OUTDOOR DESIGN $PM_{2.5}$ CONCENTRATION METHOD FOR FRESH AIR SYSTEMS BASED ON DUAL-CARBON TARGET: A CASE STUDY OF URBAN ECONOMIC REGIONS FROM CHINA

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Under the goal of "achieving carbon peak by 2030 and carbon neutrality by 2060", how to select the type of fresh air system has become a key area of energy conservation. The method of outdoor design $PM_{2.5}$ concentration is one of the important factors affecting the selection of fresh air filtration system. This paper first analyzed the $PM_{2.5}$ concentration values of 31 cities in China from 2017 to 2020 based on mathematical induction, and next gave the recommended coefficient K under six urban economic regions methods in combination with the actual situation. Finally, the selection of air filters in five typical cities was taken as an example, the differences in recommended coefficient K and selection of outdoor design $PM_{2.5}$ concentration under different recommended methods were compared and analyzed. The results showed that the recommended coefficient K under the six economic regions could meet the required K value needs of the region. The recommended coefficient K by the six economic regions methods based on per capita GDP is the best. Under that conditions, the recommended coefficient K of the five typical cities under strict and normal conditions differs from the average K values of the six methods by 0.06 and 0.04. This paper will provide a new method for the correct selection of outdoor design $PM_{2.5}$ concentration in fresh air systems to achieve the dual carbon energy-saving goal.

Keywords: *Mathematical induction; economic regions; $PM_{2.5}$; fresh air systems; selection*

1. Introduction

People are no longer only concerned about the pollution concentration of particles and harmful gases, but also comprehensively consider the distribution of viruses, bacteria, and other microorganisms in atmospheric than ever [1]. Different types of pollutants can cause varying degrees to human body [2]. Particles can enter the lungs through human respiration, leading to diseases, such as the lungs and trachea [3]. Toxic and harmful gases can have an impact on the human nervous and immune systems, causing symptoms, such as dizziness, nausea, even causing deformities, cancer, and other conditions. Biological aerosols will cause serious damage to human immune systems and lead to death [3]. Although epidemic prevention and control has entered normalization, COVID-19 is still in constant variation [4]. People might spend 80-90% of their time indoors [5]. Therefore, establishing a healthy and safe indoor environment is still the top priority.

Fresh air systems can not only ensure indoor purification function, but also introduce fresh air into the room, which increase oxygen content, and make the indoor air environment safer and more comfortable [6]. With the country promotes the implementation of the dual carbon goal, building energy conservation is an important way and method to achieve carbon peak carbon neutrality. How the fresh air system helps energy conservation and carbon reduction has also become the focus [7]. The concentration of outdoor $PM_{2.5}$ is one of the parameters for determining the selection of fresh air systems [8]. However, it causes different trends in pollution emissions in different regions due to the uneven economic development in various regions of China in recent years, and the differences in scale, structure, and production technology of economic development [5]. The development of the economy has put a certain pressure on the environment, which causes some heavily polluting cities to transfer heavy industry outside the city. There are often areas with good economic development where air pollution is more severe, while economically underdeveloped areas where air quality are relatively good and pollution is relatively less [5].

Relate literature showed the economy of 31 provinces, autonomous regions, and municipalities in China is showing a growth trend [9]. For example, the northern coastal areas have a large economic total, with GDP accounting for 1/5 of the country. However, the economic development of the Middle Yellow River region is restricted and relatively backward, that is because the fragile ecological environment and high development difficulties [10]. The air quality in Tibet is the best throughout the year, while the economy is relatively backward [11]. In addition, parts of literature show the carbon emissions per unit area of urban residential buildings in various provinces of China is greatly affected by climate zones and the economy [12]. The carbon emissions per unit area in northern heating areas is generally higher than those in non heating areas [13], especially in cold areas. While in non heating areas, coastal areas with better economic development generally have higher carbon emissions per unit area than central and western regions [14]. As a result, the uneven development of different economic regions has led to significant differences in the calculated concentration of outdoor $PM_{2.5}$, with deep differences in selection of fresh air filtration system in China.

At present, the methods of designing concentrations of outdoor $PM_{2.5}$ had been carried out [15-17]. Such as no guarantee days [15], guarantee rates [16], no guarantee days over the years [17], and the mathematical induction [5]. Although some results by the above methods had been given, it still cannot solve the differences in selection of air filters, which caused by different economic development. In addition, the urbanization rate has the greatest impact on the per capita carbon emissions of urban residential buildings in this region, with the smallest impact on per capita GDP [12]. The per capita GDP represents the overall economic development level of the region, including large, medium, and small cities, towns, and rural areas within the region, while the consumption level of people only includes urban areas [12]. Therefore, there is more urgent need for a method of designing concentrations of outdoor $PM_{2.5}$ for fresh air filtration systems under economic zoning. It is great significance for the efficient and correct selection of fresh air systems under the goal of achieving dual carbon energy conservation.

