Paper Title
User performance Vs. Building performance: Re/defining the impact of sociocultural values on CO_2 levels in super-insulated homes.

DR **SATISH BK,** BARCH, MURP, PHD, FIIA, FITP, FHEA
Welsh School of Architecture, Cardiff University, UK
Satish.bk@cardiff.ac.uk

DR **SIMON LANNON,** PHD
Welsh School of Architecture, Cardiff University, UK
lannon@cardiff.ac.uk

Abstract
The Public Health England and Welsh Government reports indicate the living conditions as a key reason for higher morbidity and death rates among ethnic minorities. There is limited understanding of householders' cultural differences and their impact on spatial organisation and energy behaviour in dwellings. This study aims to examine the indoor CO_2 levels by data collected in Cardiff, UK by survey questionnaires and Indoor Air Quality (IAQ) Data Loggers to evidence the impact of sociocultural activities on indoor CO_2 levels by comparing White British and British Asian homes with similar house typology in the same neighbourhood. This project lays the foundations for larger-scale research on the sociocultural values of the users while redefining the building performance in light of environmental change.

Keywords Indoor air quality, energy behaviour, Ethnic minority, Indoor thermal comfort, low-carbon society

1.0 Introduction
The housing sector contributes roughly 27% of carbon emissions (1). Thus, meeting the 2050 carbon target necessitates constructing new homes to meet '2050 ready' standards (2). These standards entail building homes with robust insulation and regulated ventilation systems. Qualitative studies examining the user behaviour suggest that there might be no or limited window openings for natural ventilation, to avoid heat loss (3). The effectiveness of these well-insulated residences is contingent on various factors, including the behaviour and lifestyle of occupants. Given that households in the UK spend 80% - 90% of their time indoors (4), the quality of indoor air is increasingly linked to respiratory problems caused by nitrogen dioxide emissions from heating and cooking appliances (5).

Indoor air pollution stands as a prominent environmental factor contributing to approximately 4 million premature deaths globally (6). This issue particularly impacts women and children below the age of five, who spend considerable time indoors, accounting for up to 60% of these premature deaths (7). The deterioration of indoor air quality, especially due to increased exposure to particulate matter (PM), correlates with heightened hospital admissions, especially among older adults and individuals with underlying health conditions (8). Recent research underscores the significant impact of Indoor Environmental Quality (IEQ) on individuals' cognitive abilities, subsequently influencing their learning and productivity (9). Additionally, exposure to PM is associated with cognitive impairment and oxidative stress (10, 11).

Indoor air pollution is implicated in respiratory ailments and cancer-related fatalities. Its adverse effects encompass irritation, neurotoxic behaviour, and other detrimental impacts. Recent research indicates that household customs and ventilation practices significantly influence indoor air quality (7, 12). Understanding cultural disparities among homeowners and their impact on spatial organization and energy habits within residences remains limited. The quality of indoor air directly affects the health and overall well-being of inhabitants. The emergence of the airborne COVID-19 pandemic has underscored deficiencies in controlled ventilation systems, as highlighted in recent reports (13). While interventions enhancing efficiency can render homes more cost-effective to heat, they may concurrently worsen conditions like asthma due to diminished indoor air quality and ventilation.

The higher concentration of CO_2 leads to ill feelings, tiredness, lack of focus, and even nausea. The standards recommend maintaining indoor CO_2 levels below 1,000 parts per million (ppm) as a guideline for acceptable indoor air quality in buildings (14). When the CO_2 levels cross 1,000 parts per million (ppm), occupants feel drowsier affecting their comfort and performance. However, above 2,000 parts per million (ppm) CO_2 levels will have negative respiratory effects leading to headaches, fatigue, stuffiness, poor concentration, loss of focus, increased heart rate and nausea (14).

Extensive scientific literature emphasizes the pivotal role individuals (users/occupants) play in determining a building's energy consumption. Therefore, research focusing on indoor CO_2 levels and ventilation must encompass the socio-cultural behaviours of users (7). Furthermore, households often lack a comprehensive understanding of potential health implications and comfort levels stemming from their actions (12). Routine indoor activities such as cooking and cleaning contribute to the production and re-suspension of particulate matter (PM2.5) (15, 16). Studies indicate a three-fold increase in the risk of lung cancer with a rise in the number of meals prepared daily (17). Specific cooking methods inherent to cultural practices, such as frying, roasting, and grilling, can notably impact pollutant emissions (18).

Our research findings reveal distinctions in the utilisation of households between British Asians and White-British individuals concerning spatial arrangement, cooking patterns, and ventilation approaches, all influencing indoor air quality (19). Nevertheless, there is a noticeable scarcity of data and research establishing a connection between behaviour and indoor CO_2 levels. Moreover, comprehending the energy consumption patterns specific to ethnic minorities represents a relatively novel area of study.

