Proceedings of 12th Masters Conference: People and Buildings
University of Westminster, 15th September 2023
Network for Comfort & Energy Use in Buildings: https://www.nceub.org.uk

Evaluating Indoor Air Quality in Buildings

Yaqin Tang[1] Wenzhuo Li[2]* Valentina Marincioni[3]

[1] MSc Smart Architecture and Digital Engineering, University College London, UK, may include an institutional Gower Street, London WC1E 6BT ;
[2] PHD Smart Architecture and Digital Engineering, University College London, UK, may include an institutional Gower Street, London WC1E 6BT or correspondence email wenzhuo.li@ucl.ac.uk ;
[3] PHD Smart Architecture and Digital Engineering, University College London, UK, may include an institutional Gower Street, London WC1E 6BT

Abstract:

Indoor air quality plays a vital role in maintaining the health, comfort and well-being of building occupants. This report compares indoor PM2.5 and CO2 data, outdoor PM2.5 and NO2 data and weather station data against existing guidelines to analyse the differences in air quality between rooms and the potential causes of these conditions, in addition to explaining comparisons between pollutants and the frequency distribution of pollutant concentrations and exploring the possible causes. After illustrating the main findings, the building is modeled using DesignBuilder and the recommended interventions are found, briefly exploring the potential impact of the recommended measures on other aspects such as energy consumption, noise, thermal comfort etc.

Keywords: PM2.5,CO2,Demand-controlled ventilation,Indoor air quality,Designbuilder

1.Introduction

Indoor air quality is affected by a number of factors, the main sources being emissions of volatile organic compounds (VOCs) from building materials, furniture and cleaning agents.VOCs can cause short- and long-term health problems such as headaches, dizziness, respiratory problems, and may lead to cancer in the long term. Increases in indoor air quality parameters such as CO2, resulting from inadequate ventilation, may trigger headaches and fatigue and reduce cognitive function (Satish et al., 2012). In addition, poor ventilation may exacerbate the spread of airborne diseases, especially in crowded or poorly ventilated spaces such as classrooms, offices and hospitals (Morawska and Cao, 2020). Some studies have demonstrated that improving indoor air quality can improve cognitive function and performance in office and learning environments (Allen et al., 2016)(Mendell et al., 2013).

In conclusion, maintaining good indoor air quality is essential for the health, comfort and well-being of building occupants.

2.Methodology

This section describes the dataset categorization, identifies the data categories to be compared, and explains the analysis methodology. In addition, we provide the air quality criteria needed for the next section and explain the main reasons and practices for building the DesignBuilder model.

2.1 Descriptive Data

Table "CH_4_2017" presents comprehensive monitoring data from the UCL Center Building's Rooms 418, 416, and 413, as well as an outdoor weather station for the entire duration of 2017. This data encompasses PM2.5, CO2, temperature, humidity, and illuminance levels, recorded at 15-minute intervals. Additionally, external air quality data were procured from two distinct monitoring stations located in London during the same year.

Given the circumstance of missing data for Rooms 416 and 413, the study prioritized February 9, 2017—a weekday—as the focal reference point. This decision was motivated by two primary factors: the day's complete dataset and the significant influence of human activity on air quality parameters. Utilizing the data from this particular day facilitated an in-depth exploration into the correlation between indoor parameters, outdoor parameters, and meteorological data.

For a comparative study on the variance in air parameter concentrations across the three rooms, data from June 30, 2017, was employed. To further comprehend seasonal fluctuations in PM2.5 and CO2 concentrations, monthly averages of air quality parameters were plotted using data exclusively from Room 418.

2.2 Methods of Interpretation and Analysis

Statistical descriptions are used to quantify the data.Annual average concentrations are used to reflect long- term trends in indoor air pollution. Maximum and minimum values are used to reflect the severity and fluctuation of indoor air pollution. Standard deviation is used to describe the volatility and stability of indoor air pollutant concentrations.

2.3 Designbuilder Correlation Details

Building an IAQ model using DesignBuilder identifies major sources of pollution and evaluates control strategies and tradeoffs. We assessed IAQ based on basic building information, control strategies, and local weather data, and imported outdoor pollution data into the model to simulate real-world conditions. The table shows the modeling details for natural and mechanical ventilation settings.

