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Evaluation of the Indoor Air Quality in Restaurants Before and After a Smoking Ban in Portugal

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Benzene · Indoor air quality · Smoking ban · Respirable particulate matter · Restaurants · Tobacco smoke pollution

Abstract
On 14th August 2007, Portugal instituted a smoking ban in most indoor public places. The goal of this work was to quantify the effects of this ban on indoor air quality (IAQ) in Portuguese restaurants. Ten restaurants were investigated before and after the ban and the following indoor parameters measured: respirable suspended particulate matter (RSP), total volatile organic compounds (TVOC), benzene (C_6H_6), carbon monoxide (CO), carbon dioxide (CO_2), temperature and relative humidity. Results show a statistically significant decrease in RSP and CO concentrations after the ban, as well as for TVOC and benzene concentrations. Additionally, the monitored CO_2 concentrations widely exceeded 1800 $mg{\cdot}m^{-3}$ (reference for acceptable ventilation rates), suggesting inefficient ventilation of the indoor spaces. This paper provides the first comparison of IAQ in Portugal before and after the introduction of smoke-free law and these results confirm the positive impact of the law in the indoor air that became smoke-free after the legislation. This information should be provided to decision makers as it has significant health implications. This law thus appear to achieve the aim of protecting people from exposure to unwanted pollutants resulting from poor IAQ.

Introduction

Despite the wide variety and distribution of air pollutant sources, the concentrations of indoor pollutants may be the main risk factor in personal exposure due to the fact that most people spend an average of 90% of their time in enclosed buildings.

Several studies investigating the effects of smoking in hospitality venues have determined that hospitality workers are exposed to relatively high concentrations of indoor pollutants, namely respirable suspended particulate matter

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(RSP) [1–11], implying a substantial risk for the health of both guests and staff of such establishments.

In recent years, several European countries (Ireland, Norway, Italy, Malta, Sweden, Spain, Finland, Scotland, Belgium, France and UK) have issued smoking policy rules in indoor workplaces and/or hospitality premises, including restaurants, to protect non-smoking people from environmental tobacco smoke (ETS) and consumption of tobacco products, with a good compliance [12–15].

The introduction of smoke-free legislation has been shown to dramatically improve the indoor air quality (IAQ), in particular reduction of ETS exposure, in the hospitality sector [12,16–18] and have been associated with subsequent beneficial health effects, such as a decrease in respiratory symptoms and improvement in the lung function of bar workers [19–23].

According to several studies, the most effective measure to reduce exposure to ETS is to remove the source from indoor environments [24–26].

On 14th August 2007, the Portuguese government introduced the national law ban on workplace smoking (Law 37/2007) [27] which came into force on 1st January 2008. This law contained new framework to protect individuals from passive smoking and for cutting down/stopping consumption. Therefore, smoking was banned in indoor public places (e.g. hospitality venues, schools, shopping centres, hospitals and other health care facilities).

There are, to date, no published studies in Portugal that document indoor air pollution before and after the implementation of this smoking ban. Therefore, this study was conducted to evaluate the impact of the new law on IAQ in restaurants in Portugal before and after the smoking ban took place. The goal of this study was to quantify the IAQ benefits of the ordinance and to provide this information to decision makers as this information has significant health implications in terms of ETS exposure.

Material and Methods

This study involved two different phases: the first monitoring phase was conducted between October and December 2006 prior to enactment of the 14th August 2007 smoke-free law in Portugal in 10 restaurants; and the second monitoring phase was performed 2 years later, also during wintertime, after banning smoking in the same 10 restaurants which enables comparison of results because the ventilation was dependent solely on mechanical ventilation present in all establishments.

In both phases, the visits and measurements took place/were conducted during peak business hours and when the restaurants are usually busy: on Fridays and Saturdays. The measurements of all parameters were made in between 21:30 and 01:30.

The study included the indoor air monitoring of the following parameters: RSP, total volatile organic compounds (TVOC), benzene (C_6H_6), carbon monoxide (CO), carbon dioxide (CO_2), temperature and relative humidity; as well as walkthrough surveys of restaurant buildings and individual spaces. The monitoring, walkthrough and survey phases occurred concurrently.

