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The Influence of Indoor Tobacco Smoking on Energy Demand for Ventilation

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Synopsis

The number of smokers differs mainly with age, sex, education, profession, and cultural background. The change in habits from the 2nd World War till today in form of increasing number of female smokers and decreasing number of male smokers is significant. The smoking of tobacco causes pollutants in the form of volatile organic compounds, particles, and carbon monoxide. Many of the pollutants are carcinogenic. In some cases the concentration of specific tobacco smoke related pollutants in room air may be higher than the maximum allowable concentration.

In rooms where smoking is allowed the air change rate must be kept much higher than in rooms with only normal human odour load. The extra energy demand for ventilation in a room where smoking is allowed can be deduced from the necessary flow rate when smoking not is allowed.

In this paper is discussed the ventilation energy impact of smoking. The estimation is made for the AIVC countries.

1. Introduction

The use of tobacco in the developed countries is still on a very high level even if a slight decrease has been recognized during the very last years. Smoking has gone down more among men than among women. Today the frequency is nearly the same for men and women or about 33% (men) and 30% (women). However, the range of frequency, 20 - 45%, indicates a very broad span of smoking habits in different countries. In some developing countries the frequency for men can be even higher but then nearly no women are smokers. In table 1 is given examples of today's smoking frequency and in figure 1 is given examples of the evolution of smoking habits.

Table 1. Example of smoking frequency today (ref 4, 8).

Country	Men %	Women %
Canada	33	30
U.S.A.	31	26
Finland	34	20
United Kingdom	33	30
Sweden	28	26
Denmark		45
China	61	7

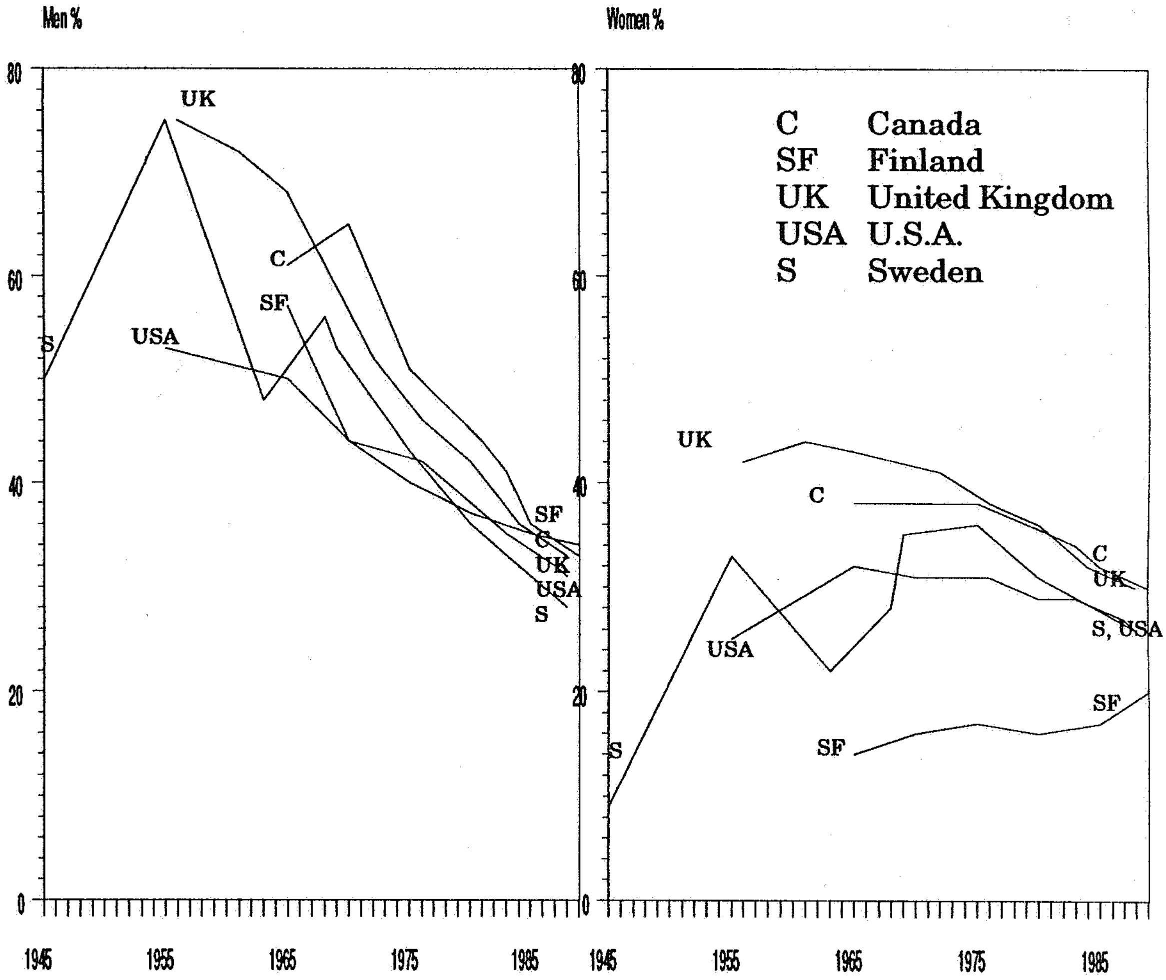

Figure 1. Development of tobacco use in some countries (ref 4, 8).

Today most people are aware of the fact that tobacco smoking causes diseases and shortens life time. More controversial is the effects of the passive smoking that all non-smokers sooner or later will be exposed to. Thousands of reports have been published on the health effects for smokers and for passive smokers.

The most appalling result is that there are no other epidemiological indications that this disease will decrease. It will for a long time remain as the most risky occupation. It is known that tobacco smoking causes several cancer diseases eg. lung cancer, heart and pulmonic affection, pregnancy risks, allergic prevalence for children with mothers' smoking etc.

A tremendous increase of death rates during the next 25 years is expected. Today the use of tobacco is estimated to account for 3 million deaths per year and will rise to about 10 million by the year 2020.

These above mentioned effects are of course the most serious results of tobacco smoking and also related to economic matters. But there are other side effects which have purely economic consequenses. When designing a ventilation system in eg. an office building, it has to be considered that tobacco smoking increases the necessary outdoor air supply rate. Higher investment for the air handling system follows. We also know that smokers are more sensitive to low temperature than non-smokers because of the reduced pulmonic function. If this has significantly called for a higher indoor temperature is still to be investigated.

2. Objective

The objective of this study is to estimate the magnitude of extra energy use for heating the outdoor air required when tobacco smoking is allowed or could be expected somewhere in a building.

3. Method

As there are very few data easily available the calculation has been based on both very detailed data and rough estimations by comparisons with the situation in a few other countries. Also data that can be compared give reasons to be quite critical because of the great variation. However, as the data still give the order of magnitude, the calculation is justified.

The calculation is made for non-industrial, non-domestic buildings in which it can be expected that smoking will be allowed. Thus the following building types are not included:

— Dwellings. The outdoor air flow rate does not take into account smoking habits. The occupants in a dwelling decide wether to smoke or not.

— Schools. Smoking is not allowed in the classrooms nor in most of the other areas

— Hospitals. Only a very small area is set aside for smokers.

The volume of the buildings must be estimated. The method used here is to use data for dwellings. Most of the AIVC countries have the same living conditions, are industrialised at the same level, have the same area for each person in the non-domestic buildings, and the same proportions of area use in the building types where smoking is allowed. The proportions between dwellings and other non-domestic buildings in Sweden and France have been compared. Both countries have the same proportion between dwellings and non-domestic buildings and the same distribution between the various building types. The same has been asssumed for all the other AIVC countries.

The estimation of the climate has been made by using a simplified degree-day method. A mean value for individual countries has been chosen, where the population density in the various climate zones has been taken into account.

The outdoor air supply for allowing smoking in the premises has been estimated to be increased, in comparison to what could have been necessary for having an acceptable indoor air quality in buildings for non-smokers. The choice of the flow rate is delicate because standards and codes give no background for the increased flow rate.

4. Assumptions and data used

In this section will be given the data on which the estimation/calculation are based. A discussion on the results and the degree of uncertanty will also be given.

Volume of the buildings

The relation between the heated area of domestic buildings and other non-industrial buildings is assumed to be the same in all countries. In Sweden and France the dwelling area is 3 times larger than that of the actually studied buildings. The distribution of the various building types for Sweden has been used as an assumption for the other countries, see table 2. The relation between some of the building types has been compared to the situation in France. The definitions used have not been the same and no total figure has been given for France. As can be seen from table 2 about 1/3 of the area can be assumed to be smoking area, which is the same as 1/10 of the dwelling area.

Table 2. The distribution of the use of non-domestic buildings and the proportion of area where smoking is allowed (ref 17).

Building type	Sweden,% Total	Smoking, % Allowed
Schools	23	-
Hospitals and health premises	20	0.2
Offices and public buildings	19	19
Retail areas (shops, supermarkets), postoffices, banks	11	-
Hotels, restaurants	5	2
Other premises	12	12
Auditoriums	5	3
Gymnasiums	3	-
Churches	2	-
Grand Total	100	36

From table 3 the dwelling area can be estimated. It must be noted that the areas are not always quite comparable. Generally the dwelling area given is excluding staircases, basements, sometimes also halls and small kitchens within the dwelling. For single family homes, however, these areas are included. For Sweden both the total heated area and the main dwelling area have been collected, and it is thereby found that the heated area is about

25% larger than the dwelling area given in table 3. From table 3 can be seen that the total dwelling area is 28400 million m^2, where Europe stand for 11200 million m^2 and North America for 17200 million m^2. With the above given assumption the smoking area can be estimated to be 3000 million m^2. Assuming the ceiling height of 3.0 m the total volume can be estimated to 9000 million m^3.

The volume in Europe might be bigger because the figures in table 3 are given for dwellings and not for heated area. Most of the domestic buildings in North America are single family homes so it seems that the area given there is close to the heated area. The conclusion is that the volume might be about 10 % bigger or totally 10000 million m^3.

Tabel 3. Dwelling area in AIVC countries (ref 5).

Country	Dwellings Millions	Area/dwelling m^2	Total area Million m^2
Belgium	3.9	130	507
Denmark	2.4	107	257
Finland	2.2	74	163
France	26.7	85	2270
Germany	33.9	90	3051
Italy	18.7	65	1216
Netherlands	6.0	110	660
Norway	1.8	85	153
Sweden	4.1	87	360
Switzerland	3.1	100	310
United Kingdom	23.6	90	2124
Canada	10.1	114	1140
U.S.A.	105.7	152	16066
New Zealand	-	-	-
Total			28400

Climate

First of all the extra energy use caused by smokers is limited to be estimated only for heating. This means that in case of cooling the energy use will be higher. There our calculation will be an underestimation. The number of buildings with cooling systems is hard to judge. However, it might be a good guess to assume that all the buildings in the U.S.A. are equipped with cooling systems and that all in Canada and Europe are not.

The main purpose of this study is to give a magnitude of the energy used for heating. For this purpose an average climate given in degree-days has to be calculated. The climate has to be given as a mean value for the individual country, where also the population density distribution within the countries is taken into account. In table 4 is given the weighted degree-days for all AIVC countries.

The mean value for all the AIVC countries is 2700 degree-days. If calculated on the inhabitants, both Europe and North America will have the same number of degree-days. If the dwelling area is used as a basis, the mean value is of course the same, but for Europe the average will be 2800 degree-days and for North America 2600 degree-days.

Table 4. Degree-days for heating in the AIVC countries, weighted in proportion to the population. Total average value 2700 degree-days

Country	Inhabitants Millions	Degree-days Heating	Total degree-days Billions (10^9)
Belgium	9.9	3200	31.7
Denmark	5.1	3600	18.4
Finland	5.0	5300	26.5
France	56.2	2200	123.6
Germany	78.6	3000	235.8
Italy	57.5	1800	103.5
Netherlands	14.8	3300	48.8
Norway	4.2	3800	16.0
Sweden	8.5	4400	37.4
Switzerland	6.6	3000	19.8
United Kingdom	57.2	3000	171.6
Canada	26.3	5400	142.0
U.S.A.	250.0	2400	600.0
New Zealand	3.3	2000	6.6
Total	**583.2**		**1583.4**
Average		**2700**	

Extra outdoor air flow rate

It is assumed that all the buildings have mechanical exhaust ventilation.

The extra outdoor air supply rate depending on tobacco smoking allowed within a building represents a much higher flow rate than necessary according to standards or building codes. In the Swedish code the outdoor air flow rate is set to 10 l/(s·p), when smoking can be expected or allowed anywhere in the building. This represents an increase by 35 % of the outdoor air flow rate when smoking is not allowed.

In the ASHRAE Handbooks and Ventilation for Acceptable Indoor Air Quality Standard no particular figure is given for the two cases smoking allowed or smoking prohibited. In fact, it seems to be normal to expect smoking anywhere in the building types described before. The outdoor flow rate is the same as in the Swedish code for offices, when smoking is allowed.

In table 5 are given some values which have been measured in projects in various countries. From this it can be concluded that the outdoor air flow rate of 10 l/(s·p) is a relatively low value. However, very few big surveys of flow rates in offices or commercial premises have been made because of the high realization cost. In the future we can expect an increased number of measurement with the passive technique, see Säteri (1991, ref 16).

Table 5. Measured outdoor air flow rates in projects reported at the Indoor Air 1990 in Toronto.

Author	Ref no	Country l/(s·p)	Flow rate	Air change rate $1/(m^2h)$
Sundell et al	10	Sweden	17	0.4-0.8
Baldwin, Farant	11	Canada		
Skov, Valbjörn	12	Denmark	8	
Jaakkola et al	13	Finland	6-23	
Putnam, Woods, Rask	14	USA	30	
Grot, Hodgson, Persily	15	USA	12-13	1.0-1.2

5. Summarized Estimation

In section 4 has been discussed the parameters to be taken into consideration, when estimating the extra heat energy use for ventilation of non-domestic areas where tobacco smoking is allowed. One further factor is the heated volume per person.Here a volume of about 40 m^3 per person is assumed. Then the outdoor air flow rate of 10l/(s·p) gives an air change rate of 0.9 per hour (h^{-1}).

For the energy calculation has been used the following formula:

$$Q = V \cdot n \cdot f \cdot \rho \cdot c_p \cdot D / 3600 \qquad \text{kWh/year} \qquad (1)$$

Where

V	=	Total volume of premises where smoking is allowed	m^3
n	=	Air change rate in the smoking case	h^{-1}
f	=	Part of air change rate depending on smoking	-
ρ	=	Density of air (1.2)	kg/m^3
c_p	=	Heat capacity of air (1.0)	kJ/(kgK)
D	=	Degree-hours (24 times degree-days)	Kh/y

Putting the deduced values into formula (1) gives:

$$Q = 10 \cdot 10^9 \cdot 0.9 \cdot 0.35 \cdot 1.2 \cdot 1.0 \cdot 2700 \cdot 24/3600 = 68 \cdot 10^9 \text{kWh/y}.$$

Thus the extra energy demand is about 70 TWh/y

With the price for energy of 0.055 ECU/kWh (0.063 US$/kWh) the total extra cost is calculated to be $3.7 \cdot 10^9$ ECU/y ($4.3 \cdot 10^9$ US$/y)

6. Discussion

Domestic building ventilation.

In this paper the scope has been to discuss the influence of energy use and cost caused by indoor smoking in non-domestic buildings. It is, however, interesting to notice that extra ventilation need in domestic buildings caused by smoking habits is of the same magnitude as that in non-domestic areas. The extra ventilation can be achieved by more frequently opened windows or by increasing speed of fans.

In the U.S.A. and some other countries where mechanical ventilation is widely used the amount of treated outdoor air often has been chosen so as to allow smoking generally. In Europe where natural ventilation is the most frequent system it is assumed that the needed extra outdoor air is povided by window-airing. It is reasonable to assume that this extra ventilation is in the order of 0.1 to 0.2 air changes per hour during the heating season.

Non-domestic building size.

The estimation on non-domestic building volume is based on the relationship between domestic and non-domestic buildings in two countries (Sweden and France) may have underestimated the area of non-domestic buildings. One reason is that figures available only present useful living floor area while heated area can be assumed to be about 30 % larger. The total volume of non-domestic buildings should be corrected accordingly.

Climate, additional heating

Possible error in the estimated degree-days calculated is most probably towards the negative side. Thus an additional energy use caused by underestimation in the order of 20 % is reasonable for both Europe and North America.

Climate, additional cooling

Additional cooling of extra ventilation air is unavailable if the control of recirculation is inadequate or if necessary filtration of return air is not installed. A minimum of 10 % of heating energy is probable. The maximum level is hard to judge, but might be up to 40 %.

Air change rate

The air change rate is sometimes lower but very often also higher than that prescribed by standards or codes. Most probably the air change rate in buildings, where smoking is allowed, is at the higher values, see table 5. Choosing a moderate value of 15 l/(s·p) from that table would double the air change rate cost shown in section 5.

Summarization

The discussion above leads to a possibility of summarizing to minimum, maximum, and average levels of cost for indoor smoking. Figures are presented in table 6.

Table 6. Summarization of discussed heating costs for ventilation caused by indoor tobacco smoking in AIVC countries

Item	Cost caused by indoor smoking. Million ECU/y		
	Lower	Upper	Average
Non-domestic	3700	5200	4800
Domestic	4000	5000	4500
Climate, heating	-1600	2000	0
Climate, cooling	800	1600	1200
Air change rate domestic	0	4800	2400
non-domestic	0	5000	2500
Summary	6900	23600	15400

For Sweden only, representing about 1,3 % of the AIVC energy turnover found in this paper, the extra cost of energy used because of indoor tobacco smoking is in the order of 100-300 million ECU/year. That amount is equal to the yearly profit (ref 18) after taxes shown by the Swedish Tobacco Company!

7. Conclusion

Even if the number of smokers seems to be stable in the developed countries still many young people start smoking. The main aim must be to reduce the smoking habit to increase the quality of both the outdoor and the indoor environment. By quitting smoking we can reduce the energy use and hence the pollutants from energy production plants.

We can see that tobacco companies try to increase the smoking habit in the developing countries and specially amongst the younger women. If this trend can be stopped we can also save energy that would else be used for cooling or heating the indoor environment.

The ambivalence shown by the politicians is, however, of a great magnitude. Many governments have not dared to tackle the multidiciplinary problems with tobacco smoking with the implications on tax revenue, employment, export income, health and welfare expenditure, energy cost etc.

The bill has to be paid by both smokers and non-smokers. Extra energy use caused by indoor smoking in non-domestic buildings outside industry production is at least about 3700 million ECU (4000 million US$) annually in the 14 AIVC countries.

8. References

1. ASHRAE Handbook 1989, Fundamentals. ISBN 0-910110-57-3.

2. CEN/TC156/WG6. Working documents on indoor air quality.

3. A. Elmroth, P. Levin. Air Infiltration Control in Housing. Swedish Council for Building Research D2:1983. ISBN 91-540-3853-7

4. C. Chollat-Traquet. Women and Tobacco. WHO, Geneva 1992. ISBN 92-4-156147-5.

5. E. Hedman (ed). Swedish Housing Market in an International Perspective (in Swedish). National Board of Housing, Building, and Planning, Report 1993:2. ISBN 91-38-12860-8.

6. The Swedish Building Code 1980 and 1988:18. National Board of Housing, Building, and Planning. ISBN 91-38-05209-1 and 91-38-09758-3.

7. L-G Månsson, S.A. Svennberg. Demand Controlled Ventilating Systems, Source Book IEA Annex 18. Swedish Council for Building Research D2:1993. ISBN 91-540-5513-X.

8. The use of tobacco products in Sweden (in Swedish). The Swedish Board for Public Health. Report 1986:9. ISBN 91-38-09131-3.

9. ASHRAE Standard ANSI/ASHRAE 62-1989 Ventilation for Acceptable Indoor Air Quality. ISSN 1041-2336.

10. J. Sundell, G. Lönnberg, S. Wall, B. Stenberg, P.A. Zingmark. The Office Illness Project in Northern Sweden. Indoor Air 1990 Toronto vol 4.

11. M.E. Baldwin, J-P. Farant. Study of Selected VOCs in Office Buildings at Different Stage of Occupancy. Indoor Air 1990 Toronto vol 2.

12. P. Skov, O. Valbjörn. The Danish Town Hall Study. Indoor Air 1990 Toronto vol 1.

13. J.J.K. Jaakkola, O.S. Miettinen, K. Komulainen, P. Tuomaala, O. Seppänen. The Effect of Air Recirculation on Symptoms and Environmental Complaints in Office Workers. Indoor Air 1990 Toronto vol 1.

14. V.L. Putnam, J.E. Woods, D.R. Rask. A Comparison of CO_2 Concentrations and Indoor Env. Acceptability in Commercial Buildings. Indoor Air 1990 Toronto vol 3.

15. R.A. Grot, A.T. Hodgson, A. Persily. IAQ Evaluation of a New Office Building. Indoor Air 1990 Toronto vol 3.

16. J.O. Säteri. The Development of the PFT-Method in the Nordic Countries. Swedish Council for Building Research D9:1991. ISBN 91-540-5317-X

17. L-G. Carlsson. Energy use in non-industrial buildings (in Swedish). Swedish Council for Building Research R30:1992. ISBN 91-540-5476-1.

18. Tobacco Act. Committee for Tobacco Control. Allmänna förlaget Report SOU 1990:29. ISBN 91-38-10545-4.