Therefore, a method of designing concentrations of outdoor $PM_{2.5}$ for fresh air filtration systems based on economic zoning and per capita GDP under the dual carbon energy-saving goal in this paper, and also comprehensively analyzed the relevant parameters at the same time. It provides a simple and fast method for the correct selection of air filters in fresh air filtration system in China.

2. Methods

2.1. Outdoor design $PM_{2.5}$ concentration

The monitoring data of outdoor $PM_{2.5}$ concentrations in this paper were from the http://www.tianqihoubao.com/aqi/xian.html [1], which were the average concentration of $PM_{2.5}$ in atmosphere for four years from January 31, 2017 to December 31, 2020. Table 1 shows the concentration changes of $PM_{2.5}$ in 31 major cities in China from 2017 to 2020.

Table 1. Changes in $PM_{2.5}$ concentrations in 31 major cities from 2017 to 2020

Cities	Average value	Maximum value	Minimum value	Cities	Average value	Maximum value	Minimum value
Beijing	46	111	23	Yinchuan	37	90	16
Shanghai	35	57	16	Zhengzhou	61	155	22
Tianjing	53	108	29	Nanjing	38	89	16
Chongqing	38	85	16	Wuhan	45	94	19
Harbin	45	154	11	Hangzhou	36	64	18
Changchun	39	116	12	Hefei	45	86	17
Shenyang	43	107	18	Fuzhou	23	35	13
Hohhot	39	163	12	Nanchang	33	70	10
Shijiazhuang	67	185	31	Changsha	46	99	18
Taiyuan	57	142	27	Guiyang	28	53	13
Xi'an	60	184	22	Chengdu	45	128	20
Jinan	55	129	29	Guangzhou	30	60	11
Urumqi	57	238	13	Kunming	25	46	11
Lasa	14	37	6	Nanning	31	57	14
Xining	37	86	15	Haikou	16	33	7
Lanzhou	40	89	17				

Table 1 showed that the average annual concentration of $PM_{2.5}$ in 31 tested in China was between 14 and 67 μg/m^3. The city with the lowest average concentration of $PM_{2.5}$ over four years was Lasa, while the largest city was Shijiazhuang. The city with the highest average daily concentration of $PM_{2.5}$ was in Shijiazhuang, with 185 μg/m^3. The city with the lowest average daily concentration of $PM_{2.5}$ was in Haikou, with 33 μg/m^3. The cities of the average annual concentration of $PM_{2.5}$ from 2017 to 2020 met the national secondary standard requirements from high to low as follows: Nanchang (33 μg/m^3), Guangzhou (30 μg/m^3), Guiyang (28 μg/m^3), Kunming (25 μg/m^3), Fuzhou (23 μg/m^3), Haikou (16 μg/m^3), and Lasa (14 μg/m^3). It can be seen that the distribution of outdoor $PM_{2.5}$ concentration values in China is uneven, which is highly correlated with urban economy and per capita GDP [18]. The concentration of $PM_{2.5}$ in southern coastal cities is relatively low, while in northern cities are relatively high. With the implementation of the national dual carbon target, there is an urgent need for a selection method that can comprehensively consider the outdoor design $PM_{2.5}$ concentration of fresh air filtration systems under economic zoning, which has practical application.

2.2. Recommended Calculation method of *K*

The sources of outdoor particulate matters were widely and affected by many influencing factors. The relevant professionals of Japan have done a lot of work on the outdoor design concentration value of $PM_{2.5}$. The design concentration value of outdoor $PM_{2.5}$ by the method of mathematical inductions was more in line with practical needs [5]. The outdoor $PM_{2.5}$ concentrations, corresponding to non-guaranteed rate of 2.5% and 5.0%, were calculated using monitoring station data. The design concentration of particulates C_D of each area was calculated by using the Formula (1) [5]:

$$C_D = KC_Y \tag{1}$$

Where: C_Y is the annual average concentration of suspended particulates in the area. K is the recommended coefficient. For strict conditions, the non-guaranteed rate was 2.5%, while for normal conditions, the non-guaranteed rate was 5% [5]. Strict conditions refer to buildings with extremely high requirements for the concentration of particulate matter, such as clean rooms and wards [5]. Normal conditions refer to environments that do not need to strictly control the concentration of indoor particulate matter, such as houses, schools, and airports [5]. The method of calculating the outdoor design $PM_{2.5}$ concentration are as follows. Firstly, the annual average $PM_{2.5}$ concentrations of each city from 2017 to 2020 were calculated. Secondly, a guarantee rate curve was drawn by using the guarantee rate method [1,5]. Thirdly, the corresponding $PM_{2.5}$ values of different guarantee rates were summarized according to the graph. Next, the ratio correlations between the particulate matter concentration of different guarantee rates and the annual average value was drawn. Finally, the corresponding recommendation coefficient K was determined by different region division methods [5].

