ARTICLE IN PRESS

Environment International xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Environment International

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

Chemical exposures in recently renovated low-income housing: Influence of building materials and occupant activities

Robin E. Dodson[a,*], Julia O. Udesky[a], Meryl D. Colton[b], Martha McCauley[c], David E. Camann[d], Alice Y. Yau[d], Gary Adamkiewicz[b], Ruthann A. Rudel[a]

[a] *Silent Spring Institute, 320 Nevada Street, Newton, MA 02460, USA*
[b] *Harvard T.H. Chan School of Public Health, 401 Park Drive, Boston, MA 02215, USA*
[c] *Battelle Memorial Institute, 505 King Ave., Columbus, OH 43201, USA*
[d] *Southwest Research Institute, P.O. Drawer 28510, San Antonio, TX 78228, USA*

ARTICLE INFO

Keywords:
Semivolatile organic compounds (SVOCs)
Volatile organic compounds (VOCs)
Indoor air
Surface wipes
Consumer products
Building materials

ABSTRACT

Health disparities in low-income communities may be linked to residential exposures to chemicals infiltrating from the outdoors and characteristics of and sources in the home. Indoor sources comprise those introduced by the occupant as well as releases from building materials. To examine the impact of renovation on indoor pollutants levels and to classify chemicals by predominant indoor sources, we collected indoor air and surface wipes from newly renovated "green" low-income housing units in Boston before and after occupancy. We targeted nearly 100 semivolatile organic compounds (SVOCs) and volatile organic compounds (VOCs), including phthalates, flame retardants, fragrance chemicals, pesticides, antimicrobials, petroleum chemicals, chlorinated solvents, and formaldehyde, as well as particulate matter. All homes had indoor air concentrations that exceeded available risk-based screening levels for at least one chemical. We categorized chemicals as primarily influenced by the occupant or as having building-related sources. While building-related chemicals observed in this study may be specific to the particular housing development, occupant-related findings might be generalizable to similar communities. Among 58 detected chemicals, we distinguished 25 as primarily occupant-related, including fragrance chemicals 6-acetyl-1,1,2,4,4,7-hexamethyltetralin (AHTN) and 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[*g*]-2-benzopyran (HHCB). The pre- to post-occupancy patterns of the remaining chemicals suggested important contributions from building materials for some, including dibutyl phthalate and xylene, whereas others, such as diethyl phthalate and formaldehyde, appeared to have both building and occupant sources. Chemical classification by source informs multi-level exposure reduction strategies in low-income housing.

Abbreviations: 13DC2P, 1,3-dichloro-2-propanol; 22BBM13P, 2,2-bisbromomethyl-1,3-propanediol; 23DB1P, 2,3-dibromo-1-propanol; 4,4′-DDT, 4,4′-DDT dichlorodiphenyltrichloroethane; ACE, acetone; AER, air exchange rate; AHTN, 6-acetyl-1,1,2,4,4,7-hexamethyltetralin (Tonalide); BBP, butylbenzyl phthalate; BDE, brominated diphenyl ether; BEH-TEBP, bis(2-ethylhexyl)tetrabromophthalate; BENZ, benzene; BP, benzophenone; BP-3, benzophenone-3; BTEX, benzene, toluene, ethylbenzene and xylene; BuAc, butyl acetate; BuOH, 1-butanol; BuPa, butyl paraben; CFORM, chloroform; CHEX, cyclohexanone; DBP, di-*n*-butyl phthalate; DCHP, dicyclohexyl phthalate; DEET, *N*,*N*-diethyl-meta-toluamide; DEHA, bis(2-ethylhexyl) adipate; DEHP, bis(2-ethylhexyl) phthalate; DEP, diethyl phthalate; DINP, diisononyl phthalate; EBENZ, ethylbenzene; EH-TBB, 2-ethylhexyl 2,3,4,5-tetrabromobenzoate; EOH, ethyl alcohol; EPA, Environmental Protection Agency; EtOAc, ethyl acetate; FORM, formaldehyde; GC/MS, gas chromatography/mass spectrometry; GM, geometric mean; HEPT, heptane; HEXA, hexane; HHCB, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[*g*]-2-benzopyran (Galaxolide); IARC, International Agency for Research on Cancer; IOH, isopropyl alcohol; MECL, methylene chloride; MEK, methyl ethyl ketone; MePa, methyl paraben; MIONE, methyl isobutyl ketone; MK, musk ketone; MMA, methyl methacrylate; MRL, method reporting limit; MX, musk xylene; NAP, naphthalene; NIC, nicotine; NO_2, nitrogen dioxide; NP, 4-*t*-nonylphenol; PCB, polychlorinated biphenyl; PERC, perchloroethylene; PM, particulate matter; PMCH, perfluoromethyl cyclohexane; PVC, polyvinyl chloride; QA/QC, quality assurance/quality control; RPD, relative percent difference; SES, socioeconomic status; STYR, styrene; SVOCs, semivolatile organic compounds; TBOEP, tris(2-butoxyethyl) phosphate; TBPP, tris(4-butylphenyl) phosphate; TCA, 1,1,1-trichloroethane; TCE, trichloroethylene; TCEP, tris(2-chloroethyl) phosphate; TCIPP, tris(1-chloro-2-propyl) phosphate; TCP, tricresyl phosphate; TCS, triclosan; TDCIPP, tris(1,3-dichloroisopropyl) phosphate; THF, tetrahydrofuran; TOL, toluene; TPHP, triphenyl phosphate; TXIB, 2,2,4-trimethyl-1,3-pentanediol di-isobutyrate; UV, ultraviolet; VOCs, volatile organic compounds; XYL, xylenes

