Measuring secondhand smoke in homes in Malaysia: A feasibility study comparing indoor fine particulate (PM$_{2.5}$) concentrations following an educational feedback intervention to create smoke-free homes during the COVID-19 pandemic

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ABSTRACT

INTRODUCTION Extensive regulations have been introduced to reduce secondhand smoke (SHS) exposure among non-smokers in Malaysia. However, there is still a need to encourage behavior change of smokers in relation to making homes smoke-free. This feasibility study aimed to use low-cost air pollution monitors to quantify SHS concentrations in Malaysian households and to explore the practicality of using personalized feedback in educating families to make their homes smoke-free.
METHODS A total of 35 smokers in three states in Malaysia were recruited via snowball and convenience sampling methods. Indoor fine particulate (PM$_{2.5}$) concentrations in participants' homes were measured for 7 days before and after educational intervention using a pre-defined template, which included personalized air-quality feedback, and information on SHS impacts were given. The feedback was delivered over two 20-minute phone calls or in-person sessions following the completion of the air-quality measurements. Data were corrected for outdoor PM$_{2.5}$ concentrations from the nearest environmental monitor.
RESULTS Despite the challenges in conducting the project during COVID-19 pandemic, the delivery of the intervention was found to be feasible. Twenty-seven (77%) out of 35 participants completed PM$_{2.5}$ measurements and received a complete intervention. The median (IQR: 25th –75th percentile concentrations) SHS-PM$_{2.5}$ concentrations at baseline and follow-up were 18.3 μg/m^3 (IQR: 13.3–28.3) and 16.2 μg/m^3 (IQR: 10.4 – 25.6), respectively. There was a reduction of SHS-PM$_{2.5}$ concentrations at follow-up measurement in the houses of 17 participants (63%). The change in corrected indoor PM$_{2.5}$ concentrations between baseline and follow-up was not statistically significant (Z= -1.01, p=0.29).
CONCLUSIONS This educational intervention, combining the use of a low-cost air particle counter with personalized air-quality feedback, was found to be feasible in the Malaysian setting. It has potential to trigger behavior change among smokers, reducing indoor smoking and consequent SHS concentrations, and increasing smoke-free home implementation. A large-scale trial is needed.

INTRODUCTION

Secondhand smoke (SHS) is a serious cause of ill-health in children. SHS

exposure in the young is associated with a wide range of poor health outcomes, including lower respiratory infections, asthma attacks, otitis media and severe diseases including meningitis[1]. These health effects are associated with a wide range of hazardous compounds present in SHS, including fine particulate matter with aerodynamic diameter of less than 2.5 microns ($PM_{2.5}$). $PM_{2.5}$ has been widely used as a reliable marker of the presence of SHS in indoor settings.

Malaysia is a middle-income country with a population of around 32 million. In 2019, around 21.3% of Malaysians aged ≥15 years were current smokers[2] but, as in many lower- and middle-income countries at earlier stages in the tobacco epidemic[3], smoking prevalence is highly gendered, with men considerably more likely to smoke (40.5%) than women (1.2%)[2].

To reduce SHS exposure, the Malaysian government has introduced a range of regulations on smoking indoors in public places. Most recently, in January 2019, Malaysia implemented a comprehensive ban on smoking in restaurants, cafes and other locations where food is served[4]. Smoking is banned or highly restricted in many other indoor environments, such as offices, healthcare facilities and public transport (though it is still permitted in bars and nightclubs)[5,6].

However, smoking within the home is still common, with a 2019 study estimating that more than half of Malaysia's households allow smoking indoors[7]. As children spend the majority of their time at home, smoking indoors is likely to lead to significant exposure to SHS, particularly during recent COVID-19-related restrictions on non-essential travel. However, no studies have objectively measured SHS in Malaysian homes, meaning that health professionals, policymakers and researchers have an incomplete understanding of the scale of this problem.

An additional concern is the lack of interventions designed to reduce home smoking in the Malaysian context. Globally, a range of interventions have been developed to help parents and guardians create smoke-free homes to protect their children's health. These have used strategies such as motivational interviewing, smoking cessation support for adults, and feedback of biomarkers of children's exposure (such as salivary cotinine), among many other techniques[8].

Interventions using air-quality feedback to engage with smokers and other family members to encourage the creation of a smoke-free home have been applied in several settings[9]. This approach uses low-cost air pollution monitors to measure SHS within the home over several days, and the results provided to householders along with contextual information to encourage smokers to alter their behavior. Several studies have found these interventions can lead to reductions in SHS concentrations in homes[10,11], and they have been adapted for studies in the Global South[12]. However, most studies have been conducted in high-income countries in the Global North, without tailoring to the Malaysian social context (such as the gender disparity in smoking).

To address these issues, this research aimed to use low-cost air pollution monitors to quantify concentrations of SHS in households in Malaysia, and to explore the practicality of using the compiled information in educating Malaysian families to make their homes smoke-free.

METHODS
Study design and recruitment of participants
This was a feasibility study conducted between January and August 2021 in three areas of the Peninsula of Malaysia including Klang Valley (Selangor and Kuala Lumpur), Kuala Terengganu (Terengganu) and Kuantan (Pahang). The snowball and convenience sampling methods were adopted to recruit study participants in these selected areas. The locations were chosen because of the diversity of sociodemographic and economic status represented by all these three areas. Kuala Lumpur is a metropolitan city. Kuantan is an urban area with high economic activity, while Kuala Terengganu is a suburban area located near the east coast of Malaysia. Several recruitment strategies were applied which included:
1. Social media advertisement (e-poster) in the Facebook and Instagram account of the MyFamily MySmoke project and WhatsApp messages.
2. Distribution of posters through the post box of residents' homes, at restaurants, shopping malls, childcare center and a local training center.

To be eligible, participants were required to be residents in one of the three areas in Klang Valley, Terengganu, or Pahang. In addition, they had to be a current smoker who smoked indoors at home or

a non-smoker living with at least one smoker. An additional criterion was that at least one child under the age of 16 years resided in the participant's home. A summary of participants' recruitment and flow of data collection is shown in Figure 1.

Training

An online course consisted of four training sessions that were provided to the researchers. The researchers were trained in: operating the air-quality monitor using the device's standard operating protocols; data entry to generate the air-quality feedback using a pre-defined template; and interpretation of the

personalized air-quality feedback. One-to-one online training sessions were also performed to rehearse the delivery session of personalized air-quality feedback.

