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COMPUTATIONAL INVESTIGATION OF VENTILATION STRATEGIES TO REDUCE EXPOSURE TO NO_2 AND CO FROM GAS COOKING

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ABSTRACT

Gas cooking in the home can release high levels of nitrogen dioxide (NO_2) and carbon monoxide (CO). This study investigated the effect of various ventilation strategies to reduce personal exposure to these pollutants. It considered the effectiveness of windows, a kitchen extract fan and trickle ventilators for different dwellings, occupant behaviour, environmental conditions etc. Strategy selection was based on the need to minimise both personal exposure and energy loss. These strategies were simulated using BRE's BREEZE multi-zonal computer code. The results showed that it is best to: (a) use a window/ windows (where energy-loss acceptable) or a kitchen fan, and, (b) open all internal doors. However, whilst opening kitchen doors may be the best option for NO_2 and CO, it may not be appropriate for other combustion products, such as moisture and odours.

KEYWORDS

Gas cooking, residences, nitrogen dioxide, carbon monoxide, multi-zonal, modeling, ventilation

INTRODUCTION

During gas cooking, NO_2 and CO are emitted into the room air. Studies suggest that in many UK homes that use gas for cooking, short-term levels of one or both of these pollutants regularly exceed World Health Organisation health-based air quality guidelines, e.g. Ross (1996, 1999). Therefore there is concern that many people are being exposed to harmful levels of pollution from gas cooking.

Ventilation is the most common planned approach to reducing levels of pollution in buildings. Approved Document F to the Building Regulations (England and Wales) provides guidance on ventilation in the home to restrict the accumulation of pollutants originating within the building, where such pollutants would otherwise become a hazard to the health of the people within.

The purpose of this study was to investigate the effect of using various ventilation strategies, some based on the guidance in Approved Document F to the Building Regulations, to reduce personal exposure to NO_2 and CO from gas cooking. These strategies were simulated using BRE's BREEZE computer program, which can model the air and pollutant movement in a building.

BREEZE

BREEZE is BRE's multi-zonal computer program to evaluate ventilation rates and airflows in buildings. The building is taken to consist of a number of inter-connected zones (typically a zone is a room) with air moving from zones at higher pressure to those of lower 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 addition to mechanical ventilation devices. BREEZE includes a contaminant analysis routine. It can allow for external sources, sources within rooms, pollutants released from surfaces and adsorption/desorption at surfaces can be modelled.

BREEZE also includes a 'consecutive analysis' routine: most input parameters (e.g. internal and external temperatures, wind speed and direction, ventilation opening areas) can be varied over time within a single run. Thus the effect of gas cooking on indoor pollutant levels can be modeled over an extended period of time, allowing for occupants' cooking and ventilation use patterns and variable environmental conditions.

For this study, BREEZE was set up to provide: (a) hourly averaged data for NO_2 and CO in each room in each house, and, (b) hourly data of the space heating gain and the air exchange rate for the whole house.

PARAMETERS FOR MODEL

Ventilation Strategies

Table 1 provides details of the ventilation devices used and their patterns of use. Eight basic conditions were selected, based on the guidance on ventilation provisions given in Approved Document F and others thought to be of interest. Case 1 is the base condition in which no ventilators are used.

TABLE 1
DESCRIPTION OF THE EIGHT VENTILATION STRATEGIES

Number	Ventilator(s)	Time used	Open area or fan extract rate
1	None	Not used	None
2	Kitchen window	During cooking	1/20th of floor area
3	Kitchen window	Constantly	1/20th of floor area
4	Kitchen window	During cooking	Fully open
5	Kitchen and living room windows	During cooking	1/20th of floor area
6	Kitchen fan	During cooking	60 l/s extract
7	Kitchen fan	During cooking and one hour afterwards	60 l/s extract
8	All trickle ventilators	Constantly	8000 mm^2 for habitable rooms 4000 mm^2 for other rooms

Dwellings

Both a two-storey terraced house (treated as an infinite row of houses) and a detached house were modeled. They had identical floor plans and are shown in Figure 1. Each floor was 2.3 m high and all doors were 0.8 m wide and 2.05 m high. The internal doors had a gap of 5 mm below and 1.5 mm around the other three sides. The window areas in the kitchen and living room were 0.89 m^2 and 1.50 m^2 respectively (no other windows were used). BRE's database of air leakage rates in UK dwellings gives a mean value of 13.1 air changes per hour at 50 Pa. This leakage was spread uniformly over all external walls and the roof.

