

A Study of Ventilation and Indoor Air Quality in Hospitality Venues Where Smoking is Allowed

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SUMMARY

Ventilation is an effective method of introducing air into and moving air through buildings to achieve indoor air quality that is comparable to outdoor air quality. However, questions have recently been raised about the effect of ventilation on indoor air quality in hospitality venues where smoking is allowed. Dilution and removal of particles and gasses from various sources within a building and controlling temperature and humidity are the primary reasons for ventilation. Some of the first mechanical ventilation systems were designed to control particles and gasses from tobacco smoke [1]. The objectives of this study were to evaluate the performance of ventilation systems in a number of typical hospitality venues in the United Kingdom where smoking is allowed, and to compare the air quality in these venues with the air quality outside of these venues.

This paper presents measurements of ventilation and indoor air quality including environmental tobacco smoke (ETS) parameters sampled in several locations within each venue to assess the effectiveness of the ventilation systems. The indoor air quality measurements included carbon dioxide, nitrogen dioxide, carbon monoxide, temperature, relative humidity, respirable suspended particles, particulate matter 2.5 (PM_{2.5}) and particulate matter 10 (PM₁₀). Particle measurements specific to ETS included Solanesol. The investigators also present measurements taken in the outdoor air as a means of comparing outdoor air quality with the indoor air quality.

This study demonstrates that ventilation is effective in hospitality venues where smoking is permitted and that the indoor air quality of these venues is comparable to the outdoor air quality.

INTRODUCTION

In order to evaluate the effectiveness of ventilation in spaces where smoking is allowed, a case study measuring ventilation and Indoor Air Quality (IAQ) in three well-ventilated hospitality venues in the United Kingdom was conducted.

METHODS

The case study consisted of:

- Phase 1 – Selection of venues
- Phase 2 – Site testing/assessment

Phase 1 – Selection Of Venues

In November 2006, researchers conducted site inspections of a total of twelve hospitality venues located in London, England and Cardiff, Wales. The purpose of the site inspections was to select three well-ventilated hospitality venues where smoking is allowed to be included in the study. Researchers gathered data on each of the twelve venues using a checklist that included the following:

- Location (busy street, city, etc.)
- Type of establishment (pub, restaurant, etc.)
- Ceiling height
- Estimated floor area
- Carbon dioxide levels and ventilation rate
- Seating capacity
- Number of smokers present
- Type of ventilation system
- Tobacco smoke control measures in place

Three of the twelve venues were selected for the case study based on the review of the data collected during the site inspections. The other nine venues were considered inappropriate for inclusion in the case study for various reasons including, ineffective or limited ventilation, low occupancy levels, low smoking densities and limited or no appropriate locations for placement of sampling equipment. Of the three venues selected, one of the venues was located in London, England and two of the venues were located in Cardiff, Wales.

Cardiff

Venue #1 - Traditional Pub

A typical small one-room pub located on the Outskirts of Cardiff with seating for approximately 60 persons.

Venue #2 – Newly Renovated Pub/Restaurant

This venue is a purpose-built restaurant/pub and is considered an up-scale venue that has undergone extensive renovations and upgrades over the past few years. It is located in the heart of Cardiff on the main street, which is heavily traveled by automobiles. This venue has a seating capacity of 850.

London

Venue #3 – Wine Bar/Restaurant

The venue is an elegant restaurant/wine bar located on the basement level of a building located in central London. The street is quite heavily traveled by automobiles and the restaurant has a seating capacity of approximately 120.

Phase 2 – Site Testing/Assessment

The benchmarks used by a consensus of indoor air quality researchers to evaluate indoor air quality in commercial and hospitality environments are carbon dioxide (metabolic activity and ventilation), carbon monoxide and nitrogen dioxide (combustion byproducts), respirable suspended particles (air cleanliness), temperature and humidity (both comfort measurements) [2][3][4][5][6][7][8].