Data collection

Indoor $PM_{2.5}$ measurement

Indoor $PM_{2.5}$ concentrations were measured using a Purple Air-II-SD (PA-II-SD) (Figure 2), a real-time air-quality monitoring device. The Purple Air PA-II SD (PurpleAir LIc, Utah, USA), is a portable air-quality assessment tool that measures and records real-time $PM_{2.5}$ concentrations in indoor or outdoor settings. The PA-II SD is a low-cost device (US$ 279)

Figure 1. Summary of participants' recruitment and flow of data collection
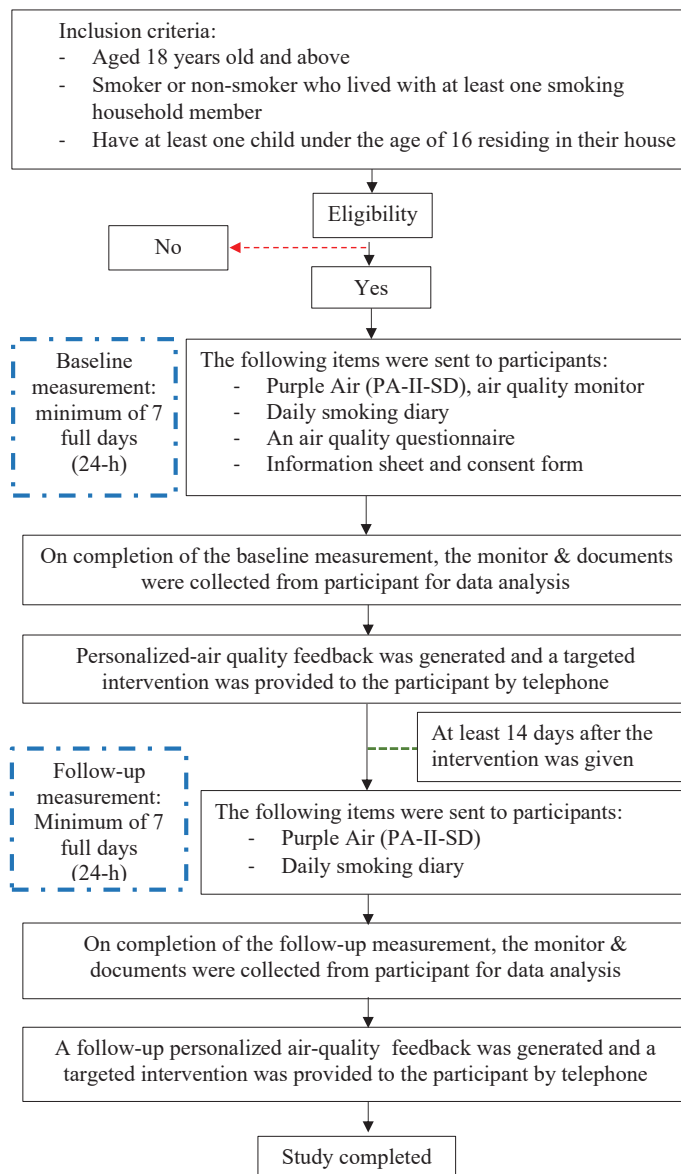
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Figure 2. Purple Air (PA-II-SD) device used to measure indoor PM$_{2.5}$

that uses laser particle-counters to provide real time measurement of PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$. This device has been used worldwide including monitoring uncontrolled forest fires in California[13] and as a tool to improve community engagement around air-quality issues in Western Canada[14]. Studies have shown that the PurpleAir performs well when compared to reference instruments[14,15].

Participants were provided with the following: a PA-II-SD, a charger with micro-USB cable, a portable electric power extension socket, a small tripod and a file of documents that consisted of an information sheet with a consent form, a smoking diary, an air-quality questionnaire and a short booklet describing how to install the PA-II-SD in the home. A video to provide further guidance on assembling, connecting and installing the PA-II-SD device was also made available to all participants. Due to the global COVID-19 pandemic and the enforcement of a Movement Control Order in Malaysia, the physical visit to participants' houses was not possible and as a result the equipment and related documents were sent to the participants using a courier delivery service.

Participants were asked to place the PA-II-SD inside the house using the following criteria: 1) the device needed to be placed in the main living area (not the kitchen); 2) ensuring a position close to an electrical power socket; 3) at least 50 cm from the floor, and at least 1m from windows or the main house entrance; and 4) avoiding any obstruction at the lower part of the PA-II-SD.

The PM$_{2.5}$ concentration data were recorded on the SD card of the device every 120 seconds. Measurements were performed for a minimum of 7 full days (24-h) excluding the 1st (installation day) and 9th day (collection/return shipment day).

The time interval between baseline and follow-up measurements was set at a minimum of 14 days to allow the preparation and delivery of personalized air-quality feedback about the measured levels of SHS in the participant's home. After completion of baseline sampling, the air-quality data were analyzed and a personalized-feedback document (Figure 3) was sent to the participants. Shortly after, participants were contacted to arrange a short (approximately 20-minute) personalized-feedback intervention call with the researcher. This session aimed to discuss the measured indoor PM$_{2.5}$ concentrations and SHS exposure from the baseline sampling period and broadly followed the methods from the AFRESH intervention[13,14].
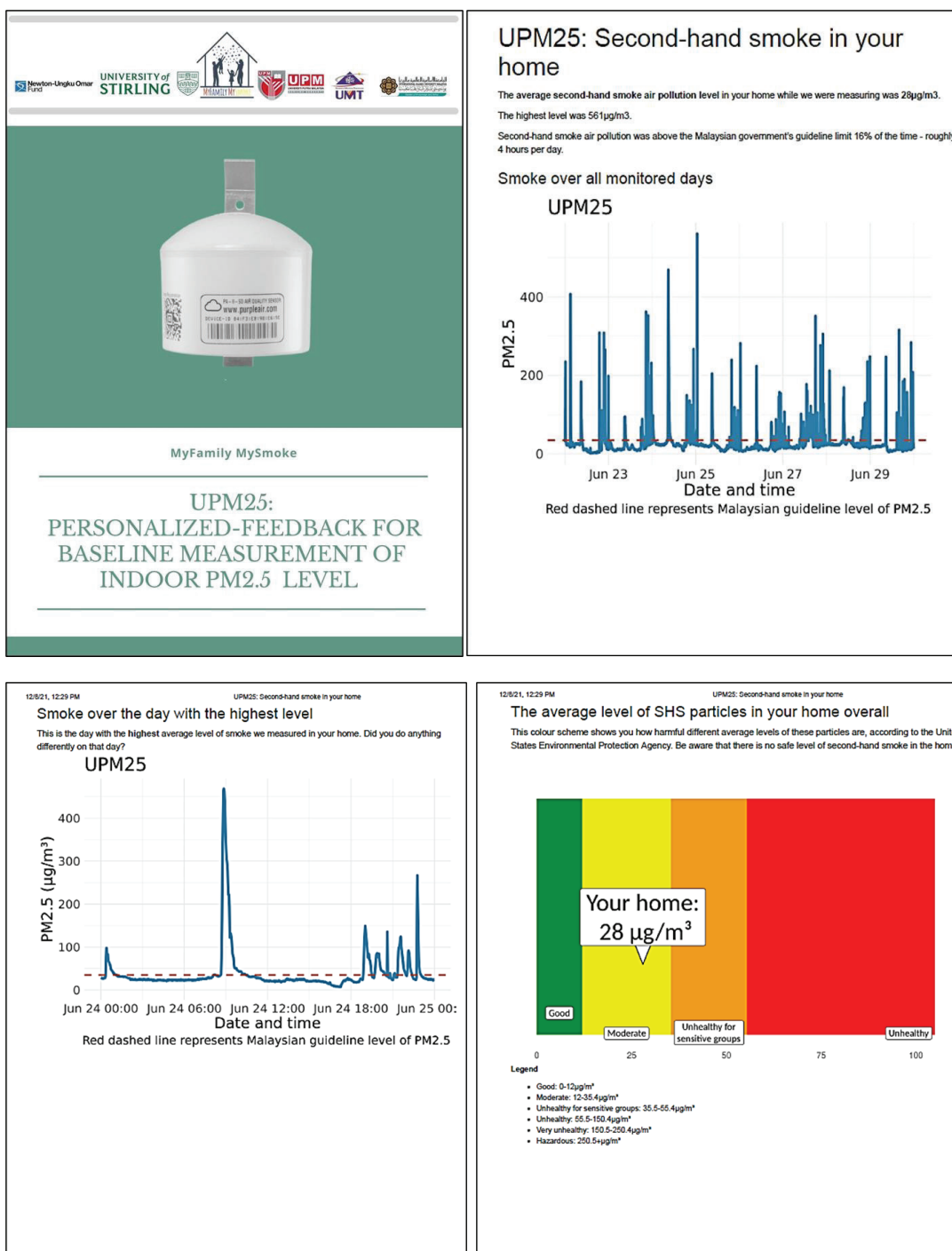
Air-quality questionnaire and smoking diary
An air-quality monitoring questionnaire was also used to gather data on: 1) sociodemographic characteristics; 2) type and house conditions; and 3) general and household smoking activities. Participants were also asked to complete daily smoking diaries to record the number of cigarettes smoked, the timing of smoking, and the specific location of smoking inside of the house. Other potential sources of PM$_{2.5}$ from household activities such as cooking during the measurement were also noted in these diaries.

