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# Dusty Outdoor Air and Natural Ventilation: A Case Study on IEQ and Energy



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Natural ventilation (NV) presents an attractive solution for achieving high energy performance and indoor environmental quality (IEQ). Yet, dusty outdoor air poses a threat to building occupants. Our study of a low-energy, high-IEQ office building in the Mediterranean region revealed indoor particulate levels that met WHO standards, even amidst dusty conditions, affirming the effectiveness of well-designed NV.

**Keywords:** passive ventilation, office building, particulate matter, pollution penetration, indoor/outdoor ratio, climate change, energy consumption

## Introduction

Natural ventilation (NV) offers energy savings and improved thermal comfort and indoor air quality (IAQ) when properly implemented and operated (Flourentzou et al., 2017). However, concerns exist regarding the ability of NV buildings to protect occupants against outdoor air pollution (Stabile et al., 2017), especially particulate matter (PM), amidst rising dust levels due to climate change in Mediterranean regions (Achilleos et al., 2023). Considering that arid and semi-arid dusty environments encompass a significant portion of the planet and accommodate billions of individuals worldwide (Katra & Krasnov, 2020), this study investigates whether an energy-efficient NV building can sustain adequate IAQ in such conditions.

## Case study building

We conducted measurements in a building located in Cyprus, an island with a semi-arid Mediterranean climate characterized by mild winters and hot summers. The building, part of the Nicosia Town Hall complex, is classified as energy class A and designed according to bioclimatic principles. It accommodates administrative offices and operates from 7 am to 4 pm on weekdays.

The building relies on NV, with no mechanical ventilation systems. Each area is equipped with air conditioning units (AC) recycling indoor air, ceiling fans, and blinds to enhance occupant comfort, with users managing these elements.

## Monitoring and survey plan

We monitored indoor air temperature, relative humidity (RH), $CO_2$ levels, and size-resolved PM concentration, along with outdoor temperature, RH, and PM concentrations. This data collection spanned from April 2021 to December 2022 for temperature, RH, and $CO_2$, recorded every five minutes, with PM measurements taken every minute from July to December 2022. Sensor positions are shown in **Figure 1**. Additionally, we monitored the building's total energy consumption to evaluate its actual usage compared to the predicted values outlined in the energy performance certificate.

To assess user perception of IEQ, interviews were conducted with 16 building occupants across six different spaces. These interviews covered various aspects including thermal comfort, air quality, ventilation, acoustic and visual comfort, and overall building satisfaction, with ratings provided on a scale from 1 to 5 (1 representing poor and 5 indicating exceptional).

## Indoor and outdoor PM levels

As presented in **Figure 2**, indoor average $PM_{2.5}$ concentrations during work hours ranged from 4.4 to 5.1 µg/m³, meeting WHO guidelines (2021) in 4 out of 5 spaces, while outdoor $PM_{2.5}$ averaged at 7.4 µg/m³. Indoor $PM_{10}$ levels varied more, averaging between 13.8 and 19.9 µg/m³, with WHO compliance in 2 out of 5 spaces. All indoor levels remained below 20 µg/m³, indicating generally acceptable levels, while outdoor $PM_{10}$ averaged at 38.1 µg/m³. Elevated indoor $PM_{10}$ levels exceeding the WHO limit may be attributed to high concentrations of coarse particles compared to the fine ones ($PM_{2.5}/PM_{10}$ ratio ~ 0.2), and particle resuspension from occupant activities, given the absence of other notable indoor sources.

In terms of short-term exposure limits (24-hour average), outdoor PM levels exceeded daily exposure limits on 14 days for $PM_{2.5}$ and 26 days for $PM_{10}$ over a 183-day period. Indoors, $PM_{2.5}$ exceeded the 24-hour average limit three times, while $PM_{10}$ never did. Hence, the building effectively protected occupants against short-term PM exposure, even during high outdoor levels.

