**Second-hand smoke in four English prisons: an air quality monitoring study**

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**ABSTRACT**

OBJECTIVE

To measure levels of indoor pollution in relation to smoking in four English prisons.

METHODS

We used TSI SidePak AM510 Personal Aerosol Monitors to measure concentrations of particulate matter less than 2.5 microns in diameter (PM₂.₅) for periods of up to 9 hours in selected smoking and non-smoking areas, and personal exposure monitoring of prison staff during a work shift, in 4 prisons.

RESULTS

PM₂.₅ data were collected for an average of 6.5 hours, collecting data from 42 locations on 25 smoking wing landings, 6 locations on 5 non-smoking wing landings, 13 prisoner cells, and personal monitoring of 22 staff members. Arithmetic mean PM₂.₅ levels were significantly higher on smoking than non-smoking wing landings (43.9 µg/m³ and 5.9 µg/m³, p<0.001) and in smoking than non-smoking cells (226.2 µg/m³ and 17.0 µg/m³ respectively, p<0.001). Staff members wore monitors for an average of 4.18 hours and were exposed to arithmetic mean PM₂.₅ levels of 23.5 µg/m³ over this period.

CONCLUSIONS

Levels of PM₂.₅ pollution in smoking areas of prisons are extremely high, with mean levels during the day that far exceed World Health Organisation long-term mean and short-term maximum air quality guidance limits. Smoking in prisons thus represents a significant health hazard to prisoners and staff.

**INTRODUCTION**

Second-hand smoke (SHS) causes a range of harmful health effects including lung cancer, lower respiratory tract infections, asthma, and cardiovascular diseases (1-3). Awareness of these effects has led governments in the UK and many other countries to introduce smoke-free legislation, and in England, legislation requiring all enclosed work and public places to become smoke-free came into force in July 2007 (4). The significant reductions in exposure to SHS that this and similar legislation has achieved (5) has resulted in marked reductions in episodes of both cardiovascular and respiratory disease (6-8).

The English legislation did however provide some exemptions, one of which applied to prisons. Prison Service Instruction (PSI) 09/2007 enabled prison Governors in England to make landings and/or wings in prisons smoke-free, but allowed prisoners aged over 18 to smoke in single cells or in cells shared with other smokers (9). Since around 80% of the approximately 85,000 prisoners currently held in the 139 UK prisons are smokers (10, 11), this suggests that levels of SHS in some indoor prison areas are likely to be very high, and that passive exposure of non-smoking prisoners, and of prison staff and visitors, may still be significant.

Concentration of airborne particulate matter <2.5 microns in diameter (PM₂.₅) is a well-established marker of indoor SHS concentration (12, 13), and previous studies have shown high levels of PM₂.₅ in environments where smoking has taken place (13, 14). Standards for indoor air quality produced by the World Health Organisation (WHO) recommend upper limit guidance PM₂.₅ levels of 25 µg/m³ as a 24-hour mean, and 10 µg/m³ as an annual mean (15). Evidence to date on levels of particulate matter in prisons is limited however (16-18), with little information on ambient levels on wings or smoking cells, and to our knowledge, no data from prisons in England. This study was therefore carried out to measure PM₂.₅ levels, as a proxy for second-hand smoke, on prison landings and in smoking and non-smoking cells; and by ambient monitoring as a measure of personal exposure of staff working in these settings.

**METHODS**

*Prisons*

Data were collected from four English Prison Service establishments selected to provide variety in relation to security level, inmate gender, structural design and size (Table 1). Her Majesty’s Prison (HMP) Eastwood Park, HMP Erlestoke and HMP Exeter were identified by National Offender Management Service as potential ‘early adopter’ sites in which to pilot a smoke-free policy, and were studied between July and August 2014. HMP Holme House was included at the request of the Prison Officers Association, and studied in October and November 2014. All four prisons had a no-smoking policy for staff members within the prison perimeter, though one had designated areas within the prison grounds for electronic cigarette use by staff members. All prisons allowed prisoners to smoke in their cells, and one permitted smoking in the exercise yard over lunch periods for those who left the wing all day to work. All had smoke-free wings which included smoke-free cells (Table 1).

**Table 1. Prison facility characteristics**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Category and function\*** | **Structural design** | **Roll Count** | **Wings** | **Smoke-free Wings** |
| HMP Eastwood Park | Female  Closed  Local | Built 1960s. Mix of original, T-shaped and quick build wings. | 262 | 7 | Mother & Baby |
| HMP Erlestoke | Male  Category C Training | Built 1960s. Mix of triangular, T-shaped and quick build wings. | 494 | 8 | Care & Separation Unit |
| HMP Exeter | Male  Category B  Local | Built 1850s. Victorian radial design. | 533 | 7 | Healthcare |
| HMP Holme House | Male  Category B  Local | Built 1992. Bullingdon design, with additional mix of wings. | 1215 | 9 | Healthcare.  Houseblock 7, Spur A. |

\*Category B prisons hold prisoners who do not need to be held in the highest security conditions but the potential for escape should be made very difficult.

