Seasonal Performance of Background Ventilation in Improving Indoor Air Quality

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# Seasonal Performance of Background Ventilation in Improving Indoor Air Quality

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**Abstract**

The quality of indoor air significantly impacts the health, comfort, and productivity of building occupants. Considering that individuals spend a significant amount of their time indoors, whether at home, work, university or other indoor environments, ensuring good indoor air quality (IAQ) is paramount. This study explores the seasonal effectiveness of background ventilation (BV) as an IAQ enhancement method in an educational building with mechanical ventilation.

Using CONTAM modeling, a multi-zonal analysis is conducted, focusing on a classroom equipped with trickle vents and air bricks. The study compares the classroom's IAQ with and without BV implementation. Results indicate seasonal variations in BV efficacy.

During summer, BV shows its best performance, leading to 305.0 ppm average reduction in $CO_2$ concentrations during occupied periods. In winter, the average reduction is at the lowest amount of 250.8 ppm. Furthermore, the implementation of BV demonstrates better performance in reducing the percentage of $CO_2$ levels higher than 1500 in the classroom during all seasons, showing a 38.5% average seasonal reduction. However, it only achieves an average reduction of 7.8% for $CO_2$ levels higher than 1000 ppm.

This study emphasizes the dependency of BV's performance on outdoor conditions and underscores the need for complementary IAQ strategies. In other words, while BV contributes to reducing indoor $CO_2$ levels, achieving the $CO_2$ level below 1000 ppm, which represents the safe level of IAQ, requires its integration with other IAQ improvement methods, such as opening windows and increasing the ventilation rate.

**Keywords:** Indoor Air Quality, CONTAM, Background Ventilation, $CO_2$ concentration, Seasonal variation

# 1 Introduction

During building refurbishments to improve energy efficiency, airtightness is often improved. Yet, it is essential to prioritize IAQ to protect occupants' health. This involves ensuring proper ventilation to prevent mold, reduce contaminants, and mitigate the spread of infections. One method used to improve IAQ is by installing BV, a type of purpose-provided ventilation that involves small ventilation openings allowing controlled amounts of fresh air to penetrate through window frames and walls [1].

The impact of installing BV was examined in a study by Roberts et al. [2], where trickle vents were implemented in the windows of a residential building in the UK post-refurbishment. The study aimed to determine whether BV could provide sufficient outdoor air to achieve acceptable IAQ. Results showed that the opening of a total of 19 trickle vents with an equivalent area (EA) of 25,000 $mm^2$ led to a modest 12.2% increase in the air change rate.

In another study, Abbaspour et al. [3] investigated the impact of implementing BV, including trickle vents and air bricks, along with mechanical ventilation in an educational building. The study focused on evaluating the $CO_2$ level, $PM_{2.5}$ concentration, and SARS-CoV-2 transmission risk. Results indicated that combining BV with mechanical ventilation could achieve acceptable IAQ.

Among the IAQ modeling tools, CONTAM, developed by the National Institute of Standards and Technology (NIST), has been extensively tested and validated as a practical tool for assessing IAQ in built environments and analyzing building airflow rates and ventilation. It is preferred over other tools due to its reliability, user-friendly interface, and specialized focus on contaminant spread in multi-zone environments. CONTAM benefits from active community support, extensive documentation, and compatibility with other tools and databases, such as EnergyPlus and TRNSYS. Many researchers have found CONTAM to be reliable and accessible for simulating complex indoor environments and understanding pollutant dispersion, making it a popular choice for IAQ assessments [4–6].

In this study, a college building is modeled using CONTAM. BV, including trickle vents and air bricks, is added as an IAQ enhancement method to one of the classrooms where mechanical ventilation is operating but insufficient to achieve acceptable IAQ level, which is considered below 1000 ppm according to Building Bulletin 101 guidelines [7]. IAQ is measured based on the $CO_2$ level of the occupied zones, and the objective of the study is to compare the classroom's IAQ with and without BV implementation during different seasons of the year.