The design and the scope of the work reported here were limited by the available budget and time.

Selection of Restaurants and Indoor Spaces

The study was developed in restaurants located in Vila Nova de Gaia city in the North of Portugal, which has a typical Atlantic climate, humid but temperate.

All studied restaurants had a similar architectural structure; similar outside and structural conditions; as well as are located in a popular tourist/entertainment site. Prior the several measurements the owners were contacted by letter describing the study and given the opportunity to decline participation.

From 22 restaurants, 4 were no longer in the business for more than 1 year; 8 refused to participate; and 10 (56%) showed willingness and interest in participating in the study. At the first monitoring phase, all participant restaurants had no smoking restrictions. In the second monitoring phase, all restaurants became smoking-free establishments, following the smoking ban. In this last case, it was judged by restaurant owners their compliance with the ban was fulfilled. This information was also verified and proven in situ during the environmental measurements.

Building Characterisation

In order to characterise the buildings, both drawings and maintenance workers were consulted, and a walkthrough survey was performed. The following building parameters were collected: age, size, number of floors, renovation and ventilation system.

A checklist was filled in each indoor space, which included information on area, finishing materials, and their condition concerning floor, walls and ceilings; candles, open kitchens, fireplaces, cleaning procedures and number of staff members; operable exterior doors and windows were identified. Also, during the monitoring of indoor air parameters, the research team filled in a diary reporting the number of building occupants.

Environmental Monitoring

Total of 22–30 air samples per visit were taken in both monitoring phases and measurements of temperature and relative humidity were recorded at five to seven locations per establishment depending of the dimension. The monitoring phase included air sampling for, at least, a 4-h period during peak hours but was discreet in order not to disturb occupants' normal behaviour.

Sampling devices were placed at a height of about 0.6–1.7 m above the floor, approximately at the breathing zone level of employees and customers. The selected place was not allowed to be closer than 1 m to a wall, a door or an active heating system and placed away from sources of potential contaminants (e.g. fireplaces or stoves). During the first monitoring period, the number of smokers was counted and reported.

All data were collected as close as possible to the centre of the main area of the restaurant. This environmental evaluation strategy was considered to be representative of the entire building. Air samples were also simultaneously collected outside each building at heights of 1.5–2 m above the ground near the fresh air intakes, to compare outdoor and indoor contaminant levels.

During the second survey period, after the legislation restricting smoking had been enforced, the same locations for the area monitoring were used.

The laboratory that performed the analytical procedure for the evaluated parameters had the respective methodologies accredited according to NP EN ISO/IEC 17025:2005 "General requirements for the competence of testing and calibration laboratories" [28].

Respirable Suspended Particulate Matter

RSP sampling was undertaken and analysed according to the US National Institute for Occupational Safety and Health (NIOSH) method no. 0600 [29]. Before sampling, the filters were stored in a desiccator for equilibration. At least one field blank per sampling was included for laboratory evaluation. Exposed and unexposed filters were transported, protected from dust and sunlight and kept away from air in a closed filter holder. Each filter was weighed under controlled conditions of temperature (20°C ± 1°C) and relative humidity (50% ± 5%) before and after the sampling. Pre- and post-weighings were determined gravimetrically using an electronic micro-balance Sartorius (Sartorius M5P with 0.001 mg of sensibility). In order to obtain good precision, static charges were eliminated using a non-radioactive, ionizing air blower (Quincomer, Osmonics). Concentrations were calculated based on the weight difference between "after sampling" and "before sampling" filters and sampled air volume.

TVOC and Benzene (C_6H_6)

TVOC and C_6H_6 were collected by drawing air through a stainless steel sampling tube (Tenax TA) using a personal air sampling pump (SKC Pocket pump) at a flow rate of $0.05\,L{\cdot}min^{-1}$ for a period of 45 min. These pumps were checked and calibrated daily prior to each sampling. Before sampling, each tube was conditioned at 250°C, 300°C and 330°C for 30 min consecutively in the helium carrier gas flow. Analysis of volatile organic compounds (VOCs) was performed by automatic thermal desorption coupled with capillary gas chromatography using Perkin Elmer equipment ATD 400 and AutoSystem GC fitted with flame ionisation detector (FID) and one apolar column, according to an internal method [30]. TVOC was quantified using the toluene response factor. The concentration was calculated as the sum of concentrations of identified and unidentified compounds eluting between hexane and hexadecane (included), expressed as toluene. During the analysis of TVOC, the concentration of benzene was also determined.

