The effect of ventilation during peak hours and cooking activities on coarse airborne particulates (PM$_{10}$ and TSP) in middle-class apartments in Surabaya: a multilevel approach

A D Syafei$^1$, T N Ciptaningayu$^1$, U Surahman$^2$, A C Sembiring$^1$, A W Pradana$^1$, A F Assomadi$^1$, R Boedisantoso$^1$ and J Hermana$^1$

$^1$ Department of Environmental Engineering, Faculty of Civil, Planning and Geo Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia
$^2$ Department of Architectural Education, Universitas Pendidikan Indonesia

*Corresponding author: dipareza@enviro.its.ac.id

Abstract. Indoor air pollution is a serious problem today in part because many people spend the majority of their time indoors. The result of multiple indoor activities and outdoor pollutants entering indoor spaces, indoor pollution can cause various potentially fatal respiratory diseases and yet is rarely studied. The purpose of this study was to determine the relationship between ventilation, peak hours and cooking activity on indoor pollutants. This research was conducted December 2017-April 2019 in 59 apartment units in Surabaya, Indonesia. A multilevel model with three models was used to determine the relationships between ventilation, peak hour, cooking activities and indoor pollutants, specifically, PM$_{10}$ and TSP. The concentrations of indoor PM$_{10}$ and TSP were generally 25-99 µg/m$^3$, and at that concentration, peak hours occurred in the afternoon. Peak hour in the morning can increase indoor PM$_{10}$ and TSP. Cooking activities carried out near an open window can increase indoor concentrations of PM$_{10}$ and TSP, likely due to higher outdoor than indoor concentrations.

1. Introduction

Indoor and outdoor air pollution are serious environmental problems. Indoor air quality (IAQ) is one important aspect of occupant perception [1] and poor IAQ affects resident health, comfort, and activity. Acceptable IAQ requires control over indoor pollutants from multiple sources, including occupant activity or emissions from furniture. Fuels such as wood or natural gas used for cooking are another source [2] and cooking using coal as fuel produces more emissions than gas or electricity [3]. Indoor pollution resulting from burning biomass for fuel is the most common cause of disease in the world [4]. Health effects can occur with continuous exposure to the gas used for cooking, depending on the cooking techniques used [5]. Most of the particulates produced by cooking are ultrafine particles. Decrease of indoor air quality will take place if emissions from cooking activities cannot be overcome [6].

Outdoor pollutants can also affect indoor air quality. Luo et al. concluded that there is a relationship between indoor air pollution and outdoor air pollution with regards to fine particles [7]. Outdoor pollutants can enter through cracks and infiltration in walls as well as via ventilation [8]. This can be especially unhealthy if the outdoor pollutant concentration is higher than the indoor. Liu et al. [9] found natural ventilation was very influential on the deposition of particles in the room. The concentration of coarse particles in the classroom is also influenced by student activity [10]. Huang et
al. [11] concluded that there is a need to improve indoor air quality and ventilation during winter due to the relationship between humidity and the formation of particulate matter. The government in Hong Kong recognized the potential health hazards caused by indoor air pollution therefore indoor air quality has become a concern [12]. Indoor air pollution has become more dangerous as people spend an increasing amount of time indoors. In some cases of respiratory disease caused by indoor pollution, the disease appears years after exposure. Mu et al. found women who did not smoke could develop lung cancer due to indoor pollution such as that from burning solid fuel [13]. In addition, children can develop respiratory infections due to coal smoke exposure [14]. Based on this evidence from other countries and acknowledging the lack of indoor pollution studies in Indonesia, the purpose of this study was to determine the effects of ventilation during peak hours and cooking activity on IAQ, specifically coarse particle concentration (PM$_{10}$) and total suspended particles (TSP).

2. Materials and Methods

2.1. Data Collection

Air pollution data was collected using the Metone Aerocet S531 particle counter (Met One, Oregon, USA) in each of 59 apartment units in Surabaya December 2017-May 2019. The counter was placed on a tripod 1.5 meters high as an approximation of the respiratory system in humans. Before use, the counter underwent calibration for approximately 5 minutes. PM$_{10}$ and TSP were measured for 24 hours at 10-minute intervals. Residents of apartment units were interviewed regarding potential pollution sources. Apartment unit data is in Table 1.

| Variables                                      | Mean   | SD (standard deviation) |
|------------------------------------------------|--------|--------------------------|
| Humidity (%)                                   | 62.76  | 8.1681                   |
| Temperature (°C)                               | 29.75  | 2.0970                   |
| Window opening (1 = window opens; 0 = window closes) | 0.2498 | 0.4330                   |
| AC time on (1 = AC on; 0 = AC off)             | 0.2771 | 0.4475                   |
| Number of pieces of furniture                 | 6.955  | 2.0064                   |
| Number of ACs                                  | 1.66   | 0.8353                   |
| Cook time (1 = cooking; 0 = not cooking)       | 0.06346| 0.2437                   |
| Number of exhaust fans                         | 0.8199 | 0.6251                   |
| Number of fans                                 | 0.2431 | 0.4677                   |
| Using fan (1 = using fan; 0 = not using fan)   | 0.04911| 0.2163                   |
| Number of bedrooms                             | 1.674  | 0.4765                   |
| Cleaning frequency (x times/week)              | 5.409  | 8.0734                   |

