Health and Housing Outcomes From Green Renovation of Low-Income Housing in Washington, DC

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Abstract **Green building systems have proliferated recently, but studies are limited of associated health and housing outcomes. The authors measured self-reported resident physical and mental health, allergens, and building conditions at baseline and one-year follow-up in a low-income housing development being renovated in accordance with green healthy housing improvements (Enterprise Green Communities standards and Leadership in Energy & Environmental Design [LEED] gold certification). Self-reported general health in adults significantly improved from 59% to 67% ($p = .026$), with large statistically significant improvements in water/dampness problems, cockroaches and rodents, and reduced pesticide use. Median cockroach (Bla g1) and mouse (Mus m1) allergen dust loadings showed large and statistically significant reductions from baseline to three months postintervention and were sustained at one year (both $p < .05$). Energy and water cost savings were 16% and 54%, respectively. Incorporating Enterprise Green Communities and LEED standards in low-income housing renovation improves health and housing conditions and can help to reduce disparities. All green housing standards should include health-related requirements.**

Introduction

The connection between housing quality and health has received renewed attention in recent years because the environmental burden of disease associated with inadequate housing is large (Braubach, Jacobs, & Ormandy, 2011; Surgeon General, 2009). Housing affects health directly and indirectly (World Health Organization, 2005), and disparities in housing quality and health outcomes are persistent, especially in low-income and minority communities (Jacobs, 2011). Physical, chemical, and biological exposures in the home that produce adverse health outcomes and those housing interventions that are known to be effective have been reviewed elsewhere (DiGuiseppi, Jacobs, Phelan, Mickalide, & Ormandy, 2010; Jacobs et al., 2010; Krieger et al., 2010; Sandel et al., 2010). Yet actual investment in housing improvements associated with health gains and environmental sustainability has been limited, in part due to lack of standardization and inadequately quantified health and housing outcomes. We conducted this study to quantify such outcomes.

Background

Several new “labeling” systems for housing have appeared recently, including the Enterprise Green Communities criteria (Enterprise Community Partners, 2005), the U.S. Environmental Protection Agency’s (U.S. EPA’s) Energy Star Plus Indoor Air Program (U.S. EPA, 2011), and the U.S. Green Building Council’s Leadership in Energy & Environmental Design (LEED) program (LEED, 2008). The systems treat health requirements differently: the Enterprise standards used in this renovation include required

TABLE **1**

Demographics

Characteristic	Baseline		One Year Post		*p*-Value
	N	Result, *n* (%)	*N*	Result, *n* (%)	
Born in the U.S.					
Adults	57	54 (95)	27	24 (89)	.331[a]
Children	62	60 (97)	31	29 (94)	.470[a]
Age at baseline (in years) (mean)					
Adults	57	36	27	38	.450[b]
Children	62	7	31	8	.278[b]
Highest level of adult education at baseline (median)	57	GED or equivalent	27	GED or equivalent	.953[c]
Female gender					
Adults	57	45 (79)	27	25 (93)	.117[a]
Children	62	41 (66)	31	20 (65)	.877[a]
Ethnicity					
Adults	57		27		1.0[d]
Black/African-American		55 (96)		26 (96)	
White/other race		2 (4)		1 (4)	
Children	62		31		1.0[d]
Black/African-American		60 (97)		30 (97)	
White/other race		2 (4)		1 (3)	
Number of people living in each apartment (mean)	44	2.8 (1.3 Adult; 1.4 Child)	25	2.3 (1.1 Adult; 1.2 Child)	.493 (All) .244 (Adult) .784 (Child)[c]
Annual household income (in dollars) (median)	44	<$10,000	25	<$10,000	1.0

[a]Chi-square test of inequality of proportions.
[b]Two-sample *t*-test of inequality of means.
[c]Wilcoxon test of inequality of medians.
[d]Chi-square test of inequality of the proportions black/African-American vs. white/other race at two time periods.

health-related specifications, while LEED only provides a certain number of optional points for health items. This project is also one of the first projects to comply with the new green building law in the District of Columbia (2006).