2.3. *K* of six methods of different economic regions

The similarity between regional economic development levels and characteristics were taking into considered, there was six regions division methods as follows: typical cities, eight economic regions [12,19], three belts economic regions [12,20], four economic regions [21,22], four types of economic regions [23], and six economic regions [12]. As shown in Tab. 2, the cities contained in each region were divided by six different methods.

Table 2. Cities corresponding to different economic regions division methods

Different methods	Number	Include content
K of city	Firstly	Beijing, Harbin, Changchun, Shenyang, Hohhot, Jinan, Lanzhou, Shijiazhuang, Tianjin, Taiyuan, Zhengzhou, Xi'an, Xining, Urumqi, Lasa, Wuhan, Changsha, Chongqing, Chengdu, Nanchang, Hangzhou, Shanghai, Nanning, Fuzhou, Hefei, Yinchuan, Kunming, Guiyang, Nanjing, Guangzhou, Haikou
K of eight economic regions [12,19]	Secondly	North Coast: Jinan, Shijiazhuang, Beijing, Tianjin
		East Coast: Shanghai, Nanjing, Hangzhou
		South Coast: Guangzhou, Haikou, Fuzhou
		Northeast regions: Harbin, Changchun, Shenyang
		Mid-Yangtze River: Wuhan, Changsha, Nanchang, Hefei
		Mid-Yellow River: Xi'an, Zhengzhou, Taiyuan, Hohhot

		Northwest regions: Lanzhou, Yinchuan, Xining, Lasa, Urumqi
		Southwest regions: Nanning, Kunming, Chengdu, Chongqing, Guiyang
K of three belts economic regions [12,20]	Thirdly	Eastern Belt: Shenyang,Shijiazhuang, Tianjin, Beijing, Jinan, Nanjing, Hangzhou, Shanghai, Nanning, Guangzhou, Haikou, Fuzhou
		Central Belt: Harbin, Changchun, Hohhot, Taiyuan, Zhengzhou, Wuhan, Changsha, Hefei, Nanchang
		Western Belt: Chengdu, Kunming, Guiyang, Xi'an, Lasa, Lanzhou, Xining, Urumqi, Yinchuan, Chongqing
K of four economic regions [21,22]	Fourthly	Northeast regions: Harbin, Changchun, Shenyang
		East regions: Shijiazhuang, Beijing, Tianjin, Jinan, Nanjing, Shanghai, Hangzhou, Fuzhou, Guangzhou, Haikou
		Central regions: Taiyuan, Zhengzhou, Wuhan, Changsha, Nanchang, Hefei
		West regions: Chongqing, Chengdu, Nanning, Guiyang, Kunming, Xi'an, Lanzhou, Hohhot, Yinchuan, Urumqi, Xining, Lasa
K of four types of economic regions [23]	Fifthly	Class I: Beijing, Tianjin, Shanghai
		Class II: Fuzhou, Hohhot, Guangzhou, Nanjing, Shenyang, Hangzhou, Jinan
		Class III: Yinchuan, Xi'an, Urumqi, Changchun, Chongqing, Shijiazhuang, Harbin, Wuhan
		Class IV: Guiyang, Lasa, Kunming, Lanzhou, Nanning, Hefei, Nanchang, Chengdu, Taiyuan, Haikou, Zhengzhou, Changsha, Xining
K of six economic regions [12]	Sixthly	Region I: Beijing, Tianjin, Shanghai
		Region II: Hohhot, Shenyang, Hangzhou, Nanjing, Fuzhou, Jinan, Guangzhou
		Region III: Shijiazhuang, Changchun, Harbin, Wuhan, Chongqing
		Region IV: Taiyuan, Zhengzhou, Changsha, Haikou, Xi'an, Urumqi
		Region V: Hefei, Nanchang, Nanning, Chengdu, Xining, Yinchuan
		Region VI: Guiyang, Kunming, Lanzhou

Note: It does not include Taiwan Province, Hong Kong Special Administrative Region, Macau Special Administrative Region.

