

# An Analytical Study of the Key Physical Factors that Affect the Health Status of the Home Isolated Residents under COVID-19

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**Abstract.** The indoor living environment has an important impact on human health, which is more obvious at home segregation under COVID-19. This paper discussed some key factors that affect the health status, including the physical and mental aspects, of people isolated at home during COVID-19. In particular, the indoor temperature, the mass concentration, including the humidity and density of contaminants, were thoroughly studied. The measurement methods and related factors under different situations were also presented. Moreover, the interaction among different factors, showing how the whole ventilation system works, was also illustrated in the paper. Those results show that temperature and concentration (humidity, CO<sub>2</sub>, and fungus) levels should be controlled in a suitable range. People could use different ventilation systems in different situations or open a proper area of windows to keep healthy. It is also important to keep distance between people.

**Keywords:** COVID-19; Ventilation; Indoor air quality; Thermal Comfort; Health status.

## 1. Introduction

With the improvement of people's quality of life, people pay more and more attention to the indoor environment. In particular, the indoor environment has a lot to do with the spread of influenza and other factors, including thermal comfort and Microbial diffusion. For example, the symptoms were least severe in building with higher ventilation rates of 15-25 l/s per person [1, 2]. Thus, related to health problems, indoor air quality (IAQ) has increasingly gained importance.

Recently, global epidemics of Corona Virus Disease 2019 (COVID-19) break out unexpectedly. Physical isolation was the best way to block the epidemic since the fact that there is no specific drug and the vaccine has not been popularized. Moreover, China has achieved good epidemic prevention and control since January last year due to the strict implementation of physical isolation policy. As a result, people must spend less time in some public places and stay with others at home more frequently. In this situation, ventilation plays a much more crucial role in people's health in recent days when there are diseases worldwide.

In the epidemic situation, some derivative factors of the indoor environment will also further affect people's health. For instance, under the stressful circumstances of COVID-19, more and more people complain about indoor air problems. Especially, an unhealthy indoor environment is more likely to cause people to catch a cold, making them even more anxious with insecurities because the symptoms of colds, such as sore throat and headache, are similar to people who suffer from coronavirus. Moreover, the problem in the indoor environment could also cause other serious problems simultaneously. According to the World Health Organization (WHO), there are 9900 deaths in Europe and 81000 in the United States, contributing to air pollution during 2012.

Therefore, people are much more aware of the importance of the indoor environment. To satisfy the demands for a healthier environment, people seek better ventilation solutions with the measurement of the Indoor Environmental Quality (IEQ) and comfort of the occupants and people. The IEQ includes the Indoor Air Quality (IAQ), the thermal environment, and other aspects, such as acoustics. The IAQ can directly or indirectly influence the comfort and health of people. The thermal comfort, served as the perceived sensation of satisfaction with the thermal environment, is different among different people since they have different metabolism. Thus, thermal comfort should be maintained in a suitable range that can satisfy most people isolated at home.

Apart from the measurement of the ventilation system, the ventilation performance in practice will be influenced by different factors. According to Liddamen, it had been found that a healthy indoor

environment is determined by several crucial aspects, which are related to the needs. It is still unclear about the quantitative impact of ventilation on the transmission of infectious diseases through many attempts concerning infectious diseases. But it can be confirmed that there is a certain relationship between ventilation, air movement in buildings, and the spread of infectious diseases. Consequently, the home isolated residents must find a better ventilation method. In earlier studies, the primary tasks of a ventilation system are indoor air quality, comfort, contaminate control, and energy performance. These four tasks can be matched as exchanging room air, removing indoor contaminants, removing heat, and protecting local occupants [6, 7, 8].

Therefore, this paper studies the impact of the indoor environment on people's health under the condition of home isolation comprehensively discusses the influence mechanism of temperature and other factors, and directionally discusses the influence degree. In this article, the aspects of heat, concentration, and the status of health of local occupants have to be taken into consideration. Among them, the concentration includes the humidity of room air and the density of contaminants. Consequently, this paper provides a reference for designing an indoor healthy living environment by exploring these influencing factors and mechanisms of human health status through research.

## 2. Temperature field

Thermal comfort has been an important measurement of ventilation. Different people have different metabolism and wearing about their thermal environment, it should provide a thermal comfort that satisfies each person. There are many control solutions in the temperature field. It had been identified as one of the IEQ criteria by the European standard EN15251 in 2007. This classification of criteria established by EN15251 is based on the Predicted Mean Vote (PMV) or the Predicted Percentage of Dissatisfied (PPD) indices .

