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THE INFLUENCE OF PARTICULATE MATTER CONCENTRATIONS ON SPECTRAL POWER DISTRIBUTION

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Abstract

Sunlight is a valuable resource with photometric and radiometric characteristics and the common characteristics of these two aspects is the spectral power distribution (SPD). The particulate matter (PM) has a great influence on SPD and this paper aims to study the relation between PM concentrations and SPD. The SPD and PM concentrations were measured by spectrometer and dust meter respectively. The results show that the negative relation has been investigated between total irradiance, illuminance and PM value, and the correlation increases with the increasing sizes of PM. PM_{10} is found having a positive influence on relative percentage of SPD (RSPD) in four medium and long wavelength ranges. PM_{10} also has a strong effect on relative percentage of spectral illuminous intensity distribution (RSLD) in five medium and long wavelength ranges. The negative relation is found in the first wavelength and the rest are positive.

Keywords: Spectral power distribution; Particulate matter concentration; Illuminance; Irradiance

1 Introduction

Sunlight is a free and valuable resource that is a key factor in maintaining the Earth's ecosystem and providing a constant sustainable energy to the planet. Sunlight has radiometric characteristic which brings solar radiation (Littlefair, 2001) into the room and it affects indoor thermal environment (Nielsen, 2005). While the sunlight also has photometric and colorimetric characteristics which bring visible light into the room and decide indoor luminous environment (Xue, 2014). The common characteristics of these two aspects is the spectrum, which has been a hot issue in both indoor thermal and luminous environment studies. Innovative coating (Marino, 2015) with high solar reflectance and high thermal emissivity has been implemented and improved to reduce the solar irradiance entering into the room than traditional material. Except for illuminance, colour temperature, colour rendering index and other indicators generated by spectrum in luminous environment have grab researchers' eyes as they have a great impact on comfort and health (Judd, 1964; Webb, 2006).

In recent years, the urban air pollution has been a critical issue in China due to its rapidly expanding economic and industrial developments (Chan, 2008; Song, 2017). Various air pollutants, especially the particulate matter (PM), shows a relatively negative impact on human health (Chen, 2012) and visual visibility (Hyslop, 2009). Therefore, the relation between air pollution and solar radiation has been attracting growing consciousness and interests for researchers.

Atmospheric pollutants reduce solar radiation reaching Earth's surface and Haywood et al. (1997) showed that increasing air pollution especially anthropogenic particulate matter scatters sunlight back into space and reduce surface radiation. Abakumova et al. (1996) stated that surface solar radiation decreases 4% at the world since 1960. Li et al. (2017) revealed that air pollution over northern and eastern China reduces annual average point-of-array irradiance (POAI) by up to 1.5 kWh/m^2 per day relative to non-pollution conditions.

Therefore, numerical studies have been carried out to predict the solar radiation with air pollution. Zhao et al. (2013) have developed and demonstrated several predicting models for a daily global radiation by introducing air pollution index (API) data as a new parameter. Wang et al. (2012) investigated the changes in sunshine hours with API in China, which indicates that spatiotemporal changes in sunshine hours in China could largely be explained in terms of API. A new method, air quality index correction, is proposed to amend the existing daily diffuse solar radiation models by Yao et al. (2017). However, few studies focus on the relations between PM and spectrum of solar radiation.

Due to the scattering effect of PM on sunlight and important influence of spectrum on indoor environment, this paper studies the relation between PM concentrations and spectral power distribution (SPD) based on the experiments conducted in Beijing. The indication with PM concentration on spectrum will be further investigated, and the detailed steps are: reveal the stronger relation PM concentrations with irradiance and illuminance; study the effect of PM_{10} on SPD.

2 Methods

2.1 Hypotheses

In this case, the SPD is affected owing to complicated attenuating properties of the atmosphere when light travelling in the atmosphere. In order to evaluate the influence of particulate matters on the SPD, some factors should be ignored and some hypotheses are shown as follows:

(1) as the effect of clouds on SPD is complicated and smog and fog are hard to be recognized by eyes, only the data of sunny days is selected for analysis;

(2) the PM concentrations with altitude is treated as uniform and the heights of particulate matters level in different days are treated as the same;

(3) the selected experimental data is measured on adjacent dates, and the difference in solar altitude is not big which could be ignored.