Educational intervention
After completion of baseline measurements, the household air-quality data were analyzed and a personalized-feedback document was sent to each participant. Shortly after, participants were contacted to arrange a short (approximately 20-minute) educational intervention call with the researcher. Generally, the session included an explanation and discussion of: 1) personalized air-quality feedback; 2) facts on secondhand smoke (SHS) organized into three topic areas 'What is SHS?', 'Why is SHS dangerous?' and 'Why are children particularly vulnerable to SHS?'; 3) the harmful effects of SHS on children's health; and 4) the availability of the government's smoking cessation service. The personalized air-quality feedback included information on the average

Figure 3. Personalized-feedback of air quality monitoring which was sent to participants once measurements completed

and the highest level of $PM_{2.5}$ during the measurement period, a graph showing temporal changes in $PM_{2.5}$ concentration over the 7-days of measurement, and a color-scheme figure showing the characterization of respondents' home indoor air quality based on the United States Environmental Protection Agency (US EPA) air-quality guidance levels. Each of the respondents received two sessions: the first after completion of baseline measurements and the second on completion of the follow-up measurements. All

these broadly followed the methods from the AFRESH intervention[16,17].

Respondents were given a token of appreciation for their participation in this study. They received a small sum of 75 MYR (17.66 US$) cash, upon completion of measurements and the intervention.

Data analysis

Summary statistics were generated in Microsoft Excel to compute average values of daily, hourly and period of $PM_{2.5}$ concentrations, as well as the frequency distribution of measured values by $PM_{2.5}$ thresholds (Supplementary file Table 1). The data recovery rate was calculated as the percentage number of hours for which $PM_{2.5}$ data were logged during the study period divided by the maximum potential number of hours based on the device sampling rate.

Outdoor $PM_{2.5}$ concentration

To assess the outdoor concentration of $PM_{2.5}$, the researchers obtained the hourly Air Pollutant Index (API) data from the Department of Environment (DOE) Malaysia for the sites closest to the participants' homes for the period 1 January 2021 to 31 October 2021. The DOE indicated that the dominant air pollutant at these particular sites throughout sampling periods was $PM_{2.5}$. Therefore, the API value was converted to produce the hourly outdoor air $PM_{2.5}$ concentration on the dates when in-home measurements took place. The API value breakpoints and the equations used to back-calculate the outdoor $PM_{2.5}$ concentrations were stated in the DOE's website[18].

RESULTS

Sociodemographic and smoking characteristics

Initially, 36 participants were recruited (Klang Valley 12; Terengganu 12; Pahang 12). Eight dropped out at various stages of the project: seven after completing the baseline measurements and one due to moving home. In total, 27 participants completed the measurement and intervention cycle in three sampling locations: 1) Klang Valley (n=7; participant IDs UPM18 – UPM30), 2) Terengganu (n=10; UMT06 – UMT20) and 3) Pahang (n=10; IIUM01 – IIUM13). Figure 4 shows the sampling points in these three sampling locations and the nearest DOE outdoor Air Quality Monitoring Stations (AQMS).
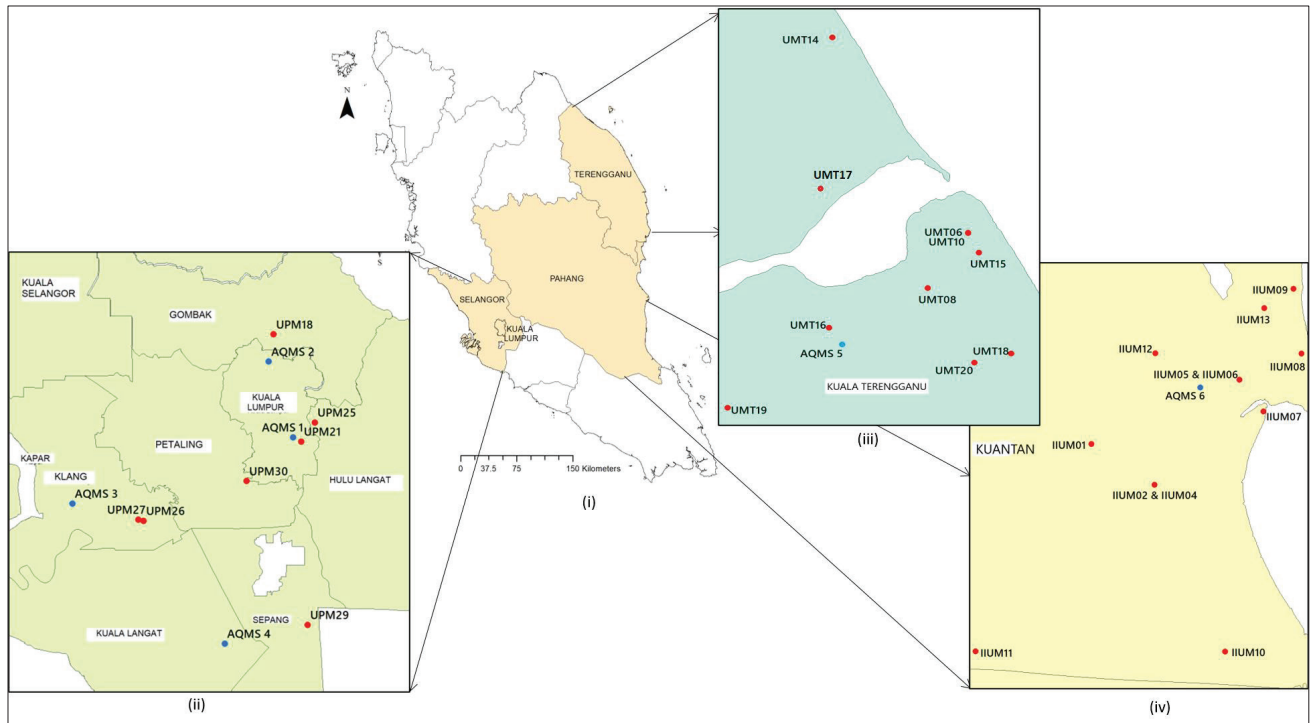
Table 1 provides a summary of the sociodemographic and smoking characteristics of the 27 study participants. The majority of participants from Terengganu and Pahang were from the 'bottom 40%'