\*Category C prisons hold prisoners who cannot be trusted in open conditions but are considered unlikely to make a determined escape attempt.

\*Female closed prisons can hold category A, B, C prisoners. Due to a smaller female population, female establishments are categorised into either ‘closed’ or ‘open’.

\*Local prisons serve the courts and receive remand and post-conviction prisoners prior to their allocation to other establishments.

\*Training prisons hold sentenced prisoners who tend to be employed in a variety of activities such as prison workshops, gardens and education and in offending behaviour programmes.

*Particulate pollution*

PM₂.₅ concentrations were measured using a battery-operated SidePak Personal Aerosol Monitor AM510 (TSI Inc, MN, USA) fitted with a PM₂.₅ impactor and set to a calibration factor of 0.30, as appropriate for tobacco smoke (19, 20). In accordance with manufacturer’s instructions, SidePak devices were cleaned, the impactor re-greased, zero-calibrated and the flow rate set at 1.7 l/min before each use. PM₂.₅ measurements were logged at 1 minute intervals, with each one minute data point being an average of 60 seconds of sample measurements.

*Data collection*

Data were collected over 3 to 4 consecutive days, typically from a Wednesday or Thursday to Saturday, so that sampling took place in both weekday and weekend regimes, and before and after the ‘canteen’ days when prisoners can purchase tobacco or other personal goods (typically Fridays). A researcher trained in the use of air quality monitoring and surveying, with the help of a prison service headquarters staff member, placed the SidePak monitors in static locations on wing landings and in prisoners’ cells, or attached the monitor to wing-based prison staff to collect personal exposure data during parts of their work shifts.

Fixed locations on wing landings were chosen to cover the range of wing designs and function. Monitors were placed as discreetly as possible to avoid disturbing prisoners’ normal behaviour, though wing officers knew where monitors were placed and for how long. Typically the device was placed half way down the wing, above head height and away from open outside doors, windows, or cooking equipment, and the monitor keypads were locked. Sampling was carried out on each day for as long as the researcher was allowed access to the wing, and subject to limitations of battery life and in the case of personal monitoring, staff shift patterns. Data on the layout of the wing, prisoner roll count and lock/unlock times were recorded. Prisoners who inquired were informed that we were measuring air quality.

Wing officers were asked to identify smoking and non-smoking prisoners who were suitable to have a SidePak monitor placed in their cell, and these prisoners were then approached by the researcher who explained the study, answered questions and requested written consent. Given consent, the SidePak monitor was generally placed on a shelf or desk around waist height in the cell. Data on each cell location, the number of prisoners in the cell, their smoking status and the style of the cell window were recorded. Due to the gentle buzz the SidePak monitor makes whilst sampling, data were typically collected for a few hours over a morning or afternoon period.

Prison Officers working in the prisons were contacted by email in advance of the study visit, or by word of mouth at the time the monitors were placed on wings or in cells, and invited to volunteer to wear a monitor for personal sampling. All who volunteered were given an explanation of the study and asked to provide written consent. We recruited both current smokers and non-smokers. We measured exhaled carbon monoxide with a Smokerlyzer (Bedfont Scientific Ltd) at the start of our monitoring period, and then attached the SidePak monitor to their belt and used a short length of Tygon tubing to sample air from their breathing zone. A second measurement of exhaled carbon monoxide was taken when sampling finished, when the staff members also returned a timed log of their work locations and activities during the data collection period.

*Data analysis*

Since the SidePak monitors were usually turned on or off before and after being placed in the sampling sites we discarded the first and last five minutes of each data record. Each set of sampling data was downloaded from the monitor using Trackpro 4.6.1 software, and transferred to a Microsoft Excel spreadsheet with the corresponding location, cell and staff member data. We then used STATA 13 to generate descriptive statistics including arithmetic means, 95% confidence intervals, standard deviations, ranges and times of maximum levels, and to estimate the proportion of time in which the PM₂.₅ concentration exceeded World Health Organisation (WHO) 24-hour mean PM₂.₅ upper limit of 25 µg/m³ (15) for each data set. Since PM₂.₅ data distributions are skewed, all comparisons of means were made after log transformation.

*Ethics*

Ethics approval for the study was provided by the University of Nottingham Medical School Ethics Committee (G06062013 CHS EPH) and the National Offender Management Service National Research Committee (Ref: 2013-202) in July 2014.