The indoor thermal environment will also relatively influence the status of air quality and people's health. Thus, it is important to find a proper solution to control the level of temperature. For example, it is not surprising to find that the lowest air change rate leads to an increase in temperature . Further details about temperature and its influence are discussed in the articles below by determining the assessment method and comparing different ventilation systems to search for a better ventilation strategy.

### 2.1 Assessment method

The ventilation level of the system can evaluate the indoor environment in the occupied area. Among these evaluations, the temperature is an important index.

According to the Effective Draught Temperature criterion, a function is established due to the measured values of air temperature and velocity at the evenly spaced points in the whole occupied area or the evenly spaced points passing through the air supply port through the vertical and central line plane. Define the Air Diffusion Performance Index (ADPI) as the total number of ventilation temperature  $T$  meeting the specified comfort limit (expressed as a percentage of the total number) :

$$T = (t_2 - t_1) - 8 * (v - 0.15) \quad (1)$$

Let  $T$ =effective draught temperature;  $t_2$ =local air temperature;  $t_1$ =average air temperature;  $v$ =local air velocity.

According to the formula 1, there is a linear relationship between the effective draught temperature  $T$  and the local air velocity  $v$ —when  $v$  increases, the  $T$  decreases correspondingly. Thus, people could adjust the temperature in the indoor environment by controlling the air velocity in ventilation systems.

### 2.2 Different ventilation systems

#### Mixing ventilation (MV)

In the beginning, Boyle Son illustrated the application of mixing ventilation (MV) in 1899, showing the distribution of indoor pollutants by giving out how the airflow mixed with the polluted

air . Recently, the mixing ventilation is used to lower the contaminant concentrations by mixing the supplied fresh air with the contaminated air room.

Displacement ventilation (DV)

The displacement ventilation (DV) is to displace contaminated room air with fresh air from outside.

Personalized ventilation (PV)

To improve the air quality of a person's working environment, personalized ventilation (PV) uses different air supply devices to supply high-quality air directly to the exposure region instead of controlling pollutants locally.

2.3 Air temperature in different ventilation systems

Concerning the ventilation effectiveness of different systems, the temperature is a momentous factor. Fig 1 shows how temperature affects the effectiveness of ventilation systems in different areas. For MV (high supply and high exhaust) system and DV system, the ventilation effectiveness increases when the temperature difference decreases. On the other hand, the ventilation effectiveness of MV (high supply and low exhaust) system and PV system increases when the temperature difference increases. Particularly, the PV system has much higher ventilation effectiveness, i.e., always achieving ventilation effectiveness higher than 1. However, the DV system and MV (high supply and high exhaust) can only reach ventilation effectiveness higher than 1 when the supply air temperature is lower than the room temperature. In contrast, the MV system (high supply and low exhaust) can only reach the effectiveness higher than 1 when the supply temperature is higher than the room temperature.

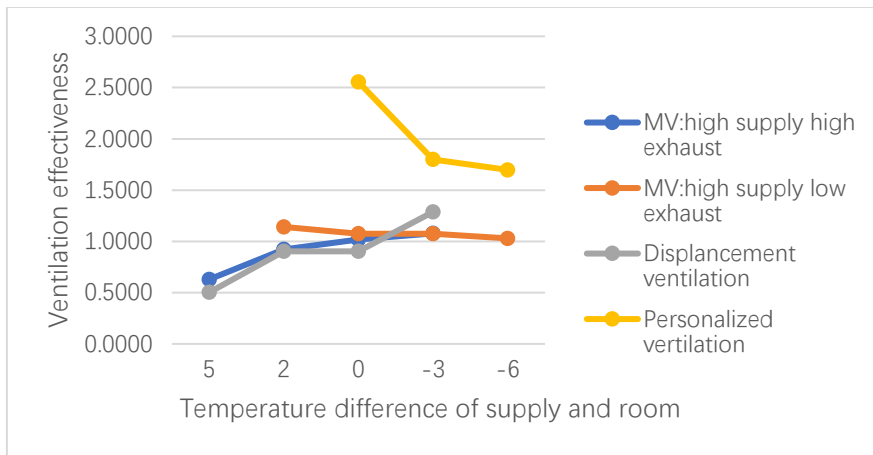


Fig. 1 Effect of temperature difference on different ventilation effectiveness .

