

# Study of Literatures for the Impact on PM2.5 Purification by Architectural Design under Haze Conditions

Cao Jian<sup>1,2</sup>, Hu Ningning, Yang Lei<sup>1,2</sup>, Yan Wei and Chu Minghao

<sup>1</sup> Zhongyuan University of Technology, Zhengzhou 451921, China

<sup>2</sup> Key Laboratory of Heating and Air Conditioning, The Education Department of Henan Province, Zhengzhou 451921, China

Email: 6092@zut.edu.cn; 994859160@qq.com; xsc\_yl@163.com ;  
yanwei1003@126.com; X16278907@sina.cn

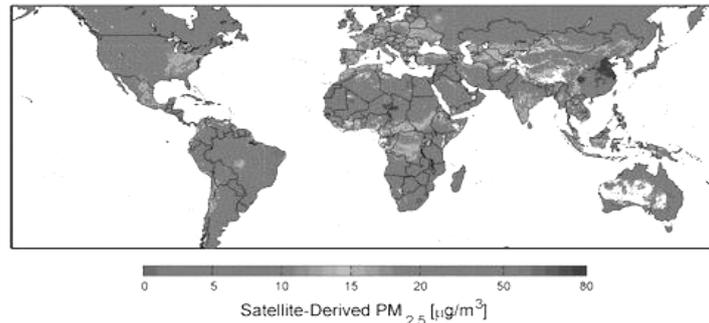
**Abstract.** This paper focuses on literatures reviewing with key words of architectural and PM2.5 based on the China Academic Journal Network Publishing Database (CKNI) and Elsevier SD database. Statistical analysis on the searched 184 related literatures show the following results. (1) 20.6% of the all targeted literatures showed that PM2.5 concentration was one of the important impact parameters of indoor & outside air quality. (2) 16.3% of the literatures illustrated that the architecture designing contributed significantly to indoor and outdoor fine particulate pollution by controlling particle generation and diffusion. It can be concluded that the three-dimensional architectural design, the total layout of the building designing strategy and the architectural space design based on green building-oriented architectural designing concept will be the future focused research and the frontier question.

## 1. Introduction

Industrial development has brought about economic development and environmental pollution in China in the past years. The high concentration of fine particles in the air has been a serious threat to people's health, especially with haze weather. From 2001 to 2006, the National Aeronautics and Space Administration (NASA) had plotted the global pollution particulate matter (PM2.5) average concentration satellite map as shown in figure 1. China's north and east were the most polluted areas in the mainland of Asia. Haze destroys the ecological environment and seriously affects human life. Haze can induce respiratory diseases and cardiovascular diseases and increase the prevalence of cancer and so on. People are apt to haze weather caused traffic accidents.

Pope et al. conducted a 16 year study of nearly 500 thousand adults in 50 states in the United States. Research findings showed that  $10\mu\text{g}/\text{m}^3$  increasing of the average concentration of PM2.5 might contribute to 8%, 6% and 4% increasing of human lung cancer mortality, heart lung disease mortality and annual total mortality, respectively [1]. People spent more than 90% of the time in building. How to keep indoor air clear is important, especially in the environment condition of haze.