## Hourly PM variation

**Figure 3** illustrates the fluctuating PM levels throughout the working days. Indoor $PM_{2.5}$ and $PM_{10}$ concentrations were higher during working hours (7-16h) due to outdoor infiltration via the NV and particle resuspension from occupant activities. Outdoor PM levels also varied, peaking during commuting hours (7-9h and 18-21h), suggesting a potential link to traffic. Morning peaks in indoor PM concentrations mirrored outdoor levels, likely due to

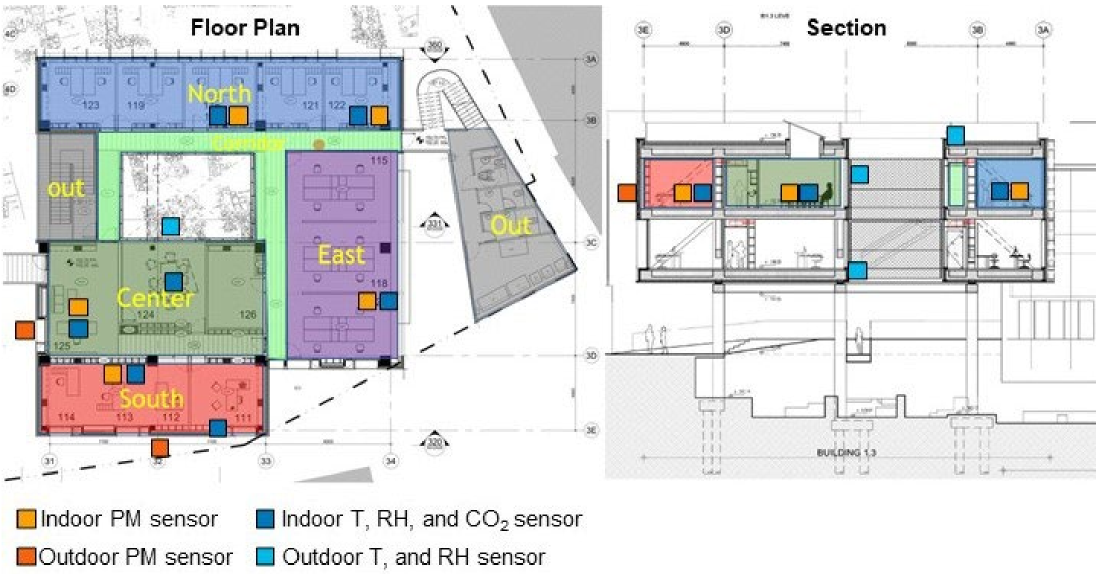


**Figure 1.** Sensor positions according to the buildings' zones.

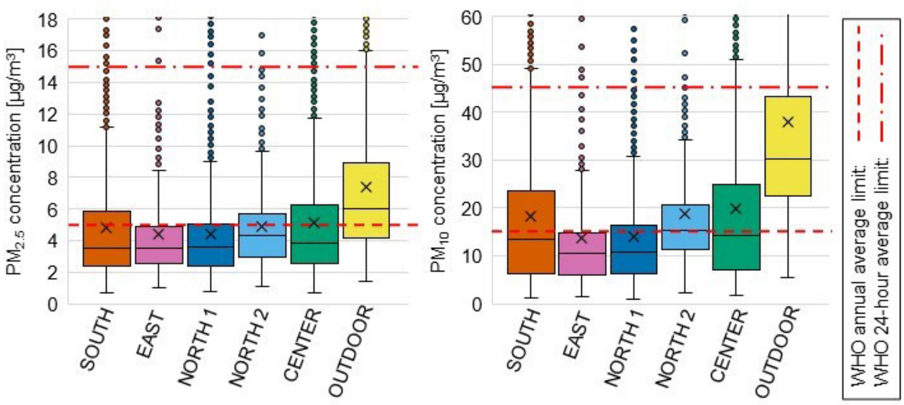


**Figure 2.** Indoor and outdoor $PM_{2.5}$ and $PM_{10}$ concentrations during working hours. Note: Box plots indicate the minimum, 1st quartile, mean (black cross), median and 3rd quartile, maximum and outlier values.

occupants opening windows during periods of high outdoor PM and increased particle resuspension from the arriving employees. Indoor-to-outdoor PM ratios were low, indicating outdoor air as the primary source of PM in the building. Considering the dynamic nature of outdoor air pollution, continuous PM monitoring could be implemented to optimize ventilation control in order to sustain high IAQ while minimizing energy consumption (Belias, 2023; Belias & Licina, 2022, 2023, 2024).