2.2. Multilevel Model

The analytical method used in this study is a multilevel model, useful for data that has a hierarchical structure. The data can be grouped by this model and coefficients calculated to distinguish each group [15]. In this study, there were three models used to determine the relationship between peak time, ventilation and cooking, and PM$_{10}$ and TSP. Using this model, concentration data is converted to log values before they are analyzed.

Model 1 : original model. This model uses all variables with various intercept coefficient models
Model 2 : full model. This model uses all variables that allow cooking coefficients to vary based on window conditions (open or closed)
Model 3: open window. This model uses all variables only if the window condition is open. Variations of this model are morning, evening, and non-peak hours.

The equations in this model are as follows:

\[ y_i = \alpha_i + \beta x_i + \epsilon_i \] (1)

\[ y_i = \alpha_i + \beta x_i + \epsilon_i \] (2)

where \( y_i \) is the PM\(_{10} \) and TSP indoor concentration (µg/m\(^3\)) of \( i \) measurement variables, \( \alpha_i, \beta, \beta_i x_i \) is the unknown parameters, \( x_i \) is the explanatory variables listed in Table 1 with random components be normally distributed and variances in the random components, which are assumed to be uncorrelated, \( i \) is the data observation of concentration, and \( j/i \) is for Equation 1 which it refers to allowing intercept to vary by peak sessions (morning, evening, and non-peak session), whereas for Equation 2 it reflects allowing intercepts and slopes of cooking activities varied by peak sessions.

Equation 1 was used in models 1 and 3 to describe the estimation of PM\(_{10} \) and TSP with various intercepts. Equation 2 was used in model 2 to describe the intercept and the various slopes of the group (open or closed window). In this study, we divided the concentration of PM\(_{10} \) and TSP in three categories e.g. low concentration 0-24 µg/m\(^3\), moderate concentration 25-99 µg/m\(^3\) and high concentration >100 µg/m\(^3\). Model diagnostics were done by analyzing residual plots of each model and ensure that models follow linearity assumptions with respect to predicted value with constant variance. For instance the residual plot of PM\(_{10} \) Original model (Table 2) and TSP Open Window Only (Table 3) shows residual plots do not indicate any deviations from their linear form and it also displays relatively constant variance across fitted range (Figure 1).

![Residual plots](a) PM\(_{10} \) Original (b) TSP Open Window Only.

**Figure 1.** Residual plot and normality of residuals of model (a) PM\(_{10} \) Original and (b) TSP Open Window Only.
3. Results

3.1. Indoor concentration patterns

The PM$_{10}$ and TSP concentration dominated with moderate concentration category (25-99 µg/m$^3$). The categories of PM$_{10}$ concentration at low concentration was lowest (0.0-24 µg/m$^3$) at 8-9 am. In the afternoon, the concentration increased and tended to decline later in the evening and then again at midnight. PM$_{10}$ concentration at moderate concentration category tended to be highest (25.0-99.0 µg/m$^3$) in the afternoon, but in the morning, the concentration decreased. At categories of high concentrations >100 µg/m$^3$, PM$_{10}$ tended to decrease during the day but was high in the morning and night (Figure 2).

TSP within the lowest concentration category of 0.0-24 µg/m$^3$ tended to be highest at midnight and late afternoon and lowest in the morning. During the daytime, concentration increased again, with a peak occurring in the afternoon. TSPs within the middle concentration category 25.0-99.0 µg/m$^3$ tended to be high in the daytime and go down in the morning. At concentrations >100 µg/m$^3$, TSP tended to be high in the morning, whereas during the daytime, TSP in this category tended to decrease and rise again at dusk until midnight (Figure 3).

![Figure 2. Concentration Distribution of PM$_{10}$ (µg/m$^3$)](image)

![Figure 3. Concentration Distribution of TSP (µg/m$^3$)](image)
3.2. Variables affecting IAQ

Model 1, the original model, used all variables with various intercept coefficient models. Model 2 is the full model, including all variables that allow cooking coefficients to vary based on window conditions (open or closed). Model 3 is open window only, including all variables only if the window condition is open. Variations of this model are morning peak hours, evening peak hours, and non-peak peak hours.

In Table 1 of the original model (Model 1), there were several factors known to influence high indoor concentration of PM$_{10}$: humidity, open windows, the amount of furniture, cooking time, and fan use. In the full model (Model 2), the factors possibly leading to high indoor PM$_{10}$ concentration are the same as in the original model. Factors that can decreased the concentration of indoor PM$_{10}$ include temperature, active air conditioning, number of air conditioners, the presence of exhaust fans, a higher number of fans, and the number of rooms.