Fig 2 shows the typical supply air temperature on different ventilation systems. Comparing the data, we can find that MV and DV systems can reach a much bigger range of supply air temperature than a PV system. (i.e., MV and DV system can heat to a higher temperature and cool to a much lower temperature)

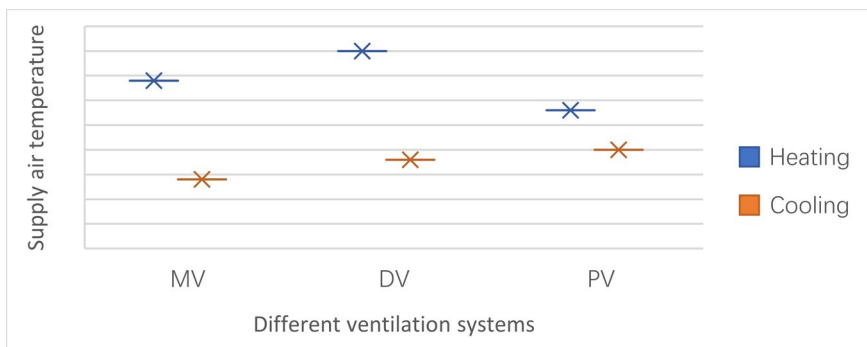


Fig. 2 Typically supply air temperature on different ventilation systems .

Consequently, staying indoors during the outbreak of COVID-19, people could use PV system when they wish to have more efficient ventilation. At the same time, it will be better for people to use MV and DV system if people wish to stay in a relatively cool or warm environment.

### 3. Concentration field

Moisture issues occur in a wide range of regions. Studies show that dampness and dampness-related agents are the main contributors to allergic and respiratory diseases [12, 13]. Those moisture issues affect the health and humidity conditions, which are listed in Table 1. Especially concerning the humidity of the indoor environment, though there are many aspects (for instance, species in mold growth) in the systems, humidity contributes to many problems. For instance, when the indoor humidity is too high, the heat inside the human body cannot be sent out in time, leading to respiratory symptoms. At the same time, people's skin will dry, making immunity decline when the humidity is small. Moreover, other factors, such as temperature and mold growth, will also be influenced by the humidity.

Consequently, the proper control of humidity and the concentration of other contaminations are precious important in reducing the health risks of moisture and related problems. The different methods and strategies are discussed below.

**Table 1.** Moisture issues

Researchers	Methods	Conclusions
Nielsen et al. (2004)	Laboratory study	An RH of 86% for mold growth was necessary on the gypsum board.
Dannemiller et al. (2017)	Chamber experiments	Fungal growth occurred above 80% RH. Bacterial growth occurred only at 100% RH after one week.
Zhang et al. (2016)	Residence measurements	Fungal growth in room air and house dust were linked to high RH.
Lin et al. (2009)	Chamber experiments	When the RH increased from 50% to 80%, the VOC concentrations and specific emission rates increased 1–32 times.

#### 3.1 Humidity

To find the suitable range of humidity, there are different assessment methods, which are shown below.

Define the risk of high humidity (RHH) as the basic indicator for assessment, which could be calculated by using formula 2 and 3:

$$RHH = \frac{\sum_{j=1}^n \sum_{i=1}^m \mu_{i,j}}{n} \quad (2)$$

$$\mu_{i,j} = \begin{cases} 1, & RH_i > RH_{th} \text{ AND } w_i > w_{th} \\ 0, & RH_i < RH_{th} \text{ OR } w_i < w_{th} \end{cases} \quad (3)$$

Let  $RH_i$  be the zone relative humidity at the  $i$ -th hour of a year;  $w_i$  be the zone humidity ratio at the  $i$ -th hour of a year;  $RH_{th}$  be the humidity threshold for relative humidity;  $w_{th}$  be the humidity threshold for the humidity ratio;  $m$  be the total hours;  $n$  be the total number of models.

Three humidity thresholds for health protection includes 50%, 60%, and 80% RH thresholds: 1)  $RH < 50\%$ , which is used to prevent most water-related substances; 2)  $RH < 60\%$ , which is used to reduce most water-related substances; 3)  $RH < 80\%$ , which is used to prevent most mold growth .

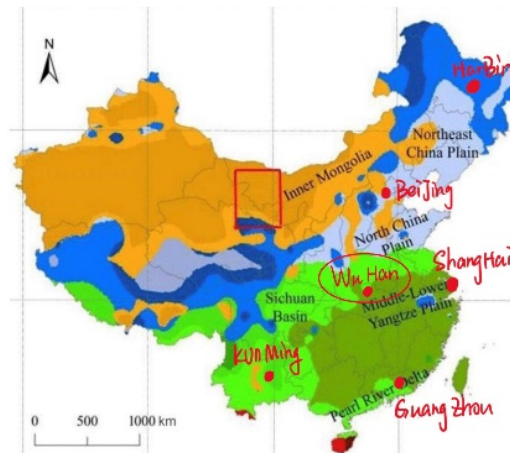
Affected by the moisture and ventilation, the indoor humidity level could be simplified as :

$$\rho V \frac{dW_z}{dt} = kg + m(W_\infty - W_z^t) - \sum_{j=1}^N \frac{W_z - W_{surf,j}}{R_{1,j}} \quad (4)$$

