CHAPTER V
DISCUSSION

5.1 Sample collection

The main objectives of the study were to evaluate the PM-10 concentrations and to assess the relationships between personal and ambient PM-10 within subjects over time. Thus, the main activity of this study was to measure the concentrations of personal, indoor and outdoor PM-10. The participants were working and living in the curbside buildings called "shop houses" on Sukhumvit road. The participants in the study were chosen based not only on the location of their homes but also based on their willingness to volunteer. The distribution of shop houses reasonably represented a wide range of interests and household environments. Although, the indoor and personal measurements to be taken would interfere with the normal life of the participants, all the subjects had committed to faithful participation in the study. Consequently, all the measurements were successfully completed without any drop-outs.

After each day of measurements, the subjects were interviewed in order to fill out a questionnaire with questions about their activities and the time they had spent in various microenvironments during the 24 hr period of the study. From interviewing it was concluded that for the most part, the activity patterns of the two participants in each house were not totally different. Most of them spent most of their time indoors with less exercise and going out. The average time spent indoors, and outdoors was about 23 hrs 15 minutes and 45 minutes respectively. There was no previous data about their activities and time budgeting to indicate whether the participants might have changed their activities during measurement. However, the data of time spent indoor-outdoor in each season showed that the average time spent outdoors in winter was similar to that in the summer season, which were 53 and 60 minutes respectively. However, the result showed that the participants spent more time indoors in the rainy season so that the time spent outdoors was reduced to a level of 21 minutes in this season. From the results, it

was reasonable to assume that changes of the participants' activities due to carrying a sampling instrument may not be as important as changes due to the season.

The PEM instrument consisted of an air sampler pump that typically creates noise during operation. To facilitate the comfort of the participants the pump was put into a leather bag lined with acoustic material in order to reduce its noise. The standard battery operating the air sampler pump had to be charged during a 24-hr measurement or it was necessary to use another power source to operate for 24 hrs. Changing to metal hydride batteries with a longer lifetime made the sampling more successful. In comparison with the other studies (11, 44) in which sampling failures related to the battery occurred, there was no battery failure during measurement in this study. This indicated that this type of battery could better serve the operational requirement, 1 min on and 1 min off intermittently for 24 hours, on one battery charge without a battery failure. For all the measurements by PEM, the measurement succeeded 765 of 792 attempts (96.5%). Twenty seven measurements were lost due to pump failure (10 samples), flow rate failure (7 samples), filter damage (5 samples) and other causes (5 samples).

In gravimetric analysis, control of temperature and humidity in the weighing room was important during analysis. The standard deviations of weighing were in the acceptable range (Table 4.4) so that the precision of the mass determination was 1 $\mu g/m^3$. The average personal PM-10 concentration was 81.5 $\mu g/m^3$ meaning that any error caused by weighing was 1.2 %. This result was similar to that obtained in the study done by Janssen et al. (11). All the procedures including duplicate weighing and reweighing were performed to avoid any outliers due to the weighing procedure. The flow rate stability was satisfactory as shown in Table 4.2. The relative standard deviation of the method with less than 5% indicating that the method was reliable with high precision as shown in Table 4.3.

The average mass increase of the field blank was 11.5 µg higher than the variation due to the weighing procedure. This suggested that the field blank mass might be caused not by the weighing procedure, but by contamination occurring during

the sampling even though all the sampling devices were cleaned before use. However the mass increase of field blank filters was less than that of sampled filters. Therefore all PM-10 measurement samples were above the detection limit.

