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Ventilation performance and end-user interaction: Comparison of natural and mechanical strategies in new-build social housing

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Abstract:

Adequate ventilation is critical to ensure effective removal of moisture, air pollutants and smells indoors. A growing body of evidence however suggests poor performance of ventilation strategies in modern housing, which raises concerns regarding the potential detrimental impact on indoor air quality. The risk of health effects resulting from exposure to indoor air pollutants is exacerbated by the reduction of natural infiltration rates brought about by improvements to the fabric performance of buildings. Whilst these improvements should help to reduce energy consumption and occupant discomfort due to draughts, there is a need to ensure ventilation does not deteriorate as a result.

To ensure effective ventilation provision in modern social housing, it is important to understand and evaluate how these different strategies perform in a real-life context. This paper presents the results of a post-occupancy evaluation of three new-build social housing developments in Glasgow, ventilated by natural, mechanical extract and mechanical heat recovery methods. The study included household surveys of the three developments (responses from 63 households) and detailed monitoring of eight dwellings, to include occupant interviews, indoor environmental monitoring (during various seasons), fabric performance testing (airtightness, u-value assessment and thermography survey), energy monitoring, ventilation testing and indoor air quality measurements.

The results provide interesting insights regarding how occupants engage and interact with the ventilation strategies, the performance of ventilation strategies in practice, and occupant awareness and understanding of ventilation. The findings indicate shortcomings in all evaluated ventilation methods.

Keywords: Ventilation, Social Housing, Energy-efficiency, Building Users

Introduction

Ventilation is the continual exchange of contaminated air with fresh air in a building. Ventilation is critical to dilute indoor pollutant concentrations to acceptable levels for occupant health and comfort. It is also necessary to remove moisture and smells indoors, to provide sufficient oxygen supply for building occupants and for the provision of direct and indirect comfort cooling or heating (Roaf and McGill, 2016). Ventilation is a fundamental determinant of indoor air quality in buildings. However, ventilation alone cannot ensure adequate indoor air quality (Borsboom et al., 2016).

Numerous scientific reviews have established biological plausibility for an association between ventilation rates in buildings and health outcomes (Wargocki, 2013). However the development of health-based ventilation standards have been impeded by the limited epidemiological evidence and inconsistencies regarding the way in which buildings, exposures, pollutant sources and outdoor air quality are characterised (Bischof et al., 2013). Whole house ventilation rates of at least 0.5 ach are recommended to reduce house dust mite infestation and associated allergic manifestations (Bornehag et al, 2005).

As heat loss through the building fabric decreases with improved thermal insulation, heat loss associated with ventilation (purpose provided and adventitious) becomes more substantial. The UK domestic sector has seen significant improvements in airtightness standards over the last two decades. Whilst these improvements should help reduce energy consumption and occupant discomfort due to draughts, there is a need to ensure ventilation does not deteriorate as a result.

The overall impact of improvements to fabric performance on whole house ventilation provision and indoor air quality (IAQ) in new-build UK housing has yet to be effectively determined. While emerging studies have highlighted concerns regarding the effectiveness of ventilation systems, robustness of systems in practice and end-user interactions (Howieson et al., 2013; Sullivan et al., 2013), a greater understanding of the problem is required, to increase awareness of potential performance gaps and to provide practical advice to architects and construction professionals.

To ensure sufficient ventilation provision in modern new-build social housing, it is important to understand and evaluate how various ventilation strategies perform in a real-life context. This study therefore aims to gather evidence of how passive stack, Mechanical Ventilation with Heat Recovery (MVHR) and decentralised Mechanical Extract Ventilation (dMEV) perform in a real-life social housing context, to establish an in-depth understanding of the possible causes of performance gaps and the potential implications of these. In addition, it aims to gain a deeper understanding of the importance of end-user interaction on ventilation performance.

Methodology

An initial large scale door-to-door survey was undertaken at the three sites using a short questionnaire to gain information on occupant behaviour, perception of indoor environmental quality and awareness and use of ventilation in the home. Information was gained from 63 households (response rate: 74%). Eight households were selected for detailed monitoring (Table 1), based on representativeness, availability and concerns expressed regarding environmental performance.

