Ventilation and Smoking – Reducing the exposure to ETS in buildings[1] The REHVA Guidebook no.4

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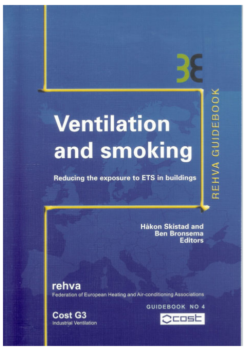
1. INTRODUCTION

REHVA is a 40 year old association of European societies in the field of HVAC and other building services. REHVA represents more than 100.000 experts from 30 European countries. REHVA´s main activity is to develop and disseminate economical, energy efficient and healthy technology for building services.

The topic of the guidebook on ventilation and environmental tobacco smoke (ETS) is extremely important in respect of indoor air quality, health and energy consumption. REHVA realises that the best protection against the environmental tobacco smoke is to restrict the smoking indoors. But if the smoking is allowed indoors, like it is in many countries, ventilation can be effectively used to reduce the exposure to ETS. The purpose of this guidebook is present the state-of-the-art technology of controlling ETS indoors. The guidebook presents latest ventilation technology and illustrates the use of the technology with several practical examples for application. The book is intended for the designers, installers, architects and building owner.



The REHVA Guidebook “Ventilation and Smoking” was presented at the international CLIMA 2005 conference in Lausanne, September 2005. As a part of this conference REHVA organised 15 workshops, one of which was dedicated to “Ventilation for reducing exposure to ETS”. A summary of this workshop was recently published. (Seppanen and Skistad 2005).

Translation of the book in other languages is appreciated. Refer to REHVA for conditions. (www.rehva.com)

As this paper reflects the contents of the guidebook only very briefly, it is strongly recommended to read the full text of the guidebook for use in the HVAC practice.

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[1] Paper based upon the guidebook. The author extends his gratitude to his co-editor and all co-authors

2. CONTENTS OF THE GUIDEBOOK

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3. ENVIRONMENTAL TOBACCO SMOKE (ETS)

Environmental tobacco smoke consists firstly of the mainstream[2] smoke that the smoker exhales after each puff, and secondly of smoke directly introduced into the room[3] by the cigarette, cigar or pipe. The higher burning temperature of the tobacco during inhalation means that the mainstream smoke is generated by more complete combustion than for side stream smoke. Some of the combustion products of the mainstream smoke do not end up in the environment because they are deposited in the human body. Side stream smoke therefore contains a higher level of harmful components than mainstream smoke.

ETS is a complex mixture of several thousand components, both gaseous substances, droplets and microscopic particles, which together have an addictive and irritating, poisonous and carcinogenic effect. Statistics which are widely reported and published by the tobacco industry relate to the “tar”, nicotine and carbon monoxide levels of cigarettes as measured in mainstream smoke by use of smoking machines. Nicotine is the addictive component; its content in various brands and makes of cigarettes can vary over a range of 0.1 to 2.0 mg per cigarette, with an average of approx. 0,9 mg. The “tar” content varies from 1.0 to 25 mg per cigarette, with an average of appr. 12 mg. (Federal Trade Commission 2000)[4]. It is broadly true that cigarettes with a higher nicotine content also contain more tar.

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[2] The mainstream is the inhaled smoke.
[3] Usually termed side stream smoke.
[4] Sales weighted yields based on U.S. cigarette consumption. Russian data show slightly higher figures.

"Tar" and nicotine ratings are not intended to reflect what any individual consumer would get from any particular cigarette. This depends mainly on how he or she smokes it. Smokers of cigarette brands with lower "tar" and nicotine ratings who take larger or more frequent puffs may get as much "tar" and nicotine as smokers of higher rated brands. (Federal Trade Commission 2000).

Many of the components of the mixture of ETS also occur in the environmental air due to emission from other sources such as industry, traffic and interior materials. Nicotine and its by-product 3-EP, on the other hand, is released solely by the combustion of tobacco and is therefore unique to ETS. That is why the nicotine and 3-EP concentrations in the air are good practical indicators for air quality protective measures and air quality. ISO has set standards for the measuring methods of ETS (ISO 2002).

Determining the nicotine concentration in air can at present only be carried out by collecting air samples and analyzing them in a laboratory, It is therefore a time consuming procedure. Further research is needed for the design of a simple measuring device for practical applications, preferably one which can operate online. This would bring demand controlled ventilation (DCV) systems within the realms of possibility. A very promising innovation is a new design particle counter, developed by Philips, calibrated for ultra fine particles PM0,5.

