

Home Environmental Interventions for the Prevention or Control of Allergic and Respiratory Diseases: What Really Works



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Home health care workers interventions have been implemented in western countries to improve health status of patients with respiratory diseases especially asthma and allergic illnesses. Twenty-six controlled studies dealing with prevention and control of these diseases through home environmental interventions were reviewed. After a comprehensive description of the characteristics of these studies, the effectiveness of each intervention was then evaluated in terms of participants' compliance with the intervention program, improvement of quality of the indoor environment, and finally improvement of health outcomes, in detailed tables. Limitations and biases of the studies are also discussed. Overall, this review aims at giving a toolbox for home health care workers to target the most appropriate measures to improve health status of the patient depending on his and/or her environment and disease. Only a case-by-case approach with achievable measures will warrant the efficacy of home interventions. This review will also provide to the research community a tool to better identify targets to focus in future evaluation studies of home health care workers action.    2016 American Academy of Allergy, Asthma & Immunology (J Allergy Clin Immunol Pract 2017;5:66-79)

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The prevalence of allergic and respiratory diseases such as asthma, chronic bronchitis, and rhinitis has increased considerably over the last 3 decades in industrialized western countries¹⁻⁴ and is now approximately 20%. The economic burden of these diseases is very high as it is estimated to cost \$23 billion in terms

of health care and indirect costs including lost work and lost school days in the United States.⁵

Atopic heredity, dietary factors, and exposure to environmental pollution are clearly identified as risk factors for these diseases.⁶⁻⁸ Among pollutants, the role of the indoor environment is of growing concern.⁹ First, people in modern societies spend a majority of time (approximately 90%) in indoor environments (home, workplace, school). Second, improved energy efficiency in modern homes with thermal insulation has resulted in confined indoor environments and thus higher exposure to contaminants. Third, there is some evidence that biological (mold, endotoxins, allergens from house dust mites, pets, cockroaches, rodents) and chemical contaminants (environmental tobacco smoke [ETS], nitrogen dioxide, formaldehyde, volatile organic compounds) have been associated with allergic and respiratory symptoms.^{7,10-19} Indoor temperature and relative humidity may also increase exposure levels to these contaminants.^{17,18}

Given the societal and economic costs of allergic and respiratory pathologies (medical care, lost productivity in the workplace, absenteeism from school and work),²⁰ changing the indoor environmental risk factors may offer an opportunity for prevention and control of such diseases.

Different initiatives based on home interventions have been implemented in western countries.^{21,22} To assess their effectiveness, we propose a review of intervention studies. We first provide a comprehensive description of the characteristics of these studies. The effectiveness of each intervention is then evaluated in terms of participants' compliance with the intervention program, improvement of quality of the indoor environment, and finally improvement of health outcomes. In conclusion, prospects for improvement are discussed, a toolbox for home health care workers is provided, and overall, this review highlights the need for further studies using a multifaceted approach to better understand the environmental determinants of these respiratory diseases.

METHODS

A systematic literature search was conducted using the Web of Science platform giving access to the Medline and Academic Search Complete databases, on articles published between 2004 and April 2015. The search was performed with the following keywords located in the abstract of the article: (environmental intervention OR home intervention) AND (indoor OR respiratory diseases OR allergic diseases OR asthma).

The inclusion criteria were peer-reviewed papers in the English language, dealing with prevention and control of allergic and

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Abbreviations used

ETS- Environmental tobacco smoke

HEPA- High-efficiency particulate air

MIEC- Medical indoor environment counselor

RCT- Randomized controlled trial

respiratory diseases through home environmental interventions. This retrieved 2022 articles. Among them many papers were cited twice. Reading the summary, papers dealing with environmental intervention of counselors at home of respiratory disease affected people were selected. Papers dealing with interventions at home of people suffering from respiratory diseases not caused by environmental factors were excluded (rehabilitation of elderly patients after discharge from hospital, occupational asthma, chronic obstructive pneumo-bronchitis for example). Additional studies cited by the selected references were also included. Finally, 33 studies met the selection criteria. Among them, 7 were pre- and postintervention studies without control group and were excluded.²³⁻²⁹ Finally, 26 studies were considered in this review. For each article, the intervention protocol in homes was analyzed and categorized, as well as the results related to behavior change among participants, the impact of intervention on the home environment, and health outcomes.

RESULTS

Study characteristics

The studies reviewed are presented in Table I. They pursued 2 types of objectives. Some intervention programs aimed at preventing the development of allergic and respiratory symptoms (mainly asthma) (primary prevention) among infants qualified as high risk,^{30,33,36,37} that is, with at least 1 parent suffering from atopy, allergic diseases, or asthma. Pregnant women were enrolled to begin the prevention program prenatally (Table I). The other programs aimed at preventing exacerbation of allergic and respiratory symptoms in patients who were sensitized to allergens or diagnosed with asthma (secondary prevention). The majority of patients enrolled in those intervention programs were children.^{39,40} Adgate et al,³⁸ Francis et al,⁴³ Krieger et al,⁴⁸ and Luczynska et al⁴⁹ targeted an adult population, whereas others did not set age criteria for inclusion^{41,44} (Table I).

Most of the studies were randomized controlled trials (RCT), where participants were assigned either to an intervention group receiving one or more intensive home-based interventions or to a reference group (Table I). This reference group received either no intervention^{37,41,48,53} or an intervention with standard information on risk factors and some limited resources,^{36,45} or placebo avoidance measures (sham air cleaners, ineffective bedding covers).^{43,49,52} The studies of Carter et al³⁹ and Corver et al³³ were implemented with both a placebo group and a control group who received no intervention. Bryant-Stephens and Li²⁰ carried out a 3-armed RCT, with an intervention group, a control group, and a case-matched control group who received neither intervention nor follow-up home visits. To conduct these intervention programs, the great majority of participants were selected via hospital databases or via physicians. The most frequent inclusion criteria were diagnosed asthma, a recent visit to an emergency department or hospitalization for asthma, and a positive skin test to one or more indoor allergens. The number of participants ranged from 20⁵² to 3312.⁴⁴

The length of the studies was highly variable according to their purpose. Prospective prenatally randomized cohort studies began before birth and continued up to 12 months for Schönberger et al³⁷ and up to 8 years for Arshad et al.³⁰ The duration of exacerbation prevention programs ranged from at least 3 months between the first home-based intervention and the last follow-up visit,³⁰ to 24 months.⁴⁰ A 12-month study is the most frequent case.

