

Research Article

Micro-scale Evaluation of the Relationship between Road Surface and Air Temperature with Respect to Various Surrounding Greenery Covers

Nasibeh Faghih Mirzaei, Sharifah Fairuz Syed Fadzil, Nooriati Binti Taib and Aldrin Abdullah
School of Housing, Building and Planning, Universiti Sains Malaysia, Penang, Malaysia

Abstract: The present study investigates the relationship between road surface temperature and air temperature above the road surface with respect to the surrounding road greenery covers. While the transition from native vegetation to artificial surfaces is a global phenomenon of rapid urbanization, the creation of roadside green areas can improve local ambient air quality. Road surfaces affected by the absorption and emission of incoming solar and outgoing long wave radiation contribute to increasing urban air temperature, which gradually impacts environmental quality and human comfort. For data collection of work, a handheld infrared thermometer and portable meteorological measuring instruments were used to measure the surface and air temperature at six experimental locations along roads oriented in different directions on the University Sains Malaysia, Main Campus in Penang, Malaysia. The data show that road surface temperature affects air temperature above the road surface. However, depending on road orientation, roadside trees can decrease the amount of solar radiation absorption by surface materials. Therefore, appropriate urban road designs can mitigate urban air temperature.

Keywords: Road orientation, road surface temperature, road surrounding greenery covers

INTRODUCTION

More than half of the worldwide populace lives in urban zones and this proportion is estimated to reach 69.6% by 2050 (United Nations, 2010). At the moment, urbanization is believed to be the most pressing driver of environmental change, specifically, resulting in worldwide temperature alteration and increasing ambient temperature which is named Urban Heat Island (McCarthy *et al.*, 2010). Past studies have noted that concentrated and quick urbanization is a result of human activities such as land cover change in which vegetation is replaced by fabricated surfaces, such as surfaced roads and buildings, which are known for their high absorption of solar energy (Jin *et al.*, 2005). As a result of the high rate at which surfaced roads soak up sunlight, their surface temperature climbs many degrees beyond the ambient temperature. The absorbed energy is initially stored inside construction mass and later discharged to the surrounding area by heat transfer through the material surfaces. Additionally, convection takes place from the physical surface to the air. The outcome of the discharged heat is elevated the outdoor and indoor temperatures (Carnielo and Zinzi, 2013). In urban areas, surfaces made of manufactured materials include asphalt and cement and both are known to cause increased heat storage and higher temperatures (Barnes *et al.*, 2001; Stathopoulou and Cartalis, 2009). The amount of paved surfaces in cities, including

streets, car parks and footpaths, was found to range between 29 and 45% (Akbari *et al.*, 1999; Rose *et al.*, 2003). Consequently, the surrounding air temperature is increased both during the day and at night caused Urban Heat Island.

The way a road is planned is an important concern in bioclimatic urban design methodology (Oke, 1988; Ali-Toudert and Bensalem, 2001). The road can be seen as the intersection between structural and urban scales, as it is made up of the shared surfaces among the buildings and the open urban canopy. Thus, the road influences both outside and inside microclimates and subsequently impacts the warmth felt by individuals and additionally the energy utilization in urban structures. The fundamental problem confronting engineers who build roads is designing a road that can withstand a tropical climate and that has the necessary safeguards to protect it from not only the tropical climate in general but also from the high levels of sunlight and subsequent radiation received throughout the characteristically long periods of intense sunshine during the day (Ali-Toudert and Mayer, 2006). As incoming sun-oriented short-wave radiation is absorbed during the day, it brings about immediate warming of the surface and the radiation is also taken in in great quantities by the road's deeper layers (Weller and Thornes, 2001).

