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House modifications for preventing malaria (Review)

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Furnival-Adams J, Olanga EA, Napier M, Garner P.
House modifications for preventing malaria.
Cochrane Database of Systematic Reviews 2020, Issue 10. Art. No.: CD013398.
DOI: 10.1002/14651858.CD013398.pub2.

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[Intervention Review]

House modifications for preventing malaria

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Editorial group: Cochrane Infectious Diseases Group.
Publication status and date: New, published in Issue 10, 2020.

Citation: Furnival-Adams J, Olanga EA, Napier M, Garner P. House modifications for preventing malaria. *Cochrane Database of Systematic Reviews* 2020, Issue 10. Art. No.: CD013398. DOI: 10.1002/14651858.CD013398.pub2.

ABSTRACT

Background

Despite being preventable, malaria remains an important public health problem. The World Health Organization (WHO) reports that overall progress in malaria control has plateaued for the first time since the turn of the century. Researchers and policymakers are therefore exploring alternative and supplementary malaria vector control tools. Research in 1900 indicated that modification of houses may be effective in reducing malaria: this is now being revisited, with new research now examining blocking house mosquito entry points or modifying house construction materials to reduce exposure of inhabitants to infectious bites.

Objectives

To assess the effects of house modifications on malaria disease and transmission.

Search methods

We searched the Cochrane Infectious Diseases Group Specialized Register; Central Register of Controlled Trials (CENTRAL), published in the Cochrane Library; MEDLINE (PubMed); Embase (OVID); Centre for Agriculture and Bioscience International (CAB) Abstracts (Web of Science); and the Latin American and Caribbean Health Science Information database (LILACS), up to 1 November 2019. We also searched the WHO International Clinical Trials Registry Platform (www.who.int/ictrp/search/en/), ClinicalTrials.gov (www.clinicaltrials.gov), and the ISRCTN registry (www.isrctn.com/) to identify ongoing trials up to the same date.

Selection criteria

Randomized controlled trials, including cluster-randomized controlled trials (cRCTs), cross-over studies, and stepped-wedge designs were eligible, as were quasi-experimental trials, including controlled before-and-after studies, controlled interrupted time series, and non-randomized cross-over studies. We only considered studies reporting epidemiological outcomes (malaria case incidence, malaria infection incidence or parasite prevalence). We also summarised qualitative studies conducted alongside included studies.

Data collection and analysis

Two review authors selected eligible studies, extracted data, and assessed the risk of bias. We used risk ratios (RR) to compare the effect of the intervention with the control for dichotomous data. For continuous data, we presented the mean difference; and for count and rate data, we used rate ratios. We presented all results with 95% confidence intervals (CIs). We assessed the certainty of evidence using the GRADE approach.

Main results

Six cRCTs met our inclusion criteria, all conducted in sub-Saharan Africa; three randomized by household, two by village, and one at the community level. All trials assessed screening of windows, doors, eaves, ceilings or any combination of these; this was either alone, or in combination with eave closure, roof modification or eave tube installation (a "lure and kill" device that reduces mosquito entry whilst maintaining some airflow). In two trials, the interventions were insecticide-based. In five trials, the researchers implemented the interventions. The community implemented the interventions in the sixth trial.

At the time of writing the review, two of the six trials had published results, both of which compared screened houses (without insecticide) to unscreened houses. One trial in Ethiopia assessed screening of windows and doors. Another trial in the Gambia assessed full screening (screening of eaves, doors and windows), as well as screening of ceilings only.

Screening may reduce clinical malaria incidence caused by *Plasmodium falciparum* (rate ratio 0.38, 95% CI 0.18 to 0.82; 1 trial, 184 participants, 219.3 person-years; low-certainty evidence; Ethiopian study). For malaria parasite prevalence, the point estimate, derived from The Gambia study, was smaller (RR 0.84, 95% CI 0.60 to 1.17; 713 participants, 1 trial; moderate-certainty evidence), and showed an effect on anaemia (RR 0.61, 95% CI 0.42, 0.89; 705 participants; 1 trial, moderate-certainty evidence).

Screening may reduce the entomological inoculation rate (EIR): both trials showed lower estimates in the intervention arm. In the Gambian trial, there was a mean difference in EIR between the control houses and treatment houses ranging from 0.45 to 1.50 (CIs ranged from -0.46 to 2.41; low-certainty evidence), depending on the study year and treatment arm. The Ethiopian trial reported a mean difference in EIR of 4.57, favouring screening (95% CI 3.81 to 5.33; low-certainty evidence).

Pooled analysis of the trials showed that individuals living in fully screened houses were slightly less likely to sleep under a bed net (RR 0.84, 95% CI 0.65 to 1.09; 2 trials, 203 participants). In one trial, bed net usage was also lower in individuals living in houses with screened ceilings (RR 0.69, 95% CI 0.50 to 0.95; 1 trial, 135 participants).

Authors' conclusions

Based on the two trials published to date, there is some evidence that screening may reduce malaria transmission and malaria infection in people living in the house. The four trials awaiting publication are likely to enrich the current evidence base, and we will add these to this review when they become available.

PLAIN LANGUAGE SUMMARY

House modifications for preventing malaria

What is the aim of this review?

House modifications, such as screening (covering potential house entry points for mosquitoes with netting or mesh), or the use of alternative construction materials, may contribute to reducing the burden of malaria. They work by blocking mosquitoes from entering houses, and reducing the number of bites householders receive indoors. Some of the house modifications under consideration additionally aim to kill any mosquitoes that attempt to enter houses by incorporating insecticide into the modification.

Key messages

Screening windows, doors, eaves and ceilings to prevent mosquitoes entering the house may reduce malaria transmission and illness in people living in the house, based on evidence from two studies conducted in Africa. Four trials awaiting publication are likely to enrich the current evidence base.

What was studied in the review?

This review summarized studies investigating the effects of house modifications on human malaria outcomes. If studies additionally reported the effect of the house modifications on mosquitoes (those with potential to carry malaria), or householders' views, we also summarized this data. After searching for relevant studies, we identified six studies conducted in sub-Saharan Africa, two of which have published data, and four of which are not yet in the public domain. All trials assessed screening (of windows, doors, eaves, ceilings, or any combination of these), either alone or in combination with eave closure, roof modification, or eave tube installation (a "lure and kill" device positioned in eave gaps).

What are the main results of the review?

The two trials with published data assessed the effect of screening alone on malaria infection. Both trials showed a reduction in malaria in screened houses, to varying degrees of effect. One trial in Ethiopia showed that people living in screened houses were around 62% less likely to experience an episode of clinical malaria (caused by *P falciparum*). However, the certainty of this evidence was low due to issues with the study design, and the trial did not study enough people for us to be confident about the results. Another trial in The Gambia showed that people living in screened houses were around 16% less likely to have *P falciparum* malaria parasites in their blood, and were less likely to experience anaemia. Our confidence in this result was moderate because the trial did not study enough people.

How up to date is this review?

The review authors searched for studies available up to 1 November 2019.