The main aim of this research therefore is to gain a deeper understanding of the contextual factors, both social and physical, that surround cooking practices within distinct cultural and environmental settings. This is accomplished by investigating the influence of cooking on indoor CO_2 levels within British-Asian homes in contrast to white British homes through a detailed study of households in Cardiff, UK.

2.0 Methodology

To achieve the objectives of this study, an analysis of behaviour patterns and spatial utilisation, particularly concerning cooking practices and associated areas, is conducted through a comparative study between British-Asian households and native British households (referred to as White British). Survey questionnaires are employed to gather data on cooking habits and related aspects. A total of 117 homes; 60 British Asians and 57 White British Asians households completed the questionnaire survey. This questionnaire study is used to shortlist six comparable homes in the same neighbourhood with similar housing typology; construction, insulation, and spatial qualities: three occupied by British-Asian households and three native-British households. Further, households of these sets of houses are of similar age groups, occupations, and numbers. Assessments of air quality are performed in these homes during both summer and winter, utilising data loggers to quantify differences in mean daily temperature, relative humidity, and the air quality index. Specifically, GE Telaire 7001 Carbon Dioxide sensors are strategically placed within the kitchens of residences in Cardiff, UK, aimed at capturing variables related to indoor climate quality. These sensors collect data at 10-minute intervals over a minimum period of fifteen days. The placement of these loggers is carefully arranged to ensure they are shielded from potential sources of heat and direct sunlight, maintaining accuracy in the gathered information.

3 Analysis and discussion

Using the data loggers in neighbouring houses, nearly 4100 sets of data are collected over 15 days. The indoor air quality is analysed in terms of CO_2 level in the kitchens of British Asian and White British homes, first and the quality of ventilation and ventilation behaviour is analysed as ventilation decay in the second section.

3.1 Indoor Carbon Dioxide (CO_2) level

The literature review suggests that there will be a normal background concentration of 250 – 400 ppm in outdoor ambient air and up to 1000 ppm of CO_2 in occupied indoor spaces. Once the CO_2 concentration increases beyond 1000 ppm, occupants will experience health effects in buildings.

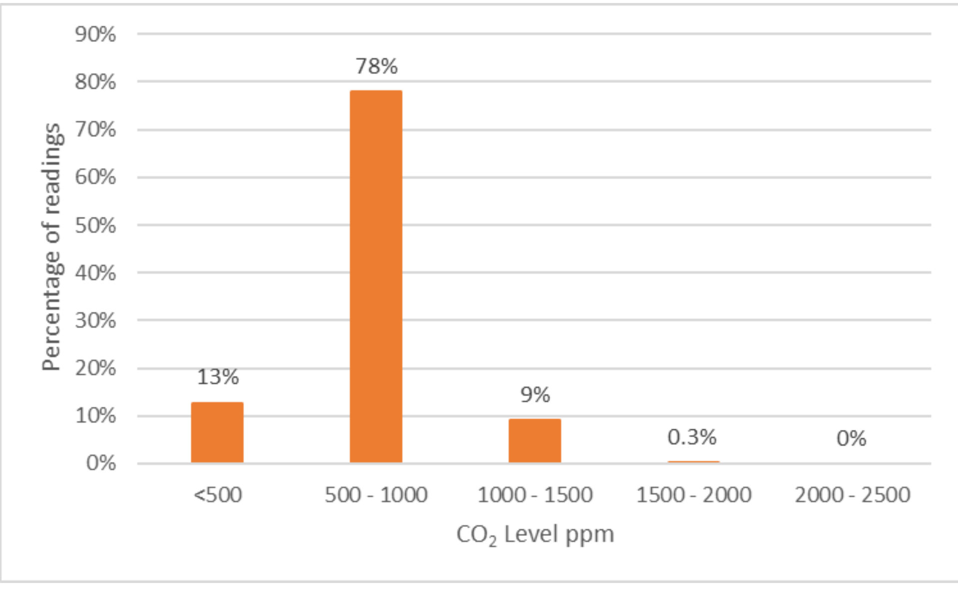

Figure 1: CO_2 concentration in the kitchen of a White British home

In the case of the two kitchens compared, the CO_2 level was below 90 per cent of the time below 1000 ppm in the White British home (Figure 1), whereas only 45 per cent of the time the kitchen air quality was below 1000 ppm. The comparison of air quality in the British Asian and White British house kitchens clearly demonstrates the poor air quality in the British Asian homes as nearly 13 per cent of the time the CO_2 level is more than 1500 ppm in the kitchen (figure 2).

