PLEA 2018 HONG KONG
Smart and Healthy within the 2-degree Limit

Particulate Concentrations in Bedrooms in Airtight Dwellings
Findings from Eleven Dwellings in Scotland

FILBERT MUSAU[1]

[1]Mackintosh School of Architecture, Glasgow School of Art, Glasgow, United Kingdom

ABSTRACT: Occupant exposure to unhealthy Particulate Matter (PM) in naturally ventilated air-tight dwellings is not fully understood. In the UK, past studies have not investigated PM in bedrooms. Yet, PM is considered the most toxic pollutant and affects more people than any other pollutant; and bedrooms are the spaces that people typically occupy for the longest cumulative periods of their lifetime; with little or no control of ventilation during sleep. This paper evaluates monitored PM_{10} and $PM_{2.5}$ in the context of occupant health in bedrooms of eleven dwellings across Scotland. It focuses on $PM_{2.5}$, the size associated with greatest impact on health. PM and window operation were monitored concurrently. Air-tightness, smoke tests, dwelling inspections, occupant surveys, questionnaires, and interviews were also conducted. The results indicate that $PM_{2.5}$ concentrations were generally above the recommended limits by WHO; and potentially unsafe in all the dwellings in the context of the EU-ESCAPE study. Bedtime mean concentrations were significantly lower than the 24hr mean, but would also have potentially negative health impacts based on the ESCAPE study. This suggests possible health burdens of particulates in bedrooms, with continuing construction of air-tight dwellings. Further work is needed on a larger sample of dwellings across different seasons.
KEYWORDS: Particulate matter, air-tight dwellings, bedrooms, occupant health

1. INTRODUCTION

Although appropriate provision of natural ventilation could address recent concerns on general indoor air quality in naturally ventilated air-tight dwellings, occupant exposure to unhealthy indoor particulates in such dwellings is not fully understood. In the UK, past studies have focussed on comparison between particulates in smoking and non-smoking traditional homes, which are less airtight; and homes that use solid fuels or gas for heating and cooking [1, 2]. Studies looking at Indoor Environmental Quality in bedrooms have focussed on CO_2, RH%, temperature, and mould conditions [3, 4, 5]; and left out Particulate Matter (PM). Yet, PM is considered the most toxic and affects more people than any other pollutant [6, 7]; and bedrooms are the spaces that people typically occupy for the longest cumulative periods of their lifetime [8], with little or no control of ventilation during sleep [9].

We spend around one-third of our lives sleeping, yet little is known as to how human exposure to indoor air pollutants during sleep impacts human health and sleep quality [10]. Based on a review of the state-of-knowledge on human exposures to pollutants in sleep microenvironments as at 2017, Boor *et al*. recommend that this area should get more attention; and future research is needed to fully understand how sleep exposures affect human health and sleep quality [10].

Outdoor $PM_{2.5}$ levels in Scotland are relatively lower than most regions, but they have been associated with significant loss of life. A study on the effects on annual mortality of anthropogenic $PM_{2.5}$ pollution [11], showed that in 2010, the deaths of people aged 25+ in Scotland, Glasgow City, and Highlands Council were: 53,800 (1.47%); 6,508 (1.59%); and 2,296 (1.43%) respectively. The mean anthropogenic $PM_{2.5}$ concentrations were 6.8, 8.3, and 4.3 μg/m^3 respectively. Another study modelled PM levels based on measured levels at the nearest stations. It reported $PM_{2.5}$ levels for Glasgow and Inverness as 10-12.5 μg/m^3 and 5-10 μg/m^3 respectively [12]. The two cities represent the higher and lower sides of the spectrum of PM concentrations across Scotland's urban areas.

With such low outdoor $PM_{2.5}$, the "build tight-ventilate right" approach advocated by Perera and Parkins in 1992 [13], would be expected to result in low indoor PM levels in Scotland. But how do you "ventilate bedrooms right" in the predominantly cold and windy climate of Scotland, while asleep? A study of 109 dwellings showed that majority of people in Scotland sleep with their bedroom windows closed in winter, and occupants cited weather as the main reason for this. 75% of them never opened bedroom windows at night, and of them 73% gave the predominant reason being weather [14].