2.2 Experiment

The experimental devices include a spectrometer, a cosine corrector and a dust meter. The absolute radiant intensity corresponding to 339,77 nm to 1026,57 nm was measured by a USB2000+ micro-fiber-spectrometer with a cosine corrector, while the particulate matter concentrations was measured by a Model 8530 DUSTTRAKTM II dust meter. The values of PM_1, $PM_{2.5}$, PM_4 and PM_{10} were respectively measured.

The experimental period is from May to September in 2018. From July 12th to July 19th, 8:00AM~16:00PM, the data was measured every 1 hour. In other measuring days, the SPD and PM data are only measured at 12 o'clock. The measuring time for each PM value is 2 minutes, and final result was calculated as the average value within this time.

2.3 Data analysis and processing

With the purpose of this study, 20 sunny days' data are selected for further analysis. Complied with mentioned hypothesis in Section 2.1, SPD and PM data are processed with R language and SPSS.

The data measured by spectrometer is not an integral value and it starts with every 0,38 nm from 339,77 nm to 1026,57 nm, while only the data in the range of visible wavelength (380 nm ~ 780 nm) is discussed in this experiment. SPD data is firstly rounded with the wavelength of each 1 nm from 380 nm to 780 nm by R language. Then, the total irradiance (indicated by E_e) and the total illuminance (indicated by E_v) could be obtained with integration.

In this case, the illuminance and irradiance could be assessed with PM concentrations by Spearman's rank correlation coefficient in SPSS.

Due to different absolute SPDs in everyday, the relative percentage of SPD (RSPD) and the relative percentage of spectral illuminous intensity distribution (RSLD) are proposed to represent the relative change of spectral power in each wavelength. The relation between SPD (RSPD&RSLD) and PM_{10} concentrations are finally revealed with correlation and regression analysis.

3 Results

3.1 The influence of PM concentrations on irradiance and illuminance

In this case, the relations of total irradiance and illuminance values are investigated with PM concentrations by correlation analysis, and the results are shown in Figure 1.

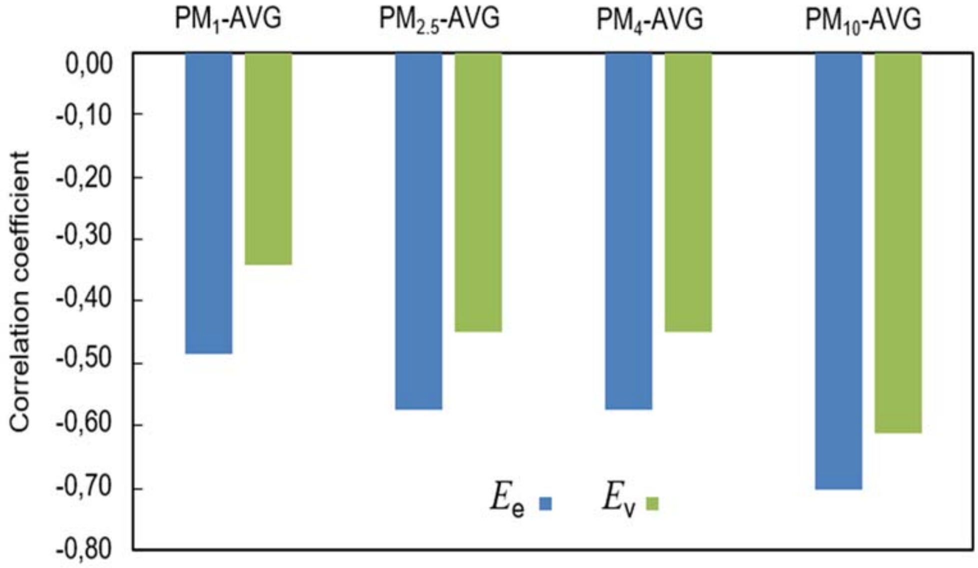

Figure 1 – The relation of irradiance, illuminance with PM concentrations

It can be seen from the results that all correlation coefficients are negative, which indicates that the illuminance and irradiance decrease with the increasing of PM concentrations. From the figure, the influences of different PM sizes on E_e and E_v are found differently. With the increasing of the PM size, the values of coefficients increase and PM_{10} has a strongest relation among four different sizes of PM.

3.2 The influence of PM_{10} concentrations on SPD

To further study the relation between PM concentrations and solar radiation, RSPD and RSLD are proposed to represent the relative change of spectral power in wavelength as absolute SPDs are different every day. The value of PM_{10} is selected for analysis since it has a strongest correlation with SPD.

3.2.1 The influence of PM_{10} concentrations on RSPD

To test the correlation between PM_{10} concentrations and RSPD, the data is calculated according to method in Section 2.3. The influence of PM_{10} on RSPD are shown in Figure 2, and the correlation coefficient is shown above and wavelength ranges are written below.