**RESULTS**

Wing landings

We collected 50 datasets from wing landing locations, two of which were discarded because the monitor had been tampered with and displayed an error message, leaving 48 datasets from 30 different locations and including 6 datasets from 5 non-smoking wings, for analysis. The locations included a three storey Victorian gallery, 1960s single-storey narrow corridors and two-storey triangular Feltham-style layouts and had prisoner roll counts between 4 and 180. The average period over which data were collected was 6.5 hours (Standard Deviation (SD) 2.0). The arithmetic mean PM₂.₅ in the 48 data sets was 40.08 µg/m³, and ranged from 0 to 1124 µg/m³. Details of wing function and design, sampling times, arithmetic mean values, range and percentage of sampling time over 25 µg/m³ are presented for each location sampled in Table 2.

**Table 2. Data collected from static SidePak monitors located on wing landings**

**(non-smoking locations in bold type)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sample location** | | | | | **PM₂.₅ (µg/m³)** |  |
| **Day\*,date,**  **dataset reference** | **Wing function** | **Wing design** | | **Sampling**  **start time**  **(duration hr:min)** | **Arithmetic mean**  **(range)** | **Time (hr:min)**  **>25 PM₂.₅ (%)** |
| HMP Eastwood Park | | | | | | |
| W 23/07  W101 | Substance misuse/IDTS | | Corridor. Trickle vent windows | 11:40 (4:34) | 28.26 (14-200) | 2:09 (47.08%) |
| W 23/07  W102 | Main | | Gallery. Fully opening windows | 18:21 (7:49) | 26.05 (8-89) | 2:54 (37.10%) |
| W 23/07  W103 | Main, first night | | Gallery. Fully opening windows | 18:21 (7:49) | 9.24 (5-33) | 00:01 (0.21%) |
| T 24/07  W104 | Substance misuse/IDTS | | Corridor. Trickle vent windows | 08:32 (8:05) | 52.87 (16-254) | 7:06 (87.84%) |
| T 24/07  W105 | Main, first night | | Gallery. Fully opening windows | 14:37(2:18) | 10.18 (6-27) | 00:01 (0.72%) |
| **T 24/07**  **W106** | **Mother & baby** | | **Corridor. Fully opening windows** | **14:52 (1:50)** | **2.67 (0-22)** | **00:00 (0%)** |
| T 24/07  W107 | Substance misuse/IDST | | Corridor. Trickle vent windows | 17:06 (9:49) | 30.78 (11-86) | 5:35 (56.88%) |
| F 25/07  W108 | Drug recovery/free | | Narrow corridor. Fully opening windows | 08:17 (8:27) | 59.78 (8-712) | 5:00 (59.17%) |
| F 25/07  W109 | Mental health assessment | | Corridor. Trickle vent windows | 08:38 (8:12) | 33.30 (10-946) | 3:42 (45.12%) |
| F 25/07  W110 | Category C regime | | Narrow corridor. Fully opening windows | 10:27 (5:56) | 46.28 (14-321) | 3:24 (57.30%) |
| S 26/07  W111 | Substance misuse/IDTS | | Corridor. Trickle vent windows | 09:23 (7:03) | 50.04 (14-453) | 5:01(71.16%) |
| S 26/07†  W112 | Mental health assessment | | Corridor. Trickle vent windows | 09:49 (4:49) | 37.82 (12-766) | 2:33 (51.17%) |
| S 26/07  W113 | Drug recovery/free | | Narrow corridor. Fully opening | 13:29 (3:03) | 97.24 (13-461) | 2:33 (83.61%) |
| HMP Erlestoke | | | | | | |
| T 31/07  R101 | Family interventions | Narrow corridor. Fully opening windows | | 10:25 (6:04) | 81.41 (15-475) | 5:14 (86.26%) |
| T 31/07  R102 | Main, enhanced | Corridor. Fully opening windows | | 10:59 (5:47) | 14.25 (6-70) | 00:34 (9.80%) |
| F 01/08  R104 | Main | Triangular gallery. Fully opening windows | | 08:09 (7:50) | 32.86 (7-107) | 4:28 (57.02%) |
| **F 01/08**  **R105** | **Care & Separation** | **Corridor. Trickle vent windows** | | **08:30 (5:35)** | **5.71 (3-18)** | **0:00 (0%)** |
| F 01/08  R106 | Enhanced | Narrow corridors. Fully opening windows | | 13:54 (2:13) | 17.50 (9-66) | 00:12 (9.02%) |
| F 01/08  R107 | Main | Triangular gallery. Fully opening windows | | 17:46 (7:49) | 42.45 (20-135) | 7:13 (92.32%) |
