NYSEARCH Study for Natural Gas Dispersion and Detection in Residential Environments

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SUMMARY

The natural gas industry, including members of NYSEARCH has been promoting the use of methane detectors to allay safety concerns of its customers and regulators. Methane detectors are presently mandated by some jurisdictions and more are anticipated to follow. The present study uses physical testing and computational fluid dynamics (CFD) to quantitatively evaluate gas detector performance as a function of placement in residential occupancies. NYSEARCH, an R&D consortium consisting of gas distribution companies across North America, has contracted Fire & Risk Alliance, LLC (FRA) to carry out experimental and modeling work to study the dispersion of natural gas in residential structures and use this data to aid in the development of a detector placement standard to improve the deployment of these detectors.

Nearly 70 tests were conducted by FRA in which methane was released until a threshold of 60% of the Lower Explosive Limit (LEL) [3% methane in air] was observed within the structure. Leakage sources varied in flow rate, type, and location within the enclosure while the configuration of the test enclosure was varied between floor plan layouts, ceiling height, and the number of stories exposed to the leakage event. The time to alarm at gas concentration thresholds of 10% (0.5% methane in air) and 25% (1.25% methane in air) LEL were compared and reported for different scenarios at each sensor location. The results of this study highlight the importance of requiring a gas detector in the same room as permanently installed fuel-gas appliances. Several key parameters were also identified to affect the gas dispersion - the enclosure volume effect on gas concentration, the impact of walls and vertical placement on sensor response, and the non-linear alarm time based on different sensor settings. Based on the results of the experimental and modeling program suggestions for detector placement and alarm thresholds were provided to support the currently in development NFPA 715, Standard for the Installation of Fuel Gases Detection and Warning Equipment.

BACKGROUND

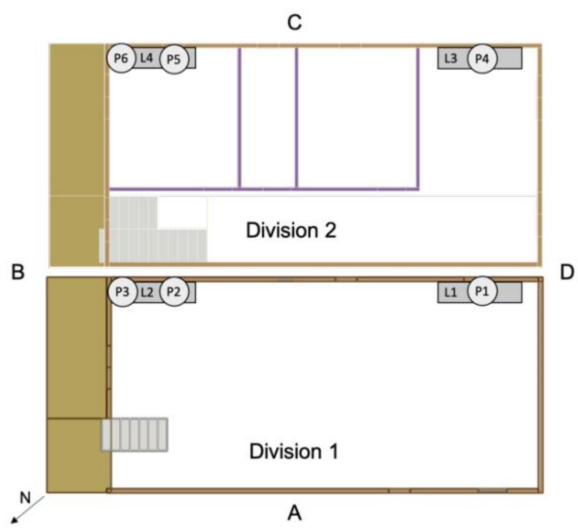
In 2017, the residential sector consumed 4,412 billion cubic feet of natural gas which accounts for 16% of the national natural gas consumption behind electric power generation and industrial applications. Natural gas systems are clean, efficient, and safe when used and maintained appropriately. While rare, natural gas leaks may result in a fire or explosion if undetected within its hazardous range of 5 to 15% by volume in air.

In May 2018, Northeast Gas Association (NGA) and Consolidated Edison were successful in gaining support from the AGA Building, Equipment, Codes and Standards Committee (BECs) for advancing an effort to develop a standard with the National Fire Protection Association (NFPA). However, to fully advance such a Standard, information was necessary on various elements of residential methane detection including ideal placement of the detector.

EXPERIMENTAL METHODOLOGY

A test enclosure (See Figure 1b) with external dimensions measuring nominally 20’ x 40’ x 20’ was constructed like a typical single-family home using standard construction techniques. The test structure contains standard insulation in the external walls and attic. A schematic of the floor plan and leak locations is shown in Figure 1a, with Division 1 being the lower floor and Division 2 constituting the upper floor. Over 60 methane sensors were placed throughout the enclosure to monitor methane spread and concentration. Sensors were placed at the ceiling level as well as offset from the ceiling to examine the stratification of gas in the structure. Temperature and humidity were also measured in numerous locations throughout the space.

Based on input from Subject Matter Expert's (SME) from NYSEARCH, a test matrix of nearly 70 tests was developed for the initial phase of this project. Methane, the primary component of natural gas, was released into the structure at flow rates between 1.0 and 150 SCFH to simulate releases from pilot lights, stoves and other gas fired appliances, and supply plumbing. The impact of leak location, leak rate, and volume of the structure were all examined with regards to methane concentration. Additionally, computational fluid dynamic simulations of the gas dispersion were performed using NIST's Fire Dynamics Simulator (FDS).



