The Economic Burden of Exposure to Secondhand Smoke for Child and Adult Never Smokers Residing in U.S. Public Housing

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ABSTRACT

Objective. The World Health Organization (WHO) reports that nonsmokers experience disease and death due to secondhand smoke (SHS) exposure in the home. We estimated the total excess burden and costs to society due to SHS exposure in U.S. public housing.

Methods. We quantified the public health burden for outcomes causally related to SHS exposure for nationally representative never-smoking residents in U.S. public housing using (*1*) WHO-recommended health outcomes and methodology, (*2*) publicly available and other large databases, and (*3*) published estimates of morbidity and mortality rates. We used published estimates of direct medical and nonmedical care costs and the value of productivity losses to estimate SHS-related societal costs for disease and death. We estimated the public health and economic burden for two serum cotinine limits of detection (LODs): 0.05 nanograms per milliliter (ng/mL) and 0.015 ng/mL.

Results. In 2011, an estimated 37,791 never-smoking child and adult U.S. public housing residents experienced illness and death due to SHS exposure at home based on an LOD=0.05 ng/mL (50,967 residents at LOD=0.015 ng/mL). Costs incurred by society for these illnesses and deaths totaled $183 million (LOD=0.05 ng/mL) and $267 million (LOD=0.015 ng/mL) annually. Of the total costs, direct costs (medical and nonmedical) accounted for $128 million and $176 million for LOD=0.05 ng/mL and LOD=0.015 ng/mL, respectively. Medical care accounted for the majority of direct costs—$110 million at LOD=0.05 ng/mL and $153 million at LOD=0.015 ng/mL. Adverse respiratory health outcomes accounted for approximately one-half (56% at LOD=0.05 ng/mL and 52% at LOD=0.015 ng/mL) of total societal costs.

Conclusion. Implementing smoke-free policies in all U.S. public housing could save lives and decrease SHS-related morbidity and mortality in never-smoking residents, resulting in annual societal savings of $183 million at LOD=0.05 ng/mL and $267 million at LOD=0.015 ng/mL.

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An estimated 15%–18% of U.S. children are exposed to secondhand smoke (SHS) at home.[1] SHS is a major cause of disease, and there is no safe level of SHS exposure.[1,2] Children and nonsmoking adults living below the federal poverty level (FPL) are more likely to be exposed to SHS than those in higher socioeconomic status households.[3] Children are especially vulnerable because their exposure patterns and developmental status enhance absorption of environmental toxicants.[4] Additionally, because many elderly people with limited mobility live in public housing, they may spend more time indoors, be exposed to more SHS, and suffer more severe adverse health outcomes than the general population.[2] People with disabilities comprise nearly one-third of the public housing population and have greater SHS exposure than those without a disability.[5,6] Because SHS migrates, residents of multiunit housing who do not allow smoking in their home are at risk for SHS exposure if other residents in their building smoke.[7] SHS migration has implications for nonsmoking public housing residents, as 88% of public housing is multiunit.[8]

The World Health Organization (WHO) reports that there is sufficient evidence of causal relationships between SHS and adverse health outcomes, including lung cancer, heart disease, and asthma in adults; and low birthweight (LBW) (i.e., birthweight ≤2,500 grams), sudden infant death syndrome (SIDS), and lower respiratory infections (LRIs)—including respiratory syncytial virus, bronchitis, otitis media (OM), and asthma—in children.[2]

Smoke-free policies significantly reduce adverse health outcomes caused by SHS.[9–13] In 2009 and 2012, the U.S. Department of Housing and Urban Development (HUD) encouraged public housing authorities to implement smoke-free policies in subsidized housing.[14,15] Recent research suggests that smoke-free policies are supported by a majority of never- and former-smoking subsidized housing residents and are associated with cessation or lower rates of smoking among smokers.[16,17] Recent data indicate that in 2013, more than 300 housing authorities had instituted smoke-free policies.[18,19]

The health and economic consequences of childhood SHS exposure in the United States are well documented,[20–28] but similar analyses are not available for nonsmoking adults. While there are published estimates of the U.S. public health burden associated with SHS exposure in adults and state-level economic studies on SHS that include nonsmoking adults, information on the national aggregate costs of SHS-related health effects in adults is sparse.[29–36]

A recent study estimated SHS-related costs in all government-subsidized housing using state-level estimates.[37] However, to our knowledge this is the first study to estimate the public health and economic burden of SHS in public housing based on nationally representative and other large-scale databases, including biomarker data. Quantifying the burden of SHS for residents may provide incentives to institute smoke-free policies in public housing.

METHODS

We used methods described by the WHO to estimate the annual public health burden for new cases (i.e., incidence) of SHS-attributable illness and death for adult and child never-smoker U.S. public housing residents.[2,38] When the number of incident cases was unavailable, we used self-reported (asthma) or treated (OM and LRI) prevalence rates. We based population-attributable fractions (PAFs) and attributable burdens for each health outcome on WHO estimates of relative risk (RR). We then estimated annual societal economic burdens for each health outcome and overall using previously described methods.[39]

Public housing never smokers

We estimated the number of adult never smokers by multiplying the national percentage of adult never smokers with a household income ≤200% FPL by the number of adults living in public housing (Personal communication, Lydia Taghavi, HUD, February 2012). We used the national prevalence of middle school and high school never smokers from the 2009 National Youth Tobacco Survey to estimate the number of never smokers among public housing adolescents because data stratified by family income or housing type were not available. We defined adults and adolescents aged 11–17 years as never smokers if they reported lifetime consumption of ≤99 cigarettes and either had not smoked (adults) or used any tobacco products (adolescents) in the past 30 days. All children <11 years of age were considered never smokers. We used the proportion of adult never smokers receiving government housing assistance in the 2010 National Health Interview Survey (NHIS) as a proxy for the proportion of adult public housing never smokers. However, government housing assistance is overreported in NHIS; therefore, we further limited NHIS never-smoker data extracted to those who reported both government-subsidized housing and a household income ≤200% FPL.[40]