Table 1. Participant's sociodemographic and smoking characteristics obtained from an air-quality questionnaire, Klang Valley, Kuantan and Kuala Terengganu, 2021 (N=27)

Characteristics	n (%)
Age (years)	
18–24	2 (7.4)
25–54	21 (77.7)
≥55–64	4 (14.8)
Gender	
Male	24 (88.9)
Female	3 (11.1)
Ethnicity	
Malay	27 (100)
Other	0 (0)
Educational level	
Secondary	15 (55.5)
Tertiary	11 (40.7)
Type of house	
Bungalow or semi-detached or terraced house made of brick or stone	16 (59.2)
A house made of wood or both brick and wood	6 (22.2)
A flat, apartment or condominium in a purpose-built block of flats	4 (14.8)
A flat, apartment or condominium in a converted or shared house	1 (3.7)
Is smoking allowed inside your home?	
Not allowed	0 (0)
Allowed	2 (7.4)
Allowed in certain places only	19 (33.3)
Only allowed when no children are present	4 (14.8)
Only allowed when children are in bed	1 (3.7)
Allowed anywhere in the home	1 (3.7)
Specific indoor areas where smoking is allowed*	
Kitchen, dining room and utility room	6
Attached garage	6
Balcony	4
Living room/lounge	9
Bedroom	5
Toilet	4
How many other people smoke in your home?	
0	11 (40.7)
≥1	16 (59.2)

Questionnaire's items might be answered by smokers or non-smoking household members. *Participants were allowed to choose more than one option.

Figure 4. Sampling locations in (ii) Klang Valley, Selangor & Kuala Lumpur, (iii) Kuala Terengganu, Terengganu, and (iv) Kuantan, Pahang, located in the (i) Peninsula of Malaysia and the nearest Air Quality Monitoring Stations (AQMS) (blue points)

(B40) of the Malaysian national income category, with monthly household income ranging from less than <2500 to 4849 MYR (where 1 MYR=0.24 US$, April 2022, estimation at this point of time; 588.65–1141.75 US$) per month. In the Klang Valley, participants came from the 'middle 40%' (M40) income bracket, with monthly household income ranging from 4850 to 10959 MYR (589–1142 US$). The majority of participants were male (89%, n=24) and aged 25–44 years (59%, n=16) while 33 % (n=9) were aged >45 years. All participants were of Malay ethnic origin. In terms of education level, 7% (n=2) had attained at least a Bachelor's degree and more than half of participants had completed secondary school (56%, n=15). More than 50% of participants lived in a house (bungalow) made of brick or stone, a terrace house or a flat, apartment or condominium. Figure 1 shows the sampling locations covered in three areas in the Peninsula of Malaysia.

The majority of participants were smokers while 15% (n=4) were non-smokers who lived with a smoker. In terms of smoking rules at home, all of the respondents (100%, n=27) reported that smoking was currently permitted in the participant's home.

Indoor $PM_{2.5}$ concentrations at baseline and follow-up measurements

All participating households achieved more than 85% data recovery in terms of $PM_{2.5}$ concentrations at baseline and follow-up (median 100%; 25th percentile 99%; 75th percentile 100%) (Supplementary file Table 1).

Table 2 shows the indoor and outdoor $PM_{2.5}$ concentrations and the calculated SHS-$PM_{2.5}$ concentration for baseline and follow-up measurements in the homes of the 27 participants who completed both baseline and follow-up. The range of indoor $PM_{2.5}$ concentration during baseline measurement was 12.3–140 μg/m³ (Klang Valley 30.7–107 μg/m³; Terengganu 25.1–71.5 μg/m³; Pahang 12.3–140 μg/m³), while the follow-up concentrations ranged from 15.8–84.1μg/m³ (Klang Valley 19.4–62 μg/m³; Terengganu 20.7–84.1 μg/m³; Pahang 15.8–68.9 μg/m³]. Using the unadjusted data of indoor $PM_{2.5}$ (unadjusted for outdoor $PM_{2.5}$ concentration), the changes of indoor $PM_{2.5}$ concentrations within

baseline and follow-up measurements were not statistically significant (Z= -1.27, p=0.20) with the median of baseline $PM_{2.5}$ concentrations being 38.9 µg/m³ and at follow-up 32.9 µg/m³.