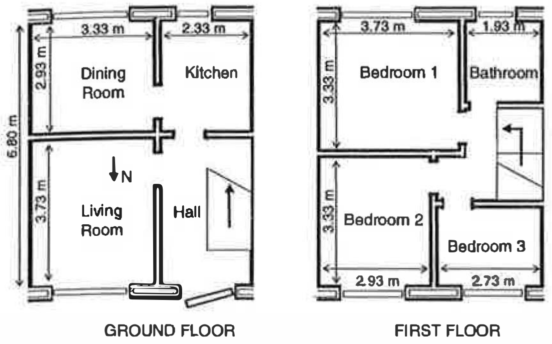

Figure 1: Plan of two-storey house

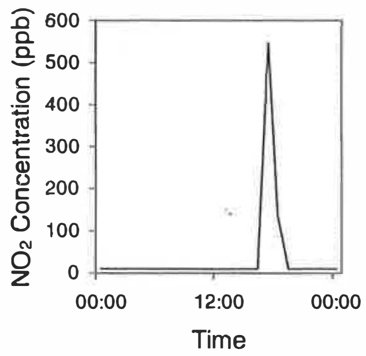

Figure 2: NO_2 concentration in the kitchen

Internal door positions

Three internal door positions were considered: (i) all internal doors closed, (ii) both kitchen doors fully open and all others closed, and, (iii) all internal doors open. A combination of one of the eight 'ventilation options' and one of the three 'door positions' is referred to as a 'ventilation strategy'.

Temperature

A difference between the internal and external temperatures creates a flow of air inside the house. The results would be expected to show a seasonal effect. With the large number of runs required, it was too time-consuming to model the entire year. A simpler alternative was to model a week in summer and a week in winter. The external temperature data were obtained from a set of Test Reference Years - TRYs (1985). Hourly weather data for London (Kew) were used for the first week in January and the first week in July. The internal temperatures were: (a) 18.5°C for the living rooms, and, (b) 16.5-17.0°C for all other rooms (range to provide mixing between adjacent rooms). During cooking, the kitchen temperature was raised to 19°C.

Wind

The air flow inside the house is also dependent on the pressure differences set up by the action of the wind on the external surfaces. BRE (1982) suggests that a typical wind speed for the UK is 4 ms^{-1}. To minimise the number of variables, a constant value of 4 ms^{-1} was used. Sensitivity analysis was performed for a wind speed of 0 ms^{-1}. Twelve wind directions were modeled: 0° to 330° in 30° incremental steps. The wind pressure coefficients were obtained from the BREEZE Cp database.

Cooking pattern

To best compare the effect of different ventilation strategies, a simple cooking pattern was used. The cooker was on from 5 - 6 p.m. each day. Sensitivity analysis assessed the effect of the time period chosen.

Source emissions and sorption

Based on a literature review, gas cooking emission rates of 0.1 $g.hr^{-1}$ and 0.5 $g.hr^{-1}$ were used for NO_2 and CO respectively. From the BRE indoor air quality database, the outside levels of NO_2 and CO were assumed to be 21.2 $\mu g.m^{-3}$ and 0.40 $mg.m^{-3}$. NO_2 is removed from the indoor air through sorption by indoor surfaces. A sorption rate of 0.84 hr^{-1} was estimated using indoor and outdoor levels of NO_2 for homes with no known sources (using BRE's indoor air quality database). Sorption is negligible for CO.