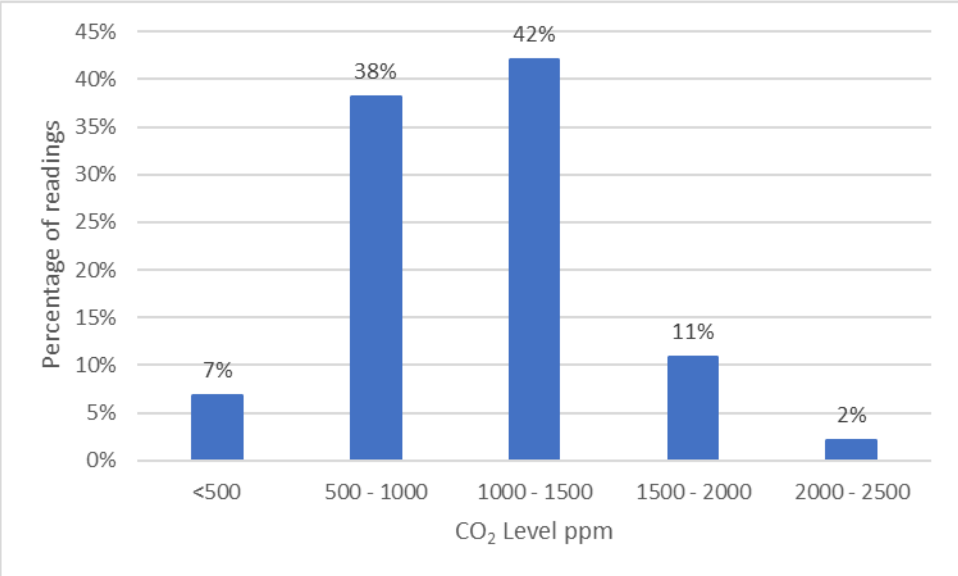

Figure 2: CO_2 concentration in the kitchen of a British Asian home

While comparing the CO_2 levels in the British Asian and White British homes. Barring a couple of days, the CO_2 level has been consistently higher in British Asian homes with many days CO_2 touching 2000 ppm and reaching 2500 ppm on three occasions (figure 3).