3. Results and discussion

3.1. *K* of existing provincial capital cities

With the rapid development of China's economy, the economy in the South is developing rapidly compared to that in the North [24]. There is a difference in recommended coefficient *K* in different cities, also differences in different non-guaranteed rates. The results of the recommended coefficient *K* for 31 provincial capital cities from 2017 to 2020 were shown in Tab. 3 under strict conditions (non-guaranteed rate of 2.5%) and general conditions (non-guaranteed rate of 5%).

Table 3. The recommended coefficient *K* of 31 provincial capital cities

Cities	Strict conditions	Normal conditions	Cities	Strict conditions	Normal conditions

Beijing	3.49	2.79	Yinchuan	2.72	2.04
Shanghai	2.75	2.09	Zhengzhou	3.43	2.48
Tianjin	3.19	2.39	Nanjing	2.95	2.37
Chongqing	2.50	1.89	Wuhan	3.01	2.28
Harbin	4.31	3.02	Hangzhou	2.80	2.19
Changchun	3.35	2.37	Hefei	2.85	2.38
Shenyang	2.93	2.20	Fuzhou	2.42	1.90
Hohhot	4.02	3.05	Nanchang	2.70	2.16
Shijiazhuang	3.23	2.53	Changsha	2.78	2.27
Taiyuan	3.07	2.38	Guiyang	2.69	2.15
Xi'an	3.43	2.83	Chengdu	3.43	2.60
Jinan	2.99	2.42	Guangzhou	2.08	1.69
Urumqi	4.15	3.53	Kunming	2.61	2.17
Lasa	2.31	1.64	Nanning	2.92	2.21
Xining	2.61	2.10	Haikou	2.57	1.91
Lanzhou	2.42	2.14			

Table 3 showed the largest recommended coefficient *K* value was in Harbin under strict conditions, with 4.31. The smallest recommended coefficient *K* value was in Guangzhou, with 2.08. The difference between them was 2.23. While the largest recommended coefficient value *K* was in Urumqi under normal conditions, with 3.53. The smallest recommended coefficient *K* value was in Lasa, with 1.64. The difference between them was 1.89. As a result, the recommended coefficient *K* of 31 provincial capital cities could not use the same. It is necessary to give the different recommended coefficient *K* under different economic regions division methods.

3.2. *K* by eight economic regions [12,19]

The recommended coefficient *K* by eight economic regions was shown in Fig. 1.

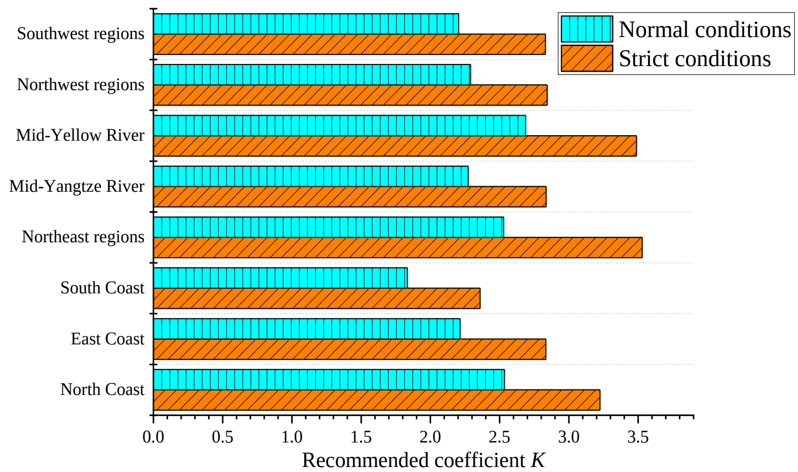

Fig. 1. The recommended coefficient *K* in eight economic regions

Figure 1. showed the largest value of the recommended coefficient *K* was in Northeast regions under strict conditions, with 3.53. While the smallest value of the recommended coefficient *K* was in South Coast, with 2.36. Value of the recommended coefficient *K* between the two was 1.17 under strict conditions. The values of the recommended coefficient *K* under strict conditions were shown:

Northeast regions>Mid-Yellow River>North Coast>Northwest regions>Mid-Yangtze River>East Coast>Southwest regions>South Coast. In addition, the largest value of the recommended coefficient *K* was in Mid-Yellow River under normal conditions, with 2.69. While the smallest value of the recommended coefficient *K* was in South Coast, with 1.83. Value of the recommended coefficient *K* between the two was 0.86 under normal conditions. The values of the recommended coefficient *K* under normal conditions were shown: Mid-Yellow River>North Coast>Northeast regions>Northwest regions>Mid-Yangtze River>East Coast>Southwest regions>South Coast. The largest difference between strict and normal conditions is in the Northeast regions, with 1.00, while the smallest difference is in the South Coast, with 0.52. The main reasons were that it was cold in winter in Northeast regions, and a large amounts of fossil fuel were needed for heating in winter [25], which would increase the energy consumption and result in a large outdoor concentration value.

