Ventilation of ETA 3 rooms in buildings

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SUMMARY
The European standard prEN 13779 – Ventilation for non-residential buildings [1] distinguishes four categories of decreasing air quality, ETA 1 to 4, for rooms in buildings. We tested the separation effectiveness between a special designed smoking porch, which is a typical ETA 3 room, and the adjoining lobby at Delft University of Technology. The ventilation effectiveness in the smoking porch, which was heated and ventilated by a pseudo-displacement ventilation system, was measured as well.

For the ETS measurements we used an innovative Ultra Fine Particle sensor, newly developed by Philips Research. The measurements were carried out at four different ventilation rates, ranging from 4.8 to 19.2 $dm^3/s.m^2$, with a difference of -1.9 $dm^3/s.m^2$ between supply and exhaust. In each test approximately 40 cigarettes were burned. The measured separation effectiveness was 0.97 in all tests, which is higher than is found in literature on this subject. The ventilation effectiveness, expressed in the Contaminant Removal Effectiveness, is low, which can be attributed to the cold downdraught along the outer facade, which mixes with the supply air. In order to realize a high separation effectiveness, a ventilation rate of 4.8 $dm^3/s.m^2$ with a difference of -1.9 $dm^3/s.m^2$ between supply and exhaust is sufficient. In order to obtain a passable air quality in the smoking porch the ventilation rate should be 5-6 times higher

INTRODUCTION
The European standard prEN 13779 distinguishes four categories of decreasing air quality, ETA 1 to 4, for rooms in buildings. Class ETA 3 represents rooms with a high degree of air pollution due, for example, to vapour emission, processes or chemical pollution which substantially reduce the air quality. Rooms cited as examples are toilets and washrooms, kitchens, some chemical laboratories, photocopying rooms and specially designed smoking rooms. The ventilation of such rooms serves two purposes. Firstly, as much as possible the air from these rooms must be prevented from escaping into the cleaner ETA 1 and ETA 2 rooms. As a parameter for this we have introduced the term separation effectiveness. This is affected by the underpressure to be created in the smoking room, whereby wind loading and infiltration, geometry and position, and the separation between ETA 3/4 and ETA 1/2 rooms play a role. Secondly, the best possible air quality must be provided for the people who visit or work in these rooms. This is affected by the ventilation rate and ventilation effectiveness.

We have conducted measurements in a special smoking porch in the Faculty of Architecture at Delft University of Technology, which can be regarded as ETA 3, and at peak usage even as ETA 4. However, the approach and results of the study can also be applied to other situations.

THE SMOKING PORCH
The smoking porch was initially an outside space in which smokers could shelter from rain and wind, and it is therefore constructed entirely of glass; in this form it was naturally ventilated. The

staff then asked if the room could be heated to some degree in the winter months. However, it was important that the smoking room formally retained the character of an unheated room, because it would otherwise have to meet the requirements of the Dutch Building Regulations in terms of thermal construction, facilities, and energy performance. The solution to this was found by ventilating the smoking porch with air extracted from a substation of the central heating system, which in winter has a temperature of approximately 25^0C. By making use of unused residual heat, the smoking porch has no effect as such on the faculty building's energy performance. The overall room temperatures to be achieved are shown in figure 1.