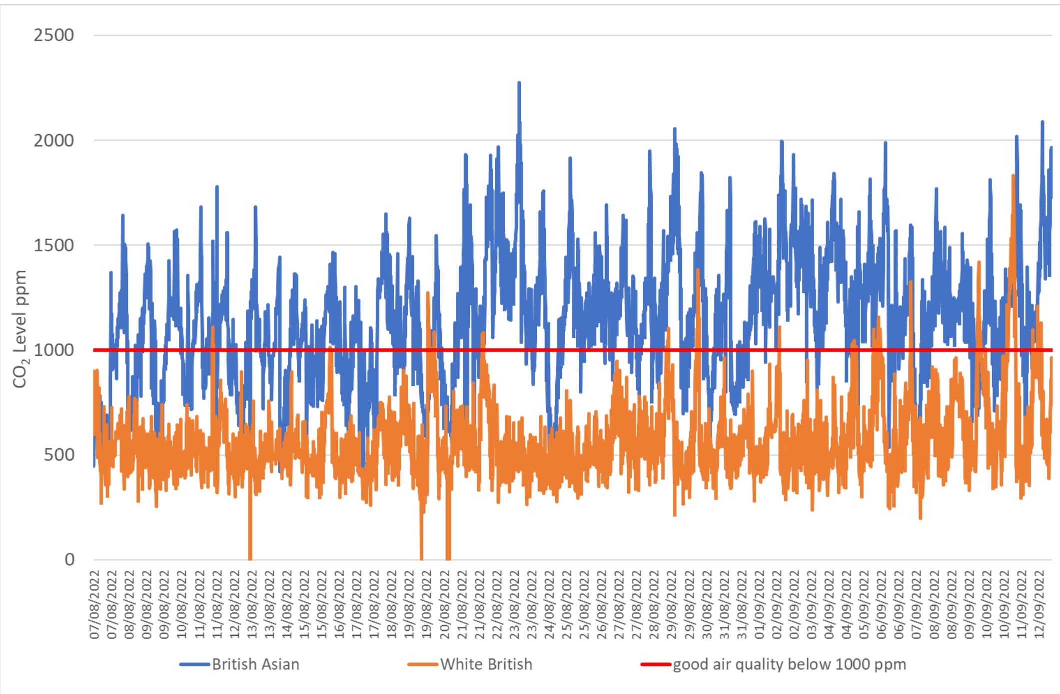

Figure 3: Comparative CO_2 level in the British Asian and White British home

Examination of a typical day distinctly illustrates the influence of cooking on CO_2 concentrations within kitchens. During the early morning hours from 2:00 am to 6:30 am, the CO_2 levels in both British Asian and White British homes are nearly identical (Figure 4). The questionnaire survey related to kitchen activities and cooking habits suggests similar usage of the kitchen space by British Asian and White British in terms of number of people and type of activities. The CO_2 levels begin to escalate in the British Asian household as kitchen activities commence in the morning. Due to the nature of cooking tasks, the CO_2 concentration consistently remains above 1000 ppm for the majority of the day and reaches its peak around 8:00 pm, coinciding with the conclusion of evening meal preparation. The increased CO_2 level could be attributed to a combination of activities like cooking practice on one hand and ventilation strategies like operation of extract fan and window openings, on the other.

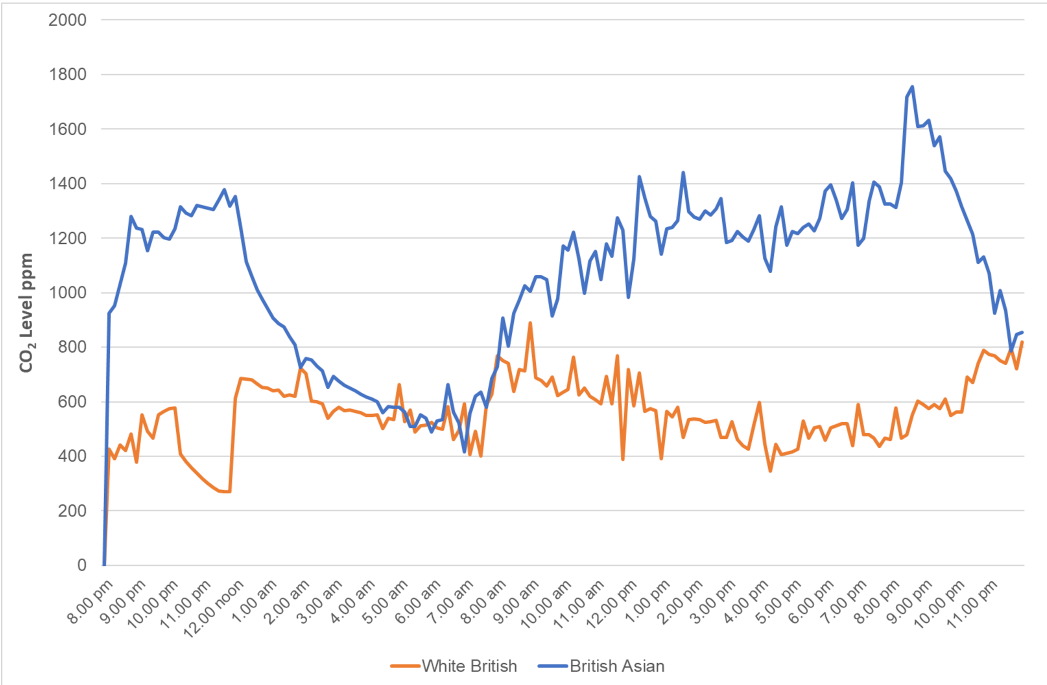

Figure 4: Comparative CO_2 level in the British Asian and White British home - one day

Further narrowing the analysis to three hours of the main meal cooking period clearly demonstrates a consistent increase in indoor temperature from the beginning until the end of the cooking period (Figure 5). The increase in indoor temperature and higher temperature in British Asian homes are attributed to individual behaviour driven by the cultural background of the residents (20, 21).

The CO_2 level in the kitchen in the case of White British House is pretty consistent and hovers between 600 – 800 ppm but goes beyond 1000 ppm only once at the peak of the cooking period. However, in the case of a British Asian house kitchen, the CO_2 level starts at the same level of around 600 ppm but quickly rises to above 1000 ppm. For nearly a hundred minutes, CO_2 is higher than 1000 ppm and it reaches 2000 ppm within an hour of the start of cooking and stays there for nearly forty minutes.

The CO_2 concentration in British Asian kitchens can be attributed to the type of cooking and also the duration of cooking. However, the lower CO_2 level in White British Houses could be attributed to the ventilation behaviour of the occupants and this could be measured in terms of ventilation decay and discussed in the next section.