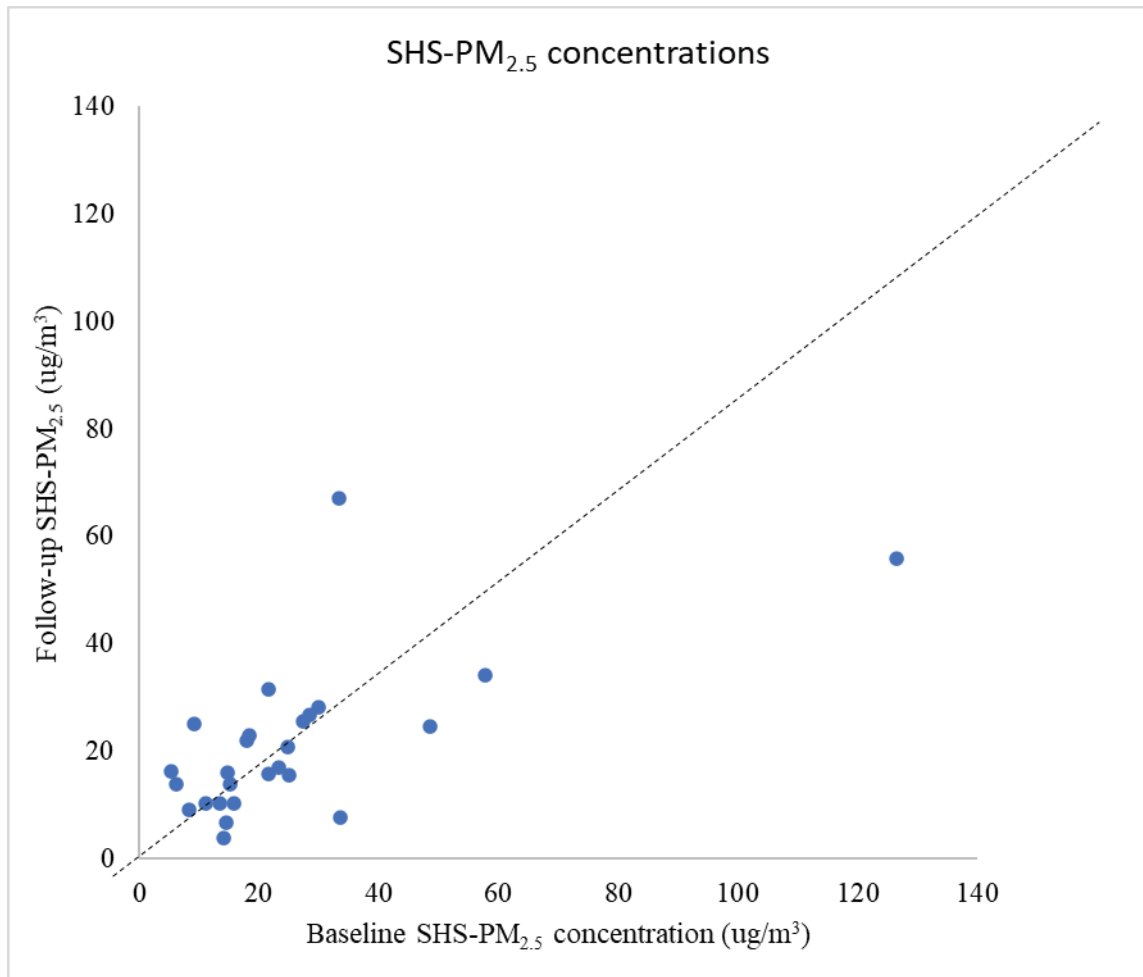Compared with the Malaysian ambient air-quality standard for $PM_{2.5}$ (35 µg/m³) (DOE, 2018), 63% (n=17) of participants experienced indoor baseline $PM_{2.5}$ concentrations that exceeded this recommended value, while only 41% (n=11) exceeded the recommended value of 35 µg/m³ during follow-up

Table 2. Indoor and outdoor $PM_{2.5}$ concentrations (µg/m³) and SHS-$PM_{2.5}$ concentrations for baseline and follow-up measurements in participant houses, Klang Valley, Kuantan and Kuala Terengganu, 2021 (N=27)

Participant ID	Baseline			Follow-up			Intervention effect *	Distance of outdoor air quality monitoring station from participant's house (km)
	$PM_{2.5}$ (Mean ± SD)		SHS-$PM_{2.5}$	$PM_{2.5}$ (Mean ± SD)		SHS-$PM_{2.5}$		
	Indoor	*Outdoor[a]*		*Indoor*	*Outdoor[a]*			
UPM21	37.8 ± 32.3	23.7 ± 10.9	14.0	26.3 ± 27.0	22.4 ± 3.94	3.9	–10.2	4
UPM25	35.8 ± 60.8	17.5 ± 4.13	18.3	49.8 ± 52.5	27.0 ± 6.89	22.9	4.6	8.8
UPM30	30.7 ± 25.5	16.3 ± 3.68	14.4	19.4 ± 24.2	12.7 ± 6.31	6.7	–7.8	14.8
UPM18	34.9 ± 24.3	21.5 ± 9.56	13.3	29.7 ± 41.0	19.4 ± 6.70	10.3	–3.1	6.8
UPM26	80.6 ± 88.0	32.1 ± 6.54	48.6	48.0 ± 94.6	23.3 ± 5.16	24.6	–24.0	14.7
UPM27	107.3 ± 100.8	49.6 ± 8.4	57.8	62.0 ± 64.6	27.8 ± 8.25	34.2	–23.6	13.8
UPM29	41.0 ± 112.4	19.5 ± 6.13	21.5	46.3 ± 174.8	14.8 ± 5.53	31.6	10.1	19.1
UMT06	44.1 ± 31.0	46.4 ± 8.89	–4.26	20.7 ± 26.2	17.9 ± 7.68	2.8	7.11	5.1
UMT08	25.1 ± 26.7	16.0 ± 5.42	9.1	47.1 ± 77.4	22.0 ± 8.46	25.1	16.0	2.8
UMT10	71.5 ± 83.0	41.7 ± 15.1	29.8	43.2 ± 64.5	15.0 ± 5.88	28.3	–1.58	5.1
UMT14	45.2 ± 72.0	11.7 ± 3.41	33.4	84.1 ± 110.1	17.0 ± 6.0	67.1	33.7	10.2
UMT15	44.9 ± 62.2	23.3 ± 10.1	21.6	27.8 ± 51.3	11.8 ± 6.39	15.9	–5.62	5.4
UMT16	49.2 ± 56.5	24.3 ± 9.60	24.9	30.3 ± 51.1	14.9 ± 9.14	15.5	–9.42	1
UMT17	49.5 ± 58.4	22.2 ± 8.07	27.3	58.4 ± 63.5	32.8 ± 9.37	25.6	–1.70	5
UMT18	34.1 ± 29.1	23.0 ± 7.71	11.1	27.5 ± 32.1	17.1 ± 5.52	10.4	–0.56	4.5
UMT19	46.2 ± 50.9	22.9 ± 8.29	23.3	47.6 ± 49.3	30.5 ± 9.21	17.1	–6.18	4.6
UMT20	41.6 ± 37.0	25.8 ± 10.6	15.8	25.5 ± 33.9	15.1 ± 4.88	10.4	–5.43	4.4
IIUM01	38.4 ± 72.9	13.6 ± 7.32	24.8	30.0 ± 42.9	9.30 ± 2.49	20.8	–4.08	12.9
IIUM13	139.8 ± 118.2	13.4 ± 3.43	126.4	68.9 ± 107.0	13.0 ± 2.45	55.9	–70.5	13.9
IIUM12	24.5 ± 29.8	9.32 ± 4.30	15.2	32.9 ± 19.3	19.0 ± 7.52	13.9	–1.31	9.5
IIUM11	18.7 ± 23.3	10.5 ± 3.84	8.2	34.1 ± 15.9	25.0 ± 1.88	9.11	0.92	29.4
IIUM02	44.1 ± 68.9	10.6 ± 5.96	33.5	15.8 ± 31.3	8.26 ± 2.15	7.57	–25.9	13.7
IIUM10	23.5 ± 30.9	8.88 ± 2.28	14.6	34.7 ± 38.3	18.6 ± 7.59	16.1	1.45	29.5
IIUM08	38.9 ± 83.1	10.6 ± 2.85	28.3	36.2 ± 100.3	9.51 ± 4.64	26.7	–1.63	12.4
IIUM07	12.3 ± 28.7	6.97 ± 2.77	5.3	26.6 ± 61.3	10.4 ± 2.43	16.2	10.9	8.5
IIUM05	27.0 ± 36.1	9.02 ± 2.40	17.9	30.1 ± 37.5	8.02 ± 2.21	22.1	4.14	4.2
IIUM09	13.9 ± 12.8	7.82 ± 2.14	6.10	24.7 ± 53.9	10.7 ± 2.78	14.0	7.94	16.1
Mean ± SD	44.5 ± 27.7	19.9 ± 11.5	24.5 ± 24.2	38.1 ± 16.2	17.5 ± 6.92	20.5 ± 14.5	–3.68 ± 18.1	10.4 ± 7.3
Median (IQR difference)	38.9 (16.9)	17.5 (12.9)	18.3 (14.2)	32.9 (20.3)	17 (9.95)	16.2 (15.0)	–1.63 (12.4)	8.8 (9.3)
Range	12.3–139.8	6.97–49.6	–4.26–126.4	15.8–84.1	8.02–30.5	3.9–67.1	–70.5–33.7	1–29.4