Summary of findings 1. Summary of findings table 1

Screening of windows, ceilings, doors and/or eaves compared to no screening for preventing malaria

Patient or population: people living in malaria transmission areas, excluding migrant populations or displaced individuals
Setting: The Gambia (one trial), Ethiopia (one trial)
Intervention: screening of windows, ceilings, doors and eaves
Comparison: no screening

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	Number of participants/person-years (studies)	Certainty of the evidence (GRADE)	Comments
	Risk/rate with no screening	Risk/rate with Screening of windows, ceilings, doors and/or eaves				
Clinical malaria incidence caused by *P falciparum* Follow-up: 6 months	91 per 1000 person-years	35 per 1000 person-years (16 to 70)	Rate ratio: 0.38 (0.18 to 0.82)	219.3 person-years (1 RCT)[a]	⊕⊕⊝⊝ LOW[b,c,d] *Due to risk of bias and imprecision*	Screening may reduce clinical *P falciparum* malaria.
Malaria parasite prevalence Follow-up: 1 year	234 per 1000	196 per 1000 (140 to 274)	Risk ratio: 0.84 (0.60 to 1.17)	713 participants (1 RCT)[e]	⊕⊕⊕⊝ MODERATE[f,g] *Due to imprecision*	Screening may have a small effect on malaria parasite prevalence.
Anaemia prevalence Follow-up: 1 year	211 per 1000	128 per 1000 (88 to 187)	Risk ratio: 0.61 (0.42 to 0.89)	705 participants (1 RCT)[e]	⊕⊕⊕⊝ MODERATE[h] *Due to imprecision*	Screening probably reduces anaemia prevalence.
Entomological Inoculation Rate (EIR) Follow-up: range 6 months to 2 years	In one study, the mean difference in EIR between the control houses and treatment houses ranged from 0.45 to 1.50 (CIs ranged from -0.46 to 2.41), depending on the study year and treatment arm; in a second study, there was a mean difference in EIR of 4.57 (95% CI 3.81 to 5.33).		-	(2 RCTs)	⊕⊕⊝⊝ LOW[i] *Due to imprecision*	Screening may reduce EIR.

*__The risk in the intervention group__ (and its 95% CI) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).
CI: confidence interval

GRADE Working Group grades of evidence
High certainty: we are very confident that the true effect lies close to that of the estimate of the effect

Moderate certainty: we are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low certainty: our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
Very low certainty: we have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

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[a]Intervention was screening of windows and doors by the researchers.
[b]Downgraded by 1 level for risk of bias: active case finding reporters aware of the allocated group.
[c]Downgraded by 1 level for imprecision: small numerator, small trial, and CIs span from a small effect to a large effect.
[d]Not downgraded for indirectness: the study was conducted in a malaria-endemic, sub-Saharan African setting, evaluating the effect of an intervention identified in our protocol on malaria in children and adults, strongly aligned with the review question.
[e]Intervention was either screening of ceilings (first group) or screening of eaves, doors and windows (second group). Both study arms showed a similar effect compared to control so are aggregated in the analysis (The Gambia).
[f]Downgraded by 1 level for imprecision: the CIs include both an increase and decrease in malaria parasite prevalence.
[g]Not downgraded for indirectness: the study was conducted in a malaria-endemic, sub-Saharan African setting, evaluating the effect of an intervention identified in our protocol on malaria in children, strongly aligned with the review question.
[h]Downgraded by 1 level for imprecision: the CIs are very wide and include risk ratios, suggesting both an important effect and little to no effect.
[i]Downgraded by 2 levels for imprecision: the CIs around the mean estimates are very wide.

BACKGROUND

Description of the condition

Preventing malaria

Malaria is a life-threatening parasitic disease caused by *Plasmodium* species, and is transmitted by female *Anopheles* mosquitoes (WHO 2018). *Plasmodium falciparum* is responsible for most malaria deaths, and 93% of those deaths occur in Africa. Although malaria can be prevented, the World Health Organization (WHO) reports that overall progress in malaria control appears to have plateaued for the first time since the turn of the century (WHO 2017a; WHO 2018). In 2018, there were an estimated 228 million cases worldwide (3 million fewer cases than estimated in 2017), with 85% of cases occurring in 19 sub-Saharan African countries and India. In sub-Saharan Africa, malaria primarily affects rural communities, due to the breeding site preferences of the major malaria vectors, *Anopheles gambiae* sensu lato and *Anopheles funestus*. These vectors are endophilic (resting and inhabiting indoors), endophagic (indoor-biting), and night-biting. These characteristics mean that most malaria transmission occurs indoors (Huho 2013).

Indoor residual spraying (IRS) and insecticide-treated nets (ITNs) have been the most widely used malaria vector control tools to date, and studies have suggested that these tools have made a notable contribution to the reductions in malaria observed in the early 21st century (Bhatt 2015). However, some specialists have commented that these alone will be insufficient to eliminate the disease (Killeen 2014). The current core interventions can fail when few people use the nets, when insecticide spraying coverage is low, or when the vector itself is not amenable to control through these mechanisms (for example, when *Anopheles* spp. bite outdoors (exophagy) or bite outside the times of bed net use). In addition, widespread insecticide resistance observed across Africa may be contributing to decreased effectiveness of these interventions (Ranson 2016; WHO 2017b).

These challenges have led researchers and policy specialists to explore other approaches to preventing malaria, especially options that are not reliant on the efficacy of the most frequently used class of insecticides, pyrethroids. In line with this, there is renewed interest in aspects of house design that may help prevent mosquitoes entering houses, biting people, and transmitting malaria. Although house modifications have been widely used for malaria prevention in the past (Gachelin 2018), since the global malaria community promoted IRS as a simple solution from the 1940s, the idea of housing interventions protecting people from malaria has fallen off the agenda. In light of the challenges associated with current vector control tools, specialists are now re-examining how housing may help protect people from malaria infection.

Housing and protection

Prior to our understanding of malaria transmission by mosquitoes, communities commonly used wire gauze to protect against flying insects (Gachelin 2018; Wilson 2020). At the end of the nineteenth century, malaria transmission by female *Anopheles* mosquitoes was discovered. Simple house proofing (screening) techniques were used in some of the early experiments that contributed to the establishment of this link (Celli 1901; Manson 1900). Celli, published in the Lancet in 1901, reported on the "mechanical protection of houses", combined with covering exposed skin and use of antimalarial drugs in railway workers in Italy, and noted that such measures were highly successful in allowing "the families of railway servants...to pass the whole summer...without contracting fever". Celli 1901 used wire gauze over windows, doors and chimneys; treated relapses; but gave no prophylaxis. The intervention was highly successful in preventing fever — unlike the situation in the previous year, or in adjacent areas. Surveys conducted in America also suggested a link between house quality and malaria (Boyd 1926). In the late 1940s, large-scale IRS campaigns were implemented as dichlorodiphenyltrichloroethane (DDT) became available; this steered vector control programmes towards insecticidal tools, and the role of housing interventions became largely forgotten.

Systematic review of association (2015)

With the renewed interest in housing for malaria control, researchers have collected data assessing housing as a risk factor for malaria in a range of geographical, epidemiological, and socioeconomic settings (Tusting 2015). These studies have investigated malaria risk in relation to roof type, wall type, floor type, closed versus open eaves, the presence/absence of a ceiling, house elevation, and 'modern' housing versus traditional housing. Tusting 2015 summarized data from a variety of study designs: case-control, cohort, cross-sectional, randomized controlled trials (RCTs); controlled before-and-after studies (when baseline measurements were comparable), cross-over studies, and interrupted time series studies. Tusting 2015 included participants of any ages (excluding migrants, displaced people, or military), and included studies that were conducted in real (not experimental) houses, which compared modern with traditional house features. Their analysis classified traditional houses as follows:

- mud or stone walls; a thatched, wood, or earth roof; and earth floors in Africa;
- wood or bamboo walls; a thatched roof; and wooden (stilted) floors in Southeast Asia;
- mud or wood walls; a thatched roof; and earth or wooden (stilted) floors in South Asia;
- adobe or mud and wood walls; a thatched roof; and earth floors in South America.