| S 02/08  R108 | Induction | Gallery. Trickle vent windows | | 08:24 (7:42) | 36.96 (14-85) | 6:29 (84.12%) |
| S 02/08  R109 | Main, enhanced | Corridor. Fully opening windows | | 08:57 (7:06) | 32.37 (6-439) | 2:55 (41.08%) |
| HMP Exeter | | | | | | |
| T 14/08  X101 | Main | Gallery. Perspex window covers | | 10:45 (5:35) | 24.20 (7-151) | 1:48 (32.35%) |
| T 14/08  X102 | Care & Separation | Corridor. Trickle vent windows | | 11:00 (5:22) | 8.03 (3-29) | 00:01(0.31%) |
| T 14/08  X103 | Main | Gallery. Perspex window covers | | 11:16 (5:03) | 20.97 (6-54) | 1:31 (30.03%) |
| T 14/08  X104 | Main | Gallery. Perspex window covers | | 17:46 (8:49) | 12.89 (4-85) | 00:21(3.97%) |
| F 15/08  X105 | Enhanced | Narrow corridor. Trickle vent windows | | 07:59 (8:14) | 23.83 (6-334) | 2:27 (29.76%) |
| F 15/08  X106 | Induction | Corridor. Trickle vent windows | | 08:09 (8:10) | 23.23 (4-164) | 2:14 (27.35%) |
| **F 15/08**  **X107** | **Healthcare/**  **Palliative care** | **Corridor. Fully opening windows** | | **08:19 (5:11)** | **3.09 (2-7)** | **00:00 (0%)** |
| F 15/08  X108 | Main | Gallery. Perspex window covers | | 17:46 (8:59) | 36.61 (8-121) | 4:00 (44.53%) |
| S 16/08  X109 | Enhanced | Narrow corridor. Trickle vent windows | | 09:07 (7:24) | 183.18 (10-1124) | 6:35 (88.96%) |
| S 16/08  X110 | Vulnerable prisoners | Gallery. Perspex window covers | | 09:16 (7:29) | 18.95 (5-92) | 1:06 (14.70%) |
| S 16/08  X111 | Main | Gallery. Perspex window covers | | 09:29 (7:18) | 31.22 (12-452) | 3:30 (47.95%) |
| S 16/08  X112 | Centre hub | No windows | | 09:39 (3:41) | 17.06 (6-44) | 00:14 (6.33%) |
| HMP Holme House | | | | | | |
| T 02/10  H101 | Main | Gallery. Trickle vent windows | | 11:41 (5:14) | 26.87 (6-79) | 2:02 (38.85%) |
| **T 02/10**  **H102** | **Main, part-time education and work** | **Gallery. Trickle vent windows** | | **11:44 (5:10)** | **5.57 (3-16)** | **00:00 (0%)** |
| T 02/10  H103 | Main | Gallery. Trickle vent windows | | 17:06 (8:39) | 40.73 (12-129) | 6:32 (74.10%) |
| **T 02/10**  **H104** | **Main, part-time education and work** | **Gallery. Trickle vent windows** | | **17:06 (8:39)** | **8.35 (3-17)** | **00:00 (0%)** |
| F 03/10  H105 | Main, workers | Gallery. Trickle vent windows | | 07:55 (8:40) | 26.38 (6-97) | 2:46 (31.92%) |
| F 03/10  H107 | Care and separation | Gallery. Trickle vent windows | | 10:49 (4:40) | 6.28(2-25) | 00:00 (0%) |
| **F 03/10**  **H108** | **Healthcare** | **Corridor. Trickle vent windows** | | **10:56 (4:28)** | **6.29 (4-15)** | **00:00 (0%)** |
| F 03/10  H109 | Main, category C regime | Squared gallery. Trickle vent windows | | 17:36 (8:49) | 23.11 (7-38) | 3:39 (41.40%) |
| S 04/10  H110 | Main, category C regime | Squared gallery. Trickle vent windows | | 08:27 (8:06) | 35.08 (5-356) | 3:17 (40.53%) |
| S 04/10  H111 | Drug recovery | Gallery. Trickle vent windows | | 08:37 (7:51) | 126.90 (22-273) | 7:40 (97.66%) |
| S 04/10  H112 | Induction | Gallery. Trickle vent windows | | 11:27 (5:13) | 15.75 (1-44) | 1:07(21.41%) |
| T 27/11  H113 | Therapeutic Community | Gallery. Trickle vent windows | | 10:47 (4:46) | 83.31 (59–118) | 4:46 (100%) |
| T 27/11  H114 | Drug recovery | Gallery. Trickle vent windows | | 10:50 (4:41) | 138.64 (72-806) | 4:40 (100%) |
| T 27/11  H115 | Drug recovery | Gallery. Trickle vent windows | | 16:51 (8:49) | 47.02 (1-194) | 4:37 (52.36%) |
| F 28/11  H116 | Drug recovery | Gallery. Trickle vent windows | | 09:10 (5:38) | 147.16 (74-188) | 5:38 (100%) |

\*W=Wednesday, T=Thursday, F=Friday, S=Saturday.

† Located outside a gated cell

IDTS (Integrated Drug Treatment System)

Canteen days: HMP Eastwood Park, Thursday; HMP Erlestoke and HMP Exeter, Friday; HMP Holme House, Thursday or Friday depending on wing location.

