Temporal and spatial variability of PM$_{10}$ in daycare centres in Perlis

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Abstract. A good indoor air quality (IAQ) is preferred for a healthy and safe indoor environment especially for children since they are more susceptible to the effects from indoor pollutants. Most of indoor air pollution researches focus on the health effect on the children but they eliminate the possibility of how the environmental factors and daycare characteristics could contribute to this problem. This study investigates the concentration level of PM$_{10}$ and its relationship with environmental factors and daycare centers characteristics and two different sampling sites, representing residential and near roadside. Gravimetrical method was used in order to present spatiotemporal analysis utilizing descriptive analysis, Pearson Correlation and Coefficient of Divergence (COD) treatments of data. The average indoor concentration in Taska Penyayang 1 Malaysia (TP1M, representing residential setting) were $105.97 \pm 40.06 \mu g/m^3$ indoor and $50.77 \pm 30.85 \mu g/m^3$ outdoor. Taska Penyayang Permata (TPP), represented near roadside setting were $59.88 \pm 18.53 \mu g/m^3$ and $69.09 \pm 23.54 \mu g/m^3$ indoor and outdoor, respectively. PM$_{10}$ variations at TP1M was observed to be originated from indoor/local strong sources and was minimally influenced by weather parameters and outdoor infiltration. Infiltration of pollutants occurred at TP1M, showed by large IOR (above unity) while exfiltration of pollutants governed at TPP, indicated by low IOR and insignificant COD values between all of its micro-location. Natural ventilation as practiced by TPP may also be the reason of very much lower levels of PM$_{10}$ concentration, evidenced by strong positive correlation between number of occupants and inverse correlation between number of activities. Lower frequency of activities accumulates PM$_{10}$, contributing to its higher level. In contrast, persistent closed-windows and doors may contribute to inadequate ventilation and accumulated air pollutants, as observed at TP1M. This has been evident by higher COD correlation, indicating similar sources of PM$_{10}$ at micro-environments with outdoor air.
1. Introduction
Indoor air quality (IAQ) refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants [1]. PM$_{10}$ describes as inhalable particles, with diameters that are generally 10 micrometers and smaller. Exposure of PM$_{10}$ can cause symptoms of respiratory infections and irritations if the exposure is of a long enough duration [2]. From young age, most of the children are sent for full time hours to the Daycare Center (DCC) premises where they would spend most of their time inside than at any other place whilst their parents are working. Children need good indoor environment since IAQ is very important for their development and wellbeing.

Good IAQ is often determined by interaction between many variables with process in which some of the determinants are controlled by building design, operators, occupants and some are extended to the building itself. There is still lack of awareness when it comes to IAQ condition in daycare centers. Most people did not aware of the possibility of optimum and adequate environmental factors’ levels and daycare characteristics, which could contribute to healthier indoor environment. In Malaysia, we do not have a proper guideline and good conducts for daycare centers’ operators which highlights acceptable indoor environmental factors and permissible levels of air pollutants inside buildings. Apart from the indoor condition itself, location of daycare center also determine the level of indoor air pollutants and its IAQ. Location next to main sources of air pollutants such as main road could also be a factor for poor indoor air quality of a dwelling. Therefore, the distance of the main road to day care center could indicate its indoor air quality, especially if there is air infiltration occurs.

This study was carried out for 5 months at 2 different locations of daycare centers in Perlis focusing on the concentration level of PM$_{10}$, relationship between the PM$_{10}$ concentration to environmental factors and daycare centers characteristics, how outdoor concentration can contribute to indoor concentration and spatial variation of PM$_{10}$ concentration in different locations at daycare centers. The daycare centers selected were Taska Penyayang 1 Malaysia (TP1M) at Kangar and Taska Penyayang Permata (TPP) at Jejawi. The environmental factors for this study were chosen to be temperature, relative humidity and air velocity while the day care characteristics were operation and maintenance of the building, occupants of the building and their activities, building contents, outdoor environment and building fabric.

2. Methodology

2.1. Sampling Plan and Gravimetric Analysis

Some text. Ambient air was drawn through a low flow inlet of AirChek XR5000 at a flow rate of 2.6 L/min. The particulate-laden air was then directed onto Polytetrafluoroethylene (PTFE) filter. The sampling was conducted for 7 hours, comparable to operation hours of the daycare centres, from November 2017 until March 2018. Samplers were placed at about 1 m above the floor and at least 1 meter from a wall or in the center of the room [3]. This height is analogous to the breathing height of a sitting student. The initial and final mass of those filters were taken using analytical balance applying blanks as control filter. To eliminate possible errors, either from samples or handling, all filters are conditioned in desiccator prior to sampling activities and immediately placed in filter cassettes. Gravimetric analysis was used to calculate the concentration of PM$_{10}$ by using the mass of PM$_{10}$ obtained at the sampling place. PM$_{10}$ concentrations are calculated, by referring to Chapter D of NIOSH Manual of Analytical Methods (NMAM 1998) and National Institute for Occupational Safety and Health method 0600.