Let  $\rho$  be the zone air density;  $V$  be the volume of the zone;  $W_z$  be the zone humidity ratio;  $kg$  be the sum of the internal moisture gains;  $m(W_\infty - W_z^t)$  be the moisture transfer;  $W_{surf,j}$  be the humidity ratio in equilibrium with the moisture content of the surface layer;  $R_{1,j}$  be the mass transfer resistance.

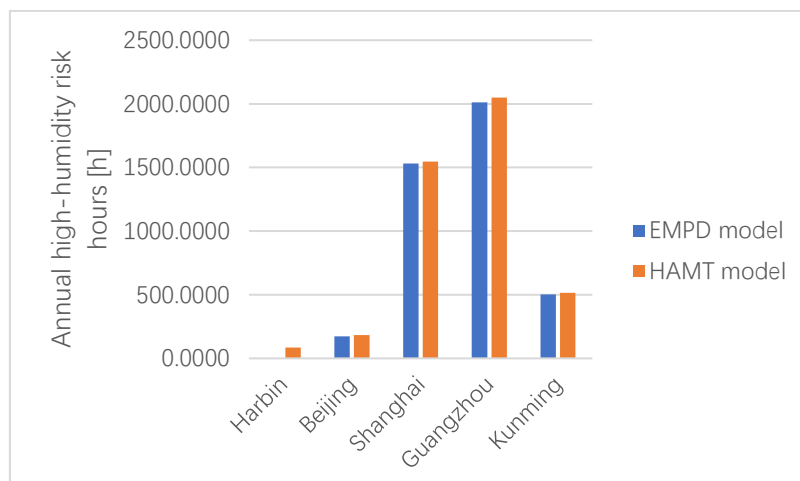
The effective moisture penetration depth (EMPD) can also be modeled according to formula 4. In addition, combining formula 4 with the zone heat balance model can get the balances of energy and moisture. It is worth mentioning that HAMT is a more precise model for the combination of heat and moisture transformation but spends much more time to calculate .

### 3.1.1 Humidity vs. Climate zones vs. Months



**Fig. 3** Climate zones and locations of the five selected cities.

Shown in Fig 3, Harbin, Beijing, Shanghai, Guangzhou, and Kunming can symbol five typical climate zones in China respectively: the severe cold zone and cold zone of Monsoon Climate of Medium Latitudes; hot summer with cold winter zone and with warm winter zone of Subtropical Monsoon Climate; Monsoon climate in the subtropical plateau. Therefore, these five cities are picked to measure the high humidity (RHH) values shown in Fig4 . We can find that the trends of EMPD and HAMT are consistent, while the change range of EMPD was slightly smaller compared with HAMT. In addition, Shanghai and Guangzhou have much higher humidity risk according to the calculation of the EMPD and HAMT models.



**Fig. 4** The effective moisture penetration depth calculated annual high humidity risk (RHH) (EMPD) and heat and moisture transfer model (HAMT) in different cities.

Similarly, people in Wuhan where COIVD-19 broke out suffer a higher humidity risk as Wuhan and Shanghai are in the same climate zone due to Fig3. As a result, to ensure that people can be in a relatively clean indoor environment to resist the epidemic, people should ensure that the humidity is not too high.

### 3.2 Mass concentration

The mass concentration of different contaminants would also influence indoor air quality. Particularly, to have a more suitable environment, the ventilation system should make sure that there will be enough O<sub>2</sub>. In other words, the concentration level of CO<sub>2</sub> in the indoor environment needs to be controlled in a proper range. Thus, the level of CO<sub>2</sub> is also an important factor of ventilation towards people's health. The differences between indoor and outdoor CO<sub>2</sub> concentration can be determined as :

$$V_i \frac{([CO_2]_2 - [CO_2]_1)}{t_2 - t_1} = n * Q + V * (([CO_2]_{outdoor} - [CO_2]_1) * 10^{-6}) \quad (5)$$

Where  $V_i$  is the interior volume of the buildings;  $V$  is the effective ventilation rate;  $[CO_2]_2$  and  $[CO_2]_1$  are the concentration level of CO<sub>2</sub> at time  $t_2$  and  $t_1$ ;  $[CO_2]_{outdoor}$  is the concentration level of CO<sub>2</sub> in the outdoor environment;  $n$  is the number of occupants in an indoor environment;  $Q$  is the CO<sub>2</sub> generation rate by one person.