In Table 1 Model 2, PM$_{10}$ indoor concentration increased in the morning and decreased in the afternoon and during non-peak hours. Another thing to note is that opening a window increased indoor concentration. Opening a window in the morning increased PM$_{10}$ indoor concentration by 0.026, and opening a window during the afternoon and at non-peak hours increased indoor concentrations by 0.018 and 0.128, respectively. Therefore, in model 3, we used the data of open windows. Using model 3, opening the window increased indoor PM$_{10}$ concentration and was dependent on the number of furniture pieces and the number of air conditioners (0.072 and 0.079, respectively), while other factors decreased the concentration of indoor PM$_{10}$. Model 3 also showed that opening a window in the morning increased the indoor concentration by 0.040, consistent with the results of Model 2. Using Model 3, cooking in the morning, evening, and non-peak hours increased indoor concentration by 0.20, 0.28, and 0.56, respectively. From this, it can be concluded that cooking by opening a window increased PM$_{10}$ indoor concentration.

Indoor TSP concentrations did not differ significantly from PM$_{10}$ indoor concentrations (Table 2). The results from Table 2 Model 1 show that indoor TSP concentrations increased as a result of humidity, open windows, the amount of furniture, presence and number of air conditioners, cooking time, the number of exhaust fans, and the use of fans. Temperature, turning on the air conditioner, and the number of fans decreased the concentration of indoor TSP. Model 2 results were similar to those of Model 1 except the amount of AC in Model 2 was found to decrease indoor TSP concentrations by 0.03. In Model 2, the morning peak time TSP concentration increased by 0.05. However, during the afternoon peak and non-peak hours, the concentration declined by 0.007 and 0.04. These results are consistent with the results of the Model 2 indoor PM$_{10}$. Opening the window during morning peak increased the indoor TSP concentration by 0.088, but opening the window during the evening peak decreased the indoor TSP concentration by 0.09.

When windows were open (Model 3), an increase in indoor TSP concentration correlated to humidity, number of furniture, number of air conditioners, number of exhaust fans, number of fans, turning on fans, and number of beds. From the Model 3 TSP, at peak hours in the morning, evening, and non-peak hours opening a window decreased the concentration of indoor TSP (0.06, 0.35, and 0.20, respectively). This result is different from that of PM$_{10}$, which increased when a window was open. Opening the window in the afternoon decreased the concentration of indoor TSP, in contrast to PM$_{10}$. Cooking while windows were open corresponded to increased indoor TSP and PM$_{10}$. The TSP concentration increased more when cooking with open windows during the evening peak than during the morning peak (0.55 and 0.24, respectively).
| Variables                                      | $PM_{10}$ Original | $PM_{10}$ Full | $PM_{10}$ Open Window Only |
|------------------------------------------------|--------------------|----------------|---------------------------|
| **Fixed Parameters**                           |                    |                |                           |
| Constant                                       | 3.7435 (26.093)    | 3.7937 (26.122)| 4.7843 (14.244)           |
| Humidity (%)                                   | 0.0129010          | 0.0128436 (13.225)| -0.0030                 |
| Temperature (°C)                               | -0.0206            | -0.0204256     | -0.0204                   |
| Window opening (1 = window opens; 0 = window closes) | 0.1018 (5.246)    |                |                           |
| AC time on (1=when AC on; 0=when AC off)       | -0.1200            | -0.1174479     | -0.1474                   |
| Amount of furniture                            | 0.0438 (10.413)    | 0.0442815 (10.502)| 0.0727 (8.299)           |
| Number of ACs                                  | -0.0164            | -0.0166844     | 0.0794 (3.026)            |
| Cook time (1=cook cooks; 0=not cook)           | 0.3767 (12.266)    | 0.3785914 (12.325)|                       |
| Number of exhaust fans                         | -0.0732            | -0.0749295     | -0.0451                   |
| Number of fans                                 | -0.2464            | -0.2471826     | -0.1578                   |
| Using fan (1=using fan; 0=not using fan)       | 0.0888 (2.165)     | 0.0895360 (2.185)| -0.0602                  |
| Number of bedrooms                             | -0.0079            | -0.0084912     | -0.1919                   |
| **Random Coefficients**                        |                    |                |                           |
| Peak morning (intercept)                       | 0.0481             | 0.0437         | 0.0402                    |
| Peak evening (intercept)                       | -0.0288            | -0.0610        | -0.0708                   |
| Non-peak (intercept)                           | -0.0193            | -0.0790        | 0.0039                    |
| Peak morning (window open = 1, closed = 0)     | 0.02648251         |                |                           |
| Peak evening (window open = 1, closed = 0)     | 0.01826492         |                |                           |
| Non-peak (window open = 1, closed = 0)         | 0.12811896         |                |                           |
| Peak morning (Cooking = 1, Not cooking = 0)    |                    |                |                           |
| Peak evening (Cooking = 1, Not cooking = 0)    |                    |                |                           |
| Non-peak (Cooking = 1, Not cooking = 0)        |                    |                |                           |
| **Random Variables**                           |                    |                |                           |
| Between peak sessions                          | 0.0020             | 0.005581       | 0.004154                  |
| Within peak session                            | 0.4091             | 0.408777       | 0.405155                  |
| Open window                                    | 0.007056           |                |                           |
| Cooking while window open                      |                    |                |                           |
| Within open window session                     |                    |                |                           |
| **Model Performance**                          |                    |                |                           |
| AIC                                            | 14803.82           | 14800.47       | 3538.141                  |
| BIC                                            | 14900.85           | 14904.43       | 3614.938                  |
| -2 * Log likelihood                            | 14775.82 (df=14)   | 14770.47 (df=15)| 3510.141 (df=14)          |
Table 3. TSP estimates with random intercept (t-values in parentheses)