4. HEALTH EFFECTS

When non-smokers are exposed to ETS, they not only experience odour nuisance, but may suffer from an increased rate of other nuisances as well, like eye -, nose – and throat irritations. In addition, exposure to tobacco smoke can lead to acute asthmatic outbursts in people with asthma and e.g. acute cardiac infarctions in heart patients. A long-term exposure to ETS even causes a risk at the development of bronchitis, pneumonia, lung cancer and heart and vascular disorder. Furthermore, some people may develop an increased sensitivity to ETS, where even very short exposure results in complaints such as shortness of breath, coughing, skin irritations and other physical responses.

It is obvious that tobacco smoking is harmful to the human health. Risking this harmful effects of smoking is a matter of personal responsibility. But smoking also effects non smokers. It is for this reason that REHVA has compiled this Guidebook. The guidebook should be useful for a majority of European countries. Therefore the editors have assembled all the technical measures that can be used for the reduction of ETS in buildings, without going into the details of laws and regulations in the various European countries.

5. REDUCING THE EXPOSURE TO ETS BY VENTILATION

The guidebook 'Ventilation and Smoking' is intended to provide guidance to reduce the exposure to Environmental Tobacco Smoke (ETS) indoor. The authors and editors of the book do not mean to interfere in the discussion of permission against prohibition of tobacco smoking in general. Nor do they claim that ventilation can guarantee 100% uncontaminated air when sources of pollutants are present.

The first priority in the control of air quality is always to remove the source of pollutants. I.e., when it comes to ensuring good air quality nothing can compare with prohibiting smoking. The book is purely an HVAC technical guide to aid in the “design of spaces where smoking occurs”. It is not claimed that ventilation can secure the same air quality as in a completely non-smoking environment.

Even the best possible ventilation system will not result in a reduction of harmful chemical compounds of tobacco smoke to an absolute zero level. But, depending on the chosen system, it will be possible to reduce the concentration of compounds to a fraction of their original level. One should be aware that the principle of “Maximum Allowable Concentration” (MAC) is general practice in many fields regarding the air quality. However, at present no health based MAC value exists for ETS.

6. MEASURING ETS CONCENTRATIONS

Environmental Tobacco Smoke is an aerosol consisting of both vapour and particulate phase components. Nicotine and 3-ethenylpyridine (3-EP) are commonly used tracers for the vapour phase of ETS; both are highly selective for tobacco smoke. While nicotine is the more commonly used marker, it is not an ideal marker, mainly because of its adsorptive tendencies an unpredictable decay rate. In contrast, 3-EP has been shown to track the vapour phase of ETS response exactly, and therefore may be a better tracer for ETS. The determination of vapour phase nicotine and 3-EP by the gas chromatic method is described in ISO 18145 (ISO 2003).

Airborne solanesol is specific to tobacco smoke and is found only in the particulate phase of ETS. It remains in a constant ratio to respirable suspended particles (RSP) contributed by tobacco smoke over a variety of ventilation conditions and sampling durations. The estimation of the particulate phase components by the method based on solanesol is described in ISO 18144 (ISO 2003).

7. VENTILATION FOR THE CONTROL OF ETS

7.1. Introduction

There are several ways of approaching the question “how much ventilation is required to control ETS”. The Guidebook discusses the required ventilation rates with regard to different air quality criteria, which can be classified in

- National building regulations
- International Standards
- ETS concentration
- Perceived air quality

To enable an effective search for technical approaches to reduce ETS concentrations in indoor spaces, performance criteria should be set based on the level of health risk that people are prepared to accept. A similar strategy is followed for many harmful substances. The acceptable health risk could provide a basis for calculating the maximum allowable exposure of people to ETS. Unfortunately the Western countries did not develop such criteria so far, mainly due to the more or less fundamentalist attitude of politicians, guided by medical doctors, who rather ban smoking. Only the Australians developed a standard, the Environmental Tobacco Smoke Harm Index, AS 1668.2 Supp. 1 -2002, which is briefly described later.

