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# Research about the impact of parallel jet spacing on the performance of stratum ventilation for energy efficiency and thermal comfort

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**ABSTRACT**

This study aims to investigate the impact of the PJS on the performance of multi-jet stratum ventilation. A validated Computational Fluid Dynamics (CFD) model was used to conduct the year-round multivariate analysis. A total of eight PJSs, four inlet locations and five climate zones were discussed synthetically. Air distribution performance index (ADPI), ventilation effectiveness ($E_t$) and economic comfort coefficient were employed as the evaluation indicators to assess the thermal comfort and energy efficiency in various scenarios. Research results indicated that the PJS showed different influences on the indoor thermal comfort and energy utilization efficiency as a result of cooperative effect including energy dissipation, air short-circuit probability, air distribution uniformity and airflow path. Combining with building energy simulation method, the optimum PJSs of stratum ventilation with different air inlet positions in five climate zones were obtained, which can help provide a comfortable indoor thermal environment and improve energy efficiency in a low-cost way.

**Keywords:** Multi-jet stratum ventilation, Parallel jet spacing, Jets flow interaction, Energy efficiency, Thermal comfort.

## 1. INTRODUCTION

Recently, the indoor thermal environment grows awareness due to that people usually spend around 90% of their time indoors [1]. Poor indoor environment can not only seriously affect occupants' health and work efficiency [2], but also increase the mortality caused by lung cancer, respiratory diseases and cardiovascular diseases [3]. More seriously, with the wide spread of novel coronavirus SARS-CoV-2 pandemic around the word, high quality indoor environment and more efficient mechanical ventilation become the new focus of scholars' attention [4]. Until now, building energy consumption has accounted for 20%~40% of the total energy consumption in China [5]. Therefore, exploring an efficient air conditioning system to build a comfort and healthy indoor environment is significant to the building energy conservation.

Existing studies indicate that improving the air flow turbulence is treated as one of the widely used methods to seek a more suitable air-conditioning mode at present [6]. Hence, stratum ventilation as a sustainable air distribution for low-energy buildings is proposed. To further enhance the performance of stratum ventilation, scholars conduct a series of parameter studies, including supply air temperature, airflow rate, supply air angle, supply air outlet type, and inlet position and so on [7]. Due to the supply air outlets of stratum ventilation are close to the occupied zone, the impact caused by airflow characteristic on the thermal performance and indoor comfort is more obvious than other ventilation methods. Parallel turbulent jets are important for the flow structure and air distribution [8]. It is well known that the interaction of parallel jets with adjacent jets or with their surroundings plays a crucial role in the effectiveness of the interacting flow. Hence, optimum jet spacing between two jet centerlines can notably enhance fluid interaction and indoor environment comfort with low energy and cost consumption [9]. However, the research about the influence of PJS on the performance of multi-jet stratum ventilation is scarce. To fill the knowledge gap and enhance the energy efficiency and thermal comfort of stratum ventilation in a low-cost way, the optimum PJS for the multiple-jet stratum ventilation in an office was investigated by an experimentally validated CFD

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model in this study. The data and conclusions obtained from this study can supplement the theoretical basis for the applications of stratum ventilation, thus to realize the improvement of thermal performance and indoor comfort in a low-cost way.

## 2. METHODOLOGY

The methods used in this study were summarized in Fig. 1. The corresponding steps were to:

(a) CFD simulation (Fig.2) was first introduced to carry out univariate and multivariate collaborative research, which can obtain the effect of various PJSs on ADPI and $E_t$ under different inlet positions.

(b) Building energy simulation (Fig.3) was secondly used to calculate the building load weight coefficient ($\lambda$) of an office located in different climate zones, which was subsequently employed to derive the year-round ventilation correction factor ($\beta$) based on economic comfort coefficient. Due to that heating is not required in hot summer and warm winter climate zone (HSWW), only severe cold A/B climate zone (SC-A/B), severe cold C climate zone (SC-C), cold A/B climate zone (C-A/B) and hot summer and cold winter climate zone (HSCW) participated in the energy consumption calculation in this section.

(c) Finally, the curve of the year-round ventilation correction factor changing with PJSs can be formed based on CFD simulation and building energy simulation. By smoothing spline fitting, the minimum value of the curve can be obtained. The optimum PJSs for stratum ventilation applied in different climate zones were recommended by considering the energy saving and indoor thermal comfort simultaneously.