What has the Scottish govt. done to regulate and enforce the "*build tight"* and "*ventilate right"* parts of the approach? For the "*build tight*" part, Scottish regulations specify a minimum airtightness for new houses of 10 m^3/(h.m^2) @50 Pa; recommend a level of 5m^3/(h.m^2), and require Mechanical ventilation if airtightness is below 5m^3/(h.m^2). For the "*ventilate right"* part, the Scottish Building Standards require CO_2 monitors to be installed in the main bedroom in all new dwellings since 2015. According to the Scottish Government's Technical Handbook of 2015, most residents have no idea what the air quality in their home is, or should be, and don't know that they need to open a window, hence the need for CO_2 monitors. The impact of such monitors is not known.

There are no regulated standards for indoor PM in Scotland and no health-based standards for most Indoor Air Pollutants (IAPs) in homes [1]. The most relevant guidance available is by the Dept. for Health Committee on the Medical Effects of Air Pollutants (COMEAP), Guidance on the Effects on Health of IAPs (Dept. of Health, 2004). It provides guidance on NO_2, CO, Formaldehyde, Benzene and Polycyclic Aromatic Hydrocarbons; but none for indoor PM. The evaluation in this paper is, therefore, based on UK, EU and WHO guidelines on PM [15, 16]; and the EU 2013 ESCAPE study, which assessed the health impacts of every 10% increase in PM levels [17]. The study involving 312,944 people in nine EU countries revealed that there was no safe level of particulates, and that for every increase of 10 μg/m^3 in PM_{10}, the lung cancer rate rose 22%. For $PM_{2.5}$ there was a 36% increase in lung cancer per 10 μg/m^3. In a 2014 meta-analysis of 18 studies globally including the ESCAPE study data, for every increase of 10 μg/m^3 in $PM_{2.5}$, the lung cancer rate rose 9% [18].

The relative impacts of PM sources and window control on PM concentrations is expected to vary across meteorological conditions and across homes with different airtightness and user actions. Scotland is wetter and colder region than the rest of the UK; and arguably the windiest country in Europe. The objective of the current study was to explore $PM_{2.5}$ and PM_{10} levels in recently built air-tight and naturally ventilated bedrooms in Scotland, in the context of occupant health. This paper discusses the $PM_{2.5}$ results only.

2. METHODOLOGY

2.1 Case Study Dwellings

Eleven dwellings (D1 to D11 in Figure 1) were selected from four developments, all completed between 2010 and 2012, with a total of 191 dwellings – representing diverse demographics, house types, geographical spread, and characteristics (Table 1). Development A has 20 houses for rent/low cost ownership and 32 for the open market. Development B has 34 Sheltered housing flats for the elderly (aged 60+). Its Mainstream housing has 18 two-storey terraced houses, 54 flats; and 11-flats for residents with mental health needs. Development C has 16 flats for older people, while D has six 1.5-storey houses for older people.

Figure 1: Views and floor plans of the case study dwellings. The monitored bedrooms are shaded in grey.

2.2 Collection of Household Data and Monitoring of Indoor Air Quality

A Standard Protocol was used for each dwelling and measurement. It included recording of the property address and time of arrival. Dwelling information was then recorded: (1) Type of Dwelling: Detached, Semi-Detached, Flat, Numbers of Storeys, units, Bedrooms, Occupants, and Construction Type; (2) Room Measurements: Length (mm), Width (mm), Height (mm), and Volume (m^3); (3) Drawings of the shape and recording of positions of doors and windows; and (4) Photography of: windows and doors – including vents, undercuts and obstructions.

Indoor air quality was monitored concurrently with window operation in the bedrooms - all naturally ventilated. A portable GrayWolf monitoring kit set (Figure 2) was used. Temperature, relative humidity, CO_2, formaldehyde, CO and PM levels were recorded. The monitoring per dwelling was approx. 72 hours during weekdays; and conditions were recorded every 5 minutes. Window opening/closing patterns were monitored with wireless contact sensors installed at windows, and linked via broadband.

Figure 2: Portable monitoring apparatus and installed t-mac wireless contact sensors at windows

Residents were informed that: (1) the aim of the study was to measure the conditions in the bedroom under typical occupation so there was no need to alter their normal behaviour; (2) that the equipment would measure temperature, humidity, carbon dioxide, particulate matter and formaldehyde levels only; and (3) there was no noise or video recording. The following instructions and questions were issued:

1. Windows should remain closed for the duration of the monitoring. This represented the typical case of windows in Scotland remaining mainly closed at bedtime, from late autumn through to early spring.
2. Trickle vents should not be adjusted for the duration of the monitoring.
3. Doors should remain closed as often as possible, especially when the bedroom is occupied (to represent the typical sleep time closed status [3]).
4. Please do not switch off or unplug the recording equipment that has been placed in the bedroom.
5. When complete, after 48 hours (unless otherwise instructed), we will return to collect equipment.
6. How many people will occupy the room? Morning, Afternoon, Evening, Night.
7. If doors can't remain closed throughout, confirm preference in the: Morning (Yes/No); Afternoon (Yes/No); Evening (Yes/No); and at Night (Yes/No).