Exposure to SHS

We used the national percentage of current nonsmokers with detectible serum cotinine levels who participated

in the 2007–2008 and 2009–2010 cycles of the National Health and Nutrition Examination Survey (NHANES) to estimate the proportion of adults and children exposed to SHS. Because NHANES participants are not asked if they live in government-assisted housing, we used SHS-exposed nonsmokers in NHANES with a reported income ≤130% FPL guidelines as a proxy for the nonsmoking public housing population. We classified adults ≥20 years of age with a serum cotinine concentration >the limit of detection (LOD) but ≤10 nanograms per millimeter (ng/mL) who did not report being a current cigarette smoker or having used any nicotine-containing products within the previous five days as nonsmokers.[3] We defined SHS-exposed nonsmoking adolescents as those aged 12–19 years who reported no smoking in the previous 30 days, no use of any nicotine-containing product within the previous five days, and a serum cotinine level >LOD but ≤10 ng/mL. All children aged 3–11 years were classified as SHS-exposed if their cotinine level was >LOD but ≤10 ng/mL. Serum cotinine is not measured in NHANES participants <3 years of age. SHS exposure prevalence for these children was assumed to be the same as in children aged 3–11 years.[41] We present results based on the current serum cotinine LOD=0.015 ng/mL as well as the historically important LOD=0.05 ng/mL to allow comparisons with previous work.

Disease status

We derived incidence, prevalence, and mortality rates for both adult and child health outcomes causally related to SHS exposure from sources listed in Tables 1 and 2. We multiplied each disease/mortality rate by the relevant number of never smokers living in public housing to estimate the number of never-smoking residents with each health outcome of interest. We estimated the public health burden attributable to SHS for each health outcome by calculating a PAF using the RR estimated by WHO (Tables 1 and 2).[2] We used SAS® version 9.2 and SUDAAN® release 10.0 to calculate population-based estimates.[42,43]

Estimates of costs of health outcomes

We conducted a literature search using PubMed, Google, and Google Scholar to identify treatment costs for each health outcome considered in our analysis. Keywords included "asthma," "cost," "cardiovascular disease," "coronary heart disease," "coronary artery disease," "economic burden," "ischemic heart disease," "lower respiratory infection," "low birthweight," "lung cancer," "myocardial infarction," "otitis media," "respiratory syncytial virus," "secondhand smoke," "smoke inhalation," and "sudden infant death syndrome." We took a societal perspective and included all costs for treatment of the health outcomes, regardless of who accrued the cost. Depending on costs considered in the source studies used, we accounted for direct costs (i.e., medical costs including hospitalizations, physician's visits, and medications; and nonmedical costs including travel and paid childcare) and/or productivity losses (e.g., caregiver time lost from work or school due to a patient's illness) (Table 3).[44]

We applied monetary valuations for morbidity-related productivity losses for all adult health outcomes, but only for asthma in children (Table 3). We used only published estimates of data from the United States.[45] We valued premature loss of life as the present value of lifetime economic productivity.[46,47] We used a human capital approach behind a "veil of ignorance" (i.e., productivity losses due to morbidity were based on annual costs using national average wages).[48] We excluded costs associated with premature death when such deaths were rare events and did not contribute substantially to the societal burden resulting from SHS exposure in public housing.

Because excess expenditures better estimate the potential cost savings of policies aimed at reducing adverse health outcomes, we calculated costs for each health outcome by multiplying per-person excess costs by number of never smokers impacted.[49] We summed these costs to derive total aggregated costs for all health outcomes. We used the personal consumption health care expenditure index to adjust direct medical costs and the gross domestic product index to adjust productivity losses and nonmedical direct costs to 2011 dollars.

RESULTS

In 2011, exposure to SHS resulted in morbidity or mortality in 37,791 (at LOD=0.05 ng/mL) and 50,967 (at LOD=0.015 ng/mL) never-smoking U.S. public housing residents. SHS caused the premature death of 14 (at LOD=0.05 ng/mL) and 21 (at LOD=0.015 ng/mL) infant U.S. public housing residents, and 116 (at LOD=0.05 ng/mL) and 215 (at LOD=0.015 ng/mL) adult U.S. public housing residents (Table 4).

Annual costs attributable to SHS in U.S. public housing were approximately $183 million (at LOD=0.05 ng/mL) and $267 million (at LOD=0.015 ng/mL) in 2011. Direct medical costs alone accounted for about $110 million (at LOD=0.05 ng/mL) and $153 million (at LOD=0.015 ng/mL) of total costs (calculations not shown). Asthma ranked highest in total SHS-attributable costs for both adults and children at both LODs. Productivity losses accounted for $54 million (at LOD=0.05 ng/mL) and $91 million (at LOD=0.015

Table 1. Annual SHS-attributable morbidity and mortality of adult never smokers residing in U.S. public housing, 2011

