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DAILY PERSONAL EXPOSURE TO BLACK CARBON IN DIFFERENT MICROENVIRONMENTS IN HANOI, VIETNAM

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Abstract

Daily personal exposure to black carbon (BC) in different microenvironments in Hanoi, Vietnam was quantified for the first time. In this study, a portable instrument, microAethe® model AE51, was used to continuously measure BC concentrations in various microenvironments within buildings and transportation modes. Overall average daily personal exposure to BC from those microenvironments was 5.46 µg/h. The highest BC exposure was during commuting 13.48 µg/h and 5.74 µg/h for the motorcyclist and car driver, respectively. In building environments, the highest BC exposure was 3.98 µg/h in a coffee shop with smoking; the lowest BC exposure was 1.54 µg/h in a hospital department; while BC exposure in an office was 1.92 µg/h. The level of BC exposure in an apartment was strongly influenced by building ventilation modes. They were 3.58 µg/h and 2.15 µg/h with doors/windows open and closed, respectively. Our finding confirmed that commuting contributes disproportionately to the total BC exposure due to the high level of BC during traffic/travel. Building ventilation and air conditioning can significantly affect indoor BC levels and should be considered as a measure to reduce BC exposure within buildings in Hanoi.

Keywords: black carbon; microenvironment; buildings; transportation; personal exposure.

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1. Introduction

Air pollution is a burning problem of every country and all over the world. In large cities in developing country like Vietnam, air pollution is a especially problem. Among the air pollutants caused by urban development is black carbon (BC). BC not only causes air pollution, climate change but also seriously affects human health. Regarding the impact of BC on human health, several studies have shown BC to be a serious pollutant, causing respiratory diseases such as pneumonia [1, 2]. Cardiovascular patients exposed to BC will have more severe disease, even affecting the birth rate and the central nervous system [3, 4]. Another report showed that high ambient BC levels were associated with respiratory and cardiovascular mortality [5].

One of the main sources of air pollution emissions is from vehicles. The rapid increase of vehicles in Hanoi has seriously affected the air quality of the city. There are a number of studies that have reported the levels of particle mass, and number and their impact on human health in Hanoi [6–12]

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as well as studies on the air quality inside the car in Hanoi [9, 13–16]. Recently, few studies has been conducted to explore BC concentrations in household buildings [17, 18] and assess the levels of BC personal exposure during traveling in Hanoi, Vietnam [19, 20]. On the other hand, people spend most of their time indoor [21].

However, a full picture of daily personal exposure to BC in Hanoi was not yet assessed. To fill this gap, our study aims to (i) quantify BC concentrations; and (ii) determine daily personal exposure to BC from different transportation modes and building microenvironments in Hanoi. Results of this study could be used to provide evidences for setting up a policy to protect human health in the city.

2. Materials and methods

2.1. Study area

The study was carried out in the capital Hanoi, one of the two most populous cities in Vietnam. Hanoi's characteristic and its potential air pollution sources were described elsewhere [20].

2.2. Instrumentation

In this study, we used one microAeth AE51 monitor (AethLabs, San Francisco, USA) to measure BC concentrations. BC concentrations (ng/m^3) are determined in this portable device by measuring changes in light attenuation (λ = 880 nm) on a filter strip. Before each measurement event, new filter strips were replaced (An event using one filter trip) according to the instruction manual. Data collection was set at a 30-s interval. The airflow was drawn into the instrument at the rate of 100 mL/min.

2.3. Study design

In this monitoring campaign, BC exposure levels from travel routes with motorcycle and car (namely R1 and R2, respectively) and four building micro environments, including an office building, a coffee shop, a hospital and a high-rise apartment (namely S3, S4, S5, S6, respectively). Detail information of each measured sites and travel routes were presented in Table 1 and Figs. 1, 2. An

