MEDWIN PUBLISHERS
Committed to create value for Researchers

Ergonomics International Journal
ISSN: 2577-2953

Residential Building PM2.5 Pollution Control from an Ergonomic and Energy Conservation Prospective

Lin Y[1]*, Yang W[2] and Gong X[3]

[1]School of Civil Engineering and Architecture, Wuhan University of Technology, China

[2]College of Engineering and Science, Victoria University, Melbourne, Australia

[3]Department of Architecture, Guilin University of Technology, China

Mini Review

Volume 1 Issue 3

Received Date: November 16, 2017

Published Date: November 22, 2017

DOI: 10.23880/eoij-16000125

***Corresponding author:** Yaolin Lin, School of Civil Engineering and Architecture, Wuhan University of Technology, Wuhan, China, Email: ylin@whut.edu.cn

Abstract

PM2.5 pollution has become a big problem in China due to rapid industrialization and high energy consumption. This critical review focuses on current research on PM2.5 particle matter, and provides an insight from ergonomic and energy conservation prospective. It is suggested that the interactions among indoor particle concentration distribution and outdoor particulate concentration, building envelope characteristics, occupants' window-opening behaviors and HVAC system operation need to be carefully considered to achieve energy savings while maintaining a healthy and productive indoor environment.

Keywords: PM 2.5 Pollution Control; Residential Building; Energy Conservation

Mini Review

PM 2.5 pollution has become a big problem in the world. A complete Ambient Air Pollution Database recently provided by the World Health Organization (WHO) shows that more than 80% of people living in urban areas that monitor air pollution are exposed to air quality levels that exceed the health limits (WHO guideline value of 20μg/m^3), especially the low income cities, and air pollution caused an estimated 6.5 million deaths in 2012 [1]. Although there are many studies on the indoor PM 2.5 concentration, a database on the resident PM2.5 indoor environment around the world could not be found. However, the indoor and outdoor PM2.5 concentrations are highly related. According to a literature study by Chen and Zhao [2], more than 2/3 has found indoor air pollutant concentration higher than outdoor. A recent AQI white paper issued jointly by Jones Lang LaSalle and Pure Living China revealed that the average indoor PM2.5 levels for Shanghai and Beijing in 2015 from January to October were 87 μg/m^3, and 115 μg/m^3, respectively [3]. Therefore, the current resident PM2.5 indoor environment is not favorable.

There are 2974 cities listed in the WHO database [1], the maximum, minimum, average and median annual mean PM 2.5 concentrations are 217 μg/m^3, 1.6 μg/m^3, 21 μg/m^3 and 14 μg/m^3, respectively. As for China, there are 210 cities listed in the WHO database, the maximum, minimum, average and median annual mean PM 2.5 concentrations are 128 μg/m^3, 11 μg/m^3, 52 μg/m^3 and 53 μg/m^3, respectively. Of the 210 cities, only 6 (2.9%) of which the annual mean PM 2.5 concentrations are lower than World Health Organization (WHO) guideline value.

In the developed countries, PM 2.5 air quality is now under control, for example, in USA, the PM 2.5 concentration decreases by 42% from 2000 to 2016 [4], even though the productivities have been increased since then and the energy consumption has dropped since 2009. However, in the developing countries, especially in China, with the rapid growth in economic and energy consumption, the PM 2.5 concentration level is now sky-high and pause a threat to human health. Therefore, it is very important from the perspectives of ergonomic and energy conservation prospective to study how to control PM 2.5 at a healthy level while maintaining the productivity.

With the rapid increase in energy consumption, China is facing a more and more severe situation on PM2.5 particulate matter pollution in the atmosphere, which cause increase in the incidence of various respiratory diseases and rate of resident mortality [5]. Wuhan, Beijing, Guangzhou and Nanjing are some of the big cities in China that are facing the PM2.5 pollution problems [6]. The outdoor PM2.5 particulate matter is the main source for indoor PM2.5 particulate matter [7]. Therefore, the PM2.5 particulate matter concentration level has great impact on the indoor air quality. Meanwhile, the increase in the PM2.5 particulate matter concentration level results in the increase in the residential energy consumption [8].

In China, coal is still the main energy source in electricity generation; therefore coal combustion is the main origin for many cities such as Wuhan [5,9-11]. For example, coal burning is an important source of winter heating in Wuhan [9], and at the same time, the ventilation and air conditioning system consumes a big proportion of electricity, while thermal power generation still accounts for about 40% of Hubei Province power generation (67% if the hydro power generated by the Three Gorges is neglected) [12]. Since the heating, ventilation and air conditioning (HVAC) system consumes about 30%-65% of the total building energy consumption, it is a big player in the increase in outdoor PM2.5 particulate matter emissions. Therefore, how to effectively control the indoor PM2.5 concentration level to improve the indoor air quality and ensure the health level of occupants, while reducing the energy consumption by the HVAC system becomes an urgent task.