Health condition	Age (in years)	Disease rate in never smokers (percent)	Disease rate data source	Relative risk associated with SHS[a]	Total public housing population[b]	Percent never smokers[c]	Public housing never smokers N	Diseased population N	LOD=0.05 ng/mL: Percent of population exposed[d]	LOD=0.05 ng/mL: Population-attributable fraction	LOD=0.05 ng/mL: Population with disease attributable to SHS N	LOD=0.015 ng/mL: Percent of population exposed	LOD=0.015 ng/mL: Population-attributable fraction	LOD=0.015 ng/mL: Population with disease attributable to SHS N
Sample calculation		*A*		*B*	*C*[e]	*D*	$E = C \times D^e$	$F = A \times E^e$	$G_{0.05}$	$H_{0.05} = G_{0.05}(B\text{-}1)/(G_{0.05}[B\text{-}1]+1)$	$I_{0.05} = H_{0.05} \times F^e$	$G_{0.015}$	$H_{0.015} = G_{0.015}(B\text{-}1)/(G_{0.015}[B\text{-}1]+1)$	$I_{0.015} = H_{0.015} \times F^e$
Adults														
Lung cancer morbidity			NPCR[f] (2009–2010)	1.21	1,301,507		689,525	72			8			12
	18–50	0.0009			754,835	54	407,611	4	48	0.09	1	81	0.15	1
	51–64	0.0105			275,962	48	132,462	14	46	0.09	2	79	0.14	2
	65–84	0.036			235,976	52	122,708	45	38	0.07	4	75	0.14	7
	≥85	0.032			34,734	77	26,745	9	38	0.07	1	75	0.14	2
Lung cancer mortality			NPCR[f] (2009–2010)	1.21	1,301,507		689,525	56			6			10
	18–50	0.001			754,835	54	407,611	3	48	0.09	1	81	0.15	1
	51–64	0.007			275,962	48	132,462	10	46	0.09	1	79	0.14	2
	65–84	0.028			235,976	52	122,708	34	38	0.07	3	75	0.14	5
	≥85	0.033			34,734	77	26,745	9	38	0.07	1	75	0.14	2
Heart disease morbidity			NHLBI[g] (2012 update)	1.27	544,689		286,563	727			71			127
	51–64	0.195			219,794	48	105,501	206	46	0.11	23	79	0.18	38
	65–84	0.257			276,429	52	143,743	369	38	0.09	34	75	0.17	63
	≥85	0.405			48,466	77	37,319	152	38	0.09	14	75	0.17	26
Heart disease mortality			CDC WONDER[h] (2009–2010)	1.27	544,689		286,563	1,163			106			200
	51–64	0.04			219,794	48	105,501	44	46	0.11	5	79	0.18	8
	65–84	0.24			276,429	52	143,743	342	38	0.09	31	75	0.17	59
	≥85	2.08			48,466	77	37,319	777	38	0.09	70	75	0.17	133

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Table 1 (continued). Annual SHS-attributable morbidity and mortality of adult never smokers residing in U.S. public housing, 2011

Health condition	Age (in years)	Disease rate in never smokers (percent)	Disease rate data source	Relative risk associated with SHS[a]	Total public housing population[b]	Percent never smokers[c]	Public housing never smokers N	Diseased population N	LOD=0.05 ng/mL			LOD=0.015 ng/mL		
									Percent of population exposed[d]	Population-attributable fraction	Population with disease attributable to SHS N	Percent of population exposed	Population-attributable fraction	Population with disease attributable to SHS N
Sample calculation		*A*		*B*	*C*[e]	*D*	*E* = *C* × *D*[e]	*F* = *A* × *E*[e]	$G_{0.05}$	$H_{0.05} = G_{0.05}(B\text{-}1)/(G_{0.05}[B\text{-}1]+1)$	$I_{0.05} = H_{0.05} \times F^e$	$G_{0.015}$	$H_{0.015} = G_{0.015}(B\text{-}1)/(G_{0.015}[B\text{-}1]+1)$	$I_{0.015} = H_{0.015} \times F^e$
Asthma morbidity			NHIS[c] (2009–2010)	1.97	1,301,507		689,525	47,150			14,579			20,462
	18–50	6.4			754,835	54	407,611	26,065	48	0.32	8,341	81	0.44	11,469
	51–64	10.3			275.962	48	132,462	13,601	46	0.31	4,217	79	0.43	5,849
	65–84	6.1			235,976	52	122,708	7,484	38	0.27	2,021	75	0.42	3,144
	≥85	NA[i]			34,734	77	26,745	NA	38	0.27	NA	75	0.42	NA
Asthma mortality			CDC WONDER[h] (2009–2010)	1.97	1,301,507		686,315	8			4			5
	18–50	0.0003			754,835	54	406,856	2	48	0.32	1	81	0.44	1
	51–64	0.0004			275,962	48	131,082	1	46	0.31	1	79	0.43	1
	65–84	0.0008			235,976	52	121,528	2	38	0.27	1	75	0.42	1
	≥85	0.0105			34,734	77	26,849	3	38	0.27	1	75	0.42	2

[a]Öberg M, Jaakkola MS, Prüss-Üstün A, Schweizer C, Woodward A. Second-hand smoke: assessing the burden of disease at national and local levels. Geneva: World Health Organization; 2010.

[b]Unpublished data: personal communication, Lydia Taghavi, U.S. Department of Housing and Urban Development, February 2012

[c]Data extracted from: Centers for Disease Control and Prevention (US). National Health Interview Survey 2009 data release [cited 2014 Feb 11]. Available from: URL: http://www.cdc.gov/nchs/nhis/nhis_2009_data_release.htm

[d]Data extracted from: National Center for Health Statistics (US). National Health and Nutrition Examination Survey questionnaires, datasets and related documentation [cited 2014 Mar 10]. Available from: URL: http://www.cdc.gov/nchs/nhanes/nhanes_questionnaires.htm

[e]Summed values may not add to totals due to rounding.

[f]Centers for Disease Control and Prevention (US). CDC WONDER: National Program of Cancer Registries Early Release publication information data: incidence 1999–2010 [cited 2014 Feb 25]. Available from: URL: http://wonder.cdc.gov/wonder/help/cancernpcr.html

[g]Roger VL, Go AS, Lloyd-Jones DM, Adams RJ, Berry JD, Brown TM, et al. Heart disease and stroke statistics—2011 update: a report from the American Heart Association. Circulation 2011;123:e18-e209.