| Variables                              | TSP Original    | TSP Full       | TSP Open Window |
|----------------------------------------|-----------------|----------------|-----------------|
| Fixed Parameters                       |                 |                |                 |
| Constant                               | 5.6404 (32.729) | 5.4653 (32.202)| 6.6272 (17.498) |
| Humidity (%)                           | 0.0160 (14.025) | 0.0168 (14.723)| 0.0087 (3.448)  |
| Temperature (°C)                       | -0.0998 (-20.113) | -0.1008 (-20.399) | -0.1220 (-11.078) |
| Window opening (1 = when window opens; 0 = window closes) | 0.0986 (4.262) | 0.0770 (1.206) |                 |
| AC time on (1=when AC on; 0=when AC off) | -0.2424 (-10.401) | -0.2286 (-9.832) | -0.2534 (-3.255) |
| Amount of furniture                    | 0.0699 (14.233) | 0.0607 (12.023) | 0.0904 (8.734)  |
| Number of ACs                          | 0.0270 (2.346)  |                 | 0.1043 (3.539)  |
| Cook time (1=cook cooks; 0=not cook)   | 0.3303 (9.074)  | 0.3457 (9.516) |                 |
| Number of exhaust fans                 | 0.0250 (1.720)  | 0.0078 (0.532) | 0.1081 (3.432)  |
| Number of fans                         | -0.1411 (-6.690) | -0.1779 (-8.301) | 0.0032 (0.052)  |
| Using fan (1=using fan; 0=not using fan) | 0.1999 (4.135) | 0.2094 (4.347) | 0.1362 (1.754)  |
| Number of bedrooms                     | -              | 0.2002 (8.054) | 0.0406 (0.800)  |
| Random Coefficients                    |                 |                |                 |
| Peak morning (intercept)               | 0.0874          | 0.0531         | -0.0611         |
| Peak evening (intercept)               | -0.0352         | -0.0078        | -0.3504         |
| Non-peak (intercept)                   | -0.0522         | -0.0453        | -0.2040         |
| Peak morning (window open = 1, close = 0) |                | 0.0883         |                 |
| Peak evening (window open = 1, close = 0) |                | -0.0974        |                 |
| Non-peak (window open = 1, close = 0)  |                | 0.0091         |                 |
| Peak morning (Cooking = 1, Not cooking = 0) |                | 0.3107         |                 |
| Peak evening (Cooking = 1, Not cooking = 0) |                | 0.5529         |                 |
| Non-peak (Cooking = 1, Not cooking = 0) |                | 0.2467         |                 |
| Random Part                            |                 |                |                 |
| Between Peak Session                   | 0.0062          | 0.0030         | 0.0619          |
| Within Peak Session                    | 0.5662          | 0.5608         | 0.5052          |
| Open Window                            | 0.0101          |                |                 |
| Cooking within Open Window Session     |                |                | 0.1635          |
| Within Open Window Session             |                |                |                 |
| Model Performance                      |                 |                |                 |
| AIC                                    | 16904.03        | 16845.62       | 3804.991        |
| BIC                                    | 16993.87        | 16956.18       | 3881.325        |
| -2 * Loglikelihood                     | 16878.03 (df=13) | 16813.62 (df=16) | 3776.991 (df=14) |
From these results, it can be concluded that the concentration of PM$_{10}$ was high in the morning, and opening a window during the morning peak further increased the concentration of indoor PM$_{10}$. This was in contrast to TSP, in which an open window during the morning peak caused the TSP concentration to decrease. While cooking clearly can increase the concentration of PM$_{10}$ and TSP, opening the window further increased the concentration of PM$_{10}$ and TSP.