Carbon Monoxide (CO), Carbon Dioxide (CO_2), Temperature and Relative Humidity

Sampling of CO, CO_2, temperature and relative humidity in all restaurants were recorded using a portable monitor of IAQ (GasData, model PAQ). Short-term measurements (30 min average for each one) were conducted sequentially, at each site, recording the respective duration. After equipment stabilisation, reading values were registered and transferred to an informatic system using PCLogger software.

Air Exchange Rate

The air exchange rate was estimated for each restaurant using Equation (1), with the following mass balance for CO_2 that assumed a well-mixed space and that the only sources of indoor CO_2 were due to the ambient outdoor levels, occupants and lit cigarettes in the restaurant:

$$V\frac{dC}{dt} = QC_o - QC + E \quad (1)$$

where V is the volume of the space (m^3), Q the ventilation flow rate ($m^3{\cdot}h^{-1}$), C_o and C the respective outdoor and

Table 1. Restaurant information including area, mean number of occupants and mean number of smokers

Restaurant information	Pre Mean ± SD; range	Post Mean ± SD; range
Area (m^2)	146 ± 96; 60–400	146 ± 96; 60–400
Occupants (no.)	84 ± 69; 23–247	90 ± 62; 28–213
Smokers (no.)	33 ± 17; 11–62	–

SD, Standard deviation.

Table 2. Environmental monitoring (indoor and outdoor) in pre- and post-ban survey at ten restaurants

	Indoor			Outdoor	
	Pre Mean ± SD; range	Post Mean ± SD; range	*p-Value*	Pre Mean ± SD; range	Post Mean ± SD; range
RSP ($\mu g \cdot m^{-3}$)	169 ± 72; 40–260	46 ± 19; 30–90	0.005	46 ± 8; 40–60	41 ± 7; 30–50
TVOC ($mg \cdot m^{-3}$)	0.52 ± 0.38; 0.10–1.21	0.10 ± 0.08; 0.06–0.32	0.005	0.05 ± 0.01; 0.05–0.06	0.05 ± 0.01; 0.04–0.06
C_6H_6 ($mg \cdot m^{-3}$)	0.05 ± 0.03; 0.01–0.12	< 0.01	0.005	< 0.01	< 0.01
CO ($mg \cdot m^{-3}$)	5.7 ± 2.3; 2.1–9.6	2.9 ± 2.1; 0.4–7.9	0.009	2.5 ± 2.1; 1.0–4.5	2.2 ± 1.8; 0.0–7.2
CO_2 ($mg \cdot m^{-3}$)	3035 ± 1354; 1501–6466	2401 ± 1083; 1249–4606	0.093	649 ± 29; 617–713	635 ± 24; 601–680
Ventilation rate (h^{-1})	5.5 ± 5.0; 0.9–14.9	8.0 ± 6.6; 2.4–24.5	0.089	–	–
Temperature (°C)	25.2 ± 2.0; 20.9–27.6	25.9 ± 2.6; 21.4–29.9	0.109	–	–
Relative humidity (%)	52 ± 6; 41–59	48 ± 3; 41–55	0.109	–	–

SD, Standard deviation.

indoor concentrations of CO_2 ($mg \cdot m^{-3}$), and E the emission rate of CO_2 ($mg \cdot h^{-1}$), which is comprised of CO_2 emissions from both occupants and burning cigarettes. Equation (1) was divided through by the volume, V, assumed to be at steady state, and rearranged to yield the Equation (2) for an estimate of the ventilation rate in number of air changes per hour (ACH), λ (h^{-1}):

$$\lambda = \frac{E}{V(C - C_o)} \qquad (2)$$

Assuming that a typical human breathing rate is $0.78\,m^3 \cdot h^{-1}$ [31] and 4% of exhaled air is CO_2 [32], the typical human would emit $51.9\,g\ CO_2 \cdot h^{-1}$. Also, assuming that a typical cigarette emits 300 mg CO_2 [33] and that it takes, on average, 6.5 min to smoke a cigarette [34], a typical cigarette would emit $2.77\,g\ CO_2 \cdot h^{-1}$. Given the assumptions inherent to Equation (2), particularly, the assumptions of complete mixing and steady-state conditions, it should be regarded as an approximate estimate of the ventilation rate.