## Perceived IEQ

Occupant feedback indicated overall satisfaction with the thermal environment, except for one space experiencing discomfort during winter. Occupants were generally satisfied with IAQ, and they perceived indoor air as cleaner than outdoor air in terms of dust. Furthermore, the outdoor air ventilation rates were adequate as indoor $CO_2$ concentrations remained below 1000 ppm for 90% of the working hours. Visual comfort received positive feedback due to ample daylight, while acoustic quality was rated average, with reported issues regarding sound privacy. Overall, over 90% of occupants rated IEQ as exceptional or very good.

## Energy consumption

**Figure 4** illustrates the monthly expected energy consumption compared to the actual measured consumption from 2020 to 2022. In 2020, the building experienced a performance gap, consuming more energy than predicted due to inadequate maintenance of the AC units, which led to malfunction and overconsumption. Once the issue was addressed, actual energy consumption aligned with predictions, averaging 153 kWh/m²y ±10%, indicating a class A, energy-efficient building for the Cypriot climate.

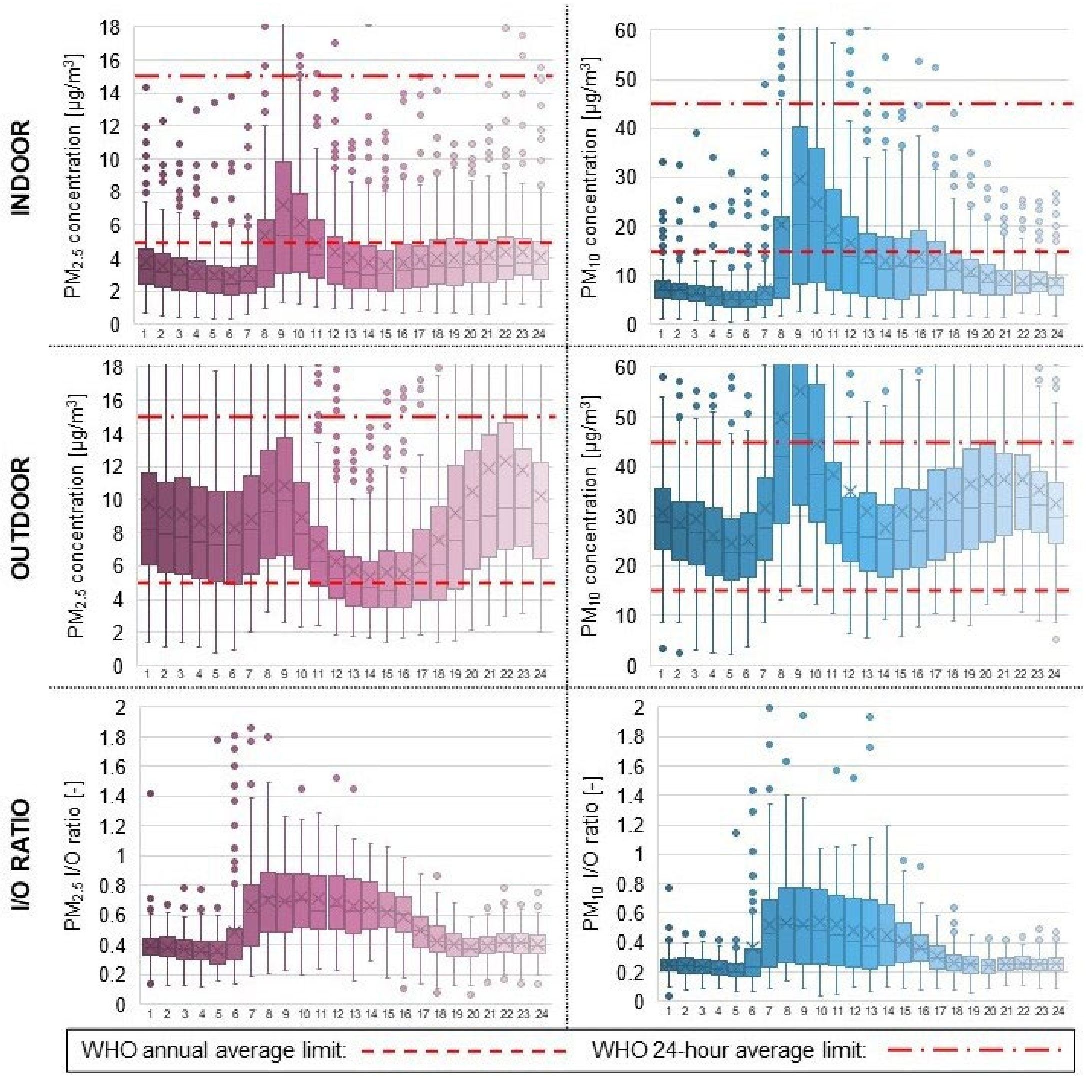


**Figure 3.** Hourly indoor and outdoor $PM_{2.5}$ and $PM_{10}$ concentrations as well as hourly indoor to outdoor $PM_{2.5}$ and $PM_{10}$ ratios.