7.2. National Building regulations

Many regulations prescribe a specific ventilation flow on the basis of floor area orroom volume. In the Netherlands a ventilation flow of 4,8 $dm^3/m^2.s$ (17,3 $m^3/m^2.h$) is required for restaurants and dayrooms, irrespective if smoking is allowed or not. The British Beer and

Pub Association require 8 dm^3/s per person, at normal occupancy rates of 1 m^2 per standing customer and 2 m^2 for seated (eating) areas. This amounts to 4,0 $dm^3/m^2.s$ for eating areas and 8,0 $dm^3/m^2.s$ for standing areas. In Switzerland 18 $dm^3/m^2.s$ is required and in Italy 18 dm^3/s per smoker. The differences between the various requirements are big; Switzerland exceeds the Netherlands by a factor of 3,75!

7.3. International Standards

Table 1 shows a selection from various international standards and guidelines. The Italian requirement of 18 dm^3/s per smoker will result in a moderate to medium air quality.

Table 1 - Ventilation capacity per person in some guidelines and standards based on acute irritative effect.

Guideline or standard	Category	Ventilation capacity in dm^3/s per person			
		no smokers	20% smokers	40% smokers	100% smokers
CR 1752	A (15% PPD)	10	20	30	30
	B(20% PPD)	7	14	21	21
	C(30% PPD)	4	8	12	21
ASHRAE[5] 62-89R	Adapted	3	6	17	25
	Non adapted	5	8	25	35
NKB-61 (91)		7	20	20	20
CIBSE – Guide A		8	16	24	43
prEN 13779		Non-smoking area		Smoking area	
		Typical	Default	Typical	Default
IDA 1	High IAQ	>15	20	>30	40
IDA 2	Medium IAQ	10-15	12,5	20-30	25
IDA 3	Moderate IAQ	6-10	8	12-20	16
IDA 4	Low IAQ	<6	5	<12	10

5 This standard has run out but has been the state of the art for many years

7.4. ETS concentration

We do not know what the maximum limit is for ETS to ensure an acceptable health risk.. The limits below give some indications of what some authorities accept or have accepted:

- In several countries, the government has imposed a total ban on smoking in catering establishments and other public spaces, i.e. a zero nicotine concentration.
- In Finland, the guideline value for maximum nicotine concentration is 0.5 $\mu g/m^3$. Finnish authorities states that this value is based on cancer risk of 10-4 if a person is exposed to ETS 40 hour a week during 40 years.
- In Norway, before a total smoking ban was introduced, the maximum accepted nicotine concentration was 1,0 $\mu g/m^3$. The basis on which this value was determined is unknown.

An important factor in ventilation is to know the source strength of the contaminants that we shall control. When dealing with tobacco smoking, the source strength is determined by how many cigarettes, cigar or pipe are being smoked per hour, and the smoke emission from each cigarette, cigar or pipe. In the following we consider the contamination source strength from cigarettes, as that is the type of smoking that dominates in most places.

Little is known about the rate at which people smoke. The Dutch Foundation on Smoking and Health (Stivoro) draws a distinction between an average smoker with a daily consumption of 20 cigarettes and a heavy smoker who consumes 30 cigarettes daily. On this basis, assuming that sleep and other activities that make smoking difficult account for 10 hours every day, an average smoker consumes 1,4 cigarettes per hour and a heavy smoker 2,1 cigarettes per hour. Assuming that 75% of smokers in catering establishments are average smokers and 25% are heavy smokers, an estimate of the average cigarette consumption of 1,6 cigarettes per “standard smoker” per hour look reasonable.

The nicotine concentration in the air can be calculated by the following formula, assuming that all nicotine stays airborne and is not absorbed in walls and other materials in the room:

$$c_{nic} = \frac{p \cdot n \cdot g \cdot 10^3}{A \cdot q_v \cdot 3,6} \qquad (1)$$

where

c_{nic} = nicotine concentration in $\mu g/m^3$
p = percentage smokers in %
n = number of cigarettes smoked per person per hour
g = average nicotine content mg/cigarette - 1 – 2,5 mg/cigarette
A = floor area per person
q_v = ventilation capacity in l/sm^2

Figure 1 illustrates the relation between nicotine concentration and ventilation rate in the above mentioned circumstances for standing areas and eating areas respectively.

If the ventilation is insufficient, nicotine concentrations can, according to the figure, quickly rise to 100 µg/m³ or more. This level agrees with actual measurements (Skistad 2002). Cutting the nicotine concentration to values such as 10 µg/m³ or less would require an unrealistically large ventilation capacity, when mixing ventilation and no zoning is assumed.