Comparison of the two different PM-10 measurement methods indicated that PM-10 concentrations measured by PEM were highly correlated with concentrations of PM-10 measured at the same time and place by the HI-VOL technique. However, by comparing the regression coefficient of the HI-VOL and PEM results obtained by placing the instruments at the On-Nuch station (the same site as the collocation study, Figure 4.5) with the regression coefficient of the HI-VOL and PEM results obtained by placing the PEM instruments at the outdoors of the shop houses while keeping the HI-VOL instrument at the On-Nuch station (outdoor-ambient collocation; Table 4.10), it was found that the correlation and regression coefficients (slope) of the same site collocation study ($r = 0.966$ and slope $=1.3$) were higher than those of outdoor-ambient collocation ($r = 0.789$, slope $= 0.695$). The result suggested that the distance between the sites of measurement might have an influence on the correlation of the PM-10 concentrations measured outdoor with the base measurement at the station. Moreover the relationship between outdoor – ambient PM-10 ratio and the distance of the house from On-Nuch station was calculated and the correlation coefficient was $r = -0.592$. Formally this result implies that the greater the distance between the house and the station, the smaller is the outdoor to ambient PM-10 concentration ratio. Therefore, in order to use ambient PM-10 concentrations as representative of outdoor concentrations, one factor that must be carefully reckoned with is the distance of the house from the central ambient monitoring station. In a more general sense, in any future studies, care must be taken to demonstrate that the ambient monitoring station is representative of outdoor air quality and does not possess any unique feature. However, in this case although the ratio was changed the results of both collocation types showed a significant correlation between these two instruments. Therefore, even though their measurement data could reflect day to day variations of PM-10 concentrations they were comparable. The HI-VOL approach was tested by duplicated sampling and the PM-10 concentrations measured by these two Hi-Vol air samplers were highly correlated ($r = 0.998$).

All the results discussed above indicated that the monitors and equipment used for PM-10 measurement in this study were reliable with high precision. Thus, the data for PM-10 concentrations in this study were reliable and could be comparable.

5.2 PM-10 concentrations

Various types of PM-10 measurements were conducted in this study including personal, indoor, outdoor and ambient PM-10 concentrations. The variations of PM-10 concentration due to seasonal effects were examined. In this study, it was found that personal, indoor and outdoor PM-10 concentrations in each season were different. Higher PM-10 concentrations in the winter as compared with the hot and rainy seasons were found in all of the types of measurement and the results correlated with the ambient roadside PM-10 concentrations measured at the On-Nuch station.

Table 5.1 presented the summarized data for PM-10 concentrations for each type of PM-10 measurements in the three seasons. Consistency was found among the personal, indoor and outdoor PM-10 concentrations in that although there were seasonal differences in the levels, the average outdoor PM-10 concentrations exceeded both the indoor and personal PM-10 concentrations in all three seasons. In addition, the average indoor concentration was less than the personal exposure concentration in all three seasons.

Personal PM-10 concentrations lie between the outdoor and indoor PM-10 concentrations. While understanding that variation occurred throughout the sampling locations on identical sampling days, nearly all of the outdoor PM-10 concentrations exceeded the indoor and personal PM-10 concentrations. Only 1 outdoor concentration out of a total of 131 samples was lower than the corresponding indoor concentration. About 15% of the personal PM-10 concentrations exceeded the corresponding outdoor concentrations (38 personal PM concentrations out of a total of 251 samples) whereas approximately 67% of the personal concentrations were higher than the indoor PM levels based on the same day measurements (174 out of a total of 259 samples). This result was quite different from previous studies that reported that personal exposure

concentrations typically exceeded outdoor concentrations and indoor concentrations (11, 38-39). This is possibly due to the vast difference in setting and living style in these Bangkok residences as compared with the locations of the previous studies. This study was performed in a high traffic urban area where the average outdoor concentration was about two times higher than in the previous studies.

Table 5.1 Personal, indoor and outdoor PM-10 concentrations in each season

		PM-10 concentration: $\mu g/m^3$		
Season		Person	Indoor	Outdoor
Winter	Mean ± SD.	100.1 ± 46.6	91.7 ± 39.2	149.5 ± 39.6
	Range	26.0 – 201.8	32.0 – 213.1	69.2 - 258.4
	N	85	121	43
Hot	Mean ± SD.	75.8 ± 29.5	67.0 ± 25.4	112.1 ± 41.8
	Range	34.3 – 152.4	32.9 - 153.7	54.5 – 258.3
	N	86	127	44
Rainy	Mean ± SD.	70.8 ± 39.5	61.9 ± 32.4	127.2 ± 70.7
	Range	14.2 – 245.9	17.1 – 206.0	36.4 – 355.8
	N	88	127	44
Total	Mean ± SD.	82.1 ± 41.0	73.2 ± 35.1	129.4 ± 54.5
	Range	14.2 – 245.9	17.1 – 213.1	36.4 – 355.8
	N	259	375	131