In the 42 datasets from locations where smoking is permitted in cells, the arithmetic mean PM₂.₅ was 43.87 µg/m³ (SD 58.95; range 1 to 1124 µg/m³), and in the five smoke-free wings 5.90 µg/m³ (SD 2.90; range 0 to 22 µg/m³). This difference was highly significant (p<0.001). In the three prisons with a single canteen day (HMP Holme House delivered over two days) PM₂.₅ levels were also higher on the day after the canteen was delivered (20.33 µg/m³ and 27.83 µg/m³, p<0.001). There was no difference in PM₂.₅ levels between wing designs. Continuous data from each smoking site sampled during the daytime are represented graphically in Figure 1.

**Figure 1**

HMP Holme House had one T shaped design wing comprising of three identical spurs, one of which was voluntarily non-smoking. The spurs were connected by gated doors which allowed air to flow between them. SidePak monitors were run on the voluntary non-smoking and one of the smoking spur simultaneously throughout the day and then again into the night (Figure 2).

**Figure 2. Levels of PM₂.₅ recorded at HMP Holme House, Houseblock 7 on smoking and voluntary non-smoking spurs.**

*Gated cell*

To measure prison officer exposure to second-hand smoke while on a constant watch of a single prisoner behind a gated cell, a SidePak monitor was placed on a chair outside a gated cell housing a prisoner who smoked on the mental health assessment wing at HMP Eastwood Park (See Figure 3, data denoted by † in Table 2). The prisoner was locked in the gated cell between 12:30-13:45 pm, after which time the prisoner left the wing for a visit.

**Figure 3. Levels of PM₂.₅ recorded outside a gated cell at HMP Eastwood Park**

At HMP Holme House several staff members and prisoners reported high levels of smoke pollution on the landings, which they thought arose from a faulty ventilation system. At their request we repeated our measures after the ventilation system had been repaired, and found no appreciable change in PM₂.₅ levels.

Prison Cells

We sampled PM₂.₅ from 14 cell locations but we had to discard data from one due to an error message on the SidePak monitor at collection, leaving 13 for analysis. All were collected from cells on wings where smoking was permitted in cells, and five of the cells sampled had occupants who smoked. The average time period for which data were collected was 4.88 hours (SD 1.76). The arithmetic mean of the 13 data sets was 103.10 µg/m³ (SD 237.47 µg/m³; range 0 - 2684 µg/m³). Details of wing function and design, cell, smoking status, sampling times, arithmetic mean values, range and percentage of sampling time over 25 µg/m³ are presented for each cell sampled in Table 3.

**Table 3. Data collected from static SidePak monitors located in prison cells**

**(non-smoking prisoners in bold type)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sample location** | | | | | **PM₂.₅ (µg/m³)** |  |
| **Day\*,date,**  **dataset reference** | **Wing function** | **Wing design** | **Cell type** | **Sampling**  **start time**  **(duration hr:min)** | **Arithmetic**  **mean**  **(range)** | **Time (hr:min)**  **>25 PM₂.₅ (%)** |
| HMP Eastwood Park | | | | | | |
| W 23/07  W201 | Main | Gallery. Fully opening windows | Double | 12:10 (4:16) | 162.90 (21-1409) | 3:51 (90.23%) |
| T 24/07  W202 | Main | Gallery. Fully opening windows | Single | 12:08 (4:47) | 62.31 (9-360) | 2:54 (60.63%) |
| **F 25/07**  **W203** | **Drug recovery/**  **free** | **Narrow corridor. Fully opening windows** | **Double** | **08:22 (8:23)** | **27.52 (14-89)** | **4:09 (49.50%)** |
| **S 26/07**  **W204** | **Main, first night** | **Gallery. Fully opening windows** | **Double** | **08:46 (7:56)** | **13.39 (8-52)** | **0:06 (1.30%)** |
| HMP Erlestoke | | | | | | |
| T 31/07  R201 | Family interventions | Narrow corridor. Fully opening windows | Single | 10:38 (5:57) | 144.76 (10-932) | 5:16 (88.52%) |
| **T 31/07**  **R202** | **Main, enhanced** | **Corridor. Fully opening windows** | **Single** | **10:53 (5:57)** | **7.13 (4-32)** | **0:01 (0.28%)** |
| **S 02/08**  **R203** | **Main** | **Narrow corridor. Fully opening windows** | **Single** | **08:41(4:56)** | **31.00 (11-102)** | **2:05 (42.23%)** |
| HMP Exeter | | | | | | |
| **F 15/08**  **X201** | **Enhanced** | **Narrow corridor. Trickle vent windows** | **Single** | **12:24 (3:51)** | **5.77(2-14)** | **0:00 (0%)** |
| F 15/08  X202 | Vulnerable prisoners | Gallery. Perspex window covers | Double | 13:39 (2:52) | 434.74 (14-1513) | 2:34 (89.53%) |
| **S 16/08**  **X203** | **Main** | **Gallery. Perspex window covers** | **Double** | **13:44 (3:08)** | **2.89 (2-10)** | **0:00 (0%)** |
| HMP Holme House | | | | | | |
| F 03/10  H201 | Main. Workers | Gallery. Trickle vent windows | Single | 11:50 (4:41) | 429.27 (8-2684) | 4:01 (85.77%) |
| **S 04/10**  **H203** | **Therapeutic Community** | **Gallery. Trickle vent windows** | **Double** | **12:17 (3:10)** | **2.35 (0-101)** | **0:56 (29.47%)** |
| **F 28/11**  **H204** | **Drug Recovery** | **Gallery. Trickle vent windows** | **Single** | **09:00 (3:35)** | **223.06 (107- 1242)** | **3:35 (100%)** |