Based on formula 5, the concentration of CO<sub>2</sub> is related to the number of people staying indoors. It can also be found that this relationship is not directly linear but also related to the outdoor carbon dioxide content. Thus, in order to control the level of CO<sub>2</sub>, it is crucial to reduce the number of people indoors and pay attention to the outdoor environment simultaneously.

## 4. Health status of People

Recently, although many countries are committed to the research of the COVID-19 virus and have successfully developed a vaccine that can be used in clinical trials, there is no effective specific drug for the epidemic. So far, the most effective way to prevent the large-scale spread of the epidemic is home isolation. As a consequence, as it has been estimated that in developed countries, people spend 80% to 90% of their time indoors, this figure will be much higher when COVID-19 occurs unexpectedly. This long exposure to indoor air may make it harder for people to get rid of physical and mental discomfort. Thus, it is crucial to pay attention to people's mental and physical health during the COVID-19. This article indicates the current state of mental and physical health and analyses the infection probability of the epidemic to find a proper solution to keep healthy.

### 4.1 Mental and Physical health status

A longer period of home isolation will aggravate people's psychological discomfort and cause a certain degree of panic. According to a Second Military Medical University survey, 9.5% of people were mentally facing anxiety disorder during the epidemic period, and 29.6% were prone to depression. In addition, 4.6% of people have post-stress disorder (PTSD) and sleep problems.

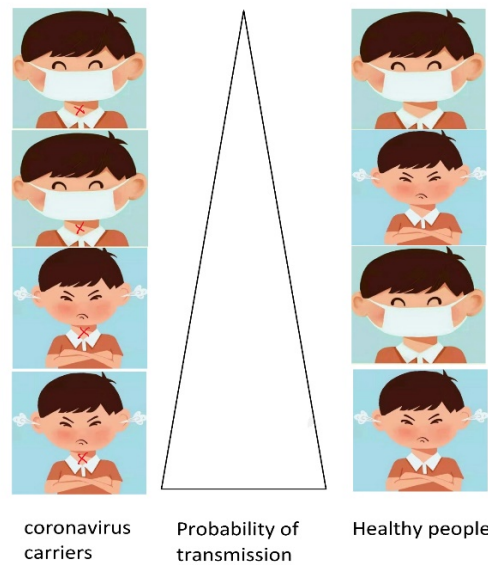
Particularly, students who don't have strong pressure resistance suffer more. Based on an investigation about students in universities, a large proportion of students had different degrees of depression under the epidemic of Covid-19 (39.4% of the non-medical students had depression, 36.5% of the medical students had depression), anxiety (24% of the non-medical students had anxiety) and stress (45.9% of non-medical students may have health risk stress, and 48% of medical students may have health risk stress).

An unhealthy indoor environment will potentially have a bad impact on people's physical health. For instance, according to the World Health Organization (WHO), 99000 deaths in Europe and 81000 in the Americas were attributable to indoor air pollution in 2012. Especially as people spend more time indoors during the COVID-19, indoor air quality becomes a major factor affecting health.

### 4.2 Infection probability of the epidemic situation

There are two main forms of epidemic infection: convective mass transfer and diffusive mass transfer. Among them, the convective mass transfer due to external factors is the most effective in the new crown transmission mode. Therefore, people are required to wear a mask to curb convective mass transfer. The reason is that masks could cut down the influence of breathing, sneezing, coughing,

and other factors to slow down the convective velocity and the risk of infection. The influence of masks can also be seen in figure 5 below.



**Fig. 5** The possible risk of infection by controlling the variable with or without a mask. It is found that wearing a mask can greatly reduce the risk of infection.

The distance between people will also directly affect the infection. We can regard the propagation of the Corona Virus as a spherical particle diffusion for the convenience of discussion.

Suppose a spherical Corona Virus with a radius of  $R_0$  is placed in an infinite space. Let the concentration of adsorption value is  $C_0$ . When the time  $t > 0$ , the adsorbate diffuses in the spherical particles. Assuming that the diffusion coefficient  $D$  is a constant, the diffusion phenomenon can be described by partial differential equation :

$$\frac{\partial q}{\partial t} = \frac{D}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial q}{\partial r} \right), \quad 0 \leq r < R_p \quad (6)$$

Let  $q'$  be the equilibrium concentration of adsorbent particle surface and solution. According to the above formula 6, the analytical solution of the diffusion equation of sphere solid phase is derived :

$$q(t, r) = q' + \frac{2R_p q'}{\pi r} \sum_{n=1}^{\infty} \frac{(-1)^n}{n} \sin\left(\frac{n\pi r}{R_p}\right) \exp\left[-(n\pi)^2 \frac{Dt}{R_p^2}\right] \quad (7)$$

Based on formulas 6 and 7, It is not difficult to see that with the decrease of distance, the distribution of adsorbate concentration becomes bigger, and the probability of infection increases simultaneously. Especially, according to the Washington Post, the public guide updated by the CDC website in the United States points out that the risk of transmission is the greatest when the distance is less than 6 meters from the source of infection. Therefore, during COVID-19, it is momentous to keep the distance between people.