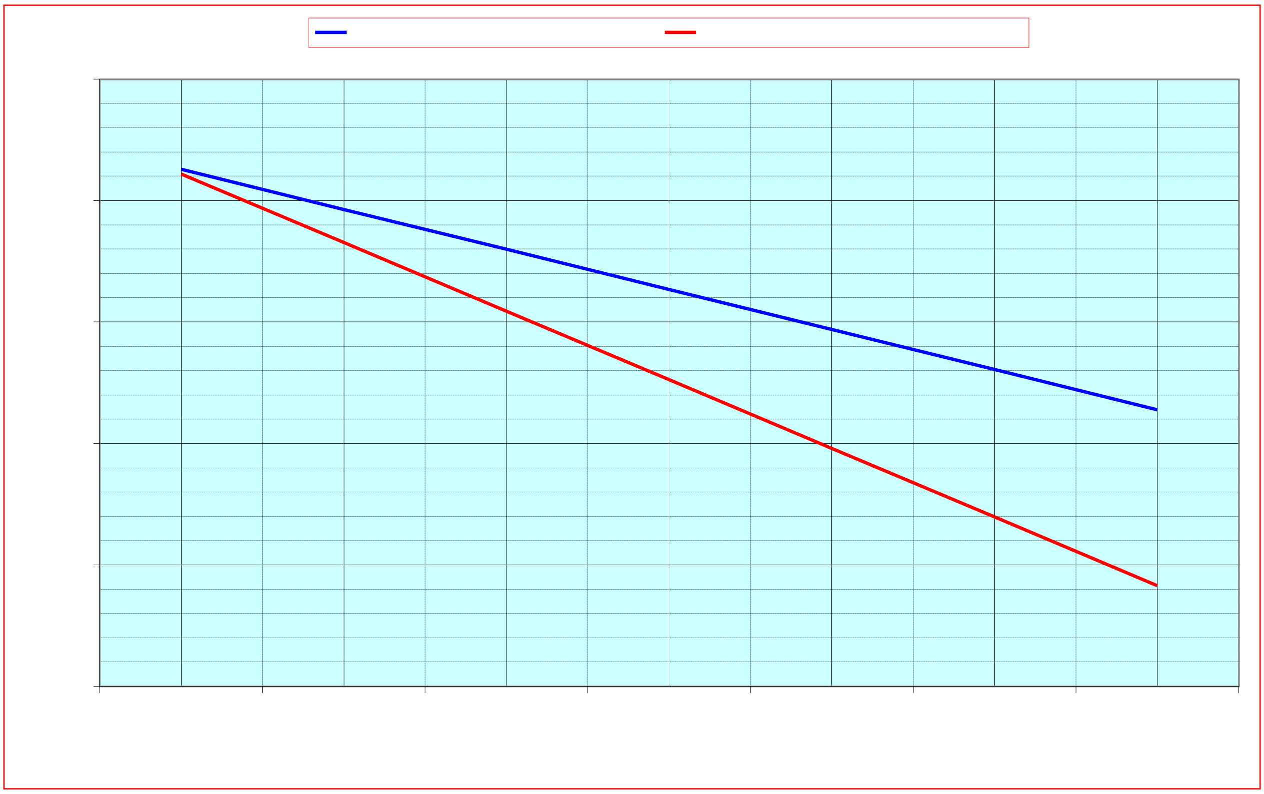

Figure 1 – Room temperature of smoking porch in relation to outside temperature

The floor area of the smoking porch is 29 m^2. The height is 6.85 m and the gross volume is approximately 200 m^3. The porch can accommodate 24 standing smokers at four smoking tables. The wishes of the staff for seating to be included were not met. See figure 2, in which the points of measurement are also shown.

VENTILATION AIRFLOW RATE OF THE SMOKING PORCH

The airflow rate was chiefly determined by the room temperature desired in the porch during the winter months; the temperature of the supply air is a given factor. On the basis of overall calculations, a total airflow rate of 1600 m^3/h has been assumed, equivalent to 8 air changes per hour and 67 m^3/h per person at maximum occupation. Dutch Building Regulations only require a ventilation rate of approximately 500 m3/h for a room such as this.

PRESSURE HIERARCHY AND AIR BALANCE

The smoking room has an east-facing glass outer facade with a surface area of approximately 140 m^2. The infiltration of this facade by a strong east wind cannot be ignored, because it could result in the extraction capacity becoming too small and in the most serious case even create overpressure in the smoking room.
The infiltration flow can be calculated using the formula in [1]:

$$V = \sum (a.l) * \sqrt[3]{\Delta p^2} \quad (1)$$

Wherein:
V = infiltration flow m^3/h
a = flow coefficient in $m^3/m^1.h.\Delta p^{2/3}$ - For unopenable sections to be set at 0.20
l = length of cracks in m - Ca 104 m
Δp = pressure difference across the outer facade in Pa - At 5 Beaufort[1] estimated at ca 50 Pa.
Using formula 1 the maximum infiltration is estimated at ca 300 m^3/h. On this basis the air balance is set as follows:

balance is set as follows:	Calm	Wind 5 m/s
Exhaust airflow	1600 m^3/h	1600 m^3/h
Infiltration from lobby	300 m^3/h	0 m^3/h
Infiltration from outside	0 m^3/h	300 m^3/h
Supply airflow	1300 m^3/h	1300 m^3/h

