Atmospheric Environment 70 (2013) 179–185

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

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

Changes to indoor air quality as a result of relocating families from slums to public housing

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HIGHLIGHTS

► We examine differences in the $PM_{2.5}$ and their sources in slums houses and public housing.
► Indoor and outdoor $PM_{2.5}$ were significantly higher in slums than in public housing.
► Differences between indoor and outdoor $PM_{2.5}$ within homes were significant only in slum houses.
► Outdoor $PM_{2.5}$ and the method for bathing water heating were the main predictors in all homes.
► A program that move slums families to public housing may improve indoor air quality.

ARTICLE INFO

Article history:
Received 10 July 2012
Received in revised form
12 December 2012
Accepted 20 December 2012

Keywords:
Environmental health
Indoor air quality
$PM_{2.5}$
Public housing
Slums
Chile

ABSTRACT

One largely unstudied benefit of relocating families from slums to public housing is the potential improvement in indoor air quality (IAQ). We compared families that moved from slums to public housing with those that remained living in slums in Santiago, Chile in terms of fine particulate matter ($PM_{2.5}$) as main indicator of change. A cross-sectional study of 98 relocated families and 71 still living in slums was carried out, obtaining indoor and outdoor samples by a Personal Environmental Monitor. Home characteristics, including indoor air pollution sources were collected through questionnaires. Multivariate regression models included the intervention (public housing or slum), indoor pollution sources, outdoor $PM_{2.5}$ and family characteristics as predictors. Indoor $PM_{2.5}$ concentrations were higher in slums (77.8 $\mu g\ m^{-3}$ [SD = 35.7 $\mu g\ m^{-3}$]) than in public housing (55.7 $\mu g\ m^{-3}$ [SD = 34.6 $\mu g\ m^{-3}$], $p < 0.001$). Differences between indoor and outdoor $PM_{2.5}$ were significant only in the slum houses. The multivariate analysis showed that housing intervention significantly decreased indoor $PM_{2.5}$ (10.4 $\mu g\ m^{-3}$) after adjusting by the other predictors. Outdoor $PM_{2.5}$ was the main predictor of indoor $PM_{2.5}$. Other significant factors were water heating fuels and indoor smoking. Having infants 1–23 months was associated with a lowering of indoor $PM_{2.5}$. Our results suggest that a public housing program that moves families from slums to public housing improves indoor air quality directly and also indirectly through air pollution sources.

1. Introduction

The goal of most housing policies is to improve overall living conditions for poor families. One potential and often overlooked benefit of rehousing is improving indoor air quality (IAQ). The slum population is a group particularly vulnerable to pollution because the general characteristics are substandard housing and a gap in access to land, services, and security (Mac Donald, 2004; Winchester, 2006). Slum families may also be exposed to higher levels and varieties of indoor pollutants, especially those resulting from the use of biomass fuels (Fullerton et al., 2008; Siddiqui et al., 2009). Furthermore, because slum housing is often poorly constructed from flimsy materials, these structures are more permeable to environmental pollutants from the outdoors. Rehoused families may enjoy better indoor air quality than families remaining in slums due to better housing infrastructure and increased opportunities to control emissions, including using windows for ventilation, opting

Abbreviations: IAQ, Indoor air quality; $\mu g\ m^{-3}$, Micrograms/cubic metric; PM, Particulate matter; $PM_{2.5}$, Particulate matter with diameter <2.5 μm.

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http://dx.doi.org/10.1016/j.atmosenv.2012.12.044

to cook in differentiated areas, or reducing heating times. Rehoused families may also be motivated to smoke cigarettes outside their homes or change fuel practices in their new dwelling. The use of dirty fuels such as wood, dung, coal, or trash is likely to be abandoned due the territorial regulations about contaminants sources or by neighbors' pressure in the new neighborhood.

International evidence regarding the health effects of housing interventions includes studies involving rehousing/refurbishment, relocation from poor areas, rehousing by medical priority, and improving energy efficiency (Thomson et al., 2003). Improved mental health, reduced smoking, better respiratory health, and decreased school absences due to asthma have been attributed consistently to rehousing interventions (Thomson et al., 2001, 2003). However, recent evidence regarding the environmental effects of rehousing on health is minimal, according to a systematic review of the literature based on forty-five studies identified (Thomson et al., 2009). A cross-sectional study, although inappropriate to ascertain the timing of effects associated with interventions, allows comparisons between different groups. Results can be examined further and used to prioritize research areas and identify populations with environmental vulnerabilities.

