Building and Environment 131 (2018) 1–11

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Purifier or fresh air unit? A study on indoor particulate matter purification strategies for buildings with split air-conditioners

Yuchen Shi[a], Xiaofeng Li[a,b,*]

[a] Department of Building Science, School of Architecture, Tsinghua University, Beijing 100084, China
[b] Beijing Key Laboratory of Indoor Air Quality Evaluation and Control, Beijing 100084, China

ARTICLE INFO

Keywords:
Air purifier
Fresh air unit
Infiltration
Particulate matter
Positive pressure control

ABSTRACT

Buildings with split air-conditioners (referred to as SAC buildings) are not equipped with mechanical ventilation systems. The fresh air supply in these buildings primarily relies on natural ventilation and air infiltration, both of which can introduce outdoor particulate matter (PM) pollutants into the indoor environment. To simultaneously satisfy fresh air and indoor PM concentration requirements, two indoor air purification strategies can be employed, including air purifiers (APs) combined with open-window ventilation (AP-Mode) and fresh air units (FAUs) combined with positive pressure control (FAU-Mode). Accordingly, an investigation is required in order to determine which of the two strategies is more suitable for various types of SAC buildings. In this study, firstly, a new method for calculating the mechanical fresh air supply rate needed to maintain a positive room pressure is proposed for SAC buildings. It is concluded that positive room pressure can be maintained if the mechanical fresh air supply rate is more than 3.2 times the natural air infiltration rate (i.e., air infiltration rate when a room is not supplied with mechanical fresh air). Then, based on the mass balance principle of indoor particulate matter, the clean air delivery rates (CADRs) are calculated for APs used in the AP-Mode and FAUs used in the FAU-Mode under different PM2.5 I/O ratios and fresh air supply rates, and the annual energy consumptions of the two strategies are compared. Consequently, it is determined that in most cases, the FAU-Mode has a lower annual energy consumption when used in SAC buildings in Beijing, Shanghai, and Guangzhou. Finally, considering the room airtightness requirement for positive pressure control and the indoor PM2.5 concentration upper limit of 35 μg/m^3, the AP-Mode should be used in rooms with fresh air requirements lower than 1 h^{-1}, whereas the FAU-Mode should be used in other cases.

1. Introduction

Adequate fresh air is essential for removing indoor pollutants and preventing sick building syndrome [1,2]. Thus, to maintain the quality of the indoor environment, the fresh air requirement for the building occupants must be satisfied. Various buildings in China are air-conditioned by split air-conditioners (hereinafter referred to as SAC buildings), including residential, school, office, and hotel buildings [3–7]. The total area of SAC buildings in China is substantially greater than the total area of buildings with central air-conditioning systems [6,7]. However, SAC buildings are not equipped with mechanical ventilation systems, and consequently, their fresh air supply relies on natural ventilation and air infiltration [8–11]. Because of the haze pollution problem in China, the two fresh air supply mechanisms for SAC buildings can introduce outdoor particulate matter (PM) pollutants into an indoor environment, significantly negatively affecting its air quality and the health of its occupants [11–13].

In addition to outdoor PM sources, there also exist several indoor PM sources, including smoking, cooking, printing, and particle resuspension induced by light human activities [14–20]. For smoking, it is concluded that the air cleaning and ventilation technologies are not able to eliminate the secondhand smoke exposures [21]. Accordingly, in most countries, smoking is prohibited in the indoor places. For cooking, according to the *2009 ASHRAE handbook* [22] and relevant standard [23], the generated particles should be directly exhausted to the outdoors by the range hoods or exhaust fans in the kitchens. And for printing, it was suggested by Wensing [24] that the pollutants generated by printing should be removed from the source and thus cannot diffuse into the indoor environment. Besides, regarding the particle resuspension, previous researchers [25–27] noted that the particle resuspension rate induced by indoor human activities is significantly lower than the particle deposition rate, so that the particle resuspension is neglectable. In summary, compared to indoor PM sources which should be avoided from the sources or are weak enough to be neglected,

* Corresponding author. Department of Building Science, School of Architecture, Tsinghua University, Beijing 100084, China.
E-mail address: xfli@mail.tsinghua.edu.cn (X. Li).

https://doi.org/10.1016/j.buildenv.2017.12.033
Received 24 October 2017; Received in revised form 28 December 2017; Accepted 30 December 2017
Available online 03 January 2018
0360-1323/

outdoor PM sources are inevitable and more serious for SAC buildings.

Two devices can be employed indoors to solve the problem of PM pollutants: air purifiers (APs) and fresh air units (FAUs) [7] [28–32], both of which are used separately in the rooms of SAC buildings. Although APs are equipped with fans and high efficiency particulate air filters (HEPA, whose filtration efficiency is over 99.97% for particles that have a diameter of 0.3 μm [33]) to circulate and purify indoor air, respectively, they cannot supply fresh air. Therefore, when using an AP, the fresh air supply relies on natural ventilation (such as open-window ventilation) and air infiltration. On the other hand, a room installed with a FAU has an air inlet on the external wall to introduce fresh air, which is equivalent to a separate small mechanical ventilation system for that room. Accordingly, FAUs—also equipped with fans and HEPAs—can directly purify outdoor air for delivery into an indoor environment. Evidently, FAUs are capable of simultaneously supplying fresh air and removing indoor PM. Therefore, which of the two devices is more suitable to satisfy both the fresh air and indoor PM concentration requirements for SAC buildings—particularly those found in the different cities of China, suffering from various degrees of PM pollution—needs to be investigated.