While such systems may improve health, evidence to support this claim is sparse in both new housing construction (Takaro, Krieger, Song, Sharify, & Beaudet, 2011) and housing rehabilitation (Breysse et al., 2011). Studies show significant improvements in asthma and other respiratory symptoms in new construction that meets energy efficiency and other green housing standards (Krieger, 2010; Leech, Raizene, & Gusdorf, 2004; Takaro et al., 2011), such as large improvements in number of trips to emergency rooms for asthma attacks, caregiver quality of life, and asthma trigger reductions using home-based asthma intervention. Leech and co-authors (2004) found important health gains in wheeze (10%), headache (23%), and fatigue (30%).

Only two studies have been conducted so far of rehabilitation of existing housing, where housing improvements and compliance with green healthy housing systems may be more constrained by existing housing conditions. A randomized controlled trial in New Zealand showed a 9% improvement in general self-reported health, 15% improvement in lost workdays, and an 11% improvement in school absences (Howden-Chapman et al., 2008). A smaller study in Minnesota showed statistically significant improvements in general health, chronic bronchitis, sinusitis, and asthma, all in adults following green renovation of low-income housing (Breysse et al., 2011). The Minnesota study showed large statistically significant improvements in excellent, very good, and good general health one year after renovation in adults.

Methods

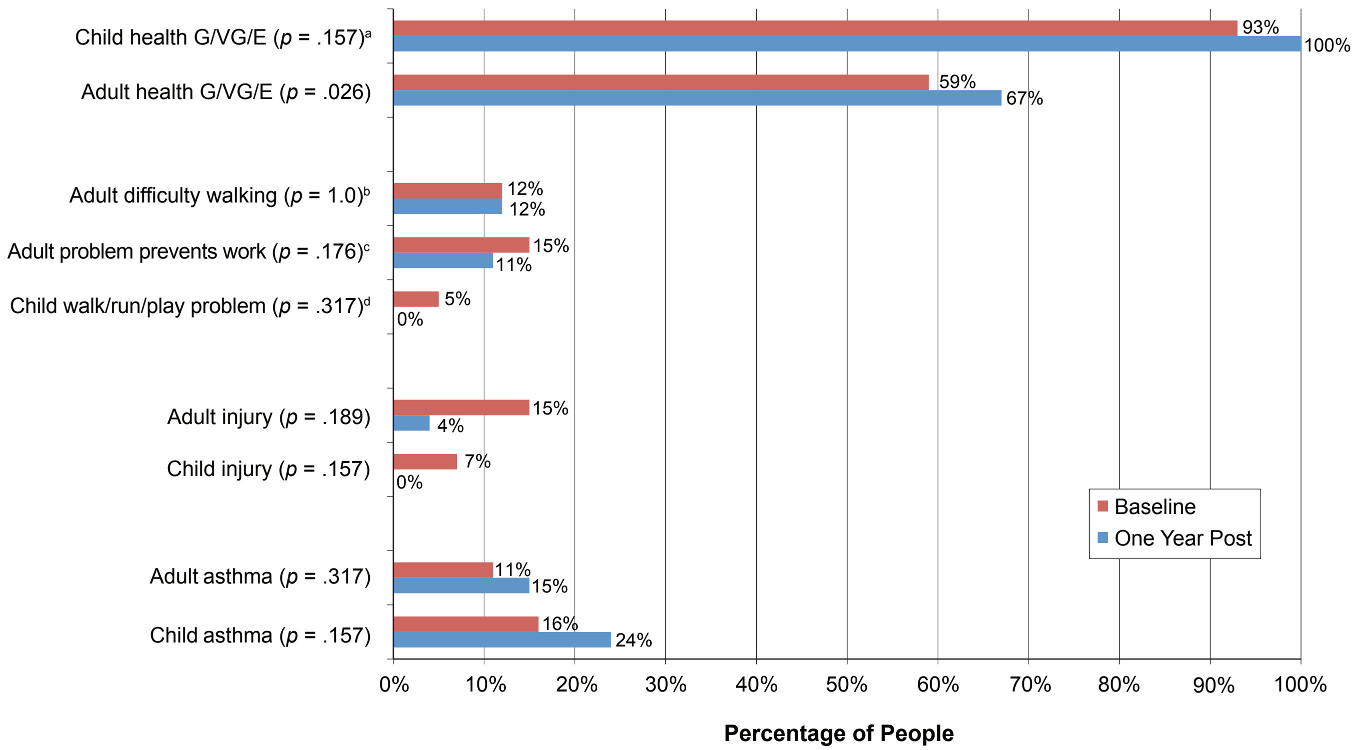
Participants and Procedures

