Research progress in association between indoor air environment and elderly cardiovascular diseases

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Abstract. The relationship between indoor air environment and elderly with cardiovascular diseases (CVD) was reviewed through literature research in this paper. In heat and humidity environment, studies have shown that changes in heat environment such as high temperature, cold and step-changes were highly associated with cardiovascular diseases in the elderly. The influence of air humidity on cardiovascular diseases was uncertain. In indoor air quality, PM10, PM2.5, CO, SO2, NO2 and ozone had correlation with cardiovascular diseases in the elderly, with the higher incidence and mortality resulting from higher concentrations of pollutants. It is significant to establish the relationship between indoor air environment and elderly cardiovascular diseases in different climatic zones. The multi-parameter joint action of indoor air environment and comprehensive characterization and evaluation method will be the future research orientation. In addition, the combined field of medicine and engineering may provide more research ideas for environmental and health issues in the future.

1. Introduction
In China, the policy “Healthy China 2030” points out that health is the necessary requirement for promoting the overall development of people and the basic conditions for economic and social development [1]. As an important index component of the “Healthy China”, the building bears the corresponding responsibility. Nowadays, the proportion of the elderly over 65 years old in China accounts for more than 10% [2] of the total population.

As the problem of population aging in China is becoming more and more serious [3]–[5], China has become one of the fastest aging countries in the world. Modern people spend more than 80% time indoors [6], especially longer for elderly people. It is of great significance to study the correlation between the health problems of the elderly and the indoor environment.

According to survey of human diseases via the World Health Organization (WHO) (Figure 1), cardiovascular diseases (CVD) had become the main cause of death in elderly people. Studies showed that nearly half of the elderly die from [7] cardiovascular diseases. In China, the deaths caused by cardiovascular diseases was about 2.6 million each year and the mortality rate of cardiovascular diseases ranked first. The mortality rate of cardiovascular diseases in rural and urban areas both had reached over 40% in China [8]. It was common to cardiovascular diseases in the elderly, which was a group of diseases of the circulatory system including heart, blood vessel and so on. Cardiovascular diseases generally resulted from hyperlipidemia, atherosclerosis, hypertension, blood viscosity, and other reasons. The main symptoms of cardiovascular diseases were hypertension, coronary heart disease, myocardial infarction, heart failure, stroke and so on [9]–[11].
In the world, due to the different speed of economic development among countries, and the difference of living standard, lifestyle, eating habits and cultural background, the incidence and mortality of cardiovascular diseases were also different. In the 1960s, JW Brant [12] started to study the relationship between air pollution and cardiovascular diseases. Recently, more and more scholars paid their attention on the association between the atmospheric environment and the incidence or mortality of cardiovascular diseases. The quantified indexes of cardiovascular diseases often used incidence and mortality and the quantified indexes of indoor air environment often used temperature and humidity, air pollutant concentration and other environmental parameters. The researches of these two kinds of parameters can establish the association between the environment and cardiovascular diseases.

In the 1980s, Yoshino Hiroshi [13] began to study the impact of the indoor environment on the elderly stroke, and the research on the relationship between the indoor air environment and the health of the elderly has also drawn the attention of other scholars. Studies had shown that the indoor air environmental factors affecting the elderly cardiovascular diseases mainly include indoor thermal and humid environment [14]–[16] and air quality [17]–[20]. The thermal and humid environment included temperature, humidity, and air quality mainly included PM_{10}, PM_{2.5} and CO, SO_{2}, NO_{2}, ozone and other pollutants, we will be based on the above factors to analyze the elderly cardiovascular diseases.

2. Effect of thermal and humid environment on CVD

Research on literatue, temperature and relative humidity were the important factors affecting the incidence of cardiovascular diseases. Under the environment of high temperature, low temperature or temperature step-changes, cardiovascular diseases of elderly people were in a state of vulnerability. Relative humidity on the impact of cardiovascular diseases showed uncertain results.