RESULTS

Room concentrations

Figure 2 shows an example of hourly averaged NO_2 concentrations in the kitchen for a day. A daily peak occurred due to cooking. Figures 3a-c show the variation of maximum hourly-averaged NO_2 concentration with wind direction for the kitchen, living rooms (maximum of the dining room and living room) and bedrooms (maximum of all three bedrooms) respectively for the terraced home with all internal doors closed and the wind blowing towards the north. The highest level in the kitchen occurred for the wind blowing from the north as the wind and stack forces act in reverse directions through the kitchen. Similarly the highest level for the living rooms occurred with the wind blowing from the north. This was due to the wind force being dominant, driving highly polluted air from the kitchen to the dining room. Finally the highest level in the bedrooms occurred with the wind blowing from the south. In this case the wind and stack forces combine to drive the NO_2 from the kitchen into the hallway and up the stairwell.

Many cases were modeled. Overall, all the results showed wind dependency. The terraced results were symmetrical about the vertical axis, as the dwelling was treated as part of an infinite row of homes, whereas this symmetry was not evident for the detached home. As more internal doors were opened, the results became less wind dependent due to the greater mixing of air with neighbouring rooms. The effect of using additional ventilators was to increase ventilation and reduce concentrations.

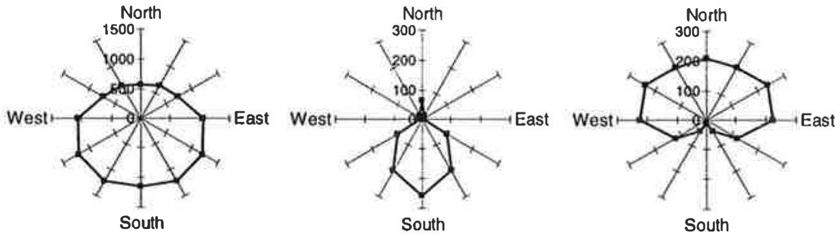

Figure 3: NO_2 concentration in: (a) the kitchen, (b) living rooms, and, (c) bedrooms

Selection by energy criteria

A simple energy criterion was used. Each ventilation strategy had to incur no net energy loss (i.e. space heating gains from cooking exceeded space heating losses from additional ventilators). Based on thermal data, the space heating gain from cooking an evening meal was 1.45 kWh. Results for each strategy were averaged over all wind directions. Ventilation options 3-5 were not acceptable during the winter period.

Selection by personal exposure

We initially considered the exposure of a person: (a) in the kitchen, and, (b) in the room of maximum exposure (apart from the kitchen). The maximum value was determined for each wind direction (typically during cooking) and the mean taken. However as this mean value was always greatest in the kitchen, and the purpose was to limit the maximum exposure, the study focused on exposure in the kitchen.

The strategies were ranked by dwelling type, season and pollutant. Tables 2-5 show the best six strategies for each parameter. The ranking is similar, if not the same, for each pollutant. Overall the results suggest it is best to:

- use a window/windows (where energy-loss acceptable) or a kitchen fan;
- open all internal doors (in some cases, it is acceptable to open only the kitchen doors).

TABLE 2

BEST STRATEGIES FOR TERRACED HOME IN SUMMER

Vent No.	Door Pos. No.	NO_2 Conc. (ppb)
5	3	56
4	3	146
6	3	150
7	3	150
2	3	153
3	3	155

Vent No.	Door Pos. No.	CO Conc. (ppb)
5	3	0.78
7	3	1.62
6	3	1.66
3	3	1.66
4	3	1.68
2	3	1.81

TABLE 3

BEST STRATEGIES FOR TERRACED HOME IN WINTER

Vent No.	Door Pos. No.	NO_2 Conc. (ppb)
2	3	116
2	2	134
6	3	148
7	3	148
6	2	173
7	2	173

Vent No.	Door Pos. No.	NO_2 Conc. (ppb)
2	3	1.25
2	2	1.40
6	3	1.59
7	3	1.59
6	2	1.80
7	2	1.80

TABLE 4

BEST STRATEGIES FOR DETACHED HOME IN SUMMER

Vent No.	Door Pos. No.	NO_2 Conc. (ppb)
5	3	29
5	2	104
4	3	122
2	3	127
3	3	128
6 or 7	3	143