Primary outcomes included epidemiological and entomological indicators of malaria infection (individuals infected with malaria parasites) or malaria transmission. All studies included in the meta-analysis were observational. Risk of bias was assessed using the Effective Practice and Organization of Care (EPOC) tool for intervention studies, and the Newcastle-Ottawa Scale (NOS) tool for observational studies. Tusting 2015 found 53 studies that reported epidemiological outcomes. In three cohort studies that evaluated mesh screening over windows, there was some evidence of an association between screening and the odds of clinical malaria (testing positive for malaria and presenting with symptoms). The odds of clinical malaria was lower in screened houses, with an effect estimate (odds ratio; OR) of 0.56; but for malaria infection incidence, results from case-control, cross-sectional, and cohort studies were inconsistent.. One study showed reduced odds of anaemia in screened houses (OR 0.52). Studies that compared malaria rates in 'modern' houses against those in 'traditional' houses consistently showed lower odds of malaria infection and clinical malaria in modern houses. Modern wall

materials were associated with a 0.27 reduced odds of malaria infection across 22 studies. Modern roof materials, such as corrugated iron, were associated with a lower incidence of clinical malaria. However, these were observational studies and likely to be confounded, which the authors note, along with other limitations. The authors evaluated risk of confounding as part of the Newcastle-Ottawa Score and showed that few studies attempted to control for household wealth. Although some did adjust for household wealth, there remains a risk of residual confounding from socioeconomic status.

Demographic and health survey analysis (2017)

In a subsequent paper, the same research team analysed data across several countries, drawing on the Demographic and Health Surveys (DHS) and Malaria Indicator Surveys (MIS) across 21 sub-Saharan countries that assessed the relationship between house quality and malaria (Tusting 2017). Wall, roof, and floor materials were classified as 'natural', 'rudimentary', or 'finished' by the DHS/MIS, and these definitions were used to create a binary housing quality variable comparing 'modern' with 'traditional' housing. DHS and MIS household wealth index scores were developed using principal component analysis (typically included variables describing durable asset ownership, access to utilities and infrastructure, and house construction materials). They then adjusted effect estimates for household wealth based on this index score. The results suggested that modern housing was associated with a 9% to 14% reduction in the odds of malaria infection after adjusting for age, gender, ITN use, IRS coverage (where measured), household wealth, and cluster-level variables such as rural/urban status. The analysis was rigorous and covered data from a large population of 284,532 children. Again, a major limitation was that, despite controlling for household wealth, the wealth index used may not have been sufficient to account for socioeconomic differences associated with the house features in question, and there may as a result have been residual confounding by wealth. In addition, given the non-randomized nature of the studies summarized in this meta-analysis and the observational studies summarized by Tusting 2015, the observed effects may have occurred by chance. Given the risk of residual confounding by household wealth and the absence of dramatic differences, these summaries of observational data are suggestive of a relationship between housing and malaria, but not proof of an effect.

Entomological studies

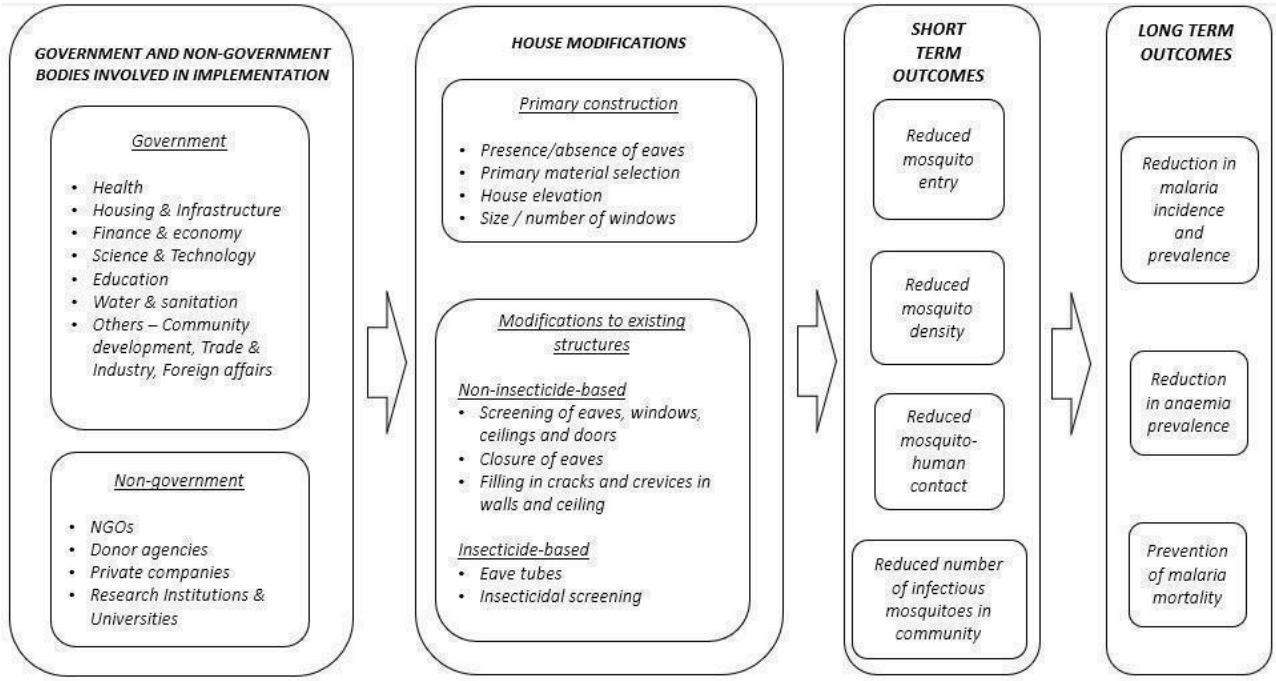
Several experimental entomological studies have also been conducted assessing the effect of full or partial screening of houses; alternative house typologies; and use of insecticidal eave tubes (Jatta 2018; Kampango 2013; Massebo 2013; Njie 2009; Ogoma 2010; Sternberg 2016; von Seidlein 2017). Preliminary studies have suggested that screening can reduce adult mosquito density: for example, Kampango 2013 showed a 61% to 84% reduction after covering gable ends with either four-year-old mosquito bed nets, untreated shade cloth, or deltamethrin-impregnated shade cloth. One household-randomized trial reported that indoor mosquito density fell by 40% after screening doors and windows, and closing wall openings and eave gaps with mud (Massebo 2013). A study assessing the effect of eave tubes, insecticide-treated netting fitted into tubes inserted into closed eaves, showed a 50% to 70% reduction in the number of mosquitoes recaptured compared to eave tubes with untreated inserts (Sternberg 2016).

These data indicate that various housing interventions show promise. Further experimental epidemiological studies will help clarify whether these are true effects, and identify what seems to work best in what circumstances.

Description of the intervention

Various aspects of the physical environment in and around the house, including proximity to breeding sites, may affect indoor mosquito density, and subsequently the risk of infectious bites to humans in their dwellings. For example, new houses or whole villages could be strategically positioned away from known breeding sites to minimize malaria risk; vegetation around the home may be cleared to minimize resting sites; improved drainage and water supply may distance breeding sites from houses; where zoophilic vectors exist (those that are attracted to and feed on animals), livestock and domesticated animals could be managed to limit their proximity to humans (Hasyim 2018; Keiser 2005; Peterson 2009). At a domestic level, physical modifications to the house design and structure may reduce mosquito entry; this is what we will focus on in this review. All these actions put together may well help to reduce the vector-borne disease burden. The WHO describes such an approach as an 'intersectoral action', whereby multiple sectors work collaboratively to engineer an environment that is less conducive to malaria transmission. Intersectoral collaboration formed a core component of the Global Vector Control Response, and is considered by researchers and policymakers to be important for developing sustainable malaria control programmes (WHO 2017b) (Figure 1).

Figure 1. Logic model showing the sectors involved, and potential long and short-term outcomes associated with house modifications.



In this review, we will only examine structural house modifications to reduce indoor malaria transmission. These house modifications can be divided into three categories, described in more detail in Table 1:

- design, detailing and material specifications for primary construction;
- modifications or additions to the physical structure of existing houses (retrofit);
- the incorporation of insecticide delivery systems into existing house structures.

There are a number of prerequisites for programmes that incorporate housing interventions to work and to be sustained for longer. Houses require a minimum level of structural integrity, where barriers such as screening can be applied and maintained. Those living in the houses also need to value change, see mosquitoes as a nuisance at the very least, and understand that malaria is a risk. Such community views will help people to introduce some of the approaches themselves; help communities accept the provision of other aspects of such control; and are important to making the interventions work, such as closing doors/windows at night, and blocking routes of entry for mosquitoes.

