Overview of Recent Dutch Studies on Environmental Tobacco Smoke

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ABSTRACT

In this study the question whether or not and to what extent ventilation and air cleaning can contribute to the reduction of exposure to environmental tobacco smoke in the hospitality industry is answered. First a literature review on ventilation and air cleaning technologies has been executed. Unfortunately, only a few papers reporting experimental data from the hospitality industry were available to answer the proposed question. Therefore a model describing the effect of different ventilation systems and building layouts has been set up. With smokers and non-smokers in the same room reductions around 98% are predicted for application of displacement ventilation. By separation of smokers and non-smokers considerable higher reductions can be obtained. Air cleaning is relatively unimportant in these cases. In the second part local displacement ventilation systems have been installed and tested in a discotheque, a dining pub and a drinking pub. The reduction of gaseous compounds in relation to the existing situation was 95, 94 and 98% respectively. The fine dust reduction in the discotheque was 92%, in the pubs the reduction was lower. Most probably, this is caused by the fact that other sources of fine dust then tobacco smoke such as clothing were relevant.

KEYWORDS

ETS, hospitality industry, displacement ventilation, experimental data, VOC, PM$_{2.5}$.

INTRODUCTION

One of the goals of the Dutch government is to protect the non-smoker, for example by creating smoke free workplaces. Since 2004 legislation forbids smoking in workplaces. The hospitality industry is currently excluded from this legislation. The sector has applied a self regulation plan. According to this plan the occurrence of smoke free zones should increase from 25% in 2005 up to 75% in 2007. Dutch law defines a smoke free zone as a part from a room where smoking is forbidden. Currently dilution ventilation is the usual application in the hospitality industry. The air change rate assumed is often between 1 and 3 ACH, although the official Dutch Building Decree requirements are approximately 6–7 ACH. Currently air-cleaning equipment is not wide spread used. The concept of smoke free zone can diminish direct complaints due to irritation. However it cannot prevent the ingress of smoke to the non-smoking zone. Therefore a smoking ban for the hospitality industry like in Ireland and some part of the US could be an option unless ventilation and/or air cleaning practically reduce the exposure to nearly zero.

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LITERATURE REVIEW

To answer the question whether or not ventilation and air cleaning can contribute to reduction of exposure to environmental tobacco smoke was answered by a literature search in the AIVC database AIR and other available sources. Unfortunately, only test room experiments representing situations in the hospitality industry were available to answer the proposed question. Therefore a model has been set up describing the effect of different ventilation systems and building layouts for a restaurant (de Gids et al (2004)). A number of combinations is shown in table 1. The exposure in each case is normalised to the exposure concerned with the minimum legal ventilation requirement according the Dutch Building Regulations (BR). The costs are roughly estimated and are based on the purchase and installation of a ventilation system for a new restaurant of 150 m². Renovation costs are not included.

**TABLE 1**
Effect of ventilation measures on relative exposure and cost involved

<table>
<thead>
<tr>
<th>Ventilation measure</th>
<th>ACH [h⁻¹]</th>
<th>Relative exposure [%]</th>
<th>Costs [k€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current situation, mixing</td>
<td>1</td>
<td>300 – 600</td>
<td>0.5 – 2.5</td>
</tr>
<tr>
<td>Minimum legal requirement (BR) Mixing</td>
<td>6</td>
<td>100</td>
<td>5 – 25</td>
</tr>
<tr>
<td>Enhanced ventilation 10×BR, mixing</td>
<td>60</td>
<td>10 – 30</td>
<td>8 – 30</td>
</tr>
<tr>
<td>Enhanced ventilation 10×BR, displacement</td>
<td>60</td>
<td>4 – 15</td>
<td>50 – 250</td>
</tr>
<tr>
<td>Displacement + separate zones for smokers/non-smokers in one room</td>
<td>60</td>
<td>0.2 – 2</td>
<td>30 – 140</td>
</tr>
<tr>
<td>Displacement + separate rooms smokers/non-smokers; overflow via an opening of 15 m²</td>
<td>60</td>
<td>0.001 – 0.01</td>
<td>30 – 140</td>
</tr>
<tr>
<td>Mixing BR + separate rooms smokers/non-smokers; overflow via an opening of 5 m²</td>
<td>6</td>
<td>0.002 – 0.02</td>
<td>8 – 30</td>
</tr>
<tr>
<td>Mixing BR + separate rooms smokers/non-smokers; overflow via an opening of 15 m² with air curtain</td>
<td>6</td>
<td>0.005 – 0.05</td>
<td>20 – 80</td>
</tr>
</tbody>
</table>
Air cleaning

Air cleaning implies that the air is returned to the room, whereas with ventilation the air is replaced by outside air. Advantage of the recirculation mode of air cleaning is a lower heating demand during the heating season and a simplified installation.