Table 1. Information of travel routes and measured sites

Micro environments	Name	Monitoring period	Duration (h)	Weather	Characteristic
Motorbike	R1	14-Nov-19	0.87	Partly cloudy/Sunny	Rush hour
Car	R2	14-16 Nov-19	9.05	Partly cloudy/Clear/Sunny	Total travel time by car
Office (staff room)	S3	14-15 Nov-19	10.34	Partly cloudy/Clear/Sunny	Close the door/ Air conditioning
Coffee shop (coffee table area)	S4	14-Nov-19	1.58	Partly cloudy/Sunny	Open the door/ smoking
Hospital (patient room)	S5	15-Nov-19	2.09	Partly cloudy/Clear	Close the door/ Air conditioning
Apartment* (living room and bedroom)	S6	14-15 Nov-19	10.96	Partly cloudy/Sunny	Open the door/ natural ventilation
Apartment** (living room and bedroom)	S6	15-16 Nov-19	13.12	Partly cloudy/Clear	Close the door/burning incense, candle inside

investigator wore the microAeth monitor for full two days (48-h). During measuring BC exposure levels on motorcycle and car, the instrument was put in the vest pocket of the investigator [22]; a tube was used to connect to the suction pump of the device with the inlet fixed at the collar of the surveyor, equal to the breathing zone [23] to reduce the impact of vibration on the result of measurement. While in the indoor building environments, the device was placed on the table next to the investigator. Noted that balcony doors of the monitoring apartment were kept open (apartment*) and then closed (apartment**) during the first and second measured days to test the influence of different building ventilation modes on BC exposure levels. A diary was used to record all activities that occurred during the monitoring campaign. Any unusual observation/activities was also noted in the diary.

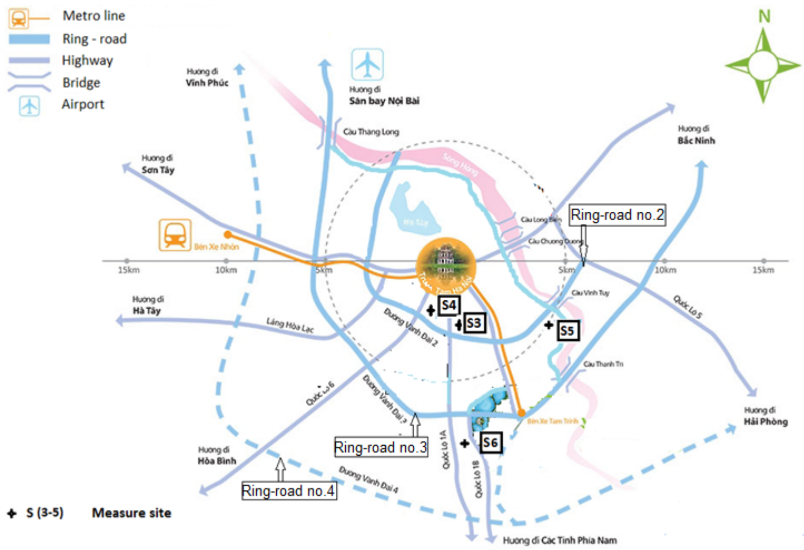
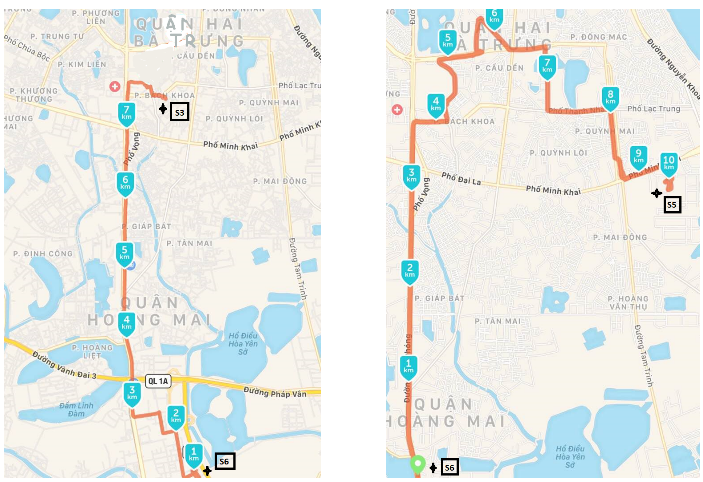


Figure 1. Locations of four measured buildings (S3 – S6)



(a) Motorcycle - R1 (b) Car - R2

Figure 2. One part of measured routines

2.4. Data analysis

The BC meter automatically records the data, after each measurement, we will download the data, using the unit μg/m^3 for the BC concentration. To ensure reliable data, we remove negative values in case of low concentration or high temporal resolution (short sampling/logging time interval) through noise reduction averaging algorithm ONA [24] according to previous research [18]. The omitted figures account for only 2.6%. Statistical analysis, comparison and verification were performed on SPSS software (version 2.0), with a confidence level of 95%.