\*W=Wednesday, T=Thursday, F=Friday, S=Saturday.

Canteen day: HMP Eastwood Park, Thursday; HMP Erlestoke and HMP Exeter, Friday; HMP Holme House Thursday or Friday depending on wing location.

High levels of PM₂.₅ were recorded in the five smokers’ cells with arithmetic means ranging from 62.31 to 434.74 µg/m³. Levels in smoking cells (226.16 µg/m³) were significantly higher than in non-smoking cells (16.98 µg/m³, p<0.001). Figure 4 shows levels of PM₂.₅ recorded in a single cell where the occupant smoked (See dataset W202 in Table 3). The prisoner reported that he had smoked four hand-rolled cigarettes during the sampling period.

**Figure 4. Levels of PM₂.₅ recorded in a single smoker cell**

Levels of PM₂.₅ in non-smokers cells were typically low, though high levels in non-smoking cells at both HMP Eastwood Park and HMP Erlestoke were recorded in closed narrow corridors. We recorded a very high mean level (223.06 µg/m³) of PM₂.₅ in one non-smoking cell at HMP Holme House, a prison in which PM₂.₅ levels on the wing landings were also very high (see Table 2).

From the data collected at HMP Eastwood Park, it is possible to compare levels on PM₂.₅ sampled simultaneously on a wing landing and in a non-smokers cell on the same location (Figure 5). The non-smokers cell had a maximum reading of 89 µg/m³.

**Figure 5. Levels of PM₂.₅ on a landing and non-smokers cell from the same wing at HMP Eastwood Park.**

Staff Members

Twenty-two staff members, of which 21 were prison officers and one a healthcare assistant, volunteered to wear a SidePak air monitor for a duration of their working shift. All were based on wings where smoking was permitted in cells, and all had prisoner contact. Data were collected for an average of 4.18 (SD 1.65) hours. The arithmetic mean of the 22 data sets was 23.51 µg/m³ (SD 34.01 µg/m³; range 2 - 608 µg/m³). Details of wing function and design, sampling times, arithmetic mean values, range and percentage of sampling time over 25 µg/m³ are presented for each cell sampled in Table 4.