Detailed monitoring consisted of the following: i) Indoor environmental monitoring (Eltek IAQ data loggers), ii) Occupant interviews, iii) Airtightness testing, iv) U-value assessment (Eltek SG44 HB transmitter), v) Thermography survey (FLIR thermacam B360), vi) Sound measurements (Pulsar Real Time Analyzer), vii) Ventilation testing (Observator air volume flow meter), viii) Energy monitoring and ix) Indoor air quality measurements (Graywolf DirectSense IAQ).

Temperature, relative humidity and carbon dioxide (CO_2) levels were monitored in the main bedroom, living room and kitchen of the selected dwellings during summer and spring/winter seasons, with simultaneous measurements of external conditions. Monitoring equipment was positioned away from direct pollutant sources, in accordance with ISO: 16000:1. An occupant diary was employed to gather information on occupancy levels and activities during the measurements. Environmental data was collected at 5 minute intervals.

Figure 1. Case Study Housing projects at Site A

Figure **2**. Case Study Housing projects at Site C

Table 1. Dwelling characteristics

Code	Ventilation strategy	Site	Typology	Orient-ation	Floor area	Sun-space	Occupancy	Home occupied	Airtightness ($m^3/h/m^2$)
PS1A	Passive stack	A	Semi-detached	N/S	108 m^2	Yes	2A, 3C	Evenings & weekends	4.76
PS2A	Passive stack	A	Semi-detached	NE/SW	107 m^2	Yes	2A, 5C	All day	5.60
ME1B	dMEV	B	Semi-detached	N/S	107 m^2	Yes	2A, 2C	Evenings & weekends	5.99
ME2B	dMEV	B	Semi-detached	E/W	88 m^2	Yes	3A	Evenings & weekends	5.42
MV1C	MVHR	C	Ground floor flat	N/W	83 m^2	No	2A	All day	---
MV2C	MVHR	C	Ground floor flat	N/W	77 m^2	No	2A	All day	11.13
MV3C	MVHR	C	Ground floor flat	S/W	56 m^2	No	1A	All day	---
MV4C	MVHR	C	First floor flat	N/W	77 m^2	No	2A 2C	Evenings & weekends	---

