HEALTH BENEFITS OF THE USE OF PORTABLE AIR PURIFIERS THAT REDUCE EXPOSURE TO $PM_{2.5}$ IN RESIDENCES: THE CASE OF CHILDHOOD ASTHMA IN LONDON

E Cooper[1], Y Wang[1], S Stamp[1], D Mumovic[1]
[1]Institute for Environmental Design and Engineering, University College London, United Kingdom.

Abstract

Home air purifiers (HAPs), utilizing HEPA filtration as the primary mechanism of air cleaning aim to reduce particulate matter (PM) concentrations that are known to be harmful to health. In the work described here, $PM_{2.5}$ concentrations were continuously monitored for 6 months inside and at the ground floor exterior of 18 flats in London. Median bedroom $PM_{2.5}$ concentration of all flats was measured at 14 µg m^{-3} in the bedroom at the start of HAP operation. In the bedrooms where the HAP was in use, a clear decay curve was seen resulting in a 45% reduction of $PM_{2.5}$ over 90 minutes of run time. Based upon these findings, and the published positive association between $PM_{2.5}$ and asthma (OR = 1.28 per 3.2µg/m^3), an estimated 1,361 additional QALYs per 10,000 children were achieved using HAPs in health impact models.

Keywords: Health impact, air purifier, particulate matter

1 Introduction

Home, for most people, represents a place of comfort, safety and wellbeing, and, on average, people spend more than 65% of their time there (Klepeis 2001). It is important, therefore, to understand the quality of the air in homes, and how best to respond if it is poor. In many locations, air pollution concentrations, including particulate matter, can exceed health-based standards developed by the World Health Organization (WHO) for both chronic and acute exposure (Logue et al. 2012), and previous studies have recognized the contribution of indoor air pollution to total exposure (Samet 1993; Weisel et al. 2005). Numerous studies have linked exposure to particulate matter to negative health outcomes (e.g.Anderson, Thundiyil, and Stolbach 2012; Pope and Dockery 2006). Technologies are rapidly being adopted to mitigate indoor air pollution, and air purifiers are one of the most effective technologies available to clean the surrounding air of harmful pollutants of both indoor and outdoor origin. The most common equipment currently available for in-home use are home air purifiers (HAPs) which utilize HEPA filtration as the primary mechanism of air cleaning. These devices have many advantages over other filtration methods, including; they are simple to install, can be located where people spend most of their time, can be relocated, and they do not require a central air handling system. Previous research has reported substantial and significant reductions in $PM_{2.5}$ in spaces using these devices (McNamara et al. 2017; Shao et al. 2017). In a modelling study by Fisk and Chan (2017) indoor air was simulated for a number of scenarios, including a 45% reduction using portable air purifiers in homes without forced air systems, a scenario which closely resembles the typical conditions in London flats.

2 Methods

2.1 Indoor air quality monitoring

18 flats in east London, U.K. (located within three buildings at two sites), were selected for the collection of air quality (AQ) data. The households were provided with a HAP for use in a bedroom. Each HAP had a built-in sensor for measuring $PM_{2.5}$ and sent information via the cloud to the manufacturer of ON/OFF status, operation mode (e.g. fan speed), and $PM_{2.5}$ levels. Outdoor $PM_{2.5}$ levels

were monitored at the ground level of each site. Information about physical characteristics of the dwelling (e.g. area, carpeted, etc.), and occupancy patterns and behaviours were surveyed.

2.2 Quantification of health impact

The focus of this work is childhood asthma due to its relatively high prevalence in the U.K., and its known association with $PM_{2.5}$ (Gehring et al. 2010). The model assumes the persistence of symptoms until approximately age 14 years because asthma in children most often improves with time and diminishes with reductions in exposure. The relationship between exposure and health outcomes is based primarily upon epidemiological studies of outdoor concentrations (Pope 2002; Gehring et al. 2010; Qiu et al. 2018). The location of the HAP was assumed to be in the bedroom of the child affected, and median daily time spent in bedrooms was estimated to be 11 hours and 31 minutes, based upon available literature on sleep patterns of children (Jones and Ball 2014; Blair et al. 2012).