In addition, the temperature will affect the diffusion coefficient  $D$ . Due to the Arrhenius empirical formula. The diffusion coefficient  $D$  can be expressed as :

$$D = D_0 \exp\left(\frac{-Q}{RT}\right) \quad (8)$$

Let  $D_0$  be the diffusion constant,  $R$  be the gas constant,  $T$  be the absolute temperature of diffusion, and  $Q$  be the diffusion activation energy.

Based on formula 8, it can be found that the higher the temperature, the larger the mass transfer coefficient and the faster the molecular motion rate, which makes it easier to diffuse. Thus, it is better to stay in a relatively cooler environment.

## 5. Influences of different factors

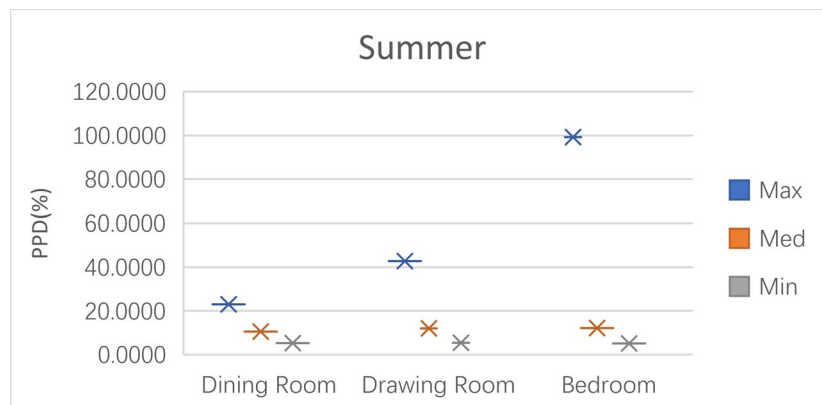
The following article shows how the temperature and concentration field affect the indoor environment separately by giving the assessment method a better ventilation strategy. Also, the article finds that the status of physical and mental health of people during COVID-19 and the ways to reduce the possibility of infection.

Each factor not only has an impact on the interior environment itself but also potentially affects other variables. In particular, the level of temperature and concentration will largely affect the health of people, which is discussed below.

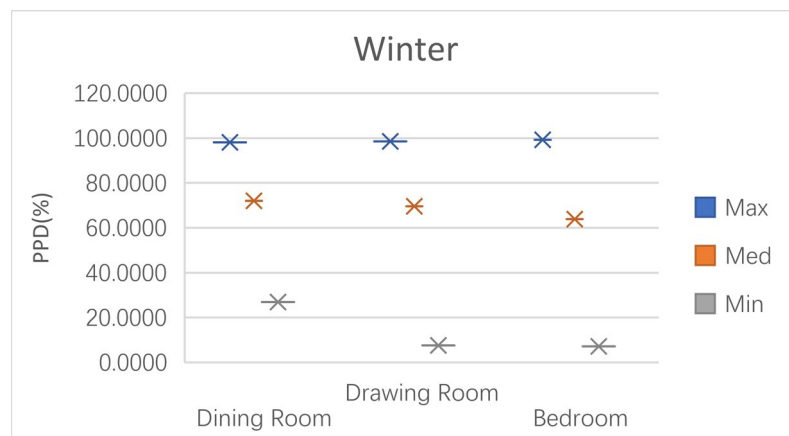
### 5.1 Temperature vs. Health

The predicted percentage of dissatisfied (PPD) indices is one of the most important thermal comfort measurements. Particularly, PPD as an index can quantitatively predict the percentage of heat dissatisfied people who feel too hot or too cold .

Based on fig6 and fig7, PPD indices in different rooms are lower during summer than during winter, which may be because of poor insulation in winter. (i.e., the winter PPD index shows more discomfort in all the areas evaluated). Thus, there should be enough ventilation systems to warm people up or have a better insulation system, particularly in winter. In addition, the dining room is the area showing minimal variability of PPD both in winter and summer, suggesting a more accurate control temperature should be taken.