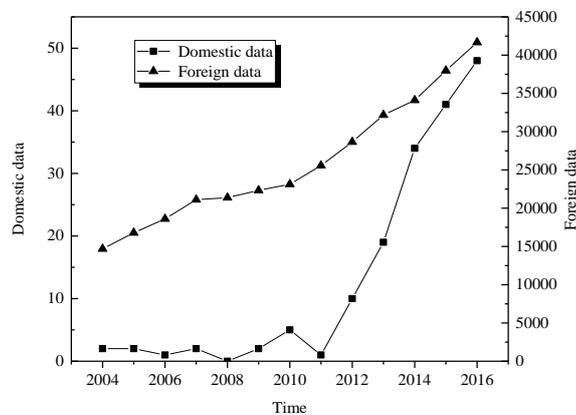


**Figure.1.** satellite remote sensing test chart

## 2. Research background of haze concentration control by Architectural design

### 2.1. Literature research status

The authors of this paper took the "building" and "PM2.5" as key words in CNKI and Elsevier SD database. The author compiled the data, and the author drew a broken line diagram. The figure 2 displays a literature review of PM2.5 control in the field of architecture both at home and abroad. There are few literatures in china before 2011. The number of domestic related literatures is not the state of growth. After 2011, the relevant domestic literature had a significant upward trend. This shows that people know and understand PM2.5 in recent years. Relevant scholars pay attention to PM2.5. As can be seen from the diagram, the international research on the control of PM2.5 had been in a steady growth trend. Our country has a wide development space for the control measures of fine particulate pollution in the ambient air.



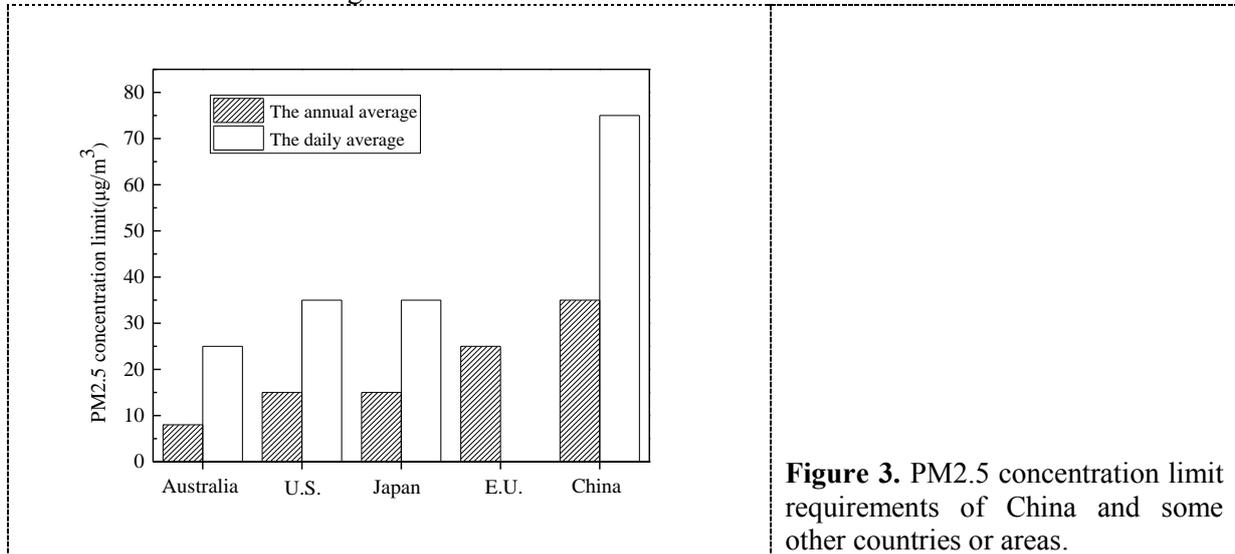
**Figure.2.** The literature research data of fine particles on the buildings at home and abroad

### 2.2. Direction of literature research

The author of this paper reviewed the domestic and foreign literatures in recent years. Building control of indoor PM2.5 concentration will be the main direction of future researches. On the views of the current literature analysis. In the construction field, the control strategies of the concentration of fine particles in buildings can be roughly divided into two parts. One is the combination of indoor ventilation system and air purification equipment of active control measures. Another is to control the indoor PM2.5 concentration passive control measures through green building design methods. The former is one of the main focuses of the current literature research, and the latter is in a gradual development trend.

## 3. Domestic and foreign standards for PM 2.5

Haze has serious threat to environment, human life and health. Relevant laws and regulations have been formulated for haze control all over the world. PM<sub>2.5</sub> concentration limits for second classes of countries are illustrated in figure 3.