The results indicated that there were significant differences among PM-10 concentrations on each floor of the shop houses. In particular the PM-10 level on the first floor was approximately 20%-30% higher than the PM-10 concentrations on the other floor levels (Table 4.7). This finding was not consistent with the previous study of PTEAM (9) where room-to-room variation was less than 10%. The difference could be explained by the fact that the higher PM-10 concentrations of outdoor air as observed in this study might penetrate into the 1st floor room easier because the 1st floor of the shop houses was a shop area with a door kept wide open or the door was opened for customers as they entered and left the shop. On the other hand, the other floors

generally were bedrooms or other living areas and mostly were air-conditioned leading to less air exchange with the outdoor air. Moreover, various personal activities typically are performed at the 1st floor (shop area) more than on the other floors especially during daytime. This could possibly lead to higher levels of re-suspended particles.

Compared to the previous study conducted in Bangkok (44), the average indoor and outdoor PM-10 concentrations of the shop houses on Sukhumvit Road were lower than those found in Odean, a very high traffic area with traffic jams frequently causing traffic to stop, but were similar to the findings from a university hospital campus which was a high traffic area more like Sukhumvit road where there are many vehicles, but they typically run smoothly. However, this previous study also reported that PM-10 concentrations in different microenvironments within the shop houses were also different. This similar finding suggested that PM-10 concentrations in shop houses varied considerably from room to room. Because of the significant differences between PM-10 concentrations of each floor level, more than one sampling site in the shop house has to be considered in order to obtain a more reliable representation of indoor PM concentrations for shop houses.

The indoor PM-10 levels varied from house to house and from floor to floor as shown in table 4.8. It was hypothesized that wind effects might be seen affecting levels of PM-10 materials within the houses. For example the shop houses on the side of the street that were downwind from the prevailing wind direction might be expected to show higher indoor levels of particulates than houses on the other side of the street. To investigate the influence of locations of the shop house on the PM-10 levels, the shop houses were divided into two groups. The first group was the shop houses which were on the left side of Sukhumvit road and the other group was on the right side of the road. The indoor PM-10 levels of these two groups in each season were shown in Table 5.2. It was found that indoor PM-10 levels of the houses on the left side of the road were not significantly different from those found for the shop houses on the right side in all seasons. This can probably be interpreted of a reflection of the reality that regardless of prevailing wind direction, the mixing effects of airflow in crowed urban areas restricts differentiation of concentration of particulate matter in nearby areas.

Table 5.2 Indoor PM-10 levels of the shop houses at the left and right side of the road

Side of the road	Indoor conc. $\mu g/m^3$			
	Winter	Summer	Rainy	Remark
Left	87.2 ± 24.3	69.5 ± 19.5	67.3 ± 18.1	T-test at 95% confidence
Right	109.5 ± 50.2	62.0 ± 16.8	51.3 ± 35.1	
p-value	0.121	0.213	0.114	

In confirmation of this assumption, the outdoor PM-10 levels of these two groups were determined as shown in Table 5.3. The results indicated that outdoor PM-10 levels of the houses on the left side of the road were not significantly different from those for the houses on the right side of the road in all seasons. Therefore it could be concluded that the variations of indoor PM-10 levels may not be totally explained by the difference of house setting in different side of the road.

Table 5.3 Outdoor PM-10 levels of the shop houses at the left and right side of the road

Side of the road	Outdoor PM-10 concentration. $\mu g/m^3$			
	Winter	Summer	Rainy	Remark
Left	152.4 ± 37.7	108.2 ± 44.5	114.6 ± 45.8	T-test at 95% confidence
Right	144.1 ± 43.8	120.4 ± 35.5	154.3 ± 103.4	
p-value	0.521	0.370	0.188	

