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TNO report

2006-D-R0198(E)/A

An investigation into the possible reduction in Environmental Tobacco Smoke (ETS) in the day-to-day operations of the hospitality industry

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Copy no	
No. of copies	
Number of pages	51
Number of appendices	
Sponsor	British American Tobacco dhr. T. Werkhoven
Project name	Omgevingstabaksrook horeca
Project number	006.51315

Summary

Basis

The Netherlands Institute for Public Health and the Environment (RIVM) and the Netherlands Organisation for Applied Scientific Research (TNO Building and Construction Research) have jointly issued a report [1] to the Dutch Ministry of Public Health, Welfare and Sports. This report indicates the possible reduction in EST based on a review of literature, as well as a theoretical consideration by TNO Building and Construction Research.

British American Tobacco has commissioned a study into the effectiveness of the indicated ventilation measures in the day-to-day operations of three types of hospitality businesses:

- a pub not serving meals (drinking pub)
- a pub serving full meals (dining pub)
- a discotheque

Conversion of ventilation systems, set-up of measurements

For effectiveness, the decision was made to use localised displacement ventilation. The characteristics and prerequisites are described in Chapters 3 and 4. Each of the three hospitality businesses has successfully installed and put into use a displacement ventilation system. The systems have been designed so that they meet the aesthetical, fire safety, robustness and comfort requirements for each specific hospitality businesses.

The discotheque has a horizontal displacement system mounted in the sidewall that provides protection on the dance floor. No physical separation has been provided and smoking is permitted everywhere. In addition to fine dust ($PM_{2.5}$), measurements were conducted for volatile organic components (TVOC) and aldehydes. The other two hospitality businesses each have a localised displacement ventilation system installed below the ceiling. Air is blown from the ceiling of the eating pub and the drinking pub over a limited surface area of 14 and 21 square metres, respectively. Compartmentalisation is achieved by this directed airflow without any physical separation. A tracer gas was used instead of TVOC and aldehyde to determine the reduction of gaseous components.

Measured reductions

Reduction is achieved in two manners. Firstly, a reduction of 80 to 90% in relation to a reference point in the rest of the space is achieved locally in the area around the displacement ventilation system. Secondly, the displacement ventilation system provides additional ventilation in relation to the existing situation so that concentrations at the reference point drop proportionally.

	Reduction (%) in relation to ventilation according to the Building Decree	Reduction (%) in relation to ventilation in the current situation
Discotheque	90*	95*
Dining pub	94	98
Drinking pub	98	99

Table 1 reduction percentages (*Smokers and non-smokers mixed in the protected area)

The results in the table show the exposure reduction rates of gaseous and solid components in a situation where ETS is the main source of these components. This situation existed in the discotheque, for example, where a relatively high number of people were smoking. Lower reduction rates were measured for fine dust ($PM_{2.5}$) in the dining and drinking pubs. This is due to the fact that localised displacement reduced the concentrations of fine dust to such an extent that other sources of fine dust, such as clothing, and the supply of fine dust via the ventilation system become more relevant than tobacco smoke.

The above observation is confirmed by the results of a EU study conducted from 1992 to 1995. This study analysed the air quality (fine dust, CO and VOCs) in 56 office buildings. Comprehensive information on these office buildings was available, including whether they were smoking or non-smoking. No significant differences could be demonstrated between the smoking and non-smoking offices in any of the 56 buildings in terms of the concentrations of smoke-determining substances.

The reduction rates in Table 1 are in agreement with the predictions described in Attachment 2 to the RIVM/TNO report [1], which predicts a reduction rate of 92% based on a review of literature and a ventilation model. It is emphasized that these reduction rates apply to the situation without any physical separation between smokers and non-smokers. Reduction rates of higher than 99% are possible with a physical separation, e.g. in the form of a glass wall in a restaurant.

Costs

The original estimates given in the RIVM/TNO report [1] for the costs of the displacement ventilation system seem relatively high in relation to the three installed systems. Costs that ar lower, by a factor of 2, would seem more realistic.

Who should be protected?

This report shows possible solutions to reduce exposure to ETS in the hospitality industry. If the Occupational Health and Safety Act had been strictly complied with, creating a smoke-free zone around the servers would have been sufficient. However, from the perspective of general public health in the Netherlands, it makes more sense to seek to reduce exposure for servers and visitors. This is particularly true because visitors widely outnumber servers. This viewpoint has resulted in the following plans:

- In the drinking pub visitors and servers are protected;
- In the discotheque primarily the visitors on the dance floor are protected; and
- In the dining pub primarily the visitors under the downflow are protected.

In all three cases, the increased level of ventilation also has a positive effect on the exposure of servers.

How do we proceed from here?

This study shows that exposure to ETS in the hospitality industry can be reduced significantly. The question is: what reduction rates would be desirable from a human health viewpoint? Once a human health limit value is available, hospitality businesses will be able to take suitable ventilation measures or decide to ban smoking on their premises.

Contents

Appendices

1 Introduction

Basis

The hospitality industry is considering whether to ban smoking or take technical measures to minimise exposure to ETS. The Netherlands Institute for Public Health and the Environment (RIVM) and the Netherlands Organisation for Applied Scientific Research (TNO Building and Construction Research) have jointly issued a report [1] to the Dutch Ministry of Public Health, Welfare and Sports. This report indicates the possible reduction in ETS based on a review of literature, as well as a theoretical consideration by TNO Building and Construction Research.

British American Tobacco has commissioned a study into the effectiveness of the indicated ventilation measures in the day-to-day operations of three types of hospitality businesses:
- a pub not serving meals (drinking pub);
- a pub serving full meals (dining pub);
- a discotheque.

Approach

The study comprised the following activities:
1. Finding and determining three suitable locations (one of each type of hospitality business) that would permit the measures from the RIVM/TNO study to be achieved.
2. Preparing the report with recommendations for one of the three locations with regard to the installation, adjustments to the heating system, and any necessary structural adjustments.
3. Preparing a consideration of characteristic components in other socially accepted situations on the basis of a review of literature.
4. Examining and, if necessary, programming the installation to be provided by an external client.
5. Determining the rates of reduction in ETS achieved in each of the three types of hospitality businesses.
6. Analysing and detailing the measuring results.
7. Consultations and meetings.
8. Reporting.

The following substances and gases of relevance to ETS were considered:
- $PM_{2.5}$
- Nicotine
- 2.5 dimethylfurane
- Formaldehyde
- Benzene
- Toluene
- Styrene
- CO
- CO_2
- TVOC

2 Consideration of exposure to ETS in other socially accepted situations

2.1 Introduction

As general hypothesis could apply:

“Is there any proof that a significant difference exists between offices where smoking is allowed, and offices where it is not, as regards the concentrations of smoke-determining substances”.

The answer to this question was obtained by reviewing literature on the distribution of concentrations of substances that are characteristic of tobacco smoke in offices, specifically non-smoking offices.

Partly on the basis of a study by the Dutch Ministry for Housing, Regional Development and the Environment into the reduction of exposure to ETS in the hospitality industry by means of ventilation and air-cleaning [1], the review of literature involved a search for the most relevant substances and gases mentioned in this report.

Various literature databases, such as AIVC and IBSEDEX, as well as the TNO in-house literature and proceedings of conferences such as Healthy Buildings and Indoor Air, were searched for information in order to confirm the hypothesis made in the introduction.

2.2 Results of literature review

A thorough review yields a significant amount of information that provides insight into the concentrations of many of the substances that are also produced during smoking, but virtually none of the literature available to us provides any unequivocal information on whether the building is a smoking or non-smoking building. This general information does not provide the insight required to answer the question and to confirm or deny the assumption. However, TNO Building and Construction Research participated in a comprehensive EU study into the air quality in office buildings a few years ago (1992-1995) [3]. During the extensive measurements conducted in 56 office buildings in 9 countries as part of this study, each building was at least assessed as to whether smoking was allowed inside the building, or part of the building. The database with all data from that study was requested from the project management for that EU study. After some searching, it turned out that the database was still present and available for this review of literature. The database was subsequently edited and analysed in relation to the main aspects for this review of literature. The results detailed in this report have not been published before in this manner as the findings of the EU study.

2.2.1 Indexed buildings used in the EU study

Given below are some of the characteristics of the buildings in the database, in order to provide an impression of the types of buildings studied.

A summary of the main characteristics of the 56 office buildings studied is shown below.

The following characteristics were detailed:
- Location
- Floor area
- Number of floors
- Number of people
- Age categories
- Smoking or non-smoking

The location was differentiated as follows:
- Rural
- Suburban
- City centre
- Industrial area

The results are shown in Fig. 1.

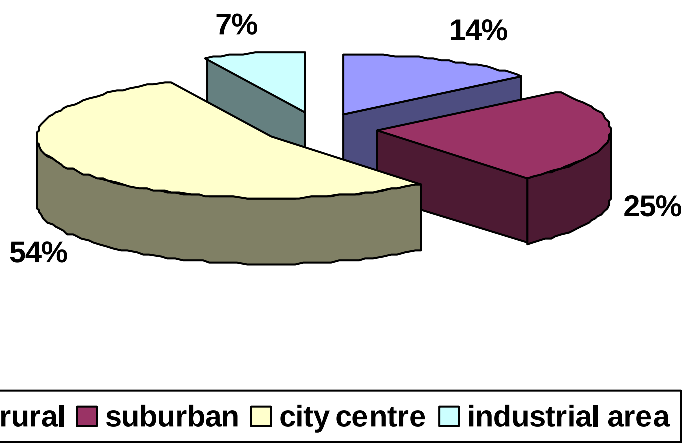


Figure 1: Relative distribution of buildings by locations

Most of the buildings are in urban areas. Buildings in rural and industrial areas account for approximately one-fifth of the indexed buildings.

The size of each building is characterised by the total floor area, the number of floors, and the number of people working there. The results of the floor area distribution are shown in Fig. 2.

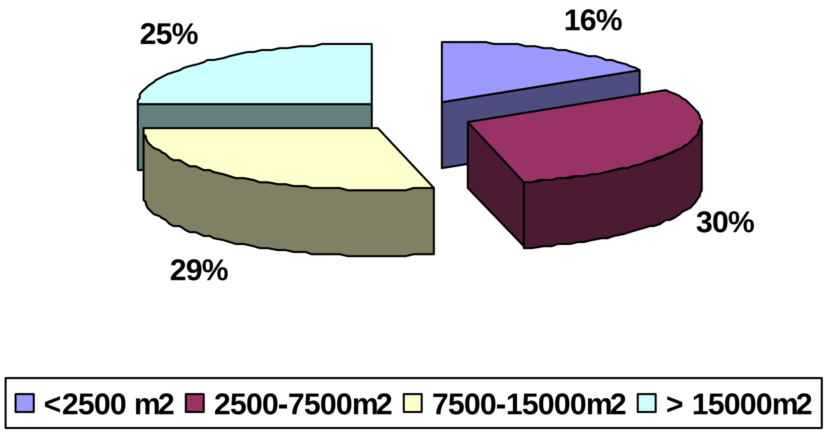


Figure 2: Relative distribution of buildings by floor area

The distribution by floor area is reasonably even for all categories selected.

The building height is characterised by the number of floors in the building. The results are shown in Fig. 3.

