Science of the Total Environment 554–555 (2016) 178–185

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Indoor air quality in green-renovated vs. non-green low-income homes of children living in a temperate region of US (Ohio)

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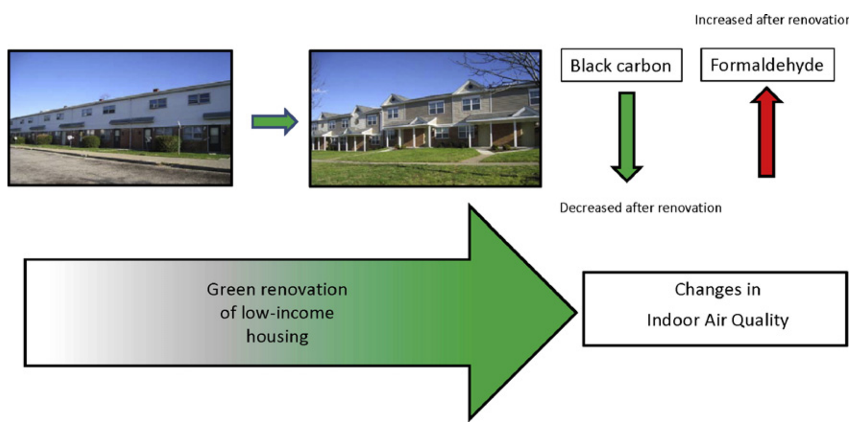
HIGHLIGHTS

- We examined the indoor air quality (IAQ) of low-income green and non-green homes in Cincinnati, Ohio, USA.
- Black carbon decreased and formaldehyde increased immediately post-renovation.
- We found that occupants' activities affect the IAQ more than the renovation status.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 October 2015
Received in revised form 16 February 2016
Accepted 19 February 2016
Available online 5 March 2016

Editor: D. Barcelo

Keywords:
Green renovation
$PM_{2.5}$
VOC
Black carbon
Formaldehyde

ABSTRACT

Green eco-friendly housing includes approaches to reduce indoor air pollutant sources and to increase energy efficiency. Although sealing/tightening buildings can save energy and reduce the penetration of outdoor pollutants, an adverse outcome can be increased buildup of pollutants with indoor sources. The objective of this study was to determine the differences in the indoor air quality (IAQ) between green and non-green homes in low-income housing complexes. In one housing complex, apartments were renovated using green principles ($n = 28$). Home visits were conducted immediately after the renovation, and subsequently at 6 months and at 12 months following the renovation. Of these homes, eight homes had pre-renovation home visits; this allowed pre- and post-renovation comparisons within the same homes. Parallel visits were conducted in non-green (control) apartments ($n = 14$) in a nearby low-income housing complex. The IAQ assessments included $PM_{2.5}$, black carbon, ultrafine particles, sulfur, total volatile organic compounds (VOCs), formaldehyde, and air exchange rate. Data were analyzed using linear mixed-effects models. None of the indoor pollutant concentrations were significantly different between green and non-green homes. However, we found differences

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http://dx.doi.org/10.1016/j.scitotenv.2016.02.136

when comparing the concentrations before and after renovation. Measured immediately after renovation, indoor black carbon concentrations were significantly lower averaging 682 ng/m^3 in post-renovation vs. 2364 ng/m^3 in pre-renovation home visits ($p = 0.01$). In contrast, formaldehyde concentrations were significantly higher in post-renovated (0.03 ppm) than in pre-renovated homes (0.01 ppm) ($p = 0.004$). Questionnaire data showed that opening of windows occurred less frequently in homes immediately post-renovation compared to pre-renovation; this factor likely affected the levels of indoor black carbon (from outdoor sources) and formaldehyde (from indoor sources) more than the renovation status itself. To reduce IAQ problems and potentially improve health, careful selection of indoor building materials and ensuring sufficient ventilation are important for green building designs.

1. Introduction

Environmental concerns for improved energy consumption and reduced carbon emissions have motivated increased adoption of green principles in new construction and remodeling practices. "Green" housing is designed by utilizing building materials with low-emissions, increasing energy efficiency and improving the health of occupants. As buildings become more "green", there have been rising concerns about the long-term effects of changes in building materials as well as operations and construction practices. Concerns about indoor air quality (IAQ) in energy-efficient buildings started as early as the 1970's. By the mid-1980's, it was reported that up to 30% of new or remodeled energy-efficient buildings might have an unusually high rate of complaints of sick building syndrome (Akimenko et al., 1986). It has been suggested that "green" housing solutions may be detrimental to residents' health if factors affecting the IAQ are not considered. Improper selection and implementation of retrofits such as continuous and adequate outdoor air flow and HVAC operational parameters can directly affect indoor environmental quality and may be detrimental to resident's health (Mudarri, 2006).