Other benefits of housing interventions may help people to value them, for example, the reduction in flies entering the home, or other mosquito species biting indoors. On the other hand, some externally imposed modifications may be inconvenient, or be disliked for other reasons (making the houses too hot, for example), and some structural changes may be strikingly different to traditional designs, so may not be accepted culturally (Ogoma 2010).

How the intervention might work

Some of the major *Anopheles* species in Africa have evolved with humans to be endophilic and endophagic, so they tend to bite during the night, when individuals are likely to be most vulnerable, i.e. asleep at home (Gillies 1968). These behaviours make houses areas of high malaria risk, and an important target for vector control interventions.

House modifications may reduce the entry of mosquitoes into the home by blocking or covering entry routes into the house, thus reducing the risk of mosquito bites to house dwellers. Different strategies exist, where all (or combinations of) doors, open eaves (i.e. where there are ventilation gaps between the roof and wall), ceilings, and windows can be modified, either by using alternative materials or by blocking holes in these features using various materials. Which of these strategies is most effective will depend on different aspects of mosquito and human behaviour.

1. Primary house construction

Certain house designs and materials used for house construction may minimize malaria risk by reducing the risk of mosquito entry, if associated with a sufficient reduction in infective mosquito bites. This effect is likely to be related to the abundance of functional holes (for example ventilation holes, doors or windows), how prone the materials of the house are to the development of holes, or the effect of house materials on indoor temperature or humidity which may affect the survival of mosquitoes indoors (Lindsay 2019).

Other considerations regarding primary construction include the following factors:

- Whether the house is elevated or left at ground level. Previous studies have suggested that mosquitoes tend to bite at ground

level, and that indoor vector density is lower in houses raised on stilts compared to houses at ground level (Charlwood 2003). Some researchers have also suggested that the more windows per house, the higher the risk of mosquito entry will be, unless windows are properly screened (Lwetoijera 2013).

- The presence/absence of eaves or gables, or both. In areas where eaves and gables are a common feature of the house, open eaves are the main port of entry for anopheline mosquitoes (Lindsay 1988).

2. Modifications or additions to existing houses

Non-insecticide-based

The need for ventilation and light means that the presence of openings in house structures is inevitable. Many of the interventions under consideration involve partial or full screening of these openings in the house structure, usually with polyvinyl chloride (PVC)-coated fibreglass or metal mesh, or filling in gaps in wall structures with cement, mortar and rubble. Eave gaps can be screened in houses where they exist. Doors (and windows, when present) are also important routes of entry; how effective the screening of doors and windows is will depend on their size, and how often they are left open (Jawara 2018).

Insecticide-based

Although the non-insecticide-based nature of many housing interventions is appealing (due to the limited risk of toxicity to humans and non-target insects, and lack of reliance on insecticide bioefficacy and mosquito susceptibility), there are ways in which insecticides can be incorporated into house structures. If effective, insecticide-based vector control tools have the advantage of killing mosquitoes, thus increasing their potential to reduce mosquito population density within the community. In some cases, insecticide-based tools can also repel mosquitoes further away from people, increasing personal protection. Eave tubes are an example of an insecticide-based house modification, whereby tubes are inserted into the wall under the roof of the house and electrostatic netting within each eave tube is coated with insecticide (Andriessen 2015). Research has indicated that the eaves are a primary route of entry for *An gambiae*, one of the major malaria vectors in Africa. Screening of houses using insecticidal netting is also possible, although challenges exist concerning the photodegradation of insecticide in treated netting, with potentially increased exposure to ultraviolet (UV) light compared to insecticides in ITNs or IRS (Kayedi 2008).

Acceptability and implementation

House modifications for vector control have several appealing characteristics: there is likely to be a reduced risk of human toxicity compared to ITNs or IRS (non-insecticidal interventions are at low risk of being toxic to humans and for insecticidal interventions, the positioning of the treated material means that they do not come into close contact with householders); there may be little or no maintenance required; they offer household-level protection; and the efficacy of non-insecticidal interventions is not threatened by insecticide resistance. It is likely that effective housing interventions will also reduce entry of nuisance insects and other disease vectors, such as day-biting mosquitoes and flies carrying diarrhoeal agents (Ogoma 2010). This would provide additional health benefits, and may also increase the attractiveness of the intervention to householders.

On the other hand, there may be unintended effects that reduce the acceptability and feasibility of these interventions. For example, adequate ventilation is important in these tropical and subtropical climates, where respiratory diseases are a major cause of death (FIRS 2017). In many parts of Africa, traditional huts tend not to have windows, and open eaves are therefore an important source of light and ventilation. The closure of eaves, for example, may therefore be uncomfortable and may increase risk of respiratory diseases (Bruce 2000).

If shown to be effective, there are uncertainties regarding how best to implement these interventions. In trials, housing interventions are likely to mimic a ‘top down' approach, with the intervention applied and paid for by the researchers. However, long-term sustainability of housing improvements to reduce malaria will depend on changes in construction practices and on the willingness and capacity for householders to implement the modifications themselves. Improving community knowledge, perception, and practices may therefore be an important aspect of the implementation strategy (Kaindoa 2018). Policymakers and public health specialists will also need to consider how implementation strategies can ensure equitability.

Considering houses need to have certain basic features for many of these interventions to be successful, house modifications may disproportionately benefit those of a higher socioeconomic status unless programmes are specifically targeted. With this in mind, our review will also examine aspects of the delivery of housing modifications to help us discuss implementation and sustainability, including the level of community involvement in the implementation of the modifications and their maintenance.

Why it is important to do this review

The evidence provided above shows clear potential for house modifications to reduce human malaria. Previous reviews have focused on observational studies and have suggested that there is an association between housing and malaria. Some small-scale entomological studies have also indicated that house modifications can reduce indoor mosquito density. Well-conducted trials with comparative data will allow this hypothesis to be tested further and guide policymakers and householders. In this review, we will therefore summarize experimental, epidemiological studies that assess whether house modifications show an effect on malaria infection in humans. This review may additionally provide an ongoing summary of which approaches have been successful, if variation in efficacy is observed.

This is an active field, so this review will provide a good global evidence summary that can be updated as new evidence emerges.

OBJECTIVES

To assess the effects of house modifications on malaria disease and transmission.

METHODS

Criteria for considering studies for this review

Types of studies

Randomized controlled trials

- Cluster-randomized controlled trials (cRCTs) with at least two clusters per arm
- Cluster-randomized cross-over studies with at least three data points both before and after the intervention is introduced
- Cluster-randomized studies using a stepped-wedge approach

Quasi-experimental trials

- Controlled before-and-after studies with baseline data, a contemporaneous control group, and at least two sites per arm
- Controlled interrupted time series (ITS) with at least three data points before and after the intervention was introduced
- Non-randomized cross-over studies with a clearly defined point in time when the cross-over occurred, and monitoring of at least two transmission seasons before and after the cross-over

Types of participants

Any individuals living in an area where malaria transmission is known to exist, excluding migrant populations or displaced individuals.

Types of interventions

We planned to group the interventions that we assessed as shown in Table 2; however, we only identified one group of interventions in the included studies.

There should have been no major structural differences between the intervention and control arm other than the intervention itself that are likely to influence mosquito entry.

We excluded the following.

- Interventions to impermanent dwellings such as tents
- Interventions where the mechanism of action underlying the house modifications under consideration did not relate primarily to blocking mosquito entry into the house; such as wall linings
- Non-physical interventions such as insecticide-treated curtains

Any co-interventions should have been balanced across the control and intervention arms.

Types of outcome measures

Primary outcomes

Studies must have included one of the following primary outcomes.