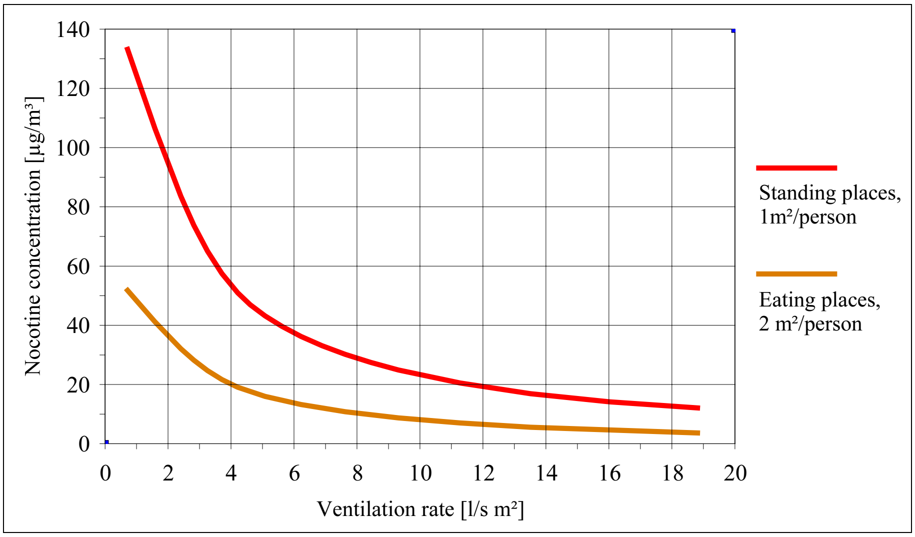

Figure 1 – Nicotine concentrations in relation to specific ventilation rate. Mixing ventilation and other data as stated above.

7.5. Perceived air quality

In 1988 Fanger introduced the concepts of an olf unit to quantify a pollution source, and the decipol unit to quantify the concentration of air pollution as perceived by humans, or nuisance (Fanger 1988). A chemical analysis of air can identify individual pollution sources, such as nicotine, "tar", carbon monoxide etc. and threshold limit values can be set for the exposure of people. However, ETS consists of several thousands of components and there may be thousands of other compounds in the indoor air at low concentrations that are difficult to measure, but which in combination can cause nuisance and complaints.

The units of pollution are defined as follows:

- An olf is the emission rate of air pollutants (bio effluents) from a standard person. Any other pollution source is expressed in terms of the equivalent source strength, defined as the number of standard persons (olfs) required to cause the same dissatisfaction as the actual pollution source.
- A decipol is the pollution caused by one standard person (one olf) ventilated by 10 l/s of unpolluted air. It is a measure of dissatisfaction, not health risk.

The units are derived from experiments with large groups of people. From these experiments the following equation gives the percentage of dissatisfied persons (PPD) caused by one standard person (1 olf) when ventilated by unpolluted air at different ventilation rates:

$$PPD = 395\exp[-1.83 \cdot q^{0,25}] \tag{2}$$

Which can also be written as

$$q/(OLF) = \left[-\frac{1}{1{,}83} \ln\left(\frac{PPD}{395}\right)\right]^4 \tag{3}$$

where:
q = specific ventilation capacity in l/s per olf
PPD = percentage of persons dissatisfied

Example

A non-smoker engaged in mild activity emits by definition 1 olf of bodily effluents; for someone who is smoking, the corresponding value is 25 olf. Since not all smokers are chain smokers, the average value per smoker has been calculated as 6 olf (Fitzner 1999). The calculation below is based on a smoking rate of 1,6 cigarettes per hour and a source strength of 1,6/1,25 * 6 olf = 7,7 olf . The total source strength of one smoker plus one non-smoker is thus 8,7 olf. The ventilation capacity is 8 l/s per person, giving a total of 16 l/s. This corresponds to a specific ventilation capacity of 1,84 l/s olf.

At a specific ventilation capacity of 1,84 l/s per olf, the formula gives a perceived air quality of 47% persons dissatisfied.

