

## The UCB particle monitor: A tool for logging frequency of smoking and the intensity of second-hand smoke concentrations in the home

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# The UCB Particle Monitor: A tool for logging frequency of smoking and the intensity of second-hand smoke concentrations in the home

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**Abstract.** Second-hand tobacco smoke (SHS) exposure generates a large public health burden. Recent legislation has moved to prohibit smoking in public places and there are concerns that this may lead to an increase in exposures in private homes. Measurement of SHS aerosol has tended to use active pumped samples or longer-term diffusive badges. Pumped methods are noisy and poorly tolerated in home settings while diffusive badges do not provide real-time data. The UCB particle monitor (UCB-PM) is a modified smoke-alarm device capable of logging changes in airborne particulate matter over extended periods and has been used successfully to measure biomass fuel smoke concentrations in developing world settings. This study has examined the use of the UCB-PM to measure SHS aerosol in both controlled laboratory conditions and a pilot field trial over a 7 day period in a smoker's home. Comparisons with a pumped sampler (TSI Sidepak Personal Aerosol Monitor) indicate good agreement over a range of exposure concentrations but there is evidence of a threshold effect at approximately  $0.5 \text{ mg/m}^3$  of fine particulate measured as  $\text{PM}_{2.5}$ . While this threshold effect undermines the ability of the device to provide useful data on the time-weighted average SHS concentration, the field trial indicates that the UCB-PM has a sensitivity of about 71% and a specificity of 98%. The device has many advantages including zero noise operation, low cost and long battery life and may be a useful tool in quitting and smoke-free home intervention studies.

## 1. Introduction:

Indoor air pollution from second-hand smoke (SHS) has been linked to a range of health effects including lung cancer [1], exacerbations of asthma [2] and cardiovascular disease including acute myocardial infarction [3]. Recent smoke-free legislation in many countries has moved to prohibit smoking in enclosed public spaces. Legislation in the UK in 2006 and 2007 has banned smoking in most workplaces including pubs and restaurants and restricted smoking to outdoors and in private spaces. There are concerns that the introduction of these restrictions would lead to a displacement of smoking activity from bars to private homes and a consequent increase in exposure to SHS among children and others living in homes where smoking is permitted. Initial data examining the levels of salivary cotinine (a metabolite of nicotine) in schoolchildren in Scotland suggests that displacement of smoking to the home has not occurred [4] but there have been few direct studies of SHS levels in home environments.

One of the major problems in collecting data on SHS levels in private domestic environments is that active sampling devices tend to produce noise that can be irritating to study participants and are generally only tolerated for short periods. Diffusive methods, particularly for nicotine or vapour-phase components, are available but these then suffer from the disadvantage of only providing average concentrations over the whole sampling period. There is a need for a diffusive-based system that can provide real-time data on SHS concentrations within a home.

The UCB Particle Monitor (UCB-PM) has been developed by scientists at the University of California, Berkeley [5] for use in studies looking at exposure to smoke generated from the use of biomass fuels in developing world environments. The device is based on a modified smoke-alarm and uses the voltage changes generated by particles passing across a photometric chamber to express airborne concentrations of fine particulate matter [6]. The device has been used successfully to measure particulate in homes burning wood, crop residues, dried cow-dung and charcoal in a number of countries [7, 8].

This pilot study aimed to determine if the UCB-PM could be used as a device to provide information on SHS concentrations and the frequency of smoking activity in domestic settings where tobacco smoking was the primary source of fine particulate matter concentrations.

## 2. Methods

### 2.1. Chamber experiments

The first series of tests compared the response from two UCB-PM devices and a co-located TSI AM510 Sidepak Personal Aerosol Monitor (TSI Inc., Shoreview, MN, USA) fitted with a PM<sub>2.5</sub> impactor, within a 9 m<sup>3</sup> exposure chamber. The Sidepak used a 0.295 calibration factor for SHS aerosol as described in previous studies [9, 10].