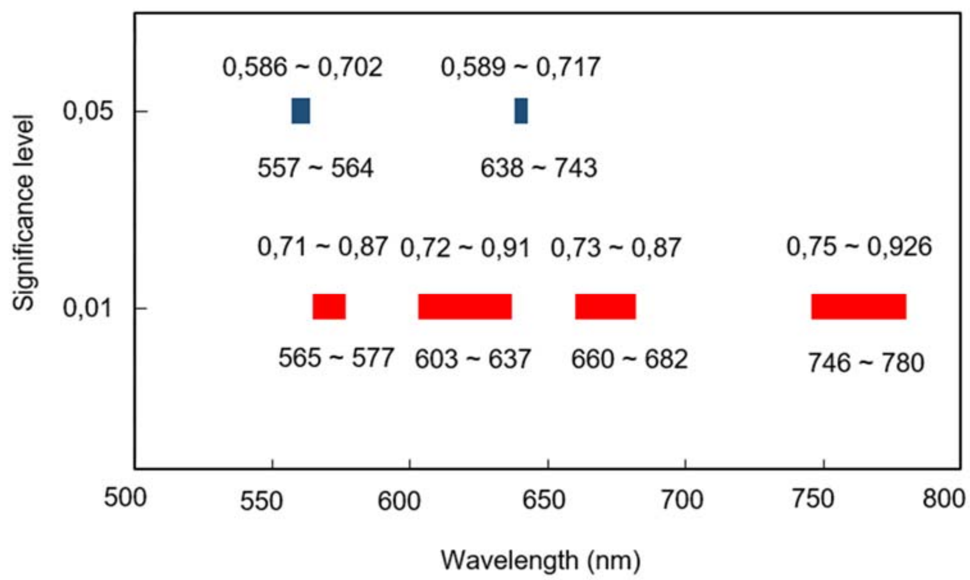

Figure 2 – The relation between PM_{10} value and RSPD

From the result, it can be seen that PM_{10} value has a great influence (with the significance level of 0,01) on several ranges of relative medium and long wavelength, which are 565 nm ~577 nm, 603 nm ~ 637 nm, 660 nm ~ 682 nm and 746 nm ~ 780 nm respectively. The coefficient value is positive, and the relation among 603 nm ~ 637 nm and 746 nm ~ 780 nm is higher (up to 0,9), which shows the SPD and PM_{10} concentrations could be indicated each other in some ranges of wavelength.

To study the quantitative relation between PM_{10} and RSPD, a higher correlation wavelength with higher significance level, 770 nm, is selected, and the results are shown in Figure 3.

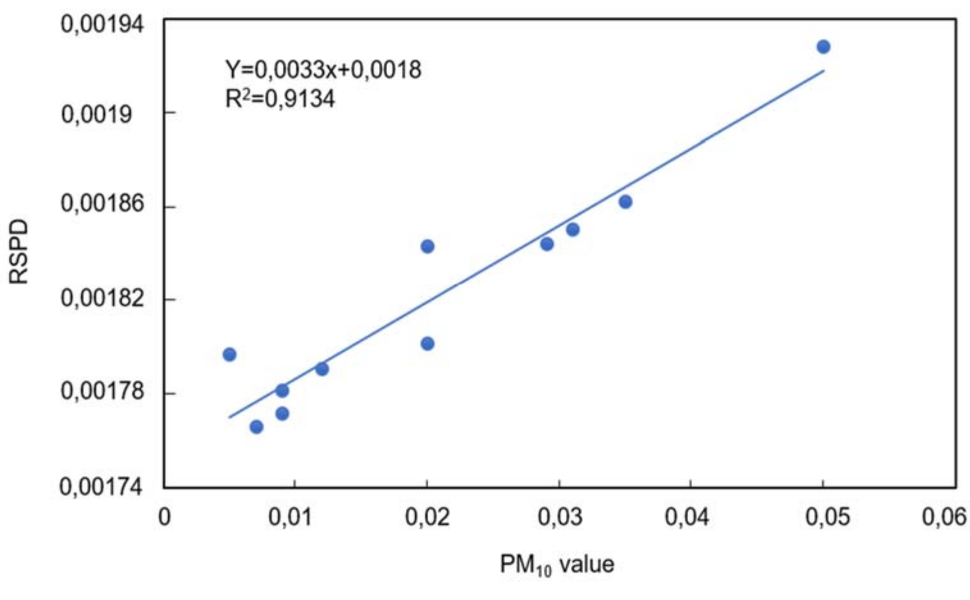

Figure 3 – The effect of PM_{10} on RSPD with a wavelength of 770 nm

As seen from results that the RSPD shows a linear relation with PM_{10} concentrations. This relation is confirmed by linear regression (R^2>0,9), where the PM_{10} value grows from 0,005 mg/m³ to 0,05 mg/m³ and RSPD changes within 0,177 % ~ 0,194 %.