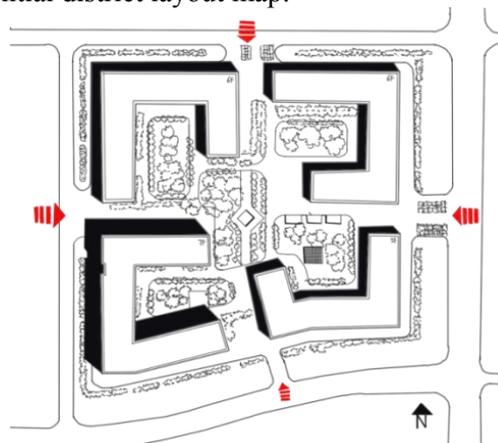
**Figure 3.** PM<sub>2.5</sub> concentration limit requirements of China and some other countries or areas.

It can be seen from figure 3, there was still a big gap between China's PM<sub>2.5</sub> concentration limits and international standards. Hence, China has a long way to improve the domestic air environmental quality to acceptable level.

#### 4. Literatures on the influence of architectural design on indoor and outdoor PM<sub>2.5</sub> concentration distribution

##### 4.1. Overall layout of building

The overall layout of the building and the green around of building can affect the PM<sub>2.5</sub> concentration around building. Wu et al. (2013) found that the height of the building layout and the way of enclosure affect the concentration of PM<sub>2.5</sub> in the air. Studies had shown that the avenue in the multi-storied courtyard layout could effectively reduce the concentration of PM<sub>2.5</sub> in the air[2]. Figure 4 displays a multi-storied courtyard residential district layout map.



**Figure.4.** Multi story courtyard building layout (hand-painted)

##### 4.2. Natural ventilation design of building

The three-dimensional greening construction can effectively reduce the concentration of fine particles around the building. The three-dimensional greening of the building includes green vegetation around the building, building wall greening, roof garden and so on. Three dimensional greening can beautify

the building environment, in which green plants have obvious ecological effects. Three dimensional greening is one of the important ways to control air pollution passively, As figure 5 shown that one of the three-dimensional greening methods.

According to Zhang (2010), each cubic meter of lawn can absorb 146kg of carbon dioxide, 0.0031kg of sulfur dioxide, and release 105.85kg of oxygen per year [3]. Therefore, increasing the green area is of great significance to improve air quality and reduce air pollution.

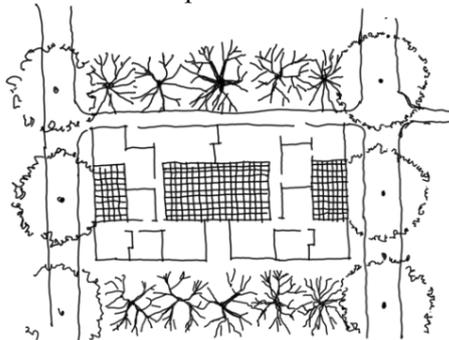


**Figure.5.** three-dimensional greening (hand-painted)

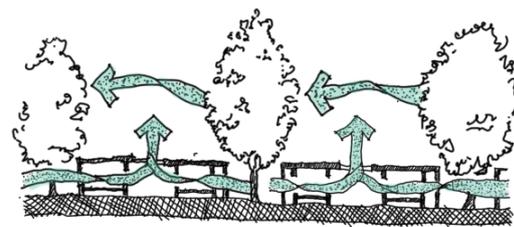
#### 4.3. Natural ventilation design of building

**4.3.1 The thermal pressure ventilation.** Brown (2008) believed that combining the sun shaded courtyard with the open courtyard could lead the air from one courtyard to another. He also thought that the principle of hot pressing could drive indoor ventilation. For example, Mareuil designed Alice Spring House. The designer had two residential courtyards into a central courtyard. The sun heated the air in the courtyard which contributed to the hot air rising in the courtyard. Moreover, Cold air entered the room from the entrance of the sunshade. The air entered the room complemented the rising hot air in the courtyard. This resulted in hot pressing ventilation, the hot pressure ventilation increases indoor natural ventilation efficiency [4], as shown in figure 6 (a, b).