The participants had been instructed to carry the PEM during all of the time of measurement. In cases of necessity for example taking a bath, the PEM could be left beside the participants for a short period of not more than 30 minutes excluding sleeping. However, the samples were excluded in case where the PEMs were left beside the participant for a total of more than two hours during the day (10% of sampling period). While carrying the PEM instrument some activities, for example carrying goods, house keeping, or exercise, would be interfered with so that the PEMs were possibly left nearby but not immediately adjacent to the participant. From observations during household visits, it was found that PEMs were sometimes left beside the participants while they went about their activities but that these situations had not

always been reported during interviewing even though the question had been asked "when had the PEM been left near you for more than half and hour?". However, the participants had reported that they had taken the PEM instruments with them while going out for a long time. This may explain why personal exposure concentrations were not significantly higher than the corresponding indoor PM-10 concentrations (Table 4.7).

From the review by Wallace (37), the explanation for the higher personal exposure levels compared with outdoor concentrations was a personal cloud that may be due to resuspension of particles during personal activities and a tendency to retain these resuspended particles near the body of the individual. Generally, the personal cloud accounted for an additional 30 $\mu g/m^3$ of PM-10 concentration. Conversely, this present study found that outdoor levels mostly exceeded the personal concentrations. The mean difference between outdoor and personal PM-10 concentration in the same measurement day was 48.7 $\pm$ 43.2 $\mu g/m^3$ (mean $\pm$ SD.). Thus the higher of outdoor concentrations compared with the personal exposure concentrations may not be explained entirely by the reduced personal cloud measurement due to the PEM devices not making measurements immediately adjacent to the participants while they doing some activities. This conclusion is supported by the above discussion suggesting that the different findings may be due to the vast differences in setting and living style in these Bangkok residences as compared with the locations of the previous studies.

In addition, the difference between two personal PM-10 concentrations within the same house was up to 43.3 $\mu g/m^3$ and there were four households where personal PM-10 concentrations between the two participants were statistically different (Table 4.8). This result supports the conclusion that personal activities could possibly affect personal exposure leading to the variation in personal PM-10 concentration readings even for individuals living in the same household. Excluding measurements data for subjects exposed to tobacco smoke (ETS), the average personal concentration was reduced to be 73.8 $\mu g/m^3$ from 82 $\mu g/m^3$. The result suggested that ETS could possibly have influence on the variations in personal exposure to PM-10.

5.3 The relationships among personal, indoor, outdoor and ambient-roadside PM-10 concentrations

The study showed that personal concentrations were highly correlated with outdoor PM-10 concentrations. Excluding the house with a strong interior PM source (parking car inside the house), the individual correlation coefficients ranged from slightly negative to strongly positive values with the median Pearson's R coefficient of 0.760 (range from -0.049 to 0.937). However, the correlation coefficients for the personal-indoor relationships (model 2) with median Pearson's R coefficient of 0.865 (range from 0.548 to 0.980) was somewhat higher than those of the personal-outdoor relationship (model 1) meaning that personal PM-10 exposure concentration was more highly correlated with indoor rather than with outdoor PM-10 concentrations. The median slopes from regression analyses were 0.488 for model 1 (person-outdoor), 1.071 for model 2 and 0.461 for model 3. These slopes were comparable with the results reported in the studies of PTEAM, THESS and Janssen et al., (11, 38, 39). These findings, consistent with previous studies, supported the conclusion that outdoor concentrations could be used as a surrogate measure of personal exposure to PM-10 for epidemiological study, even in the very different setting and living style of Bangkok, although in this Bangkok context the surrogate would be conservative in providing exposure numbers that were higher than actual exposure.

The regression equations of indoor on outdoor concentrations (N = 14) and personal on indoor (N= 28) were as following:

$$Conc._{(person)} = 0.488\ Conc._{(outdoor)} \qquad (R^2 = 0.50)$$

$$Conc._{(person)} = 1.071\ Conc._{(indoor)} \qquad (R^2 = 0.75)$$

$$Conc._{(indoor)} = 0.461\ Conc._{(outdoor)} \qquad (R^2 = 0.68)$$

By pooling all the data of personal exposure, indoor and outdoor concentrations into groups, the cross-sectional correlations coefficients were calculated among personal, indoor and outdoor concentrations into the three following models: model 1 (person-outdoor), model 2 (person-indoor), and model 3 (indoor-outdoor). The

correlation coefficients of the three models were compared with the individual (longitudinal) correlation coefficients as presented in Table 5.4

