Economic Value of Home-Based, Multi-Trigger, Multicomponent Interventions with an Environmental Focus for Reducing Asthma Morbidity

A Community Guide Systematic Review

Tursynbek A. Nurmagambetov, PhD, Sarah Beth L. Barnett, MA,
Verughese Jacob, PhD, Sajal K. Chattopadhyay, PhD, David P. Hopkins, MD, MPH,
Deidre D. Crocker, MD, Gema G. Dumitru, MD, MPH, Stella Kinyota, MD, MPH,
Task Force on Community Preventive Services

Context: A recent systematic review of home-based, multi-trigger, multicomponent interventions with an environmental focus showed their effectiveness in reducing asthma morbidity among children and adolescents. These interventions included home visits by trained personnel to assess the level of and reduce adverse effects of indoor environmental pollutants, and educate households with an asthma client to reduce exposure to asthma triggers. The purpose of the present review is to identify economic values of these interventions and present ranges for the main economic outcomes (e.g., program costs, benefit–cost ratios, and incremental cost-effectiveness ratios).

Evidence acquisition: Using methods previously developed for *Guide to Community Preventive Services* economic reviews, a systematic review was conducted to evaluate the economic efficiency of home-based, multi-trigger, multicomponent interventions with an environmental focus to improve asthma-related morbidity outcomes. A total of 1551 studies were identified in the search period (1950 to June 2008), and 13 studies were included in this review. Program costs are reported for all included studies; cost–benefit results for three; and cost-effectiveness results for another three. Information on program cost was provided with varying degrees of completeness: six of the studies did not provide a list of components included in their program cost description (limited cost information), three studies provided a list of program cost components but not a cost per component (partial cost information), and four studies provided both a list of program cost components and costs per component (satisfactory cost information).

Evidence synthesis: Program costs per participant per year ranged from $231–$14,858 (in 2007 U.S.$). The major factors affecting program cost, in addition to completeness, were the level of intensity of environmental remediation (minor, moderate, or major), type of educational component (environmental education or self-management), the professional status of the home visitor, and the frequency of visits by the home visitor. Benefit– cost ratios ranged from 5.3–14.0, implying that for every dollar spent on the intervention, the monetary value of the resulting benefits, such as averted medical costs or averted productivity losses, was $5.30 –$14.00 (in 2007 U.S.$). The range in incremental cost-effectiveness ratios was $12–$57 (in 2007 U.S.$) per asthma symptom–free day, which means that these interventions achieved each additional symptom-free day for net costs varying from $12–$57.

Conclusions: The benefits from home-based, multi-trigger, multicomponent interventions with an environmental focus can match or even exceed their program costs. Based on cost– benefit and

From the Air Pollution and Respiratory Health Branch, Division of Health Hazards and Health Effects, National Center for Environmental Health (Nurmagambetov, Barnett, Crocker, Dumitru, Kinyota) and Community Guide Branch, Epidemiology and Analysis Program Office (Jacob, Chattopadhyay, Hopkins), CDC, Atlanta, Georgia

The names and affiliations of the Task Force members are available at www.thecommunityguide.org/about/task-force-members.html.

Address correspondence to: Tursynbek A. Nurmagambetov, PhD, CDC, 4770 Buford Highway, MS F-58, Atlanta GA 30341. E-mail: ten7@cdc.gov.

0749-3797/$17.00
doi: 10.1016/j.amepre.2011.05.011

cost-effectiveness studies, the results of this review show that these programs provide a good value for dollars spent on the interventions.

(Am J Prev Med 2011;41(2S1):S33–S47) Published by Elsevier Inc. on behalf of American Journal of Preventive Medicine

Context

Asthma is one of the most prevalent and costly chronic diseases in the U.S. and the world.[1–13] The disease has the highest prevalence among chronic conditions and is a leading source of morbidity in children.[14,15] In addition to the substantial direct medical costs associated with the disease, which were $50.1 billion in 2007,[16] the economic burden of asthma also includes costs of missed work and school days, costs of traveling to a healthcare facility, the value of time spent by caregivers, and the reduction in quality of life.[5,17]

Asthma causes repeated episodes of wheezing, breathlessness, chest tightness, and nighttime or early morning coughing. Although the causes of asthma and asthma exacerbations are multifactorial and to some extent not yet fully understood, adherence to a recommended medical treatment regimen and avoidance of asthma triggers can reduce the risk and frequency of exacerbations and decrease the overall burden of the disease.[18–22]

Ambient air pollutants, such as the Environmental Protection Agency criteria pollutants, are associated with increased risk of asthma exacerbations in children and adults.[1–5] Environmental tobacco smoke creates a substantial risk for childhood and adult asthma. Smoking is a major cause of respiratory symptoms and diseases including asthma.[6–10] Asthma episodes can be triggered by not only adverse direct effects of air pollution on the respiratory system, but also psychological factors. Both parental and maternal psychosocial factors can influence asthma morbidity in children.[11] A richer discussion of the clinical and environmental aspects of asthma can be found in the systematic review of the effectiveness in this supplement to the *American Journal of Preventive Medicine*.[23]

People spend a great amount of time indoors, and the indoor environment influences health, particularly among individuals with asthma. An individual's indoor home environment can be altered with fewer resources and fewer barriers than outdoor environments.[20] Exposure to indoor allergens increases the risk of asthma symptoms and precipitates asthma exacerbations, and several studies show significant benefits of indoor asthma trigger reduction for individuals with asthma.[19,24–27]

Results of a recent systematic review of effectiveness studies (in this supplement)[23] demonstrated that home-based, multi-trigger, multicomponent interventions with an environmental focus for reducing asthma morbidity (referred to in this paper as *home-based environmental interventions*) were effective programs to reduce asthma morbidity in children and adolescents. The current review focuses on the same types of interventions evaluated by the systematic review of effectiveness studies that sought to affect the indoor environment of homes of individuals with asthma.

Home-based environmental interventions involve trained personnel making one or more visits to conduct prevention activities in the home with an asthma client. These activities focus on reducing exposures to a range of asthma triggers (allergens and irritants) through environmental assessment, education, and remediation. Most interventions include added components, such as self-management training, social support, and coordinated care, in conjunction with efforts to reduce asthma triggers in the home environment.