When the concentration of fine particles outside the room is low, natural ventilation can take away a lot of harmful fine particles in the room and bring fresh air into the room.



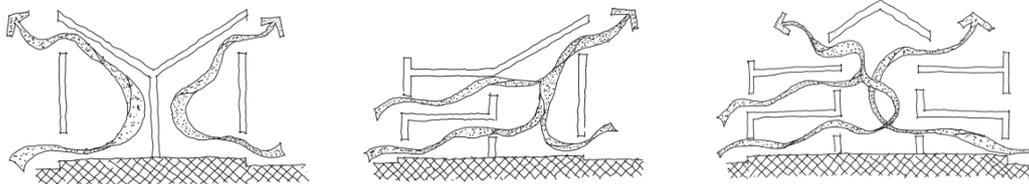
**Figure.6.** (a)Plan (hand-painted)



**Figure.6.** (b)Profile analysis chart (hand-painted)

Additionally, air ventilation by hot pressure can provide fresh air for buildings and effectively reduce energy consumption of buildings. The authors analyze the documents and monographs, author sketch below several common building hot air ventilation schematic diagram figure 7 (a-e). Figure 7 (a) is commonly used in single storey low rise buildings. It's a single building space using hot air ventilation. Figure 7 (b) is a compound architectural space. The air flow in many low spaces converged into large spaces. The airflow in the large space leads to outdoor with the principle of hot pressing. Such large spaces can be arranged in conjunction with halls and corridors. Figure 7 (c) is a common form of atrium space design. Green vegetation can be planted in the atrium. Planting green vegetation can effectively reduce the concentration of indoor fine particles. Figure 7 (d) is one of the

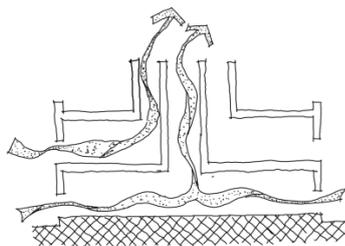
main forms of public buildings. Atrium can effectively organize indoor air flow and effectively organize indoor air flow with only one disadvantage, which is that the large space in the atrium increases the difficulty of building fire protection. Moreover, Atrium has a high demand for building fire protection.



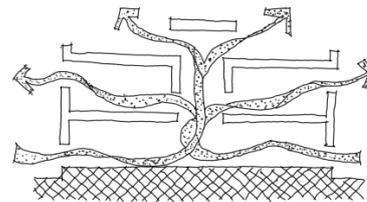
**Figure.7.**(a)Space with two sides high (b)High space around (c)Space in the middle-atrium

Multiple hot-pressing ventilation is a way of ventilation by chimney effect. This method can greatly improve the effect of indoor natural ventilation. Multiple hot air ventilation can remove the indoor PM<sub>2.5</sub> in time. Multiple hot pressed ventilation adds additional building structures and is usually used in buildings with special requirements for ventilation.

The architectural space of figure 7 (e) is often arranged in conjunction with building staircases. It is also a common form of architectural design. Indoor and outdoor temperature pressure to the indoor hot air rises. The outdoor cold air enters the room from the lower level and good circulation ventilation is formed which plays an important role in reducing the concentration of indoor particulate matter.