Table 5.4 Comparison of cross-sectional correlation coefficients (pooled data) with individual correlation coefficients for three models

Type of correlation	Correlation coefficients		
	Model 1 (person-outdoor)	Model 2 (person-indoor)	Model 3 (indoor-outdoor)
Cross-sectional (pooled)	0.318	0.817	0.451
Longitudinal: median	0.706	0.865	0.824

Cross-sectional correlation coefficients in all models were smaller than those of longitudinal correlations. The advantages of the longitudinal correlations study were that the interpersonal variability in exposures was removed and it was more relevant to the study of air pollution and health endpoints (11). This finding was similar to the other studies and the numeric values were also comparable (18). Moreover, the cross-sectional correlation results showed consistency with longitudinal correlation results in that the coefficient value for model 2 was higher than for model 1 supporting the conclusion that personal levels showed better correlation with indoor than with outdoor concentrations.

The individual correlation between personal exposure and ambient roadside PM-10 concentrations (On-Nuch station) was also determined. The individual person-ambient and indoor-ambient correlation coefficients were 0.700 and 0.777 respectively. Thus, the variations of ambient concentrations accounted for about 50% of the variations in both personal and indoor concentrations. By comparison, the longitudinal correlation coefficient between person-outdoor (model 1) concentrations was slightly higher than the coefficient obtained by consideration of person–ambient concentrations. The correlation coefficient between indoor - outdoor (model 3) was also higher than that between indoor - ambient. The results indicated that outdoor PM-10 concentrations would reflect the variations in personal or indoor concentrations better than ambient concentrations obtained some distance away from the testing location.

5.4 Factors affecting personal exposure to PM-10

The personal PM-10 concentrations were higher than the indoor concentrations but were lower than the outdoor concentrations. The differences among these types of measurement were calculated as shown in table 5.5

Table 5.5 Distributions of the differences among personal, indoor and outdoor PM-10 concentrations

PM-10 concentrations: $\mu g/m^3$					
Difference	N (#*)	Median	Mean	SD.	Range
Outdoor-Person	14 (251)	42.8	48.7	43.2	-3.0 – 166.7
Person-Indoor	28 (259)	9.4	7.4	18.2	-30.3 – 37.2
Outdoor-Indoor	14 (131)	47.1	56.3	33.1	24.6 – 136.4

* Total number of observations

The difference between personal and indoor concentrations showed that the personal concentrations generally exceeded the indoor concentrations. This observation resulted in ruling out the indoor PM-10 concentrations as explanatory of the personal PM-10 levels. While the outdoor concentrations exceeded both the indoor and personal concentrations, the outdoor levels would be better used as explanatory for personal exposure to PM. The other factors which were divided into 2 groups as shown in table 4.12 were evaluated to determine their contribution to personal PM-10 by using multiple regression analyses.

In addition to the outdoor PM-10 concentrations, the results showed that keeping the door open to the outside of the 1^{st} floor open was a major determinant of an increase in personal PM-10 levels (Table 4.13). Personal exposures would be increased by 25 $\mu g/m^3$ when the individuals lived in houses where the doors of the 1^{st} floors were kept open. This may be explained by the realization that when the first floor of the shop house is normally opened to the outside in this way, outdoor PM-10 could easily penetrate into the building resulting in increases in personal PM-10 exposure and concentrations.

Personal PM-10 concentrations in the winter season were about 18 $\mu g/m^3$ higher than either in the summer or the rainy seasons. This observation could be explained by the fact that the roadside PM-10 levels were higher in the winter than in the other seasons.

Exposure to tobacco smoke ETS also contributed significantly to exposure to PM-10. The estimated contribution of ETS was 19.5 $\mu g/m^3$ for the participants who were exposed to ETS. Although the participants were non-smokers, they might be exposed from the customers, their friends or others outside their houses. Nevertheless, the contribution of one cigarette could not be calculated because the participants could not report the number of cigarettes they were exposed to (ETS) during the sampling period. This finding made clear that ETS was one of the most important sources of excess personal PM-10 concentrations in this study.