Road climatology is essentially concerned with investigating the variables that impact the air and road

Corresponding Author: Nasibeh Faghih Mirzaei, School of Housing, Building and Planning, University Sains Malaysia, Penang, Malaysia, Tel.: +60178881103

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surface temperature along a road (Postgård and Lindqvist, 2001). A variety of studies have combined surface temperature and air temperature data (García-Cueto *et al.*, 2007; Hartz *et al.*, 2006; Lindberg, 2007; Voogt and Oke, 2003). However, particular indicators are solely calculated with either air temperatures or surface temperature (Schwarz *et al.*, 2012).

Due to rapid metropolitan development in Malaysia, amount of forests and vegetation have been replaced by artificial urban surfaces, which has led to increased ambient temperature in many Malaysian urban areas compared to rural areas (Faghih Mirzaei *et al.*, 2015).

This study focused to investigate the relationship between road surface temperature and air temperature above the road surface with regard to various roadside greenery covers and road orientations at Universiti Sains Malaysia (USM), Sungai Dua Town, Penang, Malaysia.

Thus, considering road orientation, the hypotheses tested in this study were as follows:

- Road surface temperature and the air temperature above the road are related.
- The amount of surrounding road greenery cover and road surface temperature are related.

SITE DESCRIPTION

The investigation was conducted in Sungai Dua Town, Penang, Malaysia (5.21°N, 100.18°E). The altitude is approximately 4 m above sea level. This town is characterized by a tropical climate, specifically a tropical rainforest climate bordering on a tropical monsoon climate with an average maximum temperature of 31°C, an average minimum temperature

of 23.5°C and an average humidity of roughly 50%. The annual precipitation is 2407.6 mm (20, 21). An additional characteristic of this climate is high sun radiation intensity, with annual solar radiation of 1809 kwh/m² (SEE Forum, 2009).

The study area is located on the USM campus in a part of town that contains a series of low-rise buildings surrounded by green spaces with narrow roads. The center of the roads is asphalt and there are concrete tiles on both sidewalks combined with trees, grass and soil.

As road orientation and height of the surrounding trees affect the road microclimate due to the degree of sunlight penetration, six experimental locations with various surrounding road covers were investigated (Fig. 1). Three sites (locations 1, 2 and 3) were along a road that runs north to south and three were along a road that runs east to west (locations 4, 5 and 6). Characteristics of the locations were described as follows.

Location 1 is a road surface with a single tree with great distance from the road and concrete paving on the eastern side, a single tree with a small distance from the road to the west. Location 2 consists of a road surface, concrete paving with parallel trees on the eastern side and concrete paving with grass on the western side. Location 3 is a road surface with concrete paving and a row of trees with grass on the eastern side and numerous trees with grass on the western side.

Location 4 consists of a road surface with concrete paving and grass on the southern side and shrubs with grass on the northern side of the road. Location 5 is a road surface with a row of trees along the concrete paving and a parking lot to the south and concrete paving on the north. Location 6 is a road surface with dense row of trees slightly removed from the road and concrete paving on the southern side and an asphalt surface sidewalk with grass to the north.

