Evaluating the IAQ and energy performance of two types of ventilation systems in multifamily buildings

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SUMMARY

This study evaluates the performance of Single-Flow and Dual-Flow ventilation systems in a residential building situated in Strasbourg, characterized by high $PM_{2.5}$ levels, permeable tightness, and strong wind conditions. The research examines indoor air quality by measuring CO_2 and $PM_{2.5}$ concentrations in bedrooms and compares the energy consumption of both systems across different cities. The findings indicate that the Dual-Flow system effectively maintains CO_2 levels between 500 and 1000 ppm, significantly reduces peak $PM_{2.5}$ levels, and demonstrates superior energy efficiency, particularly with heat recovery system Conversely, the Single-Flow system shows limitations in controlling indoor air quality and higher energy consumption. Overall, the Dual-Flow ventilation system proves to be a more effective solution for enhancing indoor air quality and achieving energy savings in residential buildings under similar environmental conditions.

KEYWORDS

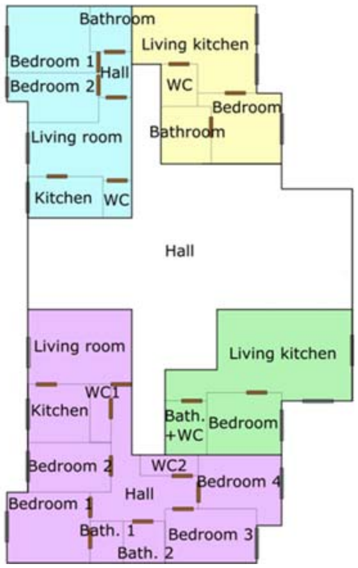
Indoor Air Quality, energy efficiency, building simulation, balanced ventilation systems, multifamily residential buildings

1 INTRODUCTION

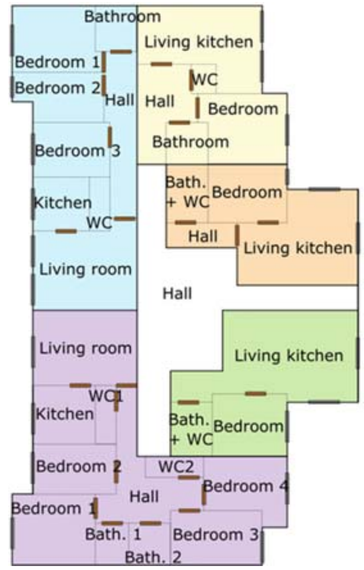
People spend most of their time indoors, exposing themselves to indoor pollutants that can cause health issues and affect productivity (WHO, 2010; Wargocki et al., 2006; Fisk, 2000). Residential buildings are critical as they account for 60 to 95% of lifetime airborne pollutant exposure (Borsboom et al., 2016). Indoor pollutants come from outdoor air and indoor activities. Improving air quality relies on increased ventilation, which is energy-intensive in temperate climates. Current standards use a prescriptive approach based on ventilation rates rather than pollutant concentrations (Chenari et al., 2016; Guyot et al., 2018). A performance-based approach, predicting pollutant concentrations through simulations, is more effective for assessing Indoor Air Quality (IAQ). This study compares the performance of Single-Flow and Dual-Flow ventilation systems installed in a two-storey residential building in terms of bedrooms' confinement, bedroom's $PM_{2.5}$ pollution level and energy consumption.

2 METHODOLOGY

The studied case is a residential two-storey building composed of 9 apartments of different sizes (Figure 1). The envelope airtightness of the building is low according to European standard EN 12831 (2017). Wind speeds imposed in this study can be considered as strong and are close to the conditions met in urban cities such as Helsinki, Athens or Strasbourg. The outdoor pollution ($PM_{2.5}$) is set to a high pollution level i.e. with a mean annual $PM_{2.5}$ concentration higher than 20 µg/m³ with peaks frequently reaching 50 µg/m³ and even 100-300 µg/m³ during winter. Simulations are performed with HEAVENLY (Holistic Evaluation tool for Air VENtiLation sYstems) based on a TRNSYS-CONTAM dynamic computations of heat, moisture, and pollutants (CO_2, Formaldehyde and $PM_{2.5}$) as described in Kiani et al. (2024).



a)



b)

Figure 1: Representation of the 1st floor (a) and 2nd floor (b).

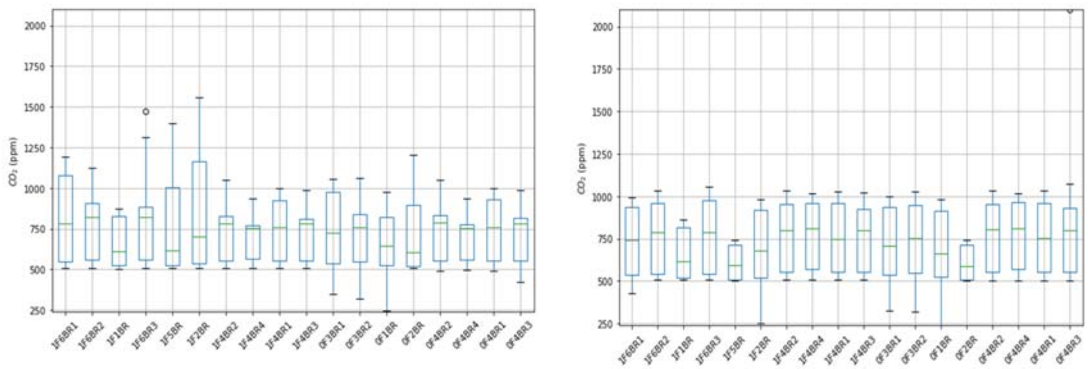
3 RESULTS AND ANALYSIS

3.1 CO_2 Concentration in bedrooms

Figure 1 illustrates the CO_2 concentration levels in the bedrooms for both Single-Flow and Dual-Flow ventilation systems. The Dual-Flow system effectively maintained CO_2 levels between 500 and 1000 ppm, demonstrating well-controlled ventilation. However, despite showing good control level CO_2, the Single-Flow system revealed shortcomings in keeping indoor air quality at an optimal level.

