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CHARACTERISTICS OF THE EMISSION OF PARTICULATE MATTERS IN CONSTRUCTION SITE: A COMPARATIVE STUDY ON A TIMBER AND A STEEL CONSTRUCTION PROJECT

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Abstract: Construction activities can produce significant amounts of air pollution having a direct effect on the surrounding environment. The level of emissions is distinct for each construction site based on the materials used for construction. Particulate matter (PM) is one of the most important pollutants produced during construction activities. This study aims to detect the concentration of PM emitted from two construction sites using different primary construction materials: cross-laminated timber (CLT) and steel. PM emissions were measured on both sites over a period of five days for four separate PM sizes ($PM_{1.0}$, $PM_{2.5}$, $PM_{4.0}$, PM_{10}) for a total of 600 data points. Data analysis performed for this study suggested that the steel building construction site had a higher concentration of PM than the CLT building construction site. Average concentration rate of the steel building construction site were found to be 55-78% higher than the CLT project. The mean concentration of PM_{10} and $PM_{4.0}$ was detected highest of all the sizes for both CLT and steel construction site. Both construction sites satisfied the United States Environmental Protection Agency (USEPA) standards for daily $PM_{2.5}$ and PM_{10} concentration level. However, the mean concentration of $PM_{2.5}$ (18.63 µg/m^3) measured at the steel building construction site was found higher than the USEPA national average concentration rate (10.78 µg/m^3). PM_{10} concentration level was found lower than the national average rate for both construction sites. The inclusion of $PM_{1.0}$ and $PM_{4.0}$, which was mostly disregarded in previous studies, will be helpful to analyze the characteristics of different PM sizes.

1 INTRODUCTION

The construction industry is considered as one of the most hazardous industries because of the nature of its activities. Generation of a significant amount of waste during construction activities results in numerous health problems not only among the construction workers, but also among the surrounding habitats making construction sites even riskier than other activities (Holton et al. 2008). Air pollution is one of the key environmental impacts that come about because of construction work (Ahmed and Arocho 2019). An imperative parameter to measure the air pollution of a specific area is to quantify the particulate matter (PM) concentration. In construction sites, emission of PM of different sizes is predominately responsible for air pollution (Chang et al. 2014). A previous study suggested that the construction workers exposed to several health hazards for PM with a diameter of 10 micrometers and 2.5 micrometers, known as PM_{10} and $PM_{2.5}$ respectively (Ketchman and Bilec 2013). Hence, it is important to assess the concentration level of PM, especially during construction activities.

The current study analyses two construction sites where different material were used: cross-laminated timber and steel. Cross-laminated timber (CLT) has been considered as an emerging construction material and now is used more frequently in the U.S. construction industry. However, because of the use of chemicals during the production process, CLT panels are identified as a potential source of air pollution. In order to compare the emissions level, a steel building construction site was used. Four different PM sizes ($PM_{1.0}$, $PM_{2.5}$, $PM_{4.0}$, and PM_{10}) were monitored while measuring the concentration level.

The study was performed focusing on three major objectives. The first objective of the study was to determine the emissions of PM from two different construction sites (CLT and steel) during the construction activities. A CLT and a steel building construction site was selected for the study and four different PM sizes were quantified during the construction works. The second objective of the study was to compare the PM concentration level from the construction sites with the United States Environmental Protection Agency (USEPA) standards. USEPA also published data on national PM_{10} and $PM_{2.5}$ concentration level and this study included this dataset to compare the emission level. The study team found that the emission level of $PM_{1.0}$ and $PM_{4.0}$ are mostly excluded in most of the previous studies, and no standard is established by any regulatory agency. In this study, $PM_{1.0}$ and $PM_{4.0}$ measured along with $PM_{2.5}$ PM_{10} to define the characteristics of the PM sizes. The third objective of this study was to characterize the air pollution potential of the construction sites based on PM emissions. Since construction sites were using two different materials, the research team considered the importance of quantifying the PM emission level individually and analyzed which construction material generates more PM.