Home interventions can be grouped into 3 categories: education-based methods, physical methods, and a combination of both. The education-based approach alone aimed at helping the patients and their families to adopt behaviors to obtain healthy home environments. On the basis of a baseline home survey (visual inspection, dust and/or air sampling) and a preliminary health evaluation (questionnaire, prick test, blood sampling, spirometry), participants were taught about avoidance measures for the risk factors identified.⁴¹ Physical methods consisted in providing the participants with equipment and supplies necessary to perform comprehensive environmental remediation (bedding covers, vacuum cleaner with high-efficiency particulate air [HEPA] filter, air purifier, intensive cleaning, pest control, ie, miticide, bait traps, professional eradication of mice, and cockroaches).^{33,43,44,48,49,52,53} For most studies, multiple risk factors were targeted. Exposure to house dust mites was studied in almost all cases. In one-half of the studies, triggers such as pet or cockroach allergens were investigated. The presence of rodents was assessed in approximately 30% of the studies. In one-third of the home interventions, investigation related to signs of mold was carried out. Except for ETS, efforts to reduce exposure to chemical contaminants (volatile organic compounds, particulate matter) were less frequent in comparison with attention paid to biological contaminants.

The number of home interventions ranged from 1 to 9 per home, with a maximum number of 17 visits in the study published by Parker et al.⁵¹ But a single intervention program remained the most frequent situation. When it was mentioned, home visits were carried out by persons trained in the clinical aspects of asthma and other respiratory diseases, asthma triggers, and avoidance measures. Some counselors were also educated about social learning theory.^{42,46,51} Several of the counselors enrolled were "Community Health Workers" who shared the same ethnic, linguistic, and cultural origins as the participants.^{46,48,51}

To assess the effectiveness of home environmental interventions for the prevention or control of allergic and respiratory diseases, follow-up surveys were conducted in the weeks and months after the end of the intervention program. This consisted in collecting data about the home environment and the health status of the participants over this period, by means of home visits and/or phone calls (Table I).

Compliance of participants

The use of bedding covers (Table II) was clearly the most commonly used measure in the intervention groups and in a significant manner compared with the control group, with rates of application up to 96%.³¹ It should be noted that the bedding covers were given free of charge to the occupants in the vast majority of cases. It can be supposed that if the bedding covers were not free of charge, the compliance would have not been so high.³⁷ Postma et al²² showed that participant compliance was clearly related to the supply of resources. de Blay et al⁴¹ mentioned that compliance depends on socioeconomic status

TABLE I. Study characteristics

References	Design	No.	Population inclusion criteria	Targeted risk factors	Intervention description	Evaluation protocol
Patients at risk of asthma: primary prevention						
30	RCT 2 groups (IG, CG)	120	Infants at high risk for asthma development identified before birth	Algn (HDM)	5HV within 12 mo/supply of bedding covers/pest management	FU: HE after 3, 6, 12 mo, 2, 4, 8 y of age
31, 32	RCT 2 groups (IG, CG)	545	Infants at high risk for asthma development identified before birth	Algn (HDM, cat, dog), ETS	3HV within 8 mo/supply of bedding covers/pest management/pet avoidance measures/smoking cessation/cleaning instructions	Baseline survey (HE, EE) FU: EE 2 wk, 4, 8, 12, 24 mo after birth, HE after 12, 24 mo, 7 y old
33	RCT 3 groups (IG, PG, CG)	1282	Infants at high risk for allergy development identified before birth	Algn (HDM)	1HV (<i>IG and PG</i>)/supply of bedding covers	FU: EE 2 mo before birth, 3 mo, 4 y after birth, HE 12 mo, 4 y after birth
34, 35	RCT 4 groups (IG, CG, HRP, LRG)	291	Infants at high risk for asthma development identified before birth	Algn (HDM)	2HV within 5 mo/supply of HEPA vacuum cleaner, bedding covers/pest management/dust reservoir removal/cleaning instructions	Baseline survey (EE) FU: EE 0, 6, 12 mo after birth, HE 12 mo after birth
36	RCT 2 × 2 factorial design (IG, CG)	516	Infants at high risk for asthma development identified before birth/not cat in the home/multiple births excluded/babies born earlier than 36-wk gestation excluded	Algn (HDM)	1HV/supply of bedding covers/cleaning, ventilating instructions	Baseline survey (EE) FU: HE, EE 1, 3, 6, 9, 12 mo after birth, then every 6 mo up to the age of 5 y
37	RCT 2 groups (IG, CG)	443	Infants at high risk for asthma development identified before birth	Algn (HDM, cat, dog), ETS	3 HV before and after birth/HDM, pet avoidance advice/supply of bedding covers/smoking cessation	Baseline survey (EE) FU: EE 12 mo after first EE, questionnaire sanitation and smoking 12 mo after birth
Patients with already diagnosed asthma and/or allergy: secondary prevention						
38	RCT 3 × 3 factorial design	47	18-65 y old/at least one child at home	Algn (HDM, cat, CR), fungi	3HV within 12 mo/education: asthma triggers, avoidance measures/cleaning with a HEPA vacuum cleaner	Baseline survey (EE) FU: EE just after intervention
20	RCT 3 groups (IG, CG, CMCG)	396	2-16 y old/at least 1 hosp or 2 ED for asthma within the previous year	Algn (HDM, cat, dog, CR, rodent), ETS	5 weekly HV/education: asthma triggers, avoidance measures/supply of vacuum cleaner bags, trash bags, bedding covers/pest management/dust reservoir removal	Baseline survey (EE) FU: monthly EE (<i>IG and CG only, CMCG no care</i>), collection of medical records during 12 mo
39	RCT 3 groups (IG, PG, CG)	104	5-16 y old/treatment for asthma	Algn (HDM, CR)	1HV (<i>IG and PG</i>)/supply of bedding covers/pest management (<i>placebo measures for PG</i>)/cleaning instructions	Baseline survey (HE) FU: EE after 3, 8, 12 mo, HE after 12 mo