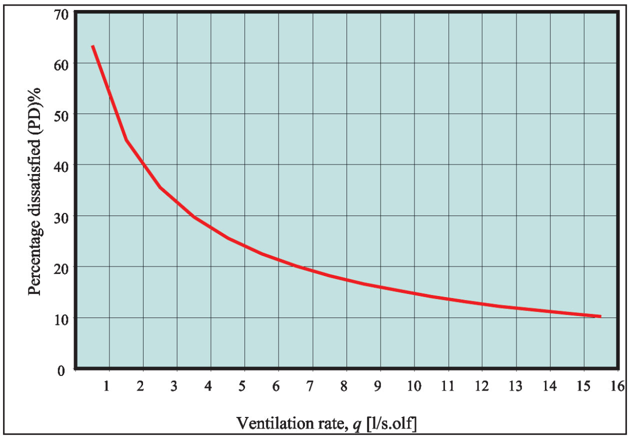

Figure 2 – Relation between ventilation rate and PPD

Figure 2 depicts the relation between specific ventilation capacity and PPD value. However, it is a question of to what extent the olf-method can be applied with respect to tobacco smoking. No matter how much ETS is diluted, smell will be perceived by people.

7.6. Chemical/ physical versus sensory evaluation

Research carried out by Dutch TNO demonstrated that chemical/physical and sensory measurements of ETS cannot be compared (Bluyssen et all 1994). The sensory method is much more sensitive, particularly at low concentrations. If nicotine and 3-EP are completely removed from ETS the perceived air quality (in decipol) has decreased by 50% only.

As mentioned before ETS consists of a complex cocktail of several thousands of components. Consequently the perceived air quality is not tied to the markers used in the chemical / physical measurements. The advantage of the sensory method is therefore that the perceived quality of his cocktail is measured as one –from the viewpoint of nuisance-representative component.

Unfortunately, due to high costs and the more or less subjective results, the sensory measurement method is little used in practice.

7.7. Environmental Tobacco Smoke Harm Index (ETSHI)

The ETSHI is described in the Australian Standard AS 1668.2 Supp 1 – 2002. (www.standards.org.au). The standard presents a methodology for estimate of the mortality risk associated with lung cancer, ischaemic heart disease and the aggregate of the two outcomes. Respirable Suspended Particles RSP is the chosen indicator of ETS concentration or exposure, and a dose response relationship is stated for lung cancer and ischaemic heart disease.

The ETSHI takes into account the number of exposed persons and the number of smokers in a building, the daily exposure time, the number of consumed cigarettes per person and per hour, the flow rates for outdoor air and return air, the filter efficiency and the potential air treatment for the removal of factors affecting ischaemic heart disease. The ETSHI is expressed in number of deaths per million exposed persons per year.

ISO/CD 16814 (ISO 2004) refers to the ETSHI, but the Index has so far not been adopted in this standard.

7.8. Case study[6]

The following case study refers to a restaurant with a floor area of 100 m2, a ceiling height of 3 m and a seating capacity of 50. The percentage of smokers is 45%. The required ventilation flow based on the methods mentioned before is depicted in table 2.

[6] This is not the case study from the guidebook

Table 2 – Comparison of the various calculation methods

method	class	vent. flow m^3/h	vent. rate h^{-1}	feasible yes/no/ special	nicotine $\mu g/m^3$	PD[7] %	ETSHI ☻/a.10^6
Bouwbesluit[8]	-	1.728	5,76	yes	20,8	42	299
EN-CR 1752	A	5.400	18,0	special	6,7	20	169
	B	3.780	12,6	yes	9,5	26	201
	C	2.160	7,2	yes	16,7	37	265
Nicot.0,5 $\mu g/m^3$	-	72.000	240	no	0,5	1,5	40
Perceived Air Quality	A	7.991	26,6	no	4,5	15	145
	B	5.529	18,4	special	6,5	20	170
	C	3.082	10,3	yes	11,7	30	221

In addition to the calculated ventilation flows in m^3/h the ventilation rates in air changes per hour (h^{-1}) are included, which give an impression of the feasibility of the room air distribution within comfort limits. Also dependent on the temperature of the supply air and the air distribution system, a ventilation rate in the magnitude of 10 - 15 ach can be considered as maximum for thermal comfort in a room. It is clear that the ventilation rates, required for the highest air quality, are unrealistic when mixing ventilation and no zoning is assumed.

7.9. Conclusion

We should clearly discriminate between 'nuisance' and 'health risk' with respect to tobacco smoke as we consider the use of the various technical measures. If nuisance is the starting point the choice between classes A, B or C is a more or less a matter of luxury. It should be noted that class A is not attainable if mixing ventilation is applied; displacement ventilation can offer a good solution in this case. If health risk is the dominant principle the choice should be made between displacement ventilation with high ventilation rates, or separation of smokers and non smokers by some kind of zoning.