2.5. BC exposure estimation

The calculation of inhalation dose was performed by being applied an established equation [23]:

$$D = C_{BC}.IR_{(\Delta t)}.\Delta t \tag{1}$$

where D is the average inhalation dose (μg); C_{BC} is the average concentration of BC in each microenvironment (μg/m^3), $IR_{(\Delta t)}$ is the respiratory rate (m^3/h), and Δt is a period of time of personal BC exposure (h).

Inhalation rates as a function of the different activities and age groups are reported by Buonanno et al. [25]. The contribution of the different microenvironment to BC Exposure is calculated as below:

$$PD = \frac{D_i}{\sum_i^n D_i} \times 100\% \tag{2}$$

where: PD is the percentage of inhalation dose (%), D_i is the inhalation dose at each building or transportation microenvironment, $\sum_i^n D_i$ are the total of inhalation doses.

3. Results and discussion

3.1. General description of BC concentrations in different microenvironments

Time series and general description of BC levels measured at different microenvironments (buildings and transportation modes) are presented in Fig. 3 and Table 2, respectively. Overall, the mean

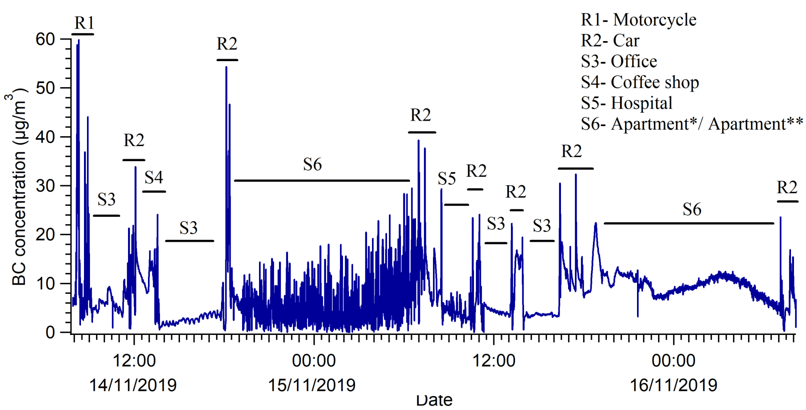


Figure 3. Time series of daily personal BC exposure

BC concentration of the whole monitoring campaign was 7.56 ± 5.21 μg/m^3. The highest BC concentration level was found on motorcycles (12.78 ± 13.85 μg/m^3). While the lowest BC level was found in an office building (4.17 ± 2.5 μg/m^3). On the contrary, the highest building microenvironment BC level was found in a smoking coffee shop (11.05 ± 3.91 μg/m^3). Detailed discussion on BC levels at each microenvironment is described below.

Table 2. General description of BC concentrations (μg/m^3) corresponding to different microenvironments

Microenvironments	Mean	SD	Min	Max	*n*
Motorbike	12.78	13.85	1.540	59.849	99
Car	9.56	6.34	0.025	54.347	1034
Office	4.17	2.50	0.000	24.104	1182
Coffee shop	11.05	3.91	1.623	33.853	180
Hospital	4.29	2.72	0.492	26.515	239
Apartment* (open doors)	5.97	4.87	0.012	39.32	1252
Apartment** (closed doors)	9.94	2.56	3.18	22.4	1499
Whole measured campaign	7.56	5.21	0.000	59.849	5485

n: number of samples.