The ventilation system is constructed as an upflow system (see below), so in principle it could function as displacement ventilation. For this to work it is important that the airflow is greater than the upward air current of 20 dm3/s (72 m3/h) which is the natural thermal caused by the human body [2]. A supply airflow of 1300 m3/h is therefore sufficient for (1300/72=) 18 persons. At the full capacity of 24 persons, (24*72=) 1.728 m3/h would be needed. However, whether and to what extent the ventilation system is suitable to function as displacement ventilation is discussed below.

THE VENTILATION SYSTEM

The smoking porch is equipped with four round tables mounted on steel tubes Ø 323.9 x 4 mm with perforations Ø 10 mm, centre to centre 60 mm, through which air is supplied. The speed at which air is blown in through the perforations is 5 m/s, aiming at a fast reduction in air temperature. If the temperature of this air were too high it would adversely affect the upflow system. On the other hand, the high speed of the air blown in and the inherent induction of room air counteract the intended displacement effect. Partly due to the cold downdraught along the outer facade of the porch, despite the supply of ventilation air at a low level, hardly any displacement effect has been found to occur (see below).

The air is extracted high up in the porch via steel tubes Ø 193.7 x 4 mm measuring ca 6 m in length, which are installed concentrically in the air supply tubes – see figure 3.

ANALYSIS OF THE VENTILATION CONCEPT

Separation effectiveness:
The separation effectiveness is defined as

$$\eta_s = \frac{C_i - C_e}{C_i} = 1 - \frac{C_e}{C_i} \quad (2)$$

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[1] An east wind at force ≥ 5 Beaufort is rare in the Netherlands.

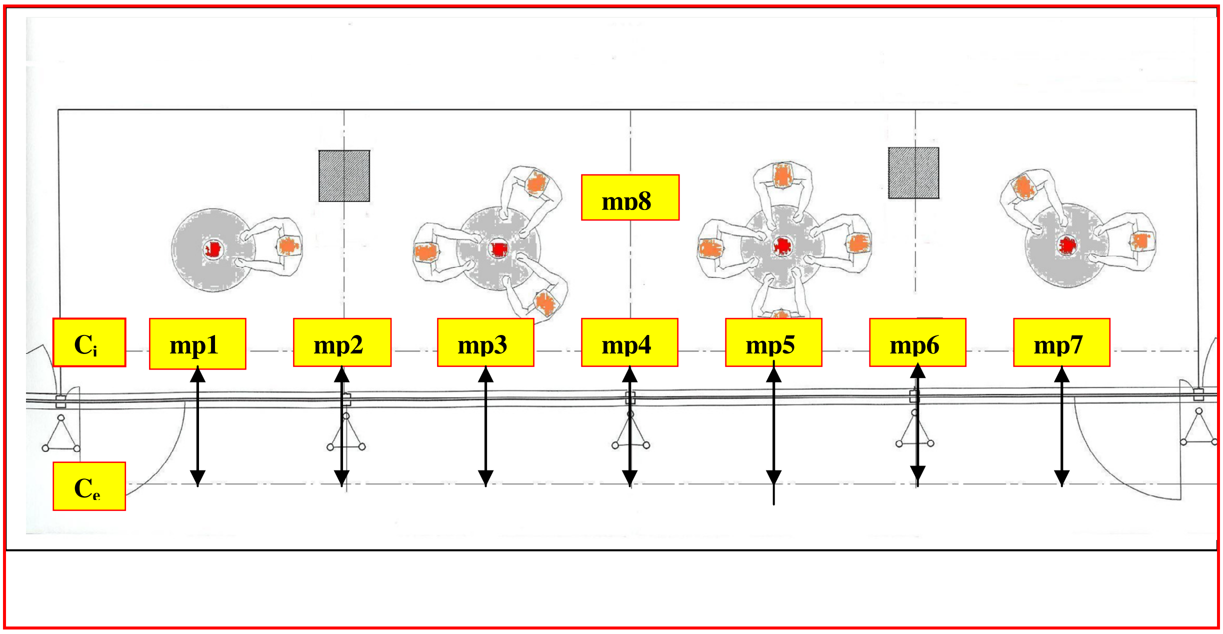

Figure 2 – Floor plan of the smoking porch with measuring points

Wherein

C_i = ETS concentration in the porch

C_e = ETS concentration in the lobby outside the porch

The ETS concentrations in the smoking room are measured at breathing height between 1.1 en 1.8 at respectively $C_{i.1,1}$ en $C_{i.1,8}$

