Summary

THE IMPACT OF UNVENTED GAS HEATING APPLIANCES ON INDOOR NITROGEN DIOXIDE LEVELS IN "TIGHT" HOMES

OVERVIEW

Unvented gas heating appliances have been routinely used for decades to provide auxiliary heat to specific rooms in homes and to provide aesthetic value to a home. Continuing a trend that has been ongoing for over a decade, ASHRAE Standard 90.2 2007 for energy-efficient design of low-rise residential buildings, the International Residential Code (IRC), the 2012 International Energy Conservation Code (IECC), and the National Green Building Standards (GBS) favor a "tighter" more insulated home that typically results in providing less natural ventilation as compared to housing stock of several decades ago. This was done in order to promote energy savings. The major impact of these standards over the last decade has been to design new homes with a higher insulation, or R factor, and to reduce the rate of exchange of indoor air with outdoor air. This study evaluates whether having normally operating unvented gas heating appliances in such "tight" residential spaces could lead to a degradation of indoor air quality, such as increased levels of nitrogen dioxide (NO_2), which is present in very small amounts as a normal combustion product of propane or natural gas.

The Vent-Free Gas Products Alliance Section of the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) commissioned a study to investigate the impacts of unvented gas heating appliances on NO_2 levels indoors in "tight homes." This study used the model developed by American Gas Association Research (AGAR)[1]. This model has been fully validated in instrumented test houses to ensure that the predicted airborne concentrations of combustion chemicals adequately match those occurring under the same conditions in test homes over a similar time period. For the current work, the AGAR vent-free model was utilized in conjunction with the commercially-available software Crystal Ball® to perform probabilistic runs over a wide range of conditions. In running the model, the focus was on tight well-insulated and poorly-ventilated homes. The air exchange rate was constrained to that for "tight" homes, specifically 0.10 to 0.35 air changes per hour (ACH). Other parameters, such as room volume, insulation value, and outdoor temperatures were varied over the anticipated ranges of variation. Simulations were conducted for each DOE heating region to represent different housing stock and house conditions. The assumptions, specific methods used to estimate airborne concentrations of NO_2, regulatory benchmarks used for comparison to predicted airborne levels of NO_2, and results of this study are discussed below.

NITROGEN DIOXIDE (NO_2) STANDARDS

National and international standards currently exist for the allowable short-term and long-term levels of nitrogen dioxide (NO_2) in indoor and outdoor environments. These are summarized in Table 1.

Table 1. Airborne Standards for Nitrogen Dioxide in Indoor and Outdoor Environments

Agency	*Type of Standard*	*Applicability*	*Averaging Period*	*Numerical Value*	
				ppm	*mg/m^3*
USEPA	NAAQS[a]	Outdoor	Annual[b]	0.053[d]	0.100
	NAAQS[a]	Outdoor	1-hour[c]	0.100	0.19
CPSC	Residential	Indoor	1-hour	0.300	0.56
WHO	----	Indoor/Outdoor	1-hour	0.110	0.20
Health Canada	Residential	Indoor	24-hour	0.050	0.094
		Indoor	1-hour	0.25	0.47

[a] See 75 FR 6474, February 9, 2010, and 61 FR 52852, October 8, 1996.

[b] Primary and secondary NO_2 standard; primary standards provide protection of public health; secondary standards provide protection from decreased visibility and from damage to animals, crops, vegetation, and buildings.

[c] Primary NO_2 standard equivalent to 100 ppb in outdoor air as the 98th percentile 1-hour average over 3 years.

[d] Equivalent to 53 ppb in outdoor air as an annual mean.

With regard to short-term standards for NO_2, the Consumer Product Safety Commission (CPSC) level of 300 ppb (0.3 ppm, or 0.56 mg/m^3) may be the most directly applicable standard. This standard is similar to the 0.25 ppm 1-hour Health Canada indoor residential benchmark. The short-term (1-hour) standards by the United States Environmental Protection Agency (USEPA) and the World Health Organization (0.10 ppm and 0.11 ppm, respectively) based on 1 hour periods are more restrictive by comparison. The available long-term (annual) standard to NO_2 of 0.053 ppm promulgated by the U.S. Environmental Protection Agency (USEPA) is similar to that established by Health Canada, which is 0.050 ppm (24-hour).

ASSUMPTIONS

The stochastic (probabilistic) model runs for each of the DOE Heating Regions were based on the parameter assumptions shown in Table 2. The outdoor temperatures used in the modeling were the region-specific average outside temperatures during the heating season.

Table 2. Input Parameter Values, Ranges, and Distribution Types for Probabilistic Runs

Parameter	*Minimum*	*Midpoint*	*Maximum*	*Type*	*Comments*
Room volume	1,400 ft^3	----	4,000 ft^3	Uniform	Equal probability of all values
Room height	8 ft	----	10 ft	Uniform	Higher ceilings less conservative.
House volume	8,000 ft^3	----	48,000 ft^3	Uniform	Equivalent to 1,000 to 6,000 sq. ft houses
Connected space	0 ft^3	½ Room	Room vol.	Uniform	Equal probability of all values
NO_2 Decay rate	0.78/hr	0.99/hr	1.33/hr	Triangular	Based on scientific literature values[2,3]
Gross input rate	10,000 Btuh	20,000 Btuh	30,000 Btuh	Triangular	----
Use duration	0 min	100 min	1440 min	Triangular	Range from recent survey[4]
Air exchange	0.1 ACH	0.225	0.35 ACH	----	Range represents "tight" homes only
External walls	1	2	3	Uniform	No. room walls with contact to outdoors

The equal probability of all values for room volume and connected space indicates that all values in the minimum to maximum range have the same likelihood of occurring. The NO_2 decay rate range is from multiple research studies[2,3] and it reflects the hourly rate for NO_2 to dissipate naturally through conversion and adsorption. The range for use time is from a recent survey of hearth products usage in Colorado.[4]

Heat exchange factors, or "U factors" (the inverse of R factors) for scenarios involving air exchange rates of 0.10 to 0.225 ACH were based on the assigned values for U factors (see Table 3) for each climate zone per the current Green Building Standards (GBS). The U factors in the GBS are virtually identical to those specified by the current International Residential Code (IRC) and the 2012 International Energy Conservation Code (IECC).