Vent No.	Door Pos. No.	CO Conc. (ppb)
5	3	0.46
5	2	1.12
4	3	1.31
2	3	1.36
3	3	1.36
3	2	1.52

TABLE 5

BEST STRATEGIES FOR DETACHED HOME IN WINTER

Vent No.	Door Pos. No.	NO_2 Conc. (ppb)
2	3	104
2	2	117
6	3	143
7	3	143
6	2	166
7	2	166

Vent No.	Door Pos. No.	NO_2 Conc. (ppb)
2	3	1.13
2	2	1.24
6	3	1.52
7	3	1.52
2	1	1.67
6	2	1.72

Sensitivity analysis

Wind speed and direction

A zero wind speed was modeled for selected strategies. This is a 'worst case scenario' for ventilation as it removes the wind-driven force (in practice there would always be some air movement, for example due to local turbulence forces). The greatest increases in pollutant levels were during the summer due to the smaller stack effect during this period. Overall the greatest increase occurred for cross ventilation. The effect of trickle ventilators had a notable wind-dependence, particularly with internal doors closed.

The main analysis considered exposure averaged over 12 wind directions. It was useful to also assess the impact of wind direction. For each ventilation strategy, the ratio was calculated between the maximum and minimum exposures, across the range of wind directions. This ratio was typically greatest for window airing. For the kitchen in the terraced house, wind direction had the maximum impact for cross ventilation (ventilation strategy 5, door position 3) where the ratio approached 6. For the kitchen in the detached house, the greatest ratios (~4) occurred with the kitchen window open to 1/20th of the floor area and internal doors closed. For other rooms, the greatest ratios typically occurred during window airing and with internal doors closed. Strategies using the fan showed the minimum variation with wind direction.

Temperature difference during cooking

It was assumed that cooking occurs from 5-6 p.m. each day. However, in practice, cooking occurs at differing times during which the environmental conditions and, consequently, airflow rates may be different. This analysis focused on the effect of the external temperature during cooking on exposure in the home - the effect of variable wind conditions was considered above. Additional runs were performed for each season at three external temperatures; weekly mean and one standard deviation either side of this mean (summer:18.0±4.3°C, winter:2.8±3.1°C). The greatest effect of choice of external temperature occurred for the window opening cases. The least impact occurred for kitchen fan use.

Thermal comfort

The airflow created by the use of a ventilator device may affect the thermal comfort of the occupants. The worst cases, with high flows of cold air, were removed by the energy criterion. The highest remaining air flow rate of 28 air changes per hour occurred during the summer for cross ventilation. This would result in a flow rate of 1.5 $m.s^{-1}$ close to the window, which is quite high. If necessary, the window open area could be reduced, with a consequent reduction in the ventilation rate and an increase of pollutant levels.

DISCUSSION

This report describes a computational investigation to select the best ventilation strategies to reduce occupants' short-term exposure to NO_2 and CO produced during gas cooking. The study suggests the best approach is to open the internal doors to dilute the pollutants rather than venting them directly to outside. The best ventilation devices are either windows or extract fans. Other considerations are discussed here.

Only two cooking pollutants were studied; others include water vapour and odours. If internal doors were open, the spread of water vapour could result in condensation problems elsewhere in the home. Similarly the spread of odours may be unacceptable. Further work should consider these and other pollutants.

A sensitivity analysis showed the significant impact of wind and temperature on the effectiveness of window airing and this should be considered further. Other ventilation devices should also be considered, e.g. an extract cooker hood and a passive stack ventilator (PSV), although the effect of a PSV may be small compared to a cooker hood for reducing short term exposure.

Finally, this study assumes that each pollutant creates a similar level of risk. Further work should employ a more quantitative approach, comparing results to known health-based guidelines. It has also been assumed that all occupants are similarly susceptible to each pollutant. If the occupants in differing locations have different sensitivities, the results would need to be weighted accordingly.

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