2 LITERATURE REVIEW

Particulate Matter (PM) is a group of polluting agents consisting of dust, smoke, and all types of solid and liquid materials that remain suspended in the air because of their small size (USEPA 2017). There are two major sources of PM: primary, and secondary. Pollution from primary sources is produced by their own processes such as wood stoves and forest fires. Secondary sources are those that let off gases that can form particles in the atmosphere (CDC 2016). The majority of the particulate matters are the by-product of sulfur dioxide (SO_2) and nitrogen oxide (NOx) (USEPA 2017). Particles which are 2.5 µm to 10 µm in diameter are called coarse particles. Particles less than 2.5 µm in diameter are called fine particles and include ultra-fine particles of less than 0.1 µm ($PM_{0.1}$) (CITEPA 2017).

As discussed earlier, PM has been considered as a major source of air pollution. According to Yan et al. (2018), the concentration level produced by the dust at construction sites in China has several degrees of impacts on the surrounding air. The average monthly contribution of construction dust to the overall PM_{10} pollution was approximately 10% in Beijing (Zhao et al. 2007). Because of the expanding pattern of the quantity of construction and demolition activities, it is anticipated that construction dust pollution will become more severe in the near future (Wu et al. 2016). According to Arocho et al. (2014), the concentration of PM during the beginning of a construction project is much higher than the concentration of the other pollutants because of the use of multiple construction equipment such as bulldozers, roller, and loader. Reddy et al. (2018) showed that construction equipment like cranes produced up to 2,450 grams of PM_{10} during construction operations. From the year of 2010 to 2011, construction activity of the city of Pittsburgh increased 48%, which listed this city in the most polluted U.S. cities in terms of PM emissions (Ketchman and Bilec 2013). Construction equipment such as backhoes, motor grades, front-end loaders, trucks, and cement mixers were also investigated for PM potential and identified as an important factor for high PM production during construction (Frey and Kim 2009). Different sizes of PM can be generated during the construction activities that directly affect the construction sites and local environment (Resende 2007).

PM emissions are accountable for causing several human health problems. Previous studies suggested that the concentration of PM is responsible for increasing human mortality and illness rate (Mastalerz et al. 1998, Shi et al. 2003, Mueller-Anneling et al. 2004). Most common health effects of particulate matters include heart and lung diseases, eye irritation, respiratory problem, and low birth weight of newborn babies etc. (USEPA 2017). The concentration of PM causes approximately 800,000 premature deaths around the world each year and ranks as the 13th leading cause of mortality (Anderson et al. 2012). PM is believed to contribute to cardiovascular and cerebrovascular diseases and research shows that long-term exposure of PM is responsible for the significantly high cardiovascular incident and mortality rate (Samet et al. 2000). A study in southern California suggested that 19 µg/m^{3}increase of PM_{10} was responsible for a 40% increase of the risk of bronchitic syndromes among the asthmatic children (McConnell et al. 1999). An examination of 12 million Medicare participants in 108 counties in the eastern USA displayed an immense increment in respiratory hospitalizations for the increments in $PM_{2.5}$ (Peng et al. 2009).

3 RESEARCH METHODOLOGY

For this study, the College of Forestry Building (known as Peavy Hall) at Oregon State University was selected as one of the construction sites. The project was developed by using cross-laminated timber as the primary construction material. Another construction site (The New Corvallis Museum Building), which was being constructed in steel, was evaluated in terms of PM emission to compare with Peavy Hall.

TSI DustTrak II 8530EP was used to monitor the PM of the selected sites. The device is an aerosol monitor that provides real-time aerosol mass readings. Unique features of the device include measuring high concentration aerosol, gravimetric sampling capacity using a 37-mm filter cassette for custom reference calibration, STEL alarm for tracking 15-minute average mass concentration for fugitive emissions at hazardous waste sites, environmental protection and tamper-proof security. The program is easy to install in Windows computer and provides sufficient statistical and graphical data. The device consists of four different diameter inlets representing four different sizes of particulate matters (PM_1, $PM_{2.5}$, PM_4, PM_{10}).