It is not easily possible to develop an analytical model to predict the separation effectiveness. The dissipation of ETS to the lobby can perhaps be modelled, but the ETS concentration in the lobby is dependent to a large extent on the volume of the room, the air movement and the ventilation of the lobby. The separation effectiveness can therefore only be determined on the basis of measurements.

Ventilation effectiveness:

The ventilation system is set up as an upflow system, but does not meet the conditions for displacement ventilation because:

- The temperature of the supply air is higher than the room temperature. After all, the air supply also serves to warm the porch.
- The doors of the porch are frequently opened and closed for smokers to leave and enter.
- The cold downdraught along the outer facade causes a downward current of contaminated air.

The smoking porch is fitted with hinged glass doors, which when opened and closed 'pump' a quantity of air from the porch into the central lobby and vice versa. Under isothermal conditions this quantity is approximately 672 dm^3 a time [3]. With an average occupation of 15 smokers, each of whom spend 15 minutes in the porch, the doors are opened and closed 120 times an hour (twice per smoker), whereby ($120*672*10^{-3}$=) 80 m^3/h ETS

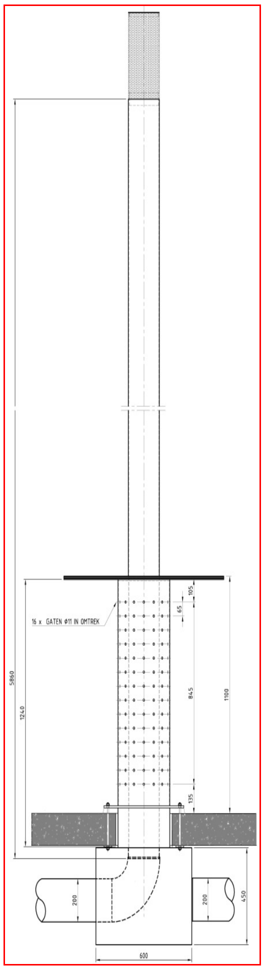

Figure 3

is transferred into the lobby. In relation to the ventilation capacity of 1600 m^3/h this is a comparatively small amount, which in itself need not disturb the upflow of displacement ventilation too seriously.

The cold downdraught along outer facades that are made only of single glazing is more of a problem. The convection flow that arises along a vertical surface can be calculated using the following formula [3]. The formula applies to turbulent flows which in this case will certainly occur.

$$q_{v,z} = 2.75 \Delta\theta^{0.4} z^{1.2} \quad (3)$$

Wherein:

$q_{v,z}$ = vertical airflow -$dm^3/s.m$

$\Delta\theta$ = temperature difference -K

z = height of the vertical surface -m

The outer facade of the porch has a surface area of (H*B= 6.65*16.40) 109 m^2. The temperature difference $\Delta\theta$ between the air in the smoking porch and the glass surface depends on the outside temperature and the wind speed. The lower the temperature outside and the higher the wind speed, the more the temperature in the porch will fall and with it the inner surface temperature of the outer facade. The cold downdraught has been quantified using formula (3); figure 4 shows the results.

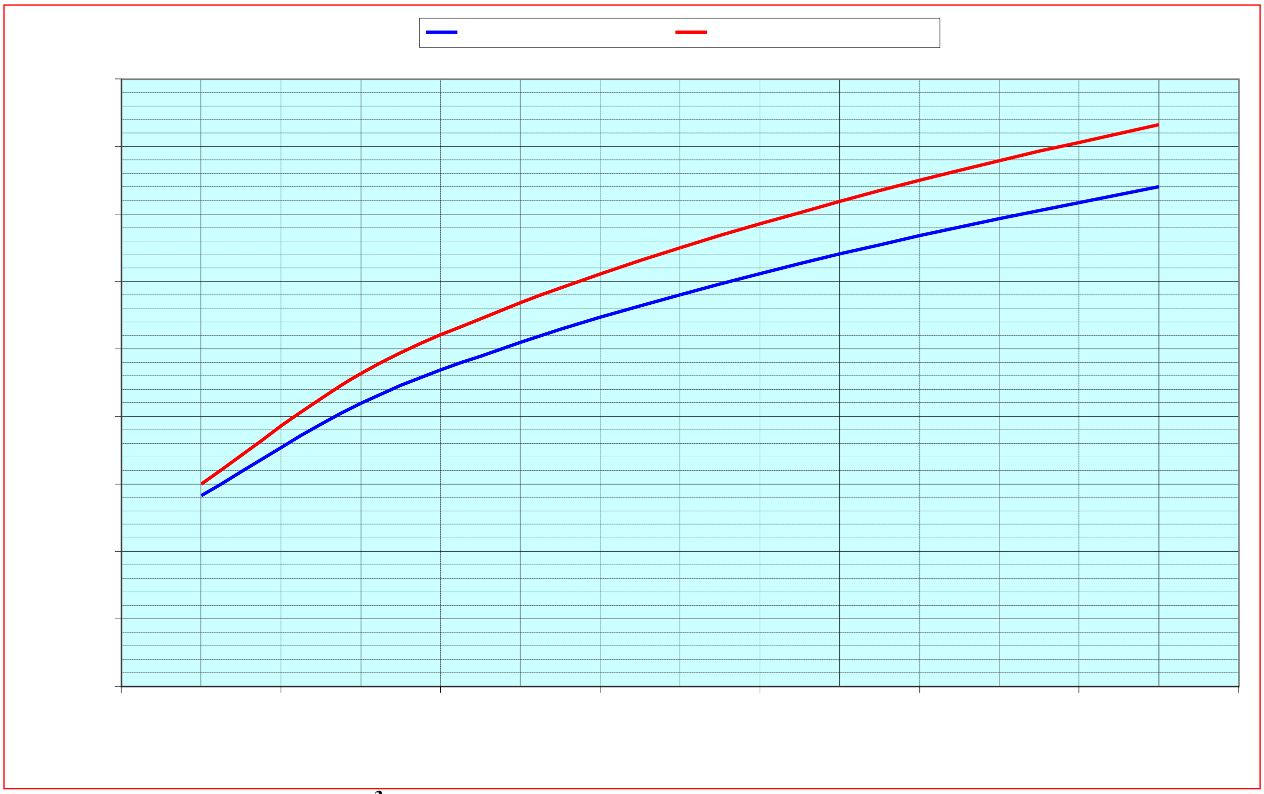

Figure 4 – Downdraught in m^3/h in relation to outside temperature

At an outside temperature of -3^{0}C, the lowest occurring during the day, a downdraught in the order of 3500 m^3/h occurs. But also at a more moderate outside temperature such as 15^{0}C the downdraught is still greater than 2000 m^3/h.

This downdraught is considerably greater than the supply flow, so displacement ventilation hardly occurs. The lower the outside temperature falls, the more the system assumes the character of mixing ventilation. This is not important for separation effectiveness, but it is for the air quality in the porch, as the downward airflow set in motion by the cold downdraught is contaminated with ETS.

DETERMINATION METHOD FOR ETS CONCENTRATION

The determination of ETS concentrations according to the international standards ISO 18144 and ISO 18145 is a time-consuming and expensive matter and moreover it cannot be carried out online. The ETS concentration has therefore been determined with the aid of an Ultrafine Particle (UFP) Sensor [4] developed by Philips Research in Eindhoven. Philips has made a prototype of this innovative sensor available for the measurements to be conducted. They therefore provide no data on nicotine, 3-EP and solanesol concentrations in theETS, which are also not required by the present measuring programme given that both for separation effectiveness and ventilation effectiveness relative values are concerned.

CONCENTRATION MEASUREMENTS

During three measurement sessions, first the separation effectiveness and then the ventilation effectiveness were determined with the aid of the UFP sensor. The values measured by the sensor are in pA. It should be noted that a considerable inhomogeneity was recorded, both in time and in place. The values measured are ± 10%.
For the measurements of separation effectiveness a mobile table was used with two surfaces at 1.0 and 1.6 m high, on which the measuring pump and analysis equipment was placed. Separation effectiveness was calculated from the values measured using equation (2).
For the measurements of ventilation effectiveness a hand-operated lift table was used. Measurements were taken at heights of 0.1 – 1.1 – 1.8 – 3.0 en 3.5 m; this was the greatest height it was possible to reach. It was therefore not possible to take the desired measurement next to the extraction point. The ventilation effectiveness, expressed in Contaminant Removal Effectiveness CRE [5], has not therefore been calculated on the basis of the concentration in the exhaust C_a, but of the concentration at a height of 3.5 m. The CRE value has been calculated respectively for a sitting height of 1.0 m and a breathing height of 1.6 m using the formula

$$CRE = \frac{C_{3.5}}{C_{1.0}} \ and \ \frac{C_{3.5}}{C_{1.6}} \quad (4)$$

The measuring points are shown in figure 2. The ventilation flows, temperatures and number of cigarettes burnt are shown in table 1. For each cigarette the doors were briefly opened and closed either one or two times.

No.	Supply flow m^3/h	Exhaust flow m^3/h	Room temp. ^0C	Outside temp. ^0C	No. of cigarettes
1	1.310	1.640	20.6	16.9	49
2	720	1.060	20.6	16.4	42
3	215	500	20.6	16.4	41

Table 1 – Measurement conditions

MEASUREMENT SESSIONS

Session 1A – Separation effectiveness η_s

The values measured in pA are shown in table 2:

concentr.	height	mp1	mp2	mp3	mp4	mp5	mp6	mp7	gem.
C_i	1.0 m	1.00	0.95	0.65	0.70	0.70	0.51	0.36	0.70
C_i	1.6 m	1.10	1.50	1.10	1.50	1.35	1.20	1.72	1.35
C_i	av.	1.05	1.23	0.88	1.10	1.03	0.86	1.04	**1.03**
C_e	1.0 m	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
C_e	1.6 m	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
C_e	av.	0.035	0.035	0.035	0.035	0.035	0.035	0.035	**0.035**

Table 2 – Values measured in measurement session 1A

Separation effectiveness $\eta_s = \frac{C_i - C_e}{C_i} = 1 - \frac{C_e}{C_i} = 1 - \frac{0.035}{1.03} = 0.97$

Session 1B – Ventilation effectiveness CRE:
The values measured in pA at mp 8, and the calculated CRE values $CRE_{1.0}$ *and* $CRE_{1.6}$ are shown in table 3.

height m	concentration at mp 8	
0.1	1.30	$CRE_{1.0} = \frac{C_{3.5}}{C_{10}} = \frac{1.4}{1.1} = 1.7$
1.0	1.10	
1.6	1.35	$CRE_{1.6} = \frac{C_{3.5}}{C_{1.6}} = \frac{1.4}{1.35} = 1.04$
3.0	1.35	
3.5	1.40	

Table 3 – Session 1B measurements and results for Contaminant Removal Efficiency CRE

Session 2A – Separation effectiveness η_s
The values measured in pA are shown in table 4:

concentr.	height	mp1	mp2	mp3	mp4	mp5	mp6	mp7	av.
C_i	1.0 m	1.38	1.40	1.23	1.35	1.32	1.31	1.28	1.32
C_i	1.6 m	1.74	1.60	1.30	1.65	1.55	1.65	1.75	1.60
C_i	av.	1.56	1.35	1.27	1.50	1.44	1.48	1.52	**1.46**
C_e	1.0 m	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
C_e	1.6 m	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
C_e	av.	0.05	0.05	0.05	0.05	0.05	0.05	0.05	**0.05**

Table 4 – Values measured in measurement session 2A

Separation effectiveness, calculated using the average values for C_i en C_e from table 2, is calculated as follows: $\eta_s = \frac{C_i - C_e}{C_i} = 1 - \frac{C_e}{C_i} = 1 - \frac{0.05}{1.46} = 0.97$

Session 2B – Ventilation effectiveness CRE
The values measured in pA at mp 8, and the calculated *CRE* values $CRE_{1.0}$ *en* $CRE_{1.6}$ are shown in table 5.

height m	concentration at mp 8	
0.1	1.20	$CRE_{1.0} = \frac{C_{3.5}}{C_{1.0}} = \frac{2.00}{1.45} = 1.38$
1.0	1.45	
1.6	1.50	$CRE_{1.6} = \frac{C_{3.5}}{C_{1.6}} = \frac{2.00}{1.50} = 1.33$
3.0	1.65	
3.5	2.00	

Table 5 – Session 2B measurements and results for Contaminant Removal Efficiency CRE

Session 3A – Separation effectiveness η_s
The values measured in pA are shown in table 5:

concentr.	height	mp1	Mp2	mp3	mp4	mp5	mp6	mp7	av.
C_i	1.0 m	1.95	1.80	1.80	2.20	2.10	2.05	2.25	2.02
C_i	1.6 m	2.38	2.28	2.13	2.05	2.03	2.18	2.25	2.19
C_i	av.	2.17	2.04	1.97	2.13	2.07	2.12	2.25	**2.10**
C_e	1.0 m	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.077
C_e	1.6 m	0.06	0.07	0.07	0.07	0.07	0.08	0.08	0.071
C_e	av.	0.06	0.075	0.075	0.075	0.075	0.08	0.08	**0.074**

Table 6 – Values measured in measurement session 3A

Separation effectiveness, calculated using the average values for C_i en C_e from table 2, is calculated as follows: $\eta_s = \frac{C_i - C_e}{C_i} = 1 - \frac{C_e}{C_i} = 1 - \frac{0.074}{2.10} = 0.965$

Session 3B – Ventilation effectiveness CRE
The values measured in pA at measurement point 8, and the calculated CRE values $CRE_{1.0}$ *en* $CRE_{1.6}$ are shown in table 6.

height m	concentration at mp 8	
0.1	2.50	$CRE_{1.0} = \frac{C_{3.5}}{C_{1.0}} = \frac{3.00}{2.50} = 1.20$
1.0	2.50	
1.6	2.56	$CRE_{1.6} = \frac{C_{3.5}}{C_{1.6}} = \frac{3.00}{2.56} = 1.17$
3.0	3.00	
3.5	3.00	

Table 7 – Session 3b measurements and results for Contaminant Removal Efficiency CRE

DISCUSSION

The concentrations measured in pA using the UFP sensor in the smoking porch are thrown into relief when they are compared with typical values in reasonably clean outside air of 0.02 pA. When it is warm outside, with moderate traffic the sensor reading rises to 0.05 – 0.06 pA. In a car on the motorway peak concentrations occur in the range of 0.2 – 0.5 pA. The air quality in the porch can therefore be regarded as being relatively poor, even at higher ventilation capacities. ETS is an infamous source of air contamination in indoor environments!

The concentration in the porch decreases sharply with increasing ventilation capacity; see figure 5. Extrapolating logarithmically, the concentration at 3.000 m3/h would come out at 0.5 pA, which would undoubtedly reduce the ETS absorbance in the clothing of visitors to the porch and hence the distribution of ETS in building. The question is whether it would also improve the air quality measurements. ETS is a complex cocktail with thousands of components. In most cases ETS concentration is below the chemical/physical detection limit. [6]
For the rest, the clear relationship between ETS concentration and ventilation capacity provides an excellent possibility for a demand controlled ventilation system. The signal from the UFP sensor can be included in the control circuit of an air quality controller. Having made enquiries within the industry, the author is not aware of any other sensors with which this possible.
The potential field of application of the UFP sensor is not limited to smoking rooms. This sensor for ventilation control can be applied anywhere where ultra fine particles ($PM_{2.5}$) form a risk. For future applications a multifunctional room sensor for temperature, relative humidity, CO_2 and $PM_{2.5}$ is also being considered.

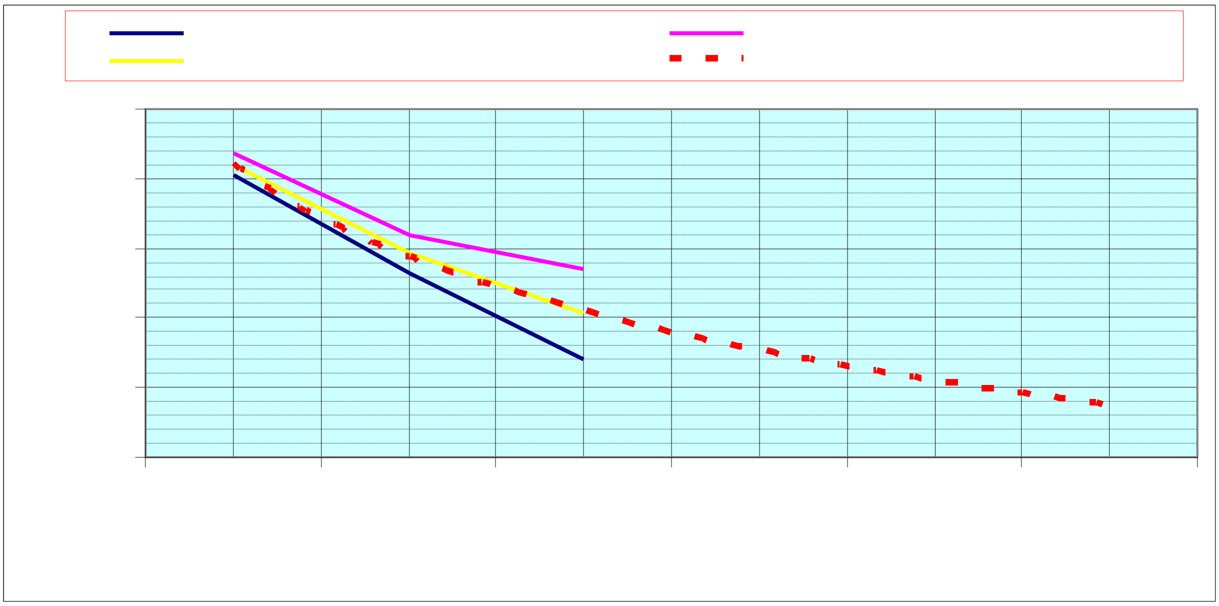

Figure 5 –ETS Concentration in smoking porch in relation to ventilation capacity

CONCLUSIONS

- At a value of 0.97 the separation effectiveness is extremely high, also at low ventilation capacities.
- The ventilation effectiveness is low. This can be attributed to the cold down draught along the porch outer facade, and to the ventilation system as such.
- To realise a high separation effectiveness, a difference between supply and exhaust flow of -1.9 $dm^3/s.m^2$ is sufficient.
- To improve the IAQ in the smoking porch the cold down draught should be decreased, combined with an increase in ventilation flow.

REFERENCES

[1]Recknagel 2000. Taschenbuch für Heizung + Klimatechnik. Recknagel Sprenger Schramek, 69th edition. R. *Oldenbourg Verlag München Wien. ISBN 3-486-26215-7.*

[2]Skistad, H (ed) 2002. Displacement Ventilation in non-industrial premises. *REHVA Guidebook no.1. Federation of European Heating and Air-conditioning Associations REHVA. ISBN 82-594-2369-3.*
[3]Wagner, J. et al 2004. Environmental Tobacco Smoke Leakage from Smoking Rooms. *Journal of Occupational and Environmental Hygiene February 2004. ISSN1545-9624 print / 1545-9632 online.*
[4]Marra, J. Combining air filtration with UPF sensor for enhanced energy efficient indoor air quality optimisation. *Proceedings CLIMA 2007 Conference - Helsinki June 2007.*
[5]Mundt, E. et al 2004. Ventilation Effectiveness. *REHVA Guidebook no.1. Federation of European Heating and Air-conditioning Associations REHVA. ISBN 2-9600468-0-3.*
[6]Bluyssen, Luscuere, van der Wal 1994. Sorptie-effecten van sigarettenrook in het binnenmilieu: chemisch/fysische versus sensorische evaluaties. Bouwfysica Vol. 5, 1994, no. 4.