4. Discussion

4.1. Distribution Pattern of PM$_{10}$ and TSP

The PM$_{10}$ concentration increased to more than 100 μg/m$^3$ in the morning at 6:50 am, suggesting increased activity that contributed to an increase in pollutants. Similarly, Braniš et al. [10] measured higher indoor PM$_{10}$ during weekday work hours than during weekend work hours and at night for all days. This is likely due to increased activity of residents and contamination from outdoors. Hassanvand et al. measured higher PM$_{10}$ concentrations in school dormitories than in retirement homes [16]. Similarly, Alves et al. found high indoor pollutant concentration was caused by high student activity in a kindergarten classroom [17]. This caused a constant resuspension of sediment particles. Braniš and Safranek considered high PM$_{10}$ concentration in a gym the result of the large number of people present [18].

The average indoor PM$_{10}$ indoor was 42.3 μg/m$^3$ on working days during working hours. Outside working hours, the indoor PM$_{10}$ concentration was 20.9 μg/m$^3$. On weekends, the PM$_{10}$ concentration during working hours was 21.9 μg/m$^3$ and outside working hours, 24.5 μg/m$^3$. There is a significant correlation between the number of students in a room and the concentration of indoor PM$_{10}$. The large number of people present on weekdays during work hours may be the main source of indoor PM. The main cause of indoor PM is from indoor activities [10].

The concentration of TSP increased to more than 100 μg/m$^3$ in the morning between 6 am to 8 am, indicating escalating occupant activities. TSP concentrations were also high in the afternoon. Alves et al. found that PM$_{10}$ concentration coincided with afternoon room cleaning activities [17].

In this study, PM$_{10}$ and TSP were assigned to low, medium, and high concentration ranges (0.0-24.0 μg/m$^3$, 24.0-99.0 μg/m$^3$, and >100 μg/m$^3$, respectively). In the medium range, the concentration of PM$_{10}$ was low in the morning but in the high range, PM$_{10}$ concentration was highest in the morning. The low and medium concentration ranges followed similar patterns of low morning concentrations and increases during the day. Indoor TSP concentrations followed a similar pattern: medium concentration range trends were the opposite of high range trends. TSP concentration in the morning in the medium range decreased while those in the high range increased. It is noteworthy that the moderate category of indoor PM$_{10}$ and TSP concentrations was more than 50% (25-99 μg/m$^3$), demonstrating that the average concentrations of both were in the medium range. The concentrations were lower than those found in Sari, Iran (400 μg/m$^3$) [19]. In Xi’an, China indoor concentrations are known to be greater than those outdoors: the PM$_{10}$ concentration found in offices was 333 μg/m$^3$. That concentration were up to 50% higher compared to restaurants and apartments [20]. The safe indoor limit of PM$_{10}$, according to WHO is 50 μg/m$^3$ [21].

4.2. Factors affecting PM$_{10}$ and TSP indoor

Model 1 and Model 2 (Tables 2 and 3, respectively) show the apartment variables contributing to an increase in PM$_{10}$ and TSP indoor were humidity, open windows, the amount of furniture, cooking time, and turning on the fan. The number of AC (Table 2 Model 1) can decrease indoor PM$_{10}$ concentrations, but in Table 3 Model 1, these increased indoor TSP. The number of exhaust fans can decrease indoor PM$_{10}$ concentration but increase TSP concentration. Temperature factors, turning on the AC, and the number of fans can decrease the concentration of indoor PM$_{10}$ and TSP.

Humidity increased PM$_{10}$. In winter, low wind speeds and high humidity outdoors cause higher PM$_{10}$ concentrations than in other seasons [22]. Indoor air humidity was lower than outdoor. Increased outdoor humidity causes the Indoor/Outdoor ratio to decrease, and vice versa [23]. Temperature decrease PM$_{10}$. Kulshreshtha and Khare found that in summer and winter, PM$_{10}$ concentrations are high but in winter, the concentration is higher [24]. Temperature and humidity moderately correlate
with indoor air quality. During the day, indoor temperatures are lower than outdoor [23]. Temperature can decrease the TSP concentration. According to Cao et al., TSP concentrations during summer tend to be lower than during winter [25]. If the indoor temperature is affected by outdoor temperature, it can be concluded that during summer, the concentration of indoor TSP will be lower than during winter.

By turning on the air conditioning, PM$_{10}$ concentration can be decreased. This is possible because, currently, air conditioners are equipped with a filter. An increase in the number of ACs negatively affect PM$_{10}$. The more AC units in an apartment, the greater the likelihood that PM$_{10}$ will be decreased, probably due to the capability to filter out dust, which can include coarse particulates. Tsai et al. states that the concentration of particles in areas that have a air conditioner to be lower than outside the room, but fan use may contribute to resuspension of deposited TSP [26]. The number of fans affected the coarse particulates in the room because the coarse particulate can accumulate or and attach to the fan. This may also coincide with the cleaning the room.