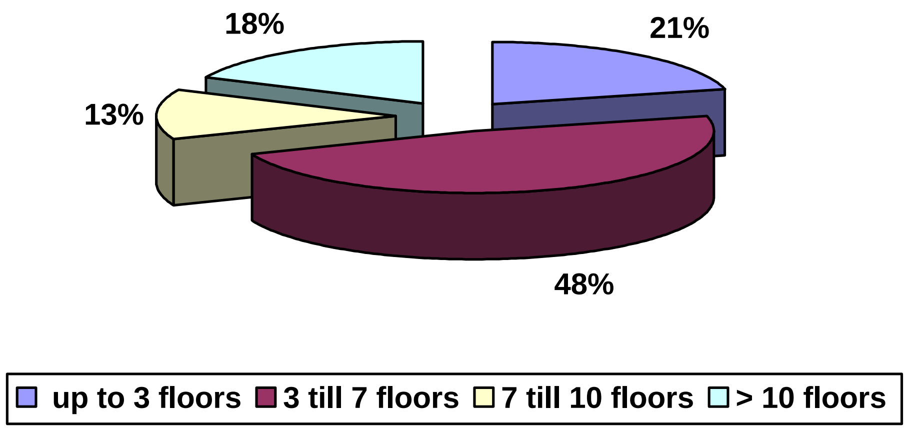


Figure 3: Relative distribution of buildings by the numbers of floors

More than three quarters of the office buildings have up to 7 floors.

The number of people working in each building is shown in Fig. 4.

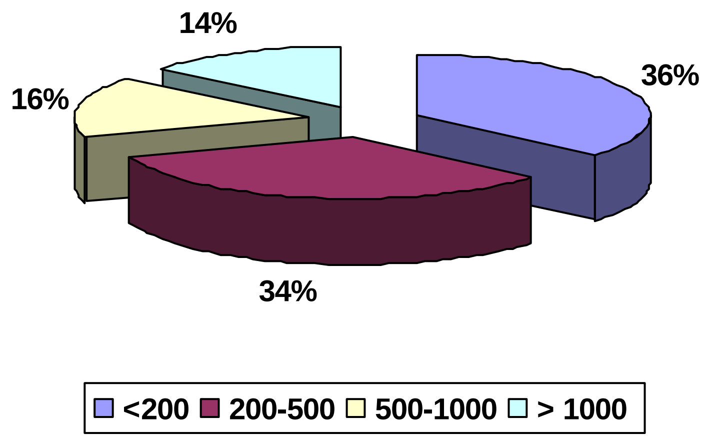


Figure 4: Relative distribution of buildings by the number of people

More than three quarters of the office buildings have fewer than 500 people.

The distribution of buildings by age category is shown in Fig. 5.

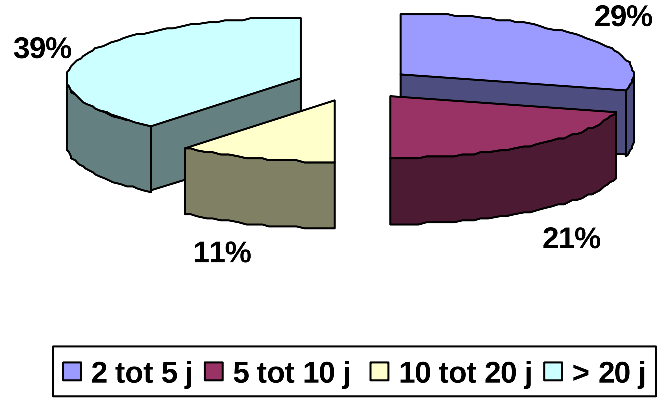


Figure 5: Relative distribution of buildings by age category

In each of the participating countries (Germany, Denmark, the UK, Greece, Norway, the Netherlands, France and Finland), six buildings were studied, except for Switzerland where eight buildings were studied.

Finally, and perhaps one of the main characteristics in relation to this review of literature: smoking. Three answers were possible for this category:

- Yes
- No
- In certain areas

The distribution of buildings by smoking category is shown in Fig. 6.

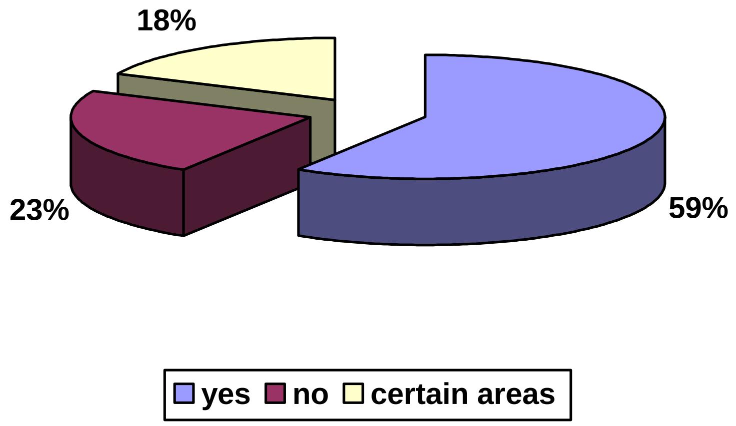


Figure 6: Relative distribution of buildings by smoking / non-smoking

The figure shows that of the 56 buildings studied, 10 do not permit smoking, 13 permit smoking only in certain areas, and 33 permit smoking throughout the building. No information is available on the extent to which people smoke. Although there is no evidence that these buildings are representative of all office buildings in Europe, it seems that the key variables of these buildings present a reasonably reliable image of office buildings as a whole.

2.2.2 *Variables research in EU study*

The EU study analysed the following variables that might be relevant to this review of literature:

- TVOC concentrations
- CO concentrations
- PM10 concentrations
- CO_2 concentrations
- Ventilation volume flows

In each building, the concentration measurements were carried out in two office areas and, in virtually all cases, in two adjacent spaces. Furthermore, all measurements were carried out in the supply air of the mechanically ventilated spaces. TVOC, CO and PM10 are substances that are definitely produced during smoking. CO_2 and ventilation flows are obviously more closely related to the ventilation of the building.

2.2.3 *Results of EU study*

Ventilation flows

Ventilation_average [m³/h]				
	Location			
Category	Ventilation	Adjacent1	Adjacent2	Infiltration
1	977	31	0	96
2	4812	37	6	335
3	532	68	6	29
0	100	0	0	2
Total	48	5	26	1151

Table 2: Ventilation flows

Categories:

1 not prohibited
2 smoking permitted in certain areas
3 smoking permitted
0 unknown or unclear

As long as the relationship between the flow rates and the number of people is basically unknown, these measuring results do not say much.

At the most, these measuring results might indicate that the infiltration rates are not evenly distributed across the various categories.

The CO_2 measuring results provide a better image of the ventilation and overall air quality.

CO_2 measuring results

CO2_average [ppm]				
	Location			
Category	Office	Supply air	Adjacent1	Adjacent2
1	608	421	592	-
2	724	494	667	593
3	712	473	666	643
0	671	484	708	-
Total	695	471	653	633

Table 3: CO_2 measuring results

Categories:

1 not prohibited
2 smoking permitted in certain areas
3 smoking permitted
0 unknown or unclear

The above figures clearly demonstrate that the ventilation of the buildings was generally quite sufficient. Concentrations in office spaces varying from approximately 600 to 700 ppm are normal for well-ventilated spaces. With an average outside air concentration of approximately 470 ppm entering the office space via the supply air, the CO_2 increase is only 220 ppm. The results for the adjacent spaces are comparable to those for the office spaces, as could be expected. It appears that in terms of CO_2 the air quality in buildings where smoking is not permitted is slightly better (the difference in ΔCO_2 being approximately 40 ppm).

CO measuring results

CO_average [ppm]				
	Location			
Category	Office	Supply air	Adjacent1	Adjacent2
1	1,1	1,0	1,4	-
2	1,2	1,0	1,7	3,2
3	0,5	0,2	0,5	0,0
0	0,9	0,5	0,9	-
Total	1,0	0,8	1,2	1,6

Table 4: CO measuring results

CO concentrations in office spaces are approximately 20% higher than in the supply air, and in the adjacent spaces they are more than 50% higher.

Categories:

1 not prohibited
2 smoking permitted in certain areas
3 smoking permitted
0 unknown or unclear

CO_stdev [ppm]				
	Location			
Category	Office	Supply air	Adjacent1	Adjacent2
1	0,6	0,7	0,7	-
2	2,2	2,1	3,2	-
3	0,5	0,3	1,0	-
0	0,5	0,1	0,0	-
Total	1,0	0,8	1,2	1,6

Table 5: CO-stdev in different locations

However, the distribution and variations between buildings are significant, as is evident from the table with the standard deviation. The absolute increase in CO in buildings where smoking is permitted is 0.25 ppm versus 0.1 ppm in buildings where smoking is not permitted.

PM10 measurment results

PM10_average [mg/m³]				
	Location			
Category	Office	Supply air	Adjacent1	Adjacent2
1	0,09	0,00	0,03	0,03
2	0,14	0,00	0,19	-
3	0,11	-	-	-
0	0,06	-	-	-
Totaal	0,12	0,00	0,09	0,03

Table 6: PM10 average measuring results

Categories:

1 not prohibited
2 smoking permitted in certain areas
3 smoking permitted
0 unknown or unclear

The PM10 concentrations in the supply air proved to be impossible to measure. Some interesting differences were found between dust concentrations in buildings where smoking is permitted (0.125 mg per cubic metre) and buildings where smoking is not permitted (0.09 mg per cubic metre). Dust concentrations in adjacent spaces of buildings where smoking is permitted were considerably higher than in office spaces where smoking is permitted. The reason for this is unclear.

TVOC measurement results

TVOC_average [mg/m³]				
	Location			
Category	Office	Supply air	Adjacent1	Adjacent2
1	0,43	0,19	0,39	0,34
2	0,36	0,22	0,40	0,44
3	0,28	0,14	0,38	0,28
0	0,13	0,05	0,03	-
Total	0,34	0,19	0,37	0,34

Table 7: TVOC measuring results

Categories:

1 not prohibited
2 smoking permitted in certain areas
3 smoking permitted
0 unknown or unclear

The increase in TVOC in relation to the supply air is the highest in buildings where smoking is not permitted. Not much else can be said with regard to the results for TVOC, except that there are considerable variations between the buildings and locations where the measurements were carried out. The amount of standard deviation is largely in agreement with the measuring result.

TVOC_stdev [mg/m³]				
	Locatie			
Categorie	Office	Supply air	Adjacent1	Adjacent2
1	0,48	0,10	0,21	0,10
2	0,39	0,23	0,41	0,20
3	0,24	0,09	0,30	0,25
0	0,11	0,01	0,01	-
Totaal	0,34	0,19	0,37	0,34

Table 8: TVOC_stdev measuring results

2.3 Conclusions based on EU study

The results of the EU study justify the conclusion that significant differences between buildings where smoking is permitted, and buildings where it is not permitted, probably exist only for PM10 (dust) and CO concentrations.

The study by TNO and RIVM [1] shows that the combination of 3-ethenylpyridine with nicotine and PM2.5 is probably the best marker for tobacco smoke, and that 2.5 dimethylfurane might be suitable as well. Measuring results with these variables are virtually impossible to find.

The available data indicates that CO and PM10 are not the most suitable markers for smoking. Nonetheless, clearly measurable differences were observed.

Variations between spaces and buildings are usually more significant than those between buildings where smoking is permitted and those where it is not permitted.

The review of literature has not produced any scientific foundations for the assumption described in the introduction:

“Is there any proof that a significant difference exists between offices where smoking is allowed, and offices where it is not, as regards the concentrations of smoke-determining substances?”

3 Ventilation principles

3.1 General

The RIVM/TNO report [1] describes the various ventilation principles and ETS reduction rates known from literature. The following chapters outline the following three principles:

- Dilution
- Displacement
- Localised ventilation

In addition, Chapter 3.5 examines a zoning system that can be deployed in combination with ventilation. A current overview of technologies can be found at: [2] www.tno.nl/ventilatie.

3.2 Dilution ventilation

In this context, dilution ventilation is defined as a ventilation system that supplies air into the space via induction grilles, with virtually complete mixing of the air occurring before the air is removed. A key characteristic of this technology is that the concentrations in the space are virtually the same throughout, except in the vicinity of the local source of pollution.

