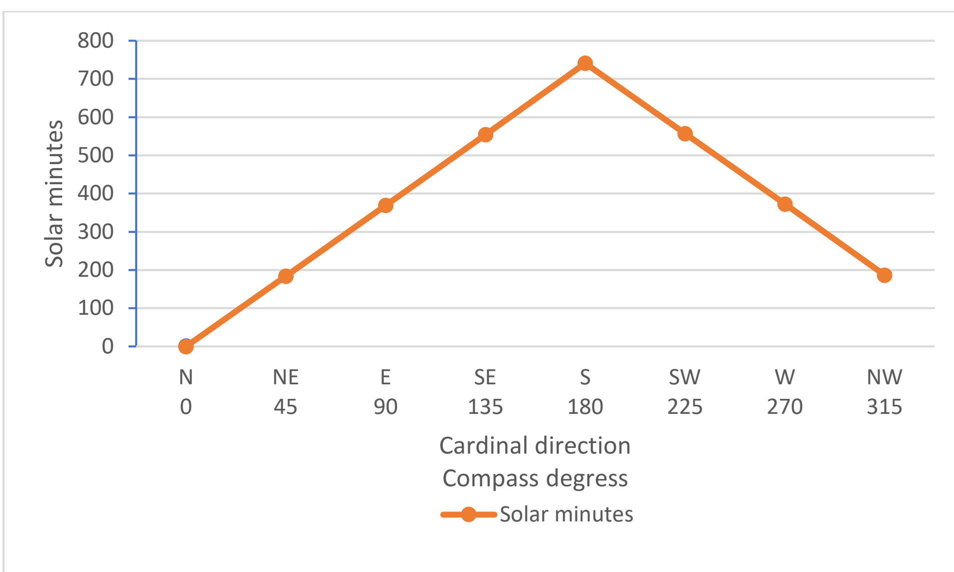


Figure 6. Solar minutes striking wall mural art per cardinal direction in Richmond, VA for June 2018.