The characteristics of home-based environmental interventions, such as location of the intervention, population features, number of home visits, type of home visitor, intensity of environmental intervention, and educational content, can vary. Although each variation of the intervention is ultimately designed to reduce asthma morbidity, that objective is achieved with different degrees of effectiveness and cost; these are the main factors that define the economic value of the intervention. After home-based environmental interventions were shown to be effective for children and adolescents with asthma, the question that emerged was whether these interventions are affordable for families, communities, local and state health departments, and other potential stakeholders and payers. This question of affordability becomes even more important because many children with asthma in the U.S. live in low-income urban families,[25,28–33] and their caregivers often cannot afford to take basic steps to reduce exposure of a family member with asthma to indoor triggers.

Whereas the effectiveness review[23] primarily focused on estimating effects of the interventions on health outcomes, this review examines the economic **efficiency** of the interventions, which was defined as the extent of health or quality-of-life outcomes (e.g., the number of days free from asthma symptoms) that could be achieved for the dollars spent on the intervention. Following the effectiveness review of home-based environmental interventions, a team of scientists from the Air Pollution and Respiratory Health and the Community Guide branches at the CDC collaborated to conduct a systematic review of economic evaluation studies. In 2009 the results of the review were presented to the Task Force on Community Preventive Services (the Task Force) at the CDC, and the findings from that presentation provided a foundation for this article.

In this systematic review, the economic values of home-based environmental interventions are represented in terms of program costs, benefit–cost ratios, and incremental cost-effectiveness ratios. To our knowledge, this is the first systematic review that summarizes recent studies on economic evaluation of home-based environmental interventions to reduce morbidity among clients with asthma.

Evidence Acquisition

Application of Methods for Systematic Review of Economic Evaluation

A systematic review of economic evaluation studies is usually conducted for community-based interventions that are recommended for use by the Task Force on the basis of intervention effectiveness.[34–37] The methods developed for and used by the *Guide to Community Preventive Services*[38] (the *Community Guide*) for conducting systematic reviews on economic evaluations across community interventions are described elsewhere.[34,36] The process for conducting a systematic review of economic evaluation studies is analogous to that for effectiveness reviews and involves the following basic steps:[39]

1. establishing inclusion/exclusion criteria for interventions and for information sources;
2. conducting a literature search;
3. screening titles and abstracts, and conducting full reviews of studies that pass initial screening;
4. reviewing and abstracting final selected papers;
5. assigning a quality rating to each study;
6. adjusting economic estimates;
7. developing a summary conclusion;
8. discussion of analysis.

The next paragraphs briefly describe how each of these steps was applied in this study.

Establishing inclusion/exclusion criteria for interventions and for information sources. The main subject of economic evaluation in this review is **home-based**, **multi-trigger**, **multicomponent interventions with an environmental focus**, referred to as **home-based environmental interventions**, which were defined in the systematic review of the evidence on effectiveness published in this issue.[23] To be considered for inclusion in this review, interventions had to: include at least one home visit; target two or more indoor asthma triggers; and include two or more intervention components, at least one of which had to be an activity directed at improving the indoor environment for a client with asthma. Interventions with two or more of the following distinct components were defined as multicomponent: environmental assessment, environmental remediation, environmental education, self-management education, general asthma education, improved access to social services, and coordinated care. A full description of the inclusion/exclusion criteria for home-based environmental interventions can be found in the accompanying article,[23] and only the economic evaluation studies with interventions that satisfied those criteria were included in this economic review.

In addition, to be included in the list of potential studies for this review, a study had to be primary research (not a review, summary report, or abstract), be written in English, and be conducted in a high-income country as defined by the World Bank (www.worldbank.org), and had to contain some numeric information on the costs associated with home-based environmental interventions.

Conducting a literature search. The economic review team adjusted the search strategy used in the effectiveness review by adding keywords specific to economic evaluation, such as *economic(s)*, *cost, benefit, cost–benefit, benefit–cost, utility, cost–utility, QALY, cost effectiveness,* and *efficiency*. In addition to the databases searched in the effectiveness review (i.e., MEDLINE, EMBASE, ERIC, PsycINFO, Web of Science, Cochrane Library, Sociological Abstracts, and CINAHL), social science databases such as EconLit, Social Sciences Citations Index, and JSTOR; databases of the Centre for Reviews and Dissemination at the University of York; and Google were also used. These searches were conducted for 1950 through July 2008.

Screening titles, abstracts, and conducting full review of studies that pass initial selection. Once the literature search identified a preliminary list of papers, reviewers read the titles and abstracts to determine which studies might satisfy inclusion criteria. In the next round, reviewers read the full text of the remaining papers and finalized the list of the studies selected for full abstraction.

Included studies had to use one or more of the four methods of economic evaluation analysis: cost, cost–benefit, cost effectiveness, or cost–utility. Studies with only program cost information also were included on the premise that they provide important information about affordability and applicability of the interventions. Details regarding these economic methods are available elsewhere.[40,41]

Reviewing and abstracting final selected papers. Reviewers read each study that met the inclusion/exclusion criteria and abstracted the information pertaining to economic evaluation of the intervention using a standardized abstraction form developed for the *Community Guide*.[34] This abstraction form facilitates summarizing key economic evaluation information on study design and methods, intervention description with sample and target populations, comparator group and effect size, descriptive study information such as intervention length and follow-up periods, costs and benefits information, and the computed economic summary measures. After one reviewer completed the full abstraction of an included study, the results of the abstraction were reviewed independently by another reviewer, and any differences in opinion were resolved by consensus of these two or, if necessary, by all reviewers.

Assigning a quality rating to each study. Program cost, which is the value of all resources required to implement the intervention, is an essential part of an economic evaluation study. Having more detailed information on program cost facilitates better understanding of factors that affect the cost and the magnitude of those effects, and provides guidance for designing, planning, and developing a budget for implementing the intervention. In this review, program cost information was reported in all included articles, albeit with different degrees of completeness.