Prior to starting data collection, the study group conversed with the respected project engineers to determine the main construction activities for each site. While collecting data, priority was given to the specific construction activities rather than a specific time of day. For the CLT project, the main activities were flying CLT panels, installing CLT panel to the positions, and moving CLT panels using scissor lift from one point to another point of the building. For the steel building site, the major activities were unloading trucks, cutting metal frames, welding, and installing metal columns and beams. The PM sensor (DustTrak) was set near (350 ft.) the identified activities in both construction sites. The DustTrak was put at a height of 5 ft. from the surface to maintain the consistency of measured data. The data collection process started when all the recognized activities were seen in the construction sites. The first measurement was $PM_{1.0}$ for all the locations followed by $PM_{2.5}$, $PM_{4.0}$, and PM_{10}. The data collection went through for 2 hours each day on two different construction sites (1 hr. /site) for 5 days. The one-hour time period was partitioned similarly into four sections to gather PM concentration of four distinctive diameter particles (15 minutes for each size). At first, $PM_{1.0}$ concentration was measured for 15 minutes. Following that, the inlet of $PM_{1.0}$ was cleaned and replaced by $PM_{2.5}$. Similarly, after 30 minutes, the $PM_{2.5}$ inlet was replaced by $PM_{4.0}$ inlet and finally, after 45 minutes, $PM_{4.0}$ inlet was replaced by PM_{10} inlet. During each replacement, inlets and the plate were cleaned with a piece of cloth to remove any other external particulate. Same data collection procedure was maintained for both construction sites to ensure the consistency of data collection method. Zero calibration was performed and two drops of oil were applied before every use. After completion of the measurement, data were processed and transferred from the device to the computer where collected data were saved for the statistical analysis. A total of 600 data points of four different PM sizes were collected from both construction sites (300 data points from each site) for a period of 5 days.

4 RESULT

In this section, detail outcomes of the data analysis section are discussed. PM was classified based on their sizes and locations and the assessment was made likewise. PM sizes were compared based on locations as well as USEPA national average concentration level. SPSS was used to perform necessary data analyses to statistically validate the research. SPSS is a tool to perform comprehensive data analysis, data mining, text analytics, and data collection.

4.1 CLT Construction Site (Peavy Hall)

The first measurement was performed at the CLT construction site. The highest mean concentration level was 11.39 µg/m^3 for PM_{10} followed by 9.05 µg/m^3 for $PM_{4.0}$. $PM_{1.0}$ and $PM_{2.5}$ exhibited a lower average concentration level (6.61 µg/m^3 and 7.17 µg/m^3 respectively). PM_{10} and $PM_{4.0}$ also exhibited a higher standard deviation value compared to $PM_{1.0}$ and $PM_{2.5}$ that indicated a more spread set of concentration level. Figure 1 shows the histograms of PM concentration from the CLT construction site.