Table 3. U Factors For Low-Rise Residential Structures per Green Building Standards

Climate Zone	*U-Factor Values for Residential Structures @ 0.1 to 0.225 ACH*[a]		
	Ceiling	*Frame Walls*	*Floor*
1	0.035	0.082	0.064
2	0.035	0.082	0.064
3	0.035	0.082	0.047
4	0.030	0.082	0.047
5	0.030	0.057	0.033
6	0.026	0.057	0.033

[a] U = 1/(R Factor); where R is in units of (m^2 °C/W).

U factors for scenarios involving air exchange rates of >0.225 to 0.35 ACH were selected based on the assigned values for U factors for each of the climate zones based on the somewhat less-stringent ASHRAE Standard 90.2-2007 for the design of "low-rise" residential buildings, as shown in Table 4. These U factors were used to represent "tight" housing stock from 5 or more years ago.

Table 4. U Factors for Low-Rise Residential Structures per ASHRAE Standard 90.2

Climate Zone	*U-Factor Values Residential Structures @ >0.225 to 0.35 ACH*		
	Ceiling	*Frame Walls*	*Floor*
1	0.063	0.274	0.066
2	0.041	0.274	0.066
3	0.041	0.094	0.051
4	0.041	0.089	0.051
5	0.036	0.089	0.039
6	0.026	0.081	0.039

METHODS

The AGAR model was enabled for stochastic (i.e. probabilistic) runs using Crystal Ball® and a Micosoft Excel macro setup. Using the above assumptions, probabilistic model runs were made based on 20,000 simulations for each DOE Heating Region. The model output was in the form of percentile values for NO_2 concentrations in indoor air, and as percent of cases below various regulatory benchmarks and standards. The predicted NO_2 levels in indoor air were compared to the available 1-hour short-term benchmarks from Table 1.

RESULTS

The results of the probabilistic modeling study of NO_2 levels using the AGAR model are:

For DOE Heating Region I (Florida and the Gulf Coast), the median (50th percentile) NO_2 level was 0.0290 ppm during normal use of an unvented gas heating appliance, and the maximum level was 0.0710 ppm. 100 Percent of all 20,000 simulated cases for NO_2 levels were below all applicable short-term 1-hour benchmarks.

For DOE Heating Region II (e.g., Southern states), the median (50th percentile) NO_2 level was 0.0377 ppm during normal use of an unvented gas heating appliance, and the maximum NO_2 level was 0.0988 ppm. 100 Percent of all 20,000 simulated cases for NO_2 levels were below all applicable short-term 1- hour benchmarks.

For DOE Heating Region III, the median (50th percentile) NO_2 level was 0.0349 ppm during normal use of an unvented gas heating appliance, and the maximum NO_2 was 0.0697 ppm. 100 Percent of all 20,000 simulated cases for NO_2 levels were below all applicable short-term 1-hour benchmarks.

For DOE Heating Region IV (e.g., mid-Atlantic region), the median (50th percentile) NO_2 level was 0.0408 ppm during normal use of an unvented gas heating appliance, and the maximum NO_2 was 0.0920 ppm. 100 Percent of all 20,000 simulated cases for NO_2 levels were below all applicable short-term 1-hour benchmarks.

For DOE Heating Region V (New England and northern Central Plains states), the median (50th percentile) NO_2 level was 0.0454 ppm during normal use of an unvented gas heating appliance, and the maximum NO_2 was 0.1058 ppm. 100 Percent of all 20,000 simulated cases for NO_2 levels were below the CPSC, WHO, and Health Canada short-term 1- hour benchmarks for indoor air. 99.9 Percent of the 20,000 simulated cases for NO_2 levels were below the 1-hour USEPA NAAQS benchmark for outdoor air.

CONCLUSIONS

In 100 percent of the 100,000 simulations across the five DOE regions, the predicted NO_2 levels associated with the use of unvented gas heating appliances in "tight" houses met all short-term 1-hour indoor NO_2 guidelines from Table 1. A major reason for the low predicted NO_2 levels may be that in well-insulated homes with low natural air exchange rates, there is less heat loss and less cold air entering the home. As a result, an unvented gas heating appliance would be operating less during the usage period, and the cumulative amount of NO_2 released would be lower.

Notes:

1. DeWerth, D. W., R. A. Borgeson and M. A. Aronov. 1996. *Development of sizing guidelines for vent-free supplemental heating products*. American Gas Association Research Division, Cleveland, OH.
2. Yamanaka, S. 1984. Decay *rates of nitrogen oxides in a typical Japanese living room*. Environmental Sciences and Technology 18: 566-570.
3. Yoo, S.J., H.J. Bae, W.H. Yang, and M.H. Chung. 2001. *Decay rate of the nitrogen dioxide in indoor residence using mass balance model.* Korean Journal of the Environmental Health Society 27 (1): 145-152.
4. Whitmyre, G.K. 2007. Survey associated with investigation of the potential impacts of vent-free gas log fireplaces on indoor air quality at the Cherry Grove East II condominium complex in Aurora, Colorado.

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March 21, 2013