## Conclusions

This study measured indoor environmental quality (IEQ) in a naturally ventilated (NV) office building situated in a dusty, semi-arid Mediterranean climate. Indoor $PM_{2.5}$ concentrations averaged at 4.4-5.1 µg/m³ during working hours, with outdoor levels at 7.4 µg/m³. Indoor $PM_{10}$ concentrations ranged from 13.8 to 19.9 µg/m³, compared to 38.1 µg/m³ outdoors. Most indoor PM levels met WHO guidelines, and $CO_2$ levels remained below 1000 ppm for over 90% of the time, indicating satisfactory indoor air quality. User satisfaction with IEQ mirrored these findings, with over 90% rating it as exceptional or very good. The building also demonstrated low energy usage, classified as energy class A. These results suggest that well-designed and operated energy-efficient NV buildings can maintain high IEQ standards, even in dusty outdoor environments. Further research is needed to investigate the impact of different ventilation techniques on IEQ and energy consumption across various building types in similarly dusty settings, promoting more sustainable building design.

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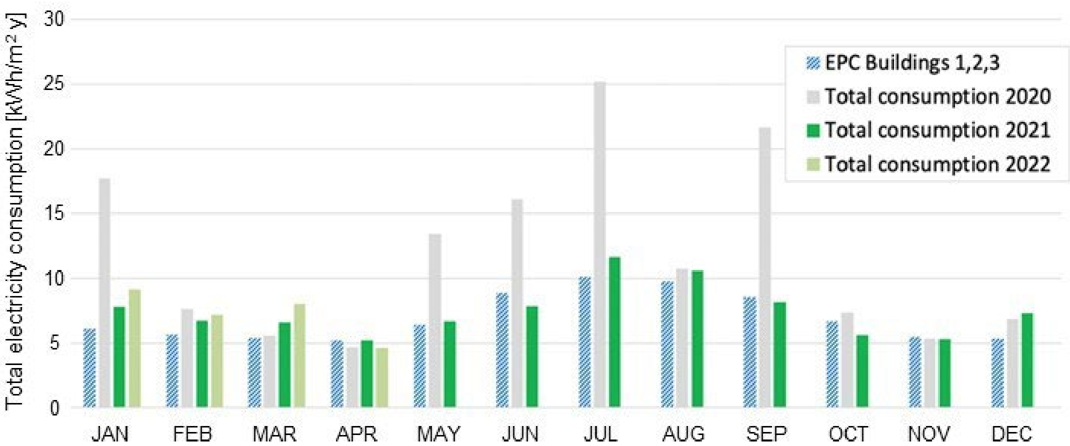


**Figure 4.** Monthly expected energy consumption according to the energy performance certificate (EPC) compared to the actual energy consumption during 2020-2022 years.

The original conference paper can be downloaded here: https://www.aivc.org/resource/can-naturally-ventilated-office-buildings-cope-dusty-outdoor-air