Even the best possible ventilation system will not result in a reduction of harmful chemical compounds of tobacco smoke to an absolute zero level. But, depending on the chosen system, it will be possible to reduce the concentration of contaminant compounds to a fraction of their original level.

8. MANAGEMENT AND INTERIOR DESIGN OF THE PREMISES

Apart from adequate ventilation several measures have to be taken in order to prevent nuisance and to reduce health risk from ETS. The guidebook describes:

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7 PPD calculated according to perceived air quality
8 Dutch Building Regulation

- Use and management of the premises
- Interior design and architectural issues
- Choice of materials for the interior.

9. PRINCIPLES OF ROOM AIR DISTRIBUTION

For several decades, the predominant way of ventilating rooms has been mixing ventilation. This implies that air is blown into the room so that it mixes with the air inside the room and dilutes the contaminants, thereby keeping the contaminant concentration below a certain level. Normally, the air is supplied and extracted through diffusers and exhaust grilles located at the ceiling. A big advantage of mixing ventilation is that the air supply units are located at the ceiling, away from the occupied zones and that temperature and air quality is evenly distributed in the whole room. A disadvantage is that contaminants are mixed with room air and spread inside the room.

A very well known air distribution method in industry, displacement ventilation, was also introduced in buildings for comfort ventilation the last decade. See figure

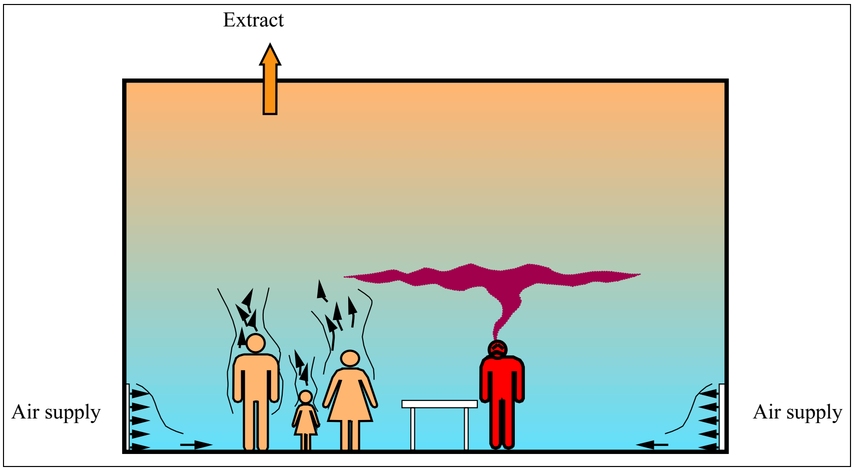

Figure 3 – Displacement ventilation with thermal stratification

Fresh air is supplied at floor level with a temperature slightly below that of the room air and will fill the room from the bottom. The contaminated air, warmed by the people in the room, ascends due to buoyancy, carrying the contaminants up above the head of the people. This can be seen by tobacco smoke rising above the smoker. This air distribution technology is described in detail in REHVA Guidebook nr.1 “Displacement Ventilation” (Skistad et al. 2002). A big advantage of displacement ventilation is that the air quality in the occupied space is better than in the upper part of the room. For a given ventilation air flow rate, the air quality may become substantially better than with mixing ventilation and the same air flow rate.

10. ZONING STRATEGIES – See figure 4

Premises where tobacco smoking is allowed should be divided into smoking zones and non-smoking zones. The ventilation and the zoning must be considered in connection with each other. Some general rules for ventilation and zoning are:

- Fresh air shall be supplied in the non-smoking zones.
- Fixed working places like the zone behind the bar shall have fresh air supply
- The used ventilation air shall be extracted in the smoking areas.
- Air that is extracted at the toilets should be free from ETS.
- The kitchen and the guest rooms shall be ventilated separately. Air from the guest rooms shall not be used as supply air for the kitchen.
- Attention should be taken to the temperature control in the smoking and the non-smoking zone. Additional cooling devices may be required in the smoking zone.