3.3. *K* by three belts economic regions [12,20]

The recommended coefficient *K* by three belts economic regions was shown in Fig. 2.

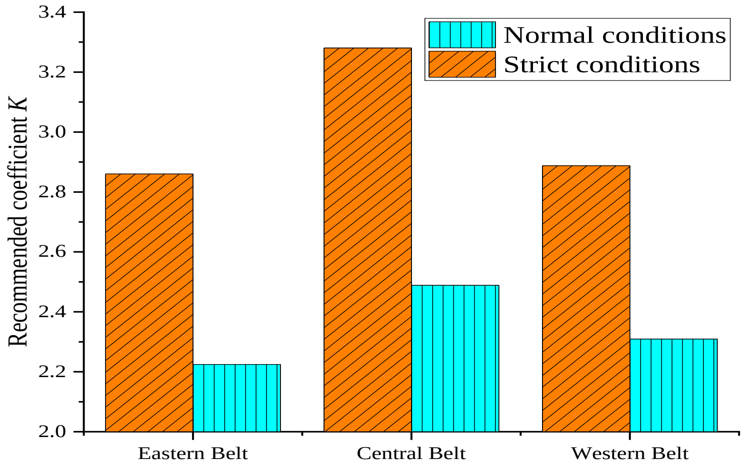

Fig. 2. The recommended coefficient *K* in three belts economic regions

Figure 2. showed the largest value of the recommended coefficient *K* was in Central Belt, it was 3.28 under strict conditions and 2.49 under normal conditions. While the smallest value of the recommended coefficient *K* was in Eastern Belt, it was 2.86 under strict conditions and 2.22 under normal conditions. The values of the recommended coefficient *K* under strict and normal conditions were all shown: Central Belt>Western Belt>Eastern Belt. The largest difference between strict and normal conditions is in Central Belt, with 0.79. This was because the economy was relatively backward and less using the new energy. In addition, the thought of protecting the environment was relatively weak at the same time. As a result, the recommended coefficient *K* is the highest, with more pollution [26]. The smallest difference is in Western Belt, with 0.58. The reason why the recommend coefficient *K* for the Western Belt is relatively small is due to the small population density.

3.4. *K* by four economic regions [21,22]

The recommended coefficient *K* by four economic regions was shown in Fig. 3.

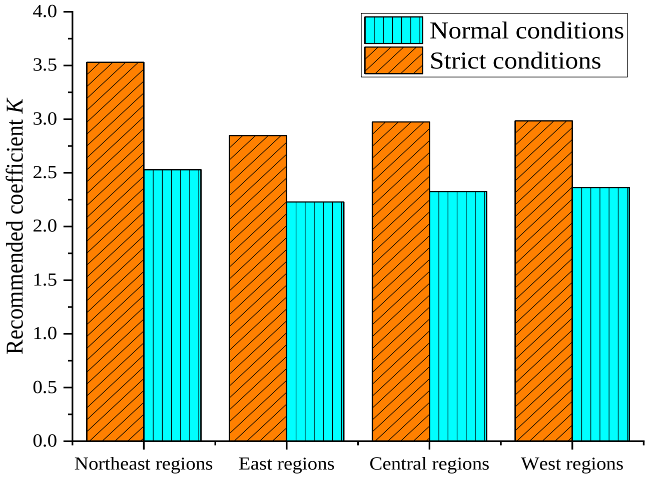

Fig. 3. The recommended coefficient *K* in four economic regions

Figure 3. showed the largest value of the recommended coefficient *K* was in Northeast regions, it was 3.53 under strict conditions and 2.53 under normal conditions. While the smallest value of the recommended coefficient *K* was in East regions, it was 2.85 under strict conditions and 2.23 under normal conditions. The values of the recommended coefficient *K* under strict and normal conditions were all shown: Northeast regions>West regions>Central regions>East regions. The largest difference between strict and normal conditions is in Northeast regions, with 1.00. This was because the winter in the Northeast regions is cold and the demand for coal and fossil fuels for heating is very high, with severe air pollution. Therefore, the recommended coefficient *K* is the highest. The smallest difference is in East regions, with 0.62.