3.2. Concentrations of BC in different building microenvironments

Mean BC concentrations measured at an apartment when balcony doors open and closed were 5.97 ± 4.87 and 9.94 ± 2.56 μg/m^3, respectively. In the first measured day when balcony doors were open, indoor BC concentrations fluctuated considerably. This phenomenon was similar to what was observed by Tran et al. [18], where indoor BC was strongly influenced by outdoor traffic sources. Interestingly, BC levels measure on the second night when the doors were closed were stable but significantly higher than those on the first night ($p < 0.05$). This BC level was also higher than that measured at the same building's space and ventilation conditions (3.7 ± 1.02 μg/m^3) [18].

The higher BC concentrations at the second night can be due to strong indoor source emissions, including candle and incense burning while closed doors. These activities contributed to the peak BC concentrations at homes, as reported elsewhere [26].

Further explanation for the higher BC in the apartment compared to those measured by Tran et al. [18] is due to the different measured time period. In the previous study, indoor BC concentrations were measured for several whole days (night and day), while in this study, they were measured only during night time. According to our diary entries, almost indoor activities, such as rice frying, re-heating food with microwave, bread toasting with oven, cleaning house, burning incense and candle happened during the evening and early morning. These activities were considered as the highest emission source in indoor environments [25–29].

Mean BC concentrations in a coffee shop where smoking was allowed were 11.05 ± 3.91 μg/m^3. These levels were significantly higher than those measured in the apartment, as mentioned above. However, they were lower compared to those measured in designated smoking rooms in the airport as previously reported [19]. It is highly likely that the higher BC concentrations measured at the smoking room was due to the high number of smokers and the lower ventilation exchange rates compared to those at naturally-ventilated coffee shops.

BC concentrations measured in an office and a patient room of a hospital were 4.17 ± 2.5 μg/m^3 and 4.29 ± 2.72 μg/m^3, respectively. They were significantly lower than those measured in the apartment and the coffee shop. In the office and the hospital room, the operation of a central air conditioning system with all doors and windows closed for energy-saving purpose is a reason to for the lower BC level as it reduces the impact of outdoor air pollution (BC) to the indoor environment. A study by Quang et al. [30] showed the positive effect of ventilation on indoor air quality. In fact, almost office and hospital buildings used ventilation systems with filters to provide fresh air. This explains why BC concentrations in these two buildings were significantly lower. The influence of air conditioning on particle level in building microenvironments was already reported in Quang et al. [31].

3.3. BC concentrations in commuting modes

Mean BC concentrations measured on the motorcycle of 12.78 ± 13.85 μg/m^3, which were higher than those measured in the car (9.56 ± 6.34 μg/m^3). This result was consistency with previous studies [19, 20].

Compared to previous studies, the BC concentrations measured in car in this study were higher than those measured in taxies in Hanoi by Le [19], but similar to those measured in car in Hanoi [20].

3.4. Inhalation exposure to BC at different microenvironments in Hanoi

To better understanding the risk of exposure to BC in different microenvironments, the average inhalation dose rate for each building and transport mode is calculated and presented Table 3 and Fig. 4. Overall, the average exposure rate is 5.46 μg/h. Motorcyclist was highly exposed to BC during the measurement period (13.48 μg/h), followed by car driver (5.74 μg/h). Next is customer in coffee shop (3.98 μg/h). The exposure rate of people who live in an apartment with doors open and closed were 3.58 μg/h and 2.15 μg/h, respectively. The lowest exposure rates were 1.92 μg/h and 1.54 μg/h for occupants in office and hospital buildings, respectively.