[h]Centers for Disease Control and Prevention (US). CDC WONDER: underlying cause of death 1999–2013 [cited 2014 Apr 1]. Available from: URL: http://wonder.cdc.gov/wonder/help/ucd.html

[i]Insufficient sample size to obtain a reliable estimate

SHS = secondhand smoke

LOD = limit of detection

ng/mL = nanograms per milliliter

NPCR = National Program of Cancer Registries

NHLBI = National Heart, Lung, and Blood Institute

CDC = Centers for Disease Control and Prevention

WONDER = Wide-ranging Online Data for Epidemiologic Research

NHIS = National Health Interview Survey

NA = not applicable

Table 2. Annual SHS-attributable morbidity and mortality of child never smokers residing in U.S. public housing, 2011

									LOD=0.05 ng/mL			LOD=0.015 ng/mL		
Health condition	*Age (in years)*	*Disease rate in never smokers Percent*	*Disease rate data source*	*Relative risk associated with SHS*[a]	*Total public housing population*[b] N	*Percent never smokers*[c]	*Public housing never smokers* N	*Diseased population* N	*Percent population exposed*[d]	*Population-attributable fraction*	*Population with disease attributable to SHS* N	*Percent of population exposed*	*Population-attributable fraction*	*Population with disease attributable to SHS* N
Sample calculation		*A*		*B*	*C*[e]	*D*	$E = C \times D^e$	$F = A \times E^e$	$G_{0.05}$	$H_{0.05} = G_{0.05}(B\text{-}1)/(G_{0.05}[B\text{-}1]+1)$	$I_{0.05} = H_{0.05} \times F^e$	$G_{0.015}$	$H_{0.015} = G_{0.015}(B\text{-}1)/(G_{0.015}[B\text{-}1]+1)$	$I_{0.015} = H_{0.015} \times F^e$
Children														
Low birthweight morbidity	<1	8.2	NVSR[f] (2009)	1.38	40,094	100	40,094	3,288	48	0.15	494	81	0.24	790
Low birthweight mortality	<1	0.11	NVSR[f] (2009)	1.38	40,094	100	40,094	44	48	0.15	7	81	0.24	11
Sudden infant death syndrome	<1	0.05	NVSR[f] (2009)	1.94	40,094	100	40,094	22	48	0.31	7	81	0.43	10
Lower respiratory infection														
Respiratory syncytial virus	<1	2.4	NHDS[g] (1997–2000 and 2006)	1.55	40,094	100	40,094	975	61	0.25	244	85	0.32	312
Pneumonia	1–2	0.28	NHDS[g] (2006)	1.55	101,764	100	101,764	288	61	0.25	72	85	0.32	93
Bronchitis/ bronchiolitis	1–2	0.25	NHDS[g] (2006)	1.55	101,764	100	101,764	255	61	0.25	64	85	0.32	82
Otitis media	0–3	31.4	NHANES III[d,h] (2003)	1.34	195,555	100	195,555	61,405	61	0.17	10,439	85	0.22	13,510

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Table 2 (continued). Annual SHS-attributable morbidity and mortality of child never smokers residing in U.S. public housing, 2011

									LOD=0.05 ng/mL			LOD=0.015 ng/mL		
Health condition	*Age (in years)*	*Disease rate in never smokers Percent*	*Disease rate data source*	*Relative risk associated with SHS*[a]	*Total public housing population*[b] N	*Percent never smokers*[c]	*Public housing never smokers* N	*Diseased population* N	*Percent population exposed*[d]	*Population-attributable fraction*	*Population with disease attributable to SHS* N	*Percent of population exposed*	*Population-attributable fraction*	*Population with disease attributable to SHS* N
Sample calculation		*A*		*B*	*C*[e]	*D*	$E = C \times D^e$	$F = A \times E^e$	$G_{0.05}$	$H_{0.05} = G_{0.05}(B\text{-}1)/(G_{0.05}[B\text{-}1]+1)$	$I_{0.05} = H_{0.05} \times F^e$	$G_{0.015}$	$H_{0.015} = G_{0.015}(B\text{-}1)/(G_{0.015}[B\text{-}1]+1)$	$I_{0.015} = H_{0.015} \times F^e$
Asthma			NHIS[i] (2009)	1.32	814,909		761,052	73,061			11,690			15,343
	1–11	9.6			505,232	100	505,232	48,503	61	0.16	7,761	85	0.21	10,186
	12–13	9.6			132,719	91[a]	120,854	11,602	61	0.16	1,857	85	0.21	2,437
	14–17	9.6			176,958	76[a]	134,966	12,957	61	0.16	2,074	85	0.21	2,721

[a]Öberg M, Jaakkola MS, Prüss-Üstün A, Schweizer C, Woodward A. Second-hand smoke: assessing the burden of disease at national and local levels. Geneva: World Health Organization; 2010.

[b]Unpublished data: personal communication, Lydia Taghavi, U.S. Department of Housing and Urban Development, February 2012

[c]Data extracted from: Centers for Disease Control and Prevention CDC (US), Office on Smoking and Health. National Youth Tobacco Survey (NYTS) 2009 [cited 2012 Jun 15]. Available from: URL: http://www.cdc.gov/tobacco/data_statistics/surveys/nyts/index.htm. The NYTS captures smoking status by status in school (i.e., middle or high school). For children >11 years of age, we assumed children aged 12–13 years were in middle school and those aged ≥14 years were in high school.

[d]Data extracted from: National Center for Health Statistics (US). National Health and Nutrition Examination Survey III questionnaires, datasets and related documentation [cited 2014 Mar 10]. Available from: URL: http://www.cdc.gov/nchs/nhanes/nhanes_questionnaires.htm

[e]Summed values may not add to totals due to rounding.

[f]Hamilton BE, Martin JA, Ventura SJ. Births: preliminary data for 2009. Natl Vital Stat Rep 2010 Dec 21;59:1-19. Also available from: URL: http://www.cdc.gov/nchs/data/nvsr/nvsr60/nvsr60_02.pdf [cited 2014 Feb 19].

[g]National Center for Health Statistics (US). National Hospital Discharge Survey, 1997–2000 and 2006 [cited 2015 Feb 4]. Available from: URL: http://www.cdc.gov/nchs/nhds/nhds_publications.htm

[h]Published estimate in: Auinger P, Lanphear BP, Kalkwarf HJ, Mansour ME. Trends in otitis media among children in the United States. Pediatrics 2003;112:514-20.

[i]National Center for Health Statistics (US). 2009 National Health Interview Survey public-use data release. Hyattsville (MD): NCHS; 2010.