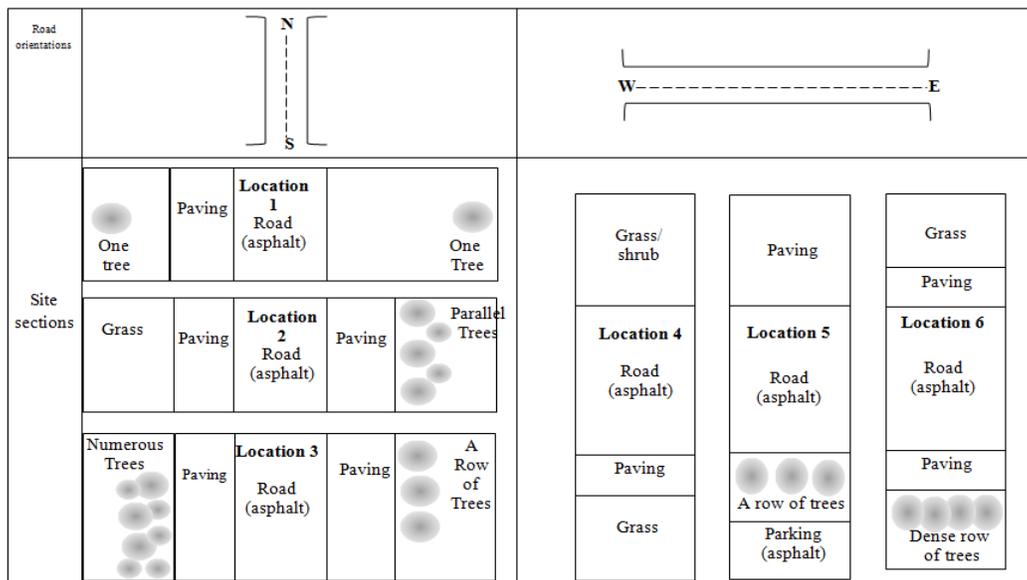


Fig. 1: The six experimental locations and the characteristics of their surrounding areas

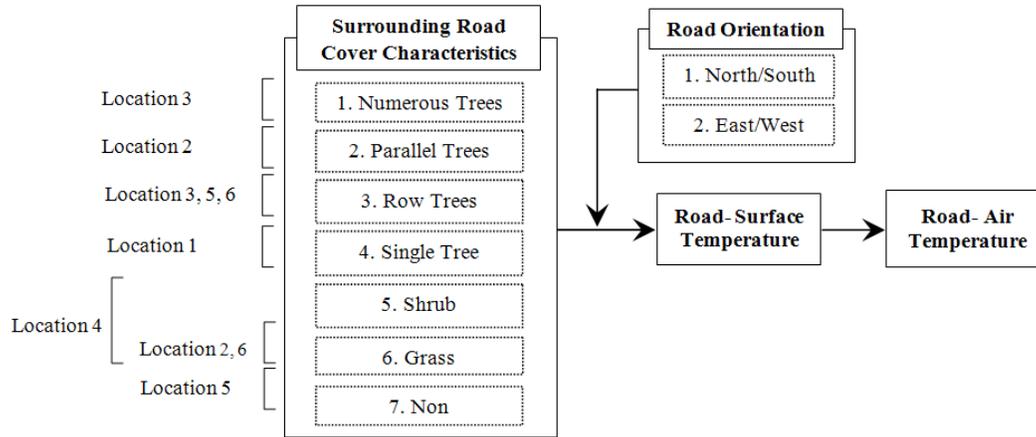


Fig. 2: Research framework design

METHODOLOGY

In order to evaluate the air and road surface temperatures within the urban road, a series of measurements were collected from the six experimental locations (Fig. 2).

The data were used to assess the relationship between road surface temperature and air temperature at 1 m above the road surface. It also allowed comparison of road surface temperatures among these locations, which were characterized by different surrounding greenery covers (i.e., numerous trees, parallel trees, rows of trees, a single tree, shrubs, grass and no greenery).

Twenty-four hour continuous field work was conducted for 3 days in February 2015: Air and surface temperatures were recorded every 4 h during this time period. The air temperatures were measured using portable meteorological instruments. In addition, a handheld infrared thermometer was used to measure surface temperatures.

RESULTS AND DISCUSSION

Relationship between air and road surface temperature: Air temperature near the road surface corresponded to increases in surface temperatures (Fig. 3). At all locations, the higher the surface temperature, the higher the air temperature 1 m above the road surface (and vice versa). The maximum surface temperature was 61.6°C at 1-2 pm at location 1, which was in the north orientation with air temperature of 32.8°C.

The minimum surface temperature was 24.7°C at 5-6 am at location 5 with air temperature of 26.7 °C along a middle of the road that runs east to west. The maximum air temperature of 35.8 °C was recorded at 1-2 pm at location 4, which was in the west orientation with surface temperature of 60.9°C. The minimum air temperature was 26.2°C at 5-6 am at location 3 with surface temperature of 27.1°C in the south orientation.