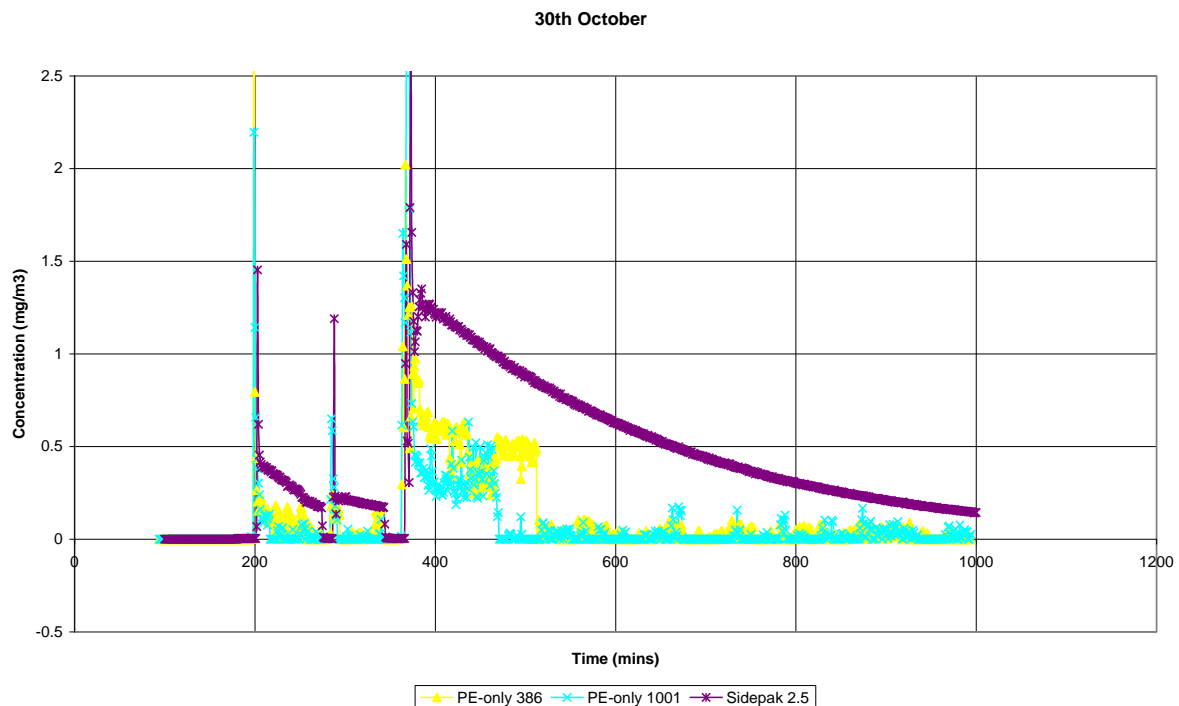
The UCB-PM devices require a zero-ing period prior to use and so were set to log and then sealed inside a ziplock bag for 30 minutes prior to the start of the chamber experiment. This complete, the UCB-PM devices were removed from their bags and placed alongside the other instruments within the chamber. The UCB-PM and Sidepak instruments were set to log data every 1 minute. A cigarette was lit within the chamber and allowed to smoulder for a short period (between 1 and 5 minutes burn time) until the real-time display on the Sidepak device indicated airborne concentrations of PM<sub>2.5</sub> between 0.5 and 5.0 mg/m<sup>3</sup>. Airborne particle concentrations then decayed over time and at various timepoints the extract ventilation was switched on to remove the SHS and bring PM<sub>2.5</sub> levels back to the baseline for the room. The experiment was repeated between 2-4 times each day for a total of 11 runs. The Sidepak device was zero calibrated each day during the study and the flow rate set to 1.7 l/ min.

On completion of the experiment, data from the Sidepak was downloaded using TSI Software (Trackpro V3.6.2), UCB data was downloaded using the UCB-PM 2.2 software using the monitor manager facility.

A graph of the output from a typical experimental run is illustrated in figure 1.

### 2.2. Use in the home

The field-testing of the devices took place in a volunteer's house over a period of 7 days. Two UCB-PM devices were co-located with a Sidepak monitor in the living-room area of the house. This room was approximately 20 m<sup>3</sup> in volume and was the location where most smoking activity took place within the home. The devices were placed on a side-table at a height of about 1 metre above the floor. The instruments were zeroed, set to log and downloaded using a similar protocol to that described for the chamber experiments. The participant was asked to record the number and approximate timing of smoking activity during the whole 7 day period.



**Figure 1.** Particulate matter levels measured during one chamber experiment. The graph shows the concentration in  $\text{mg}/\text{m}^3$  measured by two UCB-PMs (PE-only 386 and PE-only 1001) and from a Sidepak measuring  $\text{PM}_{2.5}$ . The experiment lasted over 15 hours and had three ‘smoking’ events during this time.