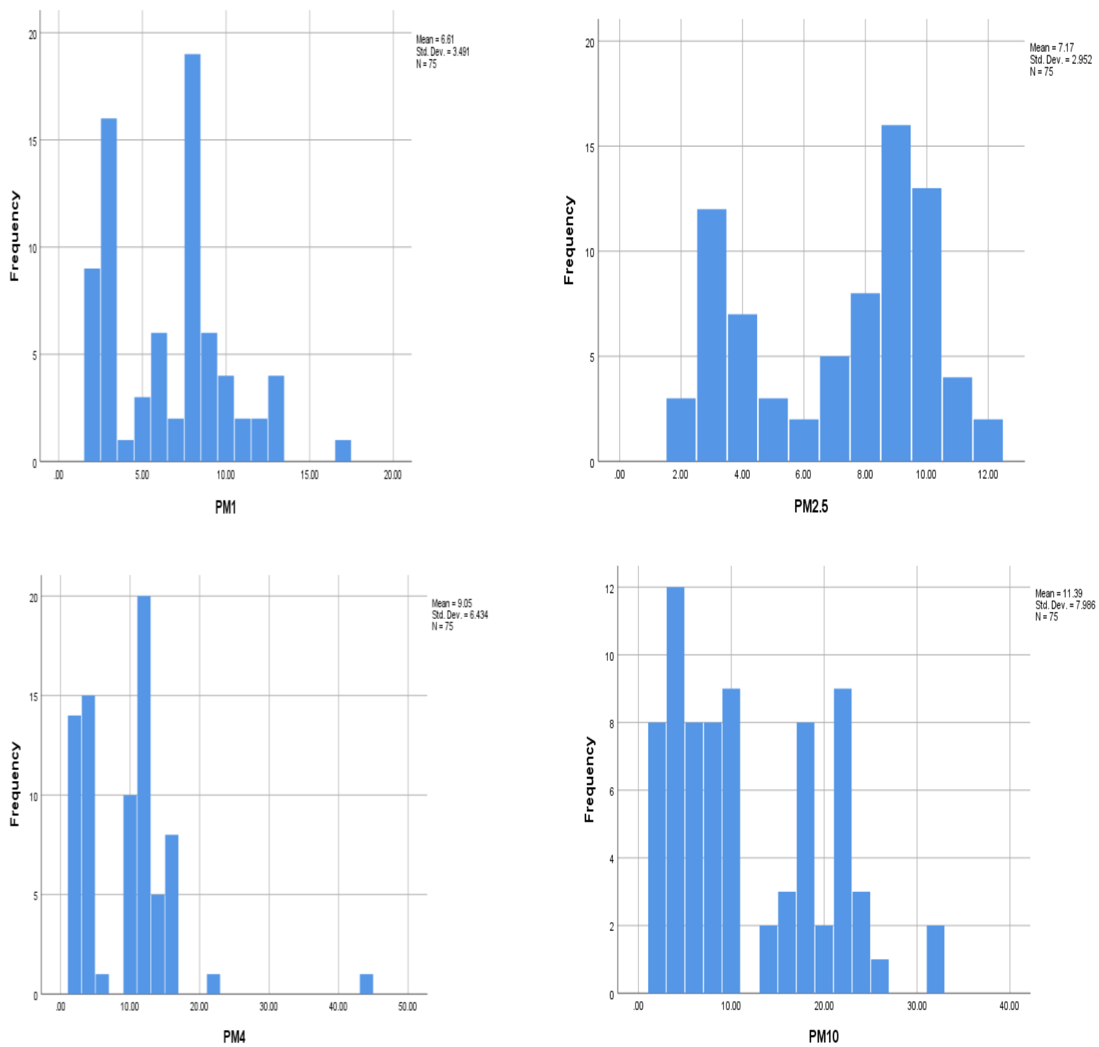

Figure 1 Histograms of PM emission from the CLT project

4.2 Steel Construction Site (Museum Building)

The steel building construction site showed significantly higher emission level of PM than the CLT building construction site. The highest mean concentration level was 30.39 µg/m^3 for $PM_{4.0}$. $PM_{1.0}$ concentration was also found very high (29.65 µg/m^3) followed by PM_{10} (25.05 µg/m^3) and $PM_{2.5}$ (18.63 µg/m^3) respectively. The high standard deviation values for different PM sizes indicating widespread sources of emission in the construction site. Figure 2 shows the histograms of the PM emission in this site.