40	RCT 2 × 2 factorial design (IG, CG)	937	5-11 y old/diagnosed asthma/at least 1 hosp or 2 ED within the previous 6 mo/sensitization to at least 1 of 11 common indoor Alln/sleep in the home at least 5 nights/wk	Algn (HDM, cat, dog, CR, rodent), ETS, mold/moisture	5 mandatory, 2 optional HV within 12 mo/education: asthma triggers, avoidance measures/supply of air purifier, HEPA vacuum cleaner, bedding covers	Baseline survey (HE, EE) FU: EE 6, 12, 18, 24 mo after first intervention, HE every 2 mo
41	RCT 2 groups (IG, CG)	378	3-50 y old/intermittent or mild and moderate persistent diagnosed asthma or rhinitis symptoms/sensitization to HDM/positive Acarex test on the mattress	Algn (HDM)	1HV/HDM avoidance advice	Baseline survey (EE) FU: EE after 5 mo
42	RCT 2 groups (IG, CG)	100	6-12 y old/diagnosed asthma/current asthma symptoms/no other chronic lung disease	Algn (HDM, cat, dog, CR, rodent), ETS, PM, ozone, nitric oxide	3 HV within 5 mo/education: asthma triggers, avoidance measures/supply of air purifier, bedding covers/pest management	Baseline survey (HE, EE) FU: EE after 6, 12 mo, HE after 12 mo
43	RCT 2 groups (IG, CG)	30	18-65 y old/diagnosed asthma/own cat or dog/sensitization to cat or dog Algn	Algn (cat, dog)	1HV (IG and CG)/supply of air purifier, Dyson vacuum cleaner (HEPA vacuum cleaner for CG)	Baseline survey (HE, EE) FU: EE after 6, 12 mo, HE after 12 mo
44	RCT 2 groups (IG, CG)	3312	Live in uninsulated dwellings/at least 1 household member with respiratory symptoms in the previous year or history of asthma, pneumonia, or chest infections	Insulation	1HV/insulation of the house	Baseline survey (HE, EE) (first winter) FU: HE, EE (second winter)
45	RCT 2 groups (IG, CG)	62	2-17 y old/diagnosed asthma/at least 2 ED or 1 hosp for asthma within the previous year/no other serious respiratory disease/visible mold in the home	Algn (HDM, CR, rodent, E), mold, HVAC, leaks	1HV/cleaning/reducing sources of mold	Baseline survey (HE, EE) FU: HE, EE after 6, 12 mo
46, 47	RCT 2 groups (IG, CG)	274	4-12 y old/diagnosed persistent asthma/sleep at least 50% of nights in the house	Algn (HDM, cat, dog, CR, rodent), ETS, mold/moisture	5-9HV within 12 mo/education: asthma triggers, avoidance measures/supply of HEPA vacuum cleaner, bedding covers, door mats, cleaning kits/pest management/smoking cessation	Baseline survey (EE) (+ <i>action plan, limited education, bedding encasements for CG</i>) FU: EE 18 mo after first intervention
48	RCT	333	18-65 y old/diagnosed asthma, not well or very poorly controlled	Alg (HDM, CR)	5 HV education: asthma triggers, avoidance measures/supply of HEPA vacuum cleaner, bedding covers, cleaning kits/pest management	Baseline survey (HE, EE) FU: HE, EE 0.5; 1.5, 3.5, 7 mo
49	RCT 2 groups (IG, CG)	55	18-54 y old/mild asthma diagnosed/sensitization to HDM, but not to cat and dog/positive Acarex test on the mattress	Algn (HDM)	1HV (IG and CG)/supply of bedding covers (<i>placebo for CG</i>)	Baseline survey (HE, EE) FU: EE after 6, 12 mo, HE after 4, 8, 12 mo

(continued)

TABLE I. (Continued)

References	Design	No.	Population inclusion criteria	Targeted risk factors	Intervention description	Evaluation protocol
50	RCT 2 groups (IG, CG)	150	6-14 y old/persistent asthma/at least 3 visits to a school-based mobile asthma clinic or a clinic/sensitization to CR or HDM/no other serious respiratory or cardiac illness/no smoking house	Algn (HDM, CR)	1HV/education: asthma triggers, avoidance measures/supply of bedding covers/pest management	Baseline survey (EE) FU: EE after 4 mo
51	RCT 2 groups (IG, CG)	298	7-11 y old/persistent asthma reported	Algn (HDM, cat, dog, CR, rodent), ETS, mold, household chemicals	9 HV every 6 wk/education: asthma triggers, avoidance measures/supply of a HEPA vacuum cleaner, bedding covers, cleaning kits/pest management	Baseline survey (HE) FU: HE after 12 mo
52	RCT 2 groups (IG, CG)	20	Children/moderate asthma/sensitization to cat or dog/presence of the relevant animal	Algn (cat, dog)	1HV (IG and CG)/supply of air purifier (placebo for CG)	Baseline survey (HE, EE) FU: HE, EE after 3, 6 mo
53	RCT 4 groups (3 IG, 1 CG)	40	4-16 and 20-67 y old/moderate to severe asthma requiring medications/sensitization to HDM, cat or dog/absence of the relevant animal	Algn (HDM), T, RH	1HV/supply of a mechanical ventilation (first IG), or HEPA vacuum cleaner (second IG), or both (third IG)	Baseline survey (HE, EE) FU: HE, EE after 1, 2, 3, 6, 9, 12 mo
54	RCT 2 groups (IG, CG)	161	2-17 y old/ED for asthma	Algn (HDM, CR, rodent), ETS, mold	1HV/supply of bedding covers cleaning/professional cleaning/pest management/cleaning instructions	Baseline survey (HE, EE) FU: HE, EE after 4, 8, 12 mo

Algn, Allergen; CG, control group; CMCG, case-matched control group; CR, cockroach; E, endotoxin; ED, emergency department visit; EE, environmental evaluation; ETS, environmental tobacco smoke; FU, follow-up; HDM, house dust mite; HE, health evaluation; HEPA, high-efficiency particulate air; hosp, hospitalization; HRP, high risk group with pets; HV, home visit; HVAC, heating, ventilating, air-conditioning; IG, intervention group; LRG, low-risk group; PG, placebo group; PM, particulate matter; RCT, randomized control trial; RH, relative humidity; T, temperature.