For quality assessment of the studies, the focus was on the completeness of program cost information. All included studies were classified into three categories—*satisfactory*, *partially complete*, or *limited*—based on completeness of program cost information. These classifications depended on whether a study provided both a list of program cost components and the cost of each component on that list (satisfactory); only a list of program cost components without full information about the cost of each component (partially complete); or only total program costs without breaking down specific cost components (limited).

Adjusting economic estimates. For a valid comparison of economic information across the studies, effectiveness and economic outcomes were adjusted to produce annual average values. Because studies were generally conducted in different years, all monetized values were converted to the base monetary unit, 2007 U.S.$, to adjust for inflation and to improve comparability of results across all studies. For conversion into 2007 U.S.$, the Consumer Price Index (CPI) was used for non-medical-related and the Medical Component of the Consumer Price Index (MCPI) for medical-related costs (both available at www.worldbank.org). In two studies[42,43] conducted in the United Kingdom, the currency unit was the British pound, and the purchasing power parities method from the World Bank was used to convert British pounds into U.S. dollars.

Developing summary conclusions. Depending on the information provided in the study, one or more of three different economic measures was used: program cost, benefit–cost ratio, or incremental cost-effectiveness ratio. These economic measures provided a tool for determining economic values of the interventions and for assessing whether home-based environmental interventions provide a good value for money invested.[44]

Discussion of analysis. Major factors that affected program costs, benefit–cost ratio, and cost-effectiveness ratio were identified and appraised based on the economic values of the interventions, study limitations, and research gaps in economic evaluation of home-based environmental interventions. The evidence was summarized to demonstrate why these interventions can provide a good value for the money invested.

Economic Evaluation Methods Reviewed to Determine the Value of Home-Based Interventions

Each study used one of three types of economic evaluation analysis: program cost, cost–benefit, or cost-effectiveness analysis, and, respectively, the final economic outcomes reported were program cost and benefit–cost or incremental cost-effectiveness ratio (ICER). To provide more accurate estimates for the economic value of an intervention, more complete information on costs, benefits, and health effects associated with the intervention is desirable.[34,40,41,45–47]

If a study included in this review provided information on program costs, monetized benefits, and symptom-free days (SFDs), the final economic outcome or the economic value of the intervention was presented as an ICER achieved as a result of the intervention. The ICER employed in this review was the ratio of net cost (i.e., program cost minus dollar values of averted medical and nonmedical services) over additional SFDs that is achieved as a result of the intervention.

If a study had information on program costs and monetized benefits but not sufficient data on any measure of health or quality of life outcomes such as SFDs, then the economic value of the intervention was reported as a benefit–cost ratio. For the studies included in this review that did not present enough data for cost–benefit or cost-effectiveness analysis, program cost was reported as the economic value of the intervention. Some studies had information on both costs and benefits of the intervention but did not specifically present a final economic outcome measure. In this case, the reviewers computed benefit–cost or ICER based on the information available in the study.[24,48–50]

Program cost analysis. In healthcare literature, the terms *program* and *intervention* are often used interchangeably,[40,41] and in this review the same convention is followed. Accordingly, throughout this article *program cost, intervention cost*, *cost of program*, or *cost of intervention* all have the same meaning: the value of all resources required to implement an intervention (or a program). Even though program cost does not represent the relationship between the costs and benefits of the intervention, it nevertheless provides important information on affordability of the program, especially if the program is shown to be effective.

Cost–benefit analysis. Benefits in this review were defined as monetized values of averted healthcare utilization and averted missed school and work days due to illness. Correspondingly, in the studies on cost–benefit analysis, the economic value of the program is presented as a benefit–cost ratio, which is the ratio of net benefits over program costs.

Cost–benefit results also can be expressed as *net costs* or *net benefits* of the intervention, which is the difference between the program costs and benefits.[41,47] However, the advantage of a benefit–cost ratio is that it is independent of the currency units used because the ratio is unit-free, as long as both costs and benefits are expressed in the same year currency. Another advantage is that a benefit–cost ratio also can be interpreted as return-on-investment outcome, which is the value of net benefits obtained per unit of investment. For example, if the benefit–cost ratio is >1, it means that every dollar spent on the intervention returns more than 1 dollar in net benefits.

Cost-effectiveness analysis. In cost-effectiveness analysis the main outcome measure is the ICER. If C_I and E_I are the total net cost and effectiveness in the intervention group, and C_C and E_C are the total net cost and effectiveness in the control (or comparator) group, then the ICER is estimated as the ratio of $C_I - C_C$ divided by $E_I - E_C$. SFDs were used as the effectiveness measure in all three cost-effectiveness studies.

An important element in a healthcare cost-effectiveness analysis is an appropriate effectiveness measure associated with the change in the health or quality of life of individuals resulting from the intervention; this measure can also be used as the denominator for an ICER. In asthma care studies, an SFD has been used widely as an effectiveness measure primarily owing to its sensitivity (or responsiveness) to various asthma interventions and its applicability across different asthma population categories such as age groups, employment status, and asthma severity.[29,51–54] Thus, the final economic outcome of cost-effectiveness studies in this review is expressed as the *net cost* (program costs minus averted medical care and productivity losses) per additional SFD; or, in other words, as an ICER. Each ICER was either reported as is in a cost-effectiveness study with adjustment to 2007 U.S.$ or was computed by the reviewers from the information provided in the study.