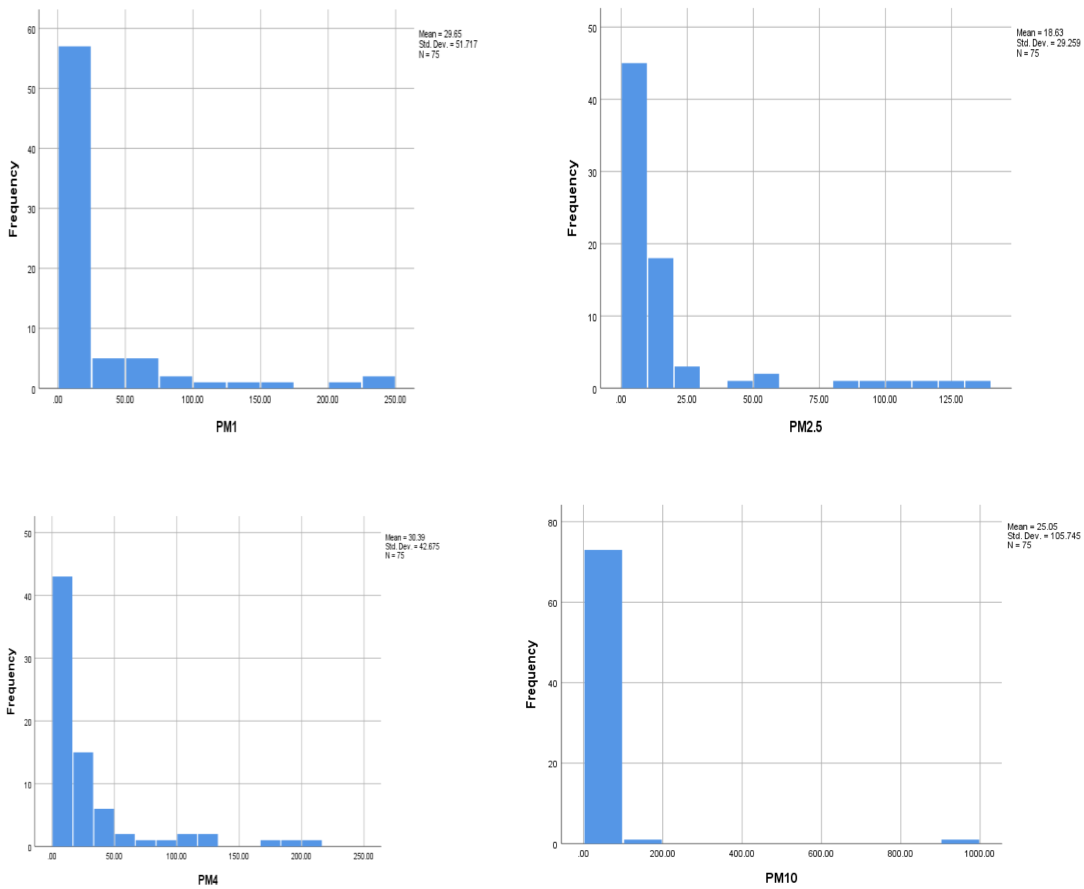

Figure 2 Histograms of PM emission from steel building project

4.3 Comparative Emission Level

Figure 3 shows the graphical representations of PM emission level for both construction sites. From the graphs, it is clearly visible that the concentration level of steel building construction site was significantly higher than the CLT construction site. For $PM_{1.0}$, the highest concentration reached at 248 µg/m^3 at the steel construction site, on the other hand, the highest concentration level of $PM_{1.0}$ at the CLT site was obtained 12 µg/m^3. For $PM_{2.5}$, $PM_{4.0}$, and PM_{10}, the highest concentration levels were measured 136 µg/m^3, 209 µg/m^3, and 914 µg/m^3 respectively at the steel construction site whereas at the CLT construction site, the highest concentration levels were measured 17 µg/m^3, 44 µg/m^3, and 32 µg/m^3 respectively for $PM_{2.5}$, $PM_{4.0}$, and PM_{10}. During sampling time, no other activities were observed other than the listed activities.

However, in the steel building construction site, the concentration level went high when welding performed in the construction site.