TABLE II. Impact of the intervention on the behavior of participants

Risk factor avoidance measure	Compliance*: frequency of application of measures		Comment	Evaluation of compliance	References
	Intervention group	Reference group†			
Using bedding covers	88%	11%	For mattress	Questionnaire	37
	86%	72%	For mattress, pillow	Visits	47
	76%	16%	For mattress, pillow	Visits	20
	71%	4%	For mattress, pillow	Visits	50
	56%	12%	For mattress, pillow	Questionnaire	51
	37%	30%	For mattress	Visits	41
	81%	81%	For mattress	Questionnaire	33
	69%	86%	For children's pillow		
	78%	85%	For parents' pillow		
	96%	n.a.	For mattress	Questionnaire	31
	53%	n.a.	For mattress, pillow	Visits	36
	27%	n.a.	For mattress, pillow	Visits	42
Washing bedding, linens	OR = 191.5	OR = 65.6	For pillows	Visits	41
	88%	70%	For linens	Questionnaire	51
	42%	42%		Visits	47
	50%	n.a.		Visits	39
Using vacuum cleaner	97%	59%		Questionnaire	51
	79%	64%		Visits	47
Changing mattresses	OR = 38.7	OR = 10.2		Visits	41
	49%	40%		Questionnaire	37
Applying CR avoidance techniques	40%	12%	For boric acid application	Visits	50
	33%	13%	For bait traps		
Removing dust reservoirs	OR = 40.6	OR = 11.7		Visits	41
	61%	64%		Visits	20
	59%	54%		Questionnaire	37
Avoidance smoking indoor	52%	28%	For mother only	Questionnaire	37
	77%	80%		Visits	47
	77%	80%		Questionnaire	31
	55%	40%		Visits	20
	44%	41%		Questionnaire	51
	40%	36%		Visits	42
Avoiding pets at home	55%	14%			37
	82%	75%		Visits	47
	69%	71%			31
Ventilating, airing	67%	70%	In the kitchen	Visits	47
	73%	68%	In the bathroom		
	67%	64%			37
Removing molds	22%	27%		Questionnaire	51
Using air purifier	48%	n.a.		Visits	42
Knowledge of trigger avoidance measures	36%	16%		Visits	50

CR, Cockroach; n.a.: information not available for the reference group; OR, odds ratio.

*Bold types indicate a between-group difference statistically significant ($P < .05$).

†The reference group receives either no intervention or experiences a mild or a placebo intervention. See Table I for information.

(particularly for use of bedding covers). Only 1.8% of low-income families followed this recommendation, compared with 21.2% in higher income families.

Other positive results were shown for measures such as using a vacuum with a HEPA filter or implementation of methods for eradication of cockroaches (boric acid, bait traps)⁵⁰ (Table II). In all these cases, the material was provided to participants in the intervention group (Table I).

By contrast, other behaviors were more difficult to change, and the results were inconclusive. This is mainly the case of avoiding smoking at home, eviction of pets, or eliminating sources of dust (Table II).

Lack of compliance can also be attributed to certain limitations and biases in the design of the studies. Sometimes the behavior was self-reported.^{50,51} For others, the biases were due to a possible Hawthorne effect, that is, drawing unintended

attention in the control group just by special care questioning about the presence of preventive measures.^{37,47} Another important point to mention is the impossibility of blinding participants, who revealed their assignment to the interviewers, which may have biased collection of self-reported measures.⁴⁷ de Blay et al⁴¹ compared the number of recommendations made by the Medical Indoor Environment Counselors (MIECs) and the physicians treating the participants. They showed that both gave a similar number of recommendations, probably because the physicians took interest in allergen avoidance, and because they were given a list of avoidance measures. If the physicians had been less involved in allergen avoidance, the measured effect of the MIECs would have been greater.

In conclusion, the most commonly applied avoidance measures were those for which material was provided (bedding covers, vacuum cleaners). The sustainability of these measures is questionable if material is not provided, because of cost constraints. Schönberger et al³⁷ hoped that if supplying bedding covers was shown to be efficient, it could be reimbursed by health insurance companies. For some risk factors, ETS in particular, education alone has not proven effective in modifying participants' behaviors, as it was also mentioned by Wu and Takaro.⁵

Impact on home environment

The impact of interventions on the quantity of allergens was most often described, with greater attention to house dust mites. Some

studies showed the effect of interventions on the presence of mold in homes and on the well-being of the occupants. Few studies examined the effectiveness of interventions on levels of chemical pollutants.

Most studies showed a decrease in the level of at least one targeted allergen in the homes of the intervention group (Table III). For Schönberger et al,³⁷ the positive impact of the intervention on the levels of mite and pet allergens may be due to good compliance of participants as regards bedding (putting on bedcovers, changing mattresses) and also keeping pets outside (Table II). Similarly, Chan-Yeung et al³¹ showed that the levels of cat allergens were lower when cats were kept outdoors. de Blay et al⁴¹ showed a direct relationship between the decrease in the level of house dust mites in mattresses in the intervention group and the participants' compliance in changing their mattresses. For a minority of studies, none of the targeted allergen levels changed significantly or differed from the reference group.^{38,43,49,52} Corver et al³³ also explained the very limited effect of bedding covers on house dust mite allergen levels by initially low mite allergen levels in samples. Francis et al⁴³ demonstrated that there was no significant effect of air cleaners plus HEPA vacuum cleaners over the use of HEPA vacuum cleaners alone on airborne allergens. They explained the absence of effect on pet allergen levels by the use of inappropriate allergen sampling tools. They added that the presence of animals during sampling might also influence the results.

The results concerning the presence of molds in homes suggest that interventions are effective against this risk

TABLE III. Impact of the intervention on the home environment

Risk factor Allergens	Change from baseline		Statistical significance between groups†	References
	Targeted environment	Within intervention group*		
House dust mite (<i>Der fl</i> , <i>Der p1</i>)	Bed	↓ <i>Der fl</i> (49%), <i>Der p1</i> (−37%)	<.05 (<i>Der fl</i> only)	40
	Mattress, living room	↓ <i>Der p1</i> (94% mattress, −89% living room)	<.05 (mattress only)	37
	Parental bedroom	↓ <i>Der p1</i> (98%) maternal mattress	<.05	34
	Child's bedroom	↑ <i>Der p1</i> (85%) very low levels (ng)	<.05	
	Living room	↓ <i>Der p1</i> (54%)	n.s.	
	Mattress	↓ <i>Der p1</i> (98%)	n.s.	49
	Bedroom, living room (homes with MV)	↓ Mite numbers, <i>Der p1</i> (84% max in bedroom carpet)	n.a.	53
	Bedroom floor (homes with VC)	↓ <i>Der p1</i>	n.a.	
	Mattress base, floor mattress	↓ House dust mite (73% mattress base, 60% floor)	<.05	41
		↓ House dust mite (54% mattress)	n.s.	
	Bedroom, living room	↓ House dust mite (33%)	<.05	31
	Bedroom	↓ >70% House dust mite for 37% of cases	n.a.	39
	Bedroom	↔ House dust mite	n.s.	45
	Bedroom	↔ House dust mite	n.s.	51
	Bed	↓ House dust mite (61%)	<.05	36
	Mattress	↓ <i>Der fl</i> (44%)	<.05 (<i>Der fl</i>)	33
	Mattress	↔ <i>Der p1</i>	n.s. (dust exposure, <i>Der p1</i>)	