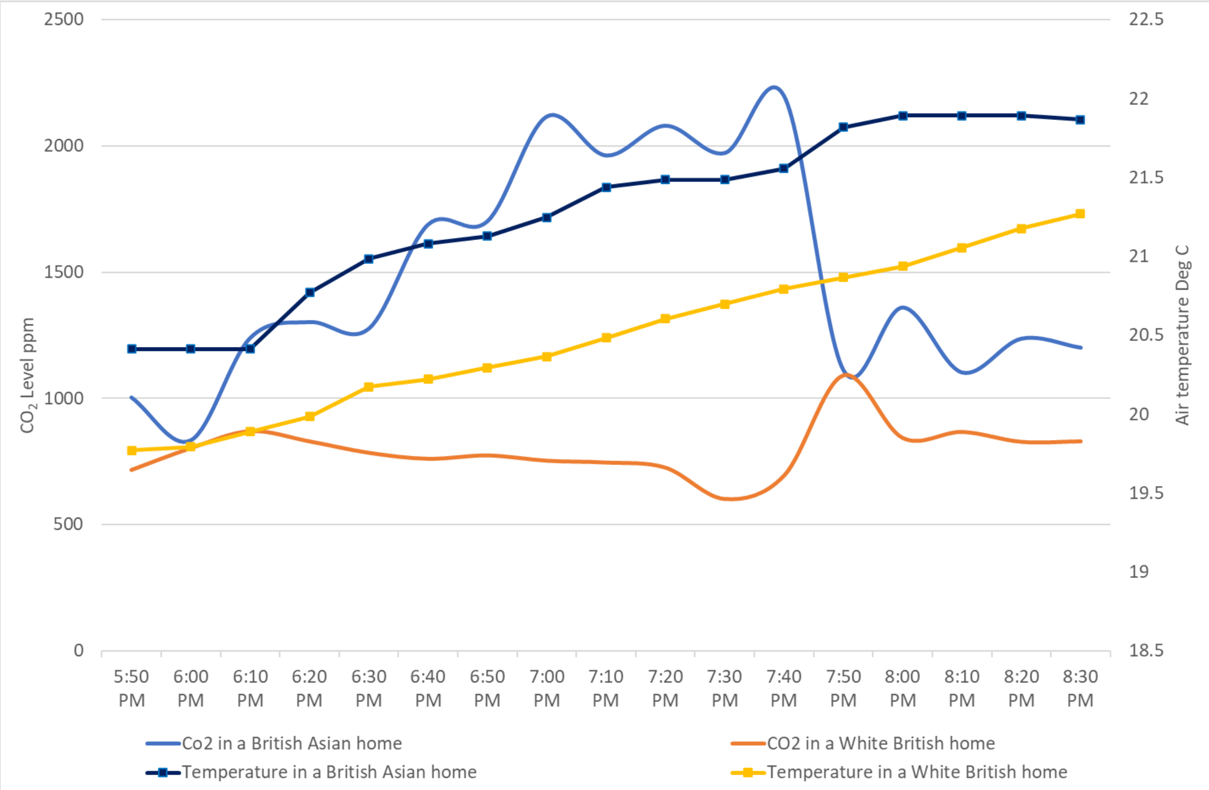

Figure 5: Comparative CO_2 level in the British Asian and White British home – three hours

The considerable contrast observed in CO_2 levels between British Asian and White British households can be attributed to several factors, predominantly stemming from differing cooking practices and ventilation routines within these homes. The prolonged and elevated CO_2 levels in British Asian households primarily result from extended periods of cooking activities. According to the survey, it was found that during weekdays, British Asians spend an average of 3.3 hours per day in the kitchen, while their White British counterparts spend approximately 1.5 hours per day on kitchen-related tasks. This gap widens significantly during weekends, with White British individuals spending around 1.75 hours per day cooking, whereas British Asians devote nearly 4.16 hours per day to culinary activities. These divergent durations of time spent in the kitchen contribute significantly to the discrepancies observed in CO_2 levels between the two demographic groups.

All the White British respondents (100%) reported that during weekdays in summer, they primarily keep their windows open. Conversely, approximately 16% of British Asian respondents indicated a habit of opening windows in the morning. A notable 22% of British Asian participants expressed a tendency to open their windows hardly ever, with nearly 40% reporting a window-opening duration of one to two hours in the morning. This behaviour exhibited a slight improvement during the weekend, dropping to 30%. During weekends, there is a higher inclination among British Asians to open their windows, with almost 30% of them doing so most of the time. The expressed concern primarily revolves around heat loss, evident in their propensity to keep windows closed for extended periods. About 30% of British Asian respondents never open their windows, and nearly 25% open them only for one to two hours in the evening. In contrast, the majority of White British respondents keep their windows open for a substantial duration.

3.2 indoor CO_2 levels analysis

Using the data collected during August to October in six homes in Cardiff the team were able to find all the decays to establish the variability of the air change rate, the detection of the decays was undertaken manually ensuring that the R-squared (R2) was above 0.8, a sensitivity test should be considered to see what threshold of R2 give consistent results.