2.1. Effect of temperature on CVD

The research on the association between high temperature and cardiovascular diseases was extensive, but mainly concentrated in the field of epidemiology. The research methods mainly included time series method, case-crossover study and meta-analysis. In 2005, Patz J.A. et al. [21] analyzed data from around the world and concluded that after the temperature was higher than the limit, the mortality rate of cardiovascular diseases rose with increasing temperature and there was a steep change at a higher temperature. In 2012, the meta-analysis study of Mengersen K. et al. [22] showed that every 1 °C increase in temperature during high temperatures, the risk of death resulting from cardiovascular diseases among the elderly increased by 2% to 5%. Chinese scholars also had similar conclusions on the impact of summer hot weather on the death of cardiovascular diseases. Zhang Xia [23] and Zheng Shan [24] pointed out that heat waves led to an increase in the incidence, mortality and hospitalization of cardiovascular diseases, especially for people over 65 years old. Cheng et al. [25] and Zeng et al. [26] found that the number of deaths from cardiovascular diseases increased significantly when the maximum daily temperature was 36 °C. Each rise of 1 °C increased the risk of death caused by cardiovascular among the elderly by 4.3%.
Similar to the atmospheric environment, Anderson et al. [15] believed that there was the most direct correlation between indoor thermal environment and health outcomes and posed health risk to susceptible people like the elderly, when the indoor temperature exceeds a certain threshold. Hwang et al. [27] found that elderly people were in an uncomfortable state when their indoor temperature was higher than 27.1 °C in summer. Wu Jing [28] pointed out that the test subjects maintained a stable blood pressure with the indoor temperature ranged 18 °C to 20 °C. When the temperature rose, the thermal activity of the central hub of test subjects led to vasodilation of blood vessels. Liu et al. [29] conducted an investigation and analysis of the thermal comfort of the elderly in Chongqing and found that when the indoor temperature was higher than 27.78 °C, they were in an uncomfortable state. Therefore, when the indoor air appeared high temperature for elderly people whose arterial wall elasticity had declined, vasodilation of blood vessels easily lead to rupture of the vessel wall to trigger thrombosis, causing cardiovascular diseases [30].

The cold environment also has an impact on the incidence and mortality of cardiovascular diseases in the elderly. The studies of Yoshino Hiroshi et al. [14], [31], [32] had shown that in the cold area of winter, promoting the indoor temperature could reduce stroke mortality, the mean indoor temperature in case group (elderly people died of stroke) was 1.3 °C lower than that in control group (healthy elderly people with other environmental factors similar to the case group), and the elderly people in the room with a higher temperature appeared a relatively healthy state. In 2015, Yoshino Hiroshi [33] continued to investigate the study and found that the conclusion was basically consistent with the results of research 30 years ago. The study also found that the temperature of the period without heating was 5 - 20 °C lower than the period with heating in the same room. After stopping heating, elderly people’s blood pressure was higher than the blood pressure during heating, which was likely to cause cardiovascular diseases like hypertension. Saeki et al. [34], [35] pointed out that cold can trigger raising blood pressure, leading to the development of cardiovascular diseases, and heating can improve the situation. For the elderly, nocturnal blood pressure was positively correlated with bed temperature and weakly correlated with outdoor temperature.

**Table 1. Climatic Regions in China**

| Partition                        | Mean temperature in the coldest month [36] | Mean temperature designed in center heating [37] |
|---------------------------------|--------------------------------------------|--------------------------------------------------|
| Severe cold area                | -10 °C                                     | 18 °C                                             |
| Cold area                       | -10 - 0 °C                                 | 18 °C                                             |
| Hot-summer and cold-winter zone | 0 - 10 °C                                  | N/A                                               |
| Hot-summer and warm-winter area | 10 °C                                      | N/A                                               |
| Temperate zone                  | 0 - 13 °C                                  | N/A                                               |

Due to the vast territory of China, the area in different climates varies greatly in the indoor and outdoor environment in winter. As shown in Table 1, in northern China (severe cold and cold areas), central heating was used in winter, causing the large temperature difference between indoor and outdoor. According to Xiong’s study [38], a large step-change temperature, such as exposure from 20 °C to 0 °C or 20 °C to -10 °C, can easily cause physical discomfort, especially the skin temperature decreases with the decrease of ambient temperature. Then, the skin temperature will cause vasoconstriction of blood vessels [28], so that cardiovascular diseases can easily occur. In southern China (hot-summer and cold-winter zone, hot-summer and warm-winter area and temperate zone), there is a high correlation between indoor and outdoor temperatures due to lack of central heating in winter. The survey on the living environment of elderly people in Shanghai of Yao Xinling [39] found that the utilization rate of winter air conditioners in the room was only 10.2%, which made the occurrence of cold weather have a greater impact on indoor temperature. Therefore, the risk of cardiovascular diseases would rise. In winter in China, the impact of the outdoor thermal environment on elderly cardiovascular diseases was dependent on the relationship...
between indoor and outdoor thermal environment in which elderly people live. At the same time, large step-change temperature and cold environment can easily lead to cardiovascular disease for the elderly.