In further details, in all locations except location 3, the surface temperature was lower than the air temperature at 5-6 am. In this area, all surface temperatures are higher than air temperatures. In the afternoon at 1-2 pm, the surface temperature was much higher than the air temperature, except at location 5. The row of trees to the south and no greenery to the north explains why the scenario was different at location 5. The maximum surface temperature was 44.1°C at 9-10 am due to high solar absorption (air temperature 32.4°C). At 1-2 pm, however, surface temperature dropped to 35.8°C and air temperature increased to 35.2°C because the road surface was shaded by the trees to the south of the road.

Road surface temperatures relative to road orientation and surroundings: Both road orientation and road surroundings greenery cover affected the road surface temperatures (Fig. 4).

Locations 1, 2 and 3 were situated in the north to south direction. The maximum surface temperature at location 1 occurred at 1-2 pm. At this site, the single tree planted at each side of the road was too far from the road to protect the road surface, allowing more solar absorption by the surface material of the road. The surface temperatures at locations 2 and 3 at 1-2 pm were much lower than that of location 1 because more trees provided shade along the side of the roads, which prevented direct impact of solar radiation. Surface temperatures at location 2 were lower in the morning compared to location 3, whereas the opposite was true in the afternoon. Locations 4, 5 and 6 were situated in the east to west orientation. Location 4 had the maximum surface temperature at 1-2 pm because there were no trees along either side of the road to provide shade. In comparison, locations 5 and 6 had trees along the southern side of the road. At 9-10 am, the surface temperature at location 5 was higher than that at location 6, whereas the opposite was true at 1-2 pm. These differences were the result of the distance of the dense row of trees from the road surface.