# 2 Materials and Methods

## 2.1 Case study

In this study, a three-story college building located in Greater London is simulated using CONTAM. The building has a total floor area of 2500 $m^2$. The floor height of the ground and first floors is 3.6 m, while the second floor measures 3.15 m, including the plenums. The building is equipped with an air handling unit (AHU) to provide mechanical ventilation. Each room has supply and return diffusers, maintaining a total ventilation rate of 1446 L/s.

All the windows in the building are fixed to mitigate noise pollution from the airport nearby. However, to compensate for the fixed windows, the impact of installing BV, as a natural ventilation method, on the IAQ is analyzed.

### 2.2 Simulation method

Indoor and outdoor contaminants with flexible schedules and generation rates can be defined in CONTAM. Through a comprehensive simulation of the entire building in CONTAM, airflow patterns, and the dispersion of contaminants through cracks and leakages, etc can be investigated. The IAQ modeling in CONTAM combines a multi-zone airflow model and mass balance equations.

In the CONTAM model of the building, plenums are considered as separate floors. Furthermore, interior and exterior wall and floor leakages are defined to calculate airflow between the outdoor areas and different zones and floors, with wall leakages defined in three elevations to capture the stack effect [5]. All zones are assumed to be well-mixed, ensuring uniform temperature, pollution levels, etc. throughout. Simulation time-step is 3 minutes. London Test Reference Year (TRY) weather data from the Chartered Institution of Building Services Engineers (CIBSE) is used in the simulation. The indoor source of $CO_2$ is the occupants' exhalation, with a generation rate of 0.0042 L/s. Furthermore, the outdoor $CO_2$ concentration and its initial level in all zones are assumed to be 400 ppm.

A trickle vent is one of the passive background ventilation methods which can be implemented in retrofitting process and is especially effective in buildings with several windows. Trickle vents with an equivalent area of 6000 $mm^2$ from the Titon manufacturer [8] have been selected and defined as orifice flow paths in the CONTAM model.

Additionally, air bricks from the same manufacturer, with an equivalent area of 10,500 $mm^2$, are added to the model. These background ventilations comply with UK building regulations part F and remain open at all times.

## 3 Results

This study focuses on the performance of BV when combined with the building's current ventilation system, specifically in one classroom. Fig. 1 displays the first-floor model of the building in CONTAM, with the location of BV in the selected classroom indicated by arrows at the bottom of the figure. It should be noted that the occupancy schedule for this classroom remains consistent throughout the year. Fig. 2 illustrates the impact of installing BV on $CO_2$ concentration in the selected classroom over the course of a year

Table 1 represents the average $CO_2$ concentration during occupied time with and without BV in different seasons. Moreover, $CO_2$ levels are divided into three intervals: $CO_2$>1000 ppm, $CO_2$>1200 ppm, and $CO_2$>1500 ppm for further comparison, as presented in Table 2.