(continued)

TABLE III. (Continued)

Risk factor Allergens	Change from baseline			References
	Targeted environment	Within intervention group*	Statistical significance between groups†	
Cat (<i>Fel d1</i>)	Bed	↓ <i>Fel d1</i> (14%)	<.05	40
	Mattress, living room	↓ <i>Fel d1</i> (79% mattress, 49% living room)	<.05 (mattress only)	37
	Bedroom, living room	↓ <i>Fel d1</i>	n.s.	31
	Living room air	↓ <i>Fel d1</i> (64%)	n.s.	43
	Bedroom, living room floor	↔ <i>Fel d1</i>	n.s.	
	Bedroom	↔ <i>Fel d1</i>	n.s.	42
	Bedroom	↔ <i>Fel d1</i>	n.s.	51
	Bedroom, living room	↔ <i>Fel d1</i>	n.s.	52
Dog (<i>Can f1</i>)	Bedroom	↓ <i>Can f1</i> (93%)	<.05	51
	Mattress	↓ <i>Can f1</i> (80%)	<.05	37
	Living room air	↓ <i>Can f1</i> (87%)	n.s.	43
	Bedroom, living room floor	↔ <i>Can f1</i>	n.s.	
	Bedroom	↑ <i>Can f1</i> (65%)	n.s.	40
	Bedroom, living room	↔ <i>Can f1</i>	n.s.	52
Cockroach (<i>Bla g1</i> , <i>Bla g2</i>)	Bedroom floor	↓ <i>Bla g1</i> (51%)	<.05	40
	Kitchen floor	↓ >70% <i>Bla g2</i> for 41% of cases	n.a.	39
	Bedroom	↓ <i>Bla g1</i> (41%)	n.s.	42
	Kitchen floor	↓ Transient, <i>Bla g1</i>	n.s.	54
	Bedroom	↔ <i>Bla g1</i>	n.s.	45
	Bedroom	↔ <i>Bla g1</i> and <i>Bla g2</i>	n.s.	51
	Kitchen (with high initial CR level)	↓ <i>Bla g1</i> (60%)	<.05	50
	Bedroom	↓ Mouse Algn (39%)	<.05	45
Rodent (<i>Mus m1</i>)	Bedroom	↓ Rat Algn (58%)	n.s.	
	Bedroom	↔ <i>Mus m1</i>	n.a.	42
Other		↓ Mold score (75%)	<.05	45
		↓ Total fungal load	n.s.	
Presence of cockroach		↔	n.s.	20
		↔	n.s.	40
		Yes		50
	Cockroach	↓ 15% presence cockroach		24
Presence of rodent		↓	n.s.	20
		↓ 23% presence		24
Comfort, energy usage		↔ Signs of water damage	n.s.	40
		Yes (T and RH)		53
		Yes (T and RH)		44
		Yes (feeling cold, ineffective heating, mold, dampness, energy usage)		
Particulate matter	Bedroom	↓ 39%	<.05	42
Nitric oxide	Bedroom	↔	n.s.	42

↔, No change at the end of the study; ↓, decrease from baseline; ↑, increase from baseline; Algn, allergen; CR, cockroach; MV, mechanical ventilation; n.a., information not available for the reference group; n.s., not significant; RH, relative humidity; T, temperature; VC, high-efficiency vacuum cleaner.

*Bold types indicate a within-group change significantly different from zero.

†Statistically significant ($P < .05$) difference between the intervention group and the reference group (in favor of the intervention group, unless otherwise stated). The reference group receives either no intervention or experiences a mild or a placebo intervention. See Table I for information.

factor^{24,28,38,45} (Table III). In the weeks after the intervention, Adgate et al³⁸ observed a significant decrease in fungal spores, with an equivalent impact for education-based interventions and interventions consisting in a thorough cleaning of the home. This positive impact was seen only for individual houses but not

for apartments, perhaps because there were considerably higher baseline fungal levels in single-family homes than in apartments (Table III). Interventions to improve the comfort of the participants were clearly beneficial (Table III). The installation of mechanical ventilation⁵³ or insulation⁴⁴ reduced the moisture

and increased the temperature significantly. This lower humidity was associated with a decrease in levels of house dust mites in carpeting.⁵³ Conversely, Eggleston et al⁴² observed a significant improvement in particle levels in the bedroom after installing a HEPA air filter.

Finally, the evaluation of the effectiveness of home interventions on chemical contaminants remains to be done because very few studies have focused on this aspect. Eggleston et al⁴² observed no change in nitrogen oxide concentrations after intervention. They gave no reason to explain these results.

All these results must be analyzed carefully because of the limitations and biases of the studies. They are inherent to the design of studies and are therefore the same as those mentioned in the "Compliance of participants" section, such as potential bias due to self-reported outcomes.⁴⁴ In Howden-Chapman's study, the bias is minimal because energy use was also assessed from data given by an external independent source (energy companies). It is also important to consider that tools to evidence allergens and pollutant are not standardized and display variable performances, as exemplified for molds.⁵⁵ Moreover, as studies are mostly nonblinded or single blinded, participants may have revealed their assignment to the interviewers, which may have biased collection of self-reported measurements. In conclusion, the home interventions proved effective in reducing exposure to allergens and improving user comfort (temperature, humidity). They seem promising for reducing the presence of molds. However, their effectiveness against chemical contaminants remains to be investigated.

To discuss the relative effectiveness of the different interventions, we must distinguish the intrinsically ineffective interventions (ineffective measure) from ineffective interventions in their applications (eg, implementation of cockroach avoidance measures in houses with low-level contamination by cockroach allergens). Given the results summarized above, the lack of environmental effects seems often due to this second category of interventions. It is worth noting that interventions based on physical methods alone, such as using bedding covers⁴⁹ and installing air filters,^{43,52} proved to be the least effective measures to improve the home environment. These findings are in agreement with the review of Gotzsche and Johansen⁵⁶ carried out on the assessment of house dust mite avoidance measures. Over a short period of time, Adgate et al³⁸ reported that intensive house cleaning and education of participants had an equivalent impact on levels of allergens. Over longer periods, the effectiveness of educational methods conducted in participants' homes should be investigated further because only de Blay et al⁴¹ used such an approach. Many interventions based on mechanical and educational approaches aimed at reducing exposure to multiple risk factors gave positive results on the home environment.^{37,39,40,47}

Impact on health outcomes

Regarding health impact, it is important to distinguish asthma prevention (primary prevention) from asthma control (secondary prevention).