Each of these steps was explained in the following sections.

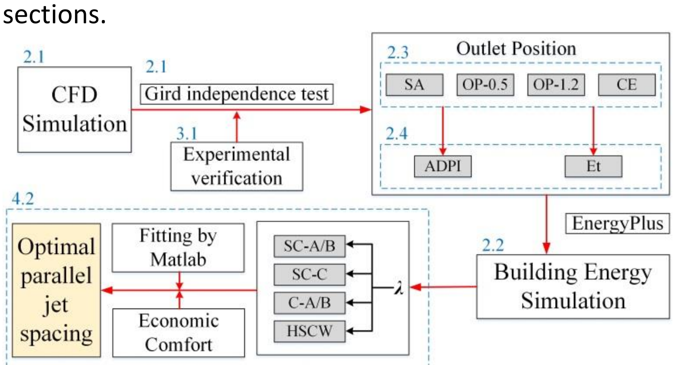


Fig. 1. Summary of the modeling approach. (SC-A/B: severe cold A/B climate zone; SC-C: severe cold C climate zone; C-A/B: cold A/B climate zone; HSCW: hot summer and cold winter climate zone)

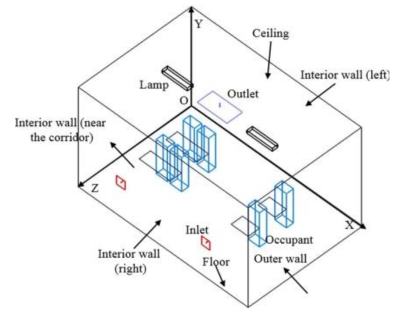


Fig. 2. 3D CFD model geometry.

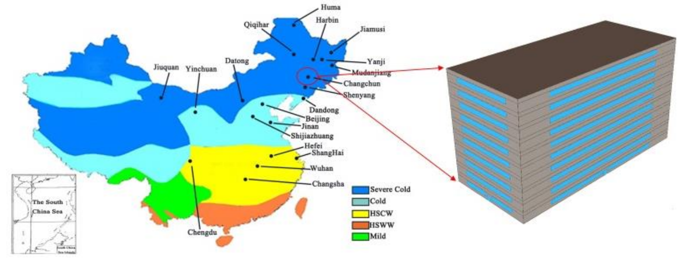


Fig. 3. The locations of the selected cities and the 3D model.

## 3. RESULTS

### 3.1 Impact analysis of PJS on ADPI

For heating condition, only considering the air distribution rationality and indoor comfort, the optimum PJS for SA-0.5, OP-0.5, OP-1.2 and CE is 0.75m, 0.54m, 0.76m and 0.78m, respectively. Meanwhile, the derivative curve indicates that the ADPI changes dramatically at certain PJSs. In the actual design, the following PJSs should be avoided. For SA-0.5, the sensitive PJSs are 0.6m, 0.84m, and 1.39m; for OP-0.5, the sensitive PJSs are 0.5m, 0.6m, and 0.71m; for OP-1.2, the sensitive PJSs are 0.6m, 0.84m, and 1.39m; for CE, the sensitive PJSs are 0.5m, 0.7m, and 0.91m.

For cooling condition, the optimum PJS for SA-0.5 and CE is both 2.0m, while that for OP-0.5 and OP-1.2 is 1.52m and 1.4m, respectively. Meanwhile, the maximum and minimum of ventilation effectiveness only differ 5.5%, 5.1% and 3.1% under OP-0.5, OP-1.2 and CE, respectively. It indicates that PJS has little effect on the ventilation effectiveness under heating mode with air inlet positions being OP-0.5, OP-1.2 and CE. Inversely, the ventilation effectiveness can be enhanced from 0.80 to 0.96 (a total improvement of 20.7 %) with the PJS increasing from 0.5m to 2.0m under SA-0.5 due to the short circuit of airflow.