3.2.2 The influence of PM_{10} concentrations on RSLD

To study the relation between PM_{10} concentrations and RSLD, the data is dealt with the principle mentioned in Section 2.3. The influence of PM_{10} on RSLD are shown in Figure 4, and the correlation coefficient is shown above and wavelength ranges are written below.

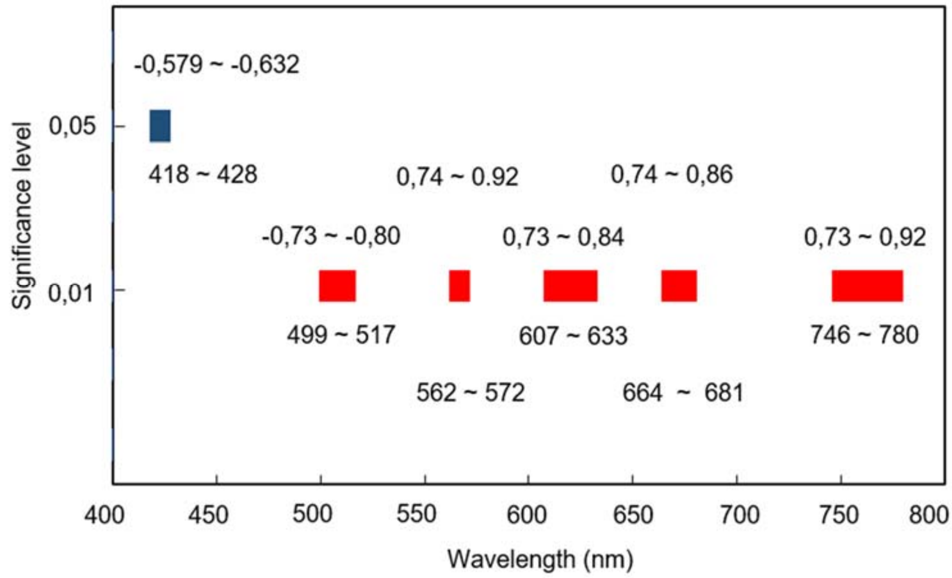

Figure 4 – The relation between PM_{10} value and RSLD

From the result, it can be seen that PM_{10} condition has a great impact on several ranges wavelength, which are 499 nm ~ 517 nm, 562 nm ~ 572 nm, 607 nm ~ 633 nm, 664 nm ~ 681 nm and 746 nm ~780 nm respectively. The significance level in all these five ranges is P<0,01. However, RSLD has a negative relation with PM_{10} values in the first wavelength range (499 nm ~ 517 nm), and it have positive relations in other ranges. The correlation coefficient differs within five ranges of wavelength and it becomes strong in 562 nm ~ 573 nm and 746 nm ~ 780 nm (up to 0,9), which shows the luminous intensity and PM_{10} concentration could be indicated well each other in these ranges of wavelength.

To quantitatively study the relation between PM_{10} value and RSLD, a wavelength of 570 nm and 500 nm (P<0,01) are selected, and the results are shown in Figure 5 and 6.