2.3 Air Permeability Testing

The testing was carried out in accordance with ATTMA (Air Tightness Testing and Measurement Association) TS1 (Technical Standard for air permeability testing of dwellings) which is broadly based on BS EN 13829:2001. The following points summarise the methodology for each test:

1. The building was measured to determine floor area, building envelope area, and volume.
2. All trickle vents, windows, and external doors were closed; none were sealed.

Table 1: Characteristics of households & occupancy patterns

	Dwelling/Households**									
	D 1	**D 2**	**D 3**	**D 4**	**D 5**	**D 6**	**D 7**	**D 8**	**D 9**	**D 11**
House type										
Semi Detached		✓		✓	✓					
Terraced	✓					✓				
Flat/Apartment			✓				✓	✓	✓	✓
Householders										
Children (00-14 yrs.)	4	0	0	1	0	0	0	1	1	0
Youth (15-24 yrs.)	1	2	2	0	1	0	0	0	0	0
Adults (25-64 yrs.)	1	1	0	2	2	0	1	2	2	0
Elderly (65 + yrs.)	0	0	0	0	0	2	1	0	0	1
Occupancy patterns*	d	A	b	e	b	d	e	a	e	d
Fuel										
Gas cooking				✓	✓					
Electricity cooking	✓	✓	✓			✓	✓	✓	✓	✓
Gas heating - water	✓	✓		✓	✓	✓	✓			
Electr. heating– water								✓	✓	✓
Solar heating – water						✓	✓	✓	✓	✓
CHP heating - water										✓
Communal biomass heating - water			✓							
Gas heating – space (in D3, gas is back-up)	✓	✓	✓	✓	✓	✓	✓			
Electr. heating - space								✓	✓	✓
Communal biomass heating - space			✓							
Ventilation										
Windows	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Trickle vents				✓	✓					
Extracts										
Kitchen	✓			✓	✓					
Bathroom				✓	✓					
Smoking	✓			✓						
Pets (cat = c, dog = d)	c d	D		d						

Typical domestic occupancy categories in UK [19]: **(a) Short Occupancy A: Adults working externally and sch. age children. Weekday: All absent-08:30-16:00 Weekend: All absent-10:30-16:00; **(b) Short Occupancy B:** Adults working externally / all with full time jobs. All absent - 08:30 - 18:00 (4 days a week) or 08:30 to 21 (3 days a week). House partially occupied when at home; **(c) Partial Occupancy:** One or more residents with part time jobs. House unoccupied 09:00-13:00; or House unoccupied 13:00- 18:00. House partially occupied when at home; **(d) Home stay A:** Retired (over 65) / Family with small children. House occupied all day. All areas of occupied when at home: **(e) Home stay B:** 2 adults one stays at home during the day. House occupied all day. House partially occupied all day. **Dwelling 10 not included, has 1 adult householder and pattern (d)*

3. Internal doors were propped open.
4. Mechanical ventilation was sealed and switched off where applicable.
5. A portable fan and frame were installed in the front entrance door, creating an airtight seal.
6. Infrared thermography was undertaken to detect areas where infiltration paths could exist.

7. The building was depressurised to an internal/ external pressure difference of at least 50Pa.
8. Infrared thermography was undertaken to detect possible infiltration paths.
9. A series of air flow measurements were recorded at varying indoor/outdoor pressure differentials.
10. The fan was set to pressurise the building to an internal/external pressure difference at 50Pa.
11. A series of air flow measurements were recorded at varying indoor/outdoor pressure differentials. The results were computed through regression analysis of the recorded measurements.

Figure 3: Air Pressure Testing fan in dwelling door (left); and air leakage smoke tests at windows, pipe routes etc.

Figure 4: All trickle air vents, mechanical air vents, and kitchen hoods were sealed off; mechanical ventilation air ingress and egress points were also sealed and the systems switched off before air pressure and air leakage tests.