SHS = secondhand smoke

LOD = limit of detection

ng/mL = nanograms per milliliter

NVSR = National Vital Statistics Report

NHDS = National Hospital Discharge Survey

NHANES III = National Health and Nutrition Examination Survey III

NHIS = National Health Interview Survey

Table 3. Source articles for cost data and selected source article study characteristics on SHS-attributable health outcomes in the U.S.

Health outcome	*Authors and year of publication*	*Sample size (n)*	*Cost data source(s)*	*Costs included*	*Type of cost estimate*	*Age of study population*	*Dollar year reported*
Adults							
Lung cancer morbidity	Chang et al., 2004[a]	Lung cancer: 2,038 Controls: 6,120	MarketScan Commercial Claims and Encounters Database, Medicare Supplemental and Coordination of Benefits Database, Health and Productivity Management Database	Direct medical: $74,172 per person per year	Incremental	CCAE: mean age 34 years Medicare: mean age 74 years	2000
Lung cancer mortality	Bradley et al., 2008[b]	NA: population based	Bureau of Labor Statistics Current Population Survey	Productivity losses: mortality: $210,330 per premature death	Present value of lifetime earnings	≥20 years of age Median age at death: 72 years[c]	2010
Ischemic heart disease morbidity	Personal communication, Justin Trogdon, RTI International, September 2011	Not provided	Medical Expenditure Panel Survey	Direct medical: $6,958 per person per year Productivity losses: morbidity: $1,787 per premature death	Incremental	≥18 years of age	2008
Ischemic heart disease mortality	Roger et al., 2011[d]	NA: population based	Unpublished estimates of lifetime earnings[e]	Productivity losses: mortality: $245,390 per premature death[f]	Present value of lifetime earnings	All ages Median age at death: 76 years (men), 84 years (women)[d]	2008
Asthma morbidity	Barnett and Nurmagambetov, 2011[g]	Asthma: 8,719 No asthma: 198,132	Medical Expenditure Panel Survey	Direct medical: $3,259 per person per year	Incremental	All ages	2009
			Medical Expenditure Panel Survey: authors' model	Productivity losses: morbidity: $301 per adult worker per year lost	Incremental	15–64 years	
Asthma mortality	Barnett and Nurmagambetov, 2011[g]	72,922	Published estimates of lifetime productivity[h]	Productivity losses: mortality: $586,422 per premature adult death[i]	Present value of lifetime earnings	All ages Median age at death: 63 years[j]	2009
Children							
Low birthweight morbidity	Russell et al., 2007[k]	Preterm/low birthweight newborns: 160,700 Uncomplicated newborns: 721,800	Healthcare Cost and Utilization Project—Nationwide Inpatient Sample	Direct medical: $15,200 per infant delivery	Incremental	<1 year	2005
	Schmitt et al., 2006[l]	<2,500 grams at birth: 25,986 ≥2,500 grams at birth: 411,525	California infant and maternal hospital discharge summaries linked with infant vital statistics data	Maternal delivery costs: $4,442 per infant delivery	Incremental	Mothers of infants born in California hospitals	2003

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Table 3 (continued). Source articles for cost data and selected source article study characteristics on SHS-attributable health outcomes in the U.S.

Health outcome	*Authors and year of publication*	*Sample size*	*Cost data source(s)*	*Costs included*	*Type of cost estimate*	*Age of study population*	*Dollar year reported*
Low birthweight mortality	Grosse et al., 2009[m]	72,922	American Time Use Survey; Employer Cost for Employee Compensation survey; Occupational Employment Statistics survey	Productivity losses: mortality: $1,180,796 per premature death	Present value of lifetime earnings	0–4 years	2007
Sudden infant death syndrome	Grosse et al., 2009[m]	72,922	American Time Use Survey; Employer Cost for Employee Compensation survey; Occupational Employment Statistics survey	Productivity losses: mortality: $1,180,796 per premature death	Present value of lifetime earnings	0–4 years	2007
Lower respiratory infection morbidity	Shi et al., 2011[n]	RSV LRI in-patient: 2,720 UBP in-patient: 5,621	MarketScanMulti-state Medicaid	Direct medical: RSV LRI: $9,151 per hospitalized infant per year; UBP: $2,823 per hospitalized infant per year	Incremental	<1 year	2006
	Leader et al., 2003[o]	Preterm infants (33–35 weeks gestation): 48; Full-term infants: 36	Tertiary-care hospitals	Direct nonmedical: $2,135 per hospitalized full-term infant per year	Total	<1 year	Not stated; assumed 2000
Otitis media morbidity	Ahmed et al., 2014[p]	Acute otitis media: 995 No acute otitis media: 10,420	Medical Expenditure Panel Survey-Health Care	Direct medical: $331 per child per year	Total	0–17 years	2009
	Alsarraf et al., 1999[q]	Acute otitis media: 12 Controls: 13	Diary	Direct nonmedical: $1,157 per child per year	Incremental	1–3 years	1996
Asthma morbidity	Barnett and Nurmagambetov, 2011[g]	Asthma: 8,719 No asthma: 198,132	Medical Expenditure Panel Survey	Direct medical: $3,259 per person per year	Incremental	All ages	2010
			Medical Expenditure Panel Survey: authors' model	Productivity losses: morbidity: $93 per student per year	Incremental	Parents/caregivers of children 3–19 years of age	

[a]Chang S, Long SR, Kutikova L, Bowman L, Finley D, Crown WH, et al. Estimating the cost of cancer: results on the basis of claims data analyses for cancer patients diagnosed with seven types of cancer during 1999 to 2000. J Clin Oncol 2004;22:3524-30.

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continued on p. 239

Table 3 (continued). Source articles for cost data and selected source article study characteristics on SHS-attributable health outcomes in the U.S.

[c]Lung cancer median age at death from Surveillance, Epidemiology, and End Results (SEER) stat fact sheets/lung and bronchus [cited 2014 Mar 12]. Available from: URL: www.seer.cancer.gov

[d]Roger VL, Go AS, Lloyd-Jones DM, Adams RJ, Berry JD, Brown TM, et al. Heart disease and stroke statistics—2011 update: a report from the American Heart Association. Circulation 2011;123:e18-e209.