In order to maintain good indoor air quality, rooms equipped with mechanical ventilation systems (including FAUs) require a positive room pressure to prevent outdoor pollutants from infiltrating into the indoor environment through the gaps on the building envelope [8,34]. Many studies have demonstrated that a mechanical fresh air supply can help maintain a positive room pressure [8] [35–38]. There exist two viewpoints in previous literature on the relationship between using FAUs and maintaining a positive room pressure in SAC buildings. One viewpoint is that when a room is supplied with mechanical fresh air by a FAU, room pressure will be positive [39–41]. However, these studies did not identify the mechanical fresh air supply rate required to maintain that pressure. Based on this assumption, Shi [40] and Ma [41] proposed two air purification strategies for SAC buildings—APs combined with open-window ventilation (hereinafter referred to as AP-Mode) and FAUs combined with positive pressure control (hereinafter referred to as FAU-Mode). By comparing the two strategies, they concluded that using FAUs in residential buildings can ensure a lower indoor PM concentration and requires a lower air supply rate than APs. Actually, a lower air supply rate requirement can help reduce operating power consumption and avoid noise problems associated with fans [42,43]. Another viewpoint is, the mechanical fresh air supplied to a room in a SAC building is too low and has little impact on the air infiltration rate so that the positive room pressure cannot be maintained, which is assumed by Jiang in the *2017 Annual Report on China Building Energy Efficiency* [7]. He concluded that the AP-Mode can better improve indoor air quality and save energy in residential buildings than the FAU-Mode. Clearly, the two viewpoints lead to opposite conclusions and cause a discussion on whether APs or FAUs are more suitable for SAC buildings to improve indoor air quality. Hence, it is necessary to determine the amount of mechanical fresh air needed to maintain a positive room pressure before comparing the applicability of the two strategies.

The currently used method for determining the mechanical fresh air rate required to maintain a positive room pressure is based on the airflow balance principle, which is widely applied in designing clean rooms and hospital operating rooms [37,38] [44–46]. The method firstly calculates the air exfiltration rate through each gap of the room envelope caused by the designed positive pressure differential to the adjoining rooms using the equations in the *2009 ASHRAE handbook* [8]. Then, the mechanical fresh air rate is calculated by summing up the air exfiltration rate and designed air exhaust rate [37,38]. Although the method is suitable for the ventilation design of clean rooms and operating rooms, its use is not quite appropriate for SAC buildings. Because clean rooms and operating rooms are in the inner locations of a building, they have stable indoor pressures and are rarely influenced by the outdoor environment [44]. However, rooms in SAC buildings are affected by outdoor wind speed, wind direction, and temperature so that the air infiltration and exfiltration through envelope gaps are constantly changing. Considering outdoor environmental effects, Chen [10] used the above method to calculate the mechanical fresh air rate required to maintain a positive room pressure in a small ($30\,m^3$) chamber. He performed 324 calculations and derived an equation for calculating fresh air supply rate via fitting. However, because of the lack of experimental validation, the accuracy and applicability of this equation remain uncertain. Consequently, a new method for determining the mechanical fresh air rate required to maintain a positive room pressure is needed for SAC buildings.

This study aims to determine which of the two indoor air purification strategies— the AP-Mode and FAU-Mode—is more suitable to simultaneously supply adequate fresh air and remove indoor PM for SAC buildings. First, via theoretical derivation and test validation, a new method is proposed for SAC buildings to determine the amount of mechanical fresh air needed to maintain a positive room pressure. Then, based on the mass balance principle of indoor particulate matter, the relationships among the fresh air supply rate, PM2.5 (PM with a maximum diameter of 2.5 μm) I/O ratio, and clean air delivery rate (CADR) of APs used in the AP-Mode or FAUs used in the FAU-Mode are investigated. Accordingly, the annual energy consumptions of the two modes are calculated. Based on these analyses, the optimal air purification strategies for SAC buildings are determined.

2. Methodology

Stack and wind pressures are the chief factors causing air infiltration into buildings [8] [47,48]. In this study, a stack pressure-driven single-sided ventilation model (hereinafter, stack pressure model) and a wind pressure-driven cross ventilation model (hereinafter, wind pressure model) are established through theoretical derivation. The relationship between air infiltration rate and mechanical fresh air supply rate is investigated under the two ventilation models. Then, formulas for calculating the minimum mechanical fresh air supply rate required to maintain a positive room pressure are derived for the two models.

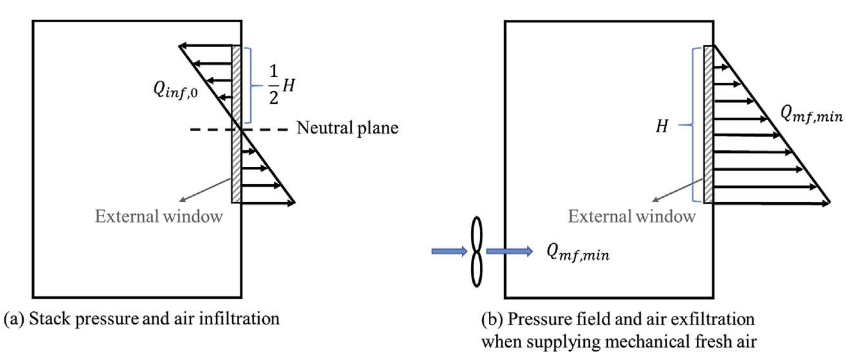

Fig. 1. Stack pressure-driven single-sided ventilation model.