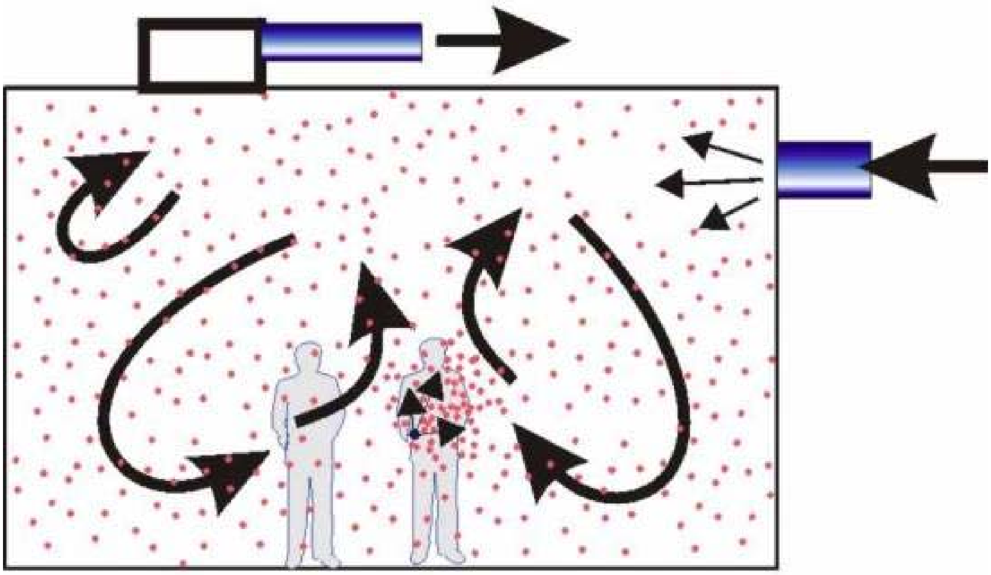
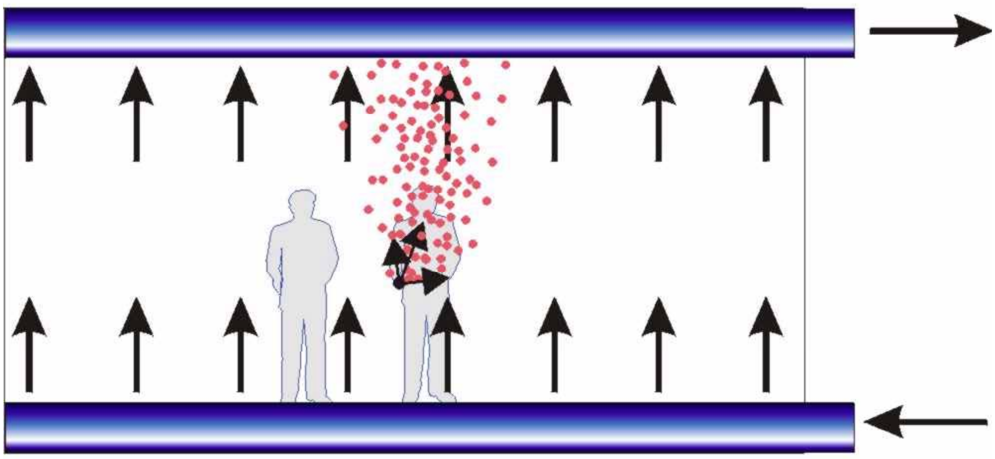


Figure 7: Schematic illustration of mixing and dilution.

3.3 Displacement ventilation

Displacement ventilation systems consist of an air supply system that is constructed in such a way that the mixing of supply air with ambient air is kept to a minimum. With displacement ventilation, the concentrations of substances in a space may vary significantly. Concentrations will be the highest near the source and along the flow path of the injected air between the source and the point of extraction, whereas concentrations along an adjacent path will be significantly lower. This means that a “dirty” zone and a “clean” zone may exist in a single space (smoking and non-smoking zones). A displacement ventilation system is designed and controlled so as to maintain a unidirectional airflow with a constant speed. Thus, the aim is to move the ventilating air through the space like a piston and thus displace pollutants. The effectiveness of displacement greatly depends on the height of the ventilation level.



Figuur 8: Schematische weergave van volledige verdringing.

3.4 Localised ventilation

The simplest method of localised ventilation is localised extraction near the source. Localised extraction aims to “catch” and remove pollutants as closely as possible to the source. In this way, the emissions into the respective space by the source are reduced. Another method of localised ventilation is a localised supply of clean air, in order to screen off the source. The most effective method of localised ventilation, however, is localised source extraction supported by air jets to screen off the source. A key characteristic prerequisite for localised ventilation is that a specific source of pollution should spread only to a limited area inside the space. For ETS, this means that smoking should be permitted only in specific areas, i.e. where a localised ventilation system is installed. Localised extraction must occur close to the source of pollution. With localised displacement, the supply air should be introduced in the clean-air zone. In general, however, the effectiveness of the extraction will greatly depend on the location and the volume of the extraction airflows.

Figure 9: Schematic illustration of localised extraction.

Localised displacement may occur as well.

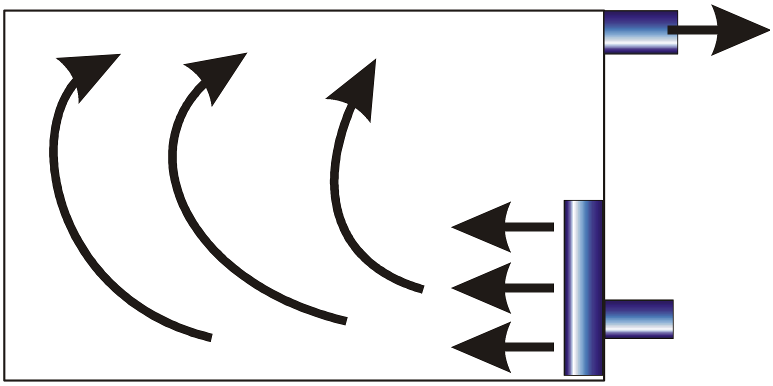


Figure 10: Schematic illustration of localised displacement.

3.5 Zoning

Zoning provides for a “clean” zone (e.g. non-smokers) and a “dirty” zone (e.g. smokers). Ventilating air is injected into the “clean” zone and extracted from the “dirty” zone. The intention is to secure, at the separation between the two zones, an airflow from the “clean” zone to the “dirty” zone in order to prevent the spreading of pollutants to the “clean” zone. For each zone, the ventilation system can be either a mixing system or a displacement system. With zoning, physical separation is an effective way to limit the flow-through surface (exchange surface) between the zones and thus improve the level of separation. Examples include serving hatches in counter areas, etc. Another possibility would be complete physical separation, e.g. in buildings with designated smoking areas.

4 Laboratory test

4.1 Objective

Two of the three selected hospitality businesses have chosen to create a smoke-free zone. The intention is to introduce displacement airflows from the ceiling at a height of 4 metres. The objective of the laboratory test is to determine the proper conditions (air velocity and under temperature) for achieving a sufficiently uniform flow profile whereby the air flows vertically down to the ground.

4.2 Setup

A box was created, of which the bottom has cloth (2.4 x 1.2 metres) stretched over it, as shown in Fig. 11. Air is blown into the box via a fan. The airflow and the temperature of the supply air can be regulated. The box is suspended from a hoist so that it can be suspended at different heights over the floor. Attached to the back of the box is a plastic sheet, which gives the effect of a wall. The experiments were conducted on 11 and 12 May 2005.

Figure 11: downflowbox in laboratory

4.3 Conclusions

The experiment with the downflow box demonstrates that a uniform velocity profile can be achieved with an airflow at 4 metres off the ground. The airflow temperature in relation to the room temperature proves to be more important than the velocity of the air stream. For example, with a supply air temperature slightly above the room temperature, an air stream velocity of 0.45 metres per second is insufficient to achieve a uniform velocity profile on the ground. However, a uniform velocity profile can be achieved with an undertemperature of approximately 1K and an air stream velocity of only 0.12 meters per second.

5 Discotheque

5.1 Description of the space

The discotheque that is the subject of this report is the Bump in Rotterdam. This 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 volume of the space is approximately 550 cubic metres. The entrance is marked by a curtain, as shown in Fig. 12. Two bars are located on the left-hand side when looking in from the entrance. The dance floor is located in the rear.

Figure 12: The entrance with the curtain and the first bar. The measuring point is visible in the back.

The space was originally ventilated by means of air supply units behind the two bars. The air flew out to the outdoors via the curtain and a staircase behind it.

5.2 Horizontal displacement ventilation system

The geometry of the space - an elongated box - was the reason for selecting a horizontal displacement system. The purpose of this system is to make the dance floor smoke-free. Outdoor air is supplied via a metal distribution grille behind the dance floor, as shown in Fig. 13. With a more than 80% open surface, the grille passage is too open and the distribution is therefore not ideal. The design value of the open surface was less than 50%. The design supply flow rate is 4.1 cubic metres per second. Ideally, i.e. with optimal distribution and no obstacles, the air travels from the air inlet by the dance floor to the curtain by the exit in a plunger-like fashion with a velocity of 0.23 metres per second. Any pollutants, e.g. cigarette smoke, are transported by the unidirectional airflow and therefore cannot reach the people on the dance floor.

Figure 13: metal air distribution grille at the end of the dance floor.

5.3 Measurement set-up and measuring conditions

The measurement was conducted during the night of 16 to 17 September 2005. The disco was open as usual that Friday night. Every five minutes during the measurement, the number of people smoking and the number of people present were counted. In order to clarify the spatial layout, the discotheque has been divided into three sections. The results of this registration are shown in Fig. 14. During the course of the night, visitors clearly shift from the exit towards the dance floor. On average, approximately 20—30% of the total number of people were found to be smoking at the same time,

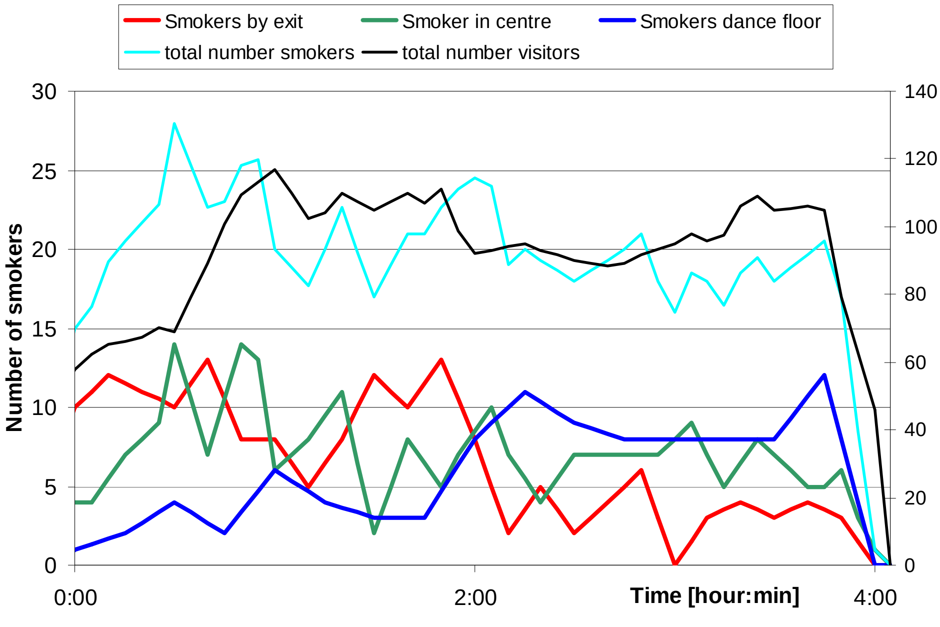


Figure 14: Number of smokers (left-hand axis) and number of visitors (right-hand axis).

The average ventilation flow rate during the measurement was 2.2 cubic metres per second (refer to Attachment C). Raising this to the design ventilation flow rate of 4.1 cubic metres per second proved to be impossible because of problems with pre-heating the air, since the disco was not yet connected to the district heating system.