[d]Kelly BB, Fuster V, editors. Promoting cardiovascular health in the developing world: a critical challenge to achieve global health. Washington: National Academies Press; 2010.

[e]Provided by the National Heart, Lung, and Blood Institute to the American Heart Association

[f]Calculated by authors based on published costs due to lost productivity (mortality) in: Roger VL, Go AS, Lloyd-Jones DM, Adams RJ, Berry JD, Brown TM, et al. Heart disease and stroke statistics—2011 update: a report from the American Heart Association. Circulation 2011;123:e18-e209, and the number of ischemic heart disease deaths from: Kochanek KD, Xu J, Murphy SL, Minino AM, Kung H-C. Deaths: final data for 2009. Natl Vital Stat Rep 2011 Dec 29;60:1-117.

[g]Barnett SB, Nurmagambetov TA. Costs of asthma in the United States: 2002–2007. J Allergy Clin Immunol 2011;127:145-52.

[h]Costs were adapted from data presented in: Grosse SD, Krueger KV, Mvundura M. Economic productivity by age and sex: 2007 estimates for the United States. Med Care 2009;47(7 Suppl 1):S94-103.

[i]Calculated by the authors based on ages and mortality costs for those aged ≥15 years presented in: Barnett SB, Nurmagambetov TA. Costs of asthma in the United States: 2002–2007. J Allergy Clin Immunol 2011;127:145-52.

[j]Calculated by the authors from number and age of asthma-related deaths published in: Barnett SB, Nurmagambetov TA. Costs of asthma in the United States: 2002–2007. J Allergy Clin Immunol 2011;127:145-52.

[k]Russell RB, Green NS, Steiner CA, Meikle S, Howse JL, Poschman K, et al. Cost of hospitalization for preterm and low birthweight infants in the United States. Pediatrics 2007;120:e1-9.

[l]Schmitt SK, Sneed L, Phibbs CS. Costs of newborn care in California: a population-based study. Pediatrics 2006;117:154-60.

[m]Grosse SD, Krueger KV, Mvundura M. Economic productivity by age and sex: 2007 estimates for the United States. Med Care 2009;47(7 Suppl 1):S94-103.

[n]Shi N, Palmer L, Chu BC, Katkin JP, Hall CB, Masaquel AS, et al. Association of RSV lower respiratory tract infection and subsequent healthcare use and costs: a Medicaid claims analysis in early-preterm, late-preterm, and full-term infants. J Med Econ 2011;14:335-40.

[o]Leader S, Yang H, DeVincenzo J, Jacobson P, Marcin JP, Murray DL. Time and out-of-pocket costs associated with respiratory syncytial virus hospitalization of infants. Value Health 2003;6:100-6.

[p]Ahmed S, Shapiro NL, Bhattacharyya N. Incremental health care utilization and costs for acute otitis media in children. Laryngoscope 2014;124:301-5.

[q]Alsarraf R, Jung CJ, Perkins J, Crowley C, Alsarraf NW, Gates GA. Measuring the indirect and direct costs of acute otitis media. Arch Otolaryngol Head Neck Surg 1999;125:12-8.

SHS = secondhand smoke

CCAE = Commercial Claims and Encounters

NA = not applicable

RSV = respiratory syncytial virus

LRI = lower respiratory infection

UBP = unspecified bronchiolitis/pneumonia

Table 4. Estimates of annual public health burden and societal costs of SHS-attributable health outcomes for child and adult never smokers in U.S. public housing, 2011

		Per-person productivity losses		*LOD=0.05 ng/mL*				*LOD=0.015 ng/mL*			
SHS-attributable health condition	*Per-person direct costs (medical and nonmedical)*	*Per-person morbidity-related productivity losses*[a]	*Per-person mortality-related productivity losses*[a]	*Number with health condition*	*Total direct costs*[a] *(medical and nonmedical)*	*Total productivity losses*[a,b]	*Total costs*[a] *(medical and nonmedical)*	*Number with health condition*	*Total direct costs*[a] *(medical and nonmedical)*	*Total productivity losses*[a,b]	*Total costs*[a]
Sample calculation	*A*	*B*	*C*	*D*	*E = A × D*	*F = B × D*	*G = E + F*	*H*	*I = A × H*	*J = B × H*	*K = I + J*
Adults											
Lung cancer morbidity	$102,761[b]	$14,489	NA	8	$822,091	$115,913	$938,004	12	$1,233,137	$173,869	$1,407,006
Lung cancer mortality	NA	NA	$214,814	6	NA	$1,288,882	$1,288,882	10	NA	$2,148,137	$2,148,137
Lung cancer total				14	$822,091	$1,404,795	$2,226,886	22	$1,233,137	$2,322,006	$3,555,143
IHD morbidity	$7,462[b]	$1,865	NA	71	$529,778	$132,446	$662,224	127	$947,632	$236,910	$1,184,542
IHD mortality	NA	NA	$244,162	106	NA	$27,152,985	$27,152,985	200	NA	$51,232,046	$51,232,046
IHD total				177	$529,778	$27,285,430	$27,815,209	327	$947,632	$51,468,956	$52,416,588
Asthma morbidity	$3,402[b]	$312	NA	14,579	$49,603,056	$4,541,568	$54,144,624	20,462	$69,619,160	$6,374,207	$75,993,367
Asthma mortality	NA	NA	$606,907	4	NA	$2,427,626	$2,427,626	5	NA	$3,034,533	$3,034,533
Asthma total				14,583	$49,603,056	$6,969,194	$56,572,250	20,467	$69,619,160	$9,408,739	$79,027,899
Adult disease total				14,774	$50,954,926	$35,659,419	$86,614,345	20,816	$71,799,929	$63,199,702	$134,999,631
Children											
Low birthweight morbidity	$25,968[b]	NC[c]	NA	494	$12,828,194	NA	$12,828,194	790	$20,514,723	NA	$20,514,723
Low birthweight mortality	NA	NA	$1,260,089	7	NA	$8,820,620	$8,820,620	11	NA	$13,860,975	$13,860,975
Low birthweight total				501	$12,828,194	$8,820,620	$21,648,814	801	$20,514,723	$13,860,975	$34,375,697
Sudden infant death syndrome	NA	NA	$1,260,089	7	NA	$8,820,620	$8,820,620	10	NA	$12,600,886	$12,600,886
Lower respiratory infection morbidity											
Respiratory syncytial virus	$13,179[d]	NC[c]	NA	244	$3,215,727	NA	$3,215,727	312	$4,111,914	NA	$4,111,914
Pneumonia	$5,952[d]	NC[c]	NA	72	$428,546	NA	$428,546	93	$553,539	NA	$553,539
Bronchitis/bronchiolitis	$5,952[d]	NC[c]	NA	64	$380,930	NA	$380,930	82	$488,066	NA	$488,066
Lower respiratory infection morbidity total				380	$4,025,203	NA	$4,025,203	487	$5,153,518	NA	$5,153,518
Otitis media morbidity	$1,972	NC[c]	NA	10,439	$20,584,149	NA	$20,584,149	13,510	$26,639,702	NA	$26,639,702
Asthma morbidity	$3,402	$96	NA	11,690	$39,773,628	$1,125,146	$40,898,775	15,343	$52,202,462	$1,476,743	$53,679,204
Children's disease total				23,017	$77,211,174	$18,766,387	$95,977,560	30,151	$104,510,405	$27,938,603	$132,449,008
Grand total				37,791	$128,166,100	$54,425,806	$182,591,905	50,967	$176,310,334	$91,138,305	$267,448,639