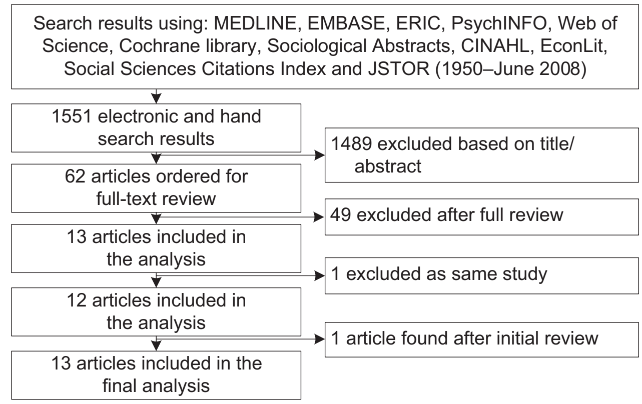

Figure 1. Flow chart of article selection

Evidence Synthesis

Search Results

The literature search based on all considered databases originally produced 1551 papers (Figure 1). After reviewing the titles and abstracts of these papers, 1489 of them were excluded because they did not meet the inclusion criteria. A review of the full text of the remaining 62 articles resulted in exclusion of 49 papers; the remaining 13 papers were selected for final economic evaluation review and full abstraction. Papers by Morgan et al.[25] and by Kattan et al.[52] described the same study of an inner-city asthma randomized trial involving environmental allergen and irritant remediation in homes housing children aged 6–11 years with moderate-to-severe asthma. Only the Kattan paper[52] was included in the analysis, based on its more comprehensive presentation of the economic evaluation analysis of the intervention; this reduced the full abstraction list to 12 articles. A paper by Bryant-Stephens and Li[55] was identified subsequent to the database search, resulting in a total of 13 included papers.[24,29,42,43,48–50,52,53,55–58] With the exception of the Lin et al.[58] and Bryant-Stephens and Li[55] studies, 11 of 13 papers were also independently identified by the systematic review of intervention effectiveness.[23]

Characteristics of Studies and Interventions

The studies and interventions included in this review varied in several ways, such as study design, study location, population size, length of follow-up period, completeness of cost and benefit information, qualification of and number of home visitors, level of remediation inten-

Table 1. Summary of economic evaluation studies

Study	Study design	Study location	Sample size	Age range (years)	Follow-up period (months)
Barton (2007)[42]	RCT	Torquay, United Kingdom	119[b]	0–65+	6–9
Somerville (2000)[43]	Pre–post[a]	Cornwall, United Kingdom	87[b]	0–15	3–22
Kercsmar (2006)[56]	RCT	Cuyahoga County, OH	62	2–17	12
Eggleston (2005)[53]	RCT	Baltimore MD	100	6–12	12
Primomo (2006)[57]	Pre–post	Tacoma–Pierce County, WA	197[b]	0–18	1
Lin (2004)[58]	Pre–post	New York State	NR	0–65+	12
Bryant-Stephens (2008)[55]	RCT	West Philadelphia	396	2–16	12
Oatman (2007)[49]	Pre–post	Twin Cities MN	64	0–18	12
Jowers (2000)[48]	Pre–post	Western Pennsylvania	317	0–65+	6, 12
Shelledy (2005)[50]	Pre–post	Little Rock AR	18	3–18	12
Krieger (2005)[24]	RCT	Seattle–King County, WA	274	4–12	6
Kattan (2005)[52]	RCT	Multi-site (7 U.S. cities)	937	5–11	12
Sullivan (2002)[29]	RCT	Multi-site (8 U.S. cities)	1033	5–11	12

Note: Asthma severity: based on a majority of asthma clients in that category as reported in the article
[a]Pre- and post- (before and after) study design
[b]Sample size in this study is the number of households.

sity, and educational content (Tables 1–4). Some studies did not report values for each of these categories. All these factors contributed to the variation in the final economic outcomes (program costs, benefit–cost ratios, or ICERs) presented in this systematic review.

Study design. The 13 studies included in this economic review were divided between two types of design: seven were RCTs,[24,29,42,52,53,55,56] and six were pre–post studies.[43,48–50,57,58] In Kercsmar et al.,[56] a study originally designed as an RCT was later modified when three children from each of two groups were moved to the opposite group after randomization. The block randomization study design used in Kattan et al.[52] takes into account changes in patients' characteristics during the study time frame; for example, the patients in the intervention group might have better controlled asthma over the time frame of the study.[59]

Study location. Two of the studies were conducted in the United Kingdom,[42,43] and the remaining 11 studies were carried out in the U.S. Two cost-effectiveness studies[29,52] were multi-site and carried-out respectively in eight and seven cities across the U.S.

Population size. The average sample size in the studies was 287 people (range: 18–1033) at baseline. The number of participants in the study at the end of the follow-up period was not consistently reported.

Age of participants. Three studies included participants of all ages[42,48,58]; participants in the remaining nine studies were aged ≤1–19 years.

Severity of asthma. The National Asthma Education and Prevention Program (NAEPP) guidelines[21,22,60] distinguish four classes of asthma severity: mild intermittent, mild persistent, moderate persistent, and severe persistent. Of 13 studies in this review, four targeted individuals with all types of asthma severity,[48,55,57,58] four targeted moderate-to-severe persistent,[29,43,50,52] three targeted mild intermittent or persistent,[42,53,56] one targeted moderate persistent,[49] and one mild-to-severe persistent[24] (Table 3).

Time frame. Some included papers were not sufficiently clear about study time frame, such as time before enrollment in intervention, length of intervention, or total duration of the program. Follow-up periods were reported in every study and ranged from 1[57] to 22 months.[43] The most frequent follow-up period was 12 months, used in seven studies (Table 1).[29,48,50,52,53,56,58]

Completeness and Major Drivers of Program Costs

Program costs for all 13 studies are shown in Table 4. Three of 13 studies had sufficient information for cost–benefit analysis, and another three studies had additional

Table 2. Completeness of program cost information

Study	List of cost components included	Cost of each component included	Completeness of program cost information
Barton (2007)[42]	No	No	Limited
Somerville (2000)[43]	No	No	Limited
Kercsmar (2006)[56]	No	No	Limited
Eggleston (2005)[53]	Yes	No	Partially complete
Primomo (2006)[57]	Yes	Yes	Satisfactory
Lin (2004)[58]	No	No	Limited
Bryant-Stephens (2008)[55]	No	No	Limited
Oatman (2007)[49]	Yes	Yes	Satisfactory
Jowers (2000)[48]	No	No	Limited
Shelledy (2005)[50]	Yes	No	Partially complete
Krieger (2005)[24]	Yes	No	Partially complete
Kattan (2005)[52]	Yes	Yes	Satisfactory
Sullivan (2002)[29]	Yes	Yes	Satisfactory

information for cost-effectiveness analysis. In all studies except one,[58] an average program cost per participant per year is presented. For the study by Lin et al.,[58] only the total program cost is presented, because the number of participants was not reported.