Results

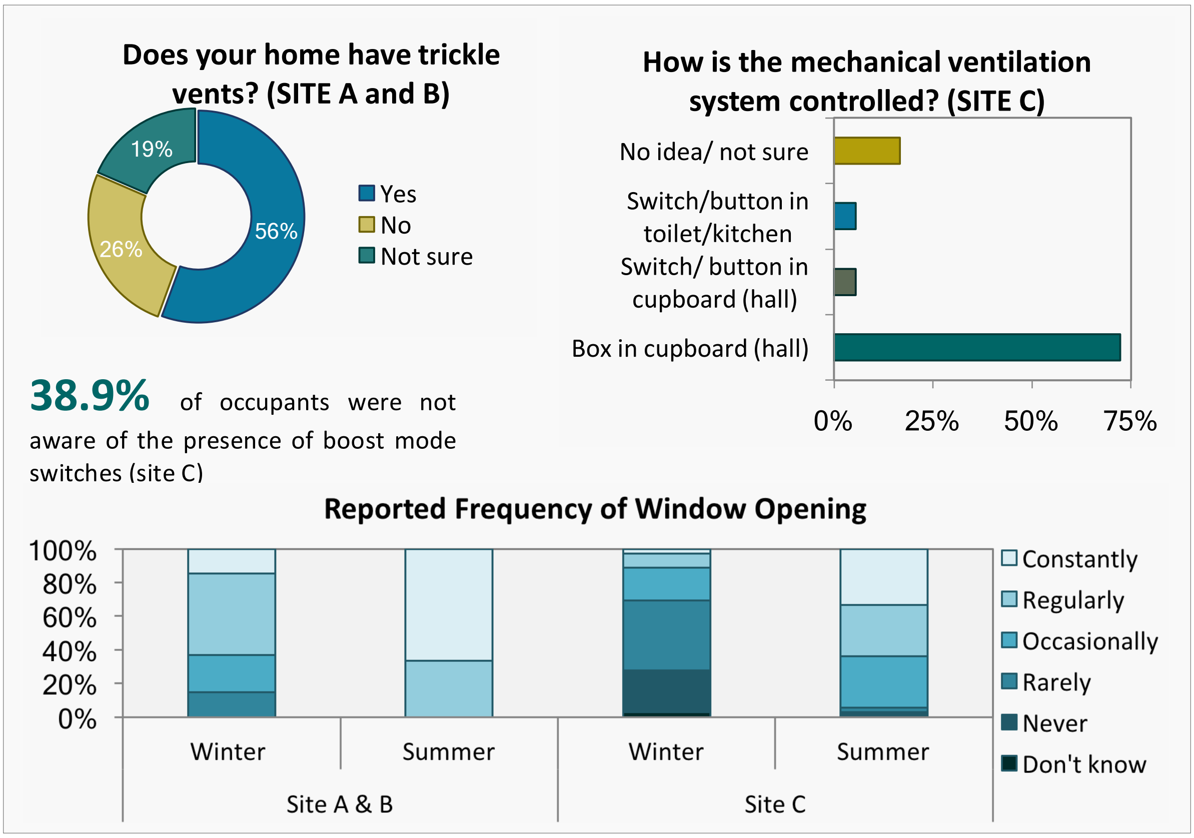

Figure **3**. Household Survey results

The household survey identified a lack of occupant awareness and understanding regarding ventilation strategies in both mechanically ventilated and naturally ventilated dwellings. As illustrated in Figure 3, in homes with dMEV and passive stack ventilation (site A & B), only 56% of households were aware of the presence of trickle vents, with 26% stating that trickle vents were not present. Most households at site A&B stated that mechanical extract fans were present in their home (93%), despite many utilising passive stack ventilation (PSV). Nevertheless, 82% of households reported that they were shown how to ventilate their home during the handover process.

Similarly, at Site C (MVHR homes), although all households were aware of the presence of the ventilation system, there appeared to be a general lack of understanding regarding how the system was controlled. 39% of households were unaware of the presence of boost switches in their home to boost the ventilation rate. Of those aware of these switches, 55% stated that they were never used. Nevertheless, 89% of households at site C stated that they have never had any issues with the MVHR system. Issues that were reported included the build-up/creation of dust (6%), discolouration (3%) or faults with the ventilation system (3%).

These results correspond with the findings from detailed monitoring in the eight case study dwellings. For example, the detailed investigation found that most dMEV systems had been turned off by the building occupants at the local isolator switch (during spring and summer visits), which is likely to result in inadequate ventilation. Similarly, in homes with adjustable vents (site B); half of these were found to be in the closed position. Interviews with the building occupants revealed that dMEV systems were turned off because they were perceived to be too noisy. This was supported by the results of sound measurements in one dwelling, were levels exceeded 35 dB LAeq with the MEV system in operation.