Of the 102 occupied housing units available, 44 units containing 57 adults and 64 children were enrolled at baseline, with 25 units containing 27 adults and 31 children completing the follow-up approximately one year after the rehabilitation was completed (retention rate = 57%). To be eligible for the follow-up, the same participants in each unit must have completed the baseline. Persons lost to follow-up either moved away from the study housing or could not be contacted at follow-up. Study participants were primarily African-American, very low-income U.S. citizens, with female heads of households (Table 1). No significant demographic differences existed between the baseline and follow-up groups.

The rehabilitation complied with the Enterprise Green Communities criteria, which include integrated design, location and neighborhood fabric, site, water conservation, energy conservation, use of sustainable and environmentally friendly materials and resources, healthy living environment, and operations and maintenance. The housing improvements likely to influence health included a mechanical ventilation system that delivered fresh air to each apartment in compliance with American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standard 62.2 (ASHRAE, 2007), control of pests, repair of leaks, elimination of mold, elimination of holes and injury hazards, and other improvements. The project architects and developers conducted a unique green charrette to facilitate a multidisciplinary approach that included development, architectural, engineering, construction, mechanical, electrical, and public health professionals, and residents.

FIGURE **1**

Health Outcomes



[a]G/VG/E = good/very good/excellent (versus fair/poor).
[b]Full question: Because of a health problem, does the person have difficulty walking without using special equipment?
[c]Full question: Does a physical, mental, or emotional problem keep a person from working at a job or business?
[d]Full question: Does child have an impairment or health problem that limits his/her ability to crawl, walk, run, or play?