Table 1 Important details in the Designbuilder modelling process

Windows	Settings
Natural Ventilation	Calculated
Windows Opening area	30%
HVAC Tab	natural ventilation checkbox
Openings	Schedule as Office_OpenOff_Occ Define% Glazing area opens as 30%
HVAC Tab:Mechanical Ventilation	4-Min fresh air(Sum per person+per area)
Location Tab	Outdoor Air CO2 and Contaminants tab
General Tab	Simulation period as 13-20 January

3.Results And Analysis

1.Annual mean and plural, median, standard deviation, maximum and minimum values for two outdoor monitoring sites (Bloomsbury and Camden Euston Road, London) and rooms 418.

Table 2 Provides a statistical description of the findings for the five monitoring sites (Because there are missing values, the conclusions here are only calculations based on the available data).

Statistical description	Annual average	Median	Plural	Maximum value	Minimum value	Standard deviation
CH_418_PM2.5 (ug/m3)	4.50	2.8	1	57.2	1	5.0
				Time:23/01/2017	Time:Many	

				02:15:00	moments	
CH_418_CO2 (ppm)	550.9	460.8	417	1838.87 Time:04/07/2017 16:00:00	381.2 Time:27/12/2017 09:45:00	233.9827
BL0_PM2.5 (ug/m3)	13.51	10.4	7.3	125.1 Time:23/01/2017 00:00:00	0.2 Time:02/01/2017 01:00:00	11.03
CD9_PM2.5 (ug/m3)	13.58	11.4	7.9	75.4 Time:26/01/2017 22:00:00 Time:08/09/2017 12:45:00	0 Time:08/09/2017 03:00:00 Time:17/06/2017 11:00:00	9.48

The WHO advises a PM2.5 annual average concentration below 10 µg/m³ (World Health Organization, 2021). While indoor PM2.5 adheres to this, the two outdoor sites don't. The ASHRAE standard sets a 1,000 ppm CO2 limit in places like offices, but the room often exceeds this. Contributing factors include inadequate building ventilation and cramped spaces. Outdoor NO2 affects indoor air, and with DEFRA setting a UK annual average of 40 µg/m³ for NO2, the Euston Road site indicates a need for better air quality measures.

2.Using data from 9 February 2017 and using line graphs to visually compare the magnitude and trend of outdoor data PM2.5 and indoor 418 data at Bloomsbury and Euston Road, London.

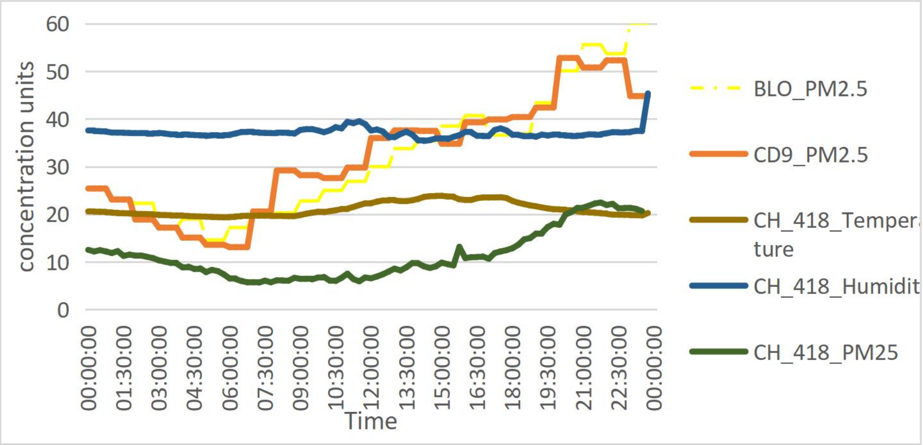

Figure1 Trend of outdoor PM2.5 versus weather-affected indoor conditions on 2 September 2017

The line graph illustrates that the PM2.5 concentration trends from the two outdoor monitoring sites on this particular day are remarkably consistent, with the lowest values observed during the early morning hours. This reduction can be attributed to decreased traffic, industrial production, and human activities (Elshorbany et al., 2021), compounded by the lower altitude of the stable atmospheric layer, which constrains pollutant dispersion (Wang et al., 2018). Throughout the day, the readings from both sites remained proximate. The indoor PM2.5 concentrations in Room 418 consistently registered values below the outdoor levels, exhibiting minimal diurnal fluctuations. Elevated concentrations during nighttime are likely due to the closure of windows, leading to diminished ventilation. The chart further depicts subtle variations in meteorological data, with notable exceptions being a significant midday surge in solar radiation and considerable fluctuations in wind direction originating from the north.