Statistical Methods

The Wilcoxon signed rank sum test was used to assess changes between pre- and post-ban measurements. The SPSS v.16.0 package for Windows was used for the statistical analysis of the data. For all statistical analysis we used a significance level of $p < 0.05$.

Results

Restaurant Building and Indoor Spaces Characteristics

All evaluated buildings had similar construction characteristics, in an estimated area of about $146\,m^2$. They were constructed of brick and concrete block and all restaurants had heating, ventilation and air conditioning systems (HVAC). Nevertheless, many restaurant owners could not provide adequate information about the ventilation system in their restaurant regarding the capacity or direction of streams of air, indicating that they had little knowledge of their ventilation system. All indoor floors were made from wood and almost all the restaurants had operable windows. However, during the environmental monitoring all windows stayed closed.

In both phases, 4 from 10 participating restaurants had fireplaces (firewood, coal) or stoves inside the dining room. Table 1 lists some information from 10 restaurants sampled.

Over all of the sites, the occupancy showed no significant difference before or after the ban when considering either the mean number of occupants over all restaurants.

Environmental Monitoring

Table 2 summarises the mean and range values of the environmental monitoring made at the 10 restaurants in pre- and post-ban periods. Values obtained outdoor are also reported.

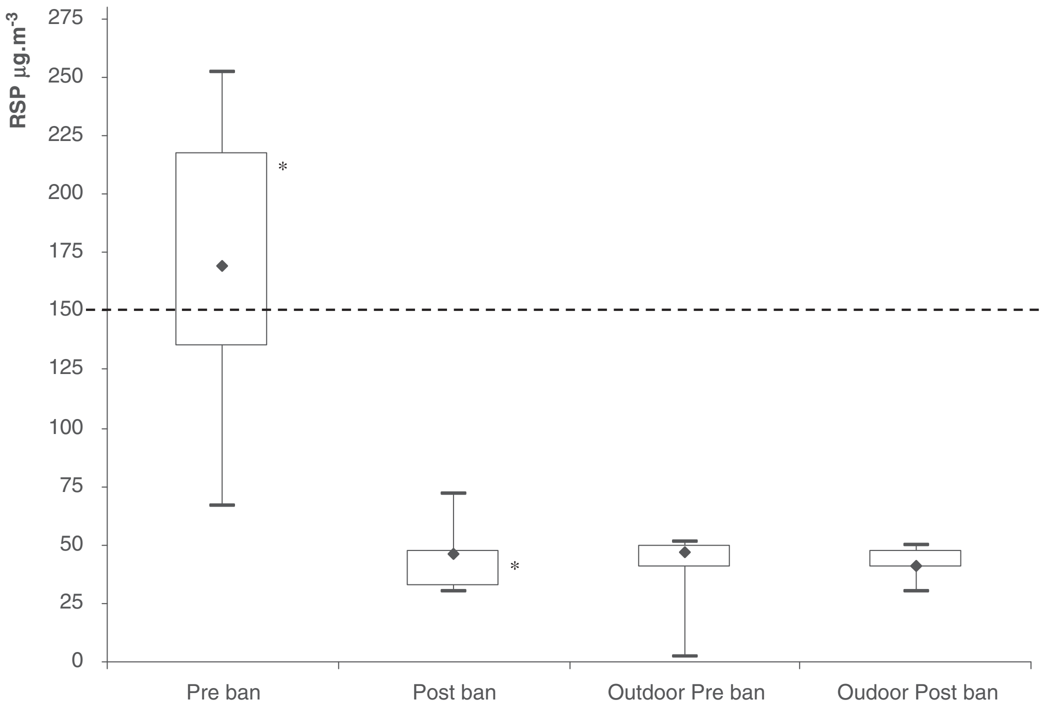

Fig. 1. Box plot of RSP levels for ten restaurants (◆ RSP mean; — Threshold limit; *$p = 0.005$ as compared with indoor RSP concentrations in pre-ban phase).

