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Impact of Precautionary Measures on Indoor Radon Levels in Retrofit Homes

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ABSTRACT

There has been substantial concern about the potential for radon levels to increase in homes undergoing energy retrofits, especially those including substantial air sealing. This study evaluated if precautionary measures could curb increases in radon in over 250 homes receiving energy efficiency retrofits. The goal of these precautionary measures was not to provide full radon mitigation, but rather to avoid increases in radon following retrofit. Primary precautionary measures included installation of exhaust ventilation, covering of bare dirt in foundation spaces, and installation of sealed sump pump covers. Large cracks in the foundation were also sealed in some homes. Radon was measured in every basement and on every ground floor for a two-week period. In an attempt to account for variability of radon due to external factors, control homes were measured at the same time. Control homes were located in the same general vicinity as retrofit homes and did not receive any energy efficiency upgrades during the project period. Radon was measured before retrofit and after retrofit. In as many homes as possible, radon was also measured approximately one year after retrofit to assess the persistence of the measures. The results showed that, relative to a prior study in which these precautionary measures were not done and radon levels increased by a statistically significant 0.4 picocuries per liter (16 Becquerels per cubic meter) in the lowest occupiable level of the home, no statistically significant changes in radon were found with the precautionary measures installed.

INTRODUCTION

Radon is an odorless, colorless soil gas that dissipates quickly in air, but can accumulate in buildings, affecting indoor air quality. While there are no safe levels of radon exposure, the World Health Organization recommends reducing radon levels in air in buildings to 2.7 pCi/L (100 Bq/m^3) or less (WHO 2009). In the United States, the Environmental Protection Agency recommends reducing radon levels in air in buildings to less than 4 pCi/L (148 Bq/m^3) in the lowest living level (LL) (U.S. EPA 2016).

The federally funded Weatherization Assistance Program (WAP) in the United States aims to reduce energy use in homes for low-income families and individuals, serving thousands of homes across the U.S. every year. Taking a "do-no-harm" approach, the weatherization program dually saves energy and addresses some health and safety items in homes that are related to the energy efficiency measures being implemented – including indoor air quality issues which can become

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exacerbated by reducing air infiltration. There is concern in the retrofit and weatherization community that air-sealing and related reductions in air infiltration in homes and buildings can increase radon levels.

A National Weatherization Evaluation Study assessed a number of contaminants, including humidity, mold and moisture, carbon monoxide, formaldehyde, and radon in 2010 and 2011 (Pigg et al. 2017). This study stated "The data from the study suggest that weatherization results in a small, statistically significant (in absolute terms) increase in indoor radon levels. Nationally, the study data suggest an average increase of 0.4 ± 0.2 pCi/L". For these homes, this corresponded to a 22% ± 11% increase.

With support from the U.S. Department of Housing and Urban Development (HUD), the Building Assessment of Radon/Moisture Reduction with Energy Retrofits study (BARRIER study) was conducted in Illinois and New Hampshire to study changes in radon in nearly 100 homes undergoing weatherization retrofits (Francisco et al. 2019). When the BARRIER study was complete, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA) funded research to expand the BARRIER study to include homes in four additional states. The goal of the study was to ascertain whether measures implemented since the Pigg study was conducted were sufficient to counter radon increases. The intent was NOT to determine average radon levels per home.

METHODOLOGY

Treatment Homes

Radon was measured in weatherized single family homes (n=276) in six states including Illinois, New Hampshire, Colorado, Iowa, Pennsylvania and Tennessee between 2013 and 2019. The study excluded mobile homes and homes on slab foundations. All participating homes were located in EPA Radon Zone 2 (n=90) or EPA Radon Zone 1 (n=186) (EPA). Homes were excluded if pre-test radon levels were less than 2.7 pCi/l in Radon Zone 1 and less than 1.5 pCi/l in Radon Zone 2. Radon was measured in the home on the first floor living level, and in the basement level, but not in crawl spaces. Radon was measured before weatherization, after weatherization completion, and one year following completion.

Radon was measured using passive Rad Elec E-Perm® electrets placed in the home for nominally fourteen days. These passive radon samplers were placed in locations in the home in accordance with manufacturer instructions; for example, samplers were not placed in kitchens, bathrooms, near windows, or in the path of space conditioning airflows. Returning to the home to re-conduct a pre-retrofit radon test due to a faulty reading was not be feasible (it would hold up the retrofit work), so the project deployed duplicate test samplers side-by-side in each location at each sampling phase. Two weeks was determined to be a good tradeoff between a short-term test and a long term test, to include multiple weather cycles.