2.2. Effect of relative humidity on CVD
In the study of the effect of air relative humidity on cardiovascular diseases, Joel Schwartz et al. used time series to study 12 cities in the United States [16], [40], which showed no obvious correlation between relative humidity and cardiovascular diseases. Pan et al. [41] also used the time series to study the number of cardiovascular diseases in Beijing, which also found no significant association between the relative humidity and the incidence of cardiovascular diseases. Cui et al. [42] concluded that the relative humidity and incidence of cardiovascular disease in Beijing were positively correlated via case-crossover study. Wang [43] and Dong et al. [44] found that in Shandong and Guangzhou relative humidity and incidence of cardiovascular disease were both negatively correlated. In addition, Guo et al. [45] found that the relative humidity below 60% prone to occurring cardiovascular diseases, while Meng [46] pointed out that the optimal value of relative humidity ranging from 55% to 60%, exceeding which will lead to increase in the incidence of cardiovascular diseases in Lanzhou.

All in all, we can see different conclusions about the relationship between relative humidity and cardiovascular diseases in different regions or regions. The relative humidity had an uncertain association with the impact of cardiovascular diseases.

3. Effect of air quality on CVD

3.1. Effects of particulate matter on CVD
The particulate matter of air pollutants on cardiovascular diseases was most widely studied. Numerous studies had shown that increased risk of cardiovascular diseases in the elderly was associated with increase of atmospheric particulate matter [18], [20], [47]. Not only outdoor rise of particulate matter, indoor rise of particulate matter also increased the risk of cardiovascular diseases in the elderly. Weinhold et al. [48] in 2011 found that indoor chronic particulate exposure was positively correlated with hypertension, and PM$_{2.5}$ in indoor air increased blood pressure. In 2012, Allen Ryan et al. [49] found that PM$_{2.5}$ in indoor air aggravated atherosclerosis. In 2014, Acevedo et al. [50] found that the effect of second hand smoking (SHS) on cardiovascular diseases resulted from PM$_{2.5}$. Soppa et al. [51] in 2017 found that indoor particulate intake will increase blood pressure via randomized cross-control study.

Indoor pollution caused by indoor combustion, smoking, cooking and other activities had led to the indoor staff showing signs of cardiovascular diseases such as increased blood pressure and increased atherosclerosis [48], [50], [51]. Wang [52] measured the PM$_{2.5}$ in the dwellings of elderly with cardiovascular diseases in Beijing and found that 62% exceeded the standard, and indoor pollution should not be ignored. The main sources of indoor particulate matter were outdoor atmospheric particulates and various types of indoor combustion, cooking, people, pets and other activities. Outdoor pollutants entered inside buildings mainly through ventilation and infiltration [53]. Zhao et al. [54] in Beijing found that outdoor PM$_{2.5}$ contribution rate of indoor PM$_{2.5}$ reached 54% - 96%. Outdoor air pollution, combined with indoor combustion, cooking and other sources of particulate matter, would make the indoor pollution of particulate matter on elderly cardiovascular diseases more serious than the atmospheric environment. Currently, in the study of parameter representation of cardiovascular diseases, epidemiology was often characterized by incidence and mortality of diseases, which was very difficult to reflect the human health when studying mechanism of cardiovascular diseases of health damage effect on indoor air environment. In the medical diagnosis, the diagnosis of cardiovascular need to be judged according to a variety of blood test indicators, so scholars had used blood test parameters in the study of particulate matter and cardiovascular diseases. For instance, Chuang et al. [55] established the relationship of indoor PM$_{2.5}$ and cardiovascular disease through the survey blood test parameters C-reactive protein. In addition, blood test parameters such as total cholesterol, triglycerides, high-density lipoprotein cholesterol, and low-density lipoprotein cholesterol [56] also reflect the severity of cardiovascular diseases (Table 2). It will be possible
to combine the medical science and engineering via the parameters above to more deeply study association of indoor air and cardiovascular diseases.