3.Using line graphs, we visualized the comparison of outdoor NO2 and indoor data for 418 in Bloomsbury and Euston Road, London, from 9 February 2017.

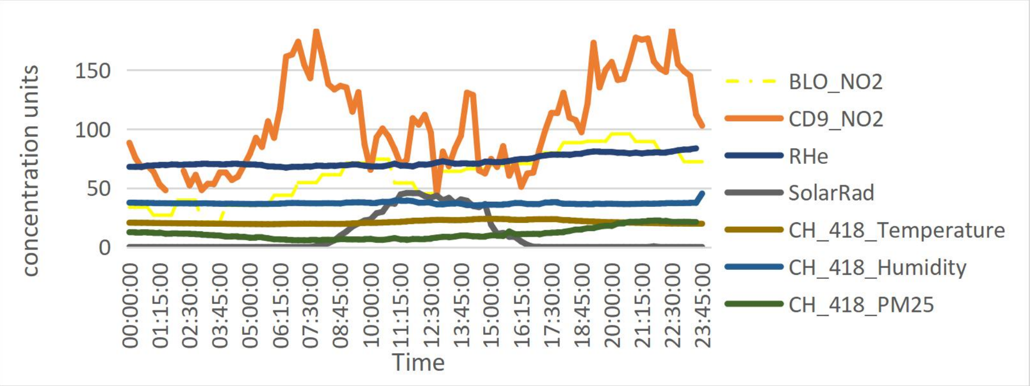

Figure2 Trend graph of outdoor NO2 and indoor conditions on February 9, 2017

The NO2 concentrations at Euston Road are significantly higher than Bloomsbury and even double during peak hours, probably because Euston Road is a transportation hub with a train station and a subway station. However, the trends are similar, such as a significant increase in the morning and evening, which may be due to the high volume of traffic at these times of the day, resulting in increased NOx emissions from vehicle exhausts.

4.A-line graph was used to visually compare the magnitude of the values and trends in pollutant concentrations in the three rooms for the day of 30 June 2017.

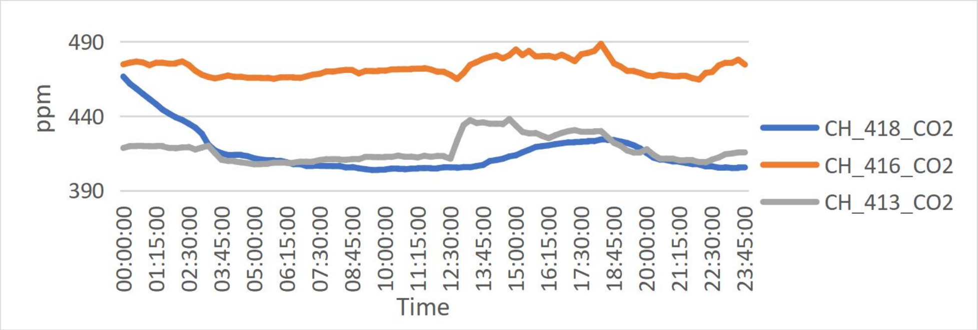

Figure 3 Magnitude of values and trends in pollutant concentrations (CO2) in the three rooms on 30/6/2017

The graph indicates that indoor PM2.5 levels surpass outdoor ones during morning and evening, and CO2 spikes in the afternoon, pointing to poor ventilation during these times, possibly from increased activity. While the three rooms are mostly similar, a notable difference arises at 3:00 p.m. Room 418 maintains the best air quality. Room 416, despite being a separate office like 418, has higher CO2 due to 1-3 more occupants. Room 413, an open space with more foot traffic, has CO2 levels lower than 416, likely because of its closer proximity to the outdoors.

5.Monthly averages plotted the seasonal variations of PM2.5 and CO2 for room 418, and PM2.5 and NO2 for the two monitoring sites.