### 2.3. Statistical analysis

SPSS v 15 and Microsoft excel software packages were used to analyse the data. Time weighted average concentrations were compared using Pearson correlation coefficients to compare UCB data with Sidepak data and UCB devices with each other.

In addition we also analysed the length of time that each instrument indicated a concentration above two threshold values. These values ( $65$  and  $250 \mu\text{g}/\text{m}^3$ ) are used by the US Environmental Protection Agency in their Air Quality Index for  $\text{PM}_{2.5}$  levels in outdoor air to represent an ‘unhealthy’ and ‘hazardous’ level respectively [11].

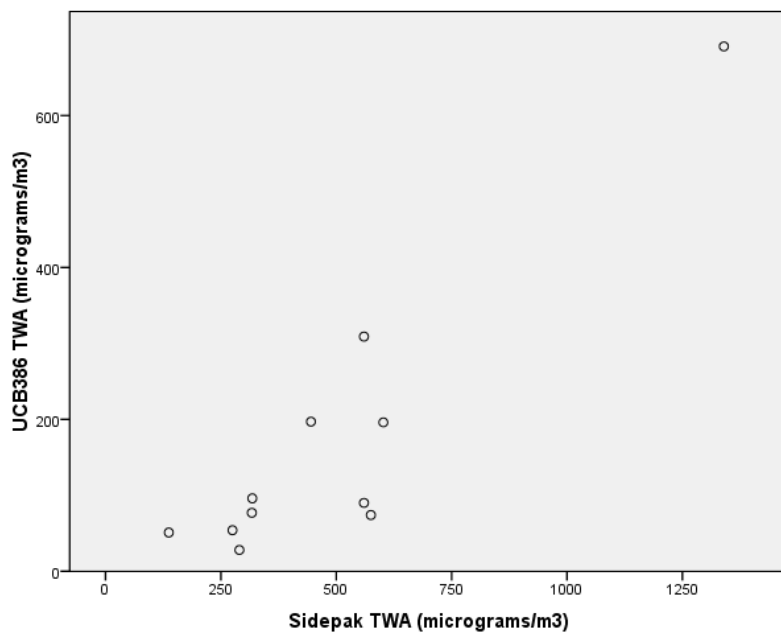
## 3. Results

### 3.1. Chamber experiments

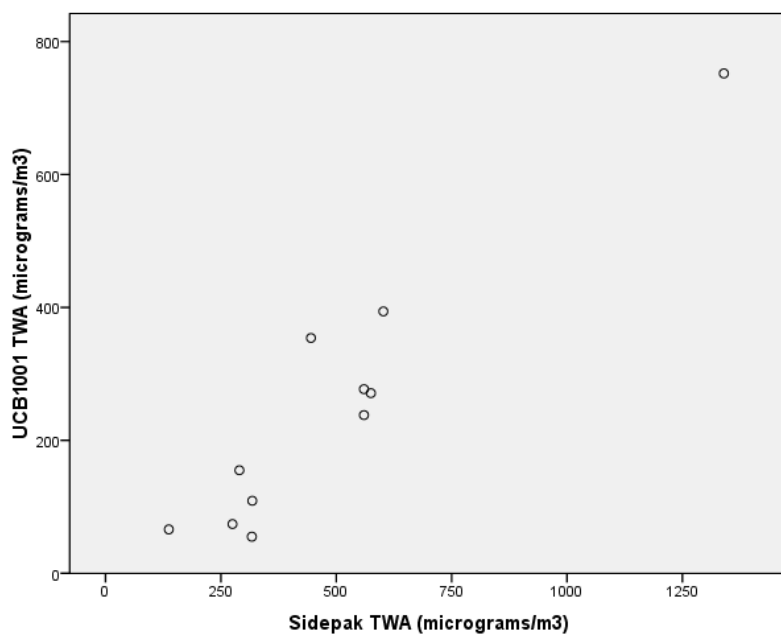
Across these 11 chamber experiments the correlation between the TWA levels measured by SP and UCB-PM devices was high with a Pearson correlation co-efficient of  $0.95$  ( $p < 0.001$ ) for the UCB1001 and  $0.92$  ( $p < 0.001$ ) for the UCB386. Correlation between the two UCB-PM devices is also highly significant at  $0.91$  ( $p < 0.001$ ). Using the duration above  $250 \text{ mg}/\text{m}^3$  as the exposure metric the relationship is less strong. The Pearson correlation coefficient for the UCB386 and Sidepak is  $0.69$  ( $p = 0.020$ ), between the UCB1001 and Sidepak is  $0.68$  ( $p = 0.021$ ) and between both UCB-PM devices is  $0.57$  ( $p = 0.067$ ).