In addition to radon measurements, details and characteristics about the home were collected including information about the house exterior, foundation, presence of exhaust fans and fan flow measurementsventilation, heating system details, water heating system and exhaust details, air flow diagnostics such as blower door tests and zone pressure tests, and all of the weatherization activities completed for the home.

Precautionary Measures. Across the U.S., weatherization grantees are required to follow certain guidelines (WPN 11-6 during the study time frame) related to the health and safety of occupants (U.S. DOE, 2011). For example, while weatherization programs tighten the building envelope through air-sealing measures, the program must also follow ASHRAE Standard 62.2 which prescribes minimum ventilation rates for residential buildings. Homes in this study followed either the 2013 or 2016 edition of the ASHRAE standard (ASHRAE 2013; ASHRAE 2016), depending on when the house was enrolled in the study. The target ventilation rate did not change between these two editions. Mold and moisture issues were addressed in homes as well. Homes with bare-dirt crawlspaces or bare-dirt basements had a minimum 6 mil plastic vapor barrier installed to curb vapor intrusion. Open sump pits were also covered. All treatment homes received energy retrofits plus health and safety related measures. The precautionary measures included in this research study were well-installed ground covers over bare dirt in foundations, sealed sump pumps, and 62.2 compliant mechanical ventilation. Sealing large cracks in foundations was also recommended where appropriate, but did not frequently occur in the study.

Control Homes

Control homes were used in the study to provide a baseline comparison of hourly radon measures for the duration of the radon testing in control homes. In the original BARRIER study there were two control homes per participating agency, for a total of ten control homes across the two states. In the expansion study, 10 control homes were recruited in each state. Control homes did not undergo any construction upgrades, remodeling, or energy retrofits for the duration of the research study.

FINDINGS

Site Characteristics. Participating retrofit homes (n=276) were diverse in home characteristics across participating states. A basement was present in 81.5% of homes. The basement was designated as occupied or occupiable in 38.8% of homes, in which case the basement was identified as the lowest living level. Unsealed sump pump pits were present in 22.5% of homes and 40.7% of homes had exposed dirt in the foundation before weatherization.

After retrofitOn average, air infiltration across homes was reduced by 33% based on blower door testing. Whenever possible and appropriate, unsealed sump pumps were sealed, bare dirt or porous floors were covered, and ventilation was installed.

Analysis. Changes in both arithmetic and geometric mean radon concentrations from pre- to post-retrofit were calculated (Table 1). With both analysis approaches, there were no statistically significant increases in radon levels in the lowest living level (LL), a combination of first floors and occupied/occupiable basements designated as the lowest living level[1]. Statistically significant changes in radon were found in basements when analyzed with both approaches. For first floors, no statistically significant increases in radon were found with either averaging approach.

Table 1. Control Adjusted Net Changes in Arithmetic and Geometric Mean Radon Level, Outliers Removed

	ARITHMENTIC MEAN (DIFFERENCES)		GEOMETRIC MEAN (RATIOS)	
Location	*n*	*Outliers removed*	*n*	*Outliers removed*
PreWx radon, pCi/L, Lowest LL	232	6.5	232	4.8
Percent change in radon level, Lowest LL		5% ± 6%		0% ± 6%
PreWx radon, pCi/L, Basement	182	8.2	182	6.1
Percent change in radon level, Basements		12% ± 8%**(+)		7% ± 7%*(+)
PreWx radon, pCi/L, First floor	233	5.5	233	4.2
Percent change in radon level, First Floors		4% ± 7%		2% ± 6%

** Significant change at the 95% level + Indicates that the change was an increase

* Significant change at the 90% level - Indicates that the change was a decrease

CONCLUSION

In the Pigg et al. 2017 study, arithmetic mean data from 2010 and 2011 showed that radon increased in homes by 22% ± 11% after weatherization. This suggested that typical WAP retrofit activities could increase radon levels in homes. With updated health and safety procedures and guidelines, and by following the newer ASHRAE 62.2-2013 or ASHRAE 62.2-2016 ventilation standards, our study found that the risk for increasing radon in the main living level through retrofit is reduced to the point that the study found no statistically-significant changes in radon levels in the lowest living level.

The study was unable to disaggregate the impact or effectiveness of individual measures, such as the impact of

[1] Table 1 reports results for lowest living level, basements, and first floors. The "lowest living level" equals both first floors and basements that are either occupied or occupiable. "Basements" are all other basements.

installing a vapor barrier on its own, or the impact of ASHRAE 62.2 ventilation on its own. Compared to the Pigg et al. study, the results demonstrate that the package of precautionary measures meet the definition of "do no harm" within the confidence interval of the measurements.

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