[*] Corresponding author.

E-mail addresses: dodson@silentspring.org (R.E. Dodson), udesky@silentspring.org (J.O. Udesky), gadamkie@hsph.harvard.edu (G. Adamkiewicz), rudel@silentspring.org (R.A. Rudel).

http://dx.doi.org/10.1016/j.envint.2017.07.007
Received 9 May 2017; Received in revised form 12 July 2017; Accepted 13 July 2017

Please cite this article as: Dodson, R.E., Environment International (2017), http://dx.doi.org/10.1016/j.envint.2017.07.007

1. Introduction

Potential health impacts of chemical exposures in homes are of particular concern in low-income communities, where there is disproportionate exposure to pollutants from industry and traffic-related sources (Miranda et al., 2011), and where behaviors (e.g. smoking) and housing characteristics (e.g. smaller home size) linked with socioeconomic status (SES) are also associated with exposure to a greater number and magnitude of indoor pollutants (Adamkiewicz et al., 2011). Since residential exposures can dominate total exposures for many chemicals of health concern, including semivolatile organic compounds (SVOCs) and volatile organic compounds (VOCs) (Rudel and Perovich, 2009; Shin et al., 2014; Dodson et al., 2007a), identifying major sources and opportunities to reduce exposure is a priority. SVOCs and VOCs have been linked to a range of health effects including hormone disruption (Rudel and Perovich, 2009), cancer (NTP, 2014; Rudel et al., 2007), neurotoxicity (Grandjean and Landrigan, 2014), and respiratory health (Hulin et al., 2012). In addition, there is a higher prevalence of health conditions that are sensitive to the environment, such as asthma, among low SES communities (Akinbami et al., 2016), increasing susceptibility to some of these indoor chemical exposures in low-income homes.

Residential design practices aimed at reducing environmental impacts—“green” building—present one opportunity to significantly change chemical levels in homes. For example, lower emissions from the materials used in green buildings could reduce some indoor exposures. In recent years, green design has been widely implemented in housing construction and renovation, and several studies have found improvements in health after residents in low-income communities moved into newly constructed (Colton et al., 2014; Jacobs et al., 2015) or renovated green buildings (Breysse et al., 2014; Breysse et al., 2015; Colton et al., 2015). This apparent health benefit may reflect improvements in indoor air quality, as evidenced by reduced levels of particulate matter ($PM_{2.5}$) (Frey et al., 2015), black carbon (Coombs et al., 2016), nitrogen dioxide (NO_2), and allergens (Jacobs et al., 2014) following implementation of green renovations.

However other elements of green design, such as tightening the building envelope to reduce energy loss, could have varying impacts on indoor exposures: lower air exchange could reduce infiltration of outdoor pollutants but could also increase exposure to chemicals originating indoors. Indoor sources encompass not only the building structure and materials but also occupant products and activities, including cooking activities (Baxter et al., 2007), use of personal care and cleaning products (Dodson et al., 2012a), smoking (Arku et al., 2015; Kraev et al., 2009), and actions that influence air exchange. Despite the potential for occupants' behavior to influence indoor air quality, there is a lack of data to guide the design of interventions based primarily on occupant education. Air quality measurements in homes are generally obtained when occupants are present, limiting the ability to distinguish which sources – occupant, building, and/or outdoor – are most important for a particular chemical or class of chemicals.