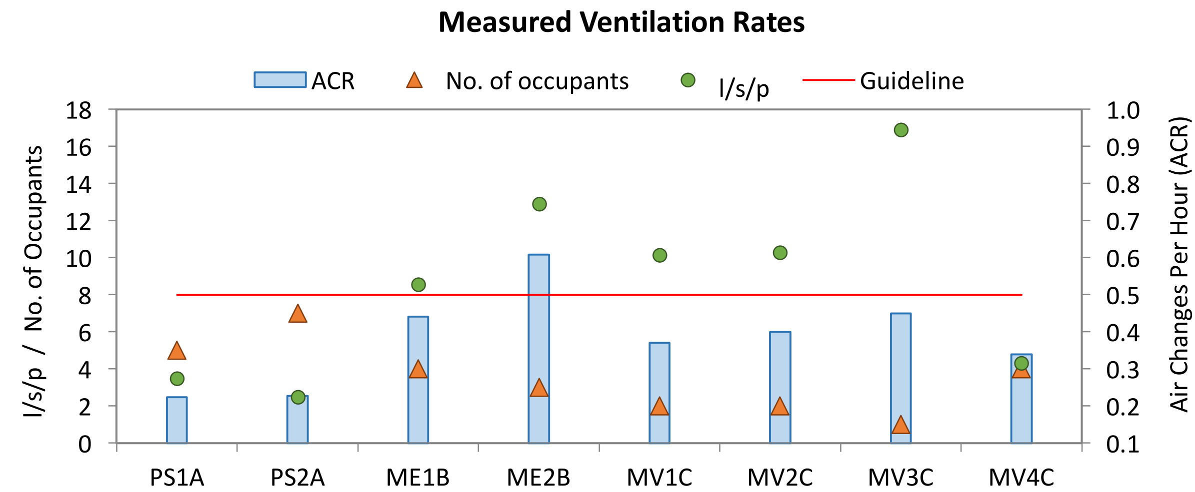

Figure **4**. Measured ventilation levels

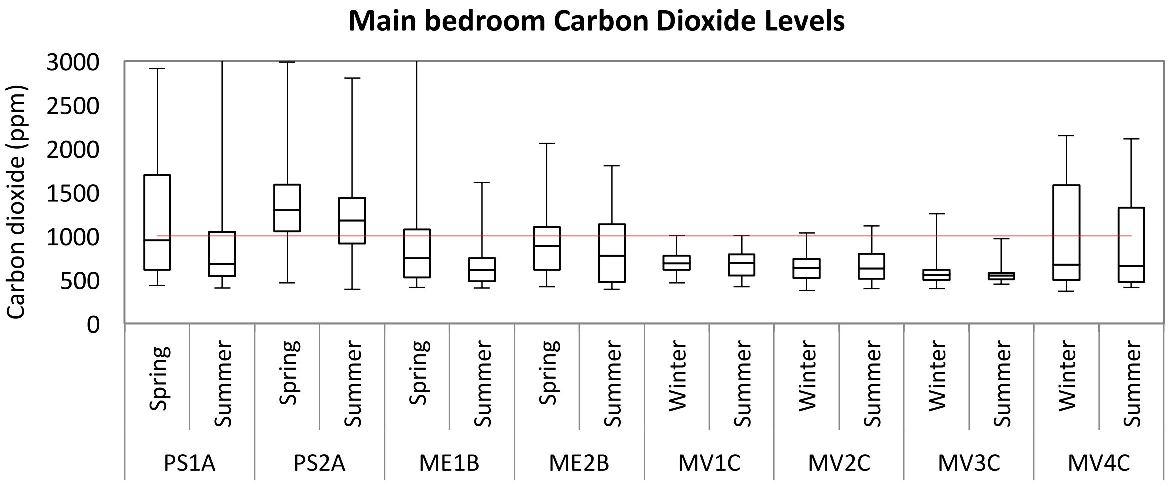

Figure **5**. Bedroom carbon dioxide levels

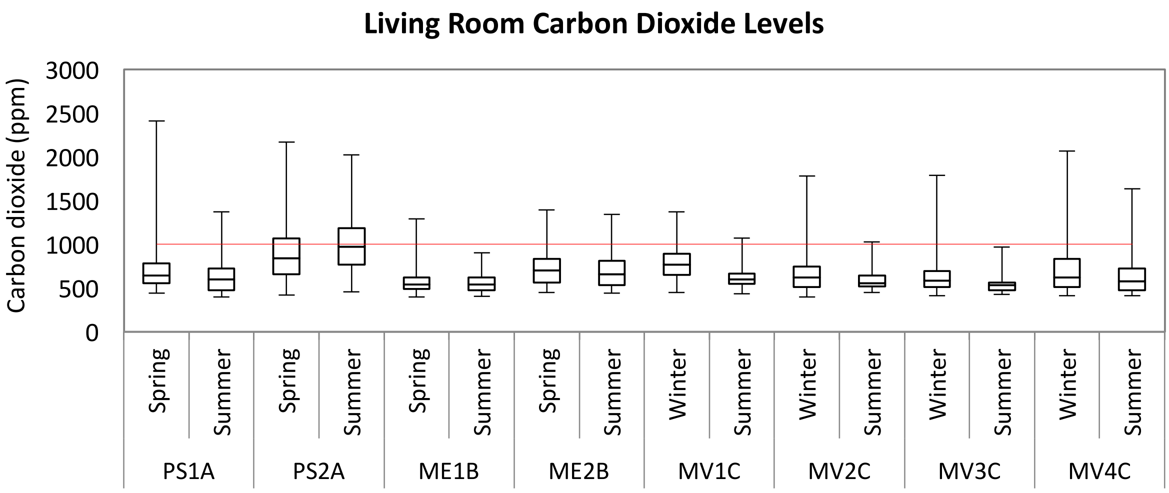

Figure **6**. Living room carbon dioxide levels

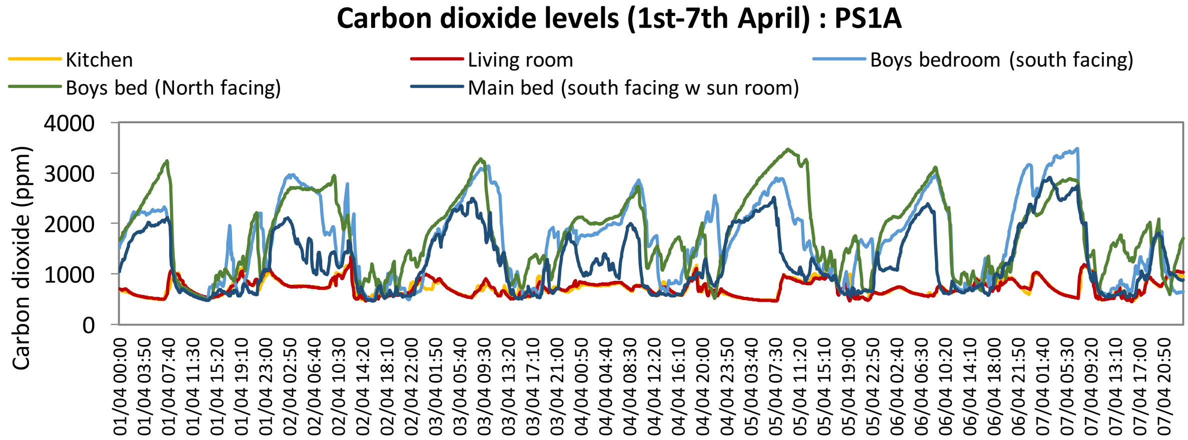

Figure **7**. Carbon dioxide levels in PS1A

Physical monitoring in the case study dwellings revealed inadequate ventilation in the majority of homes. Specifically, in the four homes with MVHR systems at site C, measured flow rates (during summer and winter) did not meet design targets under normal operation. In two of these flats, a significant imbalance (>50%) was identified between supply and extract rates (favouring extract). In one home (MV2C), the detailed inspection revealed that the living room supply vent had been closed tight by the building occupants during the winter months, due to complaints of draughts. At site B, although measured extract rates in the two homes with dMEV conformed to Scottish Building Regulations, ventilation rates were likely to be inadequate given that most of these systems were deactivated by building occupants. Measurements of extract rates in two homes with PSV at site A suggest low levels of ventilation (0.22 – 0.23 ach), however these results are dependent on external conditions at the time of measurements.

