Title of dissertation				
Chemical characterization, source identification and health risk assessment of particulate matter pollutants in indoor environment, as a case study of Hanoi, Vietnam				
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Vietnam has recently faced serious problems related to air pollution, primarily due to increased rates of urbanization in centers with high population densities, particularly in indoor air quality (IAQ). Poor IAQ can have a wide range of health consequences, including respiratory and cardiovascular illnesses, allergy symptoms, cancer, and early death (WHO, 1998). In addition, IAQ, which has a greater potential impact on public health than outdoor pollution, is considered to have been responsible for more than 3.8 million premature deaths around the word in 2016 (WHO, 2022)

This dissertation systematically examined the impact of indoor particulate matter (PM) and its components on the indoor environment, and analyzed the situation of indoor pollution in Vietnam. Specifically, this study clarified: *1)* the characteristics of PM in houses, such as mass size distribution, link between indoor and outdoor PM, and influencing factors; *2:* The chemical composition of PM (*polycyclic aromatic* hydrocarbon (PAH) and trace element (TEs); *3)* What are possible sources of indoor PM in urban area - Hanoi as case study?*; 4)* How does PM affect health assessments? Specifically, this study sought to clarify the distribution of deposited doses of PM and their composition in the human respiratory system and valuate the health risk assessments of the occupants of in the residential houses in urban area via the inhalation pathway.

In a review of 65 studies on PM pollutants and VOCs (Volatile organic compounds) in indoor and outdoor environments, a total of 19 total studies reported on PM, VOCs in different indoor contexts, and current mitigation measures related to IAQ in Vietnam. In some cases, high concentrations of PM ($PM_{2.5}$, PM_{10}, $PM_{0.1}$) and BTEXs (benzene, toluene, xylene, ethylbenzene) were observed in indoor environments such as residential houses, kitchens, parking basements, and offices in urban areas in Vietnam, in which the levels

of $PM_{2.5}$ and benzene exceeded WHO guidelines; these levels pose a significant risk to human health. A variety of mitigation efforts focusing on controlling indoor and outdoor pollutants have been published to date; however, these measures have generally been insufficient due to lack of regulations, technical standards, and effective interventions related to IAQ.

To determine the seasonal variations of the mass concentrations of size-fractionated PM, the relationships among indoor and outdoor PM, PM size distribution, and deposited dose estimation were therefore clarified in urban residential houses in Hanoi. A total of daily 1240 PM samples ($PM_{0.1}$, $PM_{0.1\text{-}0.5}$, $PM_{0.5\text{-}1}$, $PM_{1\text{-}2.5}$, $PM_{2.5\text{-}10}$, and $PM_{>10}$) was collected simultaneously at four residential houses in summer and winter by using a nano sampler (Model 3182, Kinomax, flowrate 40 L/min), both indoors and outdoors. The four sampled houses (K1, K2, K3, K4) were representative of residential buildings with natural ventilation. K1 (urban periphery, two-story house) was located near roads and industrial zones. K2 and K4 (urban multi-story houses) were located in densely populated areas. K3 (roadside multi-story house) was located adjacent to a high-traffic-density road.

The results showed that the average concentrations of indoor $PM_{0.1}$, $PM_{0.5}$, PM_1, $PM_{2.5}$, and PM_{10} ranged from 5.3 to 8.9 μg/m^3, 10.8 to 20.1 μg/m^3, 20.5- to 47.6 μg/m^3, 33.7 to 105.9 μg/m^3, and 44.7 to 135 μg/m^3 among the four houses, respectively. The concentrations of outdoor $PM_{2.5}$ and PM_{10} were considerately higher than those of indoor $PM_{2.5}$ and PM_{10}, whereas the differences in the concentrations of $PM_{0.1}$, $PM_{0.5}$ and PM_1 were negligible. Seasonal variation was observed for indoor PM_1, $PM_{2.5}$, and PM_{10}, but not for $PM_{0.1}$ and $PM_{0.5}$, and the majority of indoor fractions originated from outdoor sources. Unimodal distributions of indoor particles determined the super-micron size range (1 to 2.5 μm) with highest concentrations, the lowest concentration observed for $PM_{<0.5}$ or $PM_{>10}$. Fine particles (i.e., $PM_{0.5\text{-}1}$ and $PM_{1\text{-}2.5}$) contributed predominantly to coarse particles both indoors and outdoors, suggesting that they posed a serious threat to human health. A multi-path particle dosimetry model (MPDM) was applied to predict the deposited doses of PM at different fractions in the human respiratory tract (HRT). The total deposition fraction (DF) obtained for PM_{10} was higher than those observed for $PM_{2.5}$, PM_1, $PM_{0.5}$, and $PM_{0.1}$. However, the total lobar DF was highest for $PM_{0.1}$, followed by $PM_{2.5}$, PM_{10}, PM_1, and $PM_{0.5}$ for all age categories (except for case of adults (>21y) for PM_{10}). PM_{10} deposited the greatest in the head airways (HA), whereas $PM_{0.1}$ deposited the greatest in the alveolar region (AL) and lobe region in the HRT. The deposited doses of PM increased with increased ages and PM sizes and the adults (>21y) was considered to be the most vulnerable group in this study for exposure to chronic effects.