[a]Summed dollar amounts may not add to totals due to rounding.

[b]Includes direct medical costs only

[c]Estimate was not found in published data.

[d]Includes direct medical and nonmedical costs

SHS = secondhand smoke

LOD = limit of detection

IHD = ischemic heart disease

ng/mL = nanograms per milliliter

NA = not applicable

NC = not considered

ng/mL). The average total per-person cost due to SHS exposure in never-smoking U.S. public housing residents was an estimated $4,832 (at LOD=0.05 ng/mL) and $5,247 (at LOD=0.015 ng/mL) (calculations not shown).

Adults

SHS-related morbidity and mortality in adult U.S. public housing never smokers accounted for about $87 million (at LOD=0.05 ng/mL) and $135 million (at LOD=0.015 ng/mL) in 2011 (Table 4). Direct medical care accounted for approximately 59% (at LOD=0.05 ng/mL) and 53% (at LOD=0.015 ng/mL) of total adult costs (calculations not shown), with asthma and IHD responsible for virtually all SHS-related morbidity and mortality in adults; asthma alone accounted for 99% (at LOD=0.05 ng/mL) and 98% (at LOD=0.015 ng/mL) of the health burden, and 65% (at LOD=0.05 ng/mL) and 59% (at LOD=0.015 ng/mL) of costs for adults (calculations not shown). Lung cancer ranked highest in annual per-person direct medical care costs ($102,761) and morbidity-related productivity losses ($14,489).[50,51] However, because it is a rare condition relative to asthma and IHD, lung cancer contributed little (3% for both LODs) to the total economic burden for adults (calculations not shown).

Children

Health-care, productivity, and nonmedical direct costs for children exposed to SHS in U.S. public housing totaled $96 million (at LOD=0.05 ng/mL) and $132 million (at LOD=0.015 ng/mL) (Table 4), or 53% (at LOD=0.05 ng/mL) and 50% (at LOD=0.015 ng/mL) of total societal costs (calculations not shown). Direct costs accounted for 80% (at LOD=0.05 ng/mL) and 79% (at LOD=0.015 ng/mL) of the total economic burden for children (calculations not shown). Asthma together with OM affected 96% of children who had SHS-attributable health outcomes (11,690 [at LOD=0.05 ng/mL] and 15,343 [at LOD=0.015 ng/mL] for asthma and 10,439 [at LOD=0.05 ng/mL] and 13,510 [at LOD=0.015 ng/mL] for OM) (Table 4), and incurred nearly two-thirds of total costs for children ($61 million [at LOD=0.05 ng/mL] and $80 million [at LOD=0.015 ng/mL]) (calculations not shown). Of infants who lived in U.S. public housing and died from SIDS or LBW-related factors, 31% (at LOD=0.05 ng/mL) and 43% (at LOD=0.015 ng/mL) of deaths from SIDS and 15% (at LOD=0.05 ng/mL) and 24% (at LOD=0.015 ng/mL) of deaths from LBW-related factors were attributable to SHS (calculations not shown). Although the number of infants in U.S. public housing expected to have died from SHS-attributable deaths was small (14 [at LOD=0.05 ng/mL] and 21 [at LOD=0.015 ng/mL] out of 40,094 infants), these deaths accounted for 18% (at LOD=0.05 ng/mL) and 20% (at LOD=0.015 ng/mL) of total annual SHS-attributable costs for children in U.S. public housing (calculations not shown).

DISCUSSION

The annual economic burden of SHS-attributable illness and death of never smokers in U.S. public housing totaled approximately $183 million (at LOD=0.05 ng/mL) and $267 million (at LOD=0.015 ng/mL). The benefits of reducing SHS exposure in U.S. public housing include lower out-of-pocket expenditures for medical care, lower apartment clean-up costs, and fewer productivity losses for employers and society.[52,53] To our knowledge, this study is the first to estimate both the national public health burden and the economic impact of SHS on never-smoking U.S. public housing residents using nationally representative and other large-scale databases, and including biomarker data. Our results may help frame the problem of SHS exposure in U.S. public housing by quantifying the public health burden and associated monetary costs.