Published studies mainly focused on asthma control and included a wide variety of parameters to assess the effectiveness of home interventions on participants' health. They could be grouped into 3 categories. The first category consisted of clinical outcomes such as modification of respiratory symptoms, lung function, airway hyperresponsiveness, and allergen sensitization

(Table IV). The second group gave information on the evolution of medication and urgent care use. The last category grouped variables such as the participants' quality of life and activity limitations associated with allergic and respiratory diseases (absenteeism from school and work).

Globally, clinical outcomes were mixed, revealing mitigated effectiveness of the home interventions.

Several studies showed a significant decrease of some symptoms in the intervention group over the study period^{20,40,42,44,51} (Table IV). Even more convincing were the studies where fewer symptoms were significantly reported in the intervention group compared with the reference group at the end of the study.^{40,42,44,48} Kercksmar et al⁴⁵ attributed the positive health impact in the intervention group to a reduction of the mold spores (Table III). Morgan et al⁴⁰ showed a significant relationship between the reduction in the levels of dust aeroallergens (cockroach allergens particularly) and the decrease in the maximum number of days with symptoms in the intervention group. However, some articles showed a nonsignificant impact of the intervention program on the number of symptomatic days or on the prevalence of asthma.^{33,36,52,53} This may be attributed to a limited or inexistent impact of the intervention on the indoor environment for these studies (Table III). These interventions were mainly based on a physical approach (supply of bedding covers, air purifiers, or vacuum cleaners) and a very limited number of risk factors were targeted.

The effectiveness of home environmental interventions in improving lung function appears questionable. Except the papers of Parker et al,⁵¹ and van der Heide et al,⁵² all the articles reported a nonsignificant change in the lung function of the participants. Kercksmar et al⁴⁵ explained the absence of significance in any measure of pulmonary function between the intervention and the reference groups by the limited amount of data available.

Bronchial hyperresponsiveness was assessed in a few studies with mixed results. Francis et al⁴³ and van der Heide et al⁵² observed a significant improvement of the bronchial hyperreactivity in the intervention group compared with the reference group, despite no or limited reduction in pet allergen levels (Table III).

Besides, asthma prevention (primary prevention) among infants at high risk for allergen sensitization was performed in a few studies but with limited success. Except Arshad et al,³⁰ all authors concluded that allergen sensitization was not significantly different between the intervention and the reference groups after 4 to 7 years of prevention^{33,36} (Table IV). In the review published by Maas et al,⁵⁷ the reduction of exposure to multiple allergens compared with usual care reduces the likelihood of a diagnosis of asthma in children.

Similar to clinical outcomes, results related to the medication use of participants were rather contrasted, whatever the kind of approach adopted for the interventions (mechanical or both educational and mechanical methods). A significant decrease in urgent care use was demonstrated at the end of the study within the intervention group compared with the reference group in some cases.^{20,39,51} It is worth noting that in the paper of Bryant-Stephens and Li,²⁰ the difference existed only between the intervention group and a true control group (case-matched control group) never visited or contacted over the course of the study. There was no difference between the intervention group and the reference group followed monthly, because these recurrent visits likely increased participants' attention to asthma care. This point is addressed further in this section. The study of Carter

et al³⁹ was particularly interesting because it demonstrated the effectiveness of allergen avoidance in preventing allergic diseases and showed that the decrease in acute care visits among children with mite allergy was significantly correlated with the decrease in mite allergen concentration (Table III). This finding resulted from a double-blind protocol making it very relevant. A significant relationship between the reduction in allergen levels (cockroaches and house dust mites), the decrease in the maximum number of hospitalizations, and the number of unscheduled visits for asthma was also seen by Morgan et al⁴⁰ in both the intervention and reference groups. On the other hand, a few papers reported no change in the number of acute care visits in the intervention group after the environmental interventions or the difference with the reference group was not significant.^{40,42,44} For Kercsmar et al,⁴⁵ there was no difference between the intervention and the reference group for the number of hospitalizations and emergency department visits over the 12-month follow-up after randomization. But if only the last 6 months of follow-up were considered, the difference became significant.

Finally, a significant improvement of the disadvantages associated with allergic and respiratory diseases (absenteeism from school and work, activity limitation) was often shown for the intervention group at the end of the intervention program, even if the difference with the reference group was not always significant.^{40,42,44,45} The quality of life of the participants and their families in the intervention group improved globally over the

course of the study.^{44,45,47,51} Children's quality of life improved most in the months after the environmental interventions.

Williams et al⁵⁴ used an asthma severity score constituted of all the above variables to judge the effectiveness of home interventions on participants' health. The overall score decreased over the course of the study in the intervention group, but the difference was not significant compared with the reference group. If only the functional component of the score was examined (related asthma symptoms, activity limitation), the difference between the groups became significant, particularly for children with severe asthma.

Despite improvement of the home environment and/or good compliance of the participants, there was not necessarily a significant clinical benefit for them. Several authors suggested that the environmental changes were not major enough to produce a striking clinical effect.^{36,42} This may have been the result of an inadequate statistical power, due to small sample size.^{30,40} But the sample size may have been dictated either by the cost of the intervention⁵³ or due to a low retention rate (mobility, difficult cooperation of the participants).⁵⁴

The lack of positive health outcomes may also be attributed to the design of the studies. Conclusions about the prevalence of respiratory and allergic symptoms or the number of days off school were often drawn from family self-reporting, which could be inaccurate.²⁴ But Parker et al⁵¹ added that self-reported

TABLE IV. Impact of the intervention on health of participants with diagnosed asthma

