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ORIGINAL ARTICLE

Observational Study for the Thermal Environment Evaluation of Summertime over the Asphalt Pavement
- Case Study in Daegu 2014 -

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Abstract

To investigate the thermal environment over the summertime asphalt pavements, an automatic weather observation system was installed at a parking lot paved with asphalt to observe various meteorological parameters and surface temperature from July 1 to September 30, 2014. Since the number of rainy days in summer of 2014 particularly after the mid July is more than that of average data, a ratio of daily peak surface temperature above 45 ℃ was 28% which was lower than the average. The observational data about hourly average surface temperature and various heat balance factors at days where daily peak surface temperature is above 45 ℃ are as follows: An hour that had the daily maximum temperature was around 15 pm and the value was 49℃ approximately. Net shortwave radiation was the highest at 12pm as 800 W/m^2 and much radiation of 500 W/m^2 was absorbed at the ground between 11am and 17pm. Sensible heat that was delivered from the ground to the atmosphere was evaluated as 200 W/m^2 between 10am and 19pm. underground transfer heat up to 100 W/m^2 was measured as negative from 19pm to the next day 8am, which indicated the lower atmosphere was heated at night.

Key words : Net shortwave radiation, Sensible heat, Soil Transfer heat

1. Introduction

Global warming due to greenhouse gas increases and deepening urban heat island phenomenon due to urbanization have caused summertime high tempera-tures phenomenon and brought about hardship due to the heat wave in cities of the low-latitude regions including South Korea. Thus, the higher temperature phenomenon has been considered as environmental pollution since 1990s and a countermeasure against the urban high temperature phenomenon in summer-time has been taken as a worldwide trend.

Earth's average temperature for the last 100 years has increased by 0.74℃ reportedly. At the same time, urban temperature has increased by more than that due to the urban heat island at the same period. A rising temperature rate for the last 100 years in world's major cities has been more than that. For example, Tokyo 3℃/100 year, New York 1.7℃/100 year, Paris 1.6℃/100 year, and Seoul 2.1℃/100 year are recorded. The rising temperature rate of such cities is a summing result of global warming and urban heat island effects, which showed two to four times higher than the Earth's average temperature rise (Kai, 2013).

The most important factor of the urban heat island

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is a ground surface covered with artificial structures in cities (Moriyama, 2005). Most urban surface areas now are paved with asphalts or concretes and green spaces or wet soils and wetlands disappeared. Among artificial structures in cities, road pavements account for most urban surfaces. For example, South Korea has approximately 20% road pavement rate (Park et al., 2013). Road pavements are important and indispensable social infrastructures in cities but they can play a major role in forming a new urban climate by changing thermal functions in the surface (Kim et al., 2003; Lee et al., 2010). Impervious asphalt pavements have a much lower albedo and considerably higher thermal transfer rate than natural soils, which make high daily radiation absorption and high underground storage of absorbed heat significantly. It also increases loss of water retention and evapotranspiration that green space and soil have, resulting in losing the water evaporation effect in the surface. Once the water evaporation function is lost, latent heat due to evaporation disappears and high temperature on the urban surface is promoted (Hujibe, 2012). As a result, temperatures beside the roads are higher than that observed in meteorological stations by several degrees and in summer, it is reportedly higher by more than 6℃ (Kim et al., 2014).

In recent year, concerns about casualties due to heat wave in summer and the need of countermeasure have been raised (KMA, 2015). A heat wave is severer in urban regions than in suburban regions and high temperature phenomenon is much higher in roadsides in urban cities, which requires a countermeasure for affected regions in priority (Kim et al., 2014).

Accordingly, this study identified thermal environments above the asphalt pavements through site observation and investigated a heat environment forming process through heat balance analysis. In this study, observation data in 2014, which had more rainy days in summer than usual, were used so that it cannot provide climatological characteristics. In the future, thermal environment characteristics over the asphalt pavement road will be suggested climatologically through long-term basis observation.

2. Study Method

An automatic weather observation system was installed in a parking lot of alumni and students in Keimyung University in Dalseo-gu, Daegu Metropolitan City and various weather elements and surface temperature were observed in every 10 second for three months from July 1 to September 30 2014 using a data logger (CR-1000) to accumulate the data (Fig. 1). The measurement sensors were products from Vaisala Company to measure temperature, humidity, wind direction and wind speed and a thermocouple was connected to CR-1000 to observe surface temperatures. Radiation was observed at Daegu Weather Station and used at data analysis. In this study, one-hour average data was utilized and data collection was done in every week. The verification of surface temperatures was conducted by comparing them with manually observed values at the same data collection period using a thermal infrared thermometer.