The number of furniture pieces corresponded with a large increase in coarse particulates, perhaps because particles attach to the furniture. The more furniture, the more dust will adhere to it. This may also correspond with room cleaning. Haghighat et al. [27] found that the presence of furniture does not affect indoor air conditions, yet Lee et al. [12] contended that the high indoor PM$_{10}$ concentration can be influenced by the time of room cleaning. A room that is rarely cleaned will result in airborne particles accumulating on the floor and furniture [12]. Indoor pollutant sources come from indoor sources aside from human activities and furniture [28], but during the cleaning process, the concentration of TSP is likely to increase because cleaning forces it into the air. Alves et al. [17] considered cleaning the room by sweeping a greater source of indoor pollutants than using a vacuum. Eštoková et al.[29] stated that high TSP in the living room is due in part to the presence of furniture. The TSP may increase particles can stick to and accumulate on the surface of the furniture, similar to the air conditioner. An increase in exhaust fans increases indoor particulate, possibly due to particulate resuspension.

Model 2 showed that the concentration of PM$_{10}$ during the morning peak increased while it decreased in the afternoon and during non-peak times. In addition, PM$_{10}$ indoor concentrations also increased when opening windows in the morning, afternoon, and non-peak peak hours. Opening a window during morning peak time increased the concentration of indoor TSP and PM$_{10}$ due to high human activity both out- and indoors. Opening a window causes pollutants to enter from outdoors. By opening the window during non-peak hours, the indoor PM$_{10}$ and TSP concentration remained high because of human activity in the indoor area. Activities such as cooking or cleaning the room can increase the concentration of TSP. Opening the window during the evening peak hours decreases the TSP concentration, perhaps due to fewer outdoor and indoor activities. PM$_{10}$ and TSP concentration can also increase due to flow of outdoor air through the wall. TSP concentrations were found to be higher in nurseries located near highways than in rural areas [30], so it is possible that residence near the highway or the presence of traffic causes high outdoor pollutant concentrations so opening a window will result in increased indoor PM$_{10}$ and TSP. An increase in indoor PM$_{10}$ can occur if the outdoor concentration is higher than indoor, as found by Chen et al. [31] in a classroom in Singapore. Massey et al. [22] found that the concentration of indoor PM$_{10}$ in roadside houses was higher than that in urban houses. However, according to Branis and Safranek[18], the effect of outdoor PM on indoor PM concentrations is weak and inconsistent [18]. The penetration factor is the factor most likely to result in the inclusion of coarse particles from the outside through structural cracks and leaks [8].

This leads us to a question: if outdoor concentration is same as indoor, then what other variables or activities occur in morning but rarely occur in the evening? In our group of respondents, the two variables identified were cooking and opening windows. For this purpose, we created a varying slope and intercept multilevel model, and the results confirmed that PM$_{10}$ is higher when windows are open during cooking. Opening windows in the morning cooking session increased indoor PM$_{10}$ concentrations (Model 3). TSP concentration increased with cooking during the morning peak, afternoon peak, and non-peak peak indoor TSP concentration. In Model 3, morning peak, evening peak, and non-peak window opening can decrease indoor TSP concentration. However, opening a window in the morning and non-peak times increased the concentration of indoor PM$_{10}$. The increase
in PM$_{10}$ and TSP when windows are open is influenced by the amount of furniture and the number of air conditioners (Tables 2 and 3). Other factors that cause indoor TSP concentration to increase when opening a window are humidity, number of exhaust fans, number of fans, use of fans, and number of rooms. However, these factors can decrease the concentration of indoor PM$_{10}$ indoor. The concentration of indoor TSP when opening a window (Model 3) may decrease due to temperature and active air conditioning.

Cooking increases PM$_{10}$ and TSP indoor concentrations due to the particular cooking fuel and cooking techniques used. Sharma and Jain found use of an improved cookstove such as efficient fuel use could decrease PM$_{10}$ concentration by 21–62% [32]. In addition, they also stated that a closed kitchen can increase the accumulation of pollutants. The use of fuel when cooking can increase the concentration of PM$_{10}$, especially in winter [24]. The concentration of PM$_{10}$ in the kitchen was higher than in the living room by 67%. An increase in PM$_{10}$ concentration can be caused by cooking methods such as frying [12]. Several studies mentioned that cooking can increase the concentration of PM$_{10}$ 4–5 times more than not cooking [33]. Cooking and frying can also increase the concentration of TSP. However, according to Raiyani et al. [34] the use of LPG as fuel produces less TSP than using coal and kerosene. Indoor pollutants can also be influenced by the type of stove used. According to Parajuli et al. [35], the existence of improved cookstoves can decrease indoor PM$_{2.5}$ concentration, so it should also be possible to decrease the concentration of TSP and PM$_{10}$. Cooking during peak hours and non-peak hours also increases the TSP concentration. This can be caused by cooking techniques such as frying or during other cooking activities such as cutting or peeling ingredients. In addition, a kitchen with no ventilation or exhaust fan is also suspected to increase concentration of TSP. Opening the window while cooking will increase the TSP and PM$_{10}$ indoor concentration due to higher outdoor concentrations. Given this, the occupant should open windows during evening and non-peak cooking sessions. Furthermore, when cooking, it is recommended that the occupant close the kitchen door.