3.5. *K* by four types of economic regions [23]

The recommended coefficient *K* by four types of economic regions was shown in Fig. 4.

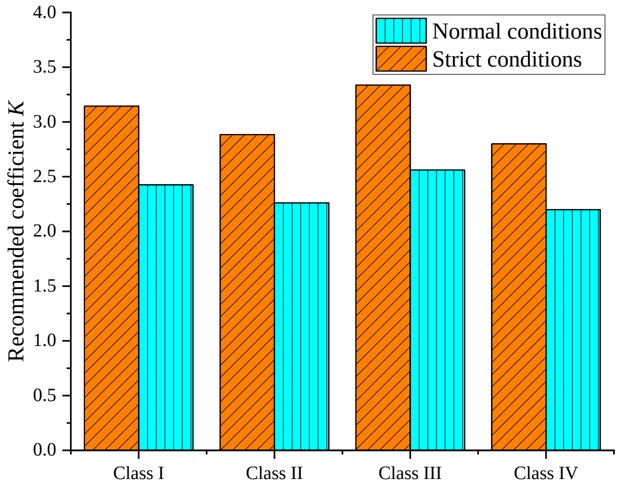

Fig. 4. The recommended coefficient *K* in four types of economic regions

Figure 4. showed the largest value of the recommended coefficient *K* was in Class III, it was 3.34 under strict conditions and 2.56 under normal conditions. While the smallest value of the recommended coefficient *K* was in Class IV, it was 2.80 under strict conditions and 2.20 under normal conditions. The values of the recommended coefficient *K* under strict and normal conditions were all shown: Class III>Class I>Class II>Class IV. The largest difference between strict and normal conditions is in Class III, with 0.78. The smallest difference is in Class IV, with 0.60.

3.6. *K* by six economic regions [12]

The recommended coefficient *K* by six economic regions was shown in Fig. 5.

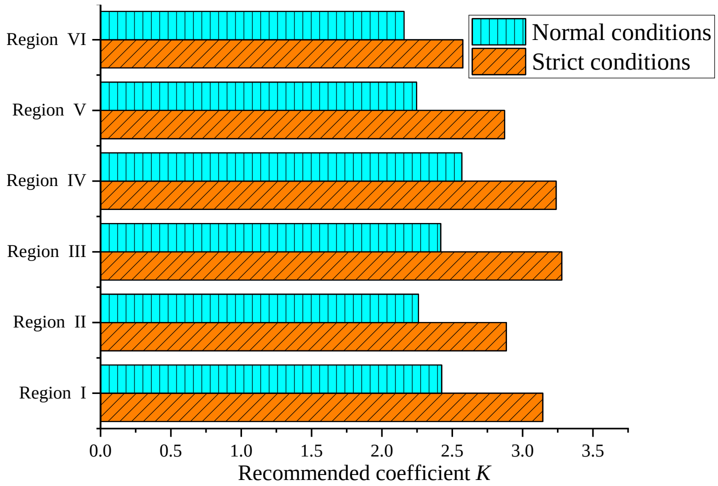

Fig. 5. The recommended coefficient *K* in six economic regions

Figure 5. showed the largest value of the recommended coefficient *K* was in Region III under strict conditions, with 3.28. While the smallest value of the recommended coefficient *K* was in Region VI, with 2.58. Value of the recommended coefficient *K* between the two was 0.70 under strict conditions. The values of the recommended coefficient *K* under strict conditions were shown: Region III>Region IV>Region I>Region II>Region V>Region VI. In addition, the largest value of the recommended coefficient *K* was in Region IV under normal conditions, with 2.57. While the smallest value of the recommended coefficient *K* was in Region VI, with 2.16. Value of the recommended coefficient *K* between the two was 0.41 under normal conditions. The values of the recommended coefficient *K* under normal conditions were shown: Region IV>Region I>Region III>Region II>Region V>Region VI.

3.7. Example of five typical cities

The recommended coefficient *K* for five cities is shown in Tab. 4 according to the different economic regions. K_1 is the recommended coefficient *K* under strict conditions, and K_2 is the recommended coefficient *K* under normal conditions.