Using the daily highest temperature observed at the asphalt surface for three month during the summer, temperatures were classified into three grades: over 50 ℃, 45 ℃ to 50 ℃, and below 45 ℃, and their occurrence frequencies were analyzed. Furthermore, heat balance analysis was conducted with respect to days over 45 ℃, which had relatively higher daily temperatures.

A relationship of heat balance between ground surface and atmosphere at the asphalt surface is as follows: The ground surface absorbs solar radiation energy ((1-α)S) and atmospheric longwave radiative energy (L) and re-emits energy into the atmosphere as a form of sensible heat (H) and Earth's longwave energy(σT_s^4). Days of high temperature without rain can ignore latent heat (lE) exchange. Remaining (insufficient) energy between atmosphere and ground is stored (emitted) as ground transfer heat (G). This can be expressed by the following equation.

$$(1-\alpha)S+L=H+lE+G+\sigma T_s^4 \quad (1)$$

where is an albedo of the asphalt surface and we assumed this as 0.15 that is correspond to that of used asphalt for some time according to Kondo (1994). refers to surface solar radiation over the sea, is atmospheric longwave radiation, is sensible heat, is latent heat, is underwater storage heat, and refers to Earth longwave radiative energy. Atmospheric longwave radiation (σT_s^4) can be calculated as follows according to Kondo (1994).

$$\frac{L}{\sigma T_s^4}=1-(0.49-0.066\times e^{0.5})(1-n\times C\times 4) \quad (2)$$

where and are given as Eqs. (3) and (4).

$$C=0.75-0.005\times e \quad (3)$$

$$h=[n_1+0.85\times n_2+0.5\times n_3)/n]+0.1\times N_r/N \quad (4)$$

where is daily average water vapor pressure (hPa), which was obtained via the Tetan method suggested in the below. N_r/N is a time of raining in a day and $n,\ n_{1,}\ n_{2,}\ n_3$ refer to cloud amount, lower, middle, and upper cloud amounts. To resolve the lack of data of middle and upper clouds, the following approximation relationship proposed by Ishi and Kondo (1993) was applied.

$$n_2=n_3=(n-n_1)/2 \quad (5)$$

$$N_r/N=0_{\text{for}}n_1<1$$
$$=0.5_{\text{for}}n_1=1 \quad (6)$$

Sensible and latent heat transport can be expressed using the bulk equation as follows:

$$H=C_p\rho C_H U(T_s-T_a) \quad (7)$$

$$lE=l\rho\beta C_H U(q_{sat}(T_s-q_a) \quad (8)$$

Note that C_p refers to constant pressure specific heat (100J/(kg · deg)), ρ is an air density (1.27kg/m^3), $C_H U$ is sensible heat transport rate, l is latent heat of vaporization (2.51×10^6J/kg), β is wetness of the surface (evaporation efficiency), which is assumed as 0 for dry asphalt roads (Kondo, 1994). T_s refers to ground surface temperature (K). T_s refers to temperature (K), q_a refers to specific humidity in the atmosphere, and $q_{sat}(T_s)$ refers to saturation specific humidity with regard to T_s. To calculate specific humidity, saturation vapor pressure calculated using the Tetan formula, which has been widely used in many studies including Kim and Yang (1995), was employed in this study.

$$e_s=6.11\times\exp\left(\frac{17.27\times T_c}{T_c+273-35.86}\right) \quad (9)$$

where e_s is a saturation vapor pressure and T_c is a Degrees Celsius (℃) of temperature. Water vapor pressure that is represented by vapor including air can be calculated by multiplying the saturation vapor pressure by relative humidity measured at the automatic weather observation system (AWS).

$$e=e_s\ \bullet\ RH\div 100 \quad (10)$$

where e is a water vapor pressure (hPa) and is a relative humidity (%). Using the water vapor pressure, specific humidity can be calculated as follows:

$$q\cong 0.622\frac{e}{P} \quad (11)$$

Fig. 1. Automatic weather observation system used in this study installed at a parking lot of Keimyung University.

where P is atmospheric pressure (hPa). The meteorological observation data used in the heat balance calculation are radiation, cloud amount, temperature, ground surface temperature, atmospheric pressure, and relative humidity in the atmosphere. As water surface parameters, albedo (α), a sensible heat transport rate ($C_H U$), and wetness of water surface ($\beta = 1$) were used. The ground transfer heat (G) was calculated using a residual term in the heat balance equation.