From 10 sampled restaurants, only one had low RSP ($< 40\,\mu g{\cdot}m^{-3}$) concentrations prior to the introduction of smoke-free legislation. For all cases, there was a statistically significant decrease ($p = 0.005$) in RSP concentrations. In comparison with indoor, outdoor RSP concentrations were significantly lower, with an average of $46 \pm 8\,\mu g{\cdot}m^{-3}$ in pre-ban phase and $41 \pm 7\,\mu g{\cdot}m^{-3}$ in post-ban phase, without statistical significance between the both phases.

Figure 1 shows a box plot of the distribution and the mean of pre- and post-ban RSP concentrations measured. The horizontal marker line represents the Institute of Environmental Epidemiology (IEE) "unhealthy" threshold ($150\,\mu g{\cdot}m^{-3}$) [35].

As other potential sources of RSP, such as the presence of stoves or fireplaces inside the dining room and outdoor sources, remained constant between the two monitoring phases it seems likely that tobacco smoke was the most important factor in increasing indoor concentrations of RSP.

Regarding VOC concentrations, Table 2 lists the results for the pre- and post-ban concentrations of TVOC as well as benzene that were detected in ten sampled restaurants. Across all restaurants sampled in this study, the difference in indoor TVOC data between smoking-permitted and smoke-free restaurants was statistically significant ($p = 0.005$), while the ambient outdoor TVOC levels as measured outside did not show any significant change between the pre- and post-ban periods. Indoor levels of TVOC were higher than those registered outdoors [Indoor/Outdoor (I/O) ratios > 1], namely in pre-ban phase, in agreement with previous studies [36–38], therefore TVOC levels were much determined by indoor sources.

Complete indoor pre- and post-ban benzene measurements also showed a statistically significant decrease after the introduction of the ban ($p = 0.005$). The indoor benzene concentration mean was $0.05 \pm 0.03\,mg{\cdot}m^{-3}$ in pre-ban period and the respective post-ban mean was lower than $0.01\,mg{\cdot}m^{-3}$. Outdoor levels of benzene in both survey phases were below $0.01\,mg{\cdot}m^{-3}$. Although benzene can induce leukaemia [39] no European legislation has regulated, to date, the indoor levels of this compound. However, a limit value for benzene has already been enforced for ambient air: according to European Directive 2000/69/EC [40], the annual mean benzene concentration in ambient air must not exceed $0.005\,mg{\cdot}m^{-3}$. Indoor mean values obtained in pre- and post-ban phases have exceeded this limit. Although not listed in the Table, ethanol was also detected at breakthrough levels, as well as toluene which had a mean concentration measured during the pre-ban phase of $0.08 \pm 0.01\,mg{\cdot}m^{-3}$. This was decreased to below $0.01\,mg{\cdot}m^{-3}$ during the post-ban phase.

Table 2 also shows the mean CO concentrations during the pre- and post-ban sampling, as well as the outdoor CO concentrations. Indoor CO concentrations decreased significantly when pre- and post-ban values were compared ($p = 0.009$). Statistical analysis showed that for all restaurants, the outdoor CO level in post-ban phase was not significantly lower than the outdoor CO level in pre-ban phase. The mean CO levels verified in the pre-ban phase were lower to results reported previously for indoor environments with a presence of ETS [41].

Carbon dioxide (Table 2) exhibited no statistically significant decrease in indoor concentrations. The elevated CO_2 concentrations are evidence that ventilation rates in the restaurants were often below levels required to achieve acceptable IAQ, regardless of whether there is smoking in the venues or not. No significant differences were detected between the outdoor mean CO_2 levels in the pre-ban and post-ban phase.

Table 2 lists the estimated ventilation rates in ACH (h^{-1}). The mean estimated ventilation rate was $5.5 \pm 5.0\,h^{-1}$ before the ban and $8.0 \pm 6.6\,h^{-1}$ after the ban.

Statistical analysis revealed no significant difference between pre- and post-ban phase in the levels of indoor temperature and relative humidity inside the restaurants.