Additionally, Americans may have increased exposure to indoor contaminants as they spend increasing amount of time indoors. It has been estimated that adults spend 90% of their time indoors, whereas children younger than 3 years spend up to 100% of their time in indoor environments. Additionally between the ages of 7–12 years, which is the age group of interest in the overarching study, children can spend up to 87% of their time indoors (Moya et al., 2011). Indoor environment in homes can present significant health risks (Samet, 1993; Weisel et al., 2005; Logue et al., 2012), with some of the most vulnerable populations affected being children and those with existing respiratory diseases (Peat et al., 1998; Emenius et al., 2004; Breysse et al., 2010). Furthermore, poor indoor air quality has increased health implications in low-income communities (Krieger et al., 2002; Perlin et al., 2001). It has been suggested that multilevel interventions are necessary to properly assess and improve the indoor environment of low-income residents (Brugge et al., 2004; Sandel et al., 2004). Previous studies have emphasized the potential for IAQ improvements through retrofit measures that also make houses more energy-efficient (Noris et al., 2013). However, even with lower emission materials, tighter homes still have the potential of poorer IAQ due to reduced air exchange. It is important to assess the extent to which green-built, low-income housing actually improves indoor air quality when compared to standard-built, low-income housing.

Green building studies that have focused on the indoor environment have been mostly qualitative and based on data collected from questionnaires rather than quantitative indoor sampling and analysis (Jacobs et al., 2010; Jacobs, 2011). Among few efforts that aimed at quantitatively assessing the overall indoor environment within green buildings, little has been reported regarding the impact of aerosol particles on the IAQ of low-income green homes (Colton et al., 2014; Frey et al., 2015; Xiong et al., 2015).

This research is a subset of the Green Housing Study (GHS), a multi-site study designed by the Centers for Disease Control and Prevention (CDC) and the Department of Housing and Urban Development (HUD). A main objective of the GHS is to investigate how green housing factors are associated with IAQ and children's respiratory health. For the current manuscript, we compare and quantitatively evaluate the indoor air quality between green and non-green low-income homes in one of the GHS sites, Cincinnati, Ohio.

2. Methods

2.1. Study design

The study site in Cincinnati was a low-income multi-family housing complex of approximately 800 apartments. The housing complex renovations were subsidized by a federal housing program. The occupants of these residences were primarily English-speaking African Americans. The corresponding control homes, located about 6 miles from the test site, belonged to a Cincinnati Metropolitan Housing Authority (CHMA) housing community built in the 1940s that is populated by low-income (mostly English-speaking African American) residents.

Subject recruitment in Cincinnati was initiated at a town hall meeting in October 2011 in order to reach a sample size goal of 64 children (established for each study site of the GHS). All residents were invited to the meeting by mailing fliers to their units. Following the town hall meeting, recruitment proceeded mainly by door-to-door home visits which likely resulted in a convenience sample of eligible households. The main inclusion criterion was having a child (ages 7–12 years) with a report of doctor-diagnosed asthma residing in the unit. Table 1 describes the elements of renovation in the "green" housing complex.

Fig. 1A & B depicts the timeline of the study in 42 homes, of which 14 were considered non-green units, and 28 were green units. Fig. 1A depicts eight homes for which we were able to also conduct assessments before (i.e., Baseline pre-renovation visit = Visit 1).

Baseline (post-renovation) data on green-renovated homes was collected within four months of renovation (Visit 2). Thereafter, data were collected from these homes every six months for a period of one year (Visits 3 and 4). Parallel assessments were simultaneously conducted

Table 1
Comparison of building features between the green-renovated homes and non-green homes.

Renovation features implemented in the "Green" homes	Present in non-green (control) homes
Integrated pest management ("green" feature)	No
Low VOC countertops, doors, and paint ("green" feature)	No
Energy efficient windows and doors ("green" feature)	No
Energy efficient lighting and bulbs ("green" feature)	No
Low flow toilets ("green" feature)	No
New roofing (not a "green" feature)	No
Whole house insulation ("green" feature)	No
Energy efficient central heating/cooling systems with programmable thermostats ("green" feature)	No
Bathroom exhaust fans	Yes
Combination smoke/carbon monoxide alarms	No
Designated parking for low emission vehicles ("green" feature)	No