3. Result

Fig. 2 shows the classified surface temperature in July, August, and September of 2014. A ratio of days where the daily peak surface temperature was more than 45 ℃ for three month of summer time in 2014 was 28%. This relatively low ratio was due to many rainy days since mid-July in 2014. In particular, rainy days were concentrated since the 12th of August so that very few days had the daily peak surface temperature over 45℃ in August and September.

Fig. 3 shows averaged hourly surface temperature and atmosphere temperature where the daily peak surface temperature was more than 45℃. The surface temperature was the highest as 49℃ at 3pm and the

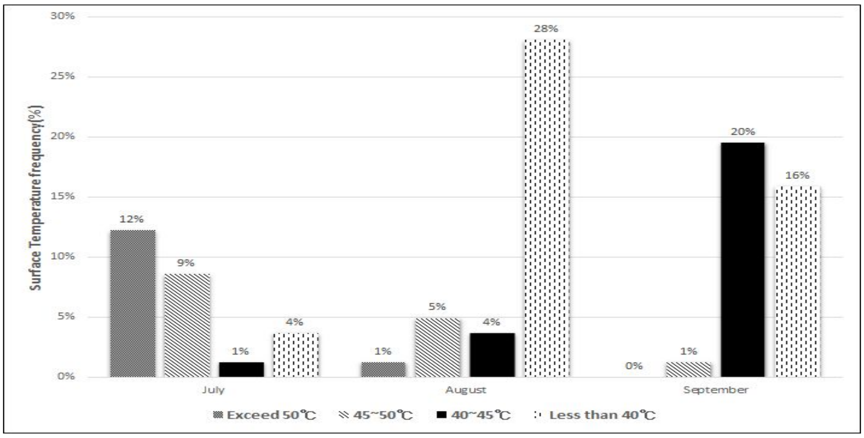

Fig. 2. Class distribution of surface temperature for 3 months in 2014.

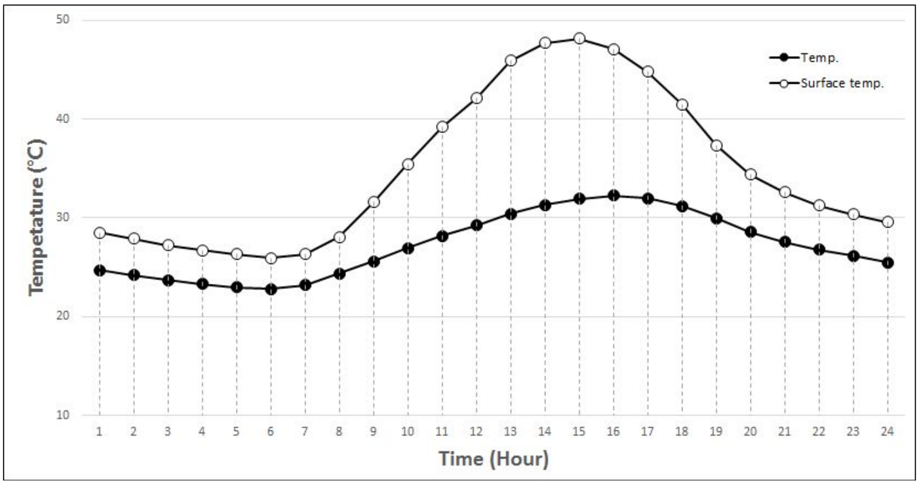

Fig. 3. Distribution of average hourly surface temperature and atmosphere temperature

atmosphere temperature was the highest as 32℃ at 4pm approximately one hour later after the highest surface temperature. The reason for the delay of emergence of daily peak temperature over the asphalt pavement compared to generally known daily peak temperature emergence was because sensible heat that is transferred from the ground to the atmosphere and longwave radiation energy was maintained very high up to late afternoon due to the high heat capacity of asphalts.

To determine the solar radiation energy amount absorbed in the ground surface at days where daily peak surface temperature was more than 45℃, hourly distribution of net shortwave radiation is shown in Fig. 4. An albedo of the asphalt surface was assumed to have 0.15, which was corresponded to used asphalt