### Table 2. Blood Test Parameters of CVD [56]

| Parameters                                      | Normal range                                                                 | Abnormal symptoms                                                                 |
|------------------------------------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Total cholesterol                               | Adult: 110 - 230 mg/dL, Children: 120 - 200 mg/dL                            | Increase: hyperlipidemia, atherosclerosis, diabetes, hypertension                  |
| Triglyceride (TG)                               | Adult: < 150 mg/dL, Children: < 100 mg/dL                                    | Increase: hyperlipidemia                                                          |
| High density lipoprotein cholesterol (HDL-c)    | Male: 1.16 - 1.42 mmol/L, Female: 1.29 - 1.55 mmol/L                         | Decrease: cerebrovascular disease, coronary heart disease, hypertriglyceridemia    |
| Low density lipoprotein cholesterol (LDL-c)     | Youth mean: 2.7 mmol/L, Middle-aged and elderly people mean: 3.37 mmol/L, More than 4.14 mmol/L was significantly. | Increase: coronary atherosclerotic heart disease (coronary heart disease), hyperlipoproteinemia, diabetes. |

#### 3.2. Effects of other air pollutants on CVD

The air pollutants of NO\textsubscript{2}, and SO\textsubscript{2} were harmful to human health. More and more studies have shown that SO\textsubscript{2} and NO\textsubscript{2} can be used as inducers or risk factors of cardiovascular diseases. Joel Schwartz et al. [18, 20] reported that there was the correlation between NO\textsubscript{2} and hospital admission rate of cardiovascular diseases in the elderly. Each increase of NO\textsubscript{2} by 5.1 ppb would increase heart failure by 6.9%. Meanwhile, the study pointed out that SO\textsubscript{2} was only associated with leukocyte, and NO\textsubscript{2} was associated with platelets and fibrinogen. These reasons might be the pathogenesis of cardiovascular diseases. Not only combustion of indoor kitchen cooking but also the body’s metabolism would both produce SO\textsubscript{2} and NO\textsubscript{2} [57]. Yoshino [58] believed that it was unhealthy for people indoors to use oil-fired stoves for heating because of the combustion. Mitter et al. [59] also believed that there was a positive correlation between the risk of indoor fossil fuel combustion and the mortality rate of cardiovascular diseases. Pan et al. [60] analyzed the air pollution in Beijing and the death of residents with cardiovascular diseases, then he found that the relationship between air pollutants and the death of cardiovascular diseases was statistically significant. Each increase of SO\textsubscript{2} and NO\textsubscript{2} by 10 g/m\textsuperscript{3} would increase the risk of cardiovascular disease death by 0.4% and 1.3%, respectively.

CO was also a major causative agent of cardiovascular diseases [57]. Tsai et al. [61] found that CO has a 2-day lag effect on cardiovascular diseases. In the study of CO on the impact of cardiovascular diseases, Joel Schwartz et al. [40] found that CO had a consistently damage effect on ischemic heart disease, myocardial infarction and heart failure. Zhang et al. [62] conducted a study on the association of cardiovascular disease and CO in elderly people in Taiyuan. The results showed that the increase of average death rate of cardiovascular diseases by 100 g/m\textsuperscript{3} resulted to the OR value by 1.006.

In addition, studies recently had shown that ozone on cardiovascular diseases also had an impact. In 2015, Gu [63] studied the combined effects of PM\textsubscript{10}, NO\textsubscript{2} and ozone to enhance the mortality of cardiovascular diseases through the study of cross-control model. In 2016, Bedada et al. [64] concluded that ozone increased the risk of myocardial infarction via the generalized additive model. In 2017, Zhang et al. [65] concluded that ozone increased the risk of cardiovascular diseases and expounds the mechanism of action by conducting tests on human body physiological indices.

All in all, PM\textsubscript{10}, PM\textsubscript{2.5} and NO\textsubscript{2}, SO\textsubscript{2}, CO and ozone were all reflected that the higher concentration, the greater risk of cardiovascular diseases occurred. In addition, there were many sources of indoor air
pollutants, and a variety of pollutants would have a combined effect, which also would make the model of association of indoor air quality and elderly cardiovascular diseases more complicated and challenging.

4. Conclusions

Studies have shown that in the indoor thermal and humid environment, high temperature, cold and large temperature step-changes on the elderly cardiovascular diseases were related, specifically over the high temperature threshold, reflecting the higher the temperature, the more risk of cardiovascular diseases. When in the cold and large temperature step-changes environment, the incidence of cardiovascular diseases would rise. Relative humidity on the impact of cardiovascular diseases was still uncertain. In the indoor air quality, there is a certain correlation between PM$_{10}$, PM$_{2.5}$, and CO, SO$_2$, NO$_2$ and ozone and elderly cardiovascular diseases, reflecting the higher concentration, the higher incidence of cardiovascular diseases.

