An investigation of MVHR system performance based on health and comfort criteria in bedrooms of low-carbon social housing in Wales

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ABSTRACT

Literature on the in-situ performance evaluation of Mechanical Ventilation with Heat Recovery (MVHR) in low-carbon social housing suggests that they can maintain a healthy ventilation rate in bedrooms in the UK. However, issues with noise and draught have been reported frequently. These issues may affect the sleep quality of occupants and have a detrimental effect on health and wellbeing. This research aims to present a quantification of these issues by carrying out detailed monitoring and evaluation at two case study sites in Wales, UK. The objectives are to calculate ventilation effectiveness via tracer gas experiment; predict thermal comfort using Predict Mean Vote (PMV); and predict acoustic comfort by measuring MVHR noise under different modes of operation. Results show that ventilation is effective despite the proximity of the supply vent to the door undercut; 90% of occupants are predicted to be thermally satisfied according to Fanger's thermal comfort model; and sound levels remain under the recommended value of 30dB(A) for bedrooms in all the cases. Results are followed by a discussion on experimental limitations and identification of opportunities for further investigation of the comfort indices mentioned.

KEYWORDS

MVHR, low-carbon housing, draught, noise, ventilation effectiveness.

1 INTRODUCTION

The Committee on Climate Change (2019) suggests that if UK is to meet its net zero carbon emissions target by 2050 then the housing stock needs to achieve high level of thermal efficiency which requires increased airtightness and the use of Mechanical Ventilation with Heat Recovery (MVHR) for maintaining healthy indoor air quality (pg 57). However, in-situ evaluation studies suggest that due to improper design, specification, installation, and commissioning of MVHR, a gap in performance exists. These issues have a negative impact on occupant health and comfort especially for the case of sleeping environments. This has been evidenced in the form of occupant complaints around draught and noise when trying to fall asleep (Sharpe et al., 2018, Gupta et al., 2018, Gupta and Kapsali, 2016, Gupta, 2016, ZCH, 2015), and potential short-circuiting of supply air when the vent is positioned too close to the bedroom door (Sharpe and Charles, 2015).

These studies however do not quantify the issues mentioned and were conducted at a time when MVHR was at its early stage of development, when most of the understanding on its design, installation and use was not there. This paper takes a case study approach to present the current practice of MVHR and investigates its performance in terms of occupant health and comfort in bedroom environments. Results from tracer gas experiments, Predict Mean Vote (PMV) experiment and acoustic measurements are presented for two case study sites in Wales, followed by a discussion on how findings compare with literature, and identification of areas for further research.

2 CASE STUDY DETAILS

Two case studies sites located in Wales were chosen for this research, both of which are social housing, 2-story, 3-bedroom dwellings equipped with MVHR system (Nuaire MRXBOX-ECO). Case Study A comprises of a cluster of 25 new build mid-terrace and end of terrace dwellings, whereas Case Study B is a single retrofit end of terrace dwelling. Dwellings in Case Study A have a measured air permeability of 4-5 m^3/m^2 h @ 50 Pa, whereas Case Study B dwelling has a measured air permeability of 10.5 m^3/m^2 h @ 50 Pa. All MVHR systems were in balance and were commissioned according to Building Regulations Part F (2021) . Thermally insulated rigid ducting was used throughout except for at ends that connect the supply and extract terminal to the vents.

(a) (b)

Figure 1: Case study sites in (a) Case Study A and (b) Case Study B.

3 METHODOLOGIES

3.1 Air Diffusion Effectiveness (ε_{ADE})

The relationship of supply vent/door undercut arrangement with ventilation effectiveness was evaluated using the Air Diffusion Effectiveness (ε_{ADE}) index developed by Fisk and Faulkner (1992). Fisk and Faulkner (1992) describe a tracer gas experimental protocol whereby a tracer gas, in this case CO_2, is filled in a room to a concentration of 2000 ppm, and is then left to decay until ambient levels are reached. The area under the curve is given by the age of air, τ, which represents the amount of time elapsed since molecules of a sample of air have entered a space, the formula is below:

$$\tau = \frac{1}{C(0)} \int_0^{t_{end}} C(t)\, dt \qquad (1)$$

C(0) is the concentration of tracer gas at initial time, t_{end} is the time at the end of the experiment, and C(t) is the decay curve function. The ratio of τ at the door undercut (τ_{DU}) and breathing level (τ_{BL}) is given by the Air Diffusion Effectiveness (ε_{ADE}) of the ventilation strategy. If τ_{DU} is less than τ_{BL} then ε_{ADE} will be less than 1, and would indicate the presence of short-circuiting, a value greater than 1 would represent displacement flow pattern, whereas a value equal to 1 would indicate perfect mixing.

The experiment was run in 3 bedrooms of a single dwelling in Case Study A. Each dwelling in the cluster has the same floor plan and mechanical design. Hence results of a single dwelling would be representative of the entire cluster, as long as they are commissioned to the same ventilation rates. The experiment was set up by placing one Telaire T5100 (0-2000 ppm, ± 30 ppm) at breathing level and one at the door undercut. The breathing level in this case was chosen to be 0.6m based on the assumption that the occupant is lying in bed. Doors and windows were kept closed throughout the experiment. Figure 2 shows the experimental set-up.

Figure 2 Tracer gas set-up in rooms of different sizes and layout

3.2 Acoustic Comfort

Sound measurements were recorded with the MVHR system on and off in three bedrooms of 6 out of the 25 dwellings in Case Study A using ATP ET-965 meter (35-130 dB(A), ± 2 dB(A)). Sound and frequency measurements were recorded with the system on, off and in boost mode in three bedrooms of the single dwelling in Case Study B using Pulsar Nova 46 meter (20-140 dB(A), 31.5-16k Hz, ± 0.1 dB(A)).

Results were compared with Part F of Building Regulation’s (2021) stipulated limit of 30dB(A) for bedroom environments and comments were made on whether sleep disruption is likely to be caused. Frequency measurements were recorded to analyse the change in sound quality with the system in different modes. Sound meters were placed at 0.6 m off the ground at locations where an occupant’s bed is likely to be. Figure 3 shows the experimental set up for one of the bedrooms in Case Study B.

Figure 3 Experimental set-up using Pulsar Nova 46 sound level meter

3.3 Thermal Comfort

The impact of having an MVHR supply vent on thermal comfort was investigated by setting up a Predict Mean Vote (PMV) experiment based on Fanger's model given under EN ISO 7730 (2005) and ASHRAE 55 (2020) standards. The experiment was run in the Third bedroom at Case Study B for 4 nights, i.e., from 27/01/23 to 31/01/23. The timing of the experiment was chosen to be in winter because the temperature of supply air is expected to be colder. The purpose was to investigate whether the difference in room temperature and supply air temperature is likely to cause the air to sink to occupant level and lead to thermal discomfort.

The set-up included: Dantec 54R10 air velocity (0.05-5 m/s, ±0.01 m/s) and air temperature (0 to 45°C, ±0.5°C) probe and TinyTag TK-4014 radiant temperature sensor (-40 to 85°C, ±0.05°C). The probe and sensor was mounted on a tripod which stood at 0.6 m off the ground. An immonit T/RH sensor (-7 to 60°C, ±3% of reading) was installed inside the supply vent and another one installed close to the bedroom door so that the difference in room and supply vent temperature can be recorded during the experiment. Figure 4 below shows placement of T/RH inside the supply vent (left) and mounting of the sensor and probe for the PMV experiment (right).

Figure 4 T/RH sensor in supply vent (left) and PMV experimental probe and sensor (right)

4 RESULTS & DISCUSSION

4.1 Tracer gas experiment

Decay curves are shown in Figure 5, whereas values for age of air at door undercut (τ_{DU}), breathing level (τ_{BL}) and Air Diffusion Effectiveness (ε_{ADE}) for the three bedrooms of a single dwelling in Case Study A are given under Table 1, respectively.

