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GAS STOVE EMISSIONS: AN ECONOMIC ANALYSIS OF THREE CONTROL OPTIONS

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Abstract

The paper proposes a methodology for evaluating and ranking specific alternatives for control of indoor air quality in existing buildings, based on comparative costs and benefits. The method avoids the difficulties of assigning a monetary value to a change in air quality by adjusting the air exchange rate in each alternative until equivalent indoor air quality is achieved. The difference in air exchange rates between alternatives allows calculation of energy savings, which can be compared to capital cost using the payback period method. The method is applied to the case of gas range emissions, evaluating two alternatives; replacement with an electric range or installation of a vent hood. The payback period for these were 28 years and 14 years, respectively.

Introduction

In recent years, there has been a trend toward conserving energy through reducing the infiltration of outdoor air into the indoor environment. The impetus behind this trend has been the increasing cost of the fuels used for residential heating.

An unintended side effect of weatherizing homes has been an increase in the indoor levels of air pollutants from all sources that are found indoors. As infiltration is reduced, the flushing action and dilution of indoor pollutants with outside air is also reduced. Weatherization without concern for indoor air quality could result in an unacceptable degradation of indoor air quality.

It has been suggested that homes could be tightened to a greater degree if indoor emission sources were eliminated. In cases where the source performs a vital function, e.g. cooking, substitution of a non-polluting alternative or source controls are advocated. What must be kept in mind is that the homeowner is not weatherizing for the sake of weatherizing; he is weatherizing to decrease heating bills. Various alternative indoor air quality control strategies involve different degrees of weatherization and different capital costs. To determine which of many alternatives will maximize the homeowner's return on investment, it is necessary to compare the costs and benefits of each.

Method

The steady state concentrations of indoor air pollutants are estimated by an adaptation of the equation used by Traynor et al (8):

$$CAVG = (PaCo + S/V)/(a + k) \quad (1)$$

where CAVG = Average indoor pollutant concentration ($\mu\text{g}/\text{m}^3$),
 P = Fraction of pollutants penetrating the shell of the home,
 a = Air exchange rate (hours^{-1}), Co = Outdoor pollutant concentration
 $(\mu\text{g}/\text{m}^3)$, S = Indoor source emission rate ($\mu\text{g}/\text{h}$),
 V = Home volume (m^3), and k = pollutant decay rate (hours^{-1}).

CAVG is directly related to the emission rate, S , and inversely related to the air exchange rate, a . When an emission rate is decreased, air exchange can be decreased while still maintaining CAVG for that pollutant at its previous level. However, other pollutants, whose emission rates remain unchanged, will now be at higher concentrations as estimated by equation 1.

The greatest difficulty in this type of analysis is determining what constitutes "comparable indoor air quality". Each scenario will have a different mix of pollutant concentrations estimated by equation (1). There is no simple means of equating the level of risk posed by a pollutant at one level with that of another pollutant at another level. However, the alternative for this type of analysis, to assign a monetary value to changes in pollutant levels, is even more difficult.

To overcome this problem of comparisons between pollutants in the case that follows, several assumptions will be made. First, that the dose response curve for both respirable particulates (RSP) and nitrogen dioxide (NO_2) is linear over the range of exposures found indoors. Second, that there is zero risk at zero exposure. With these assumptions, risk becomes directly proportional to the indoor concentration. The ratio of the slopes for RSP and NO_2 would be a measure of relative risk posed by a unit increase in RSP versus a unit increase in NO_2 .

The United States Environmental Protection Agency (USEPA) has recently proposed National Ambient Air Quality Standards (NAAQS) for both RSP and NO_2 ($50 \mu\text{g}/\text{m}^3$ and $100 \mu\text{g}/\text{m}^3$, respectively). If one assumes that both standards represent equivalent degrees of protection for the public, i.e., equivalent levels of risk, then the relative risk of RSP versus NO_2 can be estimated by a ratio of their concentration to their NAAQS. An arbitrary relative risk factor (RRF) for comparing various mixes of NO_2 and RSP could be defined by:

$$RRF = (CAVG_{\text{NO}_2}/100\mu\text{g}/\text{m}^3) + (CAVG_{\text{RSP}}/50\mu\text{g}/\text{m}^3) \quad (2)$$

where $100 \mu\text{g}/\text{m}^3$ and $50 \mu\text{g}/\text{m}^3$ are the USEPA's proposed annual standards for NO_2 and RSP, respectively.

$CAVG_{\text{NO}_2}$ and $CAVG_{\text{RSP}}$ will both change when the air exchange rate is changed, so RRF will also change. A change in S_{NO_2} or S_{RSP} will not only change CAVG for that pollutant, but will also change the estimated RRF. For any change in emission rate, an air exchange rate, a , exists such that the relative risk factor estimated by equation 2 is equal for

each alternative. The difference in air exchange rates can be used to calculate the reduction in air flowing into the home by:

$$\Delta W = 24(a_b - a)V \quad (3)$$

where ΔW = daily air flow reduction (m^3/day), a_b = base case air exchange rate (h^{-1}), and a = alternative air exchange rate (h^{-1}).

With the reduction in air infiltration known, the annual cost savings can be calculated with the equation:

$$\$/\text{yr} = (\Delta W \times 1.2 \times 0.001 \times D \times C)/E \quad (4)$$

where $1.2 =$ air density (kg/m^3), $0.001 =$ heat capacity of air ($\text{MJ}/\text{kg}\cdot^\circ\text{C}$), $D =$ annual degree days ($^\circ\text{C}\text{-days}/\text{yr}$), $C =$ heating fuel price ($\$/\text{MJ}$), and $E =$ heating unit efficiency (heat out/energy input).