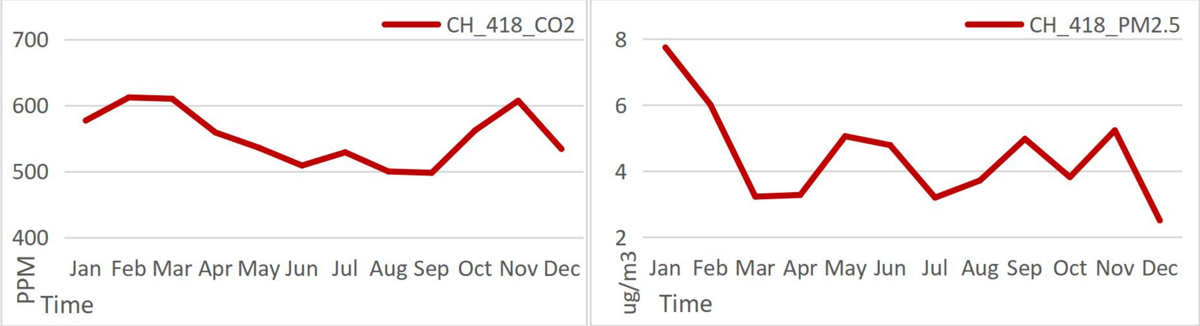

Figure 4 Seasonal variation of CO2 and PM2.5 in room418

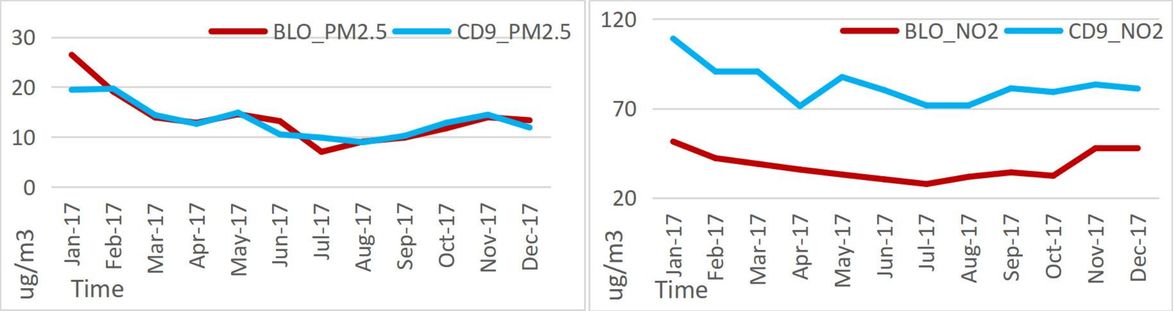

Figure 5 Seasonal variation of PM2.5 and NO2 in Outdoor monitoring stations

Room 418 has the lowest CO2 levels in summer, likely due to the use of air conditioners bringing in fresh air. However, both indoor and outdoor PM2.5 levels peak in January, influenced by cold weather, heating needs, and limited pollutant dispersion. Similarly, outdoor NO2 is higher in winter, affected by heating, weather conditions, and increased emissions.

4.Discussion

The key strategies for improving air quality in buildings are the following:

Table3 Key strategies to improve indoor air quality

Key Strategy	**Explanation**
Maintain good ventilation	Reasonable ventilation can be effective in controlling indoor air quality. This can be achieved using mechanical ventilation systems, natural ventilation systems or a combination of the two.
Carry out indoor air purification	In the case of serious air pollutants, consider setting up indoor air purifiers and other equipment to effectively remove pollutants from the indoor air and improve indoor air quality(Wolkoff, 2018).
Use low-pollution building materials	In the process of building design and decoration, you should choose low-pollution building materials as far as possible to reduce the release of harmful substances(VOCs)
Control humidity	Maintaining appropriate indoor humidity can effectively reduce the concentration of indoor air pollutants and help maintain good indoor air quality. Ventilation and dehumidification should be maintained during humid seasons.
Establish no-smoking areas	Smoking indoors is strictly prohibited to avoid the impact of tobacco smoke on indoor air quality.
Increase indoor greenery	Growing some greenery indoors can help to absorb harmful substances from the indoor air, as well as beautifying the indoor environment.

In room 418, we implemented an intervention to control ventilation based on actual CO2 levels and assessed the indoor air quality with this intervention. Demand-controlled ventilation is a type of ventilation that automatically controls the flow of indoor air according to the indoor CO2 level, in order to ensure indoor air quality.

Procedure: Go to the EMS Pollutant Control script, comment out the 'NoWindowControl' program and enable the 'CO2 Window Control' program. In the 'EnergyManagementSystem:Program' column, change the queue value.