- Malaria case incidence: measured as a count per person unit time or the number of new uncomplicated malaria cases. We used site-specific definitions as long as they demonstrated (a) a fever or history of fever, and (b) confirmed parasitaemia (by blood smear microscopy, rapid diagnostic test (RDT), or polymerase chain reaction (PCR))
- Malaria infection incidence: measured as count per person unit time or the number of new infections (individuals must have confirmed parasitaemia by blood smear, RDT, or PCR)
- Parasite prevalence (clinical and subclinical malaria): the proportion of surveyed individuals with confirmed parasitaemia at a community household survey

Secondary outcomes

Epidemiological

- All-cause mortality
- Anaemia prevalence as per WHO cut-offs, based on haemoglobin measurements taken in community household surveys (Table 3; WHO 2011)
- Other disease case incidence, including other vector-borne diseases or diarrhoeal diseases that may be influenced by house characteristics

Entomological

- Transmission intensity (measured using entomological inoculation rate; EIR): the estimated number of bites by infectious mosquitoes per person per unit time. This is measured using the human biting rate (the number of mosquitoes biting an individual over a stated period measured directly using human baits or indirectly using light traps, knock-down catches, baited huts, or other methods of biting rate determination) multiplied by the sporozoite rate.
- Adult mosquito density: measured by a technique previously shown to be appropriate for the vector (for example, using human baits, light traps, knock-down catches, baited huts, or other methods).
- Sporozoite rate: measured as the number of caught adult mosquitoes positive for malaria sporozoites. Sporozoites can be detected through molecular or immunological methods, or through dissection of the salivary glands.

User acceptability

Any measure of user acceptability collected during the conduct of the trial and reported by treatment arm. This includes cross-sectional survey data of reported acceptability and qualitative data on views about the intervention.

For consumer and implementer views, we sought studies (including qualitative studies using methods such as observations, interviews, focus groups) that had been conducted alongside studies that met the above inclusion criteria.

Unintended effects

Any data within the trials as to whether the housing interventions influence: the proportion of time spent inside or outside the house; bed net usage; and any indications of the influence of interventions on malaria incidence in neighbouring huts or houses.

Adverse effects

Any indicators of adverse effects, such as increased reports of respiratory disease.

For insecticide-based interventions:

- reports of poisoning in humans;

- environmental impacts, such as changes to the biodiversity and ecosystem due to the addition of insecticides;
- an increase in the level of phenotypic/molecular insecticide resistance respective of the class of insecticide used for IRS, confirmed by WHO cylinder assays/Centers for Disease Control and Prevention (CDC) bottle bioassays/molecular techniques;
- changes in mosquito behaviour that reduce the efficacy of vector control interventions, for example an increase in exophily, exophagy, zoophily, or changes in biting time.

Search methods for identification of studies

Electronic searches

We searched the following databases up to 1 November 2019 using the search terms and strategy described in Appendix 1: the Cochrane Infectious Diseases Group Specialized Register; Central Register of Controlled Trials (CENTRAL), Issue 11 of 12, November 2019, published in the Cochrane Library; MEDLINE (PubMed, from 1966); Embase (OVID, from 1947); Centre for Agriculture and Bioscience (CAB) Abstracts (Web of Science; from 1973); and Latin American and Caribbean Health Scences Literature (LILACS) (BIREME, from 1982). We also searched the WHO International Clinical Trials Registry Platform (www.who.int/ictrp/search/en/), ClinicalTrials.gov (www.clinicaltrials.gov), and the ISRCTN registry (www.isrctn.com/) to identify ongoing trials.

We identified qualitative research associated with the studies by:

- examining the trial reports for concomitant qualitative data collection in the methods;
- searching MEDLINE using key terms to identify the trial, such as the location or year, for qualitative studies;
- contacting the authors to determine whether qualitative studies had been conducted.

Searching other resources

We contacted researchers working in the field for unpublished data. We also checked the citations of all studies identified by the above methods.

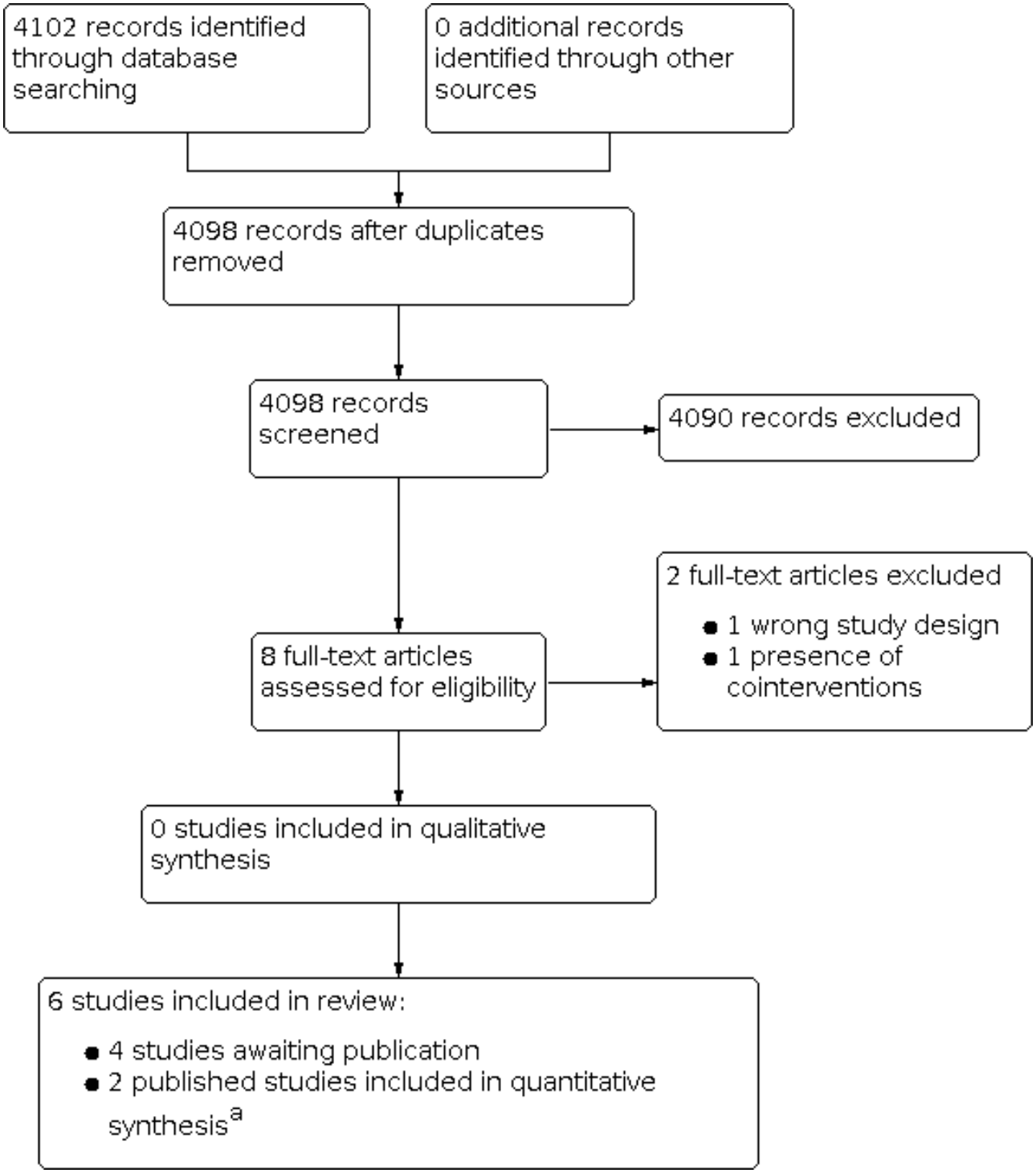
Data collection and analysis

Selection of studies

Two review authors (JFA and EAO) independently assessed the titles and abstracts of studies identified by the literature searches. These two review authors assessed full-text copies of potentially relevant studies for inclusion using an eligibility form based on the inclusion criteria. We included studies irrespective of whether data were reported in a 'usable' way. Where there were multiple publications reporting the same study, we collated information from each publication to ensure that we did not miss any important data. We compared the results of our assessments and resolved any disagreements by discussion and consensus, with arbitration by a third review author (PG) if necessary. We ensured that multiple publications of the same study were included once. We listed excluded studies, together with their reasons for exclusion, in a 'Characteristics of excluded studies' table. The study selection process is illustrated in a PRISMA diagram (Figure 2). We managed the references using Endnote and screened them using Covidence.