Information about the I/O ratio of air pollutant concentrations is a crucial component in human exposure and health impact assessments of indoor environment. At present, most of the studies involving I/O ratios are experimentally oriented and the results are diverse. Study from Huang et al. [13] show that, the hourly ambient PM2.5 mass concentrations in Beijing were 3–280 μg/m^3 with a median of 58 μg/m^3, and hourly indoor counterpart were 4–193 μg/m^3 with a median of 34 μg/m^3. The median indoor/ambient ratio of $PM_{2.5}$ mass concentration was 0.62. Study from Du et al. [14] show that when the ambient PM2.5 mass concentrations in Beijing were 0-33μg/m^3,34-65 μg/m^3, 66-129 μg/m^3, ≥130 μg/m3, the median indoor/ambient ratio of $PM_{2.5}$ mass concentration was 1.75, 1.05, 0.76 , and 0.63, respectively.

Inappropriate control of HVAC system could cause rapid spread of the particle matters while the building energy consumption increases at the same time. Therefore, careful consideration should be given on when to operate the HVAC system, how to control the supply air temperature and velocity, etc. By applying appropriate ventilation and air conditioning system control strategy, the indoor PM2.5 concentration can be held at an allowable healthy level; on the other hand, the building energy consumption will be maintained at a low level, thereby reducing the need for coal combustion, which leads to the reduction of the outdoor PM2.5 particulate matter concentration level to form a virtuous circle.

To achieve the optimal control, it is necessary to fully study the mechanism of diffusion and control of PM2.5 particles and its influencing factors. Outdoor PM2.5 particles pass through the building envelope structure and openings (such as windows) into the room and spread out, the diffusion velocity of which is affected by the particle size, indoor and outdoor pressure difference, crack size and occupants' window opening behaviors, etc.. The HVAC system can help to purify the outdoor air and the indoor circulation air, while providing enough cooling / heating to create a thermally comfortable environment for the occupants. Different supply air velocities/directions also affect the distribution of indoor particle matter. Therefore, the entire transportation process is affected by the physical characteristics of the building envelope, the occupants' window-opening behaviors, and the HVAC system operation as well as the air purification efficiency. How to deal with the relationship among the three is very important to create a healthy and comfortable indoor thermal environment while achieving energy savings with optimal HVAC system control.

Some researchers have studied the effect of outdoor PM2.5 concentration on the indoor environment [7,8,15-22], mainly focusing on the effect of different ventilation modes on the indoor PM2.5 particulate concentration. Ma et al. [15] simulated the control of indoor PM2.5 concentration and CO_2 concentration for residential buildings when the two kinds of windowing methods, full-time window-opening and short-time window-opening, were used together with air purification in a haze day, without considering the indoor temperature control and the impact on energy consumption. Shi et al. [18] simulated the PM2.5 indoor concentration and indoor exposure under natural ventilation and mechanical ventilation, and compared the energy consumption corresponding to different ventilation modes, which also did not take into account the indoor temperature control. The above mentioned studies did not consider the distribution of particulate matter. Therefore, how to take into account the energy-saving control strategies of HVAC system, the distribution of pollutant concentrations and the thermal comfort sensation of occupants is a topic worth studying. Although it is very hard to give specific advices, some suggestions to the operation of HVAC system maybe: 1) Turn on the HVAC system to purify the indoor air before occupied, 2) Close the window when AC is ON, 3) Add OA duct and filter to the AC unit if fresh air is needed, 4) After air is purified, optimally control the supply air velocity, supply air temperature and compressor speed/staging to maintain indoor air at design thermal condition. The advantages of using HVAC system are: 1) Maintain good indoor thermal comfort in respect to temperature and humidity, 2) Remove the particle quickly if HEPA is used. The disadvantages of using HVAC system are: 1) It increases the energy consumption; 2) The particle matter may spread quickly when during the initial operation of the HVAC system.

Future research should focus on the effect of outdoor PM2.5 concentration on the indoor air quality, thermal comfort and energy saving measures of HVAC system, in particular, the interactions among indoor particle concentration distribution and outdoor particulate concentration, building envelope characteristics, occupants' window-opening behaviors and HVAC system operation. And then find out the energy saving measures to optimally control indoor PM2.5 particulate concentration level based on outdoor PM2.5 concentration. This is of great scientific and practical significance to improve the quality of life and health level of urban residents and improve the livability index of the city.