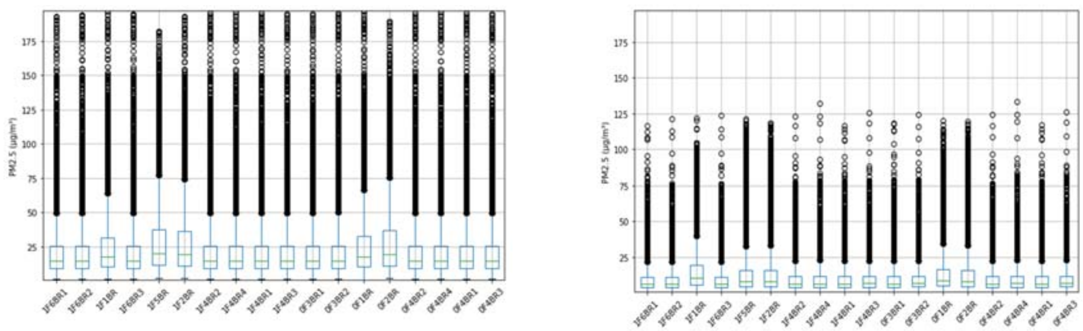
3.2 $PM_{2.5}$ Concentration in bedrooms

Figure 2 depicts the $PM_{2.5}$ concentration levels in the bedrooms. High $PM_{2.5}$ values were mainly due to outdoor pollution. The figure also highlights the effectiveness of the filtration system ($ePM_{2.5}$ = 60%) in the Dual-Flow ventilation, significantly reducing peak levels and showing a clear improvement in overall air quality.



a) Single-Flow b) Dual-Flow

Figure 2: CO_2 concentration in bedrooms – Single-Flow (a) versus Dual-Flow (b).



a) Single-Flow b) Dual-Flow

Figure 3. $PM_{2.5}$ concentration in bedrooms – Single-Flow (a) versus Dual-Flow (b).

3.3 Energy Consumption for different geographical locations

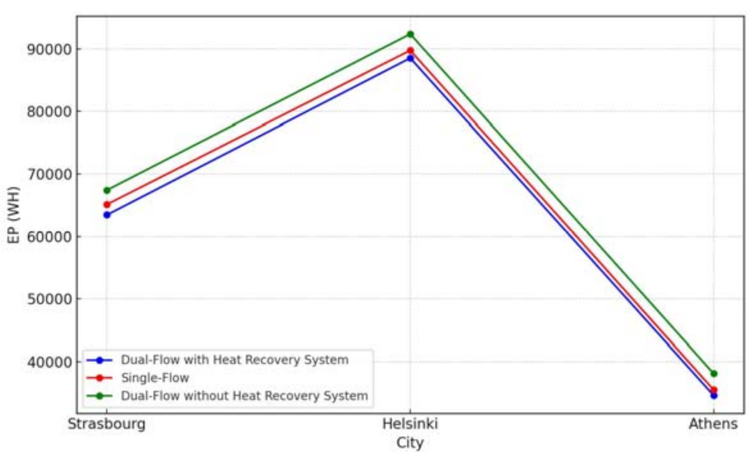


Figure 4. Comparison of energy consumption in different cities

Figure 3 compares the sum of the energy consumed by the fan(s) (electricity) and that due to thermal losses related to air renewing (gas). The resulting annual energy consumption (EP in Wh) is expressed here in terms of primary energy considering a final-to-primary energy conversion factors of 1 for gas and 2.5 for electricity. Calculations have been made to three cities presenting cold (Strasbourg and Helsinki) to mild (Athens) winters. The data shows that the Dual-Flow with heat recovery system consistently consumes less energy than the Single-Flow system. This demonstrates the energy efficiency of the Dual-Flow system, particularly in reducing heating energy needs and highlighting its potential for significant energy savings. Note that the energy consumption for dual flow without HR is higher than the single flow one because of a slightly higher airflow rate used for Dual-Flow and because of the additional fan electricity consumption.

4 CONCLUSION

The Dual-Flow ventilation system with Heat Recovery outperforms the Single-Flow system in both maintaining air quality and energy efficiency. It is a superior choice for residential buildings, especially under conditions like those of the present study, particularly the elevated outdoor pollution. However, the performance of mechanical ventilation systems in terms of IAQ and energy consumption depends on the outdoor pollution, wind intensity and building exposure, air tightness of the building envelope, urban/semi-urban site, climatic conditions… The HEAVENLY tool is designed to comprehensively assess mechanical ventilation systems by computing specific indicators for IAQ and energy consumption.

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