Table 1. *Morbidity outcomes and exposure-response relationships*

Health outcome prevalence by harm class			
Harm class	*Outcomes*	*Prevalence (children)*	*Source*
I	Mortality	(Not included)	
II	Hospital adm, resp. disease	0.001	(HHSRS* 2003)
III	Asthma, respiratory disease	0.016	As above
IV	Rhinitis, cough, wheeze	0.093	As above
Exposure-response functions by harm class			
Harm class	*Outcomes*	*Exposure-response (per 3.2ug/m³ change in $PM_{2.5}$)*	*Source*
I	(Not included)		
II	Hospital adm, resp. disease	1.17	(Qui et al., 2018)
III	Asthma, respiratory disease	1.25	(Gehring et al., 2010)
IV	Rhinitis, cough, wheeze	1.18	(Gehring et al., 2010)
QALY weights by harm class			
Harm class	*Outcomes*	*QALY weight*	*Source*
I	Mortality		
II	Hospital adm, resp. disease	0.75	(Hamilton et al., 2015)
III	Asthma, respiratory disease	0.9	As above
IV	Rhinitis, cough, wheeze	0.9	As above

Annual health benefits of air purifiers to reduce the number of children with respiratory symptoms compared to those without air purifiers, Z, is calculated from input data (Table 1) using Eq. (1):

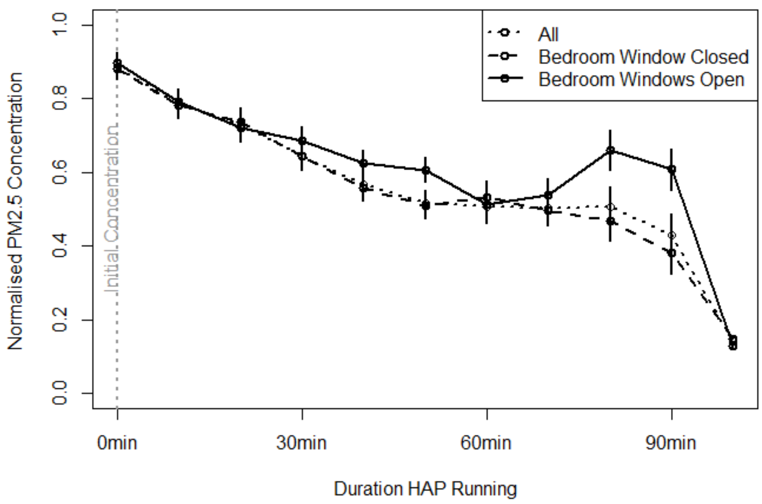
$$\sum Z_j = N\ x\ \left(\left(1 - S_j\right) x\ RR_j^{C_i/\delta_{er}}\right) xT_e) - N\ x\ \left(\left(1 - S_j\right) x\ RR_j^{C_p/\delta_{er}}\right) xT_e) \qquad (1)$$

Where, Subscript j refers to harm class (II, III, or IV); N is the number of children in the affected population; S is the harm class severity weight; RR is the relative risk; C_i is the initial concentration of PM2.5; Cp is the post-intervention concentration of $PM_{2.5}$; δ_{er} is the rate of change in exposure-response function (3.2 μg/m³); and, T_e is the length of exposure (time spent in bedroom).

3 Results

When measurements from all participant bedrooms are combined, a clear decay curve was seen from the onset of HAP use to 100 minutes run time (***Figure 1***), regardless of window opening. The median concentration of $PM_{2.5}$ in bedrooms at Time 0 (initial concentration in figure) was 14.0

Figure 1. *Change in the mean concentration of $PM_{2.5}$ in London bedrooms using home air purifiers. HAP switched ON at time 0, with minutes of run time shown. Vertical bars represent the standard deviation from the mean across all flats.*



μg/m^3 (range = 1 to 185 μg/m^3). The median percent reduction in $PM_{2.5}$ concentration after running the air purifier for 90 minutes was 45%.