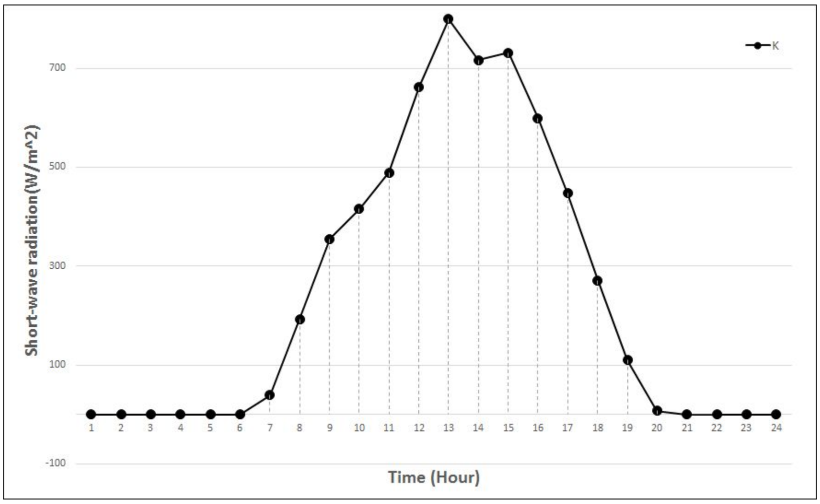

Fig. 4. Averaged hourly net shortwave radiation at the ground surface over days where daily peak surface temperature was above 45℃.

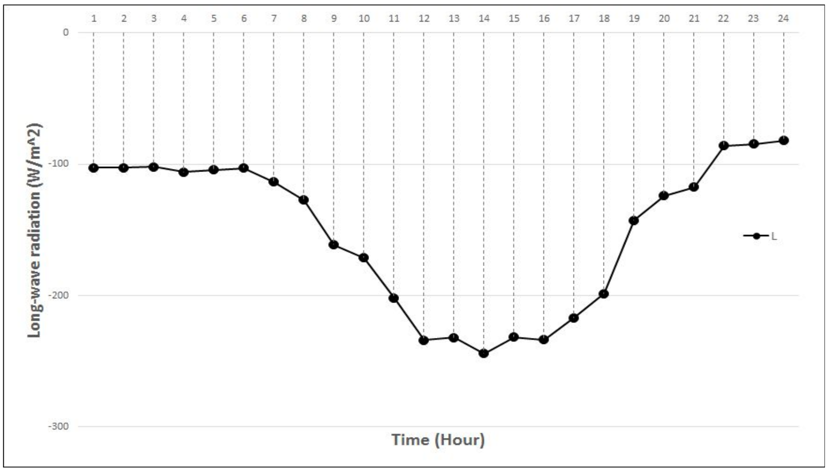

Fig. 5. Averaged hourly net longwave radiation at the ground surface over days where daily peak surface temperature was above 45℃.

for several years (Kondo, 1994). The net shortwave radiation was highest at 12pm as 800 W/㎡ approximately and hours where radiation affected the surface were 6 to 20 hours. Hours where high radiation above 500 W/㎡ was absorbed in the surface were from 11am to 5pm. Radiation at 3pm, which had the highest surface temperature, was 700 W/㎡ approximately and radiation at 4pm which had the daily peak temperature, was 600 W/㎡ approximately.

Fig. 5 shows the heat balance (downward longwave radiation energy - upward longwave radiation energy) of longwave radiation energy at the surface over days where daily peak surface temperature was above 45℃. At hours of 11am to 5pm where surface temperature was risen to 40℃ or higher due to more solar radiation energy was absorbed during all hours, long

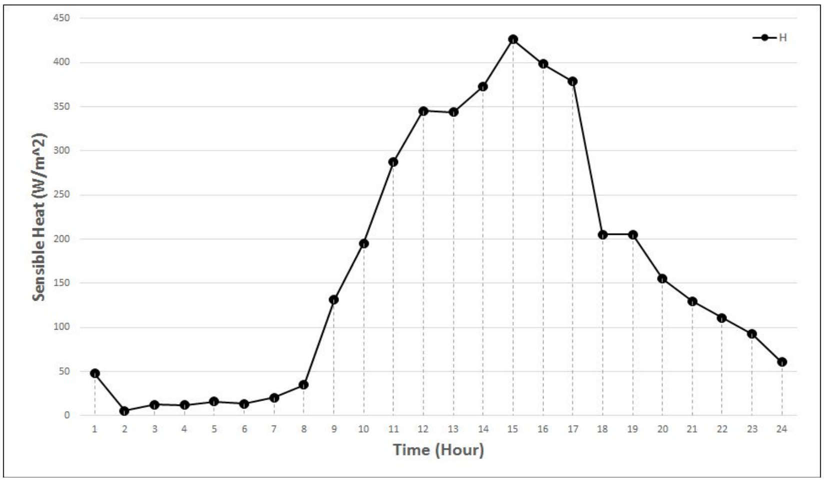

Fig. 6. Averaged hourly sensible heat flux transferred from the surface to the atmosphere over days where daily peak surface temperature was above 45℃.