This principle of ventilation and zoning requires that no smoke, or only a negligible amount of smoke, is penetrating into the non-smoking zones. However, the average air velocity through a room created by the ventilation air is very low. In order to obtain an effective separation between the zones, some provisions must be made to make the separation effective. Several kinds of separations, a wall, a threshold, an air curtain, and combinations of them are elucidated in the guidebook.

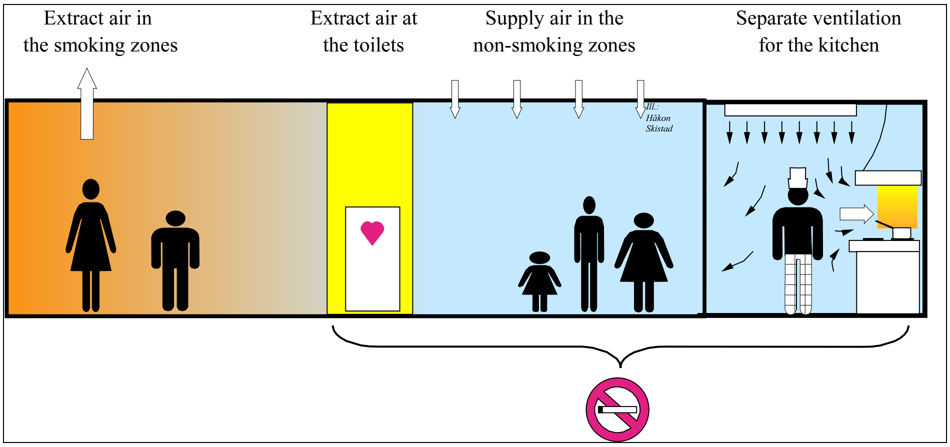

Figure 4 – Zoning and ventilation in serving premises

11. AIR CURTAINS – See figure 5

Air curtains to separate the non-smoking zone from the smoking zone may be part of the ventilation system but commercial air curtains of the recirculating type may be used as well. This was demonstrated and investigated in laboratory (Skåret and Rydoc 1999) and applied in practice and documented (Skistad and Berner 2002).

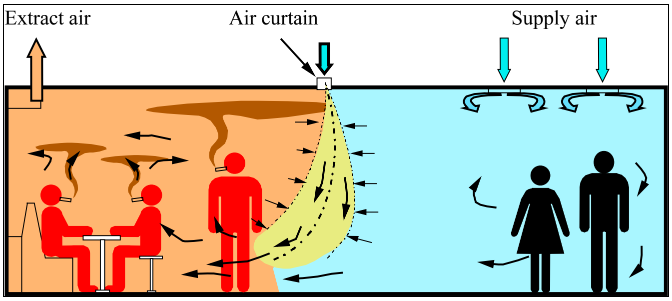

Figure 5 - Air curtain separating the smoking- and non-smoking zone.

The use of commercial air curtains for smoke separation was investigated in a research project "Smoke free Architecture" at the Faculty of Architecture of Delft University of Technology (Bronsema 2006). The most important conclusions are:

- A low discharge velocity (0,7 m/s at 3 m height) and a high discharge volume (250 m^3/m. h) has the advantage of low entrained air flow rate.
- The discharged airflow should be extracted from the smoking zone.
- The extract volume flow must larger than the entrained airflow from outside. In order to prevent excessive extract volumes the separation should be as short as possible.
- Air curtains improve the ventilation effectiveness in the smoking zone. The tests showed a contaminant removal effectiveness > 1,5
- Commercial air curtains may be provided with air cleaners in order to prevent fouling.

12. VENTILATION SYSTEM ARRANGEMENTS OUTSIDE THE ROOM

When non-smoking areas surround a smoking room or smoking area inside a building, several aspects have to be taken into account in the design, construction and operation of the ventilation system, in order to prevent spreading of contaminants to non-smoking areas, under any circumstances. All possible routes by which contaminants can be spread should be considered: i.e. transferred air from one space to another, transfer via the ventilation system or even from outside the building.

These aspects include:

- Pressure conditions within the ventilation system and within the building. The contaminants emitted in the smoking areas should not, under any circumstances, spread into adjacent spaces or any "cleaner" areas of the same building. Therefore the entire system should be kept continuously at negative pressure in relation to adjacent areas.
- Discharge the contaminated air so that it will not return mixed with the intake air. The location of, and minimum distances between, between the air intake and exhaust openings depends on the quality of extract air from different rooms and zones. This quality may be estimated using the extract air classification in EN 13779. Apply preferably a short-circuit proof air intake. See figure 6.
- The filtered extract air from a smoking room may be re-used as circulation air inside

the same room, but not as transferred air or supply air for any other room used for human occupancy.