The majority of researchers evaluating indoor air quality in spaces where smoking occurs have used respirable suspended particles (RSP) as a marker for tobacco smoke. RSP is the most commonly used marker because it is easy to measure and the equipment to measure RSP is readily available. RSP is generally defined as a particle less than 4 micrometers in size [9]. Particles are generally measured and reported as RSP, PM_{2.5} (particles less than 2.5 µm) and PM₁₀ (particles less than 10 µm).

It is important to note that particulates found in both the indoor and outdoor air, including RSP, PM_{2.5} and PM₁₀ are not specific to tobacco smoke and are contributed by many sources including human metabolism, combustion sources (e.g., cooking, heating, dust, automobile exhaust) and other activities [10][11]. However, Solanesol is a particulate that is exclusive to tobacco smoke [12]. Solanesol is known to occur in a constant ratio to the total RSP contributed by tobacco smoke [13][14][15][16]. Thus, measuring Solanesol allows the researcher to determine the total amount of RSP contributed by tobacco smoke to the indoor air. The ratio of Solanesol is approximately 3% by weight of the RSP contributed by tobacco smoke.

Three sampling locations were selected inside each of the hospitality venues. These locations were selected to be representative of occupancy and ventilation. At each of these three locations, both instantaneous and integrating air sampling techniques were utilized. In addition, one outdoor location was selected as representative of ambient conditions.

Instantaneous sampling was conducted for the following parameters both indoors and outdoors:

- Carbon dioxide (CO₂)
- Carbon monoxide (CO)
- Temperature and relative humidity
- Nitrogen dioxide (NO₂)
- Respirable suspended particulate (RSP), Particulate Matter 10 (PM₁₀) and Particulate Matter 2.5 (PM_{2.5})

Instantaneous air quality measurements for the IAQ parameters noted above were collected at one-hour intervals over the course of the 8-hour sampling day at each location.

Instantaneous measurements were collected with the following instrumentation.

Carbon dioxide (CO₂), temperature, relative humidity and carbon monoxide (CO) were measured with the TSI Q-Trak. The Q-Trak has the following specifications:

Sensor	Sensor type	Range	Resolution
Carbon dioxide	Non-dispersive infrared	0 to 5000 ppm	1 ppm
Temperature	Thermistor	0 to 50°C	0.1°C
Relative Humidity	Thin-film capacitive	5 to 95%	0.1%
Carbon monoxide	Electro-chemical	0 to 500 ppm	0.1 ppm

Nitrogen Dioxide was measured with the Biosystems Toxi Pro. The Toxi Pro has the following specifications:

Sensor	Sensor type	Range	Resolution
Nitrogen dioxide	Electro-chemical	0 to 20 ppm	0.1 ppm

Respirable Suspended Particulate (RSP), PM₁₀ and PM_{2.5} were measured using a TSI Inc. forward light scattering DustTrak™ aerosol monitor. The cyclone attachment was in place for the RSP measurements and different size selective adaptors were utilized to acquire the PM₁₀ and PM_{2.5} measurements. The sensor is a 90° light scattering laser diode sensor that has a range of 1 to 100,000 ug/m³ and a resolution of +/- 0.1% of the reading or +/- 1 ug/m³, whichever is greater.

Indoor air quality research has shown that Dustrak measurements tend to overestimate indoor particulate levels when compared to the traditional and widely accepted gravimetric sampling and analytical methodology.

The Dustrak is factory calibrated to the standard ISO 12103-1, A1 test dust (formerly Arizona Test Dust). This standard test dust is used because of its wide particle size distribution (Model 8520 Dustrak Operation and Service Manual). In recognition of the potential for the instrument to overestimate dust differing in type and composition from the factory calibration standard a methodology is presented to determine an applicable correction factor for specific aerosols in the Operation and Service Manual.

Research suggesting the need for the application of a correction factor for the Dustrak includes Heal, et al, 2000, Edwards, et al. 2006 and Jenkins 2004 [17][18][19]. This research has determined that the Dustrak overestimates particulate levels when compared to gravimetric sampling techniques by factors ranging from 2 to 3.24.

A correction factor for this case study was calculated based on the method presented in the Operation and Service Manual for the Dustrak.