(a) Layout and leakage locations (P = point source, L = line source)

(b) Gas House

Figure 1. Structural layout, leakage locations, and gas house

RESULTS

Nearly 70 tests were conducted with three different release appliances over a range of flow rates and test durations. Across all the testing several key results became clear:

- Methane sensors positioned on the ceiling closest to the leakage location were the first to detect the initial flow of methane. For all testing conducted, the stratification of the gas within the test facility was observable from the data, consistent with the presumed behavior of methane which is lighter than air and will typically accumulate at the top of the enclosure prior to filling down.
- In general, larger flow rates from a leakage source resulted in a faster accumulation of gas within the enclosure as would be expected. This results in the gas spreading throughout the space and filling the volume at a more rapid pace; however, the impact of walls and door headers slow the gas from spreading into adjacent rooms.

- Sensors were placed throughout the structure at the ceiling and along walls at various heights to examine the impact of sensor placement on response for a given release scenario. Figure 2 illustrates the impact of sensor location and height within the structure for several representative leak rates. It was observed that the closer the sensor is to the release point, the earlier the detector alarms. A delayed response is generally seen for sensors further from the source. Similarly, the closer the detector is to the ceiling the earlier an alarm condition is reached. In general, similar trends were observed in detection time up to 19" from the ceiling for a given sensor location. Sensors located more than 19" from the ceiling generally did not alarm at either the 10% or 25% thresholds except for leak rates exceeding 70 SCFH.

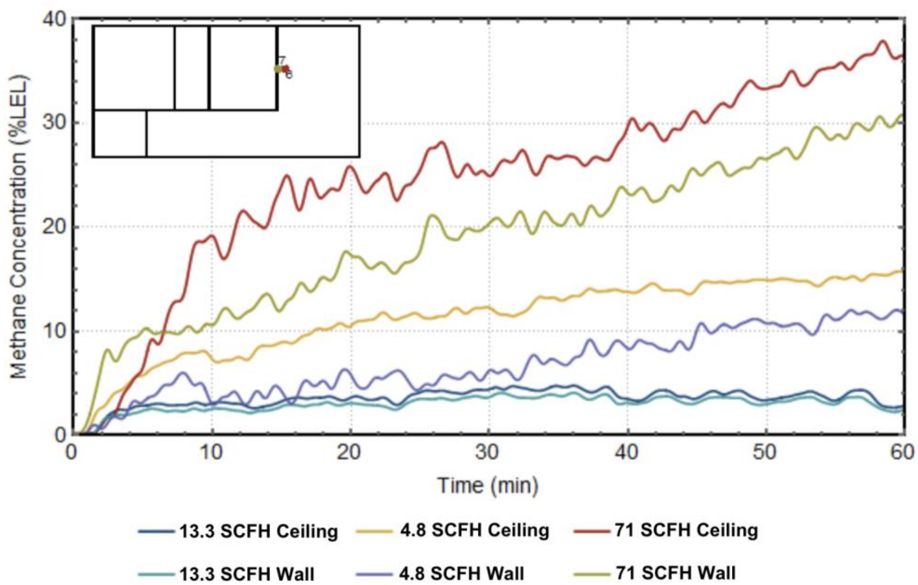


Figure 2. Leakage rate effects on measured concentration, 4.8, 13.3, and 71 SCFH leak rates measured at the ceiling and on the wall

- Alarm thresholds of 10% (advocated by NYSEARCH members) and 25% LEL (as set by UL 1484) were characterized across all tests conducted and the time required for each sensor to register the defined thresholds was recorded. It was observed in several cases that the first detectors to activate remain similar for each test scenario, though there is more variability at the 25% threshold. Additionally, for many leak rates, less than 70 SCFH, the 25% threshold was not reached within the first 60 minutes. While the sensor response by location remains consistent, the primary difference is that a 25% threshold results in a delayed response or in some cases no alarm during the first 60 minutes as shown in Figure 3. Thus, it is recommended that a 10% threshold be used as it will provide notification of most release scenarios in 60 minutes or less regardless of distance from the leak source.