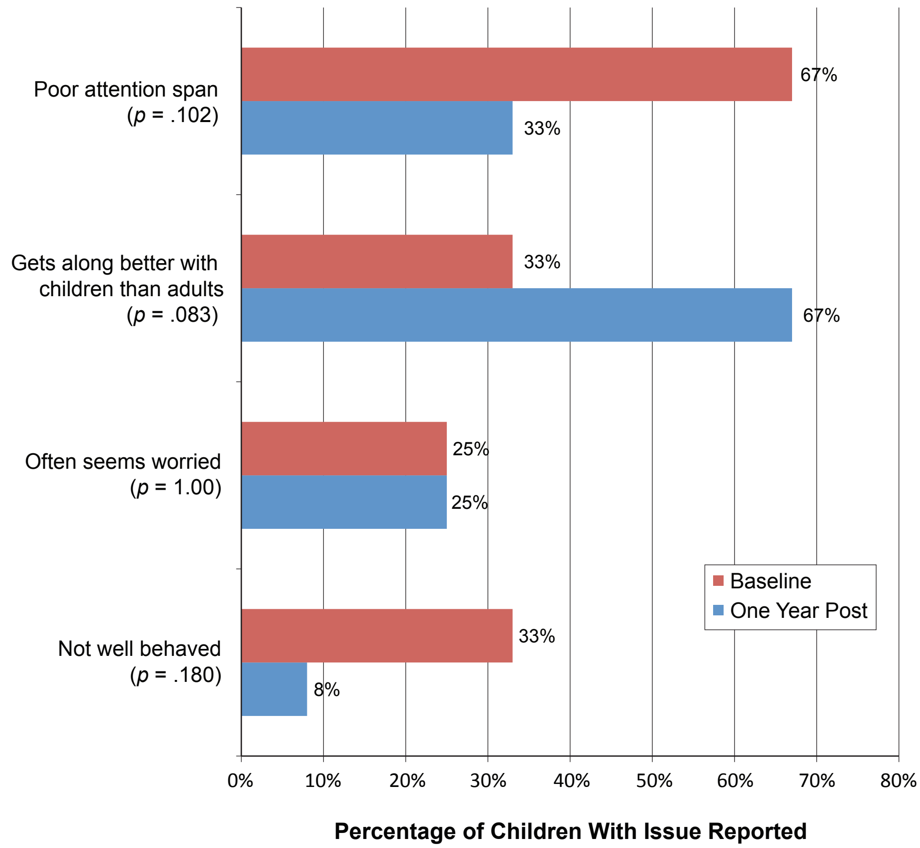
Data Collection

Before renovation and again one year after the renovation was completed, the study team administered a structured health interview, allergen sampling in settled house dust, and a visual assessment. The interview used an adaptation of the National Health Interview Survey (Centers for Disease Control and Prevention [CDC], 2005a), the Behavioral Risk Factor Surveillance System (CDC, 2005b), and the National Survey of Lead and Allergens in Housing (U.S. Department of Housing and Urban Development [HUD] & National Institute of Environmental Health Sciences, 2001). The interview also asked about physical and mental health and perceptions of building quality. We assessed housing quality visually before and after the rehabilitation using an adaptation of the CDC/Department of Housing and Urban Development (HUD) *Healthy Housing Inspection Manual* (CDC & HUD, 2005). Settled dust sampling was completed in a random sample of the units (using a random numbers generator) to estimate allergen levels using the standard HUD method (HUD, 2008) at baseline (1–6 months before renovation), again at 4–9 months after renovation, and a third time at 12–17 months after renovation.

Samples were collected from the floor of each of three rooms: the living room, kitchen, and youngest child's bedroom. We collected samples from the predominant floor surface type (e.g., bare or carpeted) within each room. Each floor dust sample was collected using a canister vacuum cleaner fitted with a dust collection sleeve. Samples were prepared and analyzed using enzyme-linked immunosorbent assays for cockroach (Bla g1), dust mite (Der f1 and Der p1), mouse (Mus m1), and rat (Rat n1) allergens and results were sent to residents. The laboratory reported sample results in micrograms of allergen per gram of dust (µg/g) for all allergens except Bla g1, which was reported in units of allergen per gram of dust (U/g). Allergen dust loadings (µg/ft^2) were calculated by multiplying allergen concentrations by sieved dust mass divided by square footage of floor area sampled in each room at each visit. Limits of detection varied among samples, ranging from 0.02 to 0.09 µg/ft^2 for both Der f1 and Der p1, 0.4 to 2.2 U/ft^2 for Bla g1, 0.001 to 0.06 µg/ft^2 for Mus m1, and 0.02 to 0.1 µg/ft^2 for Rat n1.

FIGURE 2

Child Mental Health



Statistical Analysis

For interview questions that were asked for only one person in a unit and that could be answered either yes or no, McNemar's test was used to test the hypothesis that the percentage of people answering yes changed. McNemar's test was also used for visual assessment questions. For interview questions that were asked for multiple people in a given unit and could be answered either yes or no, a generalized estimating equation (GEE) model was used to test if a change occurred in response from baseline to follow-up. If all people had the same response at one time, the GEE model did not converge; therefore, McNemar's test was used.

For questions that could be answered with a multiple list of options representing an order of intensity (e.g., whether general health was "excellent," "very good," "good," "fair," or "poor"), the Cochran-Mantel-Haenszel row mean score test for ordinal variables was used to test the hypothesis that the means at two specific times were different. When comparing interview results at two different time periods, data were first matched for both participants and apartments. Statistical significance was defined as $p < .05$ and marginal significance as $.05 \leq p < .1$. Allergen concentrations below the limit of detection (LOD) were replaced by the LOD to calculate dwelling unit averages. The Cochran-Mantel-Haenszel test of association was used to determine if the percentage of samples less than the LOD differed between two or more visits.