Completeness of cost information. Reporting of program costs varied, with some studies providing more details on program components than others. Four studies[29,49,52,57] in the review had *satisfactory*, three had *partially complete*,[24,50,53] and six studies[42,43,48,55,56,58] had *limited* cost information (Table 2).

Drivers of program costs. In this review, a driver of program costs is defined as a factor that noticeably affects the cost of the intervention. Of several possible factors, the four most common and, in the authors' judgment, key drivers of the cost of intervention were identified: home-visitor type, numbers of home visits, remediation type, and education content.

Home-visitor type. Qualifications of home visitors participating in the interventions varied greatly. Home visitors were respiratory therapists,[49,50] nurses,[42,48] sanitarians,[56] asthma educators,[49] community health workers,[24] environmental counselors,[52,53] local housing officers,[43] exterminators,[29,53] and outreach workers.[55,57,58] Visitors with higher qualifications (i.e., more education or work experience) appear generally to increase the cost of the intervention.

Numbers of home visits. The number of home visits ranged from one to nine visits per year, with two visits being the most common.[43,48,57,58] Higher numbers of home visits were likely to increase intervention costs.

Types of environmental remediation. Environmental remediation efforts were grouped in three categories: *minor*, *moderate*, and *major*. *Minor* remediation efforts[29,48,50,57] provided a low-cost item such as an allergen-impermeable cover and provided advice on recommended environmental changes to be performed by the members of the household. Moderate remediation[24,49,52,53,55,58] included provision of multiple low-cost materials and the active involvement of the trained home visitor(s). Activities in this category included providing and fitting allergen-impermeable mattress and pillow covers, installing small air filters and dehumidifiers, integrated pest management, professional cleaning services or equipment, and minor repairs of structural integrity (patching holes). Major remediation efforts[42,43,56] involved structural improvements to the home such as carpet removal, replacement of ventilation systems, and extensive repairs for structural integrity (roof, walls, and floors). Accordingly, program costs were higher for major remediation than for minor or moderate remediation (Figure 2). More details on environmental remediation and types of asthma triggers are provided in the accompanying article.[23]

Education components. Studies were grouped into two potentially overlapping categories based on the content of the education component of the interventions: *environmental education*[24,29,49,50,52,53,55–58] and *asthma self-management education*.[29,48–50,53,55–58] Examples of environmental education included instructions in basic environmental control activities, providing and discussing the results of allergy testing, discussing the results on pollutant and allergen levels in homes, and providing information about avoiding environmental tobacco smoke and indoor allergen sources along with cleaning instructions. The elements of asthma management education included providing information on asthma management plans; instruction on the correct use of asthma medications, spacer devices, nebulizers, and peak flow

Table 3. Summary of economic information

Study	SES	Asthma severity	Type of environmental remediation	Education component	Home visits	Type of home visitor
Barton (2007)[42]	Low SES	Mild intermittent or persistent	Major[a]	NR	1	Nurse
Somerville (2000)[43]	Low SES	Moderate to severe persistent	Major	NR	2	Housing officer
Kercsmar (2006)[56]	Low SES	Mild persistent	Major	EE, SM	5	Sanitarians
Eggleston (2005)[53]	NR	Mild intermittent or persistent	Moderate[b]	EE, SM	3	Environmental educator
Primomo (2006)[57]	NR	All types	Minor[c]	EE, SM	2	Outreach worker
Lin (2004)[58]	NR	All types	Moderate	EE, SM	2–3	Outreach worker
Bryant-Stephens (2008)[55]	Low SES	All types	Moderate	EE, SM	5	Outreach worker
Oatman (2007)[49]	Low SES	Moderate to severe persistent[d]	Moderate	EE, SM	3	Respiratory therapist
Jowers (2000)[48]	NR	All types	Minor	SM	2	Nurse
Shelledy (2005)[50]	Low SES	Moderate to severe persistent	Minor	EE, SM	8	Respiratory therapist
Krieger (2005)[24]	Low SES	Mild to severe persistent	Moderate	EE	5–9	Community health worker
Kattan (2005)[52]	Low SES	Moderate to severe persistent	Moderate	EE	5–7	Environmental counselor
Sullivan (2002)[29]	Low SES	Moderate to severe persistent	Minor	EE, SM	0–2	Exterminator

[a]Major remediations involve structural improvements to the home and extensive repairs for structural integrity of the home.
[b]Moderate remediations include provision of multiple low-cost materials and the active involvement of the trained home visitor.
[c]Minor remediations provide a low-cost item and advice on recommended environmental changes in the household.
[d]77% of patients had moderate-to-severe persistent asthma.
EE, environmental education; NR, not reported; SM, asthma self-management education

meters; and information on necessary steps to take when asthma symptoms occur.

Table 3 lists major drivers of intervention costs: types of home visitors, numbers of home visits, levels of remediation intensity, and educational focus of interventions. Based on the data provided in the studies, here it is stated only whether education provided by the intervention was on environmental asthma triggers, on asthma self-management, or both.

Results on Economic Values of Home-Based Environmental Interventions

Program costs. Costs of intervention for all studies included in this review were adjusted to 2007 U.S.$. The costs of interventions (shown in column 2, Table 4) ranged from $231–$14,858 per participant per year. The two most expensive home-based interventions in terms of program cost were conducted in the United Kingdom, and both involved major remediation[42,43] with costs per participant per year of $14,858 and $6424, respectively.