Ventilation requirements in buildings are inherently linked to building occupants (Bischof et al, 2013); therefore ventilation rates are expressed with reference to the number of occupants (l/s/p), in addition to room volume (ACR). Carbon dioxide (CO_2) is often used as an indicator of ventilation levels in buildings, with levels above 1,000 ppm suggesting inadequate ventilation. Figures 4-6 present the results of physical measurements of ventilation performance in the eight case study homes. As illustrated, only one dwelling (ME2B) satisfied ventilation guidelines of both >0.5 ach and >8 l/s/p (corresponding to approximately 1,000 ppm). However, it is important to note that ventilation measurements in this home were taken when the dMEV systems were in operation, which was not representative of normal conditions. In four monitored dwellings, although ventilation rates greater than 8 l/s/p were measured, air change rates below the recommended 0.5 ach were found.

CO_2 levels peaked above 1,000 ppm in all monitored living rooms and main bedrooms during winter/spring seasons. Average CO_2 levels exceeded 1,000 ppm in the main bedroom of the two homes with passive stack ventilation (PS1A and PS2A) during spring monitoring, and in one home with passive stack ventilation during summer monitoring (PSA1). As illustrated in Figure 7, bedroom CO_2 levels were consistently high overnight in PSA1, suggesting inadequate night-time ventilation.