Incense burning also contributed to increases in personal PM-10 concentrations, although there was a smaller influence than with the first four factors. The study of Lung et. al. (48) estimated that one incense stick could contribute about 0.40 $\mu g/m^3$ of PM-10 to the exposures. In contrast, the personal exposure concentrations of participants whose bedroom was fitted with an air conditioning system appeared to be lower than for those without air conditioning. This may be explained by the realization that outdoor air could penetrate only slightly into the bedroom with an air conditioning system because the windows were tightly closed.

However, some personal activities, e.g. cleaning, cooking or exercise, and some household characteristics, such as the location of the buildings on the right or left side of the road or their proximity to a sky train station, did not contribute significantly to personal concentrations.

5.5 Source identifications

From the outputs of FA/MR analysis of the results of elemental analysis of particulate matter collected on the filters from personal, indoor and outdoor PM-10 sampling, five factors or probable five source types were categorized for each type of

measurement as shown in table 5.6. Care must be taken in firmly associating the sources of the identified factors. They show elemental distributions similar to some reported sources, but there is no assurance that such sources actually exist in the vicinity of the study.

Table 5.6 Identification of source types for personal, indoor and outdoor PM-10

No.	Person PM-10	Indoor PM-10	Outdoor PM-10
1	Oil combustion/ petrol vehicle	Oil combustion/ petrol vehicle	Soil/Crustal/ Road dust*
2	Soil/Crustal*	Soil/Crustal/Road dust*	Oil combustion/Refinery
3	Steel Industry*	Steel Industry	Steel Industry
4	Zinc-smelter/ Refuse incineration	Zinc-smelter/ Refuse incineration*	Sea salt
5	Brake dust/ Refuse incineration	Refuse incineration*	Refuse incineration*

* Significant source analyzed by multiple regression analysis

The factors categorized by factor analysis of personal PM-10 were similar to those of indoor and outdoor PM-10 factor analyses. The result of multiple regression analysis revealed that only two sources contributed significantly to the variations in personal PM-10 mass concentrations. These were Soil/Crustal types and Steel industry emission types. The estimated contribution for all types of measurements was approximately 40%-50%. The first factor or the first probable source type that accounted for most of the personal PM-10 concentrations, as well as for both indoor and outdoor PM-10 concentrations were soil/crustal type. Its contribution was 45% for personal PM-10, 25% for indoor particles and 45% for outdoor PM-10. From this analysis it could be concluded that the Soil/Crustal type was the major contributing source leading to higher PM-10 air pollution.

However, the origin of more than 50% of the PM-10 exposure concentrations could not be explained from this analysis of the data. This may be due to the high correlations among elemental compositions so that factor analysis could not separate different possible sources from each other as could be done for the first factor of personal data analysis. This first factor consisted of elemental compositions which showed elemental similarities with particulates derived either from oil refinery or petrol vehicles emissions and accounts for most of the variance of the data set. Surprisingly, this factor was not significant in multiple regression analysis. The results may be explained by the fact that personal PM-10 concentrations were collected by low volume air sampler and only 2.82 m^3 of air were collected. This resulted in a comparatively small amount of PM-10 collected on the filter. Moreover, the elements used in characterization of the source types were trace elements. Thus some elements were not detectable even though ICP/MS could determine the elements at the ppb level. In addition, the reason may be that the masses of some chemicals, Ca, K, Al which are components of soil, were high and would dominate the analytical results.

A final reason may relate to the type of elements used in the factor analysis and multiple regression analysis. The tracer used should be clearly related to that type of source. For example, the elements that should be tracers of petrol vehicle were organic and elemental carbon or sulfate or nitrate ion. Because of the limitations of the chemical analysis method of this study, the concentrations of both cations and anions and carbon contents in PM-10 compositions could not be determined.

The results of factor analysis revealed that there might be some indoor sources or some activities that generated PM-10 because the probable source types of indoor particulates differed somewhat from those of the outdoor PM-10. Some of the shop houses may generate PM-10 for example by grinding, or cutting metal pipe. However, the interpretation of factor analysis would be more revealing in cases where it was based on firmer evidence.