### 3.2 Impact analysis of PJS on ventilation effectiveness

For heating condition, the optimum PJS for SA-0.5 and CE is both 2.0m, while that for OP-0.5 and OP-1.2 is 1.52m and 1.4m, respectively. Meanwhile, the maximum and minimum of ventilation effectiveness only differ 5.5%, 5.1% and 3.1% under OP-0.5, OP-1.2 and CE, respectively. It indicates that PJS has little effect on the ventilation effectiveness under heating mode with air inlet positions being OP-0.5, OP-1.2 and CE. Inversely, the ventilation effectiveness can be enhanced from 0.80 to 0.96 (a total improvement of 20.7 %) with the PJS increasing from 0.5m to 2.0m under SA-0.5 due to the short circuit of airflow.

For cooling condition, the optimum PJS for SA-0.5, OP-0.5, OP-1.2 and CE is 2.0m, 1.33m, 1.50m and 2.0m under cooling condition. Similar to the results under heating condition, no significant differences can be found in ventilation efficiency when PJSs are changing from 0.5m to 2.0m under OP-0.5, OP-1.2 and CE. Under SA-0.5, the ventilation efficiency with PJS being 0.5m is the lowest (0.797) while reaches 0.927 with PJS being 2.0m, enhanced by 16.4 % due to the “airflow short circuit”.

## 4. DISCUSSIONS

### *4.1 Sensitivity analysis*

As shown in Fig. 4, it can be concluded that: a) the impact of PJS on the ventilation efficiency is less than that on the ADPI; b) the impact of PJS on the ventilation efficiency is largest with the air inlet position being SA-0.5, and least with the air inlet position being CE under both heating and cooling conditions; c) but there is an obvious difference existing in the impact of PJS on the indoor comfort between heating and cooling conditions. Under heating condition, the effect is largest when the air inlet position is CE. While the effect shows largest with the air inlet position being SA-0.5 under cooling condition.

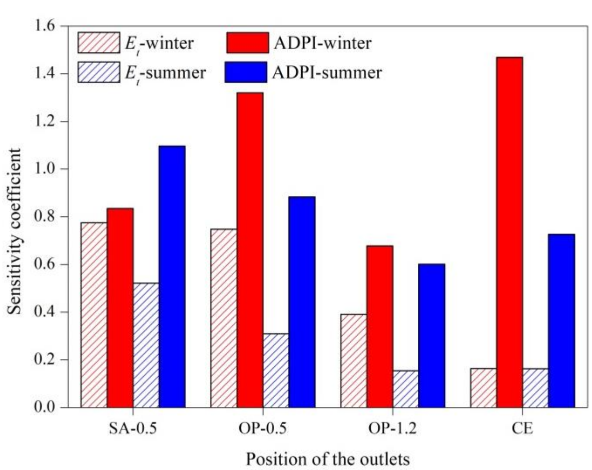


Fig. 4. Comparison of the sensitivity coefficient

### *4.2 Optimum PJS for multiple-jet stratum ventilation*

Economic comfort coefficient is proposed to balance the indoor comfort and energy conservation of stratum ventilation in this study. For the same research building, ventilation correction factor β only depends on the performance of the served ventilation method. A low β demonstrates that less energy is consumed to realize the thermal comfort for one person under the studied ventilation. Taking the ventilation correction factor β as the optimization objective, the optimum PJSs of four air inlet positions under heating and cooling conditions were obtained. As shown in Fig. 5, the optimum PJSs of SA-0.5, OP-0.5, OP-1.2 and CE under heating condition are 1.28m, 1.38m, 1.41m and 1.46m, while those under cooling condition are all 2.0m.