3. RESULTS AND DISCUSSION

The air tightness results confirmed that the dwellings were tight enough to rely on windows as the main ventilation route. Five dwellings (6 for the second test) had tightness below $5m^3/(h.m^2)$ - the threshold below which a whole house mechanical ventilation should be installed under current Scottish Standards. Of the five, D4 & D5 were designed to be less airtight. The designers thought these dwellings didn't require Mechanical Ventilation. The airtightness results, however, suggest that their natural ventilation using background ventilators is insufficient.

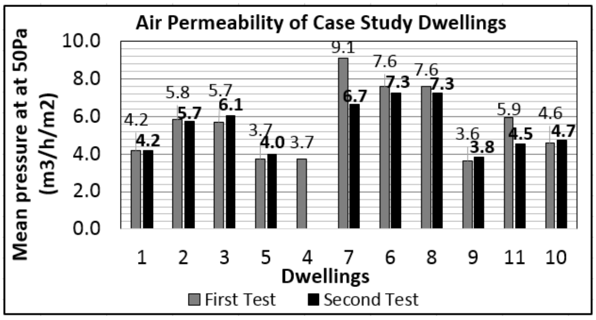

Figure 5: Comparison of first and second air permeability test results at 50Pa ($m^3/(h.m^2)$ across dwellings.

In the context of the ESCAPE study, the $PM_{2.5}$ concentrations in majority of the eleven monitored dwellings would affect occupant health negatively. In the context of the WHO guidelines, seven had mean $PM_{2.5}$ concentrations above the recommended 24-hr mean ($25\mu g/m^3$). For sensitive groups (children & the elderly), of the five dwellings with elderly householders, two had $PM_{2.5}$ concentrations over $25\mu g/m^3$, one with exactly $25\mu g/m^3$, and two had over $50\mu g/m^3$ (Figures 6 & 7). Three dwellings with children had $PM_{2.5}$ levels above the WHO guidelines. The analysis focusing on bedtime concentrations, when occupants were sleeping, shows concentrations of $PM_{2.5}$ below WHO guidelines (Figures 6 & 7). However, their concentration levels would have negative health impacts in the context of the ESCAPE study. WHO also states that there is no established threshold for safe levels of $PM_{2.5}$. All dwellings had some level of $PM_{2.5}$ and none could therefore be said to be safe. This is against the relatively low background outdoor $PM_{2.5}$ (Table 2) measured at Scottish Air Quality monitoring sites nearest to case study dwellings [20]; and calculated $PM_{2.5}$ using the Pollution Climate Mapping model [21]. For 2014, the year of monitoring the dwellings, the mean background $PM_{2.5}$ in Scotland calculated with the model was 5.9 $\mu g/m^3$. All levels across the sites, except for Feb. at Broxburn, meet the target upper limit of 10 $\mu g/m^3$ set by the Scottish Government.

Table 2: Mean monthly outdoor $PM_{2.5}$ concentrations in $\mu g/m^3$ at sites near the case study dwellings (averaged data from 2007 to 2018 available at scottishairquality.co.uk [20].

Dwellings	Nearest Site(s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
D1 to D3	Inverness	8	8	8	6	5	5	5	4	5	6	7	8
D4 & D5	Broxburn	9	10	9	8	7	8	5	3	6	5	7	8
D6 & D7	Waulkmillglen	6	6	6	6	6	7	4	3				
D8 to D11	Byres road	9	8	9	8	9	9	6	5				8
D8 to D11	Townhead	8	7	8	8	8	7	6	6	9	8	7	7

When plotted together, the air permeability and $PM_{2.5}$ results suggest a potential relationship between the extent of uncontrolled air leakage (infiltration) through the building fabric with the concentrations of $PM_{2.5}$. They show that, generally, the leakier the dwelling, the less the $PM_{2.5}$ concentrations (Figure 6).

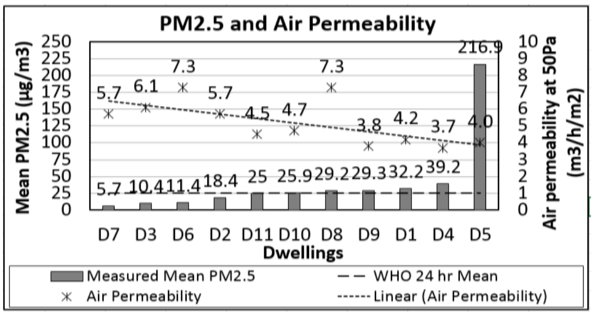

Figure 6: Air permeability and mean $PM_{2.5}$ concentrations for the monitored period.