**Table 4. Data collected from SidePak monitors worn by staff members**

**(non-smoking staff members in bold type)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sample location** | | | | **PM₂.₅ (µg/m³)** |  |
| **Day\*,date,**  **dataset reference** | **Wing function** | **Wing design** | **Sampling**  **start time (duration hr:min)** | **Arithmetic Mean (range)** | **Time (hr:min)**  **>25 PM₂.₅ (%)** |
| HMP Eastwood Park | | | | | |
| **W 23/07**  **W301** | **Mental health assessment** | **Corridor. Trickle vent windows** | **11:12 (4:48)** | **23.78 (7-340)** | **00:41 (14.24%)** |
| **W 23/07**  **W302** | **Substance misuse/IDST** | **Corridor. Trickle vent windows** | **11:27 (4:41)** | **16.21 (7-169)** | **00:28 (9.96%)** |
| **W 23/07**  **W303** | **Main** | **Gallery. Fully opening windows** | **11:59 (4:22)** | **15.79 (8-199)** | **00:23 (8.78%)** |
| **W 24/07**  **W304** | **Mental health assessment** | **Corridor. Trickle vent windows** | **07:56 (4:14)** | **25.61(10-297)** | **00:39 (15.35%)** |
| **T 24/07**  **W305** | **Main** | **Gallery. Fully opening windows** | **08:02 (3:49)** | **17.36 (7-295)** | **00:09 (3.93%)** |
| **T 24/07**  **W306** | **Substance misuse/IDTS** | **Corridor. Trickle vent windows** | **08:43 (3:42)** | **19.04 (11-66)** | **00:17 (7.66%)** |
| F 25/07  W307† | Substance misuse/IDTS | Corridor. Trickle vent windows | 08:01 (3:59) | 17.79 (4-77) | 00:46 (19.25%) |
| **S 26/07**  **W308** | **Main** | **Gallery. Fully opening windows** | **08:40 (3:54)** | **21.28 (7-137)** | **1:00 (25.64%)** |
| **S 26/07**  **W309** | **Substance misuse/IDTS** | **Corridor. Trickle vent windows** | **09:33 (6:48)** | **21.82 (11-362** | **1:27 (21.33%)** |
| HMP Erlestoke | | | | | |
| **T 31/07**  **R301** | **Interventions and programmes** | **Corridor. Fully opening windows** | **11:13 (3:43)** | **9.98 (2-166)** | **00:12 (5.38%)** |
| **F 01/08**  **R302** | **Interventions and programmes** | **Corridor. Fully opening windows** | **07:34 (5:57)** | **12.59 (4-130)** | **00:23 (6.44%)** |
| **F 01/08**  **R303** | **Enhanced and main** | **Thin corridors and Triangular gallery. Fully opening windows** | **07:47 (8:13)** | **13.62 (4-161)** | **00:38 (7.71%)** |
| S 02/08 R304 | Main | Thin corridors. Fully opening windows | 08:44 (3:50) | 9.62 (4-41) | 00:02 (0.69%) |
| HMP Exeter | | | | | |
| **T 14/08**  **X301** | **Main** | **Gallery. Perspex window covers** | **10:42 (0:58)** | **22.17 (3-218)** | **00:13 (22.41%)** |
| T 14/08  X302 | Main | Gallery. Perspex window covers | 11:09 (1:21) | 11.05 (3-29) | 00:02 (2.47%) |
| **F 15/08**  **X303** | **Enhanced** | **Narrow corridor. Trickle vent windows** | **07:54 (4:08)** | **13.34 (2-142)** | **00:28 (11.29%)** |
| **S 16/08**  **X304** | **Vulnerable prisoners** | **Gallery. Perspex window covers** | **13:49 (2:47)** | **28.05 (3-498)** | **00:33 (19.76%)** |
| HMP Holme House | | | | | |
| T 02/10  H301 | Main, category C regime | Squared gallery. Trickle vent windows | 12:10 (4:31) | 20.43 (3-218) | 1:09 (25.46%) |
| **F 03/10**  **H302** | **Main. Workers** | **Gallery. Trickle vent windows** | **07:49 (3:45)** | **25.58 (5-159)** | **00:59 (26.23%)** |
| **F 03/10**  **H303** | **Main, category C regime** | **Squared gallery. Trickle vent windows** | **19:36 (4:49)** | **34.01 (7-72)** | **4:14 (87.89%)** |
| **S 04/10**  **H304** | **Drug Recovery and Therapeutic Community** | **Gallery. Trickle vent windows** | **11:16 (5:07)** | **74.32 (2-307)** | **4:32 (88.60%)** |
| **S 27/11**  **H305** | **Drug Recovery** | **Gallery. Trickle vent windows** | **14:13 (1:25)** | **127.39 (12-608)** | **1:23 (97.65%)** |

\*W=Wednesday, T=Thursday, F=Friday, S=Saturday.

† Healthcare assistant

Canteen day: HMP Eastwood Park, Thursday; HMP Erlestoke and HMP Exeter, Friday; HMP Holme House Thursday or Friday depending on wing location.

Unlike data sampled from static landing and cell locations, the SidePak monitors were attached to staff members as they carried out their working shift. Figure 6 shows levels of PM₂.₅ sampled from a single prison officer during a morning shift alongside their self-reported timed outline of locations and duties during sampling (See data reference W308 in Table 4).

**Figure 6. Levels of PM₂.₅ sampled during a prison officer’s morning shift**

**(see \* for work details)**

*\*Prison officer self-reported locations and duties during sampling:*

*08:40-10:00 Wing landing; supervising, dealing with prisoner queries.*

*10:00-10:10 Wing office.*

*10:10-11:00 Wing landing; including entering a prisoner cell.*

*11:00-11:40 Wing office; checking emails and paperwork.*

*11:50-12:40 Wing landing; supervising lunch time and locking up prisoners.*

The location report suggests that higher exposure levels tended to occur during periods spent on the wing landings, a finding that was evident in records from all other staff members. Some of the highest levels of PM₂.₅ were recorded during duties such as locking or unlocking cells, handing out mail and cell searching. Lower levels of PM₂.₅ were recorded during periods where staff members were located in the wing office, supervising medication (when the medication hatch was not located on the wing landing) and escorting prisoners off the wing.

Carbon Monoxide concentrations in exhaled breath were measured in 21 of the staff members who wore a SidePak monitor. The readings confirmed the smoking status of the staff member participating but did not demonstrate any difference between measures at the start and end of shifts among non-smokers (data not shown). In many instances, staff members had already started their wing shift before the first carbon monoxide reading was taken.