The measuring points were in the following locations:

- At the end of the dance floor
- Between the two bars
- Immediately by the exit

These three points were sampled for fine dust ($PM_{2.5}$), Total Volatile Organic Compounds (TVOC) and aldehydes between 11.36 p.m. and 4 a.m. The measuring method is indicated in Attachment A.

In addition, two mobile measuring stations were present for $PM_{2.5}$ to determine whether geographical and/or time-dependent spreading occurs. For this purpose, the mobile measuring stations were used in the following two locations:

1) Between the bars, on both sides of the stationary measuring point (from 1.05 a.m. until 2.30 a.m.);
2) By the exit, on both sides of the stationary measuring point (from 2.45 a.m. until 4 a.m.).

In the later hours, most visitors were either on or by the dance floor, as shown in Fig. 15. There were a few instances where intoxicated visitors tried to blow cigarette smoke directly into the stationary measuring point that was present there. This may have caused an increase in the measured concentrations.

Figure 15: occupation of the dance floor during the late hours, with the outdoor air supply plenum visible in the left back corner.

5.4 Results

The results of the stationary measuring points are shown in Fig. 16. Concentrations clearly increase from the inlet by the dance floor towards the curtain by the exit. The displacement ventilation system reduces concentrations on the dance floor by approximately 80% compared to a mixing system with the same ventilation flow rate. No results are available for the mobile PM2.5 measurement carried out between the two bars due to a pump failure. The concentrations from the mobile PM2.5 measurement near the curtain (from 2.45 a.m. until 4 a.m.) are nearly identical, which indicates that the differences in latitudinal direction are insignificant. The values were nearly 20% below those from the corresponding stationary measurement during the entire night (397 mg per cubic metre). This agrees with the observation that the number of smokers in the later hours was below the average for the entire night. In addition, the injection flow rate in the later hours was also higher than the average for the entire night, as shown in Attachment C.

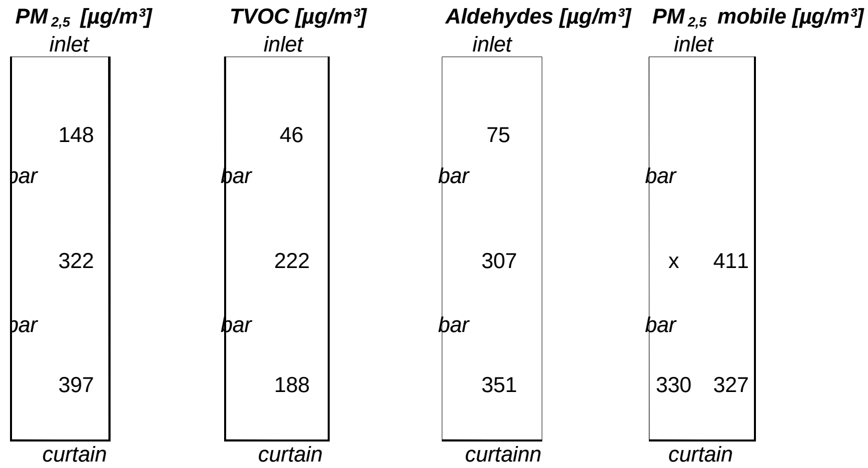


Figure 16: Aerial views of the discotheque with average concentrations for each measuring point.

5.5 Determining the reduction in relation to the original situation

The old ventilation system was partially converted and was in use before the new displacement ventilation system. The old system therefore could not be put back into operation and used during the same measurement in order to permit a comparison with the new system. For a comparison, however, it is assumed that the old system operated like a mixing system with a ventilation flow rate according to the Building Decree (an approximately six-fold increase in the ventilation rate: 0.9 cubic metres per second). The concentrations for this mixing system can be based on the outlet concentrations during the measurement of 16 September, with an adjustment (2.2/0.9) for the ventilation flow rate. The air change rate for a current disco is probably 3 ACH. Table 9 denotes this reference situation as “Mixing, current”. The concentrations for current mixing systems are a factor of two higher than those according to the Building Decree.

	Mixing current 3 ACH [µg/m³]	Mixing Building Decree 6 ACH [µg/m³]	**Exit measure-ment 16/9 [µg/m³]**	**Dance floor measure-ment 16/9 [µg/m³]**	Dance floor design [µg/m³]
$PM_{2,5}$	1940	970	**397**	**148**	80
TVOC	920	460	**188**	**46**	25
Aldehydes	1720	860	**351**	**75**	40

Table 9: measured concentrations (boldfaced) and calculated concentrations for two reference situations and with the design flow rate on the dance floor

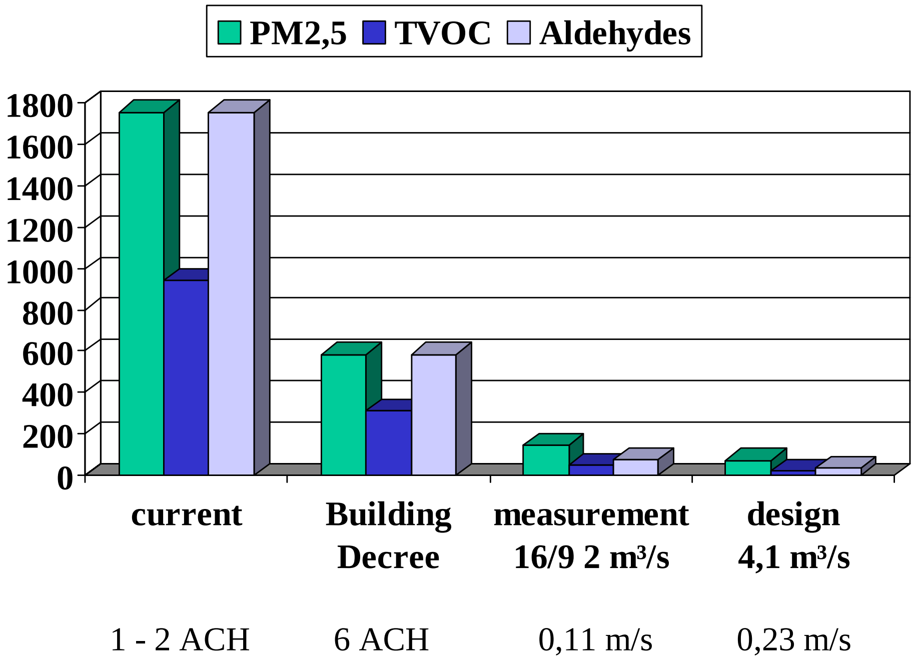


Figure 17: Concentrations on the dance floor - a comparison of measuring results of 16 September with situations according to the Building Decree, the current situation, and the design situation.

Fig. 17 illustrates a comparison between the calculated and measured concentrations for the two designs, i.e. mixing and displacement, with different ventilation flows. On the dance floor, the displacement ventilation system achieves a reduction of 85% for fine dust, of 90% for TVOC, and of 91% for aldehydes compared to the situation that the discotheque would have used a mixing system according to the Building Decree ventilation standard. Compared to a disco with a current ventilation system, the reduction rates are 92%, 95% and 96%, respectively. Now that the district heating system is in operation, ventilation with the design flow rate is possible. This was not possible at the time of the measurement. This would now permit theoretical reduction rates of 96%, 97% and 98% for the specified components when compared to the current ventilation systems used in discotheques.

5.6 Conclusion

The disco has a horizontal displacement ventilation system that protects smokers, non-smokers and staff on the dance floor. The measuring results show that a horizontal displacement ventilation system in the disco, even if used with only half the design flow rate, achieves a 90% reduction in exposure to ETS in comparison with ventilation systems according to the Building Decree standard. This reduction is achieved by two effects. Firstly, displacement ventilation delivers an approximately 80% reduction in concentrations on the dance floor when compared to a mixing system with the same ventilation flow rate. Secondly, the ventilation flow rate is increased in relation to the Building Decree. Compared to the current situation in discotheques, a 95% reduction is achieved on the dance floor of Bump.

6 Dining pub

6.1 Description of the space

Dudok, a dining pub in The Hague, consists of a large space of approximately 20 by 30 metres. Fresh outside air is supplied via the sidewall and over the bar area. The precise injection flow rate is unknown. An open kitchen along the sidewall has an extraction fan that removes the air. Design specifications indicate that 8,400 cubic metres of air per hour travel from the restaurant to the kitchen. If the exhaust system of the lavatories is included, the total ventilation flow rate should be approximately 10,000 cubic metres per hour.

Figure 18: The rear section of the dining pub, with the kitchen and its extraction fan visible in the back. This photograph was taken during the measurement at 7.40 p.m. The tables on the right are underneath the so-called downflow unit.

6.2 Design of vertical displacement ventilation system

A vertical displacement ventilation system was chosen due to the dimensions of the space. This system blows air downwards at low velocity—the so-called downflow concept, which is also used in operating rooms. In order to keep the necessary duct for the supply of outside air as short as possible, the decision was made to locate the smoke-free zone along the back wall. The height by this wall is approximately 4 meters. This situation was emulated in the laboratory in order to obtain reliable data with regard to the design parameters, such as the surface area, the type of exhaust cloth, the injection flow rate, and the injection temperature (refer to Chapter 3). An air-distribution box (plenum) consisting of three stainless-steel segments, each 1.8 by 2.5 metres, was selected for the dining pub. The total floor area of the smoke-free zone is 1.8 by 7.5 metres. For maintenance and possible cleaning, the cloth is stretched over the segments and fastened with Velcro, as shown in Fig. 19. The cloth has two purposes. Firstly, it evenly distributes the air. Secondly, it provides a decorative finish. The cloth is made of Trevira CS, a fireproof material, and meets the Building Decree requirements for ceiling and wall cladding for use in fireproof and smoke-free escape routes.

Figure 19: “down flow” cloth fastened with Velcro in segments of 0.6 by 0.6 metres.

6.3 Measurement set-up and measuring conditions

The measurement was conducted on Wednesday, 11 January 2006 between 6 p.m. and 9.30 p.m. During the measurement, the dining pub was open as usual. Three tables, each seating four persons, were placed underneath the downflow plenum. The injection flow rate was 0.19 metres per second. The distribution of the air over the segments was regulated with a so-called flow finder. The differences in air velocity between the various segments were less than 8%. The supply-air temperature was set to 20°C with a room temperature of approximately 22°C (refer to Attachment D). The number of people smoking and the total number of people present were counted at regular intervals throughout the measurement process, as shown in Table 10. These findings showed that only a small number of smokers were present.

Time	Below down flow	Near down flow	Near measuring points 4 and 5
17.20	0	0	45 (3)
18.10	4	2	35 (4)
18.25	9	0	43 (3)
19.03	9	12	38 (4)
19.40	5	14	51 (3)

20.00	3	12	40 (2)
20.30	3	27 (2)	36 (1)

Table 10: the number of people by segment, and the number of smokers in parentheses.

Instead of taking and analysing air samples, a so-called tracer gas was used to determine the reduction of gaseous components. This tracer gas was injected into the existing ventilation system of the dining pub in order to distribute this artificial pollutant over the space. The air was sampled in five locations at a height of approximately 1.2 metres, both for fine dust ($PM_{2.5}$) and tracer gas. The following measuring points were used, as shown in Fig. 20:

1) and 2) on both sides of the middle table underneath the downflow plenum
3) the serving cabinet near the downflow
4) the serving cabinet in the centre (fine dust only, not tracer gas)
5) the serving cabinet near the exit

The reduction in fine dust and gaseous components in ETS was determined by dividing the concentration of fine dust and tracer gas below the downflow plenum by the concentration of fine dust and tracer gas in the rest of the space.