We thus designed our study to characterize occupant contributions to indoor air quality in a community of recently renovated Boston low-income housing units by sampling these units pre- and post-occupancy. To our knowledge, our innovative design is the first to allow evaluation of the occupant contribution to indoor air quality in green-renovated homes by measuring $PM_{2.5}$ and a large suite of VOCs and SVOCs both before and after occupancy. We targeted chemicals that we expected to be present in the indoor environment and have potentially significant occupant sources, based on our previous research (Dodson et al., 2012a; Rudel et al., 2003; Rudel et al., 2010). This study is also part of a larger investigation of how green renovation affects indoor pollution levels and asthma symptoms in public housing (Coombs et al., 2016; Ponder-Brookins et al., 2014). Except for limited and conflicting data on levels of formaldehyde (Colton et al., 2014; Frey et al., 2015; Coombs et al., 2016; Xiong et al., 2015), there have been few measurements of the effect of green construction on levels of VOCs (Jacobs et al., 2015; Noris et al., 2013), and no investigation of SVOCs. Our goal was thus to expand knowledge about the impacts of green renovation on the indoor environment and to inform development of more comprehensive interventions to improve indoor environmental quality, especially in low-income communities.

2. Methods

2.1. Study site

In 2011, the Boston Housing Authority began redeveloping several properties according to “green” standards with support from the American Recovery and Reinvestment Act. At one federally subsidized housing development in Boston's South End, 13% of residential units were renovated. Improvements focused mainly on energy efficiency, including high efficiency windows, additional insulation, energy star appliances, low energy lighting, and low VOC paints, but also aimed to modernize the units by installing new flooring, baseboards and cabinets. The buildings were awarded a U.S. Green Building Council Leadership in Energy and Environmental Design (LEED) for Homes certification and Homes Energy Rating System (HERS) tier II energy rating of 65, meaning these units were designed to be 35% more efficient than a reference home.

Of the 30 unique units sampled, all but three were single-story, two- or three-bedroom units with average sizes of 700 ft^2 (6 units) and 850 ft^2 (21 units) respectively, in three- or four-story multi-family walk-up buildings (Table 1). We also sampled from three four-bedroom townhouse units, which averaged 1200 ft^2 in size. All units were heated with baseboard radiators controlled by the residents, and some had window air conditioners. There was no mechanical ventilation in these units.

The study population comprised mostly younger (18–39 years old) Hispanic females (Table 1). Twenty (74%) classified themselves as Hispanic or Latino and, of the 16 born outside of the United States, most (81%) were from the Dominican Republic. The majority of the participants (67%) were the only adult living in the unit, and there were at least three children living in most (82%) of the units. Most participants (89%) were new to the housing development.

2.2. Sample collection

We collected indoor air and surface wipes from 10 newly renovated units before occupancy (June to July 2013) and from 27 units one to nine months after occupants moved in (July 2013 to January 2014) (Fig. 1). We selected pre-occupancy units from the 13% renovated units in the development, which received certificate of occupancies in April 2013, mostly based on availability for sampling, as renovations had to be completed and the unit unoccupied for at least one week. For post-occupancy sampling, we recruited seven participants living in units we had sampled pre-occupancy, as well as an additional 20 participants through door knocking at the other newly renovated units. We intentionally sampled fewer pre-occupancy than post-occupancy units; we hypothesized that variability of chemical concentrations in pre-occupancy units would be low, given that all units were renovated to the same specifications, so that we would not need as many samples to characterize the concentration distributions. Study protocols were reviewed by the Office of Human Research Administration at the Harvard T.H. Chan School of Public Health.

We targeted nearly 100 SVOCs and VOCs as well as $PM_{2.5}$. Specifically, we analyzed for 35 SVOCs in indoor air and 46 on floor wipes, including phthalates, flame retardants, pesticides, antimicrobials, and fragrances, with 23 SVOCs targeted both in air and on wipes, 12 SVOCs in air only, and 23 on wipes only. Formaldehyde, chlorinated solvents, BTEX chemicals, and nicotine were among the 26 VOCS analyzed in indoor air.