GE Telaire 7001 Carbon Dioxide sensors were used to assess the pollution levels within kitchens, to ensure that the indoor environment is healthy. The air quality readings can be used to assess the ventilation performance of the space that the sensor is in. The technique used is a decay plot where after the pollution source has been removed the levels of air pollution decay (figure 6) due to mechanical and natural ventilation (22). This decay can happen for any gas or pollutant and is an established method for predicting the air change rate of a space.

The equation is:
$(Ct\text{-}Cbg) = (C0\text{-}Cbg)\ e^{-nt}$
Where

- Ct Pollutant concentration after time t
- Cbg background Pollutant concentration
- C0 initial Pollutant concentration
- n Air change rate per hour
- t time in hours

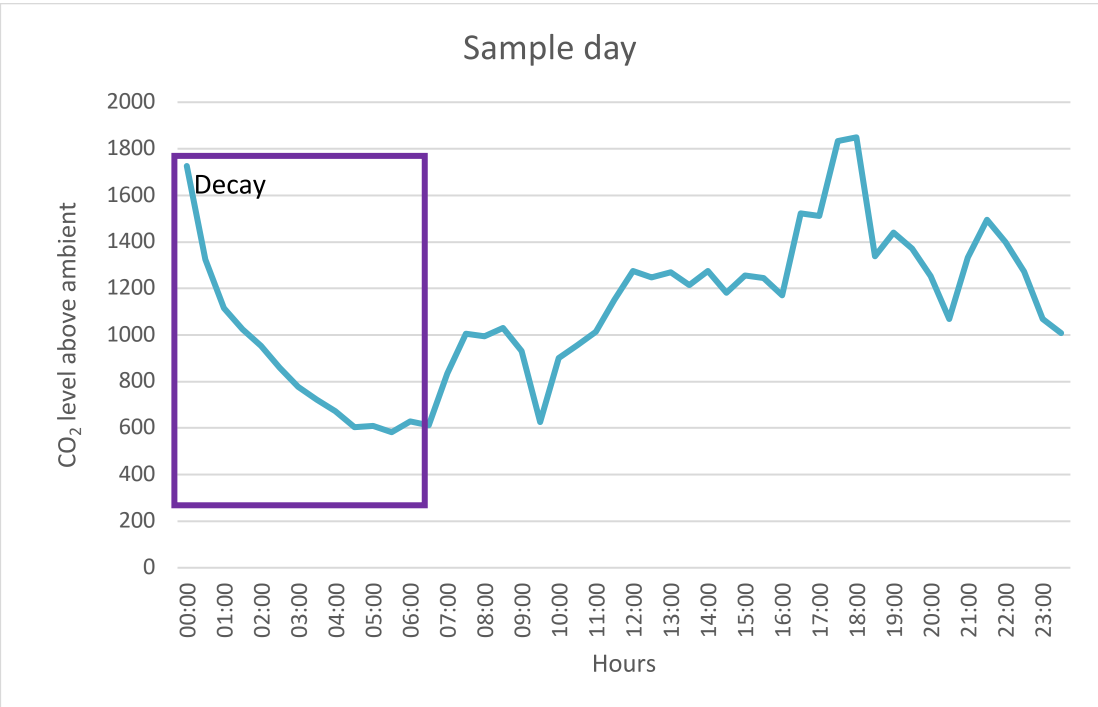

Figure 6: Sample CO_2 Decay

Across the six houses 41 decays were detected through the day (Figure 7). These decays can be considered as two types, one is the active intervention by the occupant (Active decay), the other is the decay is where no ventilation action has been taken, generally below 1ach (Passive decay). The decay analysis highlights the difference in behaviours as active decays are much higher than the background infiltration levels. The results show that many passive decays start at midnight, there are some passive decays in the day predominantly the British Asian, there are several active decays mostly from the British White occupants.