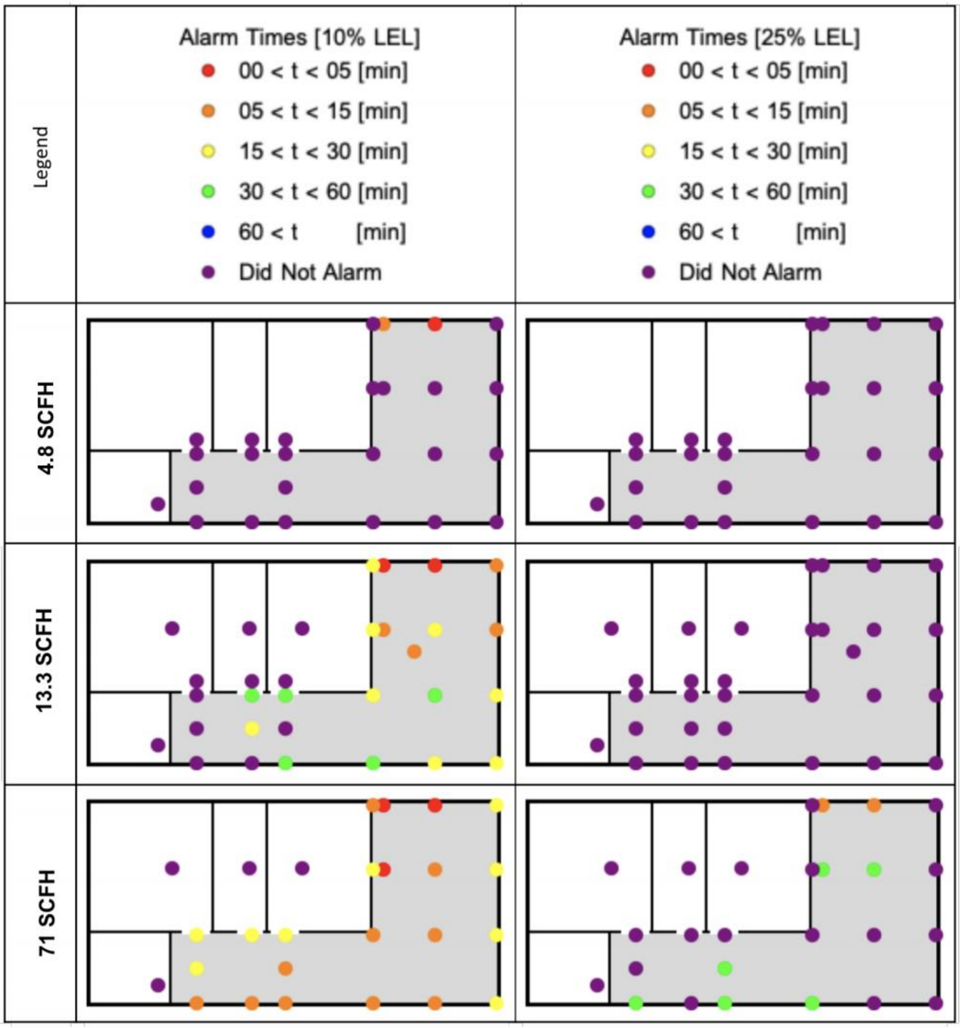


Figure 3. Impact of threshold concentration and leak rate on activation time for a 60 minute leak at P4 at various sensor locations

CFD MODELING

Modeling of the gas dispersion within the structure was conducted using NIST's Fire Dynamics Simulator (FDS), an open source computational fluid dynamics (CFD) package. The various release scenarios were modeled, and the results compared with the experimentally determined concentrations. Simulations were run until the minimum measurement threshold of 60% LEL was well established across the ceiling of the enclosure. Leakage from the structure was limited to simulate a well-sealed enclosure. Both the simulation and experimental measurements demonstrate an initial period where the measured methane concentration increases rapidly followed by a more linear, steady state filling regime. In general, the simulations matched the experiments well. The slight differences observed are due to air loss in the test structure, which is not present in modeling.

CONCLUSIONS AND FUTURE WORK

This research was aimed at providing guidance on sensor response and placement based on an extensive series of experiments and computational fluid dynamics modeling. Basic guidance on placement has been provided to NFPA Standard committee to ensure that a wide range of release conditions can be detected in a reasonable amount of time. Future work is aimed at further exploration of the impact of building leakage and HVAC on gas concentration throughout the structure volume.