5. Conclusions
Most concentrations of indoor PM$_{10}$ and TSP in the room were in the range of 25-99 µg/m$^3$. PM$_{10}$ and TSP had almost the same distribution, which is high at dawn until morning and decrease thereafter. The concentration was also high during the day until night. In this concentration range, the highest concentration occurs in the afternoon. PM$_{10}$ and TSP indoor concentrations were high during morning peaks and down during afternoon and non-peak peaks. Opening a window during peak hours in the morning caused an increase in indoor concentration of PM$_{10}$ and TSP. This can be due to the higher concentration of TSP outdoors. In addition, cooking by opening a window is also known to increase indoor concentration, likely due to higher outdoor concentrations and the specific cooking techniques and fuel used.

6. References

[1] Wong L T, Mui KW and Hui P S 2008 A multivariate-logistic model for acceptance of indoor environmental quality (IEQ) in offices, Build Environ 43 1–6
[2] Siddiqui A R, Lee K, Bennett D, Yang X, Brown K H, Bhutta Z A and Gold E B 2009 Indoor carbon monoxide and PM$_{2.5}$ concentrations by cooking fuels in Pakistan, Indoor Air 19 75–82
[3] Li T, Cao S, Fan D, Zhang Y, Wang B, Zhao X, Leaderer B P, Shen G, Zhang Y and Duan X 2016 Household concentrations and personal exposure of PM$_{2.5}$ among urban residents using different cooking fuels, Sci. Total Environ. 548–549 6–12
[4] Klasen E M, Wills B, Naithani N, Gilman R H, Tielsch J M, Chiang M, Kathry S, Breysse P N, Menya D, Apaka C, Carter E J, Sherman C B, Miranda J J and Checkley W 2015 Low correlation between household carbon monoxide and particulate matter concentrations from biomass-related pollution in three resource-poor settings, Environ. Res. 142 424–431
[5] See S W and Balasubramanian R 2006 Risk assessment of exposure to indoor aerosols associated with Chinese cooking, Environ. Res. 102 197–204
[6] Chafe Z A, Brauer M, Kliment Z, Van Dingenen R, Mehta S, Rao S, Riahi K, Dentener F and Smith K R 2014 Household Cooking with Solid Fuels Contributes to Ambient PM$_{2.5}$ Air Pollution and the Burden of Disease, *Environ Health Perspect* **122** 1314–1320

[7] Luo R, Han Y and Liu Z 2017 The Current Status and Factors of Indoor PM$_{2.5}$ in Tangshan, China. *Procedia Eng.* **205** 3824–3829

[8] Chen C and Zhao B 2011 Review of relationship between indoor and outdoor particles: I/O ratio, infiltration factor and penetration factor, *Atmos. Environ.* **45** 275–288

[9] Liu C, Yang J, Ji S, Lu Y, Wu P and Chen C 2018 Influence of natural ventilation rate on indoor PM$_{2.5}$ deposition, *Build Environ.* **144** 357–364

[10] Braniš M, Rezáčová P and Domasová M 2005 The effect of outdoor air and indoor human activity on mass concentrations of PM$_{10}$, PM$_{2.5}$, and PM$_{1}$ in a classroom, *Environ. Res.* **99** 143–149

[11] Huang C, Wang X, Liu W, Cai J, Shen L, Zou Z, Lu R, Chang J, Wei X, Sun C, Zhao Z, Sun Y and Sundell J 2016 Household indoor air quality and its associations with childhood asthma in Shanghai, China: On-site inspected methods and preliminary results, *Environ. Res.* **151** 154–167

[12] Lee S C, Li W M and Ao C H 2002 Investigation of indoor air quality at residential homes in Hong Kong case study, *Atmos. Environ.* **13**

[13] Mu L, Liu L, Niu R, Zhao B, Shi J, Li Y, Swanson M, Scheider W, Su J, Chang S C, Yu S and Zhang Z F 2013 Indoor air pollution and risk of lung cancer among Chinese female non-smokers, *Cancer Causes Control* **24** 439–450

[14] Perez-Padilla R, Schilmann A and Riojas-Rodriguez H 2010 Respiratory health effects of indoor air pollution, *Int J Tuberc Lung Dis* **14**(9) 1079–1086

[15] Gelman A and Hill J 2007 *Data Analysis Using Regression and Multilevel/Hierarchical Models* (Cambridge University Press)