Figure 2 shows the plot of TWA concentrations measured by each device for all 11 experiments.

A



B



**Figure 2.** TWA particulate matter levels measured during eleven chamber experiment. (A) presents the data from UCB386 and Sidepak devices. (B) presents the data from UCB1001 and Sidepak devices.

### 3.2. Use in the home

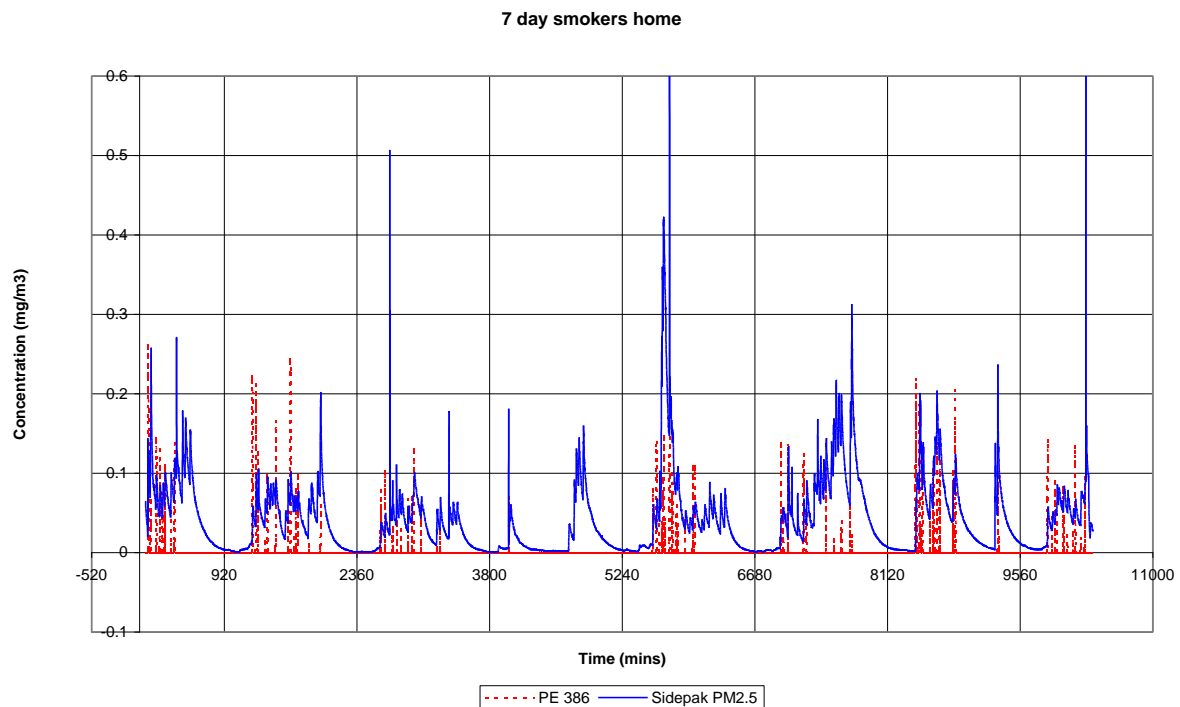
The TWA exposure concentrations and duration of exposure above the two defined threshold levels (65 and 250  $\mu\text{g}/\text{m}^3$ ) as measured by the three devices is provided in table 1.