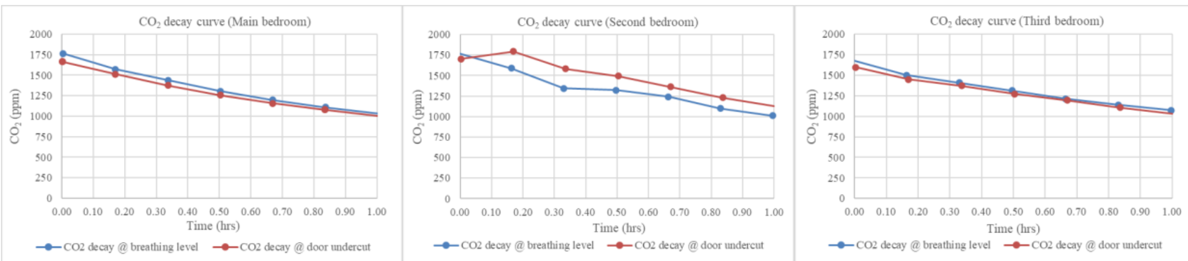


Figure 5 Tracer gas curves for the three bedrooms

Results from Table 1 show that τ_{DU} remains higher than τ_{BL}, which indicates greater air changes at breathing level than the door undercut, and hence a confirmation of ventilation effectiveness for the three bedrooms. This represents a displacement flow patterns which can be attributed to the prevalence of low air velocities in the room and to the shape of the terminal that causes the air to stick to the ceiling and walls. Computational Fluid Dynamic (CFD) modelling shall be used out to verify this further.

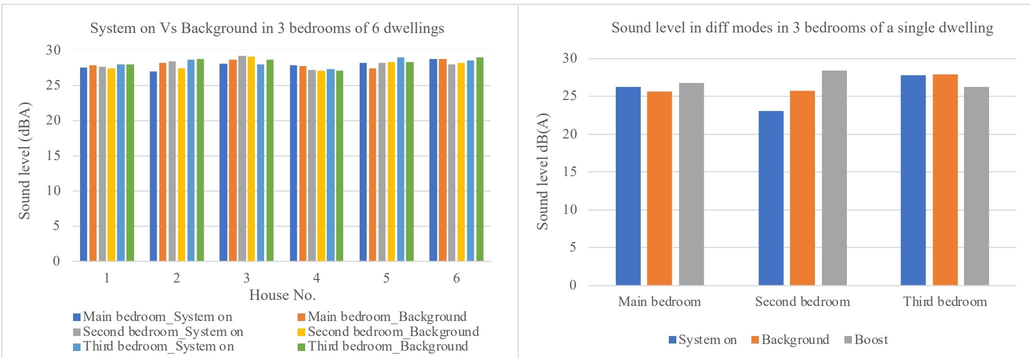
Table 1 Tracer gas experimental results

Main bedroom			Second bedroom			Third bedroom		
τ_{DU} (hr)	τ_{BL} (hr)	ε_{ADE}	τ_{DU} (hr)	τ_{BL} (hr)	ε_{ADE}	τ_{DU} (hr)	τ_{BL} (hr)	ε_{ADE}
0.78	0.76	1.02	0.84	0.81	1.04	0.81	0.79	1.02

One limitation of the experiment was the 10 min interval of recordings. Higher granularity can improve accuracy, especially for the case of bedroom 2, where unexplainable fluctuations in the curve were observed. Another limitation was that the area under the curve was calculated using trapezoid rule where curves were estimated to be straight lines.

4.2 Sound measurements

Sound level was measured with the system turned on and off in 3 bedrooms of 6 dwellings for Case Study A. No change in sound level or tonal frequency was perceived by the authors with the system on, off or in boost mode. All measurements were below 30 dB(A) as shown in Figure 6(a), which implies that sleep disruption is unlikely to be caused.