Results

Health

Adults reporting excellent, very good, or good health significantly improved from 59% at baseline to 67% at follow-up (p = .026) (Figure 1). Ninety-three percent and 100% of children were reported to be in good/very good/excellent health at baseline and one year postintervention, respectively (p = .157). Only a few children (16%) and adults (11%) had asthma at the baseline visit, and no significant change occurred in the percentage of either adults or children with current asthma. Injuries decreased in children from 7% to 0% and in adults from 15% to 4%, but both of these changes did not attain statistical significance (p = .157 and p = .189, respectively). No significant changes occurred in other physical health conditions from baseline to one year after intervention.

The percentage of children reported as not well behaved improved from 33% to 8%, and those reported to have poor attention spans decreased from 67% to 33%, although neither change was statistically significant (Figure 2). Adult mental health did not change significantly (Figure 3).

Housing

After one year, residents reported that their renovated homes were more comfortable (43% vs. 91%; $p < .001$) and easier to clean (80% vs. 96%; p = .102) (Figure 4). Large improvements occurred in reported water/dampness problems (80% vs. 16%; $p < .001$); mildew odor/musty smells were eliminated (61% vs. 0%; $p < .001$); cockroach problems improved (56% vs. 8%; p = .003); and rodent problems improved (64% vs. 12%; p = .002), with resulting reductions in residential pesticide use (44% vs. 8%; p = .007).

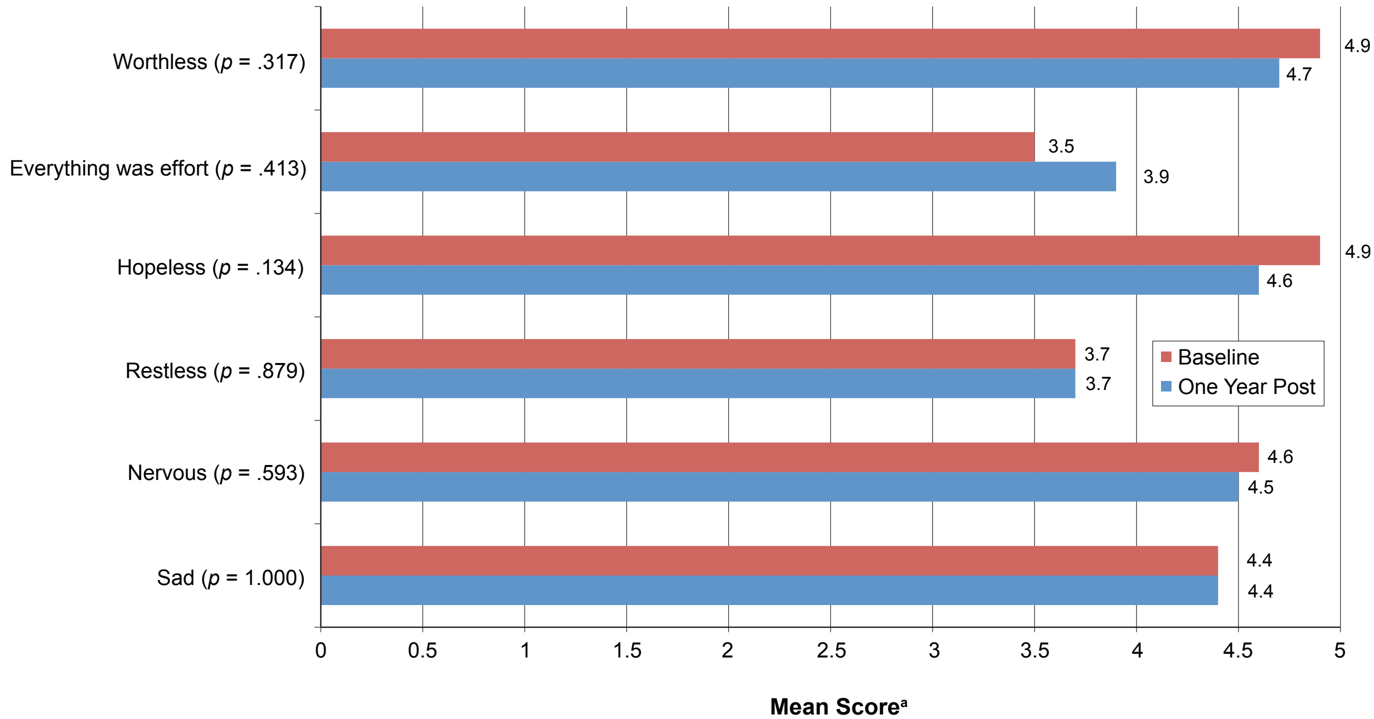
Apartments were generally in very bad condition at baseline. Almost a quarter of apartments had plumbing problems; ceilings, walls, and floors in almost all apartments had water staining/damage, mold, or peeling paint; and many doors and windows were damaged (Table 2). These issues were resolved, however, after the renovations were complete, with significantly improved housing conditions at one year postrenovation.