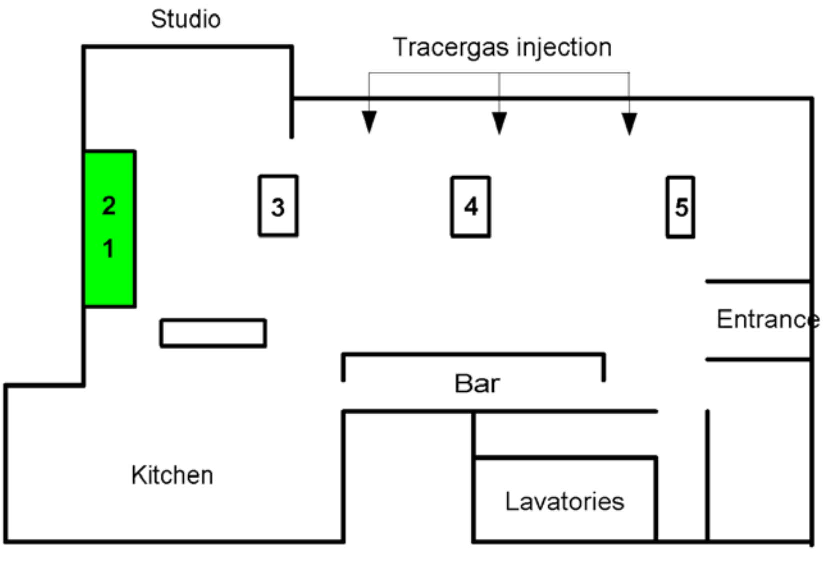


Figure 20: schematic layout of the dining pub with numbered measuring locations. The green area is the smoke-free zone.

Figure 21: a view of visitors seated below the downflow plenum and the adjacent partially screened-off section (photograph taken on 11 January at 7.40 p.m.). Measuring point no. 1 for fine dust is visible on the left.

The fine-dust measurements started at 7 p.m. and ended at 8.30 p.m.

Figure 22: table occupancy below the downflow plenum at the start of the experiment (7.03 p.m.).

6.4 Results

The complete results of the tracer gas test are listed in Attachment D. Fig. 23 illustrates the conclusion with regard to exposure. Based on the tracer gas test, a 90% reduction in exposure to ETS is expected to be achieved below the localised displacement ventilation system (downflow plenum) in relation to the rest of the space (measuring point 5).

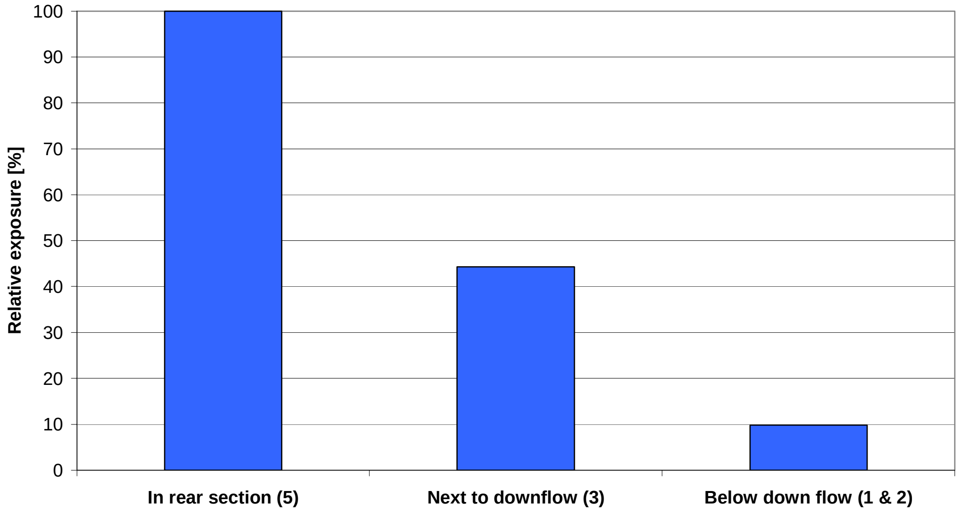


Figure 23: time-averaged exposure based on tracer gas test.

The results of the fine dust ($PM_{2.5}$) measurement are shown in Fig. 24. The concentrations are a factor of 10 lower than those measured in the discotheque. This can be explained by the smaller number of smokers in the dining pub and the higher degree of ventilation per person.

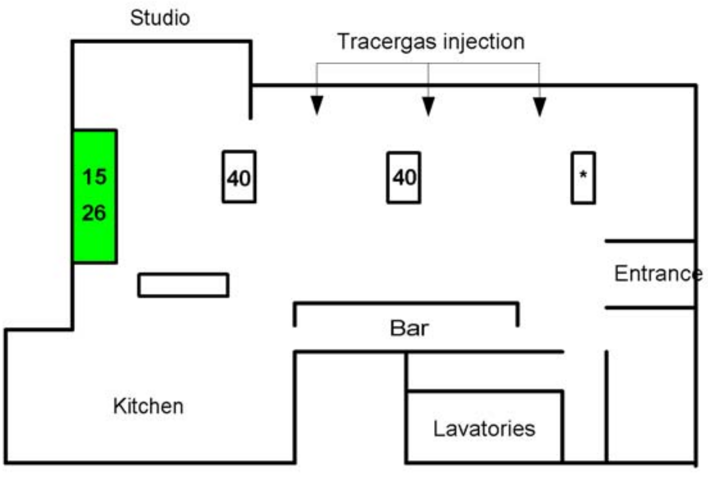


Figure 24: results for fine dust ($PM_{2.5}$) expressed in mg per cubic metre. Note: No results are available for measuring point 5 (*) due to a pump failure..

The concentrations of fine dust in the area below the downflow (indicated in green) are 50% of what they are in the rest of the pub. This small reduction in fine dust exposure when compared with the relative exposure based on the tracer gas test is probably caused by the background concentrations of fine dust in the outside air and by internal sources. With lower concentrations, fine dust is not an ETS-specific component. The outside air fine-dust concentrations are in agreement with those measured below the downflow. The filter in the air treatment unit will have an efficiency rate of 50—95% for dust particles of less than 2.5 mg. As a result, part of the dust present in the outside air, and ultra-fine dust in particular, is blown in via the downflow. Another factor with such relatively low concentrations are emissions of fine dust by people, especially from clothing.

6.5 Determining the reduction in relation to the original situation

The relative exposure in the localised displacement area is 10% in relation to the rest of the dining pub. Comparison of this exposure with exposure in the original situation requires some adjustment for the additional amount of ventilation that occurs. The available design specifications indicate that the original ventilation was approximately 2.8 cubic metres per second, which is in agreement with the Building Decree. The tracer gas measurement results in an estimate of 3.5 cubic metres per second, as shown in Attachment D. The downflow achieves an additional ventilation flow rate of 2.5 cubic metres per second. The exposure rate will therefore be reduced by a factor of (3.5+2.5)/3.5=1.7. Thus, the relative exposure below the localised displacement system is 10%/1.7=6%. Consequently, a reduction of approximately 94% was achieved in relation to the original situation. This is also evident from the graph in Attachment D. The air supply via the downflow was switched off at 8.25 p.m., after which air was supplied only via the conventional system. This caused the concentrations of tracer gas in the rear section of the space (measuring point 5) to increase to 25 ppm. Insufficient supplies of tracer gas necessitated premature discontinuation of the measurement so that the final concentrations could not be achieved. The measured concentrations are a factor of 18 higher than the concentrations at measuring point 1 while the downflow was in operation. This translates to a 94% reduction below the downflow in relation to the original situation.
On average, ventilation levels in Dutch dining pubs will be lower. In comparison with these lower ventilation levels, a reduction of approximately 98% is achieved.

6.6 Conclusion

In a limited area with displacement ventilation, the dining pub has achieved a 94% reduction in exposure to gaseous components present in ETS in relation to the original situation. This reduction is achieved by two effects. Firstly, displacement ventilation delivers an approximately 90% reduction in the localised displacement area. Secondly, the ventilation flow rate is increased in relation to the original situation. This reduces the concentrations throughout the dining pub and especially in the area next to the localised displacement system. The relative exposure to fine dust below the localised displacement system was 50% of the value in the rest of the space. The concentrations of fine dust in the localised displacement area are so low that fine dust from the outside air and from internal sources becomes relevant. In this situation, fine dust is not an ETS-specific component.

7 Drinking pub

7.1 Description of the place

De Witte Aap is a drinking pub in Rotterdam. The space has a width of 4.7 metres, a depth of 9.3 metres, and a height of 4 metres. Behind the entrance is an enclosed porch with an inside door. The bar is located about halfway down the sidewall. Left back is a small staircase leading up to the lavatories and a small kitchen. The original ventilation system consisted of a mechanical extraction in the centre of the pub and natural air supply through the cracks in the wall. This system had an estimated capacity of 600 to 1200 cubic metres per hour. The 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.

7.2 Design of vertical displacement ventilation system

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. This was the reason for locating the smoke-free zone over the bar, as shown in Fig. 25. The necessary air treatment unit is mounted below the ceiling in the back of the pub. The dimensions of this unit did not permit a downflow to be installed in this area as well. A plenum with dimensions of 4.7 by 4.5 metres was mounted below the ceiling over the bar section. The same type of air distribution cloth as in the dining pub was stapled to the timber frame. The cloth is made of the fireproof material Trevira CS and meets the Building Decree requirements for ceiling and wall cladding used in fireproof and smoke-free escape routes.

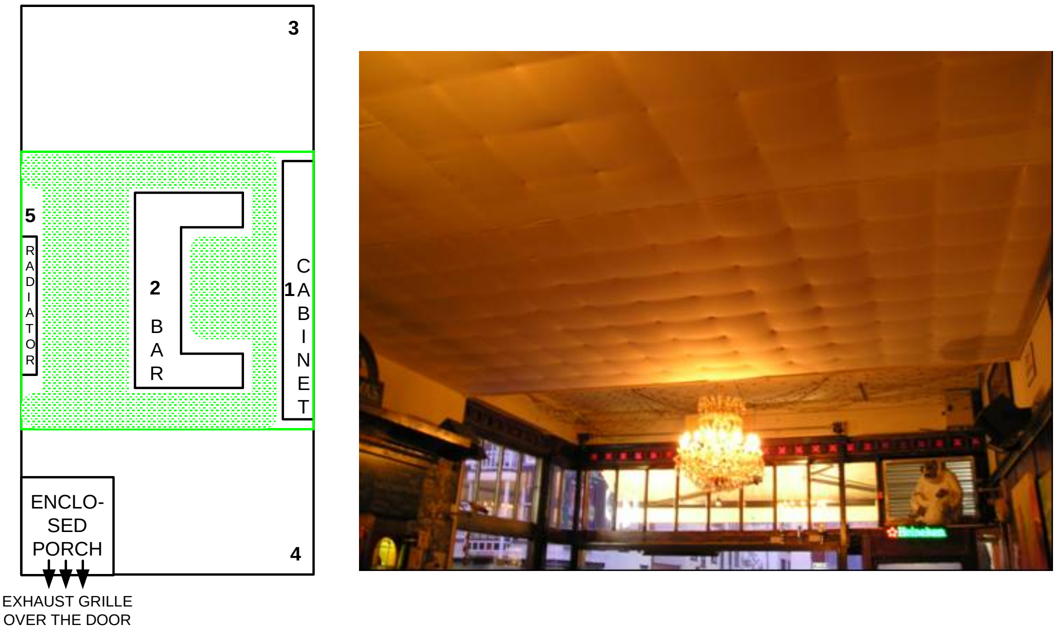


Figure 25: Left: layout of the drinking pub with the downflow plenum in the green area. Right: Ceiling-mounted plenum, photograph taken in the direction of the enclosed porch.