(a) (b)

Figure 6 Sound measurements in dB(A) at (a) Case Study A and (b) Case Study B

For the case of Case Study B, sound and frequency measurements were recorded in all bedrooms with the system on, off and on boost mode. As shown in Figure 6(b), all measurements were below 30dB(A) which implies that, sleep disruption is unlikely to be caused. However, during site visits, the authors experienced a change in tonal frequency with the system on boost mode. Figure 7 shows results of the frequency distribution with the system in the three modes. Higher sound level was observed at 250 Hz for the 3 bedrooms in boost. The sound resembled that of an MVHR unit and was confirmed by the data as well as 250Hz lie within the 125-2.5kHz range which is typical of mechanical ventilation unit, according to EN BS 8233 (2014) standard.

Literature suggests that the reasons for noise and draught are due to poor levels of air tightness (Sharpe et al., 2018), overuse of flexible ducting (ZCH, 2015) and system imbalances (Gupta and Kapsali, 2016, Gupta, 2016, Gupta et al., 2018). Although all measurements were below 30 dB(A), the change in tonal frequency observed at Case Study B could cause sleep disruption. Possible reasons for this are (a) unit located in the loft compared to being located in a dedicated utility room on the ground floor in Case Study A, and (b) air permeability being above the ideal value of 5 m^3/m^2 h @ 50 Pa for an MVHR system to operate effectively. Greater air permeability means increased system resistance which causes the fan to run on higher than recommended speed and thus generate noise.

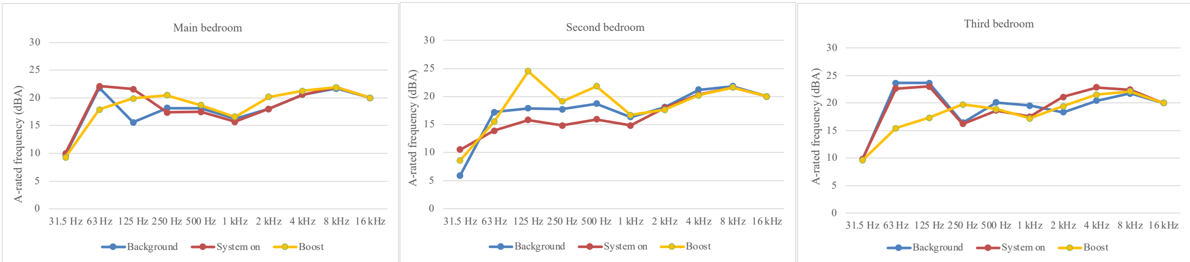


Figure 7 Frequency distribution with the system in different modes of operation at Case Study B

One limitation of the data on frequency distribution is the small sample size. Further research is required looking at a bigger sample and analysing the effect of change in tonal frequency on sleep quality. Another limitation of the work is that there are discrepancies in sound measurements for both sites. This was due to measurements being taken during morning/afternoon when background noise can be higher than night-time conditions. Another limitation was that all bedrooms were unfurnished. Furniture causes sound to dampen, which means that lower sound levels can be expected post-occupation. Future work includes carrying out an interview study with the installers, commissioners, and M&E team to verify whether a relationship between dwelling airtightness and choice of unit location exists with sound level in bedrooms.

4.3 Predict Mean Vote (PMV) experiment

PMV was calculated using Centre for Built Environment (CBE) Thermal Comfort online tool developed by Tartarini et al. (2020) based on Fanger's model. The metabolic rate chosen for the input was 0.7 and the clothing level was chosen as 3.53. A clothing level of 3.53 is representative of a typical UK bedding environment with the chest and head exposed, based on experiments conducted by Lin and Deng (2008b). Although Fanger's model given under EN ISO 7730:2005 can only be applied for a metabolic rate between 0.8-4 met and a clothing level between 0-2 clo, the online tool was used only to get an estimate for PMV.

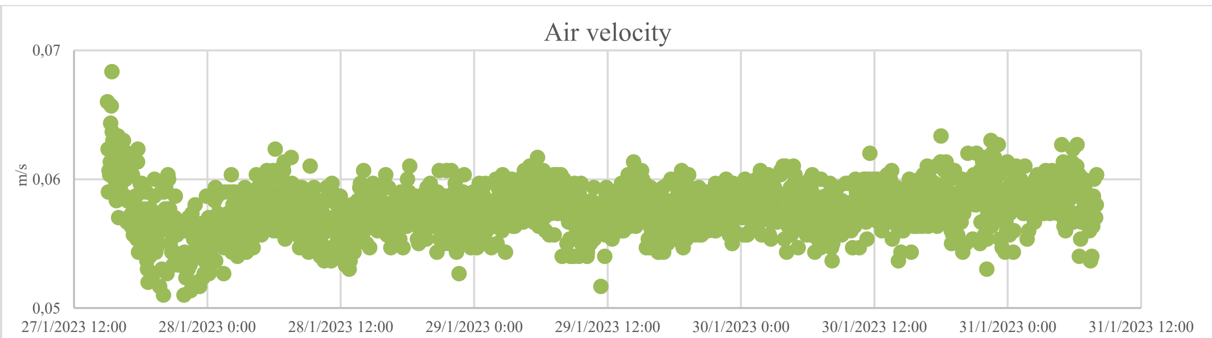


Figure 8 Results of omni-directional air velocity measurement

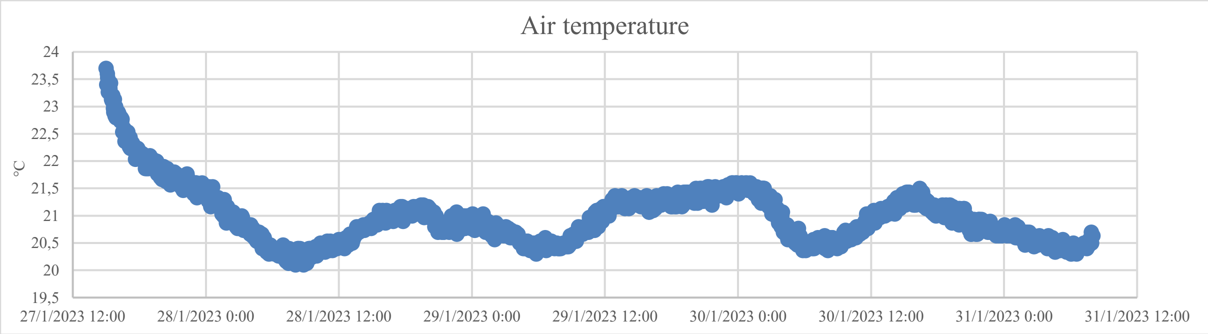


Figure 9 Results of air temperature measurement

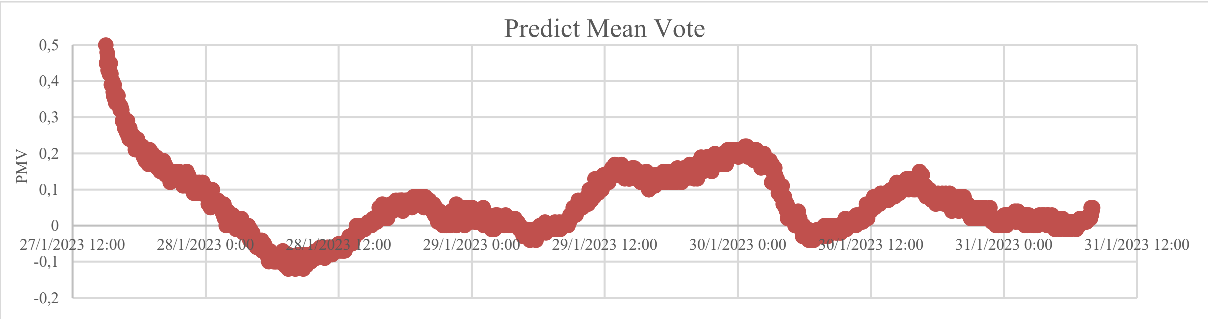


Figure 10 PMV calculated using the CBE online tool

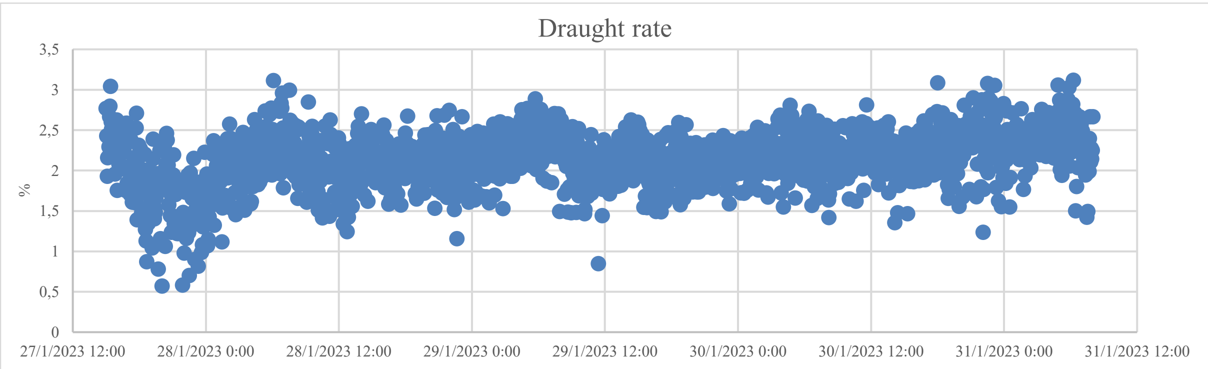


Figure 11 Draught rate calculated using EN ISO 7730 guidelines

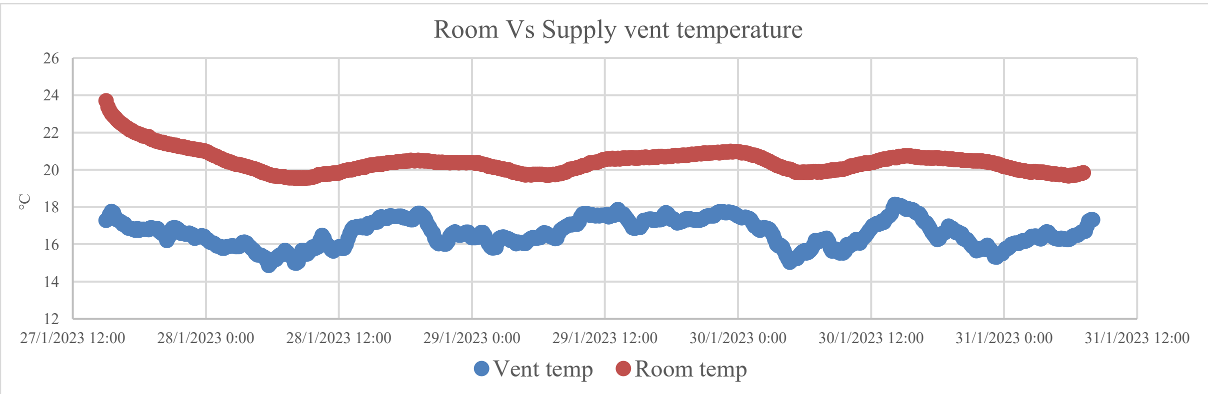


Figure 12 Comparison of room and supply vent temperature for the experiment

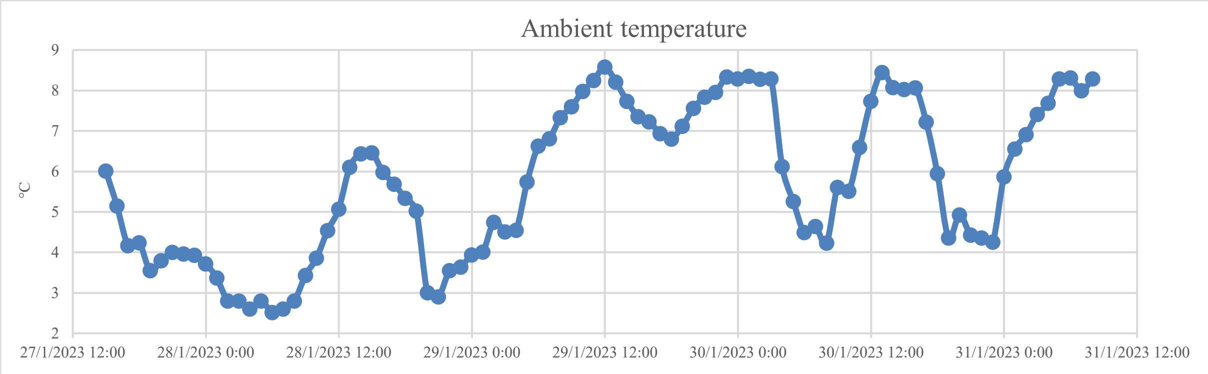


Figure 13 Ambient temperature during the experiment

At the start of the experiment, the radiator in the room was turned off so that the influence of local air currents can be avoided. This was the reason for why room temperature dropped from 24°C to approx. 21°C which was the new set point temperature for the entire dwelling, as shown in Figure 9. Results from Figure 10 show that PMV lies within ±0.5 which means that for the set environmental conditions during the experiment, 90% of occupants are predicted to be thermally satisfied. Velocities remain under 0.07 m/s hence likelihood of draught remains low (Figure 8). This is evidenced by the draught rate results as percentage dissatisfied does not exceed 3.5% (Figure 11).

No real relationship was found between air velocity and PMV whereas a direct relationship existed between air temperature and PMV. This indicates that air from the supply vent is unlikely to drop to occupant level when there is a difference in temperature of approx. 