Allergens

Mouse allergen (Mus m1) was the most frequently detected allergen at baseline, found in 100% of kitchens and living rooms, followed by cockroach (Bla g1) and dust mite (Der f1) allergens (Table 3). In each room

FIGURE **3**

Adult Mental Health



[a]Mean scores are based on the following scale: 1 = all of the time; 2 = most of the time; 3 = some of the time; 4 = a little of the time; and 5 = none of the time.

tested, the percentage of units with Mus m1 and Bla g1 below the LOD significantly improved across the three visits. Der p1 was rarely detected at any visit, and no Rat n1 was detected in any samples at any visit. The percentage of units with Der f1 below the LOD did not significantly change across visits. Median cockroach (Bla g1) and mouse (Mus m1) allergen dust loadings showed large and statistically significant reductions from baseline to three months postintervention), and were sustained at one year (both $p < .05$) (Table 3).

Energy and Water Savings

Energy efficiency and water-saving measures reduced energy consumption by an estimated 16% (measured as cost per kilowatt hour per square foot) and water consumption was reduced by 54% compared to baseline.

Discussion

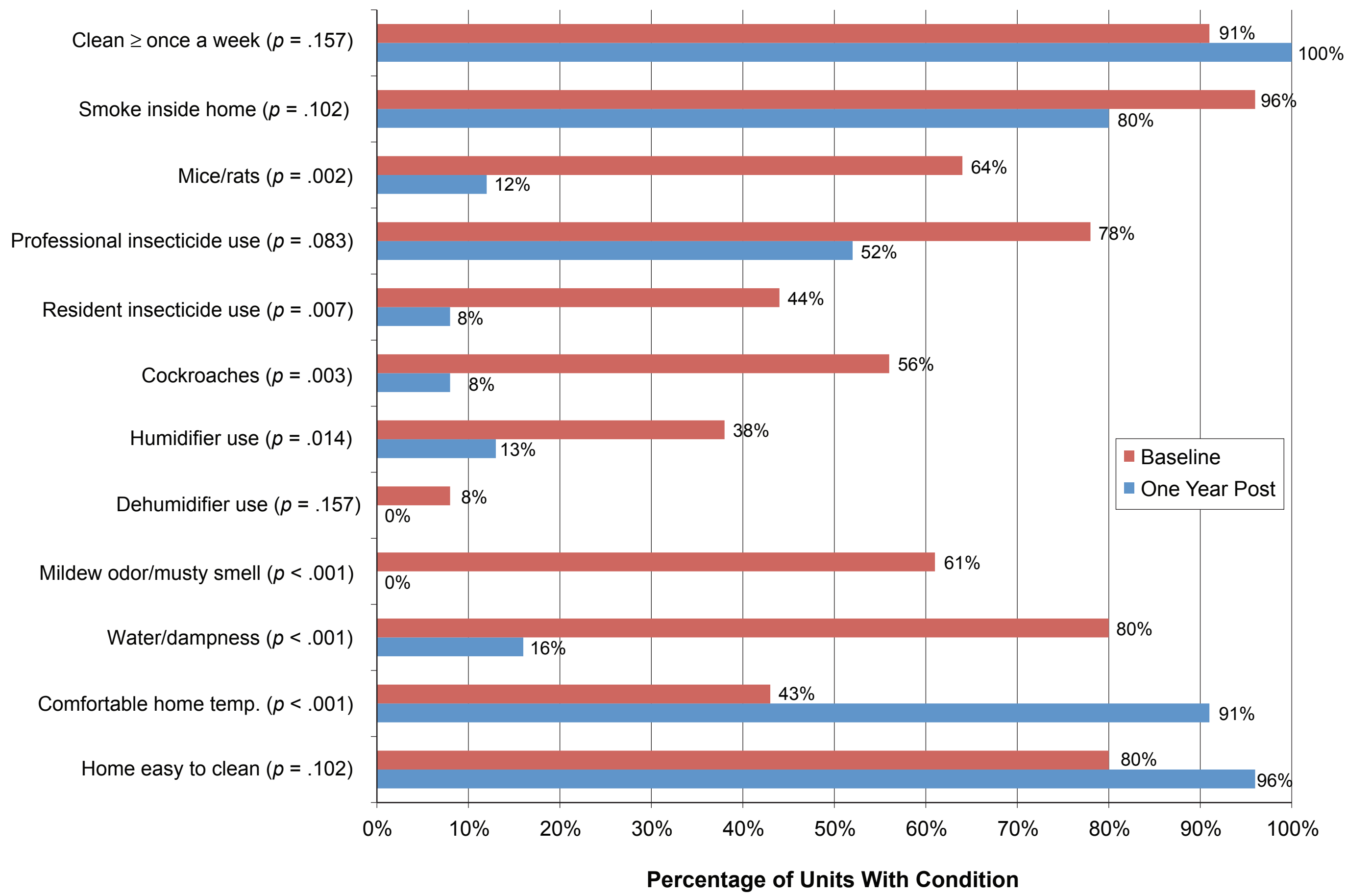
Although standards that incorporate green healthy housing principles are relatively new and for the most part voluntary, our results suggest that widespread implementation through local laws will likely result in significant health gains and housing improvements, especially for low-income at-risk populations where disparities are most pronounced. A recent review of housing disparities that influence health showed that they have remained persistent for decades, with the notable exception of childhood lead-poisoning prevention (Jacobs, 2011), where policy changes have helped to reduce (but not entirely eliminate) lead-poisoning disparities.