7.3 Measurement set-up and measuring conditions

The measurement was conducted on Wednesday, 25 January 2006, between 6 p.m. and 10.24 p.m. During the measurement, the pub was open as usual. The supply-air velocity was 0.09 metres per second. The air distribution over the segments was checked with a so-called flow finder on 23 January 2006, as shown in Attachment E. The supply-air velocity over the plenum varied from 0.06 to 0.12 metres per second, which is due to the presence of obstructions in the form of the original joisted ceiling in the plenum. The supply-air temperature was set to 20°C.

Figure 26: The number of visitors present during the measurement at around 10 p.m.

The number of people smoking and the total number of people present were counted at regular intervals throughout the measurement process, as shown in Table 3. On average, 11% of the visitors were found to be smoking at the same time.

Time	**Number of people**	**Number of smokers**
21.30	55	6
22.00	52	10
22.30	51	2
22.42	61	8
22.59	60	4
23.20	44	6
average	*54*	*6*

Table 11: The number of people and the number of smokers.

A so-called tracer gas was used to determine the reduction of gaseous components. This tracer gas was injected into the front wall of the pub, over the window, in order to distribute this artificial pollutant over the space. The air was sampled in five locations at a height of approximately 1.2 metres, both for fine dust ($PM_{2.5}$) and tracer gas. The following measuring points were used, as shown in Fig. 25:

1) below the downflow in the cabinet behind the bar
2) below the downflow at the front of the beer tap (tracer gas only)
3) in the corner at the rear
4) in the corner at the front
5) below the downflow next to the radiator at a height of 1.8 metres (fine dust only)

The reduction in fine dust and gaseous components in ETS can be determined by dividing the concentration of fine dust and tracer gas below the downflow plenum by the concentration of fine dust and tracer gas in the rest of the space.

7.4 Results

The complete results of the tracer gas test are listed in Attachment E. Fig. 27 illustrates the conclusion with regard to exposure. Based on the tracer gas test, an exposure to ETS of less than 10% is expected to be achieved, for the barman, in relation to the space next to the localised displacement ventilation system below the plenum. The positive effect of the downflow is partly evident from the report by the barman that his eyes are no longer irritated at the end of the shift since the system was put into operation. The relative exposure in the space at the rear (measuring point 3) was slightly above 10%. This low exposure rate is due to the measurement set-up that provided for the tracer gas to be introduced at the front. This rate is therefore only valid if there was no smoking in this area.

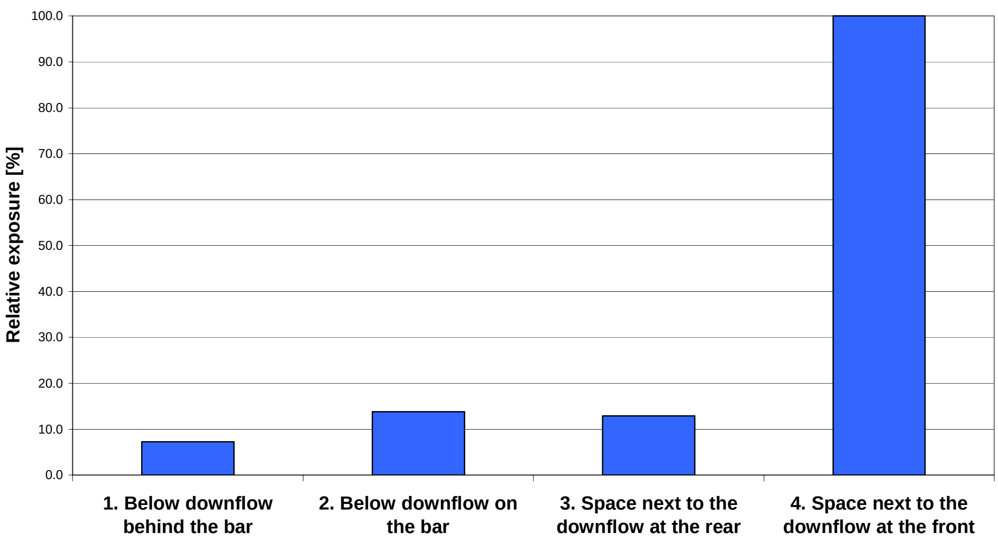


Figure 27: average exposure based on tracer gas test.

The results of the fine dust ($PM_{2.5}$) measurement are shown in Fig. 28. The concentrations are approximately a factor of two lower than those measured in the discotheque. This can be explained by the smaller number of smokers in the drinking pub and the higher degree of ventilation per person.
The difference in fine dust concentration between the area below the downflow (green) and on the front and rear of the drinking pub amounts a factor two till three.

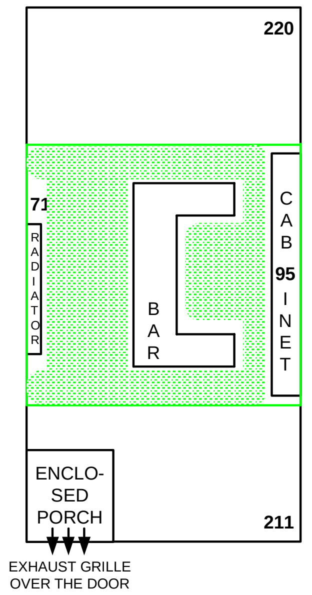


Figure 28: results for fine dust ($PM_{2.5}$) expressed in mg per cubic metre.

Based on the tracer gas test, a relative exposure to gaseous components in ETS of less than 10% in relation to the space next to the downflow (measuring point 4) is expected for the barman. The exposure to fine dust below the downflow is 33 to 45% in relation to the spaces next to the downflow (measuring points 3 and 4). This difference in relative exposure to fine dust and gaseous components is probably caused by the background concentrations of fine dust in the outside air and by internal sources of fine dust. The outside air fine-dust concentrations vary from 20 to 40 mg per cubic metre. The filter in the air treatment unit will have an efficiency rate of 50—95% for dust particles of less than 2.5 mg. As a result, part of the dust present in the outside air, and ultra-fine dust in particular, is blown in via the downflow. Another factor in the drinking pub are emissions of fine dust, e.g. from clothing. This justifies the conclusion that exposure to fine dust is only partly due to smoking.

7.5 Determining the reduction in relation to the original situation

The old ventilation system was completely replaced with the new localised displacement ventilation system. The old system therefore could not be put back into operation and used during the same measurement in order to permit a comparison with the new system. For a comparison, however, it is assumed that the old system operated like a mixing system with a Building Decree-compliant ventilation flow rate of 900 cubic metres per hour (0.25 cubic metres per second, 5 ACH). The concentrations for this mixing system can be based on the concentrations at measurement point 4 during the measurement of 25 January, with an adjustment (1.8/0.25) for the ventilation flow rate. The exposure rate in the original situation was 720% in relation to the exposure rate during the measurement. The localised reduction below the downflow is 98—99% in relation to the original situation. The reduction rate in current day-to-day operations of drinking pubs is estimated to be more than 99%.

7.6 Conclusion

The tracer gas test results justify the conclusion that the localised displacement ventilation system in the drinking pub delivers a 98 to 99% reduction in exposure to gaseous components in ETS in relation to the original situation. This reduction is achieved by two effects. Firstly, displacement ventilation delivers an approximately 90% reduction in the localised displacement area. Secondly, the ventilation flow rate is increased in relation to the original situation. This reduces the concentrations throughout the drinking pub. The positive effect is partly evident from the report by the barman that his eyes are no longer irritated at the end of the shift since the system was put into operation.

During the measurement, the exposure to fine dust below the downflow was 33 to 45% in relation to the space next to the downflow. The reduction in fine dust in relation to the original situation cannot be determined by means of calculation. This is due to the fact that fine dust emissions from clothing, etc., are starting to play a role due to the high occupancy rate. In addition, part of the fine dust originates from the outside air. This justifies the conclusion that exposure to fine dust is only partly due to smoking.

8 Considerations

8.1 Measuring accuracy

A direct comparison with the original situation was not possible in two of the three situations, since the original ventilation systems were no longer present at the time of measurement. Assumptions were made with regard to the original ventilation (efficiency) in order to still permit a comparison. Furthermore, it was assumed that the gaseous components primarily originate from ETS. Internal sources, such as the interior, are negligible. This assumption does not hold true for low concentrations of fine dust ($PM_{2.5}$). These are due to the fact that fine dust emissions from clothing, etc., start to play a role due to high occupancy rates. In addition, part of the fine dust will originate from the outside air. This is confirmed by the results of the EU study described in Chapter 2. A relevant question for a follow-up study within this context would be: “to what extent is exposure to fine dust caused by smoke, and to what extent by other sources?”

8.2 Who should be protected?

This report shows possible solutions to reduce exposure to ETS in the hospitality industry. If the Occupational Health and Safety Act had been strictly complied with, creating a smoke-free zone around the servers would have been sufficient. However, from the perspective of general public health in the Netherlands, it makes more sense to seek to reduce exposure for servers and visitors. This is particularly true because visitors widely outnumber servers. This viewpoint has resulted in the following plans:

- In the drinking pub visitors and servers are protected;
- In the discotheque primarily the visitors on the dance floor are protected; and
- In the dining pub primarily the visitors under the downflow are protected.

In all three cases, the increased level of ventilation also has a positive effect on the exposure of servers

8.3 Costs

The original estimates given in the RIVM/TNO report [1] seem relatively high in relation to the three installed systems. Costs that are a lower, by a factor of two, would seem more realistic.

8.4 How do we proceed from here?

This study shows that exposure to ETS in the hospitality industry can be reduced significantly. The question is: what reduction rates would be desirable from a human health viewpoint? In general, in the Netherlands, a death risk of one per million is considered acceptable as a basis. This approach has resulted in Maximum Acceptable Concentrations (MAC values) in industrial environments where the same potentially hazardous substances are handled. Such limit values could also be used for exposure to ETS. This would then permit hospitality businesses to take suitable ventilation measures or decide to ban smoking on their premises.

9 Conclusions

1. Conversion of ventilation systems, set-up of measurement situation
Three hospitality businesses each have successfully installed and put into use a displacement ventilation system. These businesses were:
- a pub not serving meals (drinking pub)
- a pub serving full meals (dining pub)
- a discotheque

The systems have been designed so that they meet the specific aesthetical, fire safety, robustness and comfort requirements for each specific hospitality businesses. This has resulted in three different plans based on the displacement ventilation principle.

The discotheque has a horizontal displacement system mounted in the sidewall that provides protection on the dance floor. No physical separation has been provided and smoking is permitted everywhere. In addition to fine dust ($PM_{2.5}$), measurements were conducted for volatile organic components (TVOC) and aldehydes. The other two hospitality businesses each have a localised displacement ventilation system installed below the ceiling. Air is blown from the ceiling of the eating pub and the drinking pub over a limited surface area of 14 and 21 square metres, respectively. Compartmentalisation is achieved by this directed airflow without any physical separation. Smoking was permitted in this whole area as well. A tracer gas was used instead of TVOC and aldehyde to determine the reduction of gaseous components.

2. Measured reductions
Reduction is achieved in two manners. Firstly, a reduction of 80 to 90% in relation to a reference point in the rest of the space is achieved locally in the area around the displacement ventilation system. Secondly, the displacement ventilation system provides additional ventilation in relation to the existing situation so that concentrations at the reference point drop proportionally.

	Reduction (%) in relation to ventilation according to the Building Decree	Reduction (%) in relation to ventilation in the current situation
Discotheque	90*	95*
Dining pub	94	98
Drinking pub	98	99

*Smokers and non-smokers mixed in the protected area

Table 12: measured reductions

The results in the table show the exposure reduction rates of gaseous and solid components in a situation where ETS is the main source of these components. This situation existed in the discotheque, for example, where a relatively high number of people were smoking. Lower reduction rates were measured for fine dust ($PM_{2.5}$) in the dining and drinking pubs. This is due to the fact that localised displacement reduced the concentrations of fine dust to such an extent that other sources of fine dust, such as clothing, and the supply of fine dust via the ventilation system have become more relevant than tobacco smoke.