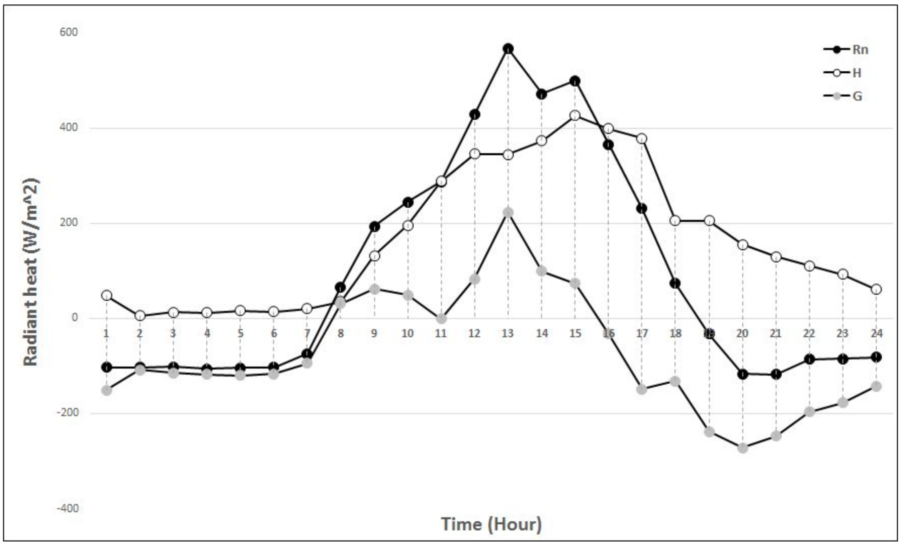

Fig. 7. Averaged hourly heat balance factors at the surface over days where daily peak surface temperature was above 45℃.

-wave radiation energy emitted from the surface to the atmosphere was more than that emitted from the atmosphere to the surface.

Fig. 6 shows the average hourly sensible heat flux transferred from the surface to the atmosphere over days where daily peak surface temperature was above 45℃. As shown in the figure, a lot of sensible heat flux over 200 W/㎡ was transferred to the atmosphere from 10am to 7pm, indicating that air was heated by the surface significantly. In particular, strong sensible heat flux over 350 W/㎡ occurred at 1pm to 5pm, indicating that lower air over the asphalt pavement surface was heated significantly. Thus, it is recommended to run the clean road system more at these hours than other hours to reduce the surface temperature thereby decreasing the atmosphere temperature as well.

Fig. 7 shows the average hourly heat balance factors over days where daily peak surface temperature was above 45℃. Most net radiation during daytime consists of solar radiation, and most net radiation energy absorbed at the surface heated lower air directly as a form of sensible heat and the remaining heat was stored as underground heat. As shown in the figure, the ground transfer heat at 7pm to 0am was negative, which indicated heat stored during daytime was transferred to the surface and consumed to heat lower air. This consumption was highest at 8pm, which was 100 W/㎡.

4. Conclusion

From July 1 to September 30, 2014 which is regarded as warm climate season, an automatic weather observation system (AWS) was installed at a school parking lot to measure meteorological factors and surface temperature continuously. As a result, this study found the following conclusions.

1) A ratio of days where daily peak surface temperature was above 45℃ was only 28% due to many rainy days since mid-August in 2014. The changes in surface temperature and atmosphere temperature over days where daily peak surface temperature was above 45℃ showed that the surface temperature was approximately 49 ℃ at 3pm and the atmosphere temperature was the highest as 32 ℃ at

4pm, which was one hour later than that of the surface highest temperature. The reason for this delay (two hour) of the daily highest temperature at parking lot compared to that observed at Daegu Weather Station (around 14pm) was because sensible heat transferred from the surface to the atmosphere and longwave radiation energy were highest up to late afternoon due to the high heat capacity of asphalts.

2) The surface radiation from 11am to 5pm over days where daily peak surface temperature was above 45℃ was 500 W/m^2. The net longwave radiation during these hours was -200 ~ -240 (“-” means upward longwave radiation was larger than downward longwave radiation) and net radiation was up to 300 -500 W/m^2. Most radiation was converted into sensible heat to be consumed to heat atmosphere air and some of them were stored inside the asphalt as a form of ground transfer heat.

3) The ground transfer heat stored inside the asphalt during daytime was transferred to the surface from 16pm to next day 8am to heat the atmosphere.

Through the heat balance analysis, our study can evaluate the role of asphalt pavement quantitatively that increased not only daytime temperature but also nighttime temperature in cities. Thus, it is important to set a countermeasure to decrease temperature at pavements at summertime in order to improve thermal environments of big cities where asphalt roads are paved much.

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