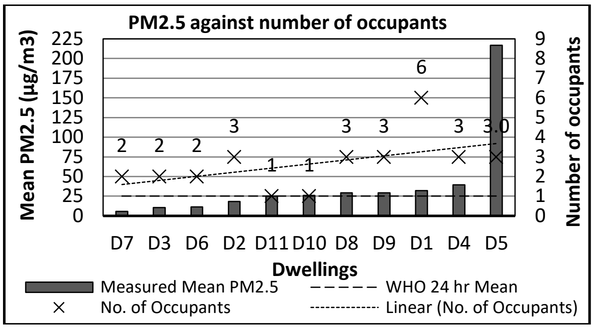

Figure 7: $PM_{2.5}$ concentrations and number of householders per dwelling for the monitored period.

The number and age of householders, and consequently the level of human activity, seem to have the greatest influence on indoor $PM_{2.5}$. In all but one of the dwellings with over two householders, $PM_{2.5}$ levels were above the WHO guidelines. Two dwellings located within one development, one with a couple in their sixties and the other with a couple in their seventies, were within the guideline levels. Only one dwelling (D10) with a single householder had concentrations above the guideline levels, and this is only slightly above. It is a flat located along a busy road. This suggests that such a location has the potential to contribute to higher indoor $PM_{2.5}$.

Dwelling D11, on the same block and location as D10, was monitored after being vacant for some time; to test the impact of being unoccupied and window operation. Windows were left closed for the first half of the monitoring period, and then opened for the second half. The results (Figure 8), show that its $PM_{2.5}$ concentrations increased and became more variable when the window was opened. Even then, its peaks did not reach the WHO guideline (25µg/m^3); and overall, had the lowest $PM_{2.5}$ across all dwellings (Figure 9). Although proximity to the busy road may influence PM levels, overall, there seems to be a stronger association between the number of householders and indoor $PM_{2.5}$ levels than between proximity to the road and indoor $PM_{2.5}$ levels. PM_{10} varied more than $PM_{2.5}$ when windows were open.

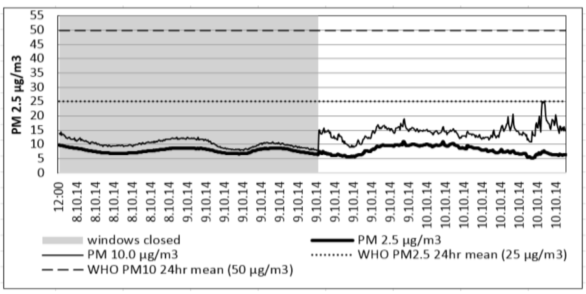

Figure 8: $PM_{2.5}$ concentrations in unoccupied bedroom with windows left closed (shaded) and then left open.

The patterns of particulate levels measured across the dwellings suggest indoor and outdoor sources of $PM_{2.5}$. When CO_2 is considered as an occupancy indicator, there was no clear evidence to determine whether the presence of occupants in bedrooms increased $PM_{2.5}$. An inverse relationship between CO_2 levels and $PM_{2.5}$ concentrations appears to happen at night in some dwellings. A rise in CO_2 is accompanied by a drop in $PM_{2.5}$, when occupants have slept - presumably when the particles have settled. This was the case in dwellings D4, D5, and D6; but there was no clear relationship in the other dwellings (Figure 9). This suggests that, although CO_2 may predict ventilation and indicate occupancy, it may be a poor predictor of $PM_{2.5}$ in bedrooms. Although $PM_{2.5}$ was measured in series instead of concurrently, Figure 9 shows the potential for dwellings in one location to have significantly different levels of indoor $PM_{2.5}$.