We believed that in the study of indoor thermal and humidity environment and elderly cardiovascular disease, we must fully consider the seasonal and regional impact on the study results. The extreme weather in summer and winter and the difference between north and south in our country both affected the research results of the correlation between indoor thermal and humid environment and the elderly with cardiovascular diseases. Therefore, it was of great significance to establish the different correlation between indoor environment and elderly cardiovascular diseases in different climates. In the indoor air quality, the combined effect of various pollutants on elderly cardiovascular diseases research were more meaningful. The comprehensive indoor thermal environment and air quality characterization and evaluation methods would become the future research trends.

In this research field, we should actively promote the combination of medicine science and engineering. Changes in environmental parameters provided a reference for medical diagnosis, and pathogenic mechanism of research provided more support for the indoor environment and health problems. In addition, genetic, diet and other factors in the field of research of association of indoor air environment and elderly cardiovascular diseases should also be emphasized.

5. References

[1] “Healthy China 2030” Outline, Central Committee of the Communist Party of China and State Council of the People’s Republic of China, 2016.

[2] National Bureau of Statistics of China, China Statistical Yearbook 2017. Beijing, China: China Statistics Press, 2017.

[3] M. Chen and G. Hao, “Research on Regional Difference Decomposition and Influence Factors of Population Aging in China,” China Population, Resources and Environment, vol. 24, pp. 136-141, 2014. (In Chinese with English abstract)

[4] H. Wang, S. Zhao, E. Zeng, C. Ma, J. Wang and L. Duan, “The Social Development and the Coping Strategies for China’s Aging Population,” Chinese Journal of Social Medicine, vol. 31, pp. 75-77, April 2014. (In Chinese with English abstract)

[5] L. He and W. Shi, “Quantitative analysis of population aging on mortality disparities for major non-communicable diseases in China,” Chin J Dis Control Prev, vol. 20, pp. 121-124, 2016. (In Chinese with English abstract)

[6] N. E. Klepeis, W. C. Nelson, W. R. Ott, J. P. Robinson, A. M. Tsang, P. Switzer, et al., “The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants,” Journal of Exposure Analysis & Environmental Epidemiology, vol. 11, pp. 231, 2001.

[7] World Health Organization (WHO), “World health statistics 2016: Monitoring health for the SDGs Sustainable Development Goals,” Geneva Switzerland WHO, vol. 41, pp. 293-328, 2016.

[8] S. Hu, Report on Cardiovascular Diseases in China 2016. Beijing, China: Encyclopedia of China Publishing House, 2016. (In Chinese)
[9] M. Rao, *Guidelines for Prevention and Treatment of Cerebrovascular Diseases in China*. Beijing, China: People’s Medical Publishing House, 2007. (In Chinese)

[10] China High Blood Pressure Prevention Guidelines Revision Committee, “Guidelines for the Prevention and Treatment of Hypertension in China 2010,” *Chinese Journal of Cardiovascular Disease*, vol. 39, pp. 701-708, 2011. (In Chinese)

[11] Chinese Society of Cardiology and Editorial Board of Chinese Journal of Cardiovascular Diseases. “Guidelines for Chinese Cardiovascular Disease Prevention,” *Chinese Journal of Cardiovascular Disease*, vol. 39, pp. 263-279, 2011. (In Chinese)

[12] J. W. Brant and S. R. Hill, “Human Cardiovascular Diseases and Atmospheric air pollution in Los Angeles, California,” *Air & Water Pollution*, vol. 8, pp. 259, 1964.

[13] F. Hasegawa, H. Yoshino, S. I. Akabayashi, “Investigation on Indoor Thermal Environment of Detached Wooden Houses in City Areas of Tohoku District in Winter,” *Transactions of the Architectural Institute of Japan*, vol. 326, pp. 91-102, 1983.

[14] F. Hasegawa, “A survey study on the room temperature in winter in various houses in the Tohoku district,” *Report of the Architectural Institute of Japan*, pp. 18-26, 2011. (In Japanese)

[15] M. Anderson, C. Carmichael, V. Murray, A. Dengel and M. Swainson, “Defining indoor heat thresholds for health in the UK,” *Perspectives in Public Health*, vol. 133, pp. 158-164, 2013.