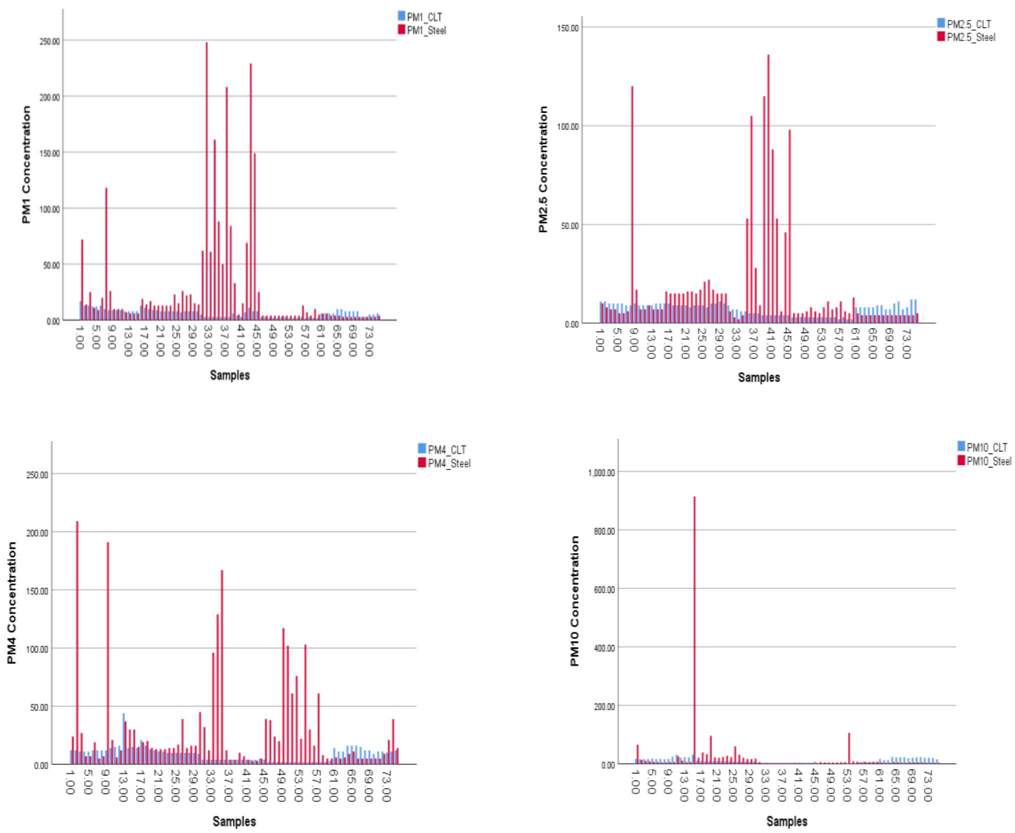

Figure 3 PM emission levels of the construction sites

4.4 Comparison with USEPA National Average Concentration Data

In order to determine the average PM concentration level in the U.S., USEPA published 17 years of data (2000-2016) for $PM_{2.5}$ that covered 455 locations in each year. According to that research, the average national concentration of $PM_{2.5}$ was 10.78 µg/m^3. USEPA also published 27 years of data (1990-2016) for PM_{10} emission that covered 149 testing in each year and according to that study, the average national PM_{10} concentration was 63.64 µg/m^3. In this study, data collected from the construction sites was compared to the U.S. national average concentration value in order to determine the compatibility of both data set. However, there is no national database available for $PM_{1.0}$ and $PM_{4.0}$ thus only $PM_{2.5}$ and PM_{10} concentrations were compared with the national average. One-sample t test was performed to determine the correlation between the data sets. Table 1 presents the outcome of the analysis.

Table 1 Comparison of $PM_{2.5}$ and PM_{10} emission levels with USEPA national average concentration levels data

One-Sample Test

	Test Value = 10.78					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
PM2.5_CLT	-10.582	74	.000	-3.60667	-4.2858	-2.9275
PM2.5_Steel	2.323	74	.023	7.84667	1.1148	14.5785

One-Sample Test

	Test Value = 63.64					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
PM10_CLT	-56.663	74	.000	-52.25333	-54.0908	-50.4159
PM10_Steel	-3.160	74	.002	-38.58667	-62.9163	-14.2570