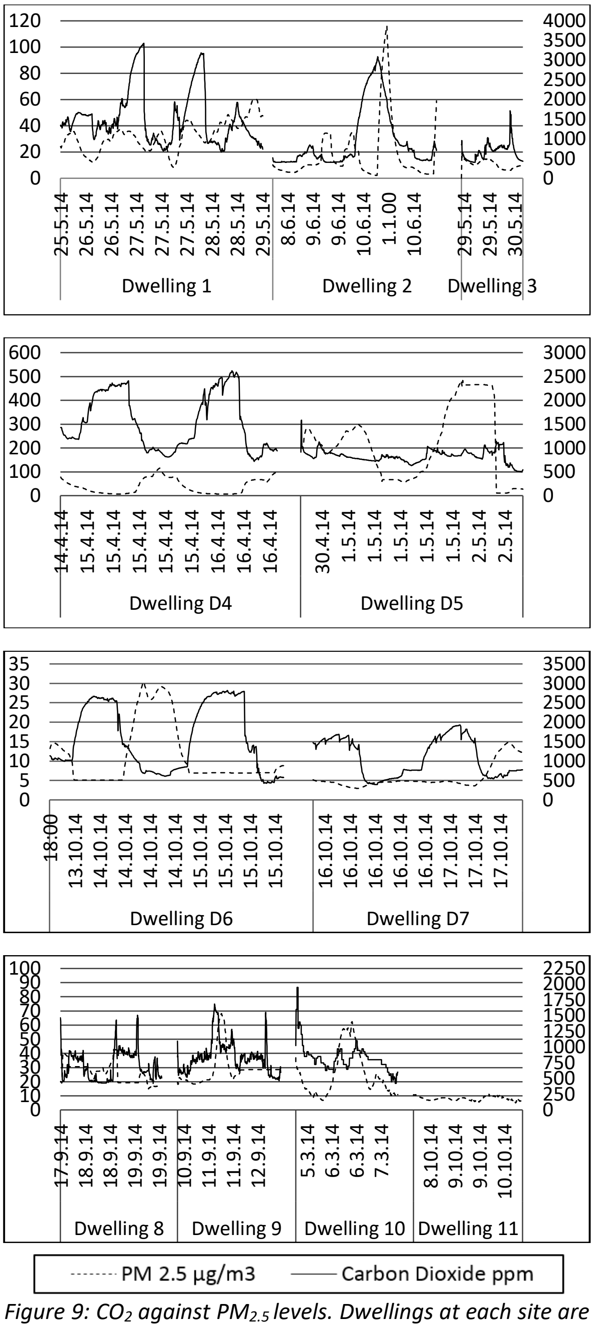

Figure 9: CO_2 against $PM_{2.5}$ levels. Dwellings at each site are plotted together. CO_2 is also an indicator of ventilation for the monitored period.

In the context of Scotland, a wet and windy country with cold climate, it may be more important to control exposure to internal than external $PM_{2.5}$. While Scotland's rainy weather and dispersion by wind may partly explain the low outdoor $PM_{2.5}$ at the sites in Table 2, it's many hills and valleys could also impede $PM_{2.5}$ dispersions. Scotland's high rainfall and low annual temperature keep people indoors for much longer than outdoors, with closed windows. Yet, the government focuses on exterior $PM_{2.5}$ reduction, despite meeting it's target outdoor mean $PM_{2.5}$ of 10μg/m^3 at most of the monitoring sites e.g. in Table 2. There are no set targets for indoor $PM_{2.5}$.

4. CONCLUSIONS

$PM_{2.5}$ levels in the eleven dwellings were generally above the set limits by WHO; and not safe in all the dwellings in the context of the EU ESCAPE study. With $PM_{2.5}$ in over half of the dwellings exceeding the WHO 48hr mean standard, the results suggest that the health burden of $PM_{2.5}$ in bedrooms could be significant. Since the dispersion of external $PM_{2.5}$ is expected to be high in Scotland, indoor $PM_{2.5}$ levels may be higher in less windy contexts. The bedtime levels were significantly lower than the 24hr mean levels, suggesting that using a 24hr mean may be misleading, if occupancy patterns are not taken into account. The bedtime indoor $PM_{2.5}$ levels were higher than the typical outdoor $PM_{2.5}$ across Scotland. Since the influence of outdoor $PM_{2.5}$; and disturbance of settled indoor $PM_{2.5}$ by occupants is expected to be low at bedtime, this suggests a need to commit efforts to the control of sources and levels of indoor $PM_{2.5}$; and to review regulations and enforcement of existing airtightness and ventilation standards. The results suggest clearer relationships between the number of householders and $PM_{2.5;}$ and between air tightness and $PM_{2.5}$; than between occupancy and $PM_{2.5}$. Further work is needed on: (i) how indoor $PM_{2.5}$ could be managed; (ii) how occupants could be informed of indoor $PM_{2.5}$ – an invisible pollutant; (iii) measures that architects could integrate in the design and planning of dwellings to control bedroom $PM_{2.5}$; and (iv) monitoring of a larger sample of dwellings, with repeat measurements at different seasons.