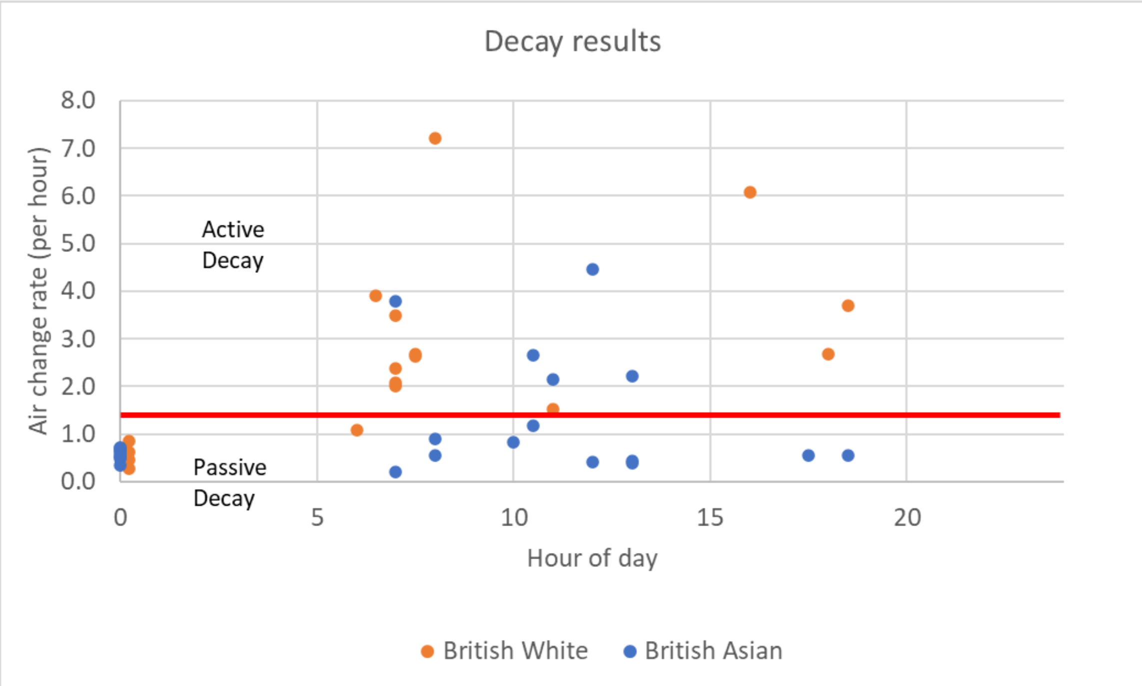

Figure 7: Kitchen CO_2 Decays from all homes

4 Conclusion

4.1 Applications for the research

The results of this study will be of key interest to government policymakers and building industry stakeholders. The study identifies the specific areas where homeowners' cultural behaviour impacts the air quality.

4.2 Summary

Recognising the necessity of constructing air-tight residences, it is essential to underscore the significance of accommodating lifestyle and cultural preferences. This study specifically concentrates on the relationship between cooking practices and indoor air quality as a social and cultural phenomenon. Exploring this aspect offers valuable insights for developing localized and contextually relevant indoor air quality and low-carbon strategies. Consequently, this research serves as a grassroots tool to facilitate the implementation of policies and targets established by professional bodies and the UK government.

The research presented in this paper, using both literature review and survey fieldwork, has underscored the resemblances and distinctions in the socio-cultural value systems prevalent in British and British Asian households, shedding light on their consequent impact on indoor air quality. Through the analysis of indoor CO_2 levels and questionnaire survey outcomes, this paper examined a pivotal aspect of lifestyle and cultural preferences.

The particular points are as follows:

1. Particularly higher levels of CO_2 in British Asian homes for a prolonged period of time are alarming and as discussed in the literature review, poor air quality in BA homes could put them at severe health risk.
2. Both household groups had passive decays that start at midnight, there are some passive decays in the day predominantly the British Asian, however, there are several active decays mostly from the British White occupants. This highlights the difference in ventilation behaviour between household groups.

4.3 Limitation and further research

Based on the findings obtained from survey questionnaires and CO_2 Data Loggers, this paper explored the influence of cultural behaviours, particularly cooking-related practices, on indoor CO_2 levels within households. To further enhance this research, future studies employing ethnographic surveys, household interviews, and environmental analyses could provide valuable insights. These complementary methods would aid in the comprehensive understanding and development of strategies to foster healthier living conditions in ethnic minority households.

The research highlights a direct correlation between social and cultural values and the energy-related behaviours exhibited by households. A more detailed investigation into specific aspects such as hourly activities within kitchens and other household spaces would offer deeper insights into how behaviours impact indoor air quality. This understanding is crucial for designing built environments that promote the health and well-being of households while fostering sustainable communities for the future.
In this paper, we have focused on higher CO_2 levels in the kitchen due to cultural practices – cooking and associated behaviour, and window openings. Further primary research is required to examine the impact of ventilation, and window opening behaviour on the indoor CO_2 level. In this paper, we have established the relation between cultural behaviour and its impact on indoor CO_2 levels and decay. The next stage of this work would be to develop inclusive design recommendations for future homes and raise awareness for better user performance.

It is important to note that this study focused on selected elements and was confined to the context of Cardiff and the British Asian community. Expanding this research to encompass diverse locations across the UK and various ethnic minority groups would contribute to a more comprehensive understanding of indoor air quality in ethnic minority households. This inclusive approach would facilitate the development of more informed policies regarding indoor air quality requirements, ensuring a more sensible and inclusive perspective in decision-making processes.