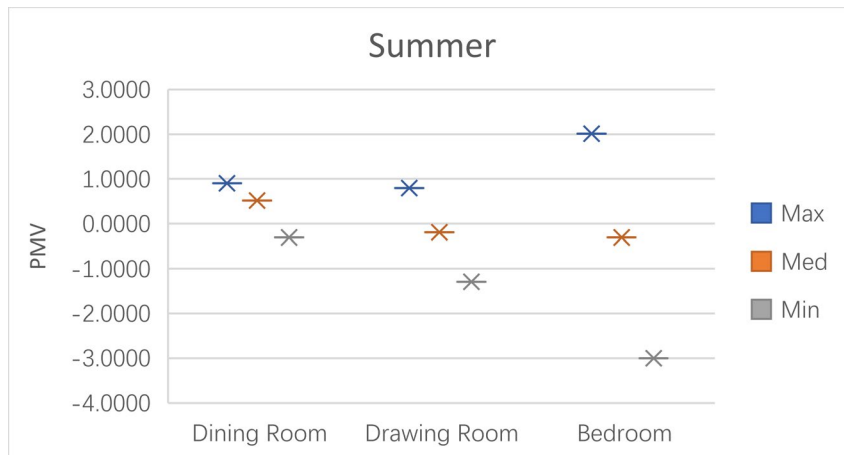
**Fig. 6** PPD index in a different room in summer



**Fig. 7** PPD index in a different room in winter .

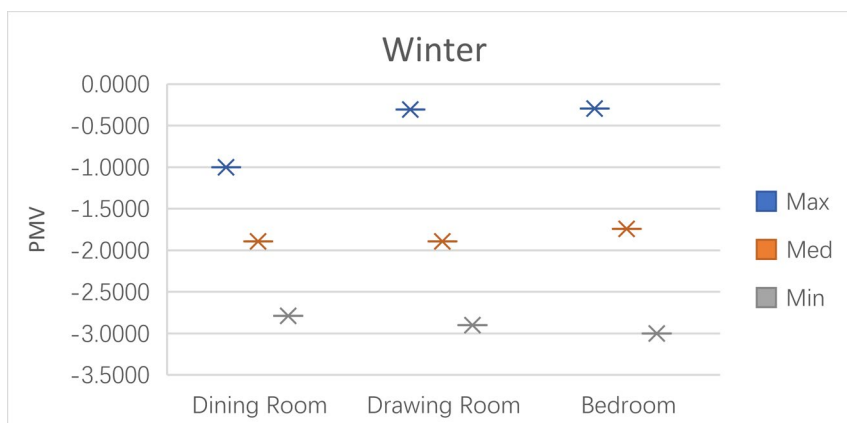
The thermal comfort can also be determined by the values of the predicted mean vote (PMV). In particular, the PMV could predict the mean value of the votes of a large group of persons exposed to the same environment .

According to Fig8, PMV indices in summer indicate the bedrooms as the area closer to the "slightly cool" point ( $\leq -1$ ), which is not the proper temperature range for people to stay indoors for a long period. Thus, to prevent COVID-19, people are supposed to make the bedrooms' temperature higher.



**Fig. 8** PMV index in a different room in summer

According to Fig 9, PMV indices in winter are all between the "slightly cool" and "cool" area (-2), possibly because of poor insulation. Consequently, people need to keep the temperature in a relatively higher range or have a better insulation system, especially during winter.



**Fig. 9** PMV index in a different room in winter

In addition, the dining room is the area showing minimal variability of PMV both in winter and summer, suggesting a more accurate control temperature should be taken.

To find the most suitable solution for the indoor environment to stay in, it is more effective to evaluate the thermal comfort and mental state. Thus, to determine total performance influence, a quality factor ( $Q$ ) is defined as follows:

$$Q = |T * M| \tag{9}$$

where  $T$  is the thermal comfort level and  $M$  is the mental state level.

By calculating the thermal comfort level and mental state level data, we can get a linear chart of the quality factor. According to the chart, the peak (i.e., the highest amount of the quality factor) would be the most suitable range of indoor environments for people to live in.

An investigation conducted about indoor air quality and thermal comfort of dormitory during winter in Beijing's University uses this method to evaluate the best window opening area for students' health. It shows that when the window opening area increases, PMV level  $T$  decreases and mental state level  $M$ . By combining the two factors according to formula9, the calculated results of  $Q$  have a peak that occurs when the window opening area is approximately 0.055m<sup>2</sup>, which is the best choice for the indoor environment.

Similarly, during the outbreak of COVID-19, people who stay indoors for a long period could open a proper area of windows or use a proper ventilation system to help maintain physical and mental health.