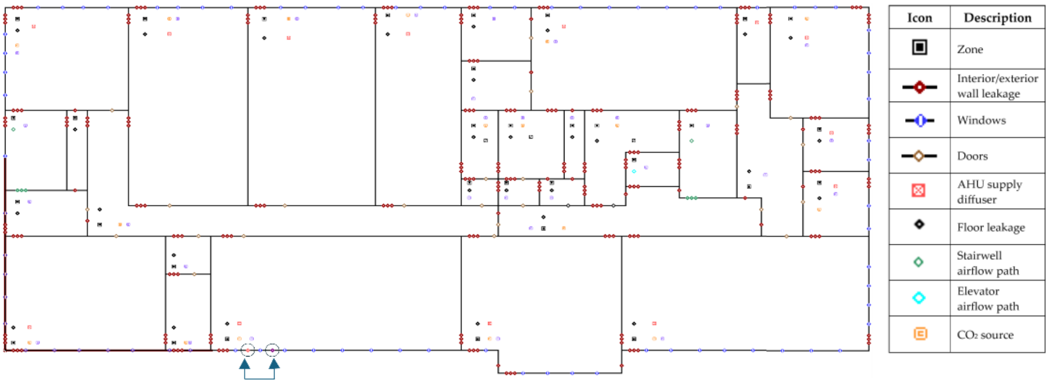


**Fig. 1.** First floor model of building in CONTAM showing the location of BV at the bottom.

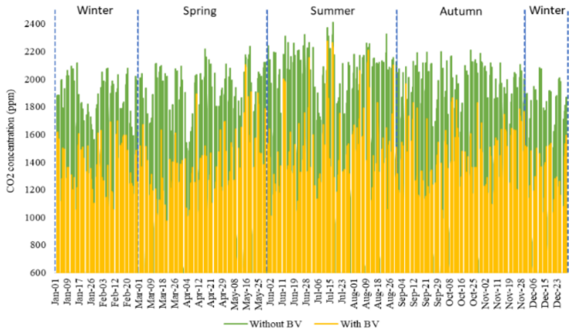


**Fig. 2.** $CO_2$ concentration with and without BV during whole year

**Table 1.** Comparison of average $CO_2$ concentration with and without BV in different seasons

| | With BV (ppm) | Without BV (ppm) | Improvement (ppm) |
|---|---|---|---|
| Spring | 1120.9 | 1395.4 | 274.5 |
| Summer | 1184.1 | 1489.1 | 305.0 |
| Autumn | 1149.5 | 1406.2 | 256.7 |

**Table 2.** Percentage of $CO_2$ concentration during occupied time

| | $CO_2$>1000 ppm (%) | | | $CO_2$>1200 ppm (%) | | | $CO_2$>1500 ppm (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | With BV | Without BV | Improvement | With BV | Without BV | Improvement | With BV | Without BV | Improvement |
| Winter | 66.7 | 73.5 | 6.8 | 38.3 | 63.0 | 24.7 | 6.0 | 45.8 | 39.8 |
| Spring | 66.7 | 76.0 | 9.3 | 42.7 | 65.7 | 23 | 9.2 | 48.6 | 39.4 |
| Summer | 70.4 | 79.4 | 9.0 | 49.6 | 69.7 | 20.1 | 16.3 | 54.6 | 38.3 |
| Autumn | 69.1 | 75.3 | 6.2 | 46.2 | 65.5 | 19.3 | 13.6 | 50.1 | 36.5 |

## 4 Discussion

As indicated in the Table 1 and Fig. 2, the building's existing ventilation system without BV, fails to maintain $CO_2$ levels below 1000 ppm, with the highest and lowest average levels observed during summer and winter, respectively. However, the introduction of

BV results in a decrease ranging between 250.8 ppm and 305.0 ppm in average $CO_2$ levels during occupied periods across different seasons, with the highest reduction in summer and the lowest in winter. Despite this improvement, Fig. 2 illustrates that BV alone does not ensure acceptable IAQ. Both this study and a previous research [3] suggest that the airflow from BV can be changed during different seasons or different sides of the building and depends on factors such as the wind speed and direction.

Furthermore, the implementation of BV demonstrates better performance in reducing the percentage of $CO_2$ levels exceeding 1500 ppm throughout the seasons, showing a 38.5% average seasonal reduction. With BV, only 6.0%, 9.2%, 16.3%, and 13.6% of occupied time during winter, spring, summer, and autumn, respectively, experience $CO_2$ levels above 1500 ppm, compared to nearly half of the time without BV. Therefore, BV proves beneficial in achieving a moderate level of IAQ (below 1500 ppm). Furthermore, after BV installation, in 29.6 % of occupied time in summer, the $CO_2$ level is below 1000 ppm, representing a 9.0 % increase compared to the BV-absent scenario.

## 5 Conclusions

This paper investigates the impact of installing BV in a classroom. Results indicate that BV performance depends on outdoor conditions, such as wind speed, and may be inconsistent, potentially less effective during certain periods.
Although BV helps reduce indoor $CO_2$ levels, it alone may not achieve levels below 1000 ppm when the ventilation rate is low. To ensure acceptable IAQ, BV should be combined with other IAQ improvement methods, such as opening windows and increasing ventilation rates.

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