Table 4. The recommended coefficient *K* for cities under different economic regions

Methods	Number	Beijing		Shenyang		Hefei		Xi'an		Urumqi	
		Strict	Normal	Strict	Normal	Strict	Normal	Strict	Normal	Strict	Normal
K of city	Firstly	3.49	2.79	2.93	2.20	2.85	2.38	3.43	2.83	4.15	3.53
K of eight economic regions	Secondly	3.22	2.53	3.53	2.53	2.84	2.27	3.49	2.69	2.84	2.29
K of three belts economic regions	Thirdly	2.86	2.22	2.86	2.22	3.28	2.49	2.89	2.31	2.89	2.31

K of four economic regions	Fourthly	2.85	2.23	3.53	2.53	2.97	2.33	2.98	2.36	2.98	2.36
K of four types of economic regions	Fifthly	3.14	2.42	2.88	2.26	2.80	2.20	3.34	2.56	3.34	2.56
K of six economic regions	Sixthly	3.14	2.42	2.88	2.26	2.87	2.25	3.24	2.57	3.24	2.57
Average	/	3.12	2.44	3.10	2.33	2.94	2.32	3.23	2.55	3.24	2.60

From the Tab. 4, the recommended coefficient *K* for six regions in Beijing under strict conditions was shown: Firstly>Secondly>Fifthly>Sixthly>Thirdly>Fourthly. While under normal conditions was shown: Firstly>Secondly>Fifthly>Sixthly>Fourthly>Thirdly. The recommended coefficient *K* for the Fifthly and Sixthly economic regions under strict and normal conditions are not significantly different from the average of the recommended coefficient *K* for six regions, with 0.02, 0.02 and 0.02, 0.02. The methods for dividing four types of economic regions and six economic regions are recommended.

The recommended coefficient *K* for six regions in Shenyang under strict conditions was shown: Secondly>Fourthly>Firstly>Fifthly>Sixthly>Thirdly. While under normal conditions was shown: Secondly>Fourthly>Fifthly>Sixthly>Thirdly>Firstly. The recommended coefficient *K* for the Fifthly and Sixthly economic regions under strict and normal conditions are not significantly different from the average of the recommended coefficient *K* for six regions, with 0.22, 0.07 and 0.22, 0.07. The methods for dividing four types of economic regions and six economic regions are also recommended.

The recommended coefficient *K* for six regions in Hefei under strict conditions was shown: Thirdly>Fourthly>Sixthly>Firstly>Secondly>Fifthly. While under normal conditions was shown: Thirdly>Firstly>Fourthly>Secondly>Sixthly>Fifthly. The recommended coefficient *K* for the Fourthly and Sixthly economic regions under strict and normal conditions are not significantly different from the average of the recommended coefficient *K* for six regions, with 0.03, 0.01 and 0.07, 0.07. The methods for dividing four economic regions and six economic regions are recommended.

The recommended coefficient *K* for six regions in Xi'an under strict conditions was shown: Secondly>Firstly>Fifthly>Sixthly>Fourthly>Thirdly. While under normal conditions was shown: Firstly>Secondly>Sixthly>Fifthly>Fourthly>Thirdly. The recommended coefficient *K* for the Fifthly and Sixthly economic regions under strict and normal conditions are not significantly different from the average of the recommended coefficient *K* for six regions, with 0.11, 0.01 and 0.01, 0.02. The methods for dividing four types of economic regions and six economic regions are also recommended.

The recommended coefficient *K* for six regions in Urumqi under strict conditions were shown: Firstly>Fifthly>Sixthly>Fourthly>Thirdly>Secondly. While under normal conditions was shown: Firstly>Sixthly>Fifthly>Fourthly>Thirdly>Secondly. The recommended coefficient *K* for the Fifthly and Sixthly economic regions under strict and normal conditions are not significantly different from the average of the recommended coefficient *K* for six regions, with 0.10, 0.04 and 0.00, 0.03. The methods for dividing four types of economic regions and six economic regions are also recommended.

The average recommended coefficient *K* of the five typical cities under strict conditions is 2.60, while under normal conditions is 2.04. The recommended coefficient *K* by the six economic regions methods based on per capita GDP is the best. The recommended coefficient *K* by the five typical cities under strict and normal conditions is not significantly different from the recommended coefficient *K* for the Sixthly economic regions, with 0.06, 0.04. This is because the per capita GDP represents the overall economic development level of the region [27]. The division results comprehensively consider the large, medium, and small cities, towns, and rural areas within the region, with higher consistency and practicality. As a result, the recommended coefficient *K* by six economic regions is the best.

3.8. Selection of fresh air filter

The existing fresh air filtration systems generally adopt a combination of secondary and tertiary filters through a preliminary investigation of the market in China. The filtration efficiency is calculated by using the following Formula (2) [5,28]:

$$\eta = \frac{C_W - C_S}{C_W} \times 100\% \quad (2)$$

Where: η is the filtration efficiency of the air filter, %. C_w is the outdoor design $PM_{2.5}$ concentration, μg/m^3. C_s is the indoor design $PM_{2.5}$ concentration, μg/m^3 (strict conditions, C_s=35 μg/m^3. normal conditions, C_s=75 μg/m^3 [29]).