[16] J. Schwartz and J. A. Patz, “Hospital Admissions for Heart Disease: The Effects of Temperature and Humidity,” *Epidemiology*, vol. 15, pp. 755, 2004.

[17] J. Cho, Y. J. Choi, M. Suh, J. Sohn, H. Kim, S. Cho, et al., “Air pollution as a risk factor for depressive episode in patients with cardiovascular disease, diabetes mellitus, or asthma,” *Journal of Affective Disorders*, vol. 157, pp. 45, 2014.

[18] J. Schwartz, “Air pollution and blood markers of cardiovascular risk,” *Environmental Health Perspectives*, vol. 109, pp. 405, 2001.

[19] J. Shi, D. Yuan and Z. Zhao, “Residential indoor PM2.5 sources, concentration and influencing factors in China,” *J Environ Health*, vol. 32, pp. 825-829, Sep. 2015. (In Chinese with English abstract)

[20] A. G. Barnett, G. M. Williams, J. Schwartz, T. L. Best, A. H. Neller, A. L. Petroeschovsky, et al., “The Effects of Air Pollution on Hospitalizations for Cardiovascular Disease in Elderly People in Australian and New Zealand Cities,” *Environmental Health Perspectives*, vol. 114, pp. 1018-1023, 2006.

[21] J. A. Patz, D. Campbellendrum, T. Holloway and J. A. Foley, “Impact of regional climate change on human health,” *Nature*, vol. 438, pp. 310, 2005.

[22] W. Yu, K. Mengersen, X. Wang, X. Ye, Y. Guo, X. Pan, et al, “Daily average temperature and mortality among the elderly: a meta-analysis and systematic review of epidemiological evidence,” *International Journal of Biometeorology*, vol. 56, pp. 569-581, 2012.

[23] X. Zhang and Q. Liu, “Research Progress of the Effect of High Temperature and Heat Wave on Cardiovascular and Cerebrovascular Diseases,” *Chin J Public Health*, vol. 30, pp. 242-243, Feb. 2014. (In Chinese)

[24] S. Zheng, M. Wang, K. Shang, S. He, L. Yin, T. Li, et al., “A case-crossover analysis of heat wave and hospital emergency department visits for cardiovascular diseases in 3 hospitals in Beijing,” *Journal of hygiene Research*, vol. 45, pp. 246-251, 2016. (In Chinese with English abstract)

[25] Y. Cheng, Y. Jin, Y. Li, J. Gong, N. Yang, M. Wang, et al., “Impacts of High Temperature on Death Caused by Cerebrocardiovascular Diseases in Wuhan,” *J Environ Health*, vol. 26, pp. 224-225, March 2009. (In Chinese with English abstract)

[26] W. Zeng, W. Ma, Y. Zhang, T. Liu, Y. Luo, J. Xiao, et al., “Moiflcation Effect of Latitude on Relationship between High Temperature and Mortality Risk among Elderly: a Mete-Analisis,” *J Environ Health*, vol. 29, pp. 639-642, July 2012.
[27] R. L. Hwang and C. P. Chen, “Field study on behaviors and adaptation of elderly people and their thermal comfort requirements in residential environments,” *Indoor Air*, vol. 20, pp. 235-245, 2010.

[28] J. Wu, “Research papers on the relationship between indoor air velocity and human comfort and physiological stress,” M.S. thesis, Chinese, Chongqing Univ., Chongqing, China, 2005.

[29] H. Liu, Y. Wu, H. Zhang and X. Du, “Field study on elderly people’s adaptive thermal comfort evaluation in naturally ventilated residential buildings in summer,” *HV&AC*, vol. 45, pp. 50-58, 2015. (In Chinese with English abstract)

[30] J. Chen, “A new trend of prevention and treatment of atherosclerosis,” *Chinese Circulation Journal*, vol. 16, pp. 163, 2001. (In Chinese)

[31] H. Yoshino, M. Momiyama, T. Sato and K. Sasaki, “Study of Cerebrovascular Disease and the Indoor Thermal Environment in Two Selected Towns in Miyagi Prefecture, Japan,” Ethnic Hgiene, vol. 55, pp. 294-305, 1989. (In Japanese with English abstract)

[32] H. Yoshino, M. Momiyama, T. Sato and K. Sasaki, “Relationship between cerebrovascular disease and indoor thermal environment in two selected towns in Miyagi Prefecture, Japan,” *Journal of Thermal Biology*, vol. 18, pp. 481-86, 1993.