- The exhaust air, from one or more smoking rooms, should be discharged outdoors via its own ductwork and through a discharge opening on the top of the roof. Heat recovery, if any, should be arranged so that the contaminated air cannot mix into the fresh air.

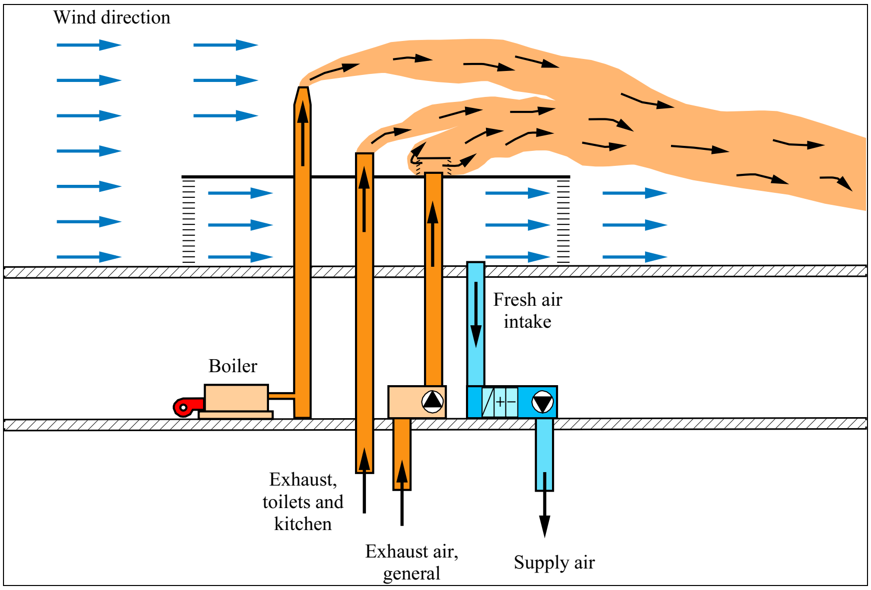

Figure 6 – Shortcircuitproof air intake

13. AIR CLEANERS – See figure 7

Correctly maintained and operated air cleaners can reduce particulate pollution from tobacco smoke in indoor environments such as bars, clubs, restaurants, casino's and smoke rooms. Air cleaners reduce the dust contamination in a room and in the ventilation extract system, thereby saving cleaning costs. If fitted with suitable additional filters air cleaners can also reduce gaseous and odour pollution. Air cleaners cannot replace ventilation, because they do not remove all gaseous contaminants, nor do they supply the fresh air needed for breathing.

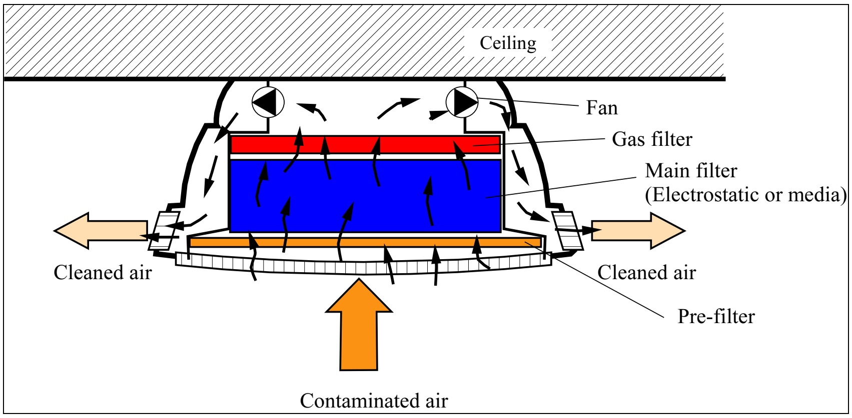

Figure 7 Components of an air cleaner. (Drawing Courtesy Euromate Netherlands)

Air cleaners can reduce the airflow rate required to ventilate a space when particulate matter is the main contamination. They can reduce the energy required to carry out any necessary treatment of the ventilation air. They can be positioned to remove particulate pollutants at, or close to their source and can help in the reduction of dust, pollen and general ambient particulate pollution.

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