Figure 2. PRISMA diagram

[a]One study examining user acceptability was identified through searching for any studies conducted alongside those identified through database searching. This study was included in both qualitative and quantitative synthesis.



Data extraction and management

Two review authors (JFA and EAO) independently extracted information from the included studies using prepiloted electronic data extraction forms. In case of differences in extracted data, the two review authors discussed these differences to reach consensus. If unresolved, we consulted a third review author (PG). In case of missing data, we contacted the original study author(s) for clarification.

We extracted data on the following:

- study design: type of study; method of participant selection; sample size; details of sampling methodology, including number of time points. For cluster-RCTs (cRCTs): adjustment for clustering; number of clusters; unit of randomization; intracluster correlation coefficient (ICC); follow-up period;
- participants: study settings; population characteristics, including age, gender, ethnicity, recruitment rates; withdrawal; and loss to follow-up. We also described participants in terms of the socioeconomic status of households or the community they live in. We anticipated that this would be estimated in studies through calculating an index based on asset ownership (such as ownership of a radio, bicycle, car, or motorbike). The indicators used to create this index often vary between studies, but we attempted to compare indicators and categorize participants into socioeconomic groups;
- interventions: full details of intervention and any co-interventions and any theory informing it; coverage of intervention and any co-interventions; compliance of any co-interventions; typology of the house;
- all outcomes: definition of outcome; diagnostic method or surveillance method; passive or active case detection; duration of follow-up; time points at which outcomes were assessed; number of events; number of participants or unit time; statistical power; unit of analysis; incomplete outcomes/missing data; *Plasmodium* species; mosquito net usage;
- entomological outcomes: primary and secondary vector(s) species; vector(s) behaviour (adult habitat, peak biting times, exophilic/endophilic (indoor/outdoor resting respectively), endophagic/exophagic (indoor/outdoor biting)), anthropophilic/zoophilic (human or animal biting respectively)); method(s) of mosquito collection; malaria endemicity; eco-epidemiological setting; population proximity and density; insecticide resistance status (where an insecticidal house improvement tool was investigated);
- other: primary construction materials; topology of study site; cost of the intervention; who was responsible for implementing the intervention.

We examined how and by whom the intervention was delivered, and we described the contribution and engagement of the householders to the process.

If studies examined single interventions, we grouped these with other studies that examined the same intervention to obtain the size of effect that might be achieved.

If studies examined multiple interventions, we grouped these as follows:

- non-insecticide-based strategies that combined at least two interventions;
- strategies that combined at least two interventions, where one or more of these interventions was insecticidal.

Assessment of risk of bias in included studies

Two review authors (JFA and EAO) independently assessed the risk of bias using the Cochrane 'Risk of bias' tool (Higgins 2011). We justified judgements made in the 'Risk of bias' tables. For trials that randomized clusters, we assessed additional components, namely recruitment bias, baseline imbalances, loss of clusters, incorrect analysis, and comparability with trials that randomized individuals. For randomized cross-over trials, we planned to assess: whether the cross-over design was suitable; whether there was a carry-over effect; whether only first period data were available; incorrect analysis; and comparability of results with those from parallel-group trials.

We did not find any observational or quasi-experimental studies suitable for inclusion; however, to assess the risk of bias in such studies we had intended to use the Cochrane 'Risk Of Bias In Non-randomized Studies - of Interventions' (ROBINS-I) tool (Sterne 2016). This tool assesses the risk of bias through a hierarchy of domains, starting with critical then serious, moderate, and low. If any domain were to have reached critical risk of bias, we would not have continued with the assessment, as further evaluation would not have influenced how we assessed the certainty of the evidence. As the risk of bias in the effect of an intervention may be different for different outcomes, we had intended to assess the risk of bias for each outcome. The confounding domains have been outlined in Appendix 2.

We assessed the quality of included qualitative studies using a modified version of the tool developed by the Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI-Centre) and outlined by Eshun-Wilson 2019.

Measures of treatment effect

We used risk ratios (RR) to compare the effect of the intervention with the control for dichotomous data. For continuous data, we presented the mean difference (MD); and for count/rate data, we used rate ratios. For non-randomized studies, we planned to use adjusted measures of effect to summarize treatment effects. We presented all results with 95% confidence intervals (CIs).

Unit of analysis issues

We took into account the unit of randomization in study designs such as cross-over trials, cRCTs, and multiple observations for the same outcome.

For cRCTs, we extracted adjusted measures of effect, where possible. If the study authors did not perform any adjustment for clustering, we adjusted the raw data using an ICC value. If the trial did not report the ICC value, we estimated the ICC value either from previous studies conducted in similar contexts, or using a range of ICCs (0.01, 0.05, and 0.1). For clinical malaria incidence, we estimated an ICC of 0.02 based on a previous study (Foy 2019), and performed a sensitivity analysis using ICCs of 0.01 and 0.06. For anaemia prevalence in Kirby 2009, the paper reported an estimated ICC of between 0.04 and 0.08, based on unpublished data. We therefore used an ICC of 0.06, and conducted a sensitivity analysis using ICCs of 0.04 and 0.08. For parasite prevalence, we used a range of ICCs (0.01, 0.05, and 0.1) and reported the data that was adjusted using 0.05 as the ICC. For bed net use, we estimated an ICC of 0.375, based on a previous study in Liberia (Babalola 2016).

For entomological outcomes, we did not perform adjustments for clustering. Reported ICCs were not available for these outcomes, and we did not consider it appropriate to estimate ICCs. We did not consider it possible to produce estimates that we could be confident had been appropriately adjusted for clustering.

For studies that had multiple intervention arms, we included data from these studies either by combining treatment arms or

by splitting the control group, so that we only included these participants in the meta-analysis once.

For studies that reported multiple follow-up times, we extracted data from all time points. For outcomes where a meta-analysis was possible, we planned to make a decision on which time point to use based on comparability with other data included in the analysis.

We did not identify any randomized cross-over trials suitable for inclusion. If we had identified any, and did not think that either carry-over or period effects were likely to have been a problem, we had intended to use a paired t-test for the analysis of continuous data from two-period, two-armed cross-over trials.

Dealing with missing data

In cases of missing data, we applied available-case analysis, only including data on the known results. The denominator was the total number of participants who had data recorded for the specific outcome. For outcomes with no missing data, we performed analyses on an intention-to-treat basis. We included all participants randomized to each group in the analyses and analysed participants in the group to which they were randomized.

Assessment of heterogeneity

For outcomes where meta-analysis was possible, we inspected forest plots for overlapping CIs and assess statistical heterogeneity in each meta-analysis using the I^2 statistic values and Chi^2 statistics. We considered heterogeneity as moderate if I^2 statistic values were between 30% to 60%; substantial if they were between 50% to 90%; and considerable if they were between 75% to 100% (Higgins 2011). We considered a Chi^2 test statistic with a P value ≤ 0.10 to indicate statistically significant heterogeneity. If substantial heterogeneity was present, we planned to explore clinical and methodological heterogeneity through consideration of the trial populations, methods, and interventions, and by visualization of trial results.

Assessment of reporting biases

If there were 10 or more trials included in each meta-analysis, we planned to investigate reporting biases (such as publication bias) using funnel plots. We planned to assess funnel plot asymmetry visually, and use formal tests for funnel plot asymmetry (Harbord 2006). If we detected asymmetry in any of these tests or by a visual assessment, we planned to explore the reasons for asymmetry.