For combined air filter, the efficiency could be calculated by Formula (3) [5,28]:

$$\eta = 1 - (1 - \eta_1)(1 - \eta_2) \cdots (1 - \eta_n) \quad (3)$$

Where: η is the filtration efficiency of the air filter in series, %. $\eta_1 - \eta_n$ are the efficiency of each level of air filter, %.

The outdoor design $PM_{2.5}$ concentrations of five typical cities are obtained according to the recommended six economic regions method. The results are carried into formulas (2) and (3) to calculate the selection results of air filters, as shown in Tab. 5.

Table 5. Results of Air filter selection.

Recommended coefficient *K*	Strict conditions		Normal conditions	
	Total efficiency/(%)	Combination of air filter	Total efficiency/(%)	Combination of air filter
Beijing	48.20	G4+F6(49.54%); G4+F8(79.02%); G4+H11(91.86%); G4+F5+F8(84.90%); G4+F5+H11(94.14%); G4+F6+F8(85.82%); G4+F6+H11(94.50%)	32.83	G4+F5(46.25%); G4+F6(49.54%); G4+F8(79.02%); G4+H11(91.86%); G4+F5+F8(84.90%); G4+F5+H11(94.14%); G4+F6+F8(85.82%); G4+F6+H11(94.50%)

Shenyang	39.23	G4+F5(46.25%); G4+F6(49.54%); G4+F8(79.02%); G4+H11(91.86%); G4+F5+F8(84.90%); G4+F5+H11(94.14%); G4+F6+F8(85.82%); G4+F6+H11(94.50%)	22.44	G4+F5(46.25%); G4+F6(49.54%); G4+F8(79.02%); G4+H11(91.86%); G4+F5+F8(84.90%); G4+F5+H11(94.14%); G4+F6+F8(85.82%); G4+F6+H11(94.50%)
Hefei	42.18	G4+F5(46.25%); G4+F6(49.54%); G4+F8(79.02%); G4+H11(91.86%); G4+F5+F8(84.90%); G4+F5+H11(94.14%); G4+F6+F8(85.82%); G4+F6+H11(94.50%)	26.08	G4+F5(46.25%); G4+F6(49.54%); G4+F8(79.02%); G4+H11(91.86%); G4+F5+F8(84.90%); G4+F5+H11(94.14%); G4+F6+F8(85.82%); G4+F6+H11(94.50%)
Xi'an	61.68	G4+F8(79.02%); G4+H11(91.86%); G4+F5+F8(84.90%); G4+F5+H11(94.14%); G4+F6+F8(85.82%); G4+F6+H11(94.50%)	51.68	G4+F8(79.02%); G4+H11(91.86%); G4+F5+F8(84.90%); G4+F5+H11(94.14%); G4+F6+F8(85.82%); G4+F6+H11(94.50%)
Urumqi	59.53	G4+F8(79.02%); G4+H11(91.86%); G4+F5+F8(84.90%); G4+F5+H11(94.14%); G4+F6+F8(85.82%); G4+F6+H11(94.50%)	48.96	G4+F6(49.54%); G4+F8(79.02%); G4+H11(91.86%); G4+F5+F8(84.90%); G4+F5+H11(94.14%); G4+F6+F8(85.82%); G4+F6+H11(94.50%)

4. Conclusion

In this paper, the outdoor design $PM_{2.5}$ concentration of each region by using the recommended coefficient *K* and the annual average value of $PM_{2.5}$ based on mathematical induction. The recommended coefficient *K* under six urban economic regions methods was compared and analyzed, and the following conclusions were initially drawn: The recommended coefficient *K* under the six economic regions could meet the required *K* value needs of the region. The average recommended coefficient *K* of the five typical cities under strict conditions is 2.60, while the average recommended coefficient *K* under normal conditions is 2.04. The recommended coefficient *K* by the six economic regions methods based on per capita GDP is the best. Under that conditions, the recommended coefficient *K* of the five typical cities under strict and normal conditions differs from the average *K* values of the six methods by 0.06 and 0.04. It is suggested to using the six economic regions methods based on per capita GDP to calculate the outdoor design $PM_{2.5}$ concentration of the fresh air filtration systems. This paper provides a new method and data reference value for the correct selection in the fresh air filtration system.

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