When the third major remediation study,[56] conducted in Cuyahoga County, Ohio, was included, the costs of interventions with the most expensive major remediation ranged from $3796–$14,858 per participant per year.[42,43,56] The range of costs for interventions with minor-to-moderate remediation was $231–$1720 per participant per year.[52,57] The costs of intervention were greater in studies conducted in the United Kingdom ($6424 or $14,858 per participant per year)[42,43] than those in the U.S. ($231–$3796).[24,29,48–50,52,53,56–58] The range of program costs per participant per year for the studies with limited cost information was $377–$14,858[42,43,48,55,56,58]; for studies with partially complete information, costs ranged from $554–$1316[24,50,53]; and for studies with satisfactory information, costs ranged from $231–$1720.[29,49,52,57]

Benefit–cost ratio. Three studies had information sufficient to conduct cost–benefit (but not cost-effectiveness) analysis of home-based environmental interventions be-

Table 4. Summary of per-participant economic information

Study	Program cost ($)	Direct medical costs averted ($)	Monetized productivity loss averted	Benefit–cost ratio	Change in SFDs	ICER ($ per SFD)
Barton (2007)[42]	14,858[a]	NR	NR	NA	NR	NA
Somerville (2000)[43]	6424	NR	NA[c]	NA	NR	NA
Kercsmar (2006)[56]	3796	NR	NR	NA	NR	NA
Eggleston (2005)[53]	554	NR	NR	NA	NR	NA
Primomo (2006)[57]	231	NR[c]	NR	NA	NR	NA
Lin (2004)[58]	Only total program cost available[b]	NR	NR	NA	NR	NA
Bryant-Stephens (2008)[55]	853	NR	NR	NA	NR	NA
Oatman (2007)[49]	497	2637	NR[c]	5.3	NR[d]	NA
Jowers (2000)[48]	377	2181	772	7.8	NR	NA
Shelledy (2005)[50]	721	10093	NA[c]	14.0	NR	NA
Krieger (2005)[24]	1316	124–147	NR	0.09–0.11	20.8	56–57
Kattan (2005)[52]	1720	555	NR[c]	0.32	37.8	31
Sullivan (2002)[29]	458	147	NR	0.32	26.6	12

[a]All numbers are average values per participant per year.
[b]The article does not provide sufficient information for average program cost.
[c]These benefits were not monetized.
[d]Only daytime changes in SFDs were significant.
ICER, incremental cost-effectiveness ratio; NA, not assessed; NR, not reported; SFD, symptom-free day

cause SFDs were not reported[48–50]; the final economic outcomes of these interventions are presented as benefit–cost ratios. All of these studies had a pre–post study design, were conducted in the U.S., and used a 12-month follow-up period. The interventions included minor to moderate environmental remediation types, and the number of visits and type of home visitors affected program costs, which ranged from $377–$721. Oatman[49] and Shelledy[50] provided information on direct medical costs averted. Jowers et al.[48] also included productivity costs averted as a result of reduction in missed work days (and although the study estimated the number of school days missed, no monetary values were assigned).

Net benefits for all three studies were computed, based on the information provided in the articles. The direct medical cost averted in the Shelledy study,[50] $10,093, was four and five times higher than in the two other studies, which may be due in part to the intensive nature of the intervention; it included eight weekly home visits by the respiratory therapists and resulted in an 80% reduction in hospital, emergency room visits, and intensive unit care, and a 90% reduction in the total costs associated with asthma care. All three studies demonstrated benefit–cost ratios >1 (range of values, 5.3–14.0; Table 4), reflecting economic benefits that are greater than program costs.

Incremental cost-effectiveness ratio. All three studies for which ICERs could be calculated were RCTs. In Kattan et al.[52] and Sullivan et al.,[29] the control groups had no intervention (status-quo group), whereas Krieger et al.[24] used a specific control group consisting of a single home visit with environmental assessment, bedding encasement, and limited education (low-intensity group). Interventions in Krieger et al.[24] and Kattan et al.[52] had an environmental remediation component of moderate intensity; Sullivan et al.[29] analyzed an intervention with minor environmental remediation. The ranges per participant per year were $458–$1720 for program costs, $124–$555 for direct medical costs averted, and 20.8–37.8 for SFDs. The final economic outcomes ranged from an incremental cost-effectiveness ratio of $12 to $57 per additional SFD.

Cost and benefits numbers in the calculation of the ICER for these three cost-effectiveness studies can also be used to compute benefit–cost ratios. Although benefit–cost ratio is generally not preferred to ICER, it is

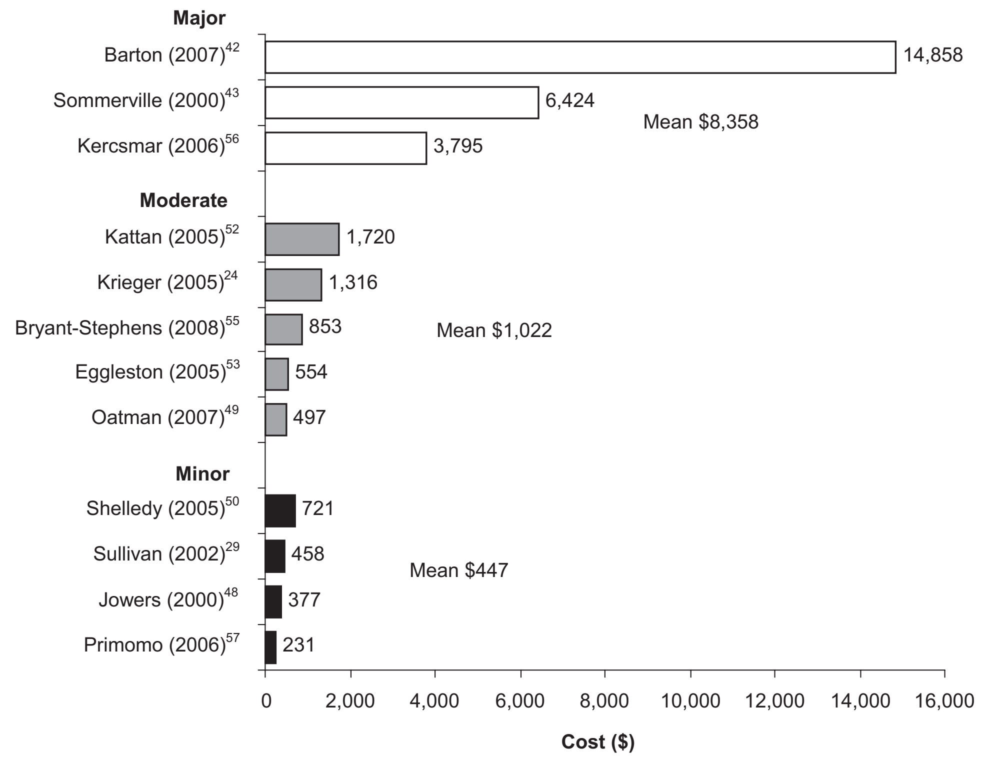

Figure 2. Program cost by environmental remediation intensity
Note: Lin (2004) does not provide sufficient information for average program cost and is omitted from the graph.

informative to compute this type of economic outcome for comparison. The three cost-effectiveness studies had benefit–cost ratios ranging from 0.09 to 0.32.[24,29,52]

Conclusion

In everyday life, people routinely make decisions about buying a good or service based on their perception or more thorough assessment of its economic value, arrived at by weighing the utility of the product or service against its cost.[45] Consumers do not necessarily buy goods or services to save money, but they do save money by shopping wisely and trying to receive greater benefits for each dollar spent.[44] One of the fundamental principles in public health economics is that a decision maker should use a similar approach when allocating limited resources to public health programs.[45,47] Therefore, determining the economic value of an intervention is an important task for public-health decision making.