**Table 1:** Results from 3 devices used to measure SHS in a smoker’s home over 7 day period.

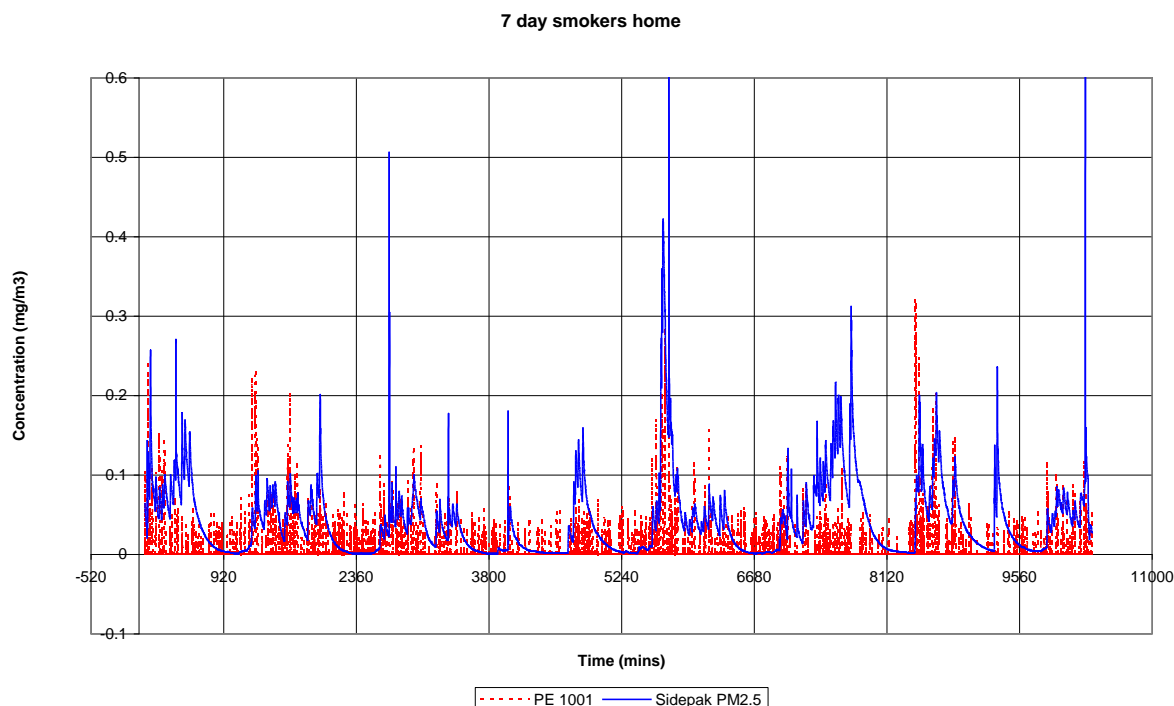
| Sampler                      | TWA concentration<br>( $\mu\text{g}/\text{m}^3$ ) | Duration (mins) above<br>65 $\mu\text{g}/\text{m}^3$ | Duration (mins)<br>above 250 $\mu\text{g}/\text{m}^3$ |
|------------------------------|---|--|---|
| Sidepak (PM <sub>2.5</sub> ) | 42  | 2298   | 61  |
| UCB386                       | 28 <sup>a</sup>                                   | 288  | 3   |
| UCB1001                      | 57 <sup>a</sup>                                   | 1568   | 32  |

<sup>a</sup>The output for UCB386 had a minimum value of 25  $\mu\text{g}/\text{m}^3$  and UCB1001 had a minimum level of 49  $\mu\text{g}/\text{m}^3$  throughout the sampling period and when this is removed the TWAs are reduced to 3 and 8  $\mu\text{g}/\text{m}^3$  respectively. Figure 2 and 3 below corrects this systematic zero-shift in values by subtracting 25  $\mu\text{g}/\text{m}^3$  (UCB386) or 49  $\mu\text{g}/\text{m}^3$  (UCB1001) from each data-point.

Figures 3 and 4 illustrate the particulate matter concentrations registered by the Sidepak and the two UCB-PM (386 and 1001) devices over the 7-day sampling period.



**Figure 3.** Particulate matter levels measured during a seven day period in the home of a smoker. The graph shows the concentration in  $\text{mg}/\text{m}^3$  measured by a UCB-PM (PE386) and from a Sidepak measuring PM<sub>2.5</sub>.



**Figure 4.** Particulate matter levels measured during a seven day period in the home of a smoker. The graph shows the concentration in mg/m<sup>3</sup> measured by a UCB-PM (PE1001) and from a Sidepak measuring PM<sub>2.5</sub>.

The output from UCB386 appears to closely match that generated by the Sidepak device however that generated by UCB1001 demonstrates much poorer agreement. There appear to be many small peaks of approximately 50  $\mu\text{g}/\text{m}^3$  in intensity even at night-time periods when smoking does not take place. This may be due to instrument noise or some processing artefact.