Discussion

This paper provides the first comparison of IAQ in restaurants in Portugal before and after the introduction of the smoke-free law. Overall, the results confirmed the positive impact of the law in the indoor air that became smoke-free after the legislation.

Given that neither this study nor two others that were similarly conducted [12,18] found evidence of a decrease in occupancy levels; a ban on smoking in restaurants does not appear to cause reductions in patronage. Further, all restaurants were visited at the same day of the week and time of the day during the pre- and post-ban testing in an effort to minimise occupancy variations. Thus, this study found that a smoking ban may not, in fact, be detrimental to business in local restaurants, as is often the prevailing public belief.

The findings of our study indicate that the levels of RSP, an accepted marker for exposure to ETS [1,42,43], showed a statistically significant decrease ($p = 0.005$) after the implementation of an indoor smoking ban in those areas that previously allowed smoking before the ban. RSP concentrations decreased 75% relative to the pre-ban levels. Such large relative decreases suggest that ETS was the main source for RSP in those restaurants where smoking was permitted, since other factors (number of building occupants as well as other alternative sources like the presence of fireplaces or stoves inside the dining room) remained similar in both survey phases.

The outdoor RSP concentrations in the pre-ban phase were lower when compared with respective indoor RSP concentrations, which reinforce the fact that in this case, RSP concentrations were provided from intrinsic sources to the restaurants.

Several studies that measured particulate matter concentrations before and after smoking bans [12,42,44–46] are consistent with our findings.

Our study also shows that, prior to smoke-free legislation 70% of the restaurants surveyed had indoor RSP concentrations above the "unhealthy" limit ($150\,\mu g{\cdot}m^{-3}$) while no restaurant exceeded the referred threshold value after smoke-free law was enacted (Figure 1). Therefore, our results suggest that particulate exposure is heavily dominated by tobacco smoke.

TVOC concentrations significantly decreased in post-ban survey when compared with pre-ban survey and the outdoor TVOC levels did not show any significant change between the pre- and post-ban periods. The TVOC results in pre-ban period were on an average five times higher than the respective results obtained in post-ban period. Therefore, TVOC concentrations were presumably due to tobacco smoke. The TVOC levels registered in this study were generally lower in smoking places than those reported by Waring and Siegel [47] and higher in non-smoking ones. Also, all these levels were generally lower than those reported in restaurants by Lee et al. [48] and Baek et al. [49], where outdoor concentrations were higher too.

Indoor TVOC mean values obtained in these restaurants in pre-ban period have exceeded the threshold limit establish by ECA (European Collaborative Action) [30] ($0.20\,mg{\cdot}m^{-3}$) in 9 of the 10 restaurants investigated, with maximum value of $1.21\,mg{\cdot}m^{-3}$ in smoking areas, and in one restaurant with maximum value of $0.32\,mg{\cdot}m^{-3}$ in post-ban period (Table 2).

Furthermore, when comparing pre-ban with post-ban period indoor benzene concentrations detected during the pre-ban sampling decreased by a factor of 5 in the post-ban sampling. Though not listed in Table 2, toluene levels decreased considerably also after the ban. Again, this fact supports the notion that a significant indoor source had to be present in "smoking places" for these compounds, which are known to be emitted from sidestream tobacco smoke [50]. So tobacco smoke was suspected to produce the higher I/O values detected.

CO is released from ETS as well as from sources including gas stoves and heaters [48,51,52], thus, it is often difficult to ascertain the contribution to indoor CO levels due to smoke as explain Guerin et al. [53]. However, for many constituents, concentrations in environments where smoking occurs are elevated above levels in comparable environments where smoking does not occur. In our study, indoor CO concentrations also decreased significantly after the smoking ban. The results show that the I/O ratios of CO for the pre-ban phase were greater than one indicating the possibility of dominance of indoor activities such as ETS. These findings are consistent with other studies conducted in restaurant environments [47,48].

Although Klepeis et al. [54] shows that tobacco smoke can emit larger amounts of CO in restaurant environments, that are comparable to CO levels on a busy freeway, even when the doors are wide open and the ventilation system is fully operating, Table 2 shows that indoor CO concentrations in studied restaurants were below the respective threshold value established by Portuguese regulation ($12.5\,mg{\cdot}m^{-3}$) [55] before and after the smoking ban.