The correction factor was calculated using data from ten (10) different indoor air quality investigations including 101 comparable data points where both gravimetric RSP data and Dustrak RSP measurements were acquired side-by-side in smoking-permitted environments. From these data and comparison of side-by-side sampling results (Dustrak and gravimetric sampling), the appropriate correction factor was calculated to be 3.84.

In addition to the instantaneous measurements of CO₂, CO, NO₂, RSP, PM_{2.5} and PM₁₀, integrated air sampling was conducted for both Solanesol and RSP (gravimetric) over an 8-hour period at each of the three monitoring locations at each of the three venues to determine time weighted average concentrations of particulates.

For determination of both Solanesol and gravimetric RSP the American Society of Testing and Materials (ASTM) Method D 6271-98 protocol was followed for both collection and analysis [13].

Within the three hospitality venues, investigators observed the following factors in addition to the air quality measurements:

- Number of cigarettes smoked per hour of testing.
- Overall occupancy load at 1-hour intervals.
- Floor layouts and space volume was determined.
- Air movement patterns using smoke pencil testing.

Measurement of Ventilation Rates

In the United Kingdom, the professional standards of practice for the design, installation, operation, maintenance and manufacturing of natural and mechanical ventilation systems are defined by the Chartered Institute of Building Services Engineers (CIBSE). CIBSE has provided recommendations for ventilation rates in smoking and non-smoking environments in “Ventilation and Air Conditioning CIBSE Guide B-2” (2001) [20]. A table of the CIBSE recommended outdoor air supply rates for smoking environments is presented below.

Table 1. Recommended Ventilation Rates – Smoking Environments

Level of Smoking	Proportion of occupants that smoke (%)	Outdoor air supply rate (litres per second per person)	Outdoor air supply rate (cfm per person)
No smoking	0	8	17
Some smoking	25	16	34
Heavy smoking	45	24	51
Very heavy smoking	75	36	76

cfm – cubic feet per minute

The performance of a ventilation system with respect to the amount of outside air provided is usually determined in indoor air quality research by measuring concentrations of CO₂ in the indoor environment [21]. For this study, ventilation rates were calculated using CO₂ as a surrogate marker. The following mass balance equation was used to determine ventilation rate in the spaces using the carbon dioxide levels measured inside and outside. This equation is presented in Appendix C of the ASHRAE Standard 62-2004 [22].

$$C_s = N/V_{oa} + C_{oa} \quad \text{or} \quad V_{oa} = N/(C_s - C_{oa})$$

Where,

C_s – carbon dioxide in the space

N – CO₂ generation rate per person based on activity level (0.0106 cfm for persons performing office work)

V_{oa} – Ventilation rate in cfm

C_{oa} – CO₂ level outside using 350 ppm estimate (expressed as 0.00035)

RESULTS

Table 2 below shows data specific to each venue with regard to ventilation and occupancy.

Table 2. Information on Each Venue – Ventilation and Occupancy

	Venue #1	Venue #2	Venue #3
Ventilation Rate	80 (40)	64 (32)	51 (25.5)
Average hourly occupant count	13	65	40
Cigarettes smoked per hour	12	29	6.0
Smoking Rate*	1	0.5	0.2

Ventilation rate – in cubic feet per minute of air per person (litres per second per person)

* - Cigarettes smoked per person per hour

All three of the venues were observed to be well ventilated. The ventilation rates measured in the venues were within the ventilation rates recommended by CIBSE for the amount of smoking observed. The occupancy rates and smoking rates were typical for hospitality venues in the UK.

The following tables present indoor and outdoor air quality measured for each of the three venues.