Using the reduction at 90 minutes as a conservative estimate of sustained reduction in $PM_{2.5}$ when the HAP is continuously operating. The number of QALYs saved by using appropriately sized and well-functioning air purifiers in the bedrooms of children during sleep is estimated to be 1,361 per 10,000 children (***Table 2***).

Table 2. *Health impact calculations by harm class and air purifier use.*

HIA calculation (for 10,000 children spending 11.51 hours/day in filtered bedroom)			
	Exposure - $PM_{2.5}$ (μg/m^3)		
No HAP	14	initial concentration	
With HAP	7.7	45% mean reduction	
Impact (QALYs)			
Harm class	*Pre-intervention with HAP*	*Post-intervention with HAP*	*Impact (pre-post)*
II	2,383.0	1,749.3	633.6
III	1,273.0	820.5	452.6
IV	989.3	714.2	275.1
Total	4,645.4	3,284.0	**1,361.3**

4 Discussion

Over 1.7 million children under the age of 15 live in London, where PM2.5 concentrations can often exceed annual WHO guidelines (10μg/m^3). These conditions behove us to find opportunities for reducing exposure to $PM_{2.5}$ indoors, where children spend most of their time. Conventionally, ventilation in U.K. residences has been through operable openings (i.e. windows and doors) as well as infiltration, and uncontrolled ventilation has been common. Building standards have changed to meet requirements for energy efficiency and carbon reduction which has lowered infiltration rates, making intentional ventilation paramount to keeping indoor air quality good. Although there are several ways in which to achieve the required air change rate, including continuous mechanical extract, or supply and extract with heat recovery, background ventilators remain a common approach. These ventilators (e.g. trickle-ventilators), as with uncontrolled ventilation, do not provide any filtration capacity, leaving the indoor air quality heavily dependent upon the quality of the outdoor air. Additionally, for events of high indoor pollutant generation (e.g. cooking), ventilation rates may be inadequate. Air purifiers, with HEPA filtration, provide a flexible and lower-cost option for reducing indoor concentrations of $PM_{2.5}$ while allowing for changes to the residential building stock that improve airtightness and thermal performance, and reduce energy use and carbon footprint. As demonstrated in the work presented here, the provision of air purifiers in the bedrooms of children living in areas with even moderate levels of $PM_{2.5}$ can provide substantial health benefits.

Future work includes additional health outcomes, including excess mortality, lung cancer, CHD, etc. using a multi-state life table model. Financial costs of interventions with air purifiers are expected to be swamped by the substantial health benefits of their use, and the magnitude of this difference will be explored. Uncertainty analyses that examines the impact of the range of $PM_{2.5}$ reduction by HAPs, health outcomes, and an assessment of structural uncertainties will also be included in future work. The results from the work reported here suggest that the use of air purifiers is a viable option for improving indoor air quality (in relation to particulate matter) in residences in the U.K. that do not have central air handling systems with filtration, and would reduce the burden of disease associated with childhood asthma.

5 Conclusion

The work described here is the first part of a larger project to assess the costs and health benefits of the use of portable air purifiers to reduce exposure to indoor $PM_{2.5}$. Key findings include: (1) The mean reduction in $PM_{2.5}$ in the bedrooms using HAPs was 45% after 90 minutes (from an initial median concentration of 14.0 μg/m^3). This result is in line with other modelling work. (2) Operating an air purifier in children's bedrooms during sleep would save 1,361 QALYs per 10,000 children annually. Applied London-wide this measure would save an estimated 466,232 QALYs. For comparison, a reduction of 1μg/m^3 $PM_{2.5}$ in outdoor air in London is estimated yield approximately 63,000 QALYs over the lifetime of adults aged over 40 (Schmitt 2016). (3) Providing HEPA filtration in the bedrooms of children would substantially reduce the health burdens associated with childhood asthma in London.

6 References

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