The comfort parameters measured from the daycare centers were temperature, relative humidity and air velocity. The temperature and relative humidity were measured using hygro-thermometer and the air velocity was measured using anemometer. The daycare centers characteristics collected on every sampling day included number of children on that sampling day, frequency of cleaning, number of activities for the children and amount of time the air-conditioner was used. The other daycare centers’ characteristics such as number and area of windows, area of the room, distance of doors and windows...
from main road, equipment and appliances in the daycare center were measured at the end of the sampling period. All these parameters were analyzed via statistical method to determine their relationship with level of air particulates matter at both sites.

2.2. Spatio-temporal Analysis of PM10
Descriptive statistics was used to find mean, median, standard deviation, minimum and maximum value of PM10 concentration, temperature, relative humidity and air velocity for all the daycare centers. Pearson Correlation was used to find how PM10 concentration influences micro-environmental elements and daycare center characteristics. Indoor-to-Outdoor Ratio (I/O) was calculated to qualitatively determine air filtration and exfiltration. The I/O ratio can exhibit considerable variation due to many factors, for example, outdoor activities, spatial variation, indoor activities, building style, location and equipment used. The I/O concentration ratio is often used to justify the presence of indoor sources (I/O > 1) or infiltration of ambient air (I/O < 1). Coefficient of Divergence (COD) was also determined to investigate spatial relationship between different places. The values in COD consists from 0 to 1 indicating that the higher the value the higher the heterogeneity. COD can be calculated as follows (equation 1):

\[ COD_{ij} = \frac{1}{n} \sum_{i=1}^{n} \frac{(x_{ij} - x_{ik})^2}{x_{ij} + x_{ik}} \]  

Where:
- \( n \) = Number of PM10 concentration
- \( x_{ij} \) = Average concentration of component ‘i’ measured at location ‘j’
- ‘j’ and ‘k’ = Two different monitoring location

3. Results and Discussion

3.1. Temporal Variation of indoor and outdoor PM10 concentration levels
Figure 1 shows the descriptive analysis and boxplots for indoor and outdoor PM10 concentration at both daycare centers. TP1M represented the residential indoor setting while TPP has been considered near roadside. Throughout sampling scheme, there was one occurrence of sampler malfunction at TP1M. Between both sites, the maximum overall concentration was recorded at 178.57 μg/m³ at TP1M, in which it was 47% higher compared to TPP (roadside). The overall average concentration of PM10 were recorded at 105.97 ± 40.06 μg/m³ and 59.88 ± 18.53 μg/m³ at both indoor TP1M and TPP, respectively as well as 50.77 ± 30.85 μg/m³ and 69.09 ± 23.54 μg/m³, at outdoor of TP1M and TPP, respectively. These values were about 2 to 4 times higher than the requirements of the World Health Organization’s (WHO) standard. Similar coefficient of variation (CV) values of indoor PM10 sampled at indoor sites (~0.30) indicated uniform variability of concentration levels between both sites. The indoor and outdoor concentration at TP1M and outdoor concentration at TPP skewed to the left while indoor concentration at TPP was symmetric. This indicates that most of the concentrations for indoor and outdoor at TP1M and outdoor TPP were greater than the mean concentration. Indoor concentration of TP1M showed the highest standard deviation which inferred that the PM10 concentration has wider distribution around the average value. Small standard deviation indicates the concentrations were clustered closely around the mean. This could infer that indoor concentration were a local problem and may not be influenced by weather and outdoor. Indoor concentration for TP1M showed a greater outlier at 180 μg/m³ indicating that unusual event happened, recurring on the first week of every month due to compound’s clearing and grass cutting at TP1M.
Distribution of indoor concentration was higher at TP1M compared to TPP, as illustrated in Figure 2, in which most of the time, the IOR was above unity. Particulates or dust accumulation due to inadequate ventilation was observed at TP1M, evidenced by the persistent closed windows and doors at the site, even though it has the largest area and windows (Table 2). The daycare centre also shut down its ventilation system during night-time which reduce the air exchange rate causing an increase in the indoor concentration [4]. Meanwhile at TPP, the outdoor concentration was higher compared to indoor concentration, evidenced by IOR ratio of below unity. The lower concentration in the indoor was due to regular cleaning in the morning and evening and good air flow between the activity room and kitchen.
Adequate ventilation also plays a role in directing the dusty air out of the rooms. Even though TPP was considered nearer to the roadside, its PM$_{10}$ concentration levels were considered significantly lower as compared to the residential site (TP1M). This may be due to its geographical setting, in which it is in the suburb area of Jejawi as compared to Kangar (TP1M).