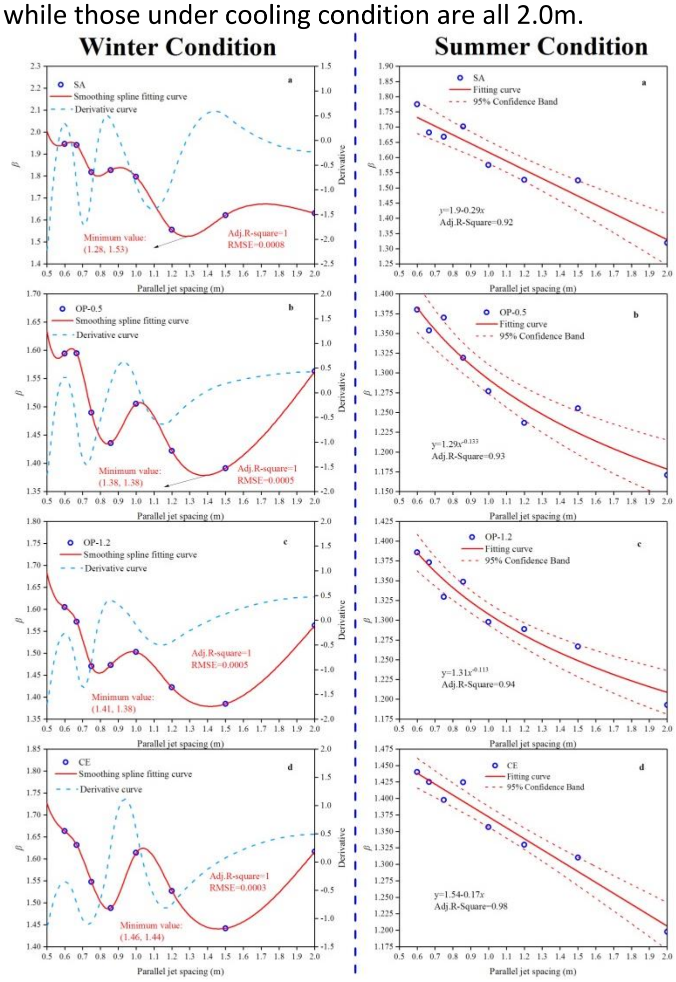


Fig. 5. Optimum PJS for multiple-jet stratum ventilation

Based on the building load weight coefficients, the optimum PJSs for offices with different air inlet positions located in five climate zones can be obtained by nonlinear fitting technique. The results can be used to guide the practical design and application of the multiple-jet stratum ventilation, which is provided in

Fig. 15. It is noted that the energy conservation measures are not considered in building load weight coefficients, therefore the energy saving line for cooling and heating is added in Fig. 6 to point to the change direction of the optimum PJSs.

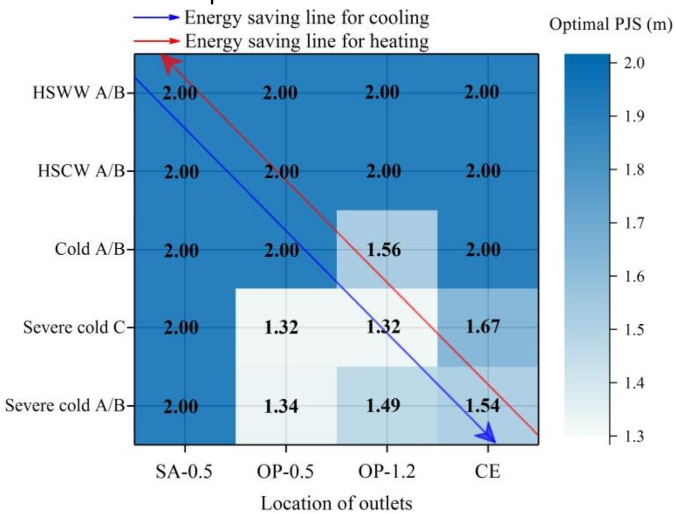


Fig. 6. Optimum PJS for year-round multiple-jet stratum ventilation

## *5. CONCLUSIONS*

This study focused on the impact of parallel jet spacing (PJS) on the thermal performance of multiple-jet stratum ventilation used in offices. A total of eight PJSs, four inlet locations and five climate zones were discussed and studied comprehensively. The research results indicated that the PJS can affect the indoor thermal comfort and ventilation efficiency with significant seasonal differences. PJS mainly affects the thermal comfort under heating condition while affects the energy utilization efficiency under cooling condition. To assess the indoor thermal comfort and energy utilization efficiency simultaneously, the economic comfort coefficient was introduced to obtain the optimum PJSs for spacing cooling and heating under various ventilation methods. Considering that the air conditioning systems are usually whole year operation in practical applications, the year-round optimum PJSs for the multiple-jet stratum ventilation in different climate zones were discussed by introducing building energy simulation. Some meaningful data and conclusions were subsequently obtained. It is therefore a better choice for multiple-jet stratum ventilation design if the performance requirements are met. The related research results can provide a comprehensive guideline for multiple-jet stratum ventilation in the practical applications and enhance its performance in a low-cost way.


## *ACKNOWLEDGMENT*

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