**Figure.7.**(d) Multiple hot pressing ventilation (hand-painted)

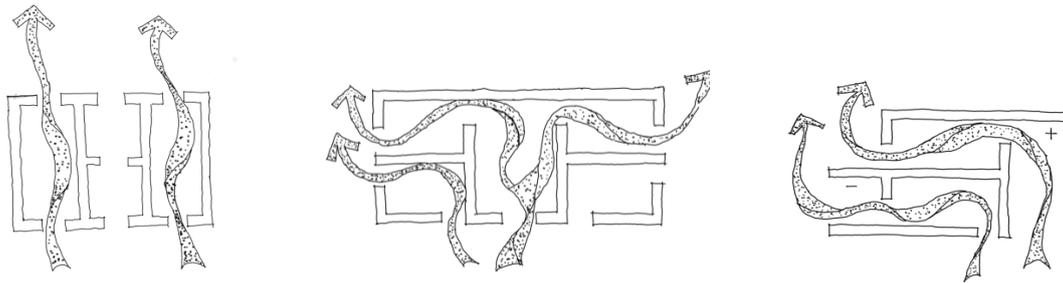


**Figure.7.**(e)Staircase for hot pressing ventilation

**4.3.2 Wind pressure ventilation.** In spring and autumn, air pressure ventilation is a good ventilation method without energy consuming. This ventilation method is more common in architectural design. For example, when the outdoor haze pollution is small in spring and autumn season, Indoor fine particulate matter is mainly due to people's activities in the indoor. Open the window at this time and air pressure ventilation can take away a lot of indoor contaminated particles. Wind pressure ventilation ventilates outdoor clean air into the room and reduces indoor PM<sub>2.5</sub> concentration.

Wind pressure ventilation mode is easy to implement in architectural design. At the same time, the window can also deal with the artistic effect of the building facade to achieve beautiful visual enjoyment.

The authors analyze and study the effect of reducing the concentration of fine particles in the room by using the ventilation space. Figure 8 (a) is a common indoor ventilation design which is often said as the draught. Windows are arranged on the opposite sides of the same space. This kind of space should be generally combined with the wind direction of the regional leading wind. Smaller windage under the influence of dominant wind causes the local wind speed larger and impacts on indoor activities because the space is straight.

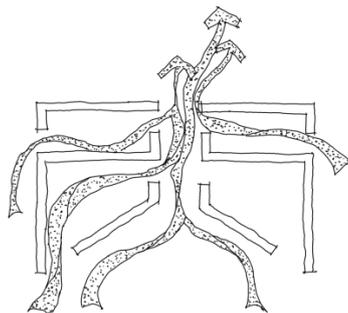


**Figure.8.(a)**Single transparent  
(hand-painted)

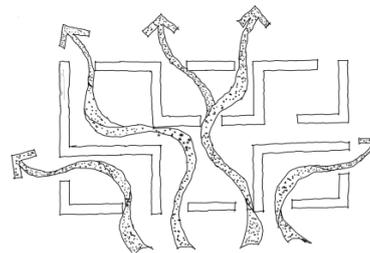
**(b)**Interlaced space  
(hand-painted)

**(c)**Wind-wall space space  
(hand-painted)

Figure 8 (b) is a common residential space in summer locating at the northern hemisphere. Open the window on the windward side of the wall (south side). South side of the window is to accommodate the dominant wind in summer. Outdoor fresh air is introduced to improve indoor air quality. Indoor temperature around south window is effectively reduced in summer. Figure 8 (c) formed a lively architectural space by windfall. Combined with architectural form to form a space staggered architectural style. Achieve flexible and diverse architectural art is a common form of architecture in modern architecture. Positive pressure appears on the windward side of building and negative pressure locates on the leeward side of the building. The building ventilation effect is good and is beneficial to reduce the concentration of indoor particulate matter.



**Figure.8.(d)**Space using Venturi effect  
(hand-painted)



**Figure.8.(e)** The space of circular ventilation with each other(hand-painted)

Venturi effect is that, a low pressure is produced on the lee side of the barrier when the wind blows through the barrier duing to the adsorption of low pressure zone. Venturi effect is a typical ventilation mode of wind pressure. Ventilation effect of venturi is very good but the space is at the end of the air flow. The flow rate is faster and have adverse effects on the daily life of indoor people. Figure 8 (e) is a space connected with each other which is more suitable for residential buildings. The interconnected building space can avoid the discomfort caused by the local gas flow. This uniform and steady airflow can take away the PM2.5 gathered in each room as to achieving a healthy and comfortable living environment.