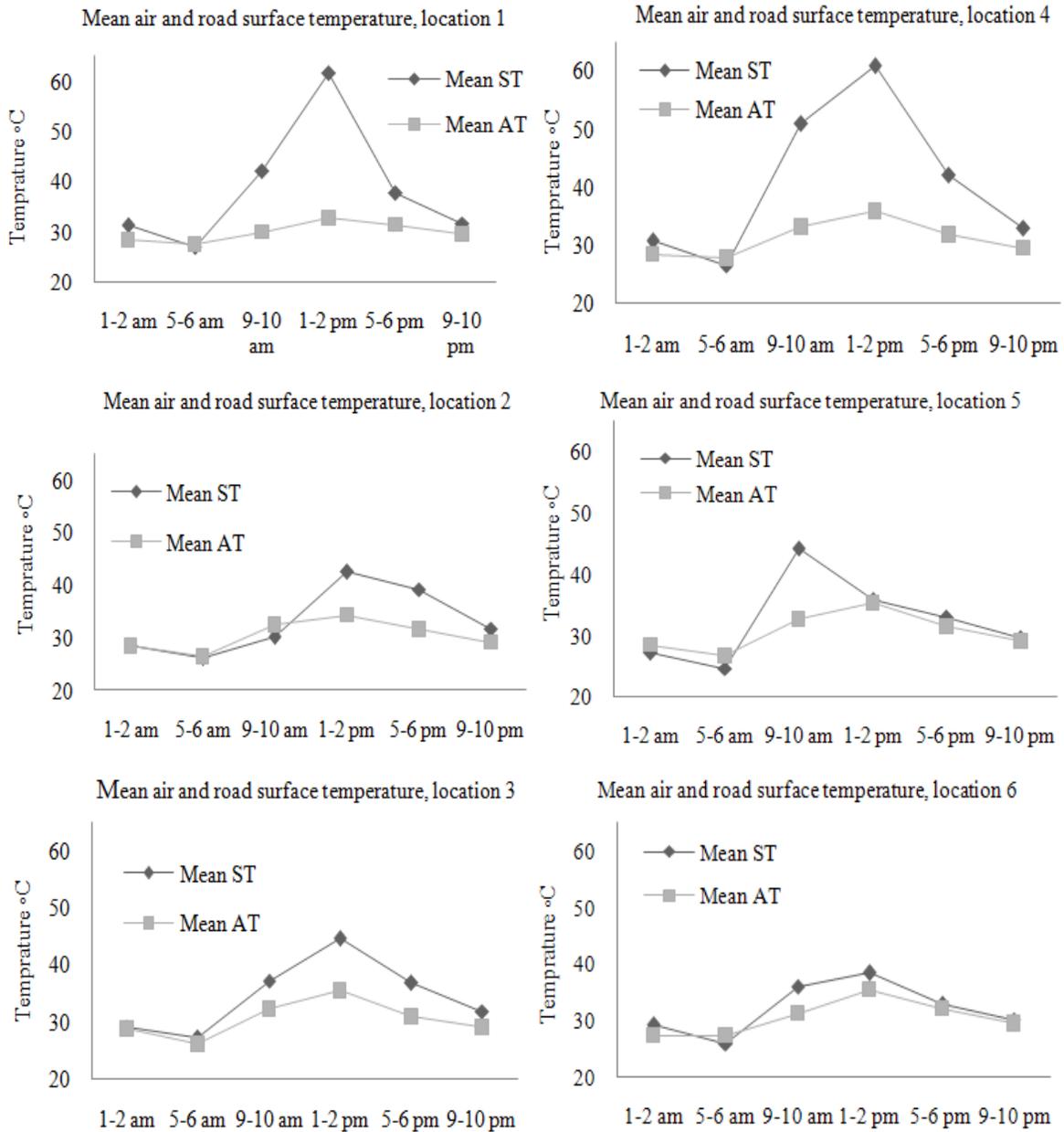
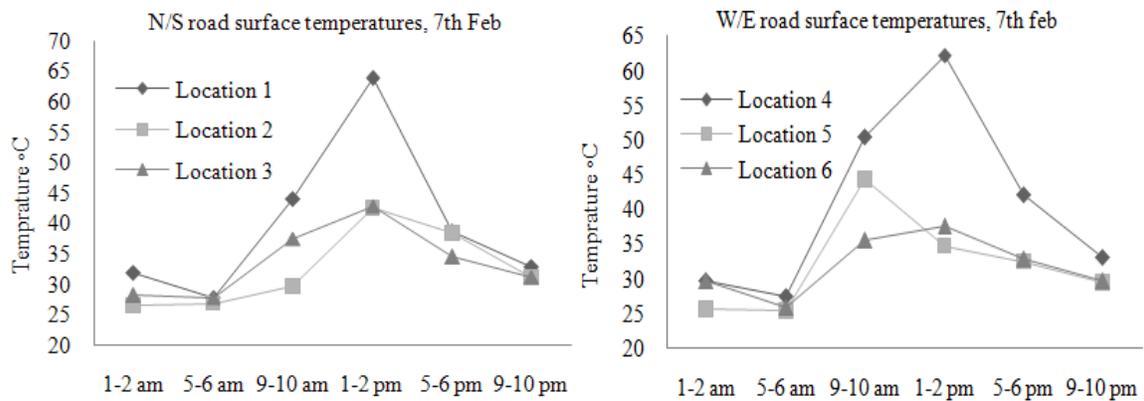


Fig. 3: Relationship between mean Air Temperature (AT) and road Surface Temperature (ST)