Analysis

What follows is an example of the use of such an analysis for a simple case of two emission sources and two pollutants; NO_2 from gas ranges and RSP from cigarette smoke. This in no way implies that homes with gas ranges need to improve indoor air quality. In fact, the estimated indoor NO_2 levels are well below the NAAQS in the example analyzed. A gas range was chosen because it is one of the few emission sources for which adequate data exists to perform the calculations. Cigarette smoke is used as a surrogate for all other emission sources in the home. Smoking was chosen because it is also well characterized and most U.S. homes have at least one smoker(7). Those that do not undoubtedly have other emission sources. The analyses are performed for a hypothetical home located in Washington, DC. Table 1 lists information about the Washington area and describes the characteristics of the home to be modelled.

Table 1. Local Data - Washington, DC

Heating degree days	2500 $^\circ\text{C}$ days/yr
Outdoor Air Quality (Annual Average):	
NO_2	$50\mu\text{g}/\text{m}^3$
RSP	$25\mu\text{g}/\text{m}^3$
Residential Energy Costs:	
Gas	$0.0075 \$\text{(US)}/\text{MJ}$
Electricity	$0.019 \$\text{(US)}/\text{MJ}$
Home Characteristics:	
Volume	250m^3
k_{NO_2}	1.4h^{-1}
k_{RSP}	0.1h^{-1}
P_{NO_2}	0.5
P_{RSP}	1.0
Gas Furnace Efficiency	70%

Table 2 lists NO_2 and SRSP for the base case and each of the three alternatives. The emission rate for RSP assumes 20 cigarettes (600 mg/cigarette) smoked per day, emitting 18 $\mu\text{g RSP/mg}$ (5). This is less than the estimated daily cigarette consumption per smoker for the United States.(7)

The emission rate for NO_2 differs for each alternative. The base case relies on emission rates of 9.9 $\mu\text{g}/\text{kJ}$ and 10.7 $\mu\text{g}/\text{kJ}$ as reported by Cole et al (2) for rangetop and oven burners, respectively. Daily emission rates are obtained by multiplying these rates by the average daily gas consumption for a pilotless gas range, 13.4 MJ/day and 10.3 MJ/day for rangetop and oven burners, respectively (6). For the case of the electric range, $\text{SNO}_2 = 0$. For the case of the vent hood, the effective emission rate is reduced by the efficiency of the vent hood in removing combustion products. Vent hood efficiencies range from 60% - 87% (8). A 75% reduction in emission rate over the base case is assumed. An air exchange rate of 0.8 is assumed for the base case and average NO_2 and RSP levels are estimated using equation 1. The relative risk factor calculated for these pollutant levels by equation 2 is 1.39.

For each alternative, trial and error procedure was employed utilizing equation 1 to find the air exchange rate for which the relative risk factor calculated by equation 2 also equals 1.39. These values are listed in Table 2. For alternative 2, a also includes air flow through the vent hood.

Table 2. Estimated Annual Savings for 2 Alternatives versus the Base Case

Cooking Fuel	Base Case	Alternatives	
		No Vent Hood	Elect No Vent Hood
$\text{SNO}_2(\text{mg/d})$	243	0	60.75
$\text{SRSP}(\text{mg/d})$	216	216	216
$a(h^{-1})$	0.80	0.60	0.65
$\text{CAVNO}_2(\mu\text{g/m}^3)$	37	15	21
$\text{CAVRSP}(\mu\text{g/m}^3)$	51	62	59
Relative Risk Factor	1.39	1.39	1.39
Infiltration reduction vs base case (m^3/d)	-	1200	900
Energy savings vs base case (MJ/yr)	-	5200	3867
Space heating savings vs base case (\$/yr)	-	39	29
Increased cooking cost vs base case (\$/yr)	-	11	0
Net savings vs base case (\$/yr)	-	28	29

Table 3. Payback Period for 2 Alternatives

	Payback Period for 2 Alternatives		
	Install Elect.	Install Range	Install Vent Hood
Capital cost	\$700	\$300	\$100
Weatherization	\$100	28	29
Savings (\$/yr)	28	28 yrs	14 yrs
Payback period	28		
Conclusion			

In this example it is interesting to note that the NO_2 levels in every case are well below the $10\mu\text{g/m}^3$ NAAQS for NO_2 while the RSP levels in every case are above the $50\mu\text{g/m}^3$ NAAQS for RSP. In this instance, emission sources other than the gas range are the limiting factor.

The payback periods for each alternative are longer than what is generally considered acceptable. Allowing for escalation in gas prices would reduce this somewhat, but this reduction may be more than offset by three factors that suggest the relative risks for the two alternatives were underestimated. First, in real life a home will have more than two emission sources. The increased levels of pollutants released by these should be included in the relative risk factor. Second, the NAAQS for RSP does not address the type of RSP emitted by cigarettes. The relative risk of NO_2 to RSP may be overstated.

Finally, the analysis ignores non-indoor air related risks such as the increase in outdoor pollution due to increased electricity generation.

Before an analytical procedure of this type could have any practical application, research would have to provide:

1. A means to compare the relative risk posed by all indoor pollutants over a range of concentrations.
2. An inexpensive, reliable method to predict pollutant decay rates and infiltration rates from observable home characteristics rather requiring expensive measurements.

With this information, engineering analyses such as described in this paper could provide a tool for comparing alternative control strategies in real life applications.

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