U.S. public housing residents have higher levels of exposure to SHS than the national population and a majority support policies aimed at eliminating SHS where they live.[16,54] Because U.S. public housing is owned by public housing authorities, there are fewer barriers to implementing a smoke-free policy compared with voucher-assisted or privately owned housing (e.g., Section 8) (Personal communication, Barry Steffen, HUD, February 2012). The health benefits of a smoke-free policy for children would be substantial because they receive most of their exposure to SHS in the home and have a higher intake of SHS than adults.[1,2] An effective U.S. public housing smoke-free policy would result in 130 (at LOD=0.05 ng/mL) and 236 (at LOD=0.015 ng/mL) fewer lives lost annually in never smokers. Even if never smokers are routinely exposed to SHS outside of the home, evidence suggests that a temporary respite from SHS may reduce adverse health outcomes such as IHD in adults.[29]

A recent study estimated $521 million in annual societal cost savings if smoking was banned in all government-subsidized U.S. housing. Our estimate of the annual societal direct medical costs ($110 million [at LOD=0.05 ng/mL] and $153 million [at LOD=0.015 ng/mL]) incurred due to SHS in U.S. public housing only is within the range ($50–$181 million) estimated by King et al.[37] However, several differences between the two studies are worth noting. First, we provide both

aggregated and health outcome-specific estimates of the public health and economic burdens; King et al. provided neither the public health burden nor health outcome-specific costs. Whereas King et al. relied on data based on self-report, we used biomarker data to determine the proportion of never smokers exposed to SHS. We calculated our estimates using both the current and previous LOD for detecting cotinine in serum (0.015 ng/mL and 0.05 ng/mL, respectively). While not explicitly stated, we assume King et al. used the previous LOD in their analysis. King et al. estimated SHS-attributable fire-related and apartment renovation costs, which were not included in our study. We used costs of illness or death from nationally representative or large-scale databases with national data when available. In contrast, the King et al. study used state-adjusted costs based on Minnesota health-care claims data. Finally, King et al. did not account for productivity losses, which were 40% (at LOD=0.015 ng/mL) and 43% (at LOD=0.05 ng/mL) of the total economic burden in our study.

Our estimate is higher than a previous estimate of the national annual per-person cost of productivity losses due to SHS-related death ($373,159 [at LOD=0.05 ng/mL] and $351,172 [at LOD=0.015 ng/mL] in 2011 dollars vs. $158,000 in 2006 dollars per premature death).[55] This difference might be because (*1*) the prevalence of smoking in low-income families is higher than the national average[3,56] and (*2*) public housing has a higher percentage of infants and children than the national population.[57,58] Premature death in the young exacts high societal costs.[46]

Our cost-of-illness study did not include the implementation costs of smoke-free policies. We speculate these costs would be outweighed by the societal benefits of such policies. However, there is scant information on the costs or cost-effectiveness of implementing or enforcing smoke-free policies.[59] Widespread adherence to a smoke-free policy in U.S. public housing would reduce adverse outcomes and societal costs from SHS exposure for both former and current smokers, which would greatly increase its benefits. Moreover, if barriers could be reduced in implementing smoke-free policies in voucher-assisted (i.e., Section 8) homes, there would be substantial additional savings produced by HUD-recommended smoke-free policies.

Limitations

Our study had several limitations. First, the RR estimates we used were not based exclusively on SHS exposures occurring solely in the home.[2] Serum cotinine measurements reflect recent SHS exposure, regardless of location. Thus, we may have overestimated the health and economic impact of SHS exposure in the home. However, young children, the elderly, and the disabled comprise a substantial proportion of public housing residents and likely spend more time at home.[5,57] Thus, the effect of exposures occurring outside the home for these groups may be small. Additionally, SHS exposure inside the home likely, but not necessarily, results in higher exposure levels than exposure due to migration between apartments. For example, it is unclear whether exposure from smoke that migrates from an apartment with one or more heavy smokers to a nonsmoker's apartment is higher or lower than the exposure experienced by never smokers with infrequent exposure to cigarette smoke in their home. Recent studies report that residents living in nonsmoking multiunit housing have higher cotinine levels and are more likely to smell smoke in their buildings than are residents of single-family homes.[60,61] These findings suggest that the proportion of people exposed to SHS in our analysis is likely higher than the values we used.

When available, we used the incremental cost of each SHS-caused disease. However, these data were not available for all health outcomes of interest (e.g., OM). Moreover, this approach has been criticized because comorbidities or related health outcomes may account for a substantial portion of total excess costs, leading to double counting of effects and, thus, overestimation of true excess costs.[62,63] On the other hand, incorrect coding for patients with comorbidities may lead to an underestimation of SHS-attributable costs.

The use of disease rates and health care based on the general population likely underestimates the amount of disease in the public housing population.[64,65] However, we used national disease rates for individuals living in government-assisted housing, where possible, in an attempt to minimize the discrepancy. However, public housing residents may differ in meaningful ways from residents receiving other government housing subsidies. Excluding respiratory syncytial virus, none of the cost estimates we used were derived from studies conducted on low-income populations. Therefore, these costs may not accurately reflect health-care expenditures or the value of productivity losses in the low-income population.[66] In particular, nearly half of people in poverty are covered by public insurance or are uninsured,[67] which may result in lower reimbursements than for those who have private insurance. Additionally, some of the published estimates we used were quite dated and may not reflect current health-care practices and costs.[63] In two cases, OM and LRI, we used morbidity-related productivity loss estimates based on small studies with convenience samples not designed to measure these losses among public housing

residents. Finally, although we used a societal perspective, we did not account for all costs that are borne by society (e.g., long-term care, copayments, and other nonmedical direct expenses), as well as the intangible costs of the health effects (e.g., pain and suffering) of SHS exposure.

CONCLUSION

Implementation of smoke-free policies in all U.S. public housing can improve the health of residents and reduce societal costs, including medical costs. Our analysis provides national estimates of the public health and economic burdens associated with SHS exposure in U.S. public housing and quantifies the benefits of implementing a smoke-free policy in all U.S. public housing.

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