According to the self-completed record form the number of cigarettes smoked in the house over the 7 day period totalled 106. From this data the number of cigarettes smoked each day was compared with identifiable peaks as indicated by the Sidepak ( $n=112$ ) and the UCB386 device (table 2). The sensitivity and specificity of the UCB386 were calculated by comparing the number of concurrent Sidepak and UCB-PM peaks and assuming that the Sidepak peaks are representative of true smoking events (i.e. the participant failed to identify 6 occasions when smoking took place). This process indicated that the UCB386 device has a sensitivity of 71% and a specificity of 98% to detect smoking within this environment. That is to say that the UCB-PM device records an identifiable peak, indicative of smoking, for nearly 3 out of every 4 cigarettes smoked while very rarely (less than 1 in 50 smoke-free periods) registering a false smoking event when smoking does not appear to be occurring.

**Table 2:** Self-reported cigarette smoking and device peaks during field-trial.

| <i>Day</i>   | <i>Self-reported #<br/>cigarettes</i> | <i>Sidepak peaks</i> | <i>Concurrent<br/>UCB386 peaks</i> | <b>Non-concurrent<br/>UCB386 peaks</b> |
|--------------|---------------------------------------|----------------------|------------------------------------|--|
| 1            | 11                                    | 13                   | 8                                  | 0                                      |
| 2            | 17                                    | 18                   | 13                                 | 0                                      |
| 3            | 12                                    | 15                   | 11                                 | 0                                      |
| 4            | 9                                     | 6                    | 1                                  | 0                                      |
| 5            | 19                                    | 17                   | 12                                 | 1                                      |
| 6            | 14                                    | 20                   | 13                                 | 0                                      |
| 7            | 15                                    | 10                   | 10                                 | 0                                      |
| 8            | 9                                     | 13                   | 12                                 | 1                                      |
| <b>Total</b> | <b>106</b>                            | <b>112</b>           | <b>80</b>                          | <b>2</b>                               |

#### 4. Discussion:

To the best of our knowledge this is the first assessment of the use of the UCB-PM to provide information on SHS levels. In chamber experiments the device performed well but did demonstrate a threshold effect at various levels between 0.5 and 1.0 mg/m<sup>3</sup> of PM<sub>2.5</sub> aerosol- when levels fell below this threshold, particularly in the decay of aged SHS aerosol, the UCB-PM devices responded by returning to baseline zero. Clearly this has important implications for the calculation of time-weighted average exposures using these devices.

From the field-trial there were similar issues with the UCB-PM instruments and in addition to a zero-shift problem the TWA concentrations from both devices were much lower than those recorded by the Sidepak. One device, the UCB-PM (1001), also appeared to suffer from some ‘noise’ that caused voltage changes unrelated to smoking activity throughout the 7-day period. The other UCB-PM (386) produced data that was much more closely correlated to that generated by the Sidepak. This device demonstrated a moderate degree of sensitivity (71%) and a high specificity (98%) to detecting smoking events. In a house where twenty cigarettes are smoked each day the device will be able to detect approximately fourteen of these smoking events and can determine with 98% accuracy when smoking does not occur.

One drawback of the device at present is the variation between two UC PM devices when monitoring SHS in the same environment. The devices variation can range from a factor of six to unity in high concentration environments. In situations where the concentration of SHS was low this device variation ranged from 1 to 1.4. Why this variation between the two devices tested in our experiments occurs is unknown at present

We acknowledge that these UCB devices have previously been used to monitor aerosols generated by burning biomass fuel and the concentrations in these studies are generally very much higher than those found during cigarette smoking activities in homes [7-8]. It is possible that modifications to these devices may allow them to measure aerosols at the lower concentrations found in homes where smoking takes place. There are however several areas where the device, as it stands, may be adequate to measure SHS concentrations. Our next trials will look at the performance of the UCB-PM device in a car. SHS concentrations in cars where smoking takes place may be sufficiently high to allow the instrument to perform at a higher sensitivity.

Despite the limitations of threshold and moderate sensitivity identified in this study, the UCB-PM device has many advantages over currently available methods for measuring SHS in domestic environments. The relative low cost of the device (350 euros), noise-free operation and long battery-life together with an ability to provide a real-time log of changing SHS levels are some of the major benefits of the device over pumped sampling or diffusive nicotine badge methods.

In its present form the device could be used to provide feedback to smokers about SHS levels and the frequency of smoking within their home and may be a useful tool to support quitting or smoke-free



home intervention programmes. The UCB-PM devices may also be useful in quantifying SHS levels in cars and other vehicles.

### Acknowledgements

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