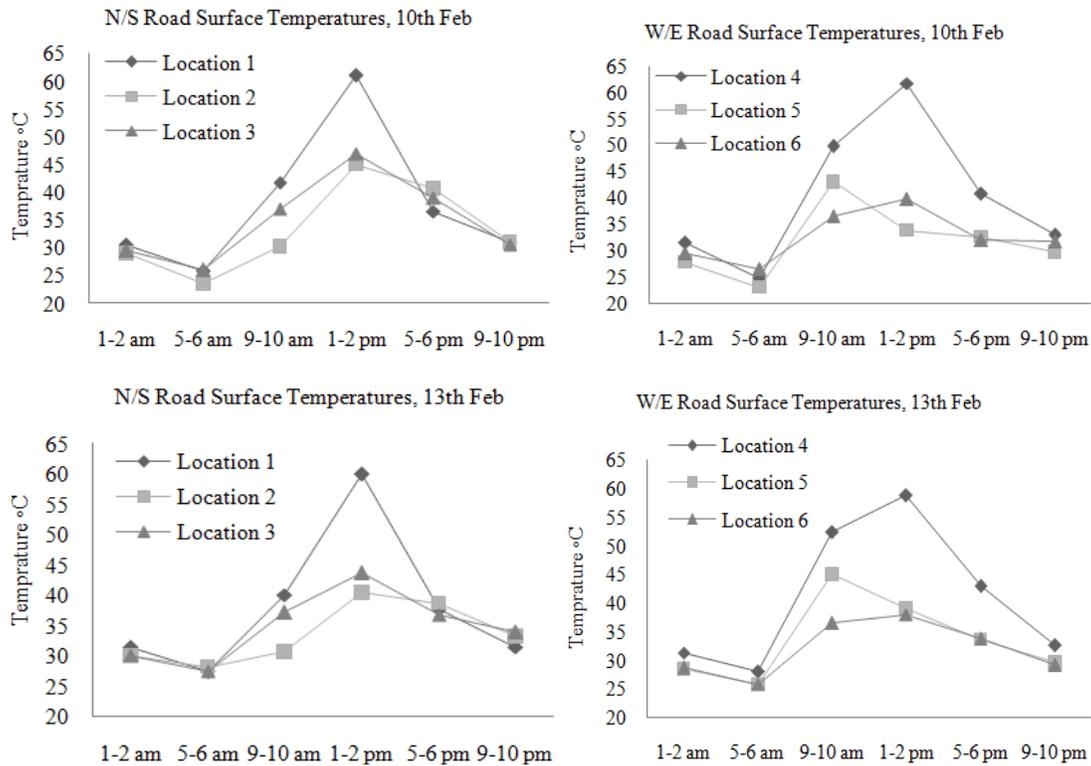


Fig. 4: Road surface temperatures at different road orientations and surroundings

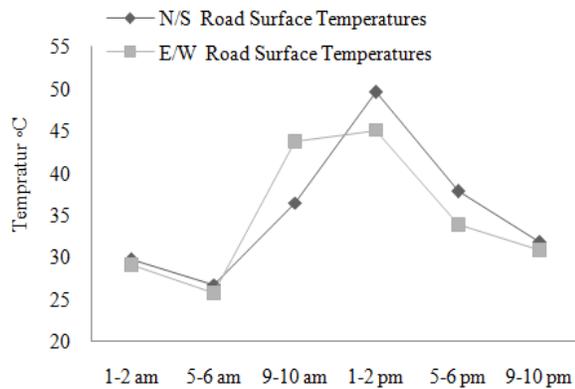


Fig. 5: Comparison of mean road surface temperatures of different road orientations

Overall, mean surface temperatures of north-south road were higher than those of the east-west, road except at 9-10 am due to exposure to solar radiation (Fig. 5).

CONCLUSION

As rapid urbanization continues, urban air temperature is being increased by the replacement of natural vegetation with paved surfaces. This study investigated the impact of road surfaces on air temperature at the USM Campus in Penang, Malaysia. The results of this study indicate that air temperature

near the road surface corresponds to the increase in surface temperatures (i.e., the higher the surface temperature, the higher the air temperature 1 m above the road surface). The maximum surface temperatures were measured at locations with fewer trees or trees planted far from the side of the road so that they were unable to shield the road surface from solar irradiation. Overall, mean surface temperatures were higher for the north-south orientation than for the east-west direction, except at 9-10 am. These findings show that sensible urban design that considers green spaces on roadsides could ease high urban air temperature.

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