SHS-$PM_{2.5}$: mean indoor – mean outdoor. * Intervention effect: (SHS-$PM_{2.5}$ follow-up) – (SHS-$PM_{2.5}$ baseline). [a] Outdoor $PM_{2.5}$ concentrations were obtained via back-calculation of Atmospheric Pollution Index values.

Figure 5. Corrected SHS-PM$_{2.5}$ concentrations (µg/m³) at the baseline and follow-up measurements in 27 participants' houses located in the Klang Valley, Kuantan and Kuala Terengganu. Dashed line shows identity (x=y) with points to the right of the line indicative of homes that experienced reduced concentrations after follow-up, and homes to the left of that line indicating an increase (2021, N=27)

measurement. Using the newly established WHO Air Quality guideline for 24-h average PM$_{2.5}$ (15 µg/m³), 93% (n=25) of participants' homes exceeded the recommended value of 15 µg/m³ during baseline measurement with this increasing to 100% (n=27) at follow-up measurement.

Outdoor PM$_{2.5}$ concentrations at baseline and follow-up measurements

The secondary data of outdoor PM$_{2.5}$ concentration of particular time period were back-calculated from the API values obtained from the DOE as reported in Table 2. Generally, the range of hourly outdoor PM$_{2.5}$ concentrations during the baseline measurement was 6.97–49.6 µg/m³ (Klang Valley 16.3–49.6 µg/m³; Terengganu 11.7–48.4 µg/m³; Pahang 6.97–13.6 µg/m³) with an overall mean (SD) of 20.0 (11.6) µg/m³ [Klang Valley 25.7 (11.7) µg/m³; Terengganu 25.9 (11.02) µg/m³; Pahang 10.1 (2.16) µg/m³]. For follow-up measurement, the range of outdoor PM$_{2.5}$ concentration was 8.02–30.5 µg/m³ (Klang Valley 12.7–27.8 µg/m³; Terengganu 11.8–32.8 µg/m³; Pahang 8.02–24.9 µg/m³) with overall mean (SD) of 17.5 (6.92) µg/m³ [Klang Valley 21.1 (5.77) µg/m³; Terengganu 19.4 (6.98) µg/m³; Pahang 13.2 (5.73) µg/m³].

In terms of intervention effect, the finding shows that there was a reduction of SHS-PM$_{2.5}$ concentration in the follow-up measurements in 17 participant houses (63%) indicated by a negative value.

Corrected indoor PM$_{2.5}$ concentrations representative of SHS–PM$_{2.5}$ level

Figure 5 shows the corrected indoor PM$_{2.5}$ concentrations (SHS-PM$_{2.5}$) at baseline and follow-up measurements. The median (IQR) SHS-PM$_{2.5}$ concentrations at baseline and follow-up were 18.3 μg/m³ (13.3–28.3) and 16.2 μg/m³ (10.4–25.6), respectively. A total of 17 participant houses exhibited lower concentration of SHS-PM$_{2.5}$ at follow-up measurement than at baseline, while another 10 participant houses showed an increase in SHS-PM$_{2.5}$ concentration at follow-up. Overall, the change in corrected indoor PM$_{2.5}$ concentrations between baseline and follow-up was not statistically significant (Z= -1.01, p=0.29).

Reported number of cigarettes smoked indoors

A total of four participants submitted incomplete smoking diaries at either baseline or follow-up. Using the data from the 23 participants with complete smoking diary data, the mean±SD number of cigarettes smoked indoors during the 7-day baseline and follow-up measurements were 46±36 sticks and 35±39 sticks, respectively. About 61% (n=14) of participants smoked a lower number of cigarettes indoors at follow-up measurement than during the baseline period. However, six (26%) participants smoked indoors more frequently during follow-up than during the baseline measurement. One participant reported no change. A statistically significant change in total number of cigarettes smoked indoors at baseline (median 40) and follow-up (median 26) measurements was demonstrated (Z= -2.436, p=0.015).

DISCUSSION

This study demonstrated the feasibility and practicality of using household air-quality information gained from the use of low-cost devices within an intervention to help promote smoke-free homes in Malaysia. Participants were successfully recruited, data collected and the intervention delivered despite the challenges of carrying out such a household intervention during the COVID-19 pandemic. We used courier delivery services, self-installation by the respondents using specially developed booklets and videos, and delivered the educational intervention through a combination of post and phone. A similar approach of using air-quality feedback to encourage smoke-free homes have been applied in previous studies[9,10,19], which were mainly conducted in European countries. Compared with the current study, the previous works have used different mediums of feedback communication such as SMS messages and emails[10] and in person sessions[19] to deliver the air-quality feedback to the participants. This is the first study in Malaysia that has used this approach to promote smoke-free home's implementation.