Table 3. Indoor and Outdoor Measurements, Venue #3 – December 7, 2006

	Venue #3	Outdoors
CO (ppm)	2.9	3.0
NO ₂ (ppm)	< 0.1	< 0.1
RSP – instantaneous (µg/m ³)	29	42
PM _{2.5} (µg/m ³)	27.6	41.3
PM ₁₀ (µg/m ³)	34.0	48.7
RSP – gravimetric (µg/m ³)	30.0	Not measured
Solanesol (µg/m ³)	< 0.5	Not measured

Table 4. Indoor and Outdoor Measurements, Venue #2 – December 5, 2006

	Venue #2	Outdoors
CO (ppm)	2.9	2.5
NO ₂ (ppm)	< 0.1	< 0.1
RSP – instantaneous (µg/m ³)	33.9	24.9
PM _{2.5} (µg/m ³)	33.7	25.3
PM ₁₀ (µg/m ³)	34.9	29.4
RSP – gravimetric (µg/m ³)	56.7	Not measured
Solanesol (µg/m ³)	< 0.5	Not measured

Table 5. Indoor and Outdoor Measurements, Venue #1 – December 4, 2006

	<u>Venue #1</u>	<u>Outdoors</u>
CO (ppm)	3.1	2.9
NO ₂ (ppm)	< 0.1	< 0.1
RSP – instantaneous (µg/m ³)	49.4	21.3
PM _{2.5} (µg/m ³)	46.3	18
PM ₁₀ (µg/m ³)	49.4	24.3
RSP – gravimetric (µg/m ³)	43.0	Not measured
Solanesol (µg/m ³)	< 0.5	Not measured

Table 6. Average Results from All Venues

	<u>Average</u>	<u>Outdoors</u>
CO (ppm)	2.97	2.8
NO ₂ (ppm)	< 0.1	< 0.1
RSP – instantaneous (µg/m ³)	37.4	29.4
PM _{2.5} (µg/m ³)	35.9	28.2
PM ₁₀ (µg/m ³)	39.4	34.1
RSP – gravimetric (µg/m ³)	43.2	Not measured
Solanesol (µg/m ³)	< 0.5	Not measured

Indoor carbon monoxide levels averaged 2.97 ppm while outdoor levels average 2.8 ppm showing that indoor results were found to be consistent with outside.

Indoor and outdoor nitrogen dioxide levels were consistently found to be below levels of detection (0.1 ppm) for the methodology used.

Indoor RSP (instantaneous), PM_{2.5} and PM₁₀ averaged 37.4 µg/m³, 35.9 µg/m³ and 39.4 µg/m³ respectively. Outdoor RSP (instantaneous), PM_{2.5} and PM₁₀ averaged 29.4 µg/m³, 28.2 µg/m³ and 34.1 µg/m³ respectively. RSP (gravimetric) averaged 43.2 µg/m³.

Based on the results of this case study measuring air quality and ventilation parameters, we conclude that the effective ventilation of the hospitality venues was able to achieve levels of particles and gases in an indoor environment, where smoking occurs, that are comparable to the levels of particles and gases present in the outdoor environment.

DISCUSSION

Ventilation is the intentional introduction into and movement of ventilation air through an enclosed space. The purpose of ventilation is to achieve levels of particles and gasses in the indoor environment that are comparable to levels of particles and gasses in the outdoor air and to control temperature and humidity. Neither air filtration (cleaning) or air conditioning is ventilation because neither process introduces air into or moves air through an enclosed space. The results of this study which includes three well ventilated hospitality venues which are typical of similar venues located throughout the UK demonstrates that ventilation systems when operated effectively can achieve levels of particles and gasses in an indoor environment where smoking occurs that are comparable to levels of particles and gasses present in the outdoor environment. It is interesting to note also that in the three hospitality venues studied

where smoking occurred the levels of particles and gasses measured were also found to be comparable or lower than levels of particles and gasses measured in similar hospitality venues where smoking is not allowed and does not occur [23][24][25][26].

This is a case study limited to three hospitality venues however the results are important because they show that ventilation can be an effective method of providing air in enclosed spaces where smoking is allowed that is of comparable quality to the ambient outside air. Further research is required to statistically validate this finding.

ACKNOWLEDGEMENT

Funding for this research project was provided by Imperial Tobacco Limited. Assistance with coordination of the equipment in the UK was provided by Jaros, Baum and Bolles UK Limited.

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