A distinction has to be made between particle filtration and gas filtration. Mechanical filters can achieve particle filtration of e.g. respirable dust. Most gas components can be adsorbed on activated coal. Most apparatus consist of a combination of a mechanical filter and activated carbon. The effect of air cleaning equipment is determined by the efficiency of the apparatus itself and by the capacity considering the room. For example a very efficient apparatus, with in relation to the room a small airflow has only a small effect on the level of pollution in that room. Table 2 mentions typical experimental values. For nicotine a large range can be seen. This suggests that the type and the amount of activated carbon have influence. Concerning other pollutants, e.g. benzene, no field test data have been found.

### TABLE 2
Measured reductions in rooms obtained with air cleaning
Sources: 1Hammond (2002), 2Mc Nall (1975), 3Pierce (1996)

<table>
<thead>
<tr>
<th>Component</th>
<th>Type air cleaning</th>
<th>Reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respirable dust</td>
<td>HEPA / electrostatic</td>
<td>50° – 70²</td>
</tr>
<tr>
<td>Nicotine</td>
<td>Activated carbon</td>
<td>0° – 50³</td>
</tr>
<tr>
<td>CO</td>
<td>Activated carbon</td>
<td>0 – 30³</td>
</tr>
</tbody>
</table>

Conclusions literature review

The maximal reduction with air cleaning ranges 30-70%. This reduction is only valid for specific components for which a filter is suited and during the filter bed lifetime. In comparison with displacement ventilation which attains reductions around 98%, this reduction is relative small. Application of air cleaning equipment seems effective to reduce the concentration in smoking rooms and therewith the effect of spread of ETS e.g. when the door of a smoking room is opened.

EXPERIMENTAL VERIFICATION OF LOCAL DISPLACEMENT VENTILATION

Local displacement ventilation systems have been installed and tested in a discotheque, a dining pub and a drinking pub. The experimental setup and the results are shortly discussed here. An extensive description is given by de Gids et al (2006).

Tenax adsorption tubes were used for VOC sampling, DNPH cartridges for aldehydes, and the gravimetric method EN 14907 with LVS inlet for PM$_{2.5}$. With all components, spatial air was sucked in by means of a calibrated pump. The concentrations for each component were calculated by dividing the mass of the component by the total amount of air sucked in. The measuring results are therefore the time-averaged concentrations. A so-called traveller sample was used for the gaseous components during all stages of the study. The concentrations from this sample, which was not opened, were subtracted from the measured value.
**Discotheque**

The discotheque consists of an elongated space with a length of 30 metres, a width of 7 metres, and a height of 2.6 metres. The dance floor is located in the rear. The space was originally ventilated by mixing ventilation system (about 3 ACH). The geometry of the space - an elongated box - was the reason to install a horizontal displacement system. Air is supplied at the rear wall via a metal distribution grille, see figure 1. The purpose is to keep the dance floor smoke-free. During the test the flow rate was 2.2 m$^3$/s. Ideally, i.e. with optimal distribution and no obstacles, the air travels from the air inlet at the rear wall over the dance floor in a plunger-like fashion with a velocity of 0.11 metres per second towards the entrance.

The measurement was executed on a regular Friday night in September 2005. About 100 visitors were present. On the average, approximately 20 – 30% of the total number of people was found to be smoking at the same time. On the dance floor smoking was allowed. Sampling took place between 11.36 p.m. and 4 a.m. at the dance floor and near the entrance (air outlet). Figure 1 shows that on the dance floor compared to the pre-existing situation a reduction of 92, 95 and 96% respectively for PM$_{2.5}$, Total Volatile Organic Compounds and Aldehydes is reached.