Discussion

This study sought to identify the degree (if any) of ventilation and environmental performance gaps, determine possible causes of these gaps and provide knowledge and insight to inform current and future developments. The household survey provided the opportunity to gain an insight into the overall performance of dwellings, while detailed monitoring helped to gain a more in-depth understanding of the possible causes of performance gaps and the potential implications of these.

The results from the household survey suggest a lack of understanding of ventilation methods in the homes. This includes confusion regarding the operation and purpose of MVHR systems (at site C), and a lack of awareness of trickle vents and confusion between passive and mechanical ventilation strategies (at site A and B). These findings are supported by the results of the detailed building surveys, which found most dMEV systems had been turned off due to complaints of noise and many adjustable trickle vents had been closed by the building occupants. Automatic humidity-sensitive trickle vents were installed in the homes with PSV, which could not be adjusted by the building occupants. Although there was no evidence of MVHR systems being deactivated in the monitored flats at site A, this is difficult to establish without prolonged metering of the ventilation system. It is important to note that whilst occupants seemed to have been briefed to refrain from interfering with the system, switches were available to deactivate the system, if they so wish to do so.

Nevertheless, households reported a high frequency of window opening, particularly during the summer season. Homes with PSV and dMEV reported a higher frequency of window opening than those with MVHR systems. However, reliance on occupants' awareness of the need for increased ventilation and subsequent response (in the form of opening windows) may be insufficient at night while occupants are asleep. This was apparent, for example, in house PS1A, where high night-time bedroom CO_2 levels evidenced poor ventilation. The findings are supported by similar studies that identified significant issues with bedroom ventilation provision (Bekö et al, 2010; McGill et al, 2015; Sharpe et al, 2014).

An important finding from the physical monitoring was the high levels of CO_2 (and low measured air change rates) in the case study dwellings. These may be attributed, in part, to occupant interference with the ventilation strategies, in the form of closing supply vents, turning off dMEV systems or closing trickle vents. The results are in agreement with those obtained by similar Building Performance Evaluation studies that identified concerns regarding ventilation noise, perceived freshness of air, perceived control, complexity and accessibility of control interfaces, and lack of understanding of ventilation in contemporary homes (Gupta and Dantsiou, 2013; Macintosh and Steemers, 2005).

Despite insufficient flow rates and lower reported window opening, bedroom CO_2 levels were generally lower in monitored homes with MVHR systems. MV4C is a notable exception; which highlights the potential risk of poor ventilation in homes dependent on MVHR. These findings however need to be envisaged in light of the poor measured airtightness (in MV2C) and lower levels of occupancy (MV2A, MV2B, MV2C) in these homes, which is likely to have significantly influenced the results. As such, the results highlight the importance of context in ventilation investigations, and support the need for detailed case studies to gain an in-depth understanding of the problem and the range of factors at play.

Nevertheless, the suggestion that modern airtight homes with MVHR systems may be better ventilated than those ventilated naturally is not surprising, given the ability of MVHR systems (in theory) to provide a continuous supply of air to a building. The findings are supported by similar studies that have demonstrated significant issues with natural ventilation strategies in contemporary housing (Dimitroulopoulou et al, 2005; Sharpe et al, 2014).

However, the application of MVHR systems in new-build dwellings represents a step change in domestic ventilation practices and as such, requires careful consideration to ensure effective design, installation, performance, maintenance and operation, particularly in a social housing context. The move towards MVHR raises further concerns, such as the longevity of systems and components, the degree of occupancy control (and resulting satisfaction), the complexity, responsiveness and transparency of systems, and the need to reduce carbon emissions (despite increasing mechanisation of buildings). These challenges need to be addressed to ensure effective, efficient, user-friendly and environmentally responsive ventilation solutions for contemporary housing.

Conclusion

The poor performance of ventilation in the majority of case study dwellings, regardless of the ventilation strategy employed, highlights the fundamental need for improvements to ventilation provision in contemporary housing, particularly those designed to high levels of airtightness. Issues with end-user engagement and interaction in homes with dMEV and MVHR suggest significant advancements are required to ensure these systems are designed and installed in a way that is user-friendly, transparent, engaging and even captivating to building users. It is hoped that the findings of this study might help to shed light on potential causes of ventilation performance gaps in contemporary housing, whilst highlighting the need for greater consideration of the end user in ventilation design.

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