Data synthesis

We analysed the data using Review Manager 5 (RevMan 5) (Review Manager 2020). For outcomes where data was meta-analysed,we used a fixed-effect meta-analysis to combine data where heterogeneity was absent. If considerable heterogeneity were present, we planned to combine data using random-effects meta-analysis and report an average treatment effect. We planned to decide whether to use fixed-effect or random-effects models based on the consideration of clinical and methodological heterogeneity between trials. We planned to stratify the analysis by study design, and place any studies conducted in epidemic settings in a separate analysis.

Subgroup analysis and investigation of heterogeneity

We intended to investigate heterogeneity by subgrouping data based on malaria endemicity (low, < 50% parasite rate; and high, > 50% parasite rate).

Sensitivity analysis

None of the included studies were at high risk of bias, however, we planned to perform sensitivity analysis on the primary outcome to see the effect of exclusion of trials at high risk of bias (for incomplete outcome data) on the overall results. For trials with estimated ICC values, we undertook sensitivity analyses to investigate the impact of varying the ICC value on meta-analysis results.

Summary of findings and assessment of the certainty of the evidence

We assessed the certainty of the evidence using the GRADE approach (Guyatt 2011). For RCTs, we rated each primary outcome as described by Balshem 2011; RCTs start as high-certainty evidence, but can be downgraded if there are valid reasons within the following five categories: risk of bias, imprecision, inconsistency, indirectness, and publication bias. Although we did not identify any non-randomized studies that met our inclusion criteria, we had planned to use the GRADE approach to rate primary outcomes for any such studies. The body of evidence from non-randomized studies begins as low certainty. This initial rating is followed by consideration of eight domains, five of which may result in rating down certainty (risk of bias, imprecision, inconsistency, indirectness, and publication bias), and three in rating up (a large magnitude of effect, a dose-response gradient, and a situation in which plausible biases, if present, would serve to increase our confidence in the effect estimate) (Guyatt 2013).

We used the following evidence grades:

- high: we are very confident that the true effect lies close to that of the estimate of the effect;
- moderate: we are moderately confident in the effect estimate. The true effect is likely to be close to the estimate of the effect;
- low: our confidence in the effect estimate is limited. The true effect may be substantially different from the estimate of the effect;
- very low: we have very little confidence in the effect estimate. The true effect is likely to be substantially different from the estimate of effect.

We summarized qualitative findings on consumer views narratively. If there had been a sufficient number of included studies, two review authors would have independently coded the studies, and used thematic synthesis to identify themes and subthemes.

We summarized the following outcomes (those considered most important to decision-making) in 'Summary of findings 1': clinical malaria incidence, parasite prevalence, anaemia prevalence and EIR.

RESULTS

Description of studies

Results of the search

We identified 4098 potentially relevant studies through our search strategy, from which we considered nine for full-text screening (Figure 2). Of these, six studies met our inclusion criteria, two of which had published data (Kirby 2009; Getawen 2018). For one study, we were able to obtain unpublished data from the authors, but we were not able to use this pending publication of the primary research (Minakawa 2016 (completed, unpublished)). Of the nine studies that we assessed at full-text screening, we excluded three: one was a duplicate, and the other two study designs did not fit the inclusion criteria (one had multiple co-interventions, and the other was a non-randomized controlled trial with no pre-intervention data).

Of the six identified studies, two are published and we report them here; the other four have been completed and are expected to be published shortly.

Included studies

Trial design and location

Of the six studies meeting our inclusion criteria, all were cRCTs. Three were household-randomized; one of these trials stratified households by village prior to randomization (Getawen 2018), another trial stratified houses by village or urban location, residential block, and the number of children per house prior to randomization (Kirby 2009); and one trial stratified houses by a block design, with village as the block (Pinder 2016 (protocol)). Two trials were village-randomized; one with a buffer size of 400 m (McCann 2017 (protocol)) and the other with a buffer size of 2 km (Sternberg 2018 (protocol)). One trial was community-randomized, and the trialists established the boundaries of the areas based on community centres, villages and political boundaries (Minakawa 2016 (completed, unpublished)).

Two studies took place in The Gambia, one in Ethiopia, one in the Ivory Coast, one in Malawi, and one in Kenya. Four were conducted in rural areas, one was conducted in both rural and urban areas, and one was conducted in an urban area. Four of the studies took place in areas with high levels of malaria transmission. One trial took place in an area of moderate transmission (Getawen 2018). One trial was based in the Upper River Region (URR) of the Gambia, where malaria transmission is seasonal. Other sources have indicated that URR is an area of moderate to high malaria transmission (*P falciparum* prevalence of around 31% to 37%) (Mwesigwa 2015).

Interventions

The interventions under consideration in each trial are detailed in Table 4.

All studies used screening with either PVC-coated fibreglass netting, wire mesh, or insecticide-treated bed net material. Screening was the only component used in three of the studies, as described below.

- One study had two intervention arms; one assessing full screening (screening of eaves, doors and windows), and one arm that assessed ceiling screening only.
- One study assessed screening of eaves with insecticide-treated netting.
- One study assessed screening of windows and doors (in an area where most houses had no eave gaps).

Three studies used screening in combination with other approaches.

- One study used eave closure and roof modification with door and window screening.
- One study used eave closure, eave tube installation, maintenance, and window and door screening.
- One study used eave closure, closure of wall openings not used for ventilation, and screening of windows, doors and other openings used for ventilation.

Insecticide-based

Four of the above trials did not incorporate insecticide into any component of the intervention. Sternberg 2018 (protocol) incorporated 10% wettable powder (WP) formulation of beta-cyfluthrin on the eave tube netting, and one trial used permethrin-treated bed net material to screen eaves and ceilings (Minakawa 2016 (completed, unpublished)).

Maintenence

Implementation strategy

In five trials, the research team implemented the interventions. In one study, volunteer community members engaged in the interventions and implemented the intervention themselves (McCann 2017 (protocol)).

Co-interventions

McCann 2017 (protocol) used a 2-by-2 factorial design, whereby the trialists assessed larval source management and house improvements independently (with national malaria control programme activities) and in combination. If the results show no interaction between larval source management and house improvements, we will include data from the arm that combines the two interventions. The remaining five trials did not include any co-interventions.

Participants

Five studies measured malaria in children to evaluate the intervention, and one study examined both adults and children (Getawen 2018).

Outcomes

Epidemiological outcomes

One study measured malaria incidence only (Getawen 2018), two studies measured parasite prevalence only (Kirby 2009; Minakawa 2016 (completed, unpublished)), and three studies measured both malaria incidence and malaria prevalence (McCann 2017 (protocol); Pinder 2016 (protocol); Sternberg 2018 (protocol)). All trials used active case detection (ACD) to survey participants for malaria. Three used RDTs to confirm the presence of parasites, one used PCR, and two used microscopy to examine blood smears.

One trial was powered to detect a difference in anaemia, where this was the primary outcome (Kirby 2009). Three other studies measured anaemia as a secondary outcome (McCann 2017

(protocol); Pinder 2016 (protocol); Sternberg 2018 (protocol)). Two of these studies defined anaemia as a haemoglobin concentration of less than 80 g/L (Kirby 2009; McCann 2017 (protocol)). Neither of the other two trials that measured this as an outcome gave a definition of anaemia.

Two studies measured respiratory infection incidence as a secondary outcome (Pinder 2016 (protocol); Sternberg 2018 (protocol)).

Entomological outcomes

Five studies measured adult mosquito density and sporozoite rate and calculated an entomological inoculation rate (EIR) from these indicators. One trial was powered to detect a difference in EIR (McCann 2017 (protocol)). Three trials used CDC light traps to measure adult mosquito density (Getawen 2018; Kirby 2009; Pinder 2016 (protocol)), one used Suna traps (McCann 2017 (protocol)); and one used human landing traps and CDC light traps (Sternberg 2018 (protocol)). Three trials measured sporozoite rate using enzyme-linked immunosorbent assay (ELISA), and one trial used PCR (Sternberg 2018 (protocol)). It was not clear how McCann 2017 (protocol) measured the sporozoite rate.