Table 1 illustrated that the two-tailed p-value of $PM_{2.5}$ and PM_{10} in the CLT construction site is smaller than 0.001, which determines that the means of the PM are significantly different from the U.S. national average concentration value. The negative value of test statistics (t) indicated that the mean concentration of both sizes collected from the CLT construction site is smaller than the national average value. In the steel building construction project, the mean concentration of PM_{10} was lower than the U.S. national average concentration level as the test statistics (t) value is negative. However, the average concentration of $PM_{2.5}$ was higher than the U.S. national average concentration level for $PM_{2.5}$. USEPA also published daily and yearly standard for $PM_{2.5}$ and PM_{10}. According to that, the daily standard for $PM_{2.5}$ was set as 35 $\mu g/m^3$ and for PM_{10}, the standard was set as 150 $\mu g/m^3$, although PM_{10} standard was revoked later because of lack of sufficient evidence. PM data collected from the construction sites were lower than the USEPA daily standards.

5 CONCLUSION

The research presented here aimed to determine the concentration of PM emissions from construction sites and the findings of the research are directly related to the objectives established above. The first objective of the study was to determine the PM emission level from two different construction sites during the construction activities. The outcomes of this study suggested that the steel building construction site is generates more PM compared to the CLT construction site. Histogram analysis showed that the steel building construction site produced between 55-78% more PM during the construction work compared to the CLT project.

The second objective of the study was to compare the emission levels from the construction sites with USEPA standards. One sample t-test suggested that PM emitted from both construction sites are lower than USEPA standards. Only $PM_{2.5}$ of the steel building site was found higher than the USEPA national average concentration value. Both sites also comply with the USEPA daily standards for $PM_{2.5}$ and PM_{10}.

The third objective was to characterize the air pollution potential of the construction sites based on PM emission. Analyzing the activities of both construction sites, the research team found that steel building construction produce more air pollution because of the types of activity. The research team observed activities like welding, fabrication of metal frames, steel cutting, and truck unloading during the construction time. All these activities are believed to be responsible for the high concentration level of PM. On the other hand, the CLT construction site exhibited activities like flying CLT panels, installing CLT panels to the position, and moving CLT panels using a scissor lift from one point to another point of the building. The nature of activities made the CLT construction site produced fewer emissions than the steel building construction site in terms of PM emission.

The outcomes of the study support the previous studies related to PM emission in construction sites. Moraes et al. (2016) found the emission range of PM_{10} in a concrete construction site is 46-214 $\mu g/m^3$. According to Haynes and Savage (2007), the average concentration levels of PM_{10} and $PM_{2.5}$ increased up to 215 $\mu g/m^3$ and 172 $\mu g/m^3$ respectively in a concrete constructed rail transport hub in London. The same study concluded that the construction activities are the primary source of PM emission followed by transport or continental secondary dust sources. Chang et al. (2014) found a maximum PM_{10} concentration of 60 $\mu g/m^3$ for a concrete construction site indicating a similar trend of PM emission during the construction activities.

A potential limitation of the study could be the short sampling duration of the data collection process. However, the device used for the study allowed to collect PM data in every 59 seconds. As a result, a very consistent and significant set of data was obtained in a 15 minutes time slot. A long sampling interval time might create a high standard deviation in the data set which would have disvalued the output of the sampling process. The 15 minutes testing time was adequate to quantify all of the activities under the same activity cycle for both construction sites. The purpose of the study was to compare two different construction sites using completely different materials, thus, an obvious focus was given to those particular construction activities explicitly identified with those materials. In this study, major construction activities were included during the data collection time. The research group tried to concentrate on explicit activities and their emission potential. Considering that, the data collection procedure was not compromised. During the data collection period, weather data (e.g. temperature, humidity, and wind speed) was also monitored and the study team did not find any significant correlation between weather data and PM concentration level. Based on that it is possible to say that PM emission is not weather dependent, rather it depends on specific construction activities.

Finally, this study reveals that PM emission levels from construction sites are, for the most part, comply with the standards established for PM emissions by USEPA. Furthermore, contrasting two distinctive construction sites suggests that, steel building construction site produced more PM compared to timber building construction site. Future research should incorporate the control process of PM emission during construction works.

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