REFERENCES

1. Semple, S., Garden, C., Coggins, M., Galea, K., Whelan, P., Cowie, H., Ayres, J. (2012). Contribution of solid fuel, gas combustion or tobacco smoke to indoor air pollutant concentrations in Irish and Scottish homes. *Indoor Air*, 22(3): p. 212–223.
2. Semple, S., Apsley, A., Azmina I., Turner, S., & Cherrie, J. (2015). Fine particulate matter concentrations in smoking households: Just how much second hand smoke do you breathe in if you live with a smoker who smokes indoors?'. *Tobacco Control*. 24: e205-e211.
3. Sharpe, T., Farren, P., Howieson, S., McQuillan, J. and Tuohy, P., (2015). Occupant Interactions and Effectiveness of Natural Ventilation Strategies in Contemporary New Housing in Scotland, UK. *International Journal of Environmental Research and Public Health*. 12: p. 8480-8497.
4. Howieson, S., Sharpe, T., and Farren, P. (2013). Building tight - Ventilating right? How are new air tightness standards affecting indoor air quality in dwellings? *Building Services Engineering Research and Technology.* 35: p. 475-487.
5. Building Research Establishment (1985). Surface condensation and mould growth in traditionally built dwellings. *Digest 297.* BRE Press, Garston.
6. Harrison R., Giorio C., Beddows D., Dall'Osto M. (2010). Size distribution of airborne particles controls outcomes of epidemiological studies. *Sci. Total Environ*. 409 p. 289-293.
7. WHO, (2014). *Ambient (outdoor) air quality and health*. World Health Organization. Fact sheet No 313.
8. Leng, Y., Wainwright, N., Cappuccio, F. (2014). Self-reported sleep patterns in a British population cohort. *Sleep Medicine*. 15(3): p. 295-302.
9. Canha, N., Lage, J., Candeias, S., Alves, C., and Almeida, S. (2017). Indoor air quality during sleep under different ventilation patterns. *Atmospheric Pollution Research*. 8(6): p. 1132-1142.
10. Boor, B., Spilak, M., Laverge, J., Novoselac, A., and Xu, Y. (2017). Human exposure to indoor air pollutants in sleep microenvironments: A literature review. *Building and Environment*. 125: P. 528-555.
11. Gowers AM, Miller BG and Stedman JR, (2014). 'Estimating Local Mortality Burdens associated with Particulate Air Pollution' Report number PHE-CRCE-010, Public Health England Centre for Radiation and Chemicals in the Environment, Didcot, Oxfordshire.
12. Brookes, D. M., Stedman, J. R., Kent, A. J., *et al* (2013). Technical report on UK supplementary assessment under the Air Quality Directive (2008/50/EC), the Air Quality Framework Directive (96/62/EC) and Fourth Daughter Directive (2004/107/EC) for 2012. Ricardo-AEA. Report Ricardo-AEA/R/3380, Issue 1.
13. Perera, E. and Parkins, L. (1992). Build tight – ventilate right. *Building Services*. Chartered Institution of Building Services Engineers, London. P. 37-38.
14. McGill G. (2018). Occupant interaction with ventilation in systems in dwellings. Unpublished report and paper in production. MEARU, Mackintosh School of Architecture.
15. WHO, (2006). Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide Global update 2005.
16. WHO, (2014). Guidelines for indoor air quality: household fuel combustion.
17. Raaschou O. *et al.* (2013). Air pollution and lung cancer incidence in 17 European cohorts: prospective analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE), *The Lancet Oncology.* 14 (9): p. 813–22.
18. Hamra B., Guha N., Cohen A.; *et al.* (2014). Outdoor Particulate Matter Exposure and Lung Cancer: A Systematic Review and Meta-Analysis. *Environmental Health Perspectives* 122 (9).
19. University of Southampton (2016). Occupancy Patterns Scoping Review Project. Final Report.
20. Scotland government. *Air Quality in Scotland,* [Online]. www.scottishairquality.co.uk/ [26 August 2018].
21. DEFRA, UK govt. *Pollution Climate Mapping Model.* [Online]. https://uk-air.defra.gov.uk/research/air-quality-modelling?view=modelling [26 August 2018].