Health outcome	Change from Baseline			References
	Within intervention group*	Sign between-group difference†	Comment	
Allergic and respiratory symptoms	↓	Yes	Wheeze	44
	↓ 0.41 d	Yes	# days/2 wk with wheeze	40
	↓ 11%	Yes	Persistent cough, cough with exercise	51
	↓ 34%	Yes	Daytime symptoms	42
	↓ 29%	No	Nighttime symptoms, symptoms with exercise	
	↓	No	Maximal symptom days, poor child physical health	45
	↓ 15%	No	Cough, wheeze	20
	↓	No	# days/2 wk with symptoms	47
	↔	No	# days with chest tightness, # reported asthma attacks	49
	↔	n.a.	Wheeze, breathless	52
		No	Asthma symptom scores	53
Lung function	↑ 8% FEV ₁ , 15% PEF	Yes	Asthma control, night with symptoms	48
		Yes	Daily nadir PEF, daily nadir FEV ₁	51
	↓	Yes	Peak flow amplitude	52
	↑	No	PEF, FEV ₁ , FVC	43
	↔	No	FEV ₁	42
	↔	No	PEFR, FEV ₁ , FVC, many missing data	45
	↔	No	PEF	49
	↔	No	PEF, FEV ₁ , FVC	40
	↔	No	PEFR	53
		No	FEV ₁ , FVC	48

(continued)

TABLE IV. (Continued)

Health outcome	Change from Baseline		Comment	References
	Within intervention group*	Sign between-group difference†		
Airway hyperresponsiveness	↓	Yes		52
	↓	Yes		43
	↓	No		53
Allergen sensitization	↓	No	Total IgE	54
Days off school	↓	Yes		44
	↓	Yes		40
	↓	No		47
Days off work	↓	Yes		44
	↔	No		47
		No		48
Activity limitation and modification	↓	Yes	# days with activity limitation	47
	↓	Yes	Lost sleep, caretaker's plan	40
	↓ 39%	No	Child's activity	42
	↓	No	Child and family activities	45
		Yes	Better physical health	48
Quality of life	↑	Yes	Vitality, happiness, general health	44
	↑	Yes	Caregiver quality-of-life score	47
	↑	No	Family emotional well-being	45
	↓ 5%	Yes	Caregiver depressive symptoms	51
	↔	No	Caregiver social support	
	↔	No	Quality-of-life score	42
	↔	No	Quality-of-life score	49
		Yes	Quality-of-life score	48
Medication use	↓	Yes		43
	↓ 21%	Yes	Inadequate use of asthma controller medication	51
	↓	No	Bronchodilator, controller medication	47
	↓ 19%	No	Bronchodilator	20
	↔	No	Controller medication	
	↔	No		49
	↔	No		53
		No	Oral steroids	48
Urgent care use for respiratory diseases	↓ 47% ED visits	Yes (IG = CG < CMCG)	hosp, ED visits, regular sick visits	20
	↓	Yes	Urgent health services use	47
	↓ 6%	Yes	Urgent health services use	51
	↓ By 33% in IG vs 30% CG	Yes (IG = PG < CG)	hosp, ED visits	39
	↓	No	GP visits	44
	↔	No	hosp	
	↓	No	hosp, ED visits	42
		No	hosp, ED visits	45
	↓ -0.017 hosp	Yes	#hosp	40
		No	Urgent health care	48
Asthma severity score‡	↓	No	Overall score	54
	↓	Yes	Symptoms and activity limitation components only	
		Yes	Asthma control	48

#, Number; CG, control group; CMCG, case-matched control group; ED, emergency department; FEV₁, forced expiratory volume in one second; FVC, forced volume vital capacity; GP, general practitioner; hosp, hospitalization; IG, intervention group; n.a., information not available for the reference group; PEF, peak expiratory flow rate; PEF, peak expiratory flow; PG, placebo group.

*Bold types indicate a within-group change significantly different from zero.

†Statistically significant difference ($P < .05$) between the intervention group and the reference group (in favor of the intervention group, unless otherwise stated). The reference group receives either no intervention or experiences a mild or a placebo intervention. See Table I for information.

‡Score constituted of 4 components: related asthma symptoms, activity limitation, medication use, and urgent care use.

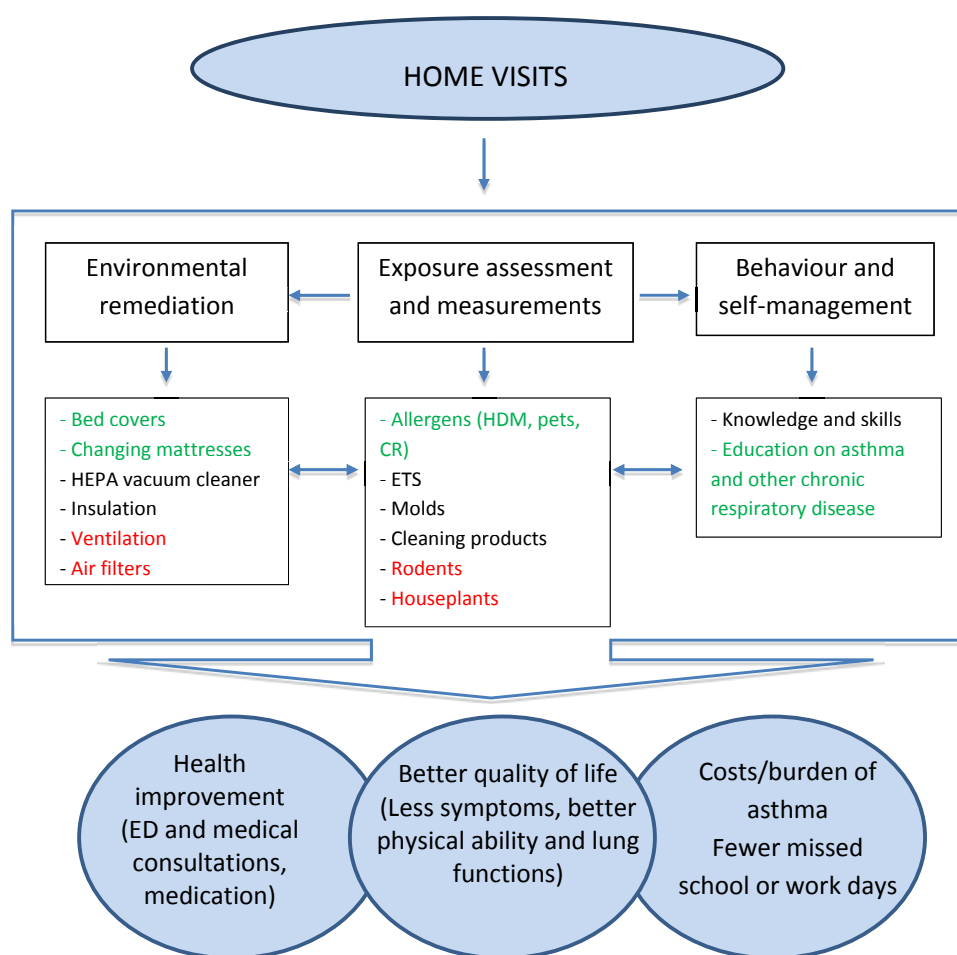


FIGURE 1. Analytical scheme of the impact of home intervention on the patient. In green are the actions that really work, in red that do not work, and in black that for which there are no sufficient data to conclude. Based on all cited references of this review, particularly Crocker et al²¹ and Kanchongkittiphon et al.¹⁶ CR, Cockroach; ED, emergency department; ETS, environmental tobacco smoke; HDM, house dust mite; HEPA, high-efficiency particulate air.