![Figure 2. Indoor-to-Outdoor Ratio of PM$_{10}$ Concentration at TP1M and TPP sites](image)

3.2. Variability of Indoor PM$_{10}$ Concentration Levels between Microenvironments and Comfort Parameters

Variation of indoor PM$_{10}$ concentrations at microenvironment settings with outdoor level along with selected comfort parameters were also investigated. Activity room and kitchen were selected to study the level of PM$_{10}$ distinctiveness with respect to different activities and room characteristics. Comfort parameters’ (temperature, relative humidity and air velocity) weekly variations were recorded and plotted in Figure 3 and Figure 4. It was observed that PM$_{10}$ concentration levels, in TP1M’s kitchen area, at most of the time was higher than in its activity room. This was due to cooking activity occurred at the site, while moderate physical activities involved during the sampling scheme. The Pearson Correlation analysis (Table 1) also showed a strong positive correlation between kitchen and activity room which was $r = 0.520$. This shows that when the concentration at kitchen increases, the concentration at activity room also increases. The cooking processes increase the PM$_{10}$ concentration in the kitchen [5]. The particle suspended may also attach itself to the occupants causing an increase in the activity room [6, 7]. High occurrences of activities only occurred during week 7 and 10, in which has caused PM$_{10}$ levels to be much higher at activity room compared to kitchen. This was also contributed by the higher relative humidity reading and significantly high outdoor concentration level, especially during week 7.
Figure 3. PM$_{10}$ Variations with Comfort parameters at Taska Penyayang 1 Malaysia

Figure 4. PM$_{10}$ Variations with Comfort parameters at Taska Penyayang Permata Perlis
Table 1. Relationship of PM$_{10}$ Concentration Levels at Various Microenvironment Settings at a) TP1M and b) TPP

|                      | a) Correlations-TP1M | b) Correlations-TPP |
|----------------------|----------------------|----------------------|
|                      | Activity Room | Kitchen | Outdoor | Activity Room | Kitchen | Outdoor |
| Activity Room        | 1           |         |         | 1           |         |         |
| Kitchen              | 0.520*      | 1       |         | 0.303       | 1       |         |
| Outdoor              | -0.281      | -0.359  | 1       | -0.090      | 0.400   | 1       |

Note: ** significant at $p = 0.05$

3.3. Relationship of PM$_{10}$ Concentration with Daycare Centers’ Characteristics

The daycare centres’ characteristics measured were number of children on that sampling day, frequency of cleaning, number of activities for the children and amount of time the air-conditioner was used. The other daycare centres’ characteristics such as number and area of windows, area of the room, distance of doors and windows from main road were measured at the end of the sampling period. Table 2 listed both TP1M and TPP building characteristics. The total surface area of the activity room and kitchen at TP1M were bigger compared to TPP. The total surface area of activity room of TP1M was 499,722 m$^2$ and TPP was 254,399 m$^2$. TP1M have more children compared to TPP. The frequency of cleaning for both daycare centres were same but TP1M have more physical activities compared to TPP. TP1M used air-conditioner while TPP utilized natural ventilation.

Table 2. Daycare center characteristics

| Daycare centers | TP1M | TPP |
|-----------------|------|-----|
| Room            | 95,108 | 35,316 |
| Kitchen         | 73,899 | 17,985 |
| Room            | 24,522 | 17,910 |
| Kitchen         | 15,130 | 17,000 |
| Total surface area of the place | 499,722 | 254,399 |
| Number of occupants | 32 | 30 |
| Frequency of cleaning | 3 | 3 |
| Number of physical activities | 5 | 4 |

The relationship between number of activities and concentration shows positive correlation which was $r = 0.060$, even with very significant value (Table 3). Children’s activities induced particles matter resuspension causing a high indoor concentration. However, there was negative correlation between PM$_{10}$ concentration and air conditioning operation hours ($r = 0.230$). The type of ventilation used in the daycare centres influenced the concentration of PM$_{10}$. The ventilation system is normally equipped with filters in which it is effective in filtering particulate matters [8] and caused lower concentration of suspended PM$_{10}$. The relationship between ventilation system and air pollutant levels revealed that mechanical ventilation system has caused a lower level of indoor air pollutants. In contrast, at TPP, even though number of children positively influence the PM$_{10}$ concentration level, children’s activities
inversely correlated to it. Since TPP only depended on natural ventilation, in which there was adequate air exchange between indoor and outdoor, particulates may have been exfiltrated out of dwelling due to increase movement of occupants.

Overall the outdoor concentration was higher at TPP compared to TP1M. This could be because of the location of TPP nearer to the main road. It also near to the school area where it will be jam during morning and afternoon hours causing more resuspension of PM$_{10}$ particles. The main sources of PM$_{10}$ are road traffic and emission from the industrial activities contributing to high level of outdoor concentration [9]. Other than that, at this daycare center the windows and doors are always open allowing good air movement from outside to indoor causing the indoor concentration to decrease.