As evidenced by the indoor CO_2 concentrations (Table 2), generally considered as an indicator of inadequate fresh air supply, restaurants were inadequately ventilated according to Portuguese regulation ($1800\,mg{\cdot}m^{-3}$) [55], as well as with ASHRAE Standard 62.1-2004 [56], suggesting an inadequate outdoor air supply in the dining areas when these are occupied leading to an accumulation of other indoor pollutants, regardless of whether there are people smoking in the restaurants or not (as also show the estimated ventilation rates). Our findings are supported by the ventilation studies of Dingle et al. [9]; Carrington et al. [57] and Lee et al. [58].

As well as Akbar-Khanzadeh et al. [59] which reported no significant difference in CO_2 concentrations between smoking and non-smoking areas of restaurants, our findings reported the same tendency in CO_2 concentrations.

Since CO_2 is produced as part of the human metabolism, it is conceivable that the CO_2 levels are more closely related to the density of occupancy in the restaurant than to the byproducts of smoking. In theory, which is also supported by some studies (Milz et al. [60]) as time passes, CO_2 accumulates if the ventilation system does not dilute the CO_2 concentration at the same rate as it was generated: CO_2 concentration would increase as the ventilation flow rate decreases.

Therefore, ventilation conditions of restaurants in pre-ban phase, associated to indoor activities, are often insufficient as demonstrated by the CO_2 levels and, consequently, are not enough to dilute the indoor air contaminants.

Note that none of the owners involving in this study reported using their ventilation systems to maintain acceptable IAQ, instead using them only for maintaining thermal comfort. The limited knowledge of patrons of the ventilation systems is likely to be an obstacle to any legal requirement for ‘‘adequate ventilation’’.

According to Repace and Lowrey [61] reducing indoor exposure, namely ETS exposure through typical ventilation means has been shown to be of limited effectiveness.

Statistical analysis showed no significant differences between the pre- and post-ban in the levels of ambient temperature. This is slightly above the recommended range for acceptable indoor air (20–23°C in winter) from the ASHRAE standard [62]. The relative humidity is well within the recommended range [62].

Thus, all indicators of ETS exposure that this study measured, was shown to have decreased considerably after the ban, and by these the smoking ban ordinance can be judged a clear success at improving IAQ and reducing exposure to unwanted pollutants, namely ETS. Furthermore, because three separate indicators of ETS exposure was shown to decrease after the ban, one can be more certain that the reduction of each individual indicator was due, in fact, to the smoking ban.

According to other studies, smoke-free regulations could be implemented at very little cost, are supported by the public opinion [63] and do not lead to loss of income for the hospitality sector [5,64,65], but result in large health and economic benefit [66]. From a public health perspective, only the implementation of a 100% smoke-free regulation would result in effective protection for staff and customers.

Conclusion

This study assessed the IAQ in ten restaurants in Portugal before and after a smoking ban that took effect on January 2008. In conclusion, the difference in the IAQ in pre-ban and post-ban phases was higher with statistical differences between these two periods in the establishments for RSP, TVOC, benzene and CO parameters. It follows that the workers exposure as well as the public in the studied restaurants had been reduced as intended by the Portuguese legislative body.

Thus, our IAQ survey indicates that there was a statistically significant decrease (75%) in RSP relative to the pre-ban levels, which was similar to other studies of the same type. CO was significantly decreased as well as TVOC and VOC which are known to exist in tobacco smoke, namely benzene. CO and TVOC were significantly higher indoor than outdoor, showing the important influence of indoor sources on IAQ. The monitored CO_2 concentrations widely exceeded $1800\,mg{\cdot}m^{-3}$ (reference for acceptable ventilation rates), suggesting inefficient ventilation of the indoor spaces and consequent accumulation of other indoor pollutants.

Clearly, these results strongly support the implementation of nation-wide smoke free policies in order to improve the IAQ of hospitality venues and workplaces and lead to the greatest reduction of risk from indoor (smoking) exposure. These findings also have implications for policy makers and legislators in other countries currently considering the nature and extent of their smoke-free workplace legislation.

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