The above observation is confirmed by the results of a EU study conducted from 1992 to 1995. This study analysed the air quality (fine dust, CO and VOCs) in 56 office buildings. Comprehensive information on these office buildings was available, including whether or not smoking was permitted in the buildings. No significant differences could be demonstrated between the smoking and non-smoking offices in any of the 56 buildings in terms of the concentrations of smoke-determining substances.

The reduction rates in table 12 are in agreement with the predictions described in Attachment 2 to the RIVM/TNO report [1], which predicts a reduction rate of 92% based on a review of literature and a ventilation model. It is emphasized that these reduction rates apply to the situation without any physical separation between smokers and non-smokers. Reduction rates of higher than 99% are possible with a physical separation, e.g. in the form of a glass wall in a restaurant.

3. Costs

The original estimates given in the RIVM/TNO report [1] for the costs of the displacement ventilation system seem relatively high in relation to the three installed systems. Costs that are a lower, by a factor of two, would seem more realistic.

4. Who should be protected?

This report shows possible solutions to reduce exposure to ETS in the hospitality industry. If the Occupational Health and Safety Act had been strictly complied with, creating a smoke-free zone around the servers would have been sufficient. However, from the perspective of general public health in the Netherlands, it makes more sense to seek to reduce exposure for servers and visitors. This is particularly true because visitors widely outnumber servers. This viewpoint has resulted in the following plans:

- In the drinking pub visitors and servers are protected;
- In the discotheque primarily the visitors on the dance floor are protected; and
- In the dining pub primarily the visitors under the downflow are protected.

In all three cases, the increased level of ventilation also has a positive effect on the exposure of servers.

5. How do we proceed from here?

This study shows that exposure to ETS in the hospitality industry can be reduced significantly. The question is: what reduction rates would be desirable from a human health viewpoint? Once such a human health limit value is available, hospitality businesses will be able to take suitable ventilation measures or decide to ban smoking on their premises.

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Indoor Air 1996: 6: 221-238
ISSN 09095-6947

10 Justification

Name and adress of the client:
British American Tobacco
dhr. T. Werkhoven

Name and function of the project co-workers:
Ing. W.F. de Gids
Ir. P. Jacobs
Ing. P. de Jong

Date of investigation:
February 2006

Signing:	Approved by:
Ing. W. F. de Gids Projectleader Gezondheid	Ir. W.A. Borsboom Manager Indoor Environment and Health

A Glossary

ACH	Air Changes Hour, i.e. the number of times per hour that spatial air is refreshed
Flow rate	Volume flow per hour or per second
Downflow	Vertical displacement system where air flows down from the ceiling
$PM_{2.5}$	Fine dust particle with a diameter smaller than 2.5 μm
PM_{10}	Fine dust particle with a diameter smaller than 10 μm
ppm	Parts Per Million, i.e. 1 ppm is equivalent to 1 cubic centimetre per cubic metre; 10,000 ppm is equivalent to 1 volume percent
μg	One millionth of a gramme
VOC	Volatile Organic Compounds, a category of hydrocarbon compounds
TVOC	Total amount of VOC

B Analytical measurement methods

Measurements were conducted for aldehydes, Volatile Organic Compounds (VOC) and nicotine in order to assess the air quality. Measurements were conducted also for $PM_{2.5}$ fine dust.

Tenax adsorption tubes were used for VOC sampling, DNPH cartridges for aldehydes, and XAD-2 cartridges for nicotine. 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 all components during all stages of the study. The concentrations from this sample, which was not opened, were subtracted from the measured value.

VOC
Tenax TA adsorption tubes were used for VOC sampling. After sampling, the adsorption tubes were thermally desorbed by means of Perkin Elmer Turbomatrix. The desorbed components were analysed on-line by means of a HP 6890 gas chromatographer equipped with a non-polar column and coupled to a HP 5793 mass spectrometer. Components were identified on the basis of retention time and comparison of mass spectra with mass spectra from a NIST database. The content of the analysed components was calculated on the basis of an external standard.

Aldehydes
DNPH cartridges were used for aldehyde sampling. Airborne aldehydes react with DNPH to form hydrazone. The formed hydrazone was subsequently identified by means of HPLC/UV and quantified on the basis of an external calibration standard.

Nicotine
OSHA versatile samplers with XAD-2 were used for nicotine sampling. After sampling, the samplers were desorbed. The obtained extract was subsequently analysed by means of GC-MS. Components were identified on the basis of retention time and comparison of mass spectra with mass spectra from a NIST database. The content of the analysed components was calculated on the basis of an external standard.

The test was carried out in accordance with the standard quality system of TNO Built Environment and Geosciences, which meets ISO-9001.

C Discotheque

Flowrates during measurement:

Time	Pressure after fan [Pa]	Flowrate [m^3/s]
Until 11.15 p.m.	260	1,5
From 11.15 p.m. until 11.35 p.m.	370	1,8
From 11.35 p.m. until 0.05 a.m.	550	**2,2**
From 0.05 a.m. until 1.15 a.m.	400	**1,9**
From 1.15 a.m. until 2.15 a.m.	550	**2,2**
From 2.15 a.m. until 4 a.m.	620	**2,3**
Average 11.35 p.m. until 4 a.m.		***2,16***

Table 13: flowrate

CO en CO_2 concentrations measured by the exit:

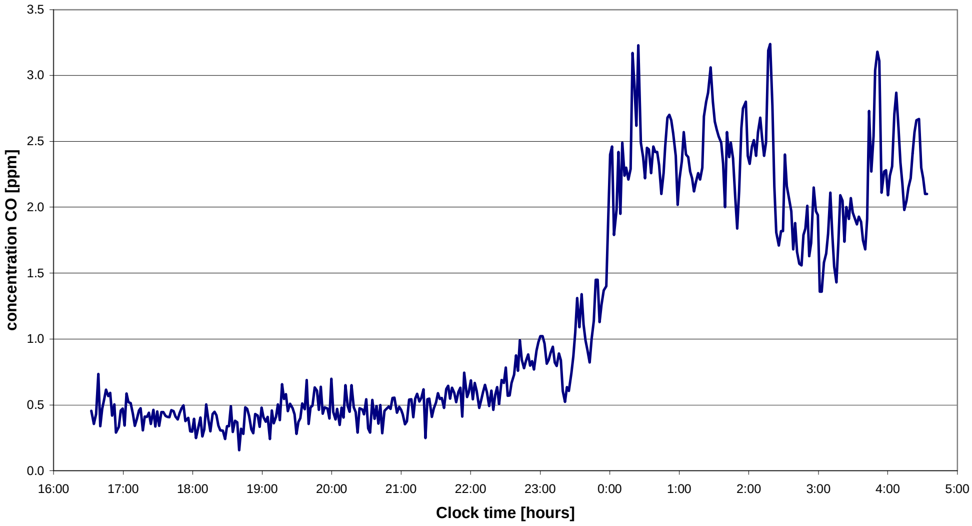

Figure 29: CO concentrations

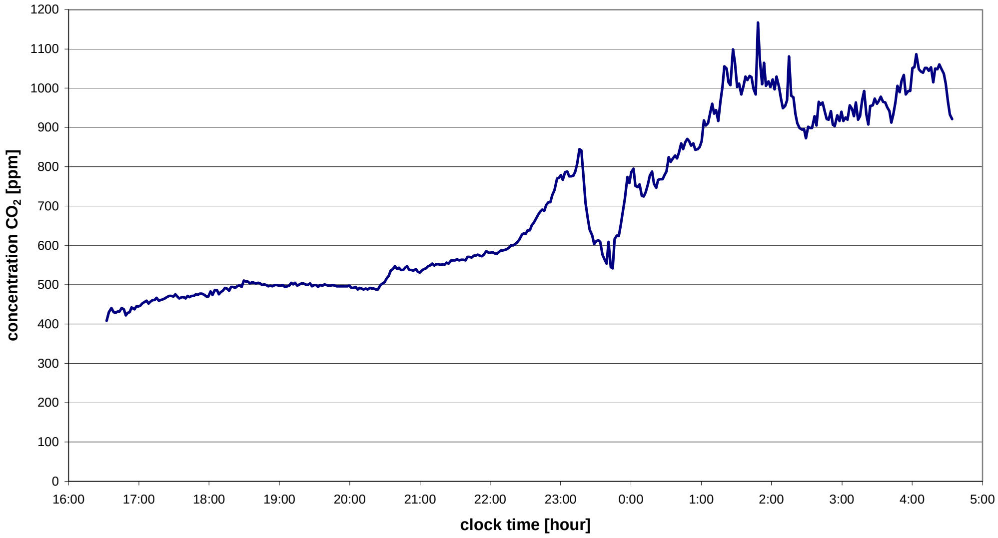

Figure 30: CO_2 concentration

CO_2 concentrations exceeding 1,200 ppm indicate an insufficient level of ventilation.

D Dining pub

Schedule used:

Tracer gas ON: 6 p.m., 20 cubic decimetres per minute SF_6
Downflow unit OFF: 8.25 p.m.
Tracer gas OFF: 9 p.m.

Measuring instruments used:

B&K 1302 and B&K 1303 (monitoring)

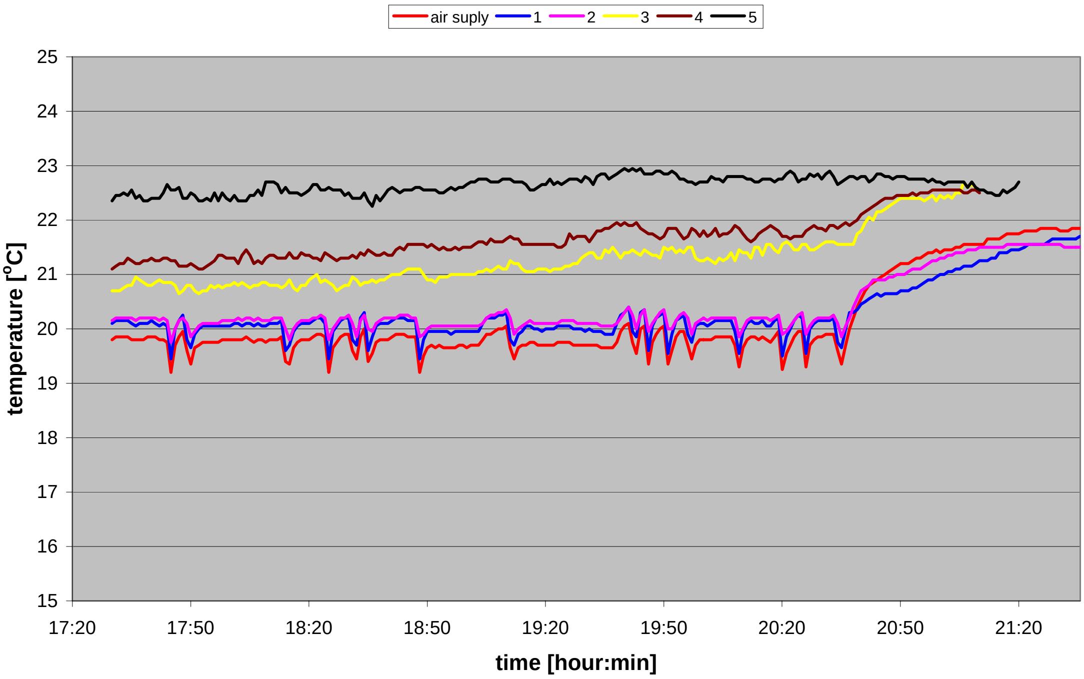

Figure 31: injection temperature at downflow and temperature at measuring points in the space (for numbers, refer to Fig. 20)

	Supply	1	2	3	4	5
Average	19,75	20,03	20,13	21,1	21,5	22,6
Minimum	19,2	19,5	19,8	20,7	21,1	22,3
Maximum	20,1	20,4	20,4	21,6	22,0	23,0