Measuring PM$_{2.5}$ in smoking households with the Purple Air in Malaysia

This is the first study performed in Malaysian homes that measured real-time indoor PM$_{2.5}$ concentrations using the PA-II-SD device, a low-cost particle counter, and the first to provide personalized air-quality feedback with the aim of reducing smoking in the home. This study found that the device is suitable for measuring indoor PM$_{2.5}$ for this purpose, as has been demonstrated in other recent studies[20-24]. The indoor SHS-PM$_{2.5}$ concentrations reported in this current study were generally lower than the levels reported in previous studies performed in European countries[10,19], with the median of 18.3 μg/m³ [vs 33.0 μg/m³ (Dobson et al.[10]) and 48.2 μg/m³ (Semple et al.[19])] (baseline) and 16.2 μg/m³ [vs 33.0 μg/m³ (Dobson et al.[10]] (follow-up). The differences in home setting in Malaysia and European countries is likely to explain some of the differences in SHS-PM$_{2.5}$. Generally, in the temperate climate United Kingdom, homes are built to be energy saving and as such the number of air changes per hour tends to be smaller than in homes in the tropical Malaysian setting. Homes in Malaysian will often have open windows or doors or be air-conditioned, leading to high levels of dilution ventilation.

Efficacy and acceptability of the intervention

This was a first study performed in Malaysian household setting that incorporated the data of PA-II-SD into the educational intervention to encourage SFH implementation. This feasibility study did not set out to address the efficacy of this intervention and this is for future researchers to study. The study was unsuitable for this purpose due to its small sample size, the variability in feedback-delivery sessions between centers and the short period of follow-up measurement. The MCO resulted in more people spending more time at home, so the extent to which this intervention could reduce exposure to SHS-PM$_{2.5}$ might be obscured by high emissions of PM$_{2.5}$ from

other non-smoking sources.

However, a small reduction of SHS-PM$_{2.5}$ concentrations ranging from 5.29% to 77% were shown in nearly two-thirds of participant homes (63%; n=17). This was in line with the significant reduction of total number of cigarettes smoked indoor reported by more than half of participants (54%) in the follow-up measurement. These reductions in SHS-PM$_{2.5}$ concentrations in the smokers' homes suggests there is potential to have impact with this type of the intervention in Malaysia.

Strengths and limitations

The major strength of this study is the range of components included. This study provided real-time PM$_{2.5}$ data to the participants demonstrating the impact of smoking on the indoor air quality of their houses. The personalized-evidence illustrated in the air-quality feedback can lead to the behavior change of smokers in reducing indoor smoking habit[25,26] and encouraging action to introduce smoke-free home rules[9]. Thus, the comprehensive and active approach adopted in this study was able to translate the scientific evidence into public health action.

Limitations of this study include the use of PM$_{2.5}$ as an indicator of secondhand smoke exposure. There are other potential sources of indoor PM$_{2.5}$ emitted from household activities such as cooking, sweeping, use of candles and ambient air pollution. We have addressed this last concern by comparing indoor to outdoor PM$_{2.5}$ from a nearby monitoring station, and the other concerns through the use of smoking diaries (used during feedback). Unreliable or incomplete diary use may, however, form another source of potential error.

Furthermore, the COVID-19 pandemic created challenges in terms of delivering an intervention to the respondents. Due to the Movement Control Order (MCO) in Malaysia, physical visits to participants' houses were restricted. Therefore, adjustments to the research protocol were made. The device toolbox packages and personalized air-quality feedback documents were sent via instant delivery services. Participants installed the devices at home by referring to a booklet and video as a guide. In order to ensure the device was correctly installed, participants were requested to take a picture of the device to be sent to the researchers and participants were encouraged to

contact the researchers throughout the sampling period if they had any questions. However, some participants did not turn the monitors on immediately after receiving them. Due to that limitation, four households did not reach the minimum seven days of measurements. Therefore, follow-up procedures are recommended in further studies to improve compliance.

The majority of feedback delivery sessions were performed virtually via phone call. This contrasts with previous studies, where intervention delivery was either in person (face-to-face)[19], and/or by SMS and email[10]. To make the sessions more effective and impactful, the personalized air-quality feedback documents were provided to participants before the session to ensure that participants could access the documents in hard-copy while speaking on the phone.

Another limitation of the intervention portion of this study was variation in feedback delivery between the three research centers. This arose due to changes in the feedback template adopted in one center which were not adopted in the other two. While this may affect efficacy, it provides a valuable opportunity to study the acceptability of different methods of providing feedback.

The need for publicly available real-time data in Malaysia

Ambient PM$_{2.5}$ data were not publicly available in the official website of DOE. Therefore, back-calculation of API values on particular sampling time and date were performed in order to generate the ambient PM$_{2.5}$ concentration data. These data were important for the research team to understand the relative contribution of smoking to indoor PM$_{2.5}$ compared to outdoor air pollution. Therefore, this study suggests the importance of making ambient PM$_{2.5}$ data publicly accessible in Malaysia. This is common practice in the United Kingdom[27] and the US[28]. API data cannot always be back-calculated to PM$_{2.5}$ (if, for example, the primary ambient pollutant is ozone) so, it is important that real-time PM$_{2.5}$ data are freely available to researchers in Malaysia.

CONCLUSIONS

This study demonstrated the feasibility of delivering an air-quality feedback intervention to smoking-permitted households in Malaysia. The work provides details of practical measures to facilitate delivery of

such an intervention, with significant learning arising from having to deliver the study during the movement restrictions imposed during the COVID-19 pandemic. Although the intervention was delivered remotely, the intervention using personalized air-quality feedback shows potential to trigger behavior change among smokers, particularly in relation to their indoor smoking habit. Using this study's protocol, future research should be carried out on a large number of smokers with longer follow-up in order to study the efficacy of this intervention.