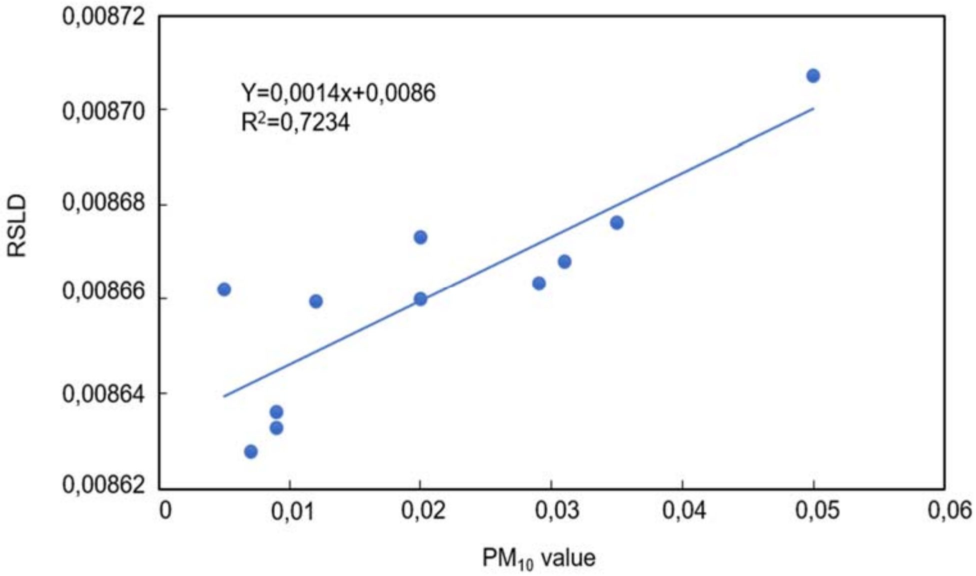

Figure 5 – The effect of PM_{10} on RSLD with a wavelength of 570 nm

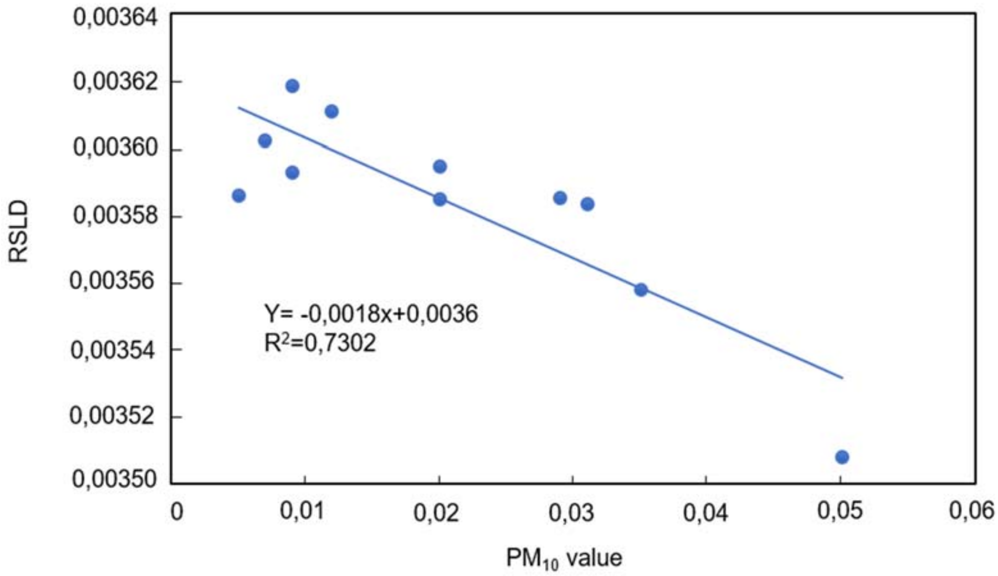

Figure 6 – The effect of PM_{10} on RSLD with a wavelength of 500 nm

From the results, the RSLD shows a linear relation with PM_{10} concentrations. This relation is confirmed by the linear regression (R^2>0,7), where the PM value increases from 0,005 mg/m³ to 0,05 mg/m³ and RSLD results in 0,862 % ~ 0,872 %. On the contrary, the other relation (shown in Figure 6) is confirmed by the linear regression (R^2>0,7), which the PM10 value starts from 0,005 mg/m³ to 0,05 mg/m³ and the RSLD decreases from 0,364 % to 0,350 %.

4 Conclusions

In this study, the influence of PM concentrations on irradiance and illuminance is investigated with on-site measurement. With the data measured by spectrometer and dust meter from May to September in 2018, and PM_{10} has a strongest relation with illuminance and irradiance among four different sizes of PM.

To quantitatively study the influence of PM_{10} on spectrum, RSPD and RSLD are proposed to show the relative intensity of irradiance and illuminance in each wavelength. In the result of irradiance, PM_{10} concentrations have stronger relation with RSPD in four medium and long wavelength ranges and the relation are all positive. While in the result of illuminance, RSLD has a negative relation with PM_{10} concentrations in a short wavelength and has positive relations with other medium and long wavelength ranges.

The monotonic relation between the SPD and the PM10 concentrations could provide a reference for the mutual characterization between atmospheric spectrum and particulate matters. The results could also offer spectral boundary condition for the indoor thermal and luminous environment studies in the future.

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