A study of housing renovation in London also showed important health improvements following substantial renovation (Ambrose, 2001). Together with other work, this has enabled Great Britain to estimate the health costs of inadequate housing, which is at least £1.5 billion annually (U.S. $1.6 billion) (Nichol, Roys, Davidson, Ormandy, & Ambrose, 2010). A cost/benefit study of unhealthy housing (or the monetized benefit of healthy housing) in the U.S. has not yet been completed, although the net monetized benefit of lead-safe housing in the U.S. has been shown to be substantial (Nevin, Jacobs, Berg, & Cohen, 2008), as has the benefit of multifaceted home interventions for asthmatic children. For example, CDC showed that for every one dollar spent on asthma intervention, the monetary value of the resulting benefits, such as averted medical costs or averted productivity losses, was $5.30–$14.00 (Tursynbek et al., 2011).

A strength of our study is that the ability to sustain low allergen loadings for at least a one-year period underscores the importance of providing smooth and cleanable sur-

FIGURE **4**

Apartment Condition



faces. Another is that it used several different ways to estimate both the housing and health improvements. The use of a structured health interview, visual assessment, and allergen sampling in settled house dust enabled us to quantify improvements. The residents' perception of housing quality is an important metric that should be included in future studies of health outcomes associated with green housing improvements and is an important element of community-engaged research. The residents reported their renovated homes were more comfortable, easier to clean, less damp and less moldy, and far less likely to have pest problems. Our study underscores the need for longer and larger studies to improve the quantification of health gains associated with housing improvements. Finally, our study trained community leaders to help educate residents about how to maintain a healthy home.