#### 4.4. Ventilation of building machinery

The research shows that the most serious period of haze pollution in China is from January to March. At this point, a large number of fine particles in the atmosphere is difficult to disperse[5]. Moreover, outdoor PM2.5 concentration is greater than indoor. Natural ventilation is clearly not appropriate. It is necessary to combine mechanical ventilation with air purifier to reduce the concentration of fine particles in the room. That's now called active control. The main way is to use fresh air equipment purified and introduce outdoor air into the room. When outdoor haze is serious the tightness of building is also an important factor affecting the concentration of indoor fine particles. Li (2015) proposed that building tightness is bad for indoor personnel when exposed to outdoor PM2.5 high concentrations. Cold air infiltration will increase heating energy consumption [1]. Window should be

closed to avoid severe haze penetrating into the room in winter. Indoor air purification equipment and fresh air system can be used to purify indoor air.

#### 4.5. *Building water system*

Water is one of the most important parts of the building environment. Water can change the microclimate around the building because the surface of the water can take away a lot of heat in the process of evaporation and reduce temperature and increase humidity.

Water can produce negative ions which has certain adsorption effect and adsorb fine particles in the air to achieve the purpose of air purification. According to the experts from the United Nations air environmental protection field research confirmed that small particles with negative ions in the air can capture PM<sub>2.5</sub> in the air and agglomerate it.

#### 4.6. *Building water system*

At present, the study for the adsorption particles of building materials research showed appropriate environmental protection building wall material could also slow down the increase of PM<sub>2.5</sub> concentration in air to some extent. Such as new fly ash block and cork material were relatively environmentally friendly building materials and had very good absorptive capacity for carbon dioxide in the air. Cork material was renewable and degradable. Excellent performances were shown in heat insulation, sound insulation, vibration resistance, fire prevention and so on. Wang (2015) believed that cork made of wood can absorb dust. It can also resist bacterial and fungal adverse effects [6]. Using diatomite as wall material in the laboratory can not only decorate indoor environment and fine particles of negative ions generated on the interior of the diatomite with certain absorption to purify indoor air well.

The dust pollution caused by the construction is also an important reason for the increase of outdoor PM<sub>2.5</sub> concentration. Ni (2014) think that the reduction of fine particles produced by construction can be improved mainly from the following aspects[7]:

Firstly, reasonable architectural function should be designed to avoid construction secondary pollution and reducing the potential waste of building materials.

Secondly, using environmentally friendly building materials to avoid dust generated during construction to aggravate the pollution of PM<sub>2.5</sub> in the air.

Thirdly, promoting green construction with reasonable planning for the construction site. Appropriate water should be sprayed before and after the construction of the construction area to ensure the construction site humidity and reduce dust diffusion,

## 5. **Conclusions**

Comprehensive analysis above can be summed as the following. Through the layout design of the building and the construction of three-dimensional greening, it can reduce the concentration of fine particles around the building. The ventilation design of building space can control the concentration of PM<sub>2.5</sub> indoors. For example, the atrium with hot pressing ventilation. Wind pressure ventilation is conducive to the rational arrangement and use of building space. Wind pressure can effectively increase indoor ventilation effect and reduce the aggregation of fine particles in the room. These methods are passive control of indoor and outdoor particulate matter concentration. In addition, the concentration of indoor particulate matter directly and effectively can be controlled through the construction machinery ventilation and indoor purification equipment combination of active control measures. However, active control measures increase building energy consumption relative to passive measures. In addition, the building water system. the construction of three-dimensional green similar and the negative ions produced can not only adsorb PM<sub>2.5</sub> but also beautify the environment. The negative ion on people's physical and mental health has an important contribution. This is also an important part of architectural design. Overall, Passive control measures with green building design can effectively control the concentration of indoor air particulate matter. At the same time, the use of

natural ventilation principle greatly reduces the energy consumption of buildings and indirectly controlling the production of PM2.5 in the atmosphere.

### **Acknowledgement**

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