[33] K. Hasegawa, H. Yoshino and T. Goto, “Study on association between indoor environment factors and cerebral vascular accident - Influence of indoor temperature on the blood pressure fluctuation of elderly persons,” presented at the JSSI & JSSE Joint Conference, Matsumoto, Japan, Sep. 13-16, 2015. (In Japanese)

[34] K. Saeki, K. Obayashi, J. Iwamoto, N. Tone, N. Okamoto, K. Tomioka, et al., “Stronger association of indoor temperature than outdoor temperature with blood pressure in colder months,” *Journal of Hypertension*, vol. 32, pp. 1582, 2014.

[35] K. Saeki, K. Obayashi and N. Kurumatani, “Short-term effects of instruction in home heating on indoor temperature and blood pressure in elderly people: a randomized controlled trial,” *Journal of Hypertension*, vol. 33, pp. 2338-2343, 2015.

[36] Code for thermal design of civil buildings, Chinese Standard GB50176-2016.

[37] Y. Lu, *Practical Handbook of heating and air conditioning design*, 3rd ed. Beijing, China: China Building Industry Press, 2008.

[38] J. Xiong, Z. Lian and H. Zhang, “Effects of exposure to winter temperature step-changes on human subjective perceptions,” *Building & Environment*, vol. 107, pp. 226-234, 2016.

[39] X. Yao, “Investigation and analysis of indoor thermal environment in welfare centers for the aged in Shanghai,” *HV&AC*, vol. 41, pp. 66-70, 2011. (In Chinese with English abstract)

[40] A. L. F. Braga, A. Zanobetti and J. Schwartz, “The effect of weather on respiratory and cardiovascular deaths in 12 U.S. cities,” *Environmental Health Perspectives*, vol. 110, pp. 859, 2002.

[41] L. Liu, X. Pan, Y. Zheng, H. E. Wichmann and U. Franck, “Relationship between Temperature, Relative Humidity and Wind Speed and Cardio-cerebral Diseases Hospital Emergency Room Visit Number in a Certain District of Beijing: a Time-Series Analysis,” *J Environ Health*, vol. 25, pp. 578-82, July, 2008. (In Chinese with English abstract)

[42] M. Cui, L. Yu, J. Zhang D. Zhang and X. Wang, “Association between meteorological factors and the incidence of acute cardiovascular disease,” *Chin J Emerg Med*, vol. 23, pp. 465-469, April 2014. (In Chinese with English abstract)

[43] S. Wang, D. Liu and X. Gao, “Study on the relation between blood pressure and weather factor in patients with essential hypertension,” Chin J Clinicians (Electronic Edition), vol. 5, pp. 1570-1574, March 2011. (In Chinese with English abstract)

[44] H. Dong, X. Li, H. Liu, G. Lin, Yan Li and K. Li, “Time series study on the association of daily meteorological factors with mortality of cardiovascular disease in Guangzhou from 2012 to 2013,” *Journal of Tropical Diseases and Parasitology*, vol. 14, pp. 155-159, 2016. (In Chinese with English abstract)
[45] D. Guo, X. Wang and R. Wang, “Relationship between the occurrence of acute myocardial infarction and meteorological factors,” Chinese Journal of Integrative Medicine on Cardio/Cerebrovascular Disease, vol. 9, pp. 1423-1424, 2011. (In Chinese)

[46] J. Meng, “Meteorological factors in three cities of Gansu Province and residents of cardiovascular system disease day admission number of time series,” M.S. thesis, Chinese, Lanzhou Univ., Gansu, China, 2013.

[47] J. Wu, L. Zhou, B. Xu, Q. Wang, Z. Ding, X. Chen, et al., “Air particular matter pollution and cardio-cerebrovascular diseases death: a case-crossover study,” J Environ Health, vol. 31, pp. 569-571, 2014. (In Chinese with English abstract)

[48] B. Weinhold, “Indoor PM pollution and elevated blood pressure: cardiovascular impact of indoor biomass burning,” Environmental Health Perspectives, vol. 119, pp. A442, 2011.