IAQ is one of the major contributors to disease burden in the world; in fact, an estimated 3.7% of the total burden of disease can be attributed to indoor smoke from solid fuels (Lopez et al., 2006). Observational evidence shows that several other housing characteristics are strongly associated with poor health, including substandard infrastructure and specific indoor agents such as particles, dust mites, allergens, and dampness (Institute of Medicine [IOM], 2000). Furthermore, the health effects of particulate matter and toxic gas concentrations have been described in studies comparing interventions involving woodstoves (Brauer et al., 1996; Naeher et al., 2000a, 2000b; Clark et al., 2009; Siddiqui et al., 2009). Fine particulate matter (<2.5 μm) has been a focus of attention because of its ability to penetrate the lower respiratory tract.

In Chile, the number of slums increased from 490 to 706 between 2007 and 2011 (Ministerio de Vivienda y Urbanismo [MINVU], 2011). Slums have been the target of systematic intervention since 1996 (MINVU, 1997), but no evidence regarding IAQ in a rehousing context has been reported in Chile. The first public housing program in Chile ("Chile-Barrio") was implemented during 1998–2007 to provide integrated support for slum families, including access to housing units. While the main goal of the program was social benefits, externalities of the intervention may have impacted other indicators of welfare including environmental quality. Therefore, the primary aim of the present study was to compare IAQ for relocated families with families remaining in slums, using particulate matter $PM_{2.5}$ and indoor air pollution sources as indicators of environmental change. A secondary aim was to identify potential predictors of $PM_{2.5}$ concentration related to the intervention.

2. Materials and methods

2.1. Study setting

The present study was conducted in Santiago, Chile in an urban area about 7 km^2 west of the city. It is an area in which the population with a majority of families lives below the poverty line, with lower family income (US$990) and fewer years of education (8.9 years) than others areas of Santiago (Ministerio de Planificación [MIDEPLAN], 2010). Santiago has a Mediterranean–temperate climate and topographic conditions that result in poor ventilation in the winter season. Local studies have indicated that the study area is exposed to higher accumulations of $PM_{2.5}$ than other areas of the city (Gramsch et al., 2004; Prieto et al., 2007).

2.2. Study design

A cross-sectional study was conducted to assess 169 houses in Santiago, Chile between June and September of 2009. The sample included 98 families who had completed the public housing tenancy process during 2000–2001 and 71 slum families still in the process of acquiring public housing. The families rehoused in public housing lived in the same general area as the slums in this study, with less than 5 km of distance between the communities' two most extreme locations. The question addressed in the present work is part of a larger primary study whose purpose is to assess respiratory outcomes in children. Thus, an inclusion criterion for families was the presence of at least one child under the age of eight years who had been born in the current residence.

Relocation was completed through the public housing program *Chile-Barrio*. The program assigned the intervention to communities according to an economic criterion (families were required to have savings of about US$300) and the technical feasibility for relocation (Saborido, 2005). The public housing consisted of apartments 46–69 m^2, organized in blocks with three floors and forming a cluster within a larger social village. With this housing solution, the program provided interventions in several domains: economic, educational, and social support, including proper maintenance and use of housing. Information on relocated families was provided by the Chile-Barrio Program and information about current slums was provided by a non-governmental organization, *Un Techo Para Chile* (CIS/UTCH, 2007).

Recruited families signed an informed consent document before participating. Study procedures were approved by the Ethics Committee of the University of Chile Medical School and Emory University Institutional Review Board. Of the 327 eligible families that had lived in the slums for at least two years and in the same geographical areas under study, 108 families were not invited to participate because no resident was available when the household was approached on multiple occasions. Of the total households invited to participate ($N = 219$), 86% met the criteria for inclusion (home with children <8 years) and accepted the particulate matter measurement and the interview. No differences in participation rates between the slums and public housing families were observed. Twenty households were subsequently removed from analysis because of incomplete data, resulting in a total of 169 complete questionnaires.

2.3. Air measurements

To determine $PM_{2.5}$ concentrations, we used a 230 V pump (SKC 222-44XR, USA) with a vacuum range of 0.05–5 L min^{-1} and a gravimetric sampler (SKC Personal Environmental Monitor; PEM Sampler, USA). Pumps were installed in indoor and outdoor locations in each home. One measurement was taken each day at two slum homes and three public housing homes, respectively. $PM_{2.5}$ concentrations were measured during a 24-h period during winter. Indoor locations for the pumps were placed in children's bedrooms at breathing height (about five feet above the ground). Outdoors, the pumps were installed in the backyards of the houses in the slums or on the balconies of the public houses.

Samples were collected using a 37 mm Teflon filter with 2.5 μm pore size at a rate of 4 L min^{-1}. The filters were weighed and analyzed by gravimetry at CHESTER LABnet laboratory (Tigard, Oregon, USA). Results were expressed in micrograms/cubic centimeter (μg m^{-3}). Pumps were adjusted to the target flow-rate at the start and the finish of each measurement. An electronic calibrator (SKC Ultraflow, USA) was used according to the manufacturer's calibration guide. Because the temperature and relative humidity affect the thermal environment, they were registered in real time with