[16] Hassanvand M S, Naddaf K, Faridi S, Nabizadeh R, Sowlat M H, Momeniha F, Gholampour A, Arhami M, Kashani H, Zare A, Niazi S, Rastkari N, Nazmara S, Ghani M, and Yunesian M 2015 Characterization of PAHs and metals in indoor/outdoor PM$_{10}$/PM$_{2.5}$/PM$_{1}$ in a retirement home and a school dormitory, *Sci. Total Environ.* **527–528** 100–110

[17] Alves C, Nunes T, Silva J, and Duarte M 2013 Comfort Parameters and Particulate Matter (PM$_{10}$ and PM$_{2.5}$) in School Classrooms and Outdoor Air, *Aerosol and Air Quality Research* **13** 1521–1535

[18] Braniš M and Šafránek J 2011 Characterization of coarse particulate matter in school gyms, *Environ. Res.* **111** 485–491

[19] Mohammadyan M and Shabankhani B 2013 Indoor PM$_{1}$, PM$_{2.5}$, PM$_{10}$ and Outdoor PM$_{2.5}$ Concentrations in Primary Schools in Sari, Iran, *Arch. Hig Rada Toksikol* **64** 371–377

[20] Niu X, Guinot B, Cao J, Xu H and Sun J 2015 Particle size distribution and air pollution patterns in three urban environments in Xi’an, China, *Environ Geochim Hlth* **37** 801–812

[21] World Health Organization (WHO) 2005 *Guidelines for Air Quality* World Health Organization

[22] Massey D, Kulshrestha A, Masih J, and Taneja A 2012 Seasonal trends of PM$_{10}$, PM$_{5.0}$, PM$_{2.5}$ & PM$_{1.0}$ in indoor and outdoor environments of residential homes located in North-Central India, *Build Environ.* **47** 223–231

[23] Chithra V S and Shiva Nagendra S M 2014 Impact of outdoor meteorology on indoor PM$_{10}$, PM$_{2.5}$ and PM$_{1}$ concentrations in a naturally ventilated classroom *Urban Clim.* **10** 77–91

[24] Kulshreshtha P and Khare M 2011 Indoor exploratory analysis of gaseous pollutants and respirable particulate matter at residential homes of Delhi, India, *Atmos. Pollut. Res.* **2** 337–350

[25] Cao J, Li H, Chow J C, Watson J G, Lee S, Rong B, Dong J and Ho K 2011 Chemical Composition of Indoor and Outdoor Atmospheric Particles at Emperor Qin’s Terra-cotta Museum, Xi’an, China, *Aerosol and Air Quality Research* **11** 70–79

[26] Tsai F C, Smith K R, Vichit-Vadakan N, Ostro B D, Chestnut L G, and Kungskulniti N 2000 Indoor/outdoor PM$_{10}$ and PM$_{2.5}$ in Bangkok, Thailand, *J Expo Sci Environ Epidemiol* **10** 15–26
[27] Haghighat F, Huo Y, Zhang J, and Shaw C 1996 The Influence of Office Furniture, Workstation Layouts, Diffuser Types and Location on Indoor Air Quality and Thermal Comfort Conditions at Workstations, *Indoor Air* 6 188–203

[28] Pegas P N, Alves C, Evtyugina M G, Nunes T, Cerqueira M, Franchi M, Pio C A, Almeida S M, Verde S C, and Freitas M C 2011 Seasonal evaluation of outdoor/indoor air quality in primary schools in Lisbon, *Journal of Environmental Monitoring* 13 657

[29] Eštoková A, Stevulová N and Kubincová L 2010 Particulate Matter Investigation in Indoor Environment, *Glob. Nest J.* 12 20-26

[30] Mainka A and Zajusz-Zubek E 2015 Indoor Air Quality in Urban and Rural Preschools in Upper Silesia, Poland: Particulate Matter and Carbon Dioxide, *Int. J. Environ. Res. Public Health* 12 7697–7711

[31] Chen A, Gall E T and Chang V W C 2016 Indoor and outdoor particulate matter in primary school classrooms with fan-assisted natural ventilation in Singapore, *Environ. Sci. Pollut. Res.* 23 17613–17624

[32] Sharma D and Jain S 2019 Impact of intervention of biomass cookstove technologies and kitchen characteristics on indoor air quality and human exposure in rural settings of India, *Environ. Int.* 123 240–255

[33] Wang Z, Bai Z, Yu H, Zhang J and Zhu T 2004 Regulatory standards related to building energy conservation and indoor-air-quality during rapid urbanization in China, *Energ Buildings* 36 1299–1308

[34] Raiyani C V, Shah S H, Desai N M, Venkaiah K, Patel J S, Parikh D J, and Kashyap S K 1993 Characterization and problems of indoor pollution due to cooking stove smoke, *Atmos. Environ.* 27 1643–1655

[35] Parajuli I, Lee H, and Shrestha K R 2016 Indoor Air Quality and ventilation assessment of rural mountainous households of Nepal, *Int. J. Sustain. Built Environ.* 5 301–311