REFERENCES

1. U.S. Department of Health and Human Services. The Health Consequences of Involuntary Exposure to Tobacco Smoke: A Report of the Surgeon General. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, Coordinating Center for Health Promotion, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health; 2006. Accessed May 11, 2022. https://www.ncbi.nlm.nih.gov/books/NBK44324/pdf/Bookshelf_NBK44324.pdf

2. Ministry of Health Malaysia - Institute for Public Health. NCDs – Non-Communicable Diseases: Risk Factors and other Health Problems. Volume 1: The National Health and Morbidity Survey 2019 Technical report. Institute for Public Health; 2020. Accessed May 11, 2022. https://iku.moh.gov.my/images/IKU/Document/REPORT/NHMS2019/Report_NHMS2019-NCD_v2.pdf

3. Thun M, Peto R, Boreham J, Lopez AD. Stages of the cigarette epidemic on entering its second century. Tob Control. 2012;21(2):96-101. doi:10.1136/tobaccocontrol-2011-050294

4. Malaysia: Ban on Smoking in All Eateries Comes into Effect. Library of Congress. January 17, 2019. Accessed December 10, 2021. https://www.loc.gov/item/global-legal-monitor/2019-01-17/malaysia-ban-on-smoking-in-all-eateries-comes-into-effect/

5. Food act 1983: Control of tobacco product regulations 2004. Akta makanan 1983: Peraturan - Peraturan kawalan hasil tembakau 2004. Malaysian Government Gazette. September 23, 2004. Accessed May 11, 2022. https://www.tobaccocontrollaws.org/files/live/Malaysia/Malaysia%20-%20TC%20Regs%202004.pdf

6. Campaign for Tobacco-Free Kids. Tobacco Control Laws: Legislation by Country Malaysia. Campaign for Tobacco-Free Kids; 2020. Accessed December 10, 2021. https://www.tobaccocontrollaws.org/legislation/country/malaysia/sf-indoor

7. Lim KH, Teh CH, Pan S, et al. Prevalence and factors associated with smoking among adults in Malaysia: Findings from the National Health and Morbidity Survey (NHMS) 2015. Tob Induc Dis. 2018;16(January):1-12. doi:10.18332/tid/82190

8. Behbod B, Sharma M, Baxi R, Roseby R, Webster P. Family and carer smoking control programmes for reducing children's exposure to environmental tobacco smoke. Cochrane Database Syst Rev. 2018;1(1):CD001746. doi:10.1002/14651858.CD001746.pub4

9. Dobson R, O'Donnell R, de Bruin M, Turner S, Semple S. Using air quality monitoring to reduce secondhand smoke exposure in homes: The AFRESH feasibility study. Tob Prev Cessat. 2017;3(June):1-5. doi:10.18332/tpc/74645

10. Dobson R, O'Donnell R, Tigova O, et al. Measuring for change: A multi-centre pre-post trial of an air quality feedback intervention to promote smoke-free homes. Environ Int. 2020;140:105738. doi:10.1016/j.envint.2020.105738

11. Ratschen E, Thorley R, Jones L, et al. A randomised controlled trial of a complex intervention to reduce children's exposure to secondhand smoke in the home. Tob Control. 2018;27(2):155-162. doi:10.1136/tobaccocontrol-2016-053279

12. Mdege ND, Fairhurst C, Wang HI, et al. Efficacy and cost-effectiveness of a community-based smoke-free-home intervention with or without indoor-air-quality feedback in Bangladesh (MCLASS II): a three-arm, cluster-randomised, controlled trial. Lancet Glob Health. 2021;9(5):e639-e650. doi:10.1016/S2214-109X(21)00040-1

13. Gupta P, Doraiswamy P, Levy R. Impact of California Fires on Local and Regional Air Quality: The Role of a Low-Cost Sensor Networkand Satellite Observations. Geohealth. 2018;2(6):172-181. doi:10.1029/2018GH000136

14. Karch D, Brito J, Sievwright J, et al. Small Air Quality Sensor Applications to Improve Community Engagement in Western Canada. Poster presented at: Advancing Citizen Science in Alberta: Changing Perspectives, Breaking Barriers; September 26-27, 2018; Edmonton, AB. Accessed May 11, 2022. https://www.rockies.ca/CitSciAlberta/pdfs/ParsonsPoster.pdf

15. Li J, Mattewal SK, Patel S, Boswas P. Evaluation of Nine Low-cost-sensor-based Particulate Matter Monitors. Aerosol Air Qual Res. 2020;20(2):254-270. doi:10.4209/aaqr.2018.12.0485

16. Medical Research Council. The AFRESH programme. University of Aberdeen; 2016. doi:10.5334/hpb.20.s7

17. O'Donnell R, Dobson R, de Bruin M, Turner S, Booth L, Semple S. Development of a Smoke-Free Homes Intervention for Parents: An Intervention Mapping Approach. Health Psychol Bull. 2019;3(1):67-86. doi:10.5334/hpb.20

18. Malaysian Ministry of Environment and Water. Air pollutant index (API). Accessed January 1, 2021. https://www.doe.gov.my/2021/10/04/english-air-pollutant-index-api/

19. Semple S, Turner S, O'Donnell R, et al. Using air-quality feedback to encourage disadvantaged parents to create a smoke-free home: Results from a randomised controlled trial. Environ Int. 2018;120:104-110. doi:10.1016/j.envint.2018.07.039

20. Mousavi A, Wu J. Indoor-Generated PM2.5 During COVID-19Shutdowns Across California: Application of the PurpleAir Indoor-Outdoor Low-Cost Sensor Network. Environ Sci Technol. 2021;55(9):5648-5656. doi:10.1021/acs.est.0c06937

21. Awokola BI, Okello G, Mortimer KJ, Jewell CP, Erhart A, Semple S. Measuring Air Quality for Advocacy in Africa (MA3): Feasibility and Practicality of Longitudinal Ambient PM2.5 Measurement Using Low-Cost Sensors. Int J Environ Res Public Health. 2020;17(19):7243. doi:10.3390/ijerph17197243

22. Bi J, Wildani A, Chang HH, Liu Y. Incorporating Low-Cost Sensor Measurements into High-Resolution PM2.5 Modeling at a Large Spatial Scale. Environ Sci Technol. 2020;54(4):2152-2162. doi:10.1021/acs.est.9b06046

23. Mehadi A, Moosmüller H, Campbell DE, et al. Laboratory and field evaluation of real-time and near real-time PM2.5 smoke monitors. J Air Waste Manag Assoc. 2020;70(2):158-179. doi:10.1080/10962247.2019.1654036

24. Feenstra B, Papapostolou V, Hasheminassab S, et al. Performance evaluation of twelve low-cost PM2.5 sensors at an ambient air monitoring site. Atmos Environ. 2019;216:116946. doi:10.1016/j.atmosenv.2019.116946

25. Becker AM, Marquart H, Masson T, Helbig C, Schlink U. Impacts of Personalized Sensor Feedback Regarding Exposure to Environmental Stressors. Curr Pollut Rep. 2021;7(4):579-593. doi:10.1007/s40726-021-00209-0

26. Boso À, Álvarez B, Oltra C, Garrido J, Muñoz C, Hofflinger Á. Out of sight, out of mind: participatory sensing for monitoring indoor air quality. Environ Monit Assess. 2020;192(2):104. doi:10.1007/s10661-019-8058-z

27. 24 Hour Summary, based on data provided by Environment Agency. UK Air. Accessed January 18, 2022. https://uk-air.defra.gov.uk/latest/currentlevels?period=24

28. IQAir. Air quality in USA. Accessed January 18, 2022. https://www.iqair.com/us/usa