Our study has limitations. It is difficult to discern whether health improvements are due to the nature of "green" renovation versus "normal" renovation. A loss of participants to follow-up occurred, primarily because they moved away from study housing, although the demographics of the baseline and follow-up groups were not significantly different. One adult answered the health questions for both themselves and the children in the household, potentially introducing bias. Cultural differences between interviewers and interviewees may have caused misunderstanding of some questions. Self-reported health at two points in time may be subject to recall bias and uncertainty.

Although recall reports are reasonably well correlated with actual health (Miilunpalo, Oja, Pasanen, & Urponen, 1997), future studies should endeavor to collect objective medical data as well as self-reported health data. Ideally, our study would have included households that underwent housing renovation that was not "green," in order to estimate the incremental health and housing benefits associated with green renovation, although the District of Columbia law made such a study design impossible, because virtually all housing renovation was required to comply with the new law.

Conclusion

Incorporating Enterprise Green Communities and LEED standards in low-income housing renovation improves health and housing conditions. Such standards should be included in designs and, where required, implemented through local law or incentives to help contain avoidable medical care expenses and reduce the suffering from poor health associated with inadequate housing. These standards may also help to reduce long-standing housing and health disparities. Quantifying avoidable medical care costs from improved housing should be completed in the U.S., as has been done in Great Britain to help inform health care reform as well as housing policy. All green housing standards should include health-related requirements.

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TABLE **2**

Visual Assessment of Building Conditions

System/Characteristic	#	% With Condition at Baseline	% With Condition at One Year Post	*p*-Value
Bathroom				
Plumbing leaks	25	24	4	.025
Exhaust fan not working/not present	25	100	0	<.001
Ceilings/floors/walls of apartment				
Holes/missing tiles/panels/cracks	25	96	20	<.001
Peeling/needs paint	25	96	4	<.001
Water stains/water damage/visible mold	25	92	0	<.001
Kitchen				
Cabinets/countertops missing/damaged	24	71	4	<.001
Plumbing: leaking faucets/pipes	25	12	0	.083
Stove/sink missing/damaged/inoperable	21	43	5	.011
Apartment				
Damaged doors	24	58	4	<.001
Light fixtures: missing or not working	23	30	8	.198
Smoke detector: not working	20	15	10	.564
Paint damage on windows	24	67	0	<.001
Window glass cracked/missing	24	8	0	.157
Sharp edges	24	54	17	.013
Tripping hazards	24	67	29	.013
Pests (cockroaches, rodents, other insects/vermin)	22	50	41	.527
Building/common areas				
Foundation: cracks/gaps	7	14	0	.317
Water stains/peeling paint on walls	7	57	0	.046
Visible mold on floors	7	29	0	.157
Water stains/water damage/visible mold on ceilings	7	43	0	.083

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TABLE 3

Allergen Dust Loadings

Allergen Type and Location	*n*	Baseline		Three Months Post		One Year Post		*p*-Value
		% <LOD[a]	Median	% <LOD	Median	% <LOD	Median	
Bla g1 (U/ft^2)								
Kitchen	11	27	6	100	<LOD	91	0.8	<.001
Living room	10	50	17.9	100	<LOD	80	2.7	.042
Der f1 (µg/ft^2)								
Bedroom	11	27	3.8	27	6.7	18	12	.779
Living room	10	50	1.2	70	0.07	50	0.3	.513
Der p1 (µg/ft^2)								
Bedroom	11	91	0.1	73	0.4	82	0.4	.549
Living room	10	100	<LOD	80	0.08	80	0.1	.368
Mus m1 (µg/ft^2)								
Kitchen	11	0	2.1	36	0.06	54	0.04	<.001
Living room	10	0	1.8	80	0.03	40	0.06	.005
Rat n1 (µg/ft^2)								
Kitchen	11	100	<LOD	100	<LOD	100	<LOD	N/A
Living room	10	100	<LOD	100	<LOD	100	<LOD	N/A

[a]LOD = limit of detection.

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