outcomes were often used in environmental intervention studies and they were demonstrated to be consistent and reproducible. To limit this bias, data could also be collected from external independent sources (general practitioners).⁴⁴

Moreover, the studies generated a Hawthorne effect.^{20,32,40} When the reference group was regularly visited or called over the course of the study, this could have contributed to a reduction in asthma-related symptoms by increasing participants' attention to asthma care, and thus reducing the difference in findings between the 2 groups. To detect any bias in the control group behavior, Bryant-Stephens and Li²⁰ carried out an RCT, with an intervention group, a control group who received follow-up visits, and a case-matched control group to whom no care was given. As mentioned earlier, a significant difference was found between the intervention group and the case-matched control group for urgent care use only. According to Krieger et al,⁴⁷ it is not ethical to enroll participants and not provide them care. Carter et al³⁹ and Corver et al³³ preferred to use an intervention group as well as a placebo group who received a sham intervention, and a control group who received follow-up visits.

Finally, the results may have been biased by a seasonal influence because the enrolment of participants was a long process and the asthma questionnaires were repeated at different times of year.⁵¹

Synthesis and perspectives

Overall, the studies described support the effectiveness of home interventions by health care workers, demonstrating decreased respiratory symptoms and urgent care use. Globally, home visits consist in exposure assessment and measurements leading to environmental remediation to improve asthma and other chronic respiratory diseases via education of patients and caretakers (Figure 1).

The effectiveness of home interventions was assessed in terms of participants' compliance with the intervention program, improvement of the quality of the indoor environment, and improvement of health outcomes. From this comprehensive analysis, at least 4 issues can be discussed. The first involves determining which component showed the most improvement (behavior, environment, health). Most of the studies analyzed the impact of the visits on environmental and health conditions. By

contrast, fewer studies focused on behavior endpoints. Although the difference is very small compared with other outcomes, behavior appears to be the most improved component. Good compliance of participants in adopting behaviors that may favorably modify exposure to risk factors is observed in approximately 60% of cases. The most difficult habits to change are smoking and the presence of pets inside homes. Half of the targeted parameters related to the home environment or health status are improved after the intervention program.

The second point involves determining which is the most effective approach for home interventions. The effectiveness of interventions based on mechanical methods and combined methods is not fully demonstrated because of mixed results (approximately 50% of the reported parameters are improved by each kind of intervention). This was already emphasized by MacDonald et al⁵⁸ in their meta-analysis. One reason given is the multitude of parameters used across the studies to assess the effectiveness, which makes comparison difficult. Interventions based on educational methods alone seem more effective. As shown by de Blay et al,⁴¹ patient education via home visits induced good compliance because the MIECs who assessed the actual exposure made participant-specific recommendations and suggested appropriate avoidance measures, unlike physicians who gave standard, often inappropriate recommendations.

Third, studies directed at a single trigger showed mixed results. The study of Luczynska et al⁴⁹ is the only one to show no effectiveness of the intervention either on the home environment or on health status. The intervention aimed at avoiding house dust mites simply by using bedding covers (Table I). This supports the conclusions of Gotzsche and Johansen,⁵⁶ who were unable to demonstrate the effectiveness on clinical status of physical measures against house dust mites, through the review of 54 studies. For Custovic et al,³⁴ a reduction in a single trigger (house dust mite in their case) can succeed but several avoidance methods must be combined. The value of interventions aimed at reducing exposure to multiple indoor asthma triggers has also been shown by Postma et al.²² Such interventions were implemented by several authors.^{20,39,40,42,45,51,54} The effectiveness of home interventions on the levels of chemical contaminants remains to be investigated because very few studies focused on these risk factors.⁴² However, some substances such as formaldehyde or phthalates are significantly associated with an increase of allergies, asthma, and other respiratory symptoms in children and adults¹⁷ and therefore should be measured.

Fourth, the counselors themselves can affect the outcomes. Some interventions succeed because the counselors share community, culture, and life experiences with the participants.⁵¹

The cost of interventions should be discussed relative to the health benefits. When this has been assessed, the cost ranges from \$120²⁰ to \$3182.⁴⁵ The highest costs were observed when many interventions were performed.⁴⁰ These costs must be compared with the benefits derived from fewer emergency department or physician visits and lower medication consumption. However, even only few studies evaluated the cost effectiveness of the intervention, but both of the interventions were cost effective.⁵ An educational approach might make home interventions more sustainable over a longer period than costly professional cleaning and extermination.⁵⁰ Finally, as suggested by Warner et al,⁵³ the most successful long-term intervention measures are likely to be those that are the least time consuming for the participants.

Overall, the mixed results of this review highlight the need to further assess the value of home environmental interventions for the prevention or control of allergic and respiratory diseases. Patients with asthma are the first targets who benefit such interventions; however, more neglected diseases such as chronic bronchitis or cystic fibrosis are in the scope.⁵⁹ Future programs should implement a multifaceted approach to better understand the environmental determinants (chemical, biological, and physical) of these diseases. Some risk factors have never or rarely been targeted, such as some chemical contaminants (formaldehyde, phthalates). Home interventions based on education by counselors sharing community, culture, and life experiences with the participants seem to be the most effective, cost beneficial, and sustainable over a prolonged period regarding behavior changes. The targeted population should also be well defined. Large RCT (to avoid any lack of statistical power) reporting participant compliance in applying multiple trigger avoidance measures recommended by the counselors, assessing the changes in participant exposure level to risk factors, and measuring the positive health outcomes would be of great value for public health authorities in drafting recommendations and/or legislation. One way to gain statistical power would be to implement multicentric evaluation programs with shared protocols.

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