Table 3. Pearson Correlation for Taska Penyayang 1 Malaysia

|                        | PM$_{10}$ | Number of children | Frequency of cleaning | Number of activities | Air-cond hours |
|------------------------|-----------|--------------------|-----------------------|----------------------|----------------|
| **PM$_{10}$**          | 1         |                    |                       |                      |                |
| Number of children     | -0.341    | 1                  |                       |                      |                |
| Frequency of cleaning  | 0.422     | -0.275             | 1                     |                      |                |
| Number of activities   | 0.060     | 0.000              | 0.401                 | 1                    |                |
| Air-cond operation hours | -0.230   | 0.218             | -0.156                | -0.195               | 1              |

Table 4. Pearson Correlation for Taska Penyayang Permata

|                        | PM$_{10}$ | Number of children | Frequency of cleaning | Number of activities |
|------------------------|-----------|--------------------|-----------------------|----------------------|
| **PM$_{10}$**          | 1         |                    |                       |                      |
| Number of children     | 0.377     | 1                  |                       |                      |
| Frequency of cleaning  | -0.047    | 0.367              | 1                     |                      |
| Number of activities   | -0.424    | -0.211             | -0.183                | 1                    |

3.4. Spatial Variations of PM$_{10}$ Between Sites

Coefficient of divergence (COD) was used to evaluate the differences in the average concentration at each site. Table 5 shows the spatial variation for each sampling points at both daycare centers. The spatial variability shows good results for almost all of sampling points except for activity room-kitchen (TP1M and TPP), activity room-outdoor (TPP) and kitchen-outdoor (TPP). A high value of COD implies spatial homogeneity where the sampling points are affected by similar sources [10]. The high COD value could be due to the higher concentration at that both places [11]. Low COD value indicates differences between the concentration at the sampling points [12], as observed at all micro-environments at TPP. This was due to distinct role of natural ventilation and adequate exfiltration to move air pollutants out of building.
Table 5. Spatial Variation between Micro- and Macro-environments at TP1M and TPP Daycare Centres

|          | AR (TP1M) | K (TP1M) | O (TP1M) | AR (TPP) | K (TPP) | O (TPP) |
|----------|-----------|----------|----------|----------|---------|---------|
| AR (TP1M)| COD       |          |          |          |         |         |
| K (TP1M) | COD       | 0.1854   |          |          |         |         |
| O (TP1M) | COD       | 0.485    | 0.4947   |          |         |         |
| AR (TPP) | COD       |          |          |          | 1       |         |
| K (TPP)  | COD       |          |          | 0.2107   |         |         |
| O (TPP)  | COD       |          |          | 0.2932   | 0.2429  | 1       |

Note: AR = activity room; K = Kitchen; O = Outdoor

4. Conclusion
The study has outlined several findings of PM$_{10}$ concentration levels with respect to building characteristics and comfort parameters observed throughout the sampling scheme, such as:
1. Average concentration of PM$_{10}$ at both sites were 2 to 4 times higher than 24-hours average standard of the World Health Organization (WHO). These values were alarming since they were sampled at daycare centres, where younger aged children spent almost 8 to 10 hours. Those values were also having similar variability in terms of indoor PM$_{10}$ concentrations (CV = ~0.30). Most of the indoor PM$_{10}$ concentration readings at TP1M were greater than its average value and their distribution were much wider. Meanwhile, the distribution of concentrations at TPP was much symmetrical inferring that most of the data was around the average value.
2. PM$_{10}$ levels at different microenvironments (kitchen, activity room and outdoor) was investigated and correlated using Pearson correlation analysis. At TP1M, activity area was positively well-correlated to kitchen area ($r = 0.520$), implying that increment in PM$_{10}$ levels at each area will significantly increase the other. This inferred that there was an easy access of airflow seeping between these areas. Since most of readings showed that they were exceeding the average concentration by WHO standard, it is important to provide proper restriction or blockage of air between kitchen and other areas.
3. At TPP where natural ventilation was applied, it was found that outdoor infiltration occurred showed by moderate positive correlation with kitchen ($r = 0.400$) and activity room ($r = 0.303$). Therefore, operator need to provide proper mitigation and control of PM$_{10}$ pollution especially during dry season and occurrences of haze. IOR was also found to be low, implying that higher outdoor PM$_{10}$ as compared to indoor.
4. Differences in average concentration between spaces was also investigated by using coefficient of divergence (COD) spatial statistics. Low COD implying heterogeneity or variation of average PM$_{10}$ concentration occurred between activity room and kitchen at TP1M and between outdoor to activity room and kitchen at TPP.

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