Table 13: temperature measured at the measurement points (numbering see figure 20)

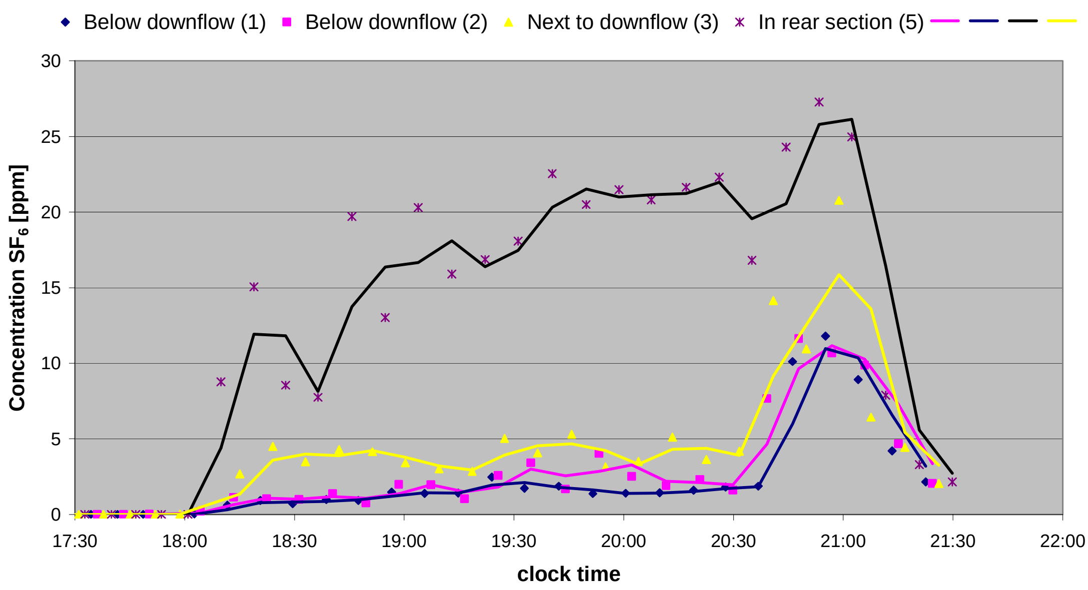

Figure 32: Concentration SF6 (ppm)

Estimation of ventilation rates of conventional ventilation system

Mass balance results in the following formula for the reduction in tracer-gas concentrations in time:

$$C_t = C_o \cdot e^{-(\frac{t \cdot q}{V})}$$

C_t concentration after t seconds [ppm]
C_o initial concentration [ppm]
Q ventilation flowrate [m^3/s]
V space volume [m^3]

The supply was turned off via the downflow at 8.25 p.m., after which air was supplied only via the conventional system. The tracer gas supply was turned off at 9 p.m. After half an hour (1,800 s) the concentrations at the measuring points had decreased by an average factor of eight. Using the formula, this results in a ventilation flow rate of 3.5 cubic metres per second. The air in the space is refreshed 4.2 times per hour with this flow rate (4.2 ACH).

Analysis of causes of disturbance of the downflow.
The operation of the downflow can be disturbed by the following causes:
- Walking movements by waiters
- Induction of spatial air
- Fluctuations in temperature
- Draught

Walking movements
Walking movements by waiters and visitors have a disturbing effect on displacement ventilation. The number of movements was registered during the measurement, as shown in the following figure. The number of movements was relatively high in the

early evening because all three tables were occupied. The visitors occupying the outer tables then left between 7.30 p.m. and 8 p.m.. The number of walking movements then dropped—until shortly before 9 p.m. when the waiter came to clear and clean all of the tables.

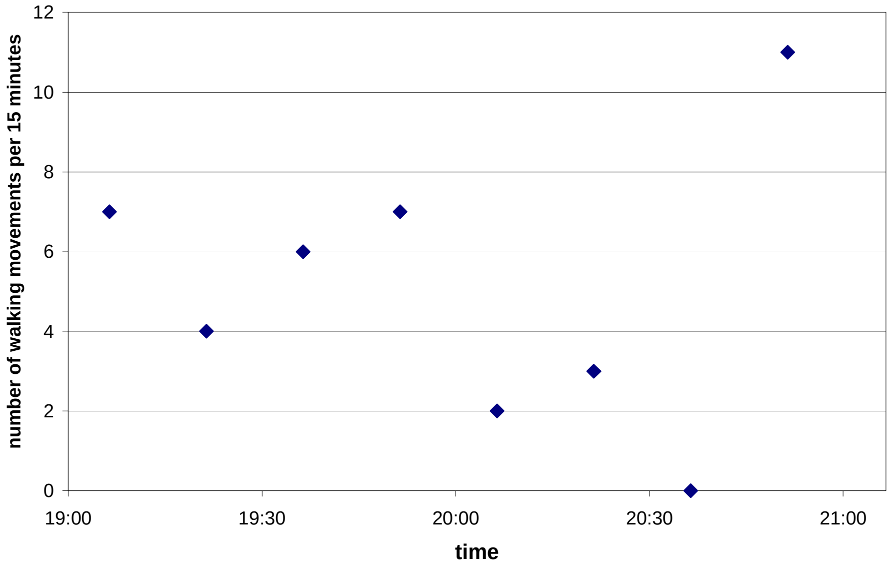

Figure 33: number of walking movements per 15 minutes

Seven walking movements per 15 minutes is equivalent to 28 per hour. With each walking movement, air is dragged along in the wake of the walking person. The amount depends on the person's posture and walking speed. The average amount of dragged air per walking movement is 0.5 cubic metres, which is equivalent to 14 cubic metres per hour. An amount of 9,330 cubic meters per hour is supplied via the downflow. The possible disturbance due to walking movements is 0.15% max. Walking movements therefore have no significant effect on the reduction rates.

Induction of spatial air
The exhaust on the outside of the injection plenum causes spatial air to be sucked in and mixed with the injected air. The concentrations of pollutants directly depend on the amount of air sucked in.

Fluctuations in temperature
The downflow plenum works perfectly as long as the injection temperature is 1 to 2 K (°C) lower than the spatial temperature. As soon as isotherm is injected, the conditioned outside air will flow away sideways and thus not reach the people. The temperature registration (refer to Attachment D) shows that the injection temperature continuously remained at least 0.8 K below the spatial temperature. Based on these findings, it is expected that the injected air will reach the ground.

Draught
Open doors may cause air movements that disturb the downflow. One open door to the studio may have had a negative effect..

E Drinking pub

The following figure provides an aerial view of the plenum, showing the exhaust velocity in metres per second. The bold lines indicate the locations of the joists. The joists occupy approximately half the 40 cm height of the plenum. As a result, the joists cause a slight upward pressure on the side of the injection unit.

air supply

0.058	0.072	0.065	0.079
0.079	0.094	0.058	0.043
0.101	0.122	0.108	0.108
0.115	0.101	0.101	0.101

door

Figure 34: aerial view of air supply plenum with air velocities in [m/s]

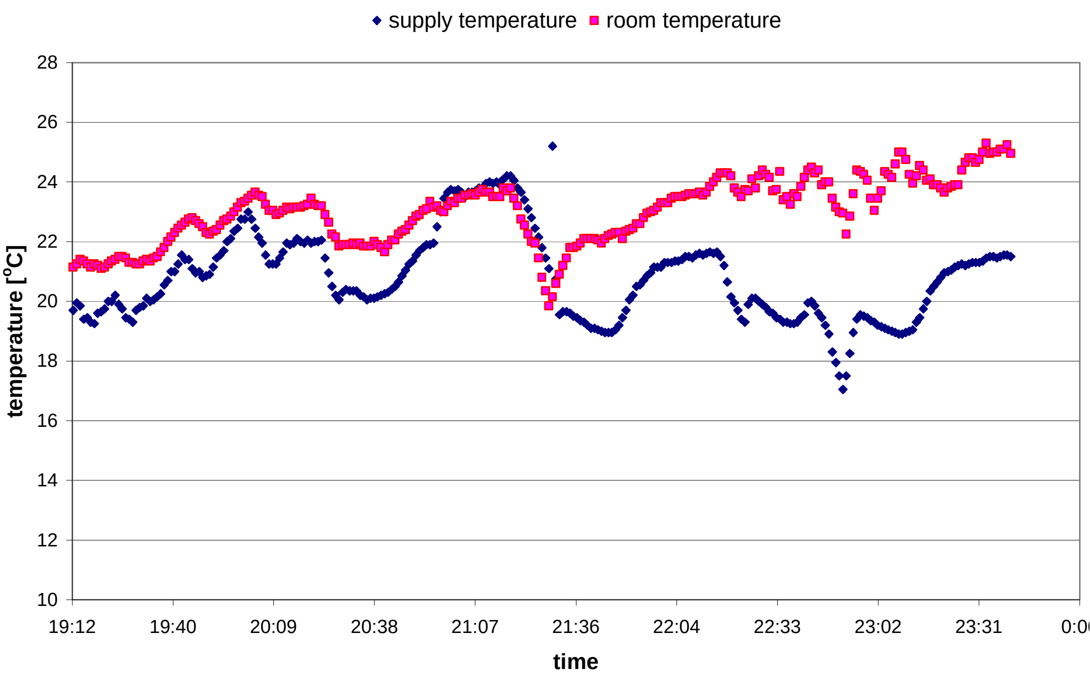

Figure 35: temperature of supply air and spatial temperature during the night

Period from 20.20 - 23.30 h	Air supply temperature	Room temperature
Gemiddelde	20.7	23.2
Minimum	17.1	19.9
Maximum	25.2	25.0

Figure 14: air suppy and room temperature during measurement

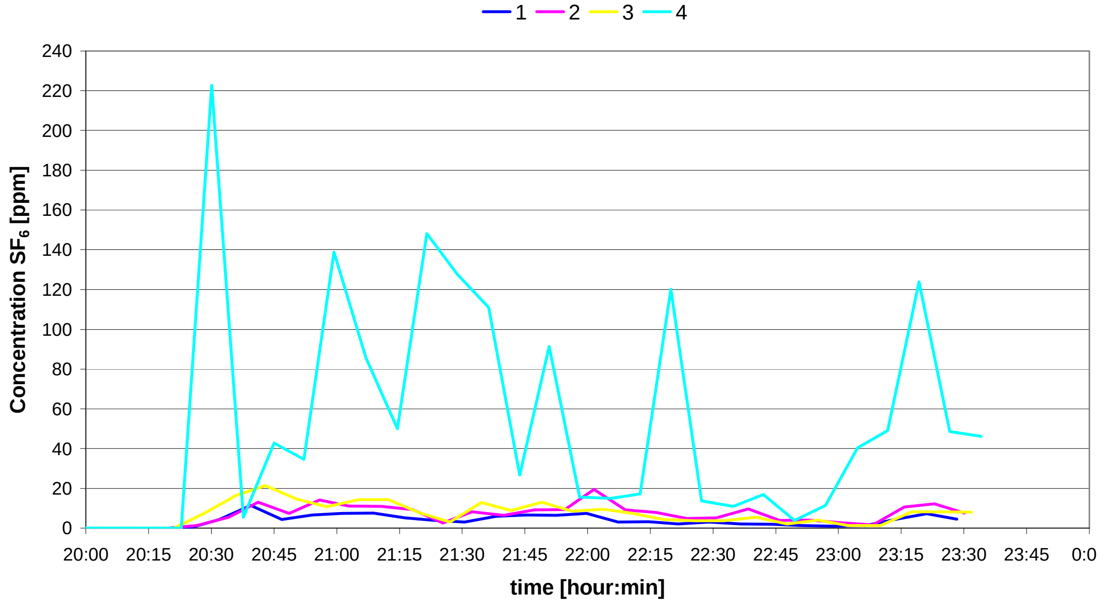

Figure 40: tracergas measurement data: