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Natural Ventilation Strategies to Mitigate Passive Smoking in Homes

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SYNOPSIS

This paper investigates possible natural ventilation strategies to reduce exposure to environmental tobacco smoke (ETS) in dwellings. Particular attention is paid to the migration of tobacco smoke from the living room (usually the smoking room) to the bedrooms which may be occupied by children. This addresses an area of current concern regarding the possible association between passive smoking and adverse health conditions; in particular the link between parental smoking and respiratory illness in children.

The study used the multizoned airflow prediction program BREEZE to evaluate the movement of tobacco smoke from the smoking rooms to the bedrooms in typical detached, semi-detached and terraced dwellings for a variety of natural ventilation strategies. Typical smoking patterns were emulated and contaminant movements analysed, taking into account factors such as wind speeds and direction and air temperatures. Some of the results obtained were compared with limited full-scale measurements acquired elsewhere to provide the necessary confidence in the predictions.

Controlling pollutant concentration by ventilation can be an energy intensive process, especially during the heating and cooling season. Since almost all dwellings in the U.K. are naturally ventilated, providing optimum ventilation with minimum ventilation heat loss is of concern only during the heating season. Results from the study indicate three possible strategies to mitigate the effect of passive smoking in dwellings; two which could be used during the heating season and one for the remaining times of the year.

INTRODUCTION

Environmental Tobacco Smoke and Health Effects

In 1988 the UK Independent Scientific Committee on Smoking and Health published a report which concluded that there was "a small increase in the risk of lung cancer from exposure to environmental tobacco smoke." This increase was in the range of 10 to 30% and was calculated to amount to several hundred out of the current annual total of about 40,000 lung cancer deaths in the UK [1]. Reports with similar conclusions have also been published in other countries [2]. It is also believed that the impact of ETS on people with respiratory illnesses may be larger than the impact indicated by its carcinogenic effects [3]. ETS can impair the respiratory health of children. In particular, during a child's infancy, ETS is associated with increased prevalence of acute lower-respiratory tract infections such as bronchitis and pneumonia; also with increased prevalence of fluid in the middle ear, symptoms of upper respiratory tract irritation, a small but significant reduction in lung function and with additional episodes and increased severity of symptoms in children with asthma. ETS exposure is a risk factor for new cases of asthma in children who have not previously displayed symptoms. Finally, research [3, 4] indicates a linkage with other health effects including coronary heart disease and hazard to the foetus during pregnancy. For the above reasons, ETS is considered a most important contaminant of indoor air and 'no smoking' or 'restricted smoking' policies are established in many work and leisure environments. However, regulation cannot be imposed on people in their homes, although passive smoking is potentially as harmful in houses as in work places. The effect is considered to be more severe in babies, small children, young and old people.

In addition to these health effects, ETS in buildings has an energy cost through increased ventilation necessary to dilute and/or remove the pollutant. This cost is estimated [5] to be about 4500 million ECU/year in domestic buildings within the 14 countries participating in AIVC (approximately £3400 million//year).

ETS in houses

ETS distribution and removal in houses has received less attention than in commercial buildings. A recent field study on the distribution of ETS in homes [6] concluded that smoking in the home will expose non-smoking occupants to tobacco smoke throughout the home at levels which could represent a health threat. In addition, another study has demonstrated that high relative humidity (RH) levels increase perception of annoyance and nasal irritation from ETS [7]. Bearing in mind that RH levels are usually high in UK bedrooms, this finding has a direct consequence regarding the effect of ETS on non-smokers.

Approach used in the present study

In the UK, almost all dwellings are naturally ventilated. This paper addresses ways of minimising the effects of ETS in bedrooms using natural ventilation strategies. BREEZE, an airflow/contaminant multizoned computer model [8] was used to assist in this analysis. It was used to predict ETS contaminant concentrations within three typical UK house types and to assess the ETS risk in bedrooms.

ANALYSIS PROCEDURE

Computer Model

BREEZE is a suite of integrated and user-interactive computer programs to evaluate ventilation rates and inter-zonal airflows in buildings, from single-celled to large multi-storey, multi-celled buildings. The building is taken to consist of a number of inter-connected zones with air moving from zones at high pressure to those of low pressure. The pressure differences are set up both by the actions of wind on the external surface of the building and by the temperature difference between air inside and outside.

In BREEZE, the user describes the geometry of the building by drawing the plans of the building on screen. He then superimposes air paths onto these plans, each air flow path being a window, a door, a crack, a vent or a fan.

BREEZE also includes a contaminant analysis routine which, given a contaminant emission, employs an adaptive step-length method to determine cell concentration histories and determine the time weighted average (TWA) for user set-time intervals. Possible contaminant sources can include those from outside air, sources within rooms or pollutants released from surfaces. Adsorption and desorption by surfaces can also be addressed. User contaminant inputs include emission rate, initial concentration and adsorption characteristics.

Housing types

Three types of houses were used for the analysis; one detached, one semi-detached and one terraced house. These are typical housing units in the UK and they are all two-storey structures. Their size, layout and window areas have been taken from 'benchmark' buildings developed for thermal modelling [9]. The plans of the houses are shown in Fig 1. It can be seen that they differ in size, internal layout and exposure to outside elements.

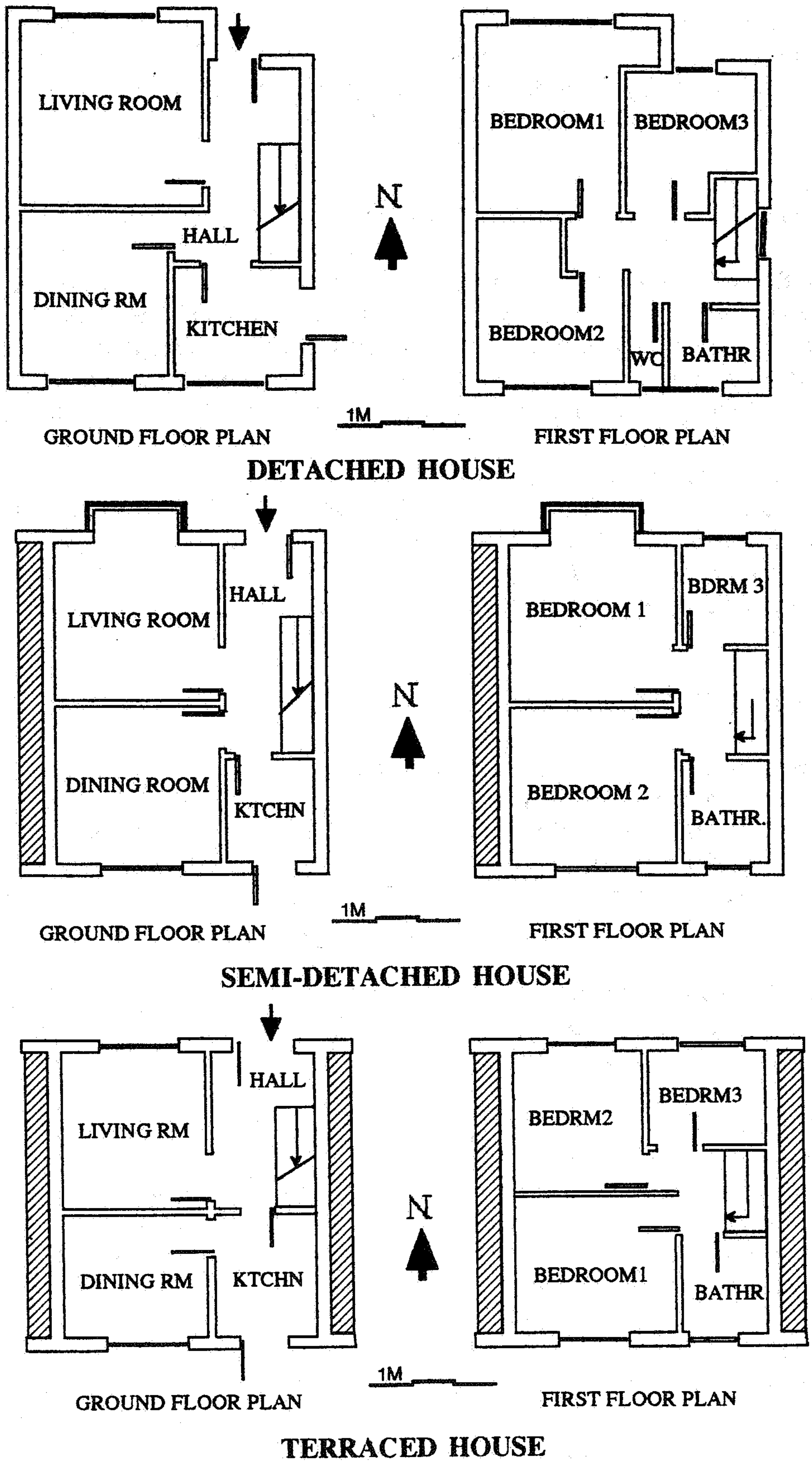


Figure 1: Floor plans of the detached, semi-detached and terraced housing types.

The ventilation strategies that were simulated fall into two categories:

a) preventing the spread of ETS from the source; and

b) diluting ETS concentration levels remote from source by fresh air ventilation.

Prevention (strategy a) is made possible by rapidly ventilating the smoking room, while dilution is carried out by removing the ETS that has migrated from the smoking room to the rest of the house. In these simulations, fresh air to remove and dilute is provided through external openable windows. Trickle ventilators, complying with the UK Building Regulations [10], are provided in each room of the house.

The following ventilation strategies were examined:

trickle ventilators; closed or open, upstairs or downstairs;

position of internal doors; closed or open;

opening windows;

operating extractor fans in the kitchen or bathrooms.

In all 21 simulations were carried out for each of the housing types (Table 1).

Table 1: House openings' configuration

Simulation Number	Windows	Internal doors	Trickle Ventilators
1	all closed	all closed	all open
2	all closed	all closed	all closed
3	all closed	all closed	closed upstairs
4	all closed	all closed	closed downstairs
5	all closed	s/r open	all open
6	all closed	b/r open	all open
7	all closed	b/r closed	all open
8	all closed	s/r closed	all open
9	all closed	all open	all open
10	all closed	all open	all closed
11	all closed	all open	closed upstairs
12	all closed	all open	closed downstairs
13	s/r open, ($0.1m^2$)	all closed	all open
14	b/r open. ($0.05m^2$)	all closed	all open
15	s/r open, ($0.1m^2$)	s/r closed	all open
16	s/r open, ($0.1m^2$)	b/r closed	all open
17	s/r open, ($0.1m^2$)	all open	all open
18	b/r open, ($0.05m^2$)	all open	all open
19	s/r + b/r open	s/r closed	all open
20	all closed	b/r closed	all open*
21	all closed	b/r closed	all open~

Note: s/r - smoking room, b/r - bedroom

* A fan is operated in the bathroom with extract flow rate 15 l/s

~A fan is operated in the kitchen with extract flow rate 30 l/s

Weather conditions

The outside air temperature was taken as 0°C to take into account winter conditions and the wind speed 4m/s. Wind from twelve equispaced directions were simulated for each of the ventilation strategies. Pressure coefficients were selected from a database available for UK houses [11]. Internal temperatures were fixed as 21°C in the living room, 20°C in all the other downstairs rooms and 17°C in the upstairs bedrooms.

Simulating cigarette smoking

Carbon monoxide (CO) and respirable particulate matter were used as markers for ETS. Although, these are two of the most important components in ETS, they are sometimes criticised as markers for ETS. This criticism usually refers to field studies where there is interference from other pollution sources [12]. However, this is not a problem in modelling.

The ETS simulation assumed light smoking by one adult in the household and, in this case, was represented by three cigarettes per hour being smoked in the living room (nominated as the smoking room) over a period of two consecutive hours. In this study we used an emission value of 34.4 mg/cigarette of particulate and CO together obtained from the EPA Indoor Air Database [13]. This is equivalent to an emission rate of 1.72 mg/min.

This study did not consider adsorption/desorption of ETS by internal surfaces although this does play an important part in ETS migration. However, it was considered that a useful investigation could still be undertaken to assess different ventilation strategies without including adsorption/desorption.

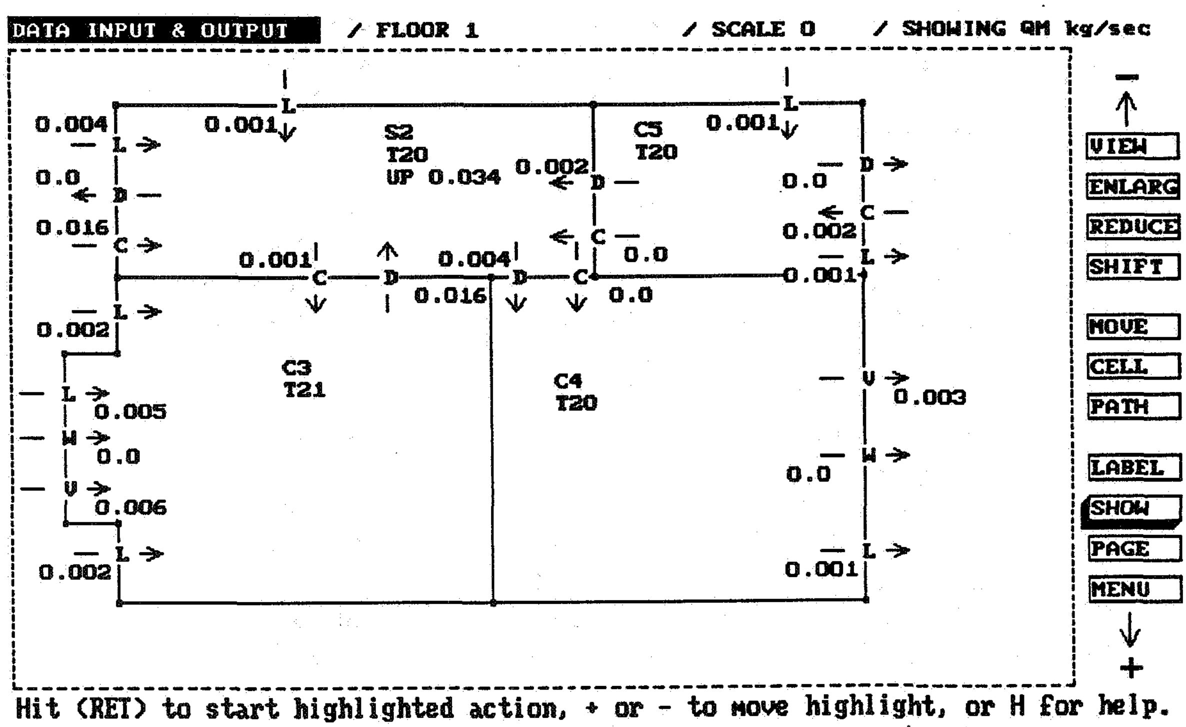


Figure 2: Graphical output from BREEZE. It shows the ground floor of the semi-detached house for one of the simulations.

SIMULATION RESULTS

Table 1 lists the ventilation strategies simulated. Figure 2 shows an example of the air flow results produced by BREEZE. The numbers indicate the air flow in kg and the arrows the direction of the flow. The symbols on the walls stand for doors (D), windows (W), ventilators (V), leakage (L) and crack (C). The symbols inside the rooms indicate a cell (C) or a stairwell (S). In addition the temperature of the rooms is shown (T).

BREEZE output also includes the pollutant concentrations from which TWA values are calculated and displayed. In these simulations, 15-minute TWAs of the combined concentration of CO and particulate matter were calculated for each of the simulations. Figure 3 shows examples of the individual simulation results for the twelve wind directions for the case of the terraced house.

Internal doors and windows closed

Figure 3a shows results from simulation # 1 with internal doors and external windows closed but with trickle ventilators open. The resulting air change rate for the whole house is 0.7 per hour, an average value for the 12 wind directions. ETS concentrations are highest for wind direction east to west with the smoking room facing north. The ETS concentration is high in the smoking room (average value 4 ppm with a minimum of 2 ppm for wind direction 0°(North), and a maximum of 5.5 ppm for wind direction 90° (east) and 270° (west). However, the concentration in the upstairs bedrooms is considerable lower, < 1 ppm in all cases (Fig 3a). Because of the high concentration in the smoking room ETS will migrate to the bedrooms long after smoking has ceased.

Internal doors open and windows closed

Figure 3b shows the results of simulation # 9 where all the internal doors were now opened. Compared to simulation # 1, the air change rate has increased by about 25% to 0.9 per hour. As a result, the ETS concentration in the smoking room is now reduced considerably to an average value of 1.5 ppm and in the bedrooms is lower than 1 ppm for all wind directions. As in the previous case, ETS concentration is greater for wind direction east to west with the smoking room facing north.

Smoking room window open

Figure 3c shows the results of simulation # 15 where the smoking room door is now closed and the window is kept slightly open. All other internal doors open are still kept open. The whole house air change rate has increased to 1.2 per hour. The ETS concentration in the smoking room is now less than 1 ppm for all wind directions and the concentration in the bedrooms. becomes very small (less than 0.25 ppm in all cases).

Extractor fans

Figure 3d shows the results of simulation # 21 where an extractor fan with flow capacity of 30 l/s (as required by the 1990 Building Regulations for England and Wales for removal of excess humidity [10]) was operated in the kitchen during the 2 hrs that smoking took place in the living room. All windows in the house are assumed closed, trickle ventilators open and the bedrooms' doors closed to reduce migration of ETS. The ETS concentration in the living room is less than 1.5 ppm and the concentration in the bedrooms is very small.

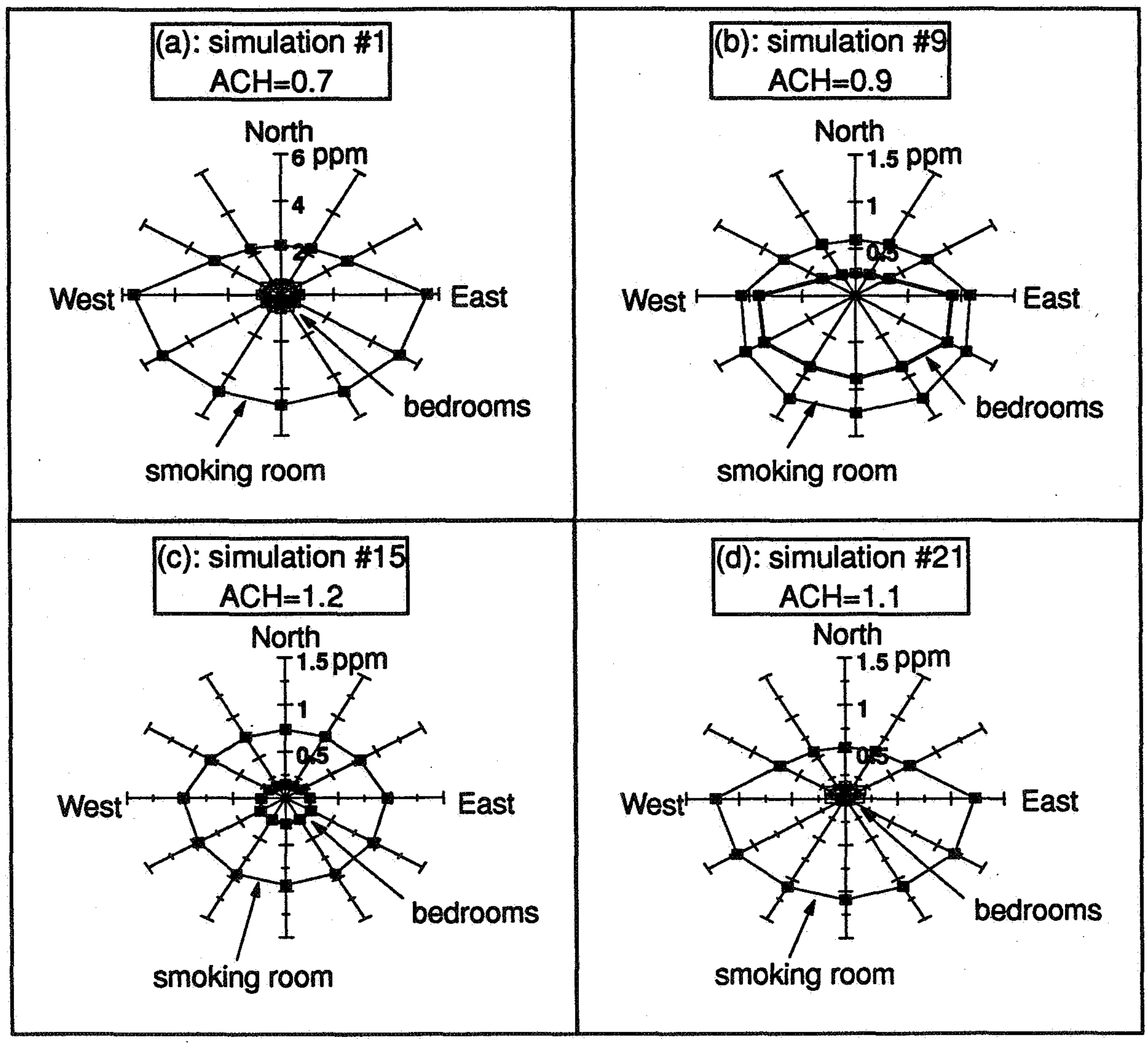


Figure 3: ETS concentration in the smoking room and the three bedrooms for 12 wind directions for four simulations. The wind speed is 4m/s, internal temperature 17-21°C and the external temperature 0°C.

Summary of simulation results

Figure 4 shows the mean TWAs for the 12 wind directions for all the simulations. The whole house predicted air change rate is shown on the graph. The lowest concentration of ETS is observed in the detached house and the highest in the terraced house. Air change rates are higher in the terraced house than in the detached. The higher concentration of pollutants could be attributed to the difference in their volumes, ie the pollutants are diluted more in the bigger volume of air of the detached house. Common sense suggests that smaller dwellings like flats and maisonettes might be more problematic. It should be noted that, many young families tend to live in smaller accommodation where babies might be exposed to higher ETS levels for similar smoking patterns. It is a similar problem to the one where high moisture levels are usually more evident in small densely occupied dwellings.

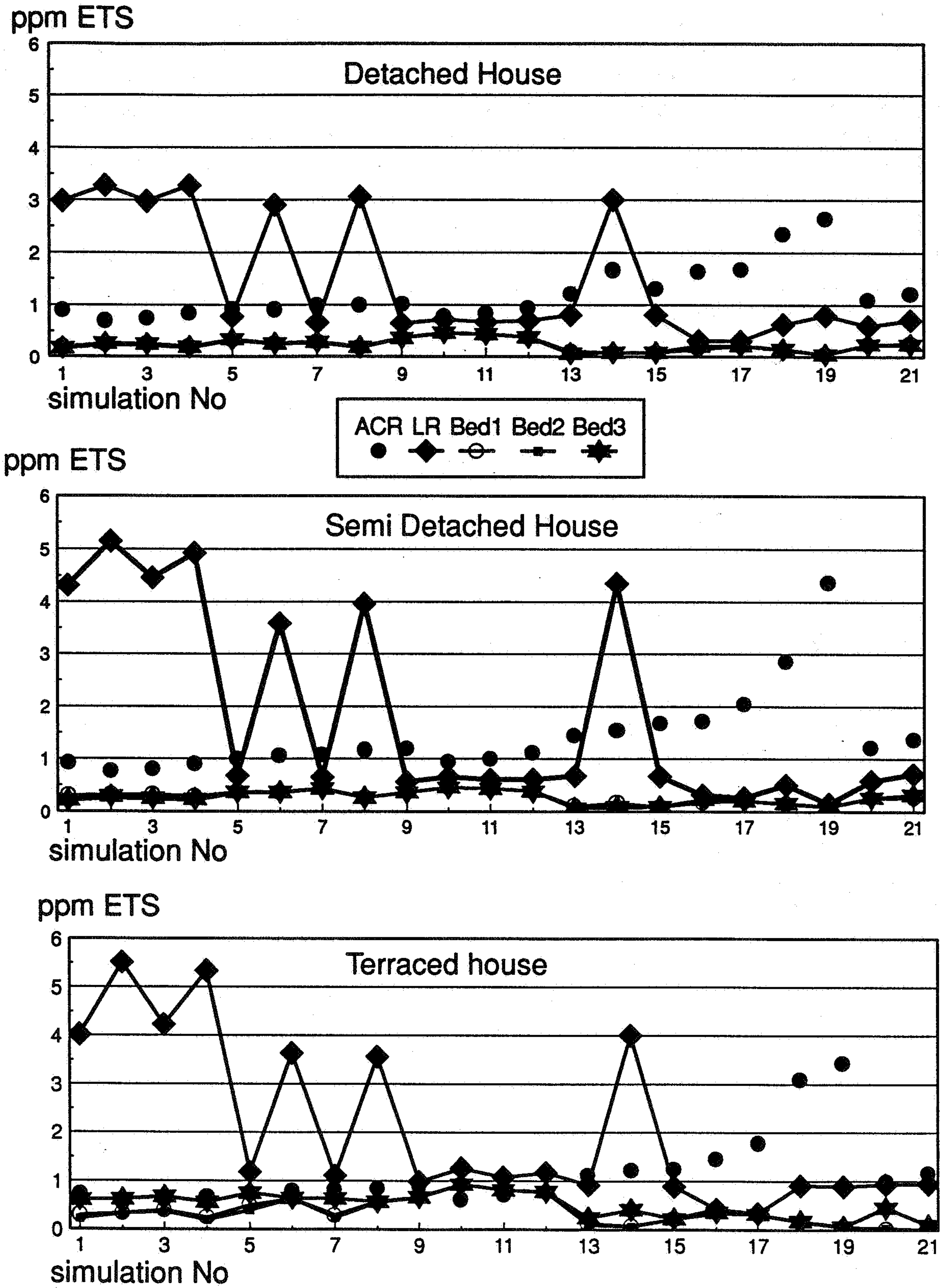


Figure 4: The average concentrations of ETS and air change rates for the three housing types for the 12 wind directions. The wind speed is constant at 4m/s, the external temperature 0°C and the internal temperature 17-21°C.

This suggests that measures that have been used to reduce problems associated with high moisture levels in homes could be also useful for the extraction of ETS pollutants. This strategy was investigated with simulations 20 and 21. It was found that using a (kitchen or bathroom) fan, the air change rate increased marginally (as expected) but that the ETS concentrations were considerably reduced; compared with simulations where the windows were kept closed. On average, kitchen or bathroom extract devices can more than halve the concentrations in the bedrooms.

However, these concentrations can be further reduced if windows are opened instead. There are exceptions such as when using the kitchen fan in the terraced house where concentrations are lower than in cases with open windows. This finding poses a dilemma as to which is the best approach and the choice would depend on external conditions (cold or warm days)

During warmer days, ETS levels can be kept low throughout (simulation no 19) by closing the smoking room door whilst opening windows in the smoking rooms and the bedrooms and leaving all other internal doors open. This will also provide enhanced ventilation for cooling.

Another interesting observation concerns the presence of trickle ventilators. Their effect could be seen in the smoking room for simulation 1 to 4. Opening the trickle ventilators affects the ETS concentration in the living room only marginally. Although the effect is shown to be small in this particular case, it might be significant for other internal pollutants such as metabolic CO_2 both in houses and commercial buildings.

Comparison with field studies

The results presented here were compared with measurements carried out in a recent field study of ETS in houses [6]. In that study, measurements were carried out with the doors of the house open. The air change rate was measured between 0.5-1.0 per hour and the smoking session lasted 4.5 hrs with a frequency of one cigarette every 20 to 30 mins. Particulate matter in the range of 330-500$\mu g/m^3$ (equivalent to 0.4-0.6 ppm) was measured. This is similar to simulations # 9 to 12 in our study where the particulate matter ranged between 0.2 and 0.45 ppm assuming a 1:2 split between CO and particulate matter.

Similarly, CO and respirable dust was measured in a range of renovated Dutch homes[15]. Respirable dust was found to be a problem in smokers' houses and measurements in the range of 2000 $\mu g/m^3$ (approximately 2.5 ppm) were observed in rooms where people smoke. This is certainly consistent with our simulations which indicate that particulate concentrations could range between 0.5 and 4.5 ppm during smoking in the smoking room and the concentration depends both on the pollutant removal strategy and on the ventilation rate.

CONCLUSIONS

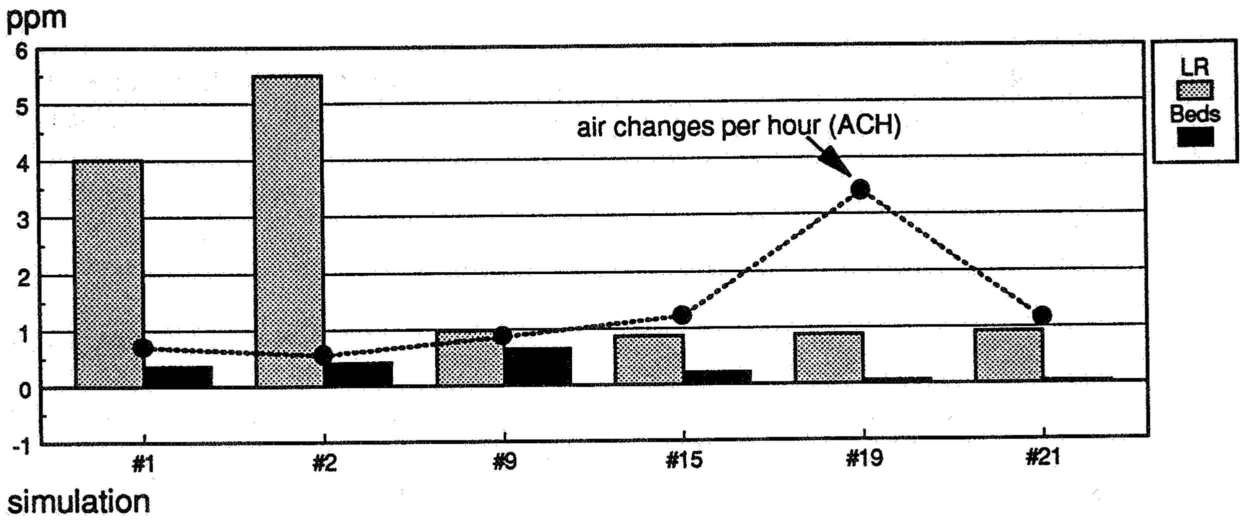
This is the initial phase of a programme of the work for DOE Toxic Substances Division to investigate various simple natural ventilation strategies which could mitigate the effect of ETS on children in their bedrooms caused by tobacco smoking in the living room. The multizoned air flow and pollution transport software package BREEZE was used to simulate the transport and time-averaged concentration for various internal door and external opening configurations and a variety of external conditions to include different wind directions and temperature ranges.

We considered the impact of two obvious ventilation strategies to assess this evaluation process. The strategies considered here are;

a) isolation of the source and,

b) dilution of the contaminant.

In summary we can extract the key cases which provide us with alternative suitable strategies which are discussed below. Figure 5 shows the simulation results for the case of the terraced house.



simulation	windows	internal doors	trickle vents	fans
1	closed	all closed	open	off
2	closed	closed	closed	off
9	closed	all open	open	off
15	s/r open	s/r closed	open	off
19	s/r+b/r open	s/r closed	open	off
21	closed	b/r closed	open	kitchen 30l/s

Figure 5: The ETS concentration levels in the terraced house for six alternative ventilation strategies

During the heating season, the best protection is to prevent the spread of ETS by opening the smoking room window slightly and closing the smoking room door. In this way, low concentrations of ETS are established in the smoking room and in the rest of the house. The position of the internal doors in the rest of the house does not have any significant effect on the migration of ETS. However, extract devices such as fans or passive stack ventilators usually installed for humidity control in the bathrooms and kitchens could be used alternatively to reduce the concentration levels considerably without the uncomfortable effects of opening windows during cold days in winter. Using the kitchen fan appears to be more effective in smaller dwellings. In the larger house the bathroom or kitchen fan appear to be equivalent and produce relatively smaller changes. This is due to the large volume of air in the building which helps to dilute the ETS.

During warmer days, an alternative approach is to open the windows in the bedrooms, but still keeping the smoking room internal door closed and its window open. Higher air change rates will be created this way which will help to dilute the ETS further.

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