References

1. DECC, Treasury H. Policy paper - 2010 to 2015 government policy: greenhouse gas emissions. Committee on Climate Change, Department of Energy & Climate Change: https://www.gov.uk/government/publications/2010-to-2015-government-policy-greenhouse-gas-emissions/2010-to-2015-government-policy-greenhouse-gas-emissions; 2015.
2. Trust ES. Save energy at home: http://www.energysavingtrust.org.uk/; 2017
3. Satish BK, 'Beyond Energy- efficient Built Environment - Examining the Relationship Between the Users' Cultural Values and Energy Consumption'. SBE2019 International Sustainable Environment: Policy to Practice; 2019; Cardiff, UK 24 & 25 September 2019.
4. Group AQE. Indoor Air Quality. http://uk-air.defra.gov.uk; 2022.
5. Parliament U. UK indoor air quality, November 2010, Postnote 366. In: post-parliament-uk.abc.cardiff.ac.uk/research-briefings/post-pn-366, editor.: UK Parliament; 2010.
6. NIH. Indoor Air Quality. In: Sciences NIoH, editor. https://www.niehs.nih.gov/health/topics/agents/indoor-air2023.
7. Lueker J, Bardhan R, Sarkar A, Norford L. Indoor air quality among Mumbai's resettled populations: Comparing Dharavi slum to nearby rehabilitation sites. Building and environment. 2020;167:106419.
8. Buczyńska AJ, Krata A, Van Grieken R, Brown A, Polezer G, De Wael K, et al. Composition of PM2.5 and PM1 on high and low pollution event days and its relation to indoor air quality in a home for the elderly. The Science of the total environment. 2014;490:134-43.
9. Wang C, Zhang F, Wang J, Doyle JK, Hancock PA, Mak CM, et al. How indoor environmental quality affects occupants' cognitive functions: A systematic review. Building and environment. 2021;193:107647.
10. Amato F, Rivas I, Viana M, Moreno T, Bouso L, Reche C, et al. Sources of indoor and outdoor PM2.5 concentrations in primary schools. The Science of the total environment. 2014;490:757-65.
11. Wan M-P, Wu C-L, Sze To G-N, Chan T-C, Chao CYH. Ultrafine particles, and $PM_{2.5}$ generated from cooking in homes. Atmospheric environment (1994). 2011;45(34):6141-8.
12. Behar C, Chiu LF. Ventilation in energy efficient UK homes: A user experience of innovative technologies. ECEEE Summer Proceedings; 2013. p. 2389 - 99.
13. Women and Equalities Committee 3rd Report. Unequal impact? Coronavirus and BAME people Volume 1. Report: HC 384. Dandy Booksellers; 2020.
14. ASHRAE. ASHRAE 62.1-2016, Standard 62.1-2016 -- Ventilation for Acceptable Indoor Air Quality (ANSI Approved). https://www.techstreet.com/ashrae/standards/ashrae-62-1-2016?product_id=1912838 2016
15. Wang L, Zheng X, Stevanovic S, Wu X, Xiang Z, Yu M, et al. Characterization particulate matter from several Chinese cooking dishes and implications in health effects. Journal of environmental sciences (China). 2018;72:98-106.
16. Escobedo LE, Champion WM, Li N, Montoya LD. Indoor air quality in Latino homes in Boulder, Colorado. Atmospheric environment (1994). 2014;92:69-75.

17. Gao J, Jian Y, Cao C, Chen L, Zhang X. Indoor emission, dispersion and exposure of total particle-bound polycyclic aromatic hydrocarbons during cooking. Atmospheric environment (1994). 2015;120:191-9.
18. Kim K-H, Pandey SK, Kabir E, Susaya J, Brown RJC. The modern paradox of unregulated cooking activities and indoor air quality. Journal of hazardous materials. 2011;195:1-10.
19. Satish BK, Brennan J. Understanding the energy use behaviour of British Indian households to shape optimised sustainable housing strategies in existing housing stock. Sustainable Cities and Society. 2019:101542.
20. Satish BK, 'Modelling energy use behaviour of British Asian households'. Sustainable Earth 2017: A global forum for connecting research with action; 2017; Plymouth, UK: Plymouth University.
21. Satish BK, 'Two degree rise in indoor temperature: energy use behaviour of British Asians'. International Conference of Passive and Low energy Architecture; 2018; Hong Kong.
22. Cui S, Cohen M, Stabat P, Marchio D. CO_2 tracer gas concentration decay method for measuring air change rate. Building and environment. 2015;84:162-9.

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