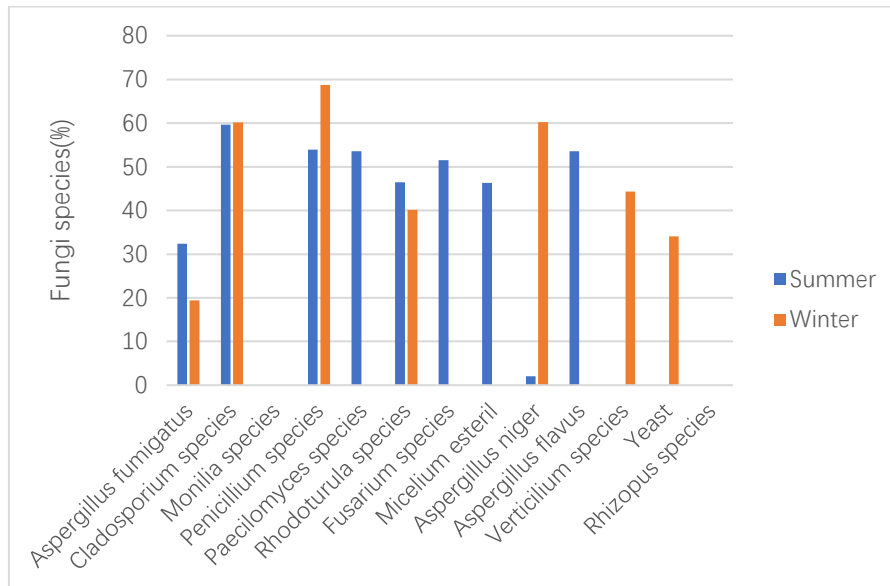
### 5.2 Concentration vs. Health

The increase of PM10, TVOC, CO2, bacteria, and fungi, which are the most important source of exposure in indoor pollution, will compromise indoor air comfort and worsen the symptoms if there are diseases like COVID-19. For instance, there is a certain relationship between the increase of toluene and o-xylene and breathlessness among the elderly population in French dwellings [29, 30].

If people use inadequate ventilation, it will increase exposure. There is not enough supply air to dilute emissions from indoor contaminants and make the indoor air pollutants away from rooms. Therefore, to reduce infection, enough ventilation strategies, such as using effective ventilation systems like PV systems or opening windows properly, should be considered.

Moreover, it is also possible to control the level of concentration by controlling the level of temperature. For example, the existence of fungi species, which is one factor determining indoor air quality, can be influenced by temperature. According to Fig 10, the mean percentage of some fungi species, including *Aspergillus fumigatus*, *paecilomyces* species, *fusarium* species, *mycelium esteril* and *aspergillus flavus*, is especially high in summer while low in winter. In addition, the mean percentage of some species, which includes *aspergillus niger*, *verticillium* species and yeast, is precious high in winter while low in summer. Moreover, the mean percentage of other species, including *Cladosporium* species, *penicillium* species, and *rhodoturula* species, is very high in summer and winter.

Therefore, based on the different percentages of different fungi species, people could take corresponding measures to reduce the number of fungus in different seasons.



**Fig. 10** Indoor fungi species (mean percentage) are affected by the temperature.

## 6. Conclusion

This study investigates the impact of the indoor environment on people's health under the condition of home isolation during the outbreak of COVID-19. The evaluation includes three aspects—heat, concentration, and the status of health of local occupants—and the relationship between different aspects.

The major findings could be summarized as follows:

When people need to have effective ventilation, the PV system is a great choice, while it will be better for people to use MV and DV systems if people wish to stay in a relatively cool or warm environment.

People could adjust the temperature in the indoor environment by controlling the air velocity in ventilation systems.

During COVID-19, it is momentous to keep the distance between people.

To reduce the risk of infection, it is better to stay in a relatively cooler environment. On the other hand, concerning thermal comfort, PMV and PPD indicate that being too cold is not ideal for people. As a result, a proper range of temperature, which is not very hot and cold, should be chosen when isolated at home.

Humidity, which plays a pivotal role in the indoor environment, is variable in different climate zone. In particular, people in Wuhan should ensure that the humidity is not too high.

It is crucial to control the level of CO<sub>2</sub> by reducing the number of people indoors and paying attention to the outdoor environment simultaneously.

During COVID-19, people who stay indoors for a long period could open a proper area of windows or use an effective ventilation system to keep healthy and make the indoor air pollutants away from rooms.

People could take corresponding measures to reduce the number of different species of fungus in different seasons, resulting in maintain a clean indoor environment.

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