This review is the first study that systematically addresses the economic value of home-based interventions to reduce exposure of individuals with asthma to indoor triggers. The methods for systematic review provide some level of comparability for a variety of home-based interventions from an economic perspective. The review helps to identify the major elements of economic evaluation for these types of interventions and facilitates conducting cost–benefit or cost-effectiveness analysis as an integral part of effectiveness studies.

Three types of economic outcomes were considered in assessing the value of an intervention: program cost, benefit–cost, and ICER. An analysis of these economic outcomes allows researchers and the public to consider whether these interventions present a good value for money invested; or, in other words, whether these interventions represent high economic value from a public health perspective. The following paragraphs expound on these outcomes and subsequent conclusions.

Program costs provide valuable information for decision makers about affordability and appropriate scale of an intervention in the community. Even though it is preferable for economic analyses to include economic information on realized benefits, decision makers may weigh the cost of the program against the expected health outcome benefits.

Three studies had information sufficient to conduct cost–benefit analysis with **benefit–cost ratios** ranging from 5.3–14.0, which indicates that the average benefits of averted medical care and missed work days due to asthma exceed average program costs. This suggests that these interventions provided net savings, and therefore were a good value for money invested in these programs.

Interventions analyzed in three cost-effectiveness studies provided a good value even though they did not provide net savings. These three studies were all RCTs and had ICERs ranging from $12–$57 per additional SFD achieved as a result of the interventions.[24,29,52] Although the intervention reviewed measured SFDs, in health economics a quality-adjusted life-year (QALY) is a more general health outcome measure applicable to any type of healthcare intervention.[40,41,45,47] QALYs have been used as effectiveness measures for cost-effectiveness analysis in asthma care studies.[61–65] The following discussion of the numeric relationship between QALYs and SFDs is intended to determine if ICERs reported in cost-effectiveness studies represent a good value for money invested in these interventions.

The approach in this review is based on studies where both SFD and QALY were used concurrently in estimating the ICER of asthma interventions. Paltiel et al.[66] studied cost effectiveness of inhaled corticosteroids for mild-to-moderate asthma and found that the ICER of $7.50 per SFD was equivalent to $13,500 per QALY; this implies that, in their analysis, 1 QALY was approximately equal to 1800 SFDs gained. Buxton et al.[67] analyzed cost effectiveness of budesonide medication for asthma care, using both SFD and QALY, and their results were $24,000 per QALY gained or $13.30 per additional SFD as an ICER of budesonide treatment of individuals with asthma. Based on these studies it is reasonable to assume that, for asthma interventions, 1 QALY is equal to 1800 SFDs.

In public health, researchers are still debating the threshold at which an intervention is considered a good value.[68,69] In 1982, for example, the threshold from the public health perspective was $50,000 (in 1982 U.S.$) per QALY, which can be translated into either $107,000 or $189,000 per QALY in 2007 U.S.$, depending on whether the Consumer Price Index or the Medical Component of the Consumer Price Index is used.[69] In the cost-effectiveness studies, the highest ICER was $57 per SFD gained (in 2007 U.S.$), which translates into $102,600 per QALY, well below the public perspective threshold.[52] Therefore, based on these considerations, home-based environmental interventions are a good value for the money invested in these programs.

Potential Contributors to Higher Value of Home-Based Environmental Interventions

Important contributors to the burden of asthma are indirect costs such as missed school or work days due to asthma, as well as intangible costs such as reduction in the quality of life, and pain and suffering for asthma patients and their caregivers. In all studies included in the review, the benefits of reduction in indirect costs were not fully taken into account when estimating the value of interventions, with the exception of one paper that included the value of missed work days.[48] Not including these benefits can potentially lead to underestimation of the actual benefit–cost ratios or ICERs; therefore, the values of the interventions could actually be greater than reported in the review.

Although program costs are predetermined by fixed budget resources, the benefits of asthma interventions may last beyond the length of the follow-up period, particularly considering the chronic character of asthma. For example, if a family member of an asthma client acquires knowledge and skills about environmental management of asthma or air filters and humidifiers as a result of the intervention and makes behavioral modifications accordingly, the risk of asthma attacks could be reduced for many years after the intervention ends.

Home-based environmental interventions implicitly employ two general economic concepts— economy of scope and economy of scale—that contribute to increased economic value. Combining several components in one multifaceted intervention increases the value of home-based environmental interventions both by improving their effectiveness, as emphasized in the National Asthma Education and Prevention Program Expert Panel-3 Report (NAEPP EPR-3) guidelines (pp. 93 and 109)[20] and by reducing the combined cost of the interventions. In economics, this concept is referred as *economies of scope*,[45,70] in which the combined cost of conducting two or more interventions together is less than the sum of the costs of conducting each intervention individually. For example, it is reasonable to expect that combining remediation of indoor environmental triggers and teaching household members about asthma self-management during a single home visit would be less costly than delivering these two intervention components in two separate visits.

The average per-participant cost of the program can be reduced if the size of the population covered can be increased. This concept is referred as *economies of scale*.[45,47,70] It suggests that to justify (or recover) investment in some fixed costs of the program (e.g., initial planning and development of the program, recruiting and training home visitors, and collecting and testing materials for these interventions), it makes economic sense to apply these programs to a larger number of participants, thereby lowering the average intervention cost per participant. But above a given threshold, increasing the number of participants can start increasing average cost per participant, because of crowding or congestion effects due to the fixed nature of some resources.[45] Developers and implementers of these programs should be aware of existence of this threshold.