**FIGURE 1**
Left: occupation of dance floor during the late hours, supply plenum is visible in the left back corner. Right: concentrations [µg/m$^3$] as measured on the dance floor compared to calculated values for a mixing ventilation system operated according the Building Decree and the pre-existing situation

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**Dining pub**

The dining pub consists of a large space of approximately 20 by 30 meters, the lay out is schematically shown in figure 2. Fresh outside air is supplied via the sidewall and above the bar area. Based on the kitchen exhaust flow the ventilation flow rate is estimated at 2.8 m$^3$/h. Due to the dimensions and geometry of the space here a local vertical displacement ventilation system was installed. The air distribution plenum consists of three stainless-steel segments of 1.8 by 2.5 m each. The total floor area of the smoke-free zone below the down flow is 1.8 by 7.5 m. For maintenance and the possibility of cleaning a fire retardant cloth was stretched over each segment fastened with Velcro. The air supply velocity was 0.19 m/s. The supply air was approx 2 K below room temperature.

The measurement was conducted on Wednesday, 11 January 2006 between 6 p.m. and 9.30 p.m. Three tables, each seating four non-smokers, were placed underneath
the down flow. On the average 6% of the about 50 people present was found to be smoking at the same time. Instead of taking and analysing air samples, a so-called tracer gas was used to determine the reduction of gaseous components. The tracer gas was injected in the existing ventilation system of the dining pub in order to distribute this artificial pollutant over the space.

Figure 2 shows 90% reduction of tracer gas is achieved below the down flow. Taking into account the dilution effect of the additional displacement flow a reduction of 94% compared to the original situation can be calculated. The fine dust concentration below the down flow is 50% lower than in the rest of the dining pub. The lower reduction for fine dust can be explained by the fact that aside tobacco smoke other sources for fine dust were present. Therefore the reduction in fine dust in relation to the original situation cannot be determined by means of calculation.

**FIGURE 2**
Schematic layout of the dining pub with smoke-free zone in dark and the fine dust concentrations in µg/m³ in the boxes (left). The numbering of the measuring locations refers to the tracer gas concentrations (right)

Drinking pub

The drinking pub has a width of 4.7, a depth of 9.3 and a height of 4 meters. The layout is schematically shown in figure 3. The original ventilation system consisted of a mechanical extraction in the centre of the pub and natural air supply through cracks in the wall. The original system had an estimated capacity of 600 to 1200 m³/h (3 - 7 ACH). Problems reported by the barman – irritated eyes at the end of each shift - justify the conclusion that the capacity of the system was insufficiently geared to the needs of the space.

Based on the possibilities, a localised vertical displacement ventilation system was selected. The design is comparable to the design of the system installed in the dining pub, except that in the drinking pub it is initially the barman who is protected. A plenum with dimensions of 4.7 by 4.5 meters was mounted below the ceiling over the bar section, see figure 3. The measurement was conducted on Wednesday, 25 January 2006 between 8.46 p.m. and 10.24 p.m. On the average 6% of the 54 people present was found to be smoking at the same time. The supply air velocity was 0.09 m/s and the supply temperature was 0 – 4 K below the room temperature. Tracer gas was injected above the window on the front side, next to the enclosed porch. Air was sampled in five locations at a height of approximately 1.2 m, both for fine dust (PM$_{2.5}$) and tracer gas. Figure 3 shows about 90% reduction of tracer gas is
achieved below the down flow. Based on the tracer gas results a reduction of 98 - 99% compared to the original situation can be calculated for gaseous components. The fine dust concentration below the down flow is 55 - 67% lower than in the rest of the dining pub. The lower reduction for fine dust can be explained by the fact that aside tobacco smoke other sources for fine dust were present. Therefore the reduction in fine dust in relation to the original situation cannot be determined by means of calculation.

**FIGURE 3**
Schematic layout of the drinking pub with the down flow area shaded and the fine dust concentrations in µg/m³ (left). The numbering of the measuring locations refers to the tracer gas concentrations (right)

Conclusions experimental verification

The experimental results confirm the model prediction that a reduction of gaseous compounds of more than 98% can be reached with displacement ventilation. The measured reduction of fine dust (PM$_{2.5}$) is lower. Most probably, this is caused by the fact that in case of a relative low number of smokers other sources of fine dust then tobacco smoke such as clothing and outside air become relevant.

**References**


Gids de, W.F., Jacobs, P. (2006), An investigation into the possible reduction in Environmental Tobacco Smoke (ETS) in the day-to-day operations of the hospitality industry, TNO report 2006-D-R0198/A, available through: www.tno.nl/ventilation