Table 3. Personal exposure to BC at different microenvironments

Microenvironment	Motorbike	Car	Office	Coffee shop	Hospital	Apartment*	Apartment**
Age	19-40	19-40	19-40	19-40	19-40	19-40	19-40
IR (m^3/h)	0.60	0.60	0.46	0.36	0.36	0.36	0.36
BC average (μg/m^3)	12.78	9.56	4.17	11.05	4.29	5.97	9.94
Exposure time (h)	0.83	8.62	9.85	1.50	1.99	10.43	12.49
Exposure rate (μg/h)	13.84	5.74	1.92	3.98	1.54	2.15	3.58
Exposure dose (μg)	11.42	49.43	18.89	5.97	3.08	22.42	44.70
% of exposure (PD)	7.32	31.70	12.12	3.83	1.97	14.38	28.67
% of time	1.80	18.85	21.55	3.28	4.36	22.83	27.33

The contributions of time and BC exposure showed in Fig. 5. Our critical finding is that commuting accounted for a small-time (20.66%) but responsible for a disproportionate exposure of a large amount of BC (39.09%). It is inconsistent with what Dons et al. [3] and William and Knibbs [32] have reported in previous studies about the total human daily exposure to BC. Time spent and BC exposure in the apartment microenvironment was more balanced at 50.15% and 43.05%, respectively.

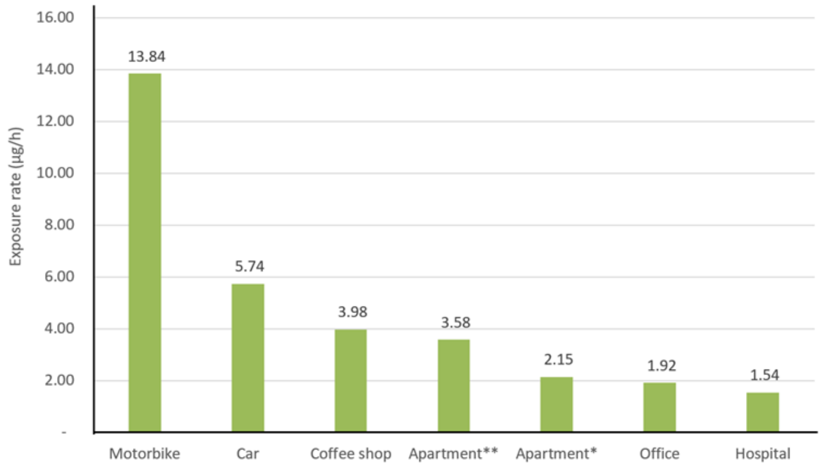


Figure 4. The BC personal exposure rate at different microenvironments

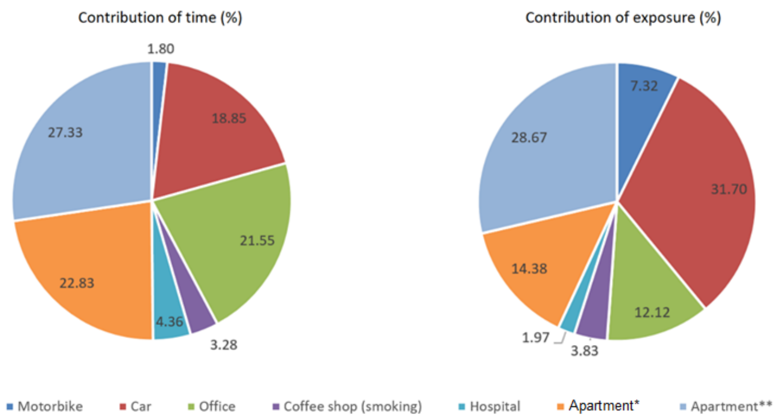


Figure 5. Contribution of different microenvironments to BC Exposure

4. Conclusions

It is the first time the personal BC exposures in different microenvironments of different buildings and transportation modes were quantified and their contributions to the total daily exposure were estimated. The overall average personal exposure to BC was 5.46 µg/h. The highest BC exposure was during commuting with 13.48 µg/h and 5.74 µg/h for motorcyclists and car drivers, respectively. In the indoor environments, the highest BC exposure was 3.98 µg/h in the coffee shop with smoking; while the lowest BC exposure was 1.54 µg/h in the hospital department; the levels of BC exposure in the apartment were 3.58 µg/h and 2.15 µg/h with doors/windows open and closed, respectively. Our finding confirmed that commuting contributes disproportionately to the total BC exposure due to the high level of BC during traffic/travel. Building ventilation and air conditioning can significantly affect indoor BC levels and should be considered as a measure to reduce BC exposure in buildings.

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