Intervention: Control the window opening according to the indoor CO2 level and run DCVs with different CO2 quotas. use CO2 quotas of 800ppm, 1000ppm and 1200ppm. Compare the effect of the different CO2 ratings on indoor air quality (Figure11).

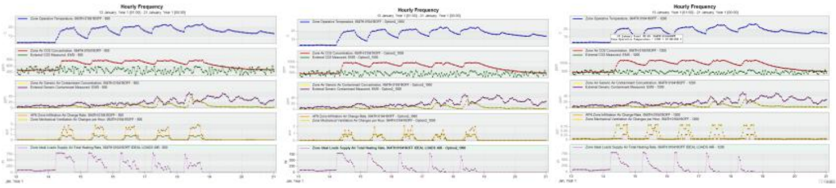

Figure6 The result of setting the CO2 quotient to 800ppm ,1000ppm,1200ppm

From the above results it can be observed that:(1).Zone air changes decrease with increasing queue: 3 times at 800ppm, 2 times at 1000ppm, and 0.80 times at 1200ppm.(2).External CO2 fluctuates between 350 and 600ppm, while indoor peaks rise with the threshold values: 800ppm, 1000ppm, and 1200ppm.(3).PM2.5 levels have minor variations across queue scenarios, but consistently peak near 50ug/m^3.(4).After implementing demand-controlled ventilation, indoor temperatures stabilize, aligning with optimal settings by week's end.(5).As the CO2 setting queue increases, total heating energy use in the room decreases. Lower queue settings lead to more frequent ventilation and increased heating use.

Demand-controlled ventilation also introduces:(1).Energy Consumption: It increases the HVAC system's energy usage, necessitating a balance between air quality and energy.(2).Noise: While open windows introduce external noise, demand-controlled ventilation can mitigate such disturbances.(3).Thermal Comfort: This system adjusts room comfort by controlling ventilation, requiring apt control parameters.

5.Conclusion

Indoor air quality involves factors such as pollutant concentration, temperature and humidity, which have a significant impact on people's health and comfort. Indoor air quality can be improved through better ventilation, use of air purifiers and environmentally friendly building materials.

Indoor air quality is even more important in the context of a COVID-19 pandemic, as viruses are often airborne. If indoor air quality is poor, it may increase the risk of infection.

In this report, we ensure indoor air quality by installing CO2 sensors and automatically controlling the ventilation system. This approach not only improves air quality but also reduces energy consumption. In addition, it increases indoor comfort and reduces noise.

Ventilation in cellular buildings is often difficult, but by installing ventilation equipment it is possible to improve air quality.

This report intervenes only on CO2, but in the future more data on pollutants including PM10, formaldehyde and benzene could be collected to improve indoor air quality more comprehensively.

References

1.Allen, J.G. *et al.* (2016) ‘Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments’, *Environmental Health Perspectives*, 124(6), pp. 805–812. Available at: https://doi.org/10.1289/ehp.1510037.

2.Elshorbany, Y.F. *et al.* (2021) ‘The Status of Air Quality in the United States During the COVID-19 Pandemic: A Remote Sensing Perspective’, *Remote Sensing*, 13(3), p. 369. Available at: https://doi.org/10.3390/rs13030369.

3.Morawska, L. and Cao, J. (2020) ‘Airborne transmission of SARS-CoV-2: The world should face the reality’, *Environment International*, 139, p. 105730. Available at: https://doi.org/10.1016/j.envint.2020.105730.

4.Satish, U. *et al.* (2012) ‘Is CO2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO2 Concentrations on Human Decision-Making Performance’, *Environmental Health Perspectives*, 120(12), pp. 1671–1677. Available at: https://doi.org/10.1289/ehp.1104789.

5.Wang, Y. *et al.* (2018) ‘Temporal and spatial variation relationship and influence factors on surface urban heat island and ozone pollution in the Yangtze River Delta, China’, *Science of The Total Environment*, 631–632, pp. 921–933. Available at: https://doi.org/10.1016/j.scitotenv.2018.03.050.

6.Wolkoff, P. (2018) ‘Indoor air humidity, air quality, and health – An overview’, *International Journal of Hygiene and Environmental Health*, 221(3), pp. 376–390. Available at: https://doi.org/10.1016/j.ijheh.2018.01.015.

7.World Health Organization (2021) *WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization. Available at: https://apps.who.int/iris/handle/10665/345329 (Accessed: 21 March 2023).