3°C between the room and supply air (Figure 12). The system was in balance, ductwork was rigid and insulated, and unit was located in a thermally insulated loft; hence a higher factor of heat exchange efficiency was achieved, and as a result the possibility of cold air dumping remains low. Future work includes (a) applying Lin and Deng (2008a) adaptation of Fanger's model to calculate PMV for sleeping environments, (b) interviewing building professionals to further explore reasons behind draught in bedrooms, (c) carrying out CFD modelling to better understand cold air dumping by simulating air movement under different environmental conditions.

5 CONCLUSIONS & FURTHER WORK

Building performance evaluation was conducted to investigate health and comfort of having an MVHR supply vent in bedrooms of low-carbon case study dwellings for the two case studies. From a health perspective, a tracer gas experiment was carried out in bedrooms in Case Study A to investigate the relationship of supply vent/door undercut arrangement with Air Diffusion Effectiveness (ε_{ADE}). Results showed that ventilation was effective in all cases, despite the close proximity of the supply vent to the door undercut. This was attributed to the shape of the supply vent and to the prevalence of low velocities in the bedroom environment.

From a comfort perspective, acoustic and thermal comfort indices were considered. Results showed that sound measurements in all bedrooms on both sites were below the recommended value of 30dB(A), which means that likelihood of sleep disruption is low. However, change in tonal frequency was recorded at the Case Study B with the system on boost mode. This was attributed to (a) having the unit installed in the loft and (b) having an air permeability greater than the recommended value of 5 m^3/m^2 h @ 50 Pa for an MVHR system to be installed.

Results from a PMV experiment conducted in one of the bedrooms to investigate the likelihood of an MVHR supply vent to cause thermal discomfort at night showed that for a difference in room temperature and supply vent temperature of approx. 3°C, more than 90% of occupants are thermally satisfied. This was attributed to the high heat exchange efficiency, which was achieved in the bedroom, mostly likely due to the system being in balance and due to the ductwork being insulated and rigid.

Further work includes recording the response of building professions who were involved at the two case study sites in MVHR design, commissioning, and installation to comment on the influence of unit location and airtightness on noise and on the impact of system imbalances and overuse of uninsulated flexible ducting on heat exchange efficiency. Lastly, CFD modelling technique will be used to investigate the difference in room temperature and supply air temperature that is likely to cause the air to sink to occupant level. The CFD model will also be used to visualise the air movement and hence aid in verifying the tracer gas experiments.

Although findings presented are of a limited sample, they provide a useful insight into the conditions that might exist in properties of similar built in Wales. Knowledge gained from this research will be useful for designers, manufacturers, installers, and commissioners on designing and specifying MVHR such that sleep disruptions can be minimised in low-carbon housing in the UK.

6 ACKNOWLEDGEMENTS

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