[49] R. W. Allen, S. D. Adar, E. Avol, M. Cohen, C. L. Curl, T. Larson, et al., “Modeling the Residential Infiltration of Outdoor PM2.5 in the Multi-Ethnic Study of Atherosclerosis and Air Pollution (MESA Air),” Environmental Health Perspectives, vol. 120, pp. 824-830, 2012.

[50] V. Acevedo-Bolton, W. R. Ott, K. C. Cheng, R. T. Jiang, N. E. Klepeis and L. M. Hildemann, “Controlled experiments measuring personal exposure to PM2.5 in close proximity to cigarette smoking,” Indoor Air, vol. 24, pp. 199, 2014.

[51] V. J. Soppa, R. P. F. Schins, F. Hennig, M. J. Nieuwenhuijsen, B. Hellack, U. Quass, et al., “Arterial blood pressure responses to short-term exposure to fine and ultrafine particles from indoor sources - A randomized sham-controlled exposure study of healthy volunteers,” Environmental Research, vol. 158, pp.225-232, 2017.

[52] Y. Wang, W. Huang, T. Wang, Y. Chen, Y. Su and L. Zhang, “Characterization and assessment of exposure to PM2.5 and CO for a cardiovascular elderly panel in summer in Beijing,” China Environmental Science, vol. 29, pp. 1005-1008, 2009. (In Chinese with English abstract)

[53] S. Chai, “Air conditioning and non-air-conditioned room with the concentration of particulate matter changes,” M.S. thesis, Chinese, Donghua Univ., Shanghai, China, 2006.

[54] W. Ji and B. Zhao, “Contribution of outdoor-originating particles, indoor-emitted particles and indoor secondary organic aerosol (SOA) to residential indoor PM2.5 concentration: A model-based estimation,” Building & Environment, vol. 90, pp. 196-205, 2015.

[55] H. C. Chang, K. F. Ho, L. Y. Lin, T. Y. Chang, G. B. Hong, C. M. Ma, et al., “Long-term indoor air conditioner filtration and cardiovascular health: A randomized crossover intervention study,” Environment International, vol. 106, pp. 91-96, 2017.

[56] Y. Jiang and L. Yu, Pathology and pathophysiology, Beijing, China: Peking Union Medical College Press, 2012.

[57] Y. Zhu, Building Environmental Science, Beijing, China: China Building Industry Press, 2010.

[58] K. Hasegawa, “Investigation and study on the relationship between the stroke and the living environment and the relationship between Yamagata prefectures and Japan,” Japanese Journal of Public Health, vol. 32, pp. 181-193, 1985. (In Japanese)

[59] X. Gao, Z. Bai, Y. You, J. Miao and B. Liu, “Investigation of Human Exposure Levels of Volatile Organic Compounds and Effects on Health,” J Environ Health, vol. 23, pp. 300-303, 2006. (In Chinese with English abstract)

[60] M. Yang and X. Pan, “Time-series Analysis of Air Pollution and Cardiovascular Mortality in Beijing, China,” J Environ Health, vol. 25, pp. 294-297, 2008. (In Chinese with English abstract)

[61] D. H. Tsai, J. L. Wang, K. J. Chuang and C. C. Chan, “Traffic-related air pollution and cardiovascular mortality in central Taiwan,” Science of the Total Environment, vol. 408, pp. 1818-1823, 2010.

[62] X. Zhang, Z. Zhang, B. Su, B. Feng and H. Li, “Acute Effects of Ambient Air CO Pollution on Cerebrocardiovascular Diseases Mortality in People Aged 65 Years and over in Taiyuan City,” J Environ Health, vol. 25, pp. 672-675, 2008. (In Chinese with English abstract)
[63] Y. Gu, “Study on the Interaction between PM10, NO2 and O3 Pollution on the Mortality Risk in Guangzhou,” M.S. thesis, Chinese, Jinan Univ., Guangdong, China, 2015.

[64] G. B. Bedada, A. Raza, B. Forsberg, T. Lind, P. Ljungman, G. Pershagen, et al., “Short-term Exposure to Ozone and Mortality in Subjects With and Without Previous Cardiovascular Disease,” Epidemiology, vol. 27, pp. 663, 2016.

[65] D. B. Day, J. Xiang, J. Mo, F. Li, M. Chung, J. Gong, et al., “Association of Ozone Exposure With Cardiorespiratory Pathophysiologic Mechanisms in Healthy Adults” Jama Internal Medicine, vol. 177, pp. 1344-1353, 2017.

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