The role of economies of scope and scale in the effectiveness and higher economic value of home-based environmental and other asthma interventions needs to be studied further. From the public health perspective, considering the optimal balance of the number of components, asthma triggers, home visits, and population size versus the benefit–cost or incremental cost-effectiveness ratio can help in designing feasible and effective interventions to reduce the burden of asthma.

Limitations and Further Research

Six studies included in this review provided information on the benefits of the interventions in addition to the program cost.[24,29,48–50,52] Three studies (pre–post designs) had information sufficient to conduct cost–benefit (but not cost-effectiveness) analysis,[48–50] with benefit–cost ratios ranging from 5.3–14.0, and the three cost-effectiveness studies (RCTs) had benefit–cost ratios ranging from 0.09–0.32.[24,29,52] One of the reasons for the differences in the benefit–cost ratios is in the magnitudes of program costs and benefits. Columns 2 and 3 of Table 4 show larger program costs and smaller benefits in RCTs compared to pre–post studies. The number of home visits ranging from five to nine may have also contributed to the higher costs of interventions in RCTs (Table 3).

The differences in the benefits of interventions also might be due partially to the regression to the mean, which can always be an issue in pre–post studies,[71] whereas in RCTs changes in benefits were more likely due to the real effect of the interventions. Additional effects of the regression to the mean in the pre–post studies were particularly likely to take place in two of them,[49,50] where patients at baseline had moderate-to-severe persistent asthma severity; in another pre–post study,[48] patients with all types of asthma severity were included at baseline. Because direct medical cost and productivity averted are correlated with healthcare use, predominantly choosing patients with higher asthma severity at baseline could have made possible stronger effects of the regression to the mean.

It is important to note that most of the studies included in this review were not designed as economic evaluation analyses. They were papers focused primarily on the effectiveness of the intervention, including economic evaluation results as supplementary information. Some studies had ambiguous information about time frame of the interventions. Even though these articles provided limited data for conducting cost-effectiveness or cost–benefit analyses, they were included in this review because state health programs might be interested in implementing these interventions based on the effectiveness review results, and the program costs provide information on affordability and feasibility of these interventions.

The limited number of available articles and the heterogeneity of the studies included in this review precluded use of multivariable statistical analysis to measure the effect of program factors, including the effect of different intervention components on the final economic outcomes while holding all other factors constant. More rigorous statistical analysis of economic factors of these interventions should be done in the future.

Comparing the values of two or more interventions, such as program costs, benefit–cost ratios, or ICERs that have the same final economic measures is straightforward. Comparison is more challenging, however, when the value of one intervention is presented as a benefit–cost ratio and the value of another as an ICER. Thus, studies with program cost provided only limited comparability from an economic perspective. As the number of economic evaluation studies grows over the years, it will be important to conduct another systematic review of these interventions by including only cost-effectiveness studies with RCT study designs. As emphasized in the NAEPP EPR-3 guidelines (p. 109),[19] "further research to evaluate the cost effectiveness and the feasibility of widespread implementation of these programs will be helpful."

A number of factors have been identified that can influence the risk and severity of asthma exacerbation, including outdoor air pollutants, environmental tobacco smoke, and psychological stress. Respiratory infections, changing weather conditions, and exercise can trigger asthma attacks. Wood smoke from wood-burning heating stoves and fireplaces can release irritating chemicals, such as sulfur dioxide, and medications, such as aspirin and sulfites, also can contribute to triggering of asthma symptoms.[72–86] This review focuses on the indoor environment only: on its effect on asthma, how these effects can be mitigated, and for what costs.

People in developed societies spend about 60% of their time at home.[28,87] Both ambient outdoor and indoor environments affect asthma morbidity and mortality, but interventions to reduce exposure of individuals with asthma to indoor allergens can be more effective, less costly, and achieved sooner, and therefore deliver greater economic value from the societal perspective. Home-based environmental interventions encompass a variety of programs with the ultimate goal of reducing asthma morbidity. Understanding the program costs of an intervention is an essential part of determining the economic feasibility of an intervention. The 13 studies included in this review provide some baseline information on program costs, which fills a research and programmatic knowledge gap. Researchers and programs are urged to conduct thorough and complete economic evaluations of home-based environmental interventions so that state and local governments and organizations can employ interventions that meet the needs of their communities.

Multicomponent interventions to prevent asthma attacks or to reduce their severity can be effective and efficient because asthma is a multifactorial disease. Although the studies in the current review all include an environmental component aimed at improving the indoor environment, other multicomponent interventions that address exposure to environmental factors outside the home or that address psychological factors may also be effective. Although economic evaluation of other types of multicomponent programs was beyond the scope of this review, it should be the subject of further studies, as well as the economic evaluation of individual program components.

The majority of studies in this review were interventions for children with asthma, and studies that included adults also included children. The studies that included adults had limited cost information,[42,48,58] and therefore there is more economic evidence for home-based environmental interventions conducted on children. However, the results of the current review are based on these interventions as a group and cannot be generalized to subgroups of people. As the evidence base for home-based environmental interventions grows, this field of research may be able to provide guidance to specific subgroups of people with asthma. Home-based environmental interventions that tailor the intervention to the client's allergen sensitivity or environmental exposure may affect the economic value of the intervention and should also be evaluated by future research.

Although the benefits of these interventions can match or even exceed the cost of the interventions themselves, saving in total asthma cost should not be the only priority of an asthma program. Rather there should be evidence that the program provides substantial benefits for money invested in it. Based on the results of included cost–benefit and cost-effectiveness studies, this systematic review concludes that home-based, multi-trigger, multicomponent interventions with an environmental focus provide a good value for the dollars spent on these programs.

This project was funded by the Air Pollution and Respiratory Health Branch, CDC. This research was also supported in part by the Community Guide Branch, CDC.

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the CDC.

Publication of this article was supported by the Centers for Disease Control and Prevention through a Cooperative Agreement with the Association for Prevention Teaching and Research award # 07-NCHM-03.

No financial disclosures were reported by the authors of this paper.

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