Acknowledgment

This work was supported by the Natural Science Foundation of Hubei Province under grants [2017CFB602, 2015CFB532].

References

1. WHO (2017) WHO's Urban Ambient Air Pollution database 2016.
2. Chen C, Zhao B (2011) Review of relationship between indoor and outdoor particles: I/O ratio, infiltration factor and penetration factor. Atmospheric Environment 45(2): 275-288.
3. Yang Lan (2017) Staying indoors is not a solution to Shanghai's air pollution. Global times.
4. EPA (2017) Particulate Matter (PM2.5) Trends.
5. Kan H, Chen B (2004) Economic Evaluation of Residents' Health Effects by Airborne Particulate Pollution in Urban Area of Shanghai. China Health Economics 23(2): 8-11.
6. Xiao J, Zhou J, Guo H, Wang L, Zhou Y, et al. (2013) Analysis of the Source of a PM2.5 Sample in summer in Wuhan by Using Positive Definite Matrix Factorization. Environmental Pollution and Prevention 35(5): 6-12.
7. Cyrys J, Pitz M, Bischof W, Wichmann He, Heinrich J (2004) Relationship between indoor and outdoor levels of fine particle mass, particle number concentrations and black smoke under different ventilation conditions. Journal of Exposure Analysis and Environmental Epidemiology 14(4): 275-283.
8. You S, Neoh KG, Tong YW, Dai Y, Wang C (2017) Variation of household electricity consumption and potential impact of outdoor PM2.5 concentration: A comparison between Singapore and Shanghai. Applied Energy 188(C): 475-484.
9. Zhou Y, Zhou J, Wang L, Xiao J, Guo H (2013) Distribution and Sources of Polycyclic Aromatic Hydrocarbons in Atmospheric PM2.5 Particles in Wuhan in Autumn and Winter. Ecology and Environment 22(3): 506-511.
10. Zhou Y, Zhang H, Wang Q, Xu L, Wang C (2015) Pollution Characteristics and Source Analysis of PM2.5 in Winter Season in Qingshan District of Wuhan City. Environmental Science and Technology 38(11): 160-164.
11. Zhang L, Zhang Y, Qi S, Li H, Xing X, et al. (2015) PM2.5 Concentration and Polycyclic Aromatic Hydrocarbon Composition in Hongshan District of Wuhan City in Spring. China Environmental Science 35(8): 2319-2325.
12. (2017) Hubei Provincial Development and Reform Commission.
13. Huang L, Pu Z, Li M, Sundell J (2015) Characterizing the Indoor-Outdoor Relationship of Fine Particulate Matter in Non-Heating Season for Urban Residences in Beijing. PLoS One 10(9): e0138559.
14. Du Y, Zhang Y, Li T (2016) A Study on the resident indoor PM 2.5 exposure level and relationship between Indoor-Outdoor PM 2.5 concentration in Beijing. Journal of Environment and Health 4(33): 283-268.

15. Ma H, Shao X, Lian C, Wang H, Wu C, et al. (2016) Feasibility Study on Combined Strategy of Ventilation through Window Opening and Air Purification in Residence Under Fog Haze. Journal of HV&AC 46(2): 18-23.

16. Chen Q (2016) Residential building indoor ventilation strategy and indoor air quality enhancement. Journal of HV&AC 46(9): 143-144

17. Wang Q, Li G, Meng C, Zhao L, Wang J, et al. (2015) Outdoor Fine Particles (PM2.5) Building Envelope Penetration and Passive Control Measures. Journal of HV&AC 45(12): 8-13.

18. Shi S, Jin W, Zhao B (2013) Simulation and comparison of indoor fine particle mass concentration and indoor exposure rate under different ventilation modes. Journal of HV&AC 43(12): 34-38

19. Marsika T, Johnson R (2008) HVAC air-quality model and its use to test a PM2.5 control strategy. Building and Environment 43: 1850-1857.

20. Martins NR, da Graça GC (2017) Impact of outdoor PM2.5 on natural ventilation usability in California's nondomestic buildings. Applied Energy 189: 711-724.

21. Wang F, Meng D, Li X, Tan J (2006) Indoor-outdoor relationships of PM2.5 in four residential dwellings in winter in the Yangtze River Delta, China. Environmental Pollution 215: 280-289.

22. Morawska L, Jamriska M, Guo H, Jayaratne ER, Cao M, et al. (2009) Variation in indoor particle number and PM2.5 concentrations in a radio station surrounded by busy roads before and after an upgrade of the HVAC system. Building and Environment 44 (1): 76-84.