DISCUSSION

This is the first study to estimate second-hand smoke (SHS) levels in prisons in England. Our findings demonstrate that on wings where smoking was permitted, the concentration of PM₂.₅ sampled on the landings and from staff member working on them were high and often exceeded the WHO upper guidance limit of 25 µg/m³ as a 24-hour mean (15), and in some locations did so for the entire period of monitoring. Smoking in prisons is thus a significant cause of ambient pollution to smokers and non-smokers, whether prisoner or staff. Some of the staff we monitored were exposed above the WHO limit for over 80% of their working day. Since second-hand smoke contains several thousand toxins and many carcinogens (2), the hazards associated with this exposure are likely to be significant.

We used levels of PM₂.₅ as a marker for second-hand smoke (12, 13), since direct measurement of tobacco-specific toxins in the atmosphere is expensive and sampling impractical in prison settings. Second-hand smoke is not the only source of indoor PM₂.₅, since particulate matter is also released from sources such as open fires, toasters and microwaves. Where toasters and microwaves were present on the wings, every effort was made to place the SidePak monitors as far away from these as possible. We carried out much of our sampling during the summer months when natural ventilation to the wings and cells through open windows and doors would have been greater than during the winter months, potentially leading to underestimates of pollution levels. Safe locations for the SidePak monitors were limited, but we tried to collect data from a broad selection of locations. Since we were obliged to answer questions from staff members and prisoners who enquired about the monitoring, our measurements were not carried out blind. However, whilst it is possible that prisoners or staff changed their behaviour in response to being monitored, we think that is unlikely to have occurred to any appreciable degree over the course of our measurements. Our maximum sampling time was determined by a battery life of around 9 hours, though in practice we were also constrained by restrictions on the times that we could leave and collect the monitors, whilst prison staff who wore monitors were also limited by their shift patterns. For all these reasons our sampling does not provide fully representative 24-hour sampling in the prisons; rather reflects pollution levels at times during the day when prisoners were awake and more likely to be smoking. The proportion of monitoring times spent above WHO guidelines therefore likely overestimates the true 24 hour figures; however many of the absolute times reflect significant periods of very high exposure. As a best case scenario, extrapolating the samples from wing locations to cover a 24 hours period with an assumption that the times not sampled had a reading of zero, two wings still produced an arithmetic mean above the 25 µg/m³ WHO upper guidance limit.

In an evaluation of smoke free policy within correctional facilities in North Carolina, USA, four facilities with no smoke-free legislation pre-policy recorded an arithmetic mean concentration of PM₂.₅ of 93.11 µg/m³ (17). The arithmetic mean reported for all datasets in this study is less than half (arithmetic mean 43.87 µg/m³) of that reported in North Carolina, even though they report a 65% prisoner smoking prevalence which, anecdotally, is broadly similar to that in the UK. Twelve datasets were collected from smoking locations in North Carolina (compared with 42 in this study) and the average time for data collection was 1.28 hours (compared to 6.67 hours in this study). Another study, conducted in prisons in New Zealand, (18) recorded levels of PM₂.₅ before a smoke-free policy was introduced; producing a geometric mean before the policy of 6.58 µg/m³. Although much lower than the geometric mean recorded across smoking locations in this study (30.78 µg/m³) the authors acknowledge that the representativeness of their findings was constrained by their decision, out of fears that the monitors would be tampered with, not to sample air in common areas used by prisoners. Samples were therefore taken only from the ‘staff base’, and did not reflect levels elsewhere in the prison.

Research by the WHO and others suggests that there is no safe level of exposure to SHS (15, 21, 22). Data collected from staff members gave an insight into locations where exposures to PM₂.₅ were highest, and these included the wing landing, and at the doorway and inside a prisoner’s cell. Taken together, these findings can offer some guidance as to the types of wings or duties where staff members are exposed to the highest levels of SHS and therefore when protection from SHS is particularly needed.

Prisoners also require protection from SHS within prison establishments. Our findings suggest that being in a non-smoking cell does not necessarily offer protection against SHS, especially for those on wings with closed narrow corridors. Second-hand smoke exposure of pregnant women is also a significant potential problem, since pregnant women are not usually transferred to a smoke-free environment until they have given birth. Exposure of mothers to SHS during pregnancy reduces birth weight and may also effect risk of prematurity and being small for gestational age (3). During data collection at HMP Eastwood Park there were 18 pregnant women living on main prison locations, though their smoking status was not known.

Our findings thus provide strong evidence that smoking in prisons in England is a source of high pollution levels that affect both staff and prisoners. They also demonstrate that this exposure will be prevented by making prisons comprehensively smoke-free.

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*Conflicts of Interest*

None of the authors from The University of Nottingham have any competing interests. S.D-W is the NOMS smoke-free policy lead.

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