To determine the chemical composition, source identification and health risk assessment

associated with $PM_{0.1}$ and $PM_{2.5}$, 320 daily $PM_{0.1}$ and $PM_{2.5}$ samples were collected at the three dwellings (K1, K2, and K3, representing the urban periphery house, the roadside house, and the urban house, respectively) in Hanoi in summer and winter. The samples were analyzed for ten trace elements (TEs) (Cr, Mn, Co, Cu, Ni, Zn, As, Cd, Sn, Pb) and 15 PAHs (Nap, Acy, Ace, Flu, Phe, Ant, Flt, Pyr, BaA, Chr, BbF, BaP, Ind, DahA, BghiP). Samples of indoor and outdoor daily $PM_{0.1}$ were collected using quartz filters (55 mm in diameter) by two identical Nano Sampler II (Model 3182, Kinomax). Samples of indoor and outdoor daily $PM_{2.5}$ were also collected in quartz filters (47 mm in diameter) using two similar cyclone samplers with a fiber holder (URG-2000-30EH, University Research Glassware Co., Chapel Hill, NC, USA) at a flowrate of 16.7 L/min. The enrichment factors, diagnostic ratios, and principal component analysis (PCA) were used to identify the possible sources of PM. The International Commission on Radiological Protection (ICRP) model was used to calculate the distribution of deposited of TEs or PAHs bound to PM in the HRT during exposure to these elements via the inhalation. The health risk assessment model of USEPA was applied to evaluate non carcinogenic risk (non-car risk) and carcinogenic risk (car risk).

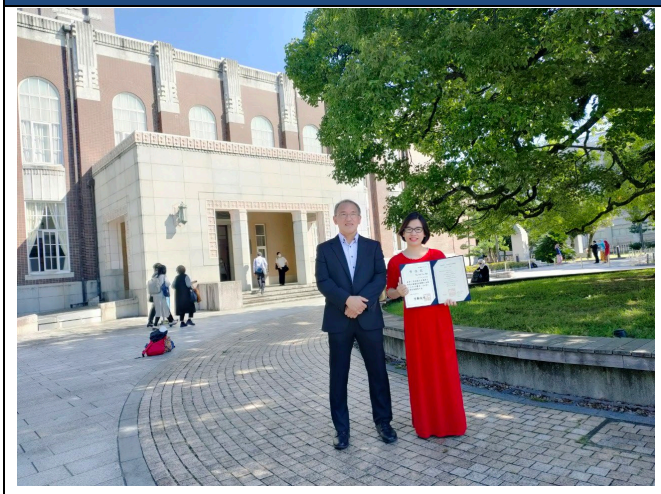
The obtained results showed that the average concentrations of indoor $PM_{0.1}$ and $PM_{2.5}$ ranged from 7.0 to 8.9 μg/m^3 and 43.3 to 105.8 μg/m^3, respectively. The average concentrations of TEs bound to indoor PM varied from 66 to 216 ng/m^3 for $PM_{0.1}$ and 391 to 2356 ng/m^3 for $PM_{2.5}$. Meanwhile, the average $\sum_{15}$PAHs concentrations ranged from 102.9 ng/m^3 to 155.6 ng/m^3 and 25.3 to 52.9 ng/m^3 for indoor $PM_{2.5}$ and $PM_{0.1}$, respectively. The average concentrations of BaP bound to $PM_{2.5}$ and $PM_{0.1}$ were 2.6 ±0.4 ng/m^3 and 1.6 ±0.2 ng/m^3, respectively, which exceeded the threshold of the European guidelines, resulting in damage to the health of the occupants at three investigated houses

Domestic coal burning, industrial, and traffic emissions were considered to be outdoor sources, whereas household dust and indoor combustion were considered to be indoor sources. The outdoor sources (traffic, coal, biomass combustion) contributed significantly to PM at the urban periphery house and the roadside house, while indoor sources (combustion of incense, candle, natural gas, camphor usage, evaporation of building materials, paint wall, movements etc.) were the main sources of PM at the urban house.

The majority of ∑TEs or $\sum_{15}$PAHs or $\sum BaP_{(eq)}$ bound to $PM_{2.5}$ were deposited in the head airways (HA), whereas the dominant proportion of $\sum_{15}$PAHs or $\sum BaP_{(eq)}$ or ∑TEs bound to $PM_{0.1}$ was deposited in the alveolar region (AL) region. Doses of $BaP_{(eq)}$ bound to PM deposited greater in main extra-thoracic region (ET2) than in anterior nasal region (ET1); and bronchiolar region (bb) than in bronchial region (BB). The Monte Carlo simulation indicated that the intake of TEs in $PM_{2.5}$ can lead to high carcinogenic risk for people over 60 years old and unacceptable non-

carcinogenic risks for all ages at the roadside house in winter. However, the occupants of the urban house were exposed to the highest risk, as the intake of BaP and DahA can lead to an increase in the potential cancer risk to the elderly group considering for individual setting threshold for cancer risk of USEPA (10^{-6}), although the cumulative cancer risk was within acceptable levels (10^{-4}) for all occupants of the three houses. Sensitivity analysis revealed that the concentration of TEs or $\sum BaP_{(eq)}$ was the most influencing factors on ICLR (Incremental cancer lifetime risks) variation, which_contributed approximately 87% to 98% of the ILCR variance in micro-environment. The other variables such as BW, ET, AT etc. contributed the insignificance. In the macro-environment, the calculated ILCR showed a high potential cancer risk when based on the WHO method, while those ILCRs based on the CalEPA and US EPA methods showed that cancer risk was within acceptable limits.

Photos



Degree conferment ceremony with supervisor

Dissertation defense