Sternberg 2018 (protocol) measured resistance to the respective insecticides in ITNs (deltamethrin) and eave tubes (beta-cyfluthrin) using CDC bottle bioassays.

Qualitative research associated with the included trials

User acceptability

Four studies measured indicators of user acceptability/community acceptance. One study measured this through semi-structured questionnaires, with questions related to effect of screening, problems with screened doors, perception of screening on appearance of house, maintenance and cost of replacement (Getawen 2018). One study measured this through focus group discussions on general perceptions of the types of screening that aimed to identify the key concerns and benefits of the screening (Kirby 2009). Pinder 2016 (protocol) captured the acceptability of the intervention using: 1) observations and informal conversations during the house modification process; 2) photo-voice (a participatory action research technique enabling people to record and reflect on their concerns, promote critical dialogue, and reach policy makers); and 3) focus group discussions. Sternberg 2018 (protocol) used thematic analysis to evaluate ethnographic and focus group information related to user acceptability.

Other outcomes

Two studies used questionnaires to record bed net usage (Getawen 2018; Kirby 2009).

Excluded studies

We excluded two articles at full-text screening for the following reasons:

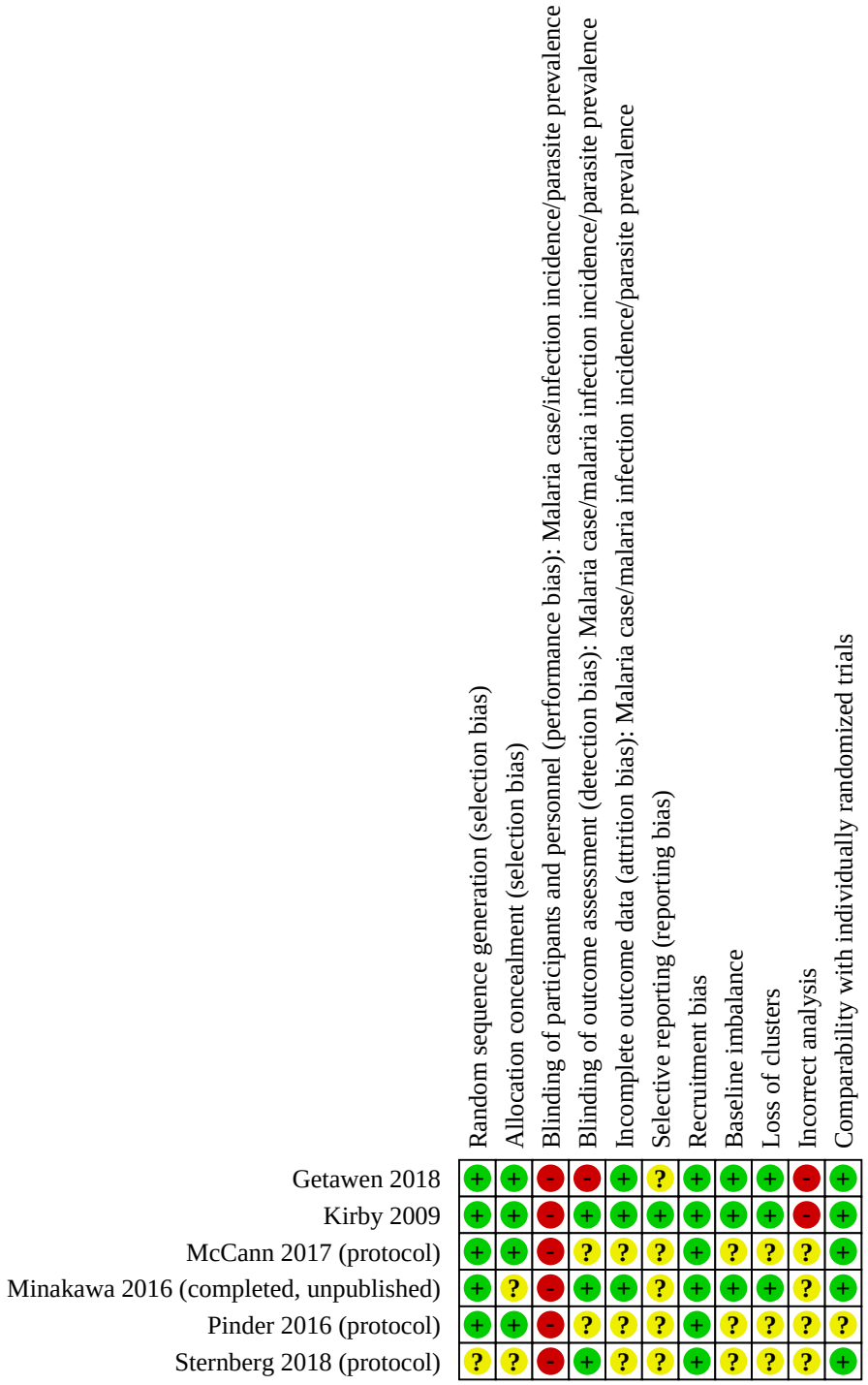
- one had the wrong study design; and
- one used multiple co-interventions.

Risk of bias in included studies

Allocation

This is displayed in Figure 3.

Figure 3. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.



Five of the trials used adequate random sequence generation methods to select participants; three used computer-generated sequences (Kirby 2009; Getawen 2018; Pinder 2016 (protocol)), one used a lottery method (Minakawa 2016 (completed, unpublished)), and one used a community raffle drawing method (McCann 2017 (protocol)). For one trial, the method of sequence generation was unclear (Sternberg 2018 (protocol)). Four trials adequately concealed assignment to treatment group (Kirby 2009; Getawen 2018; McCann 2017 (protocol); Pinder 2016 (protocol)). However, in the remaining two trials, it was not clear whether participants' group allocation was adequately concealed from the researchers prior to allocation (Minakawa 2016 (completed, unpublished); Sternberg 2018 (protocol)).

Blinding

The nature of these interventions meant that it was not possible to blind participants or personnel in any of the included trials. Five of the six trials used passive case detection to monitor malaria in participants (Kirby 2009; McCann 2017 (protocol); Pinder 2016 (protocol); Sternberg 2018 (protocol)). However, one trial monitored malaria exclusively through active case detection, where reporters were not blinded (Getawen 2018). In four trials, the outcome assessors interpreting blood slides or RDTs were blinded to the intervention status of the participants (Kirby 2009; Getawen 2018; Minakawa 2016 (completed, unpublished); Sternberg 2018 (protocol)); however, it was not clear if this was the case in two trials (McCann 2017 (protocol); Pinder 2016 (protocol)). Given the use of molecular diagnostics (RDTs or PCR in four of the six trials), and that in most cases outcome assessors were blinded, we considered it unlikely that the lack of blinding of participants and field staff influenced the results.

Incomplete outcome data

Loss to follow-up rates were similar in control and intervention arms in three of the trials (Kirby 2009; Getawen 2018; Minakawa 2016 (completed, unpublished)). We were not able to assess this in the remaining three trials, where the results have not yet been published (McCann 2017 (protocol); Pinder 2016 (protocol); Sternberg 2018 (protocol)).

Selective reporting

We considered one trial to be at low risk of reporting bias; the outcomes measured reflected what was outlined in the protocol (Kirby 2009). For two trials, the risk of reporting bias was unclear because protocols were not published a priori (Getawen 2018; Minakawa 2016 (completed, unpublished)). Three trials had published the protocol but not yet published the results, so we were unable to assess the risk of bias for this domain (McCann 2017 (protocol); Pinder 2016 (protocol); Sternberg 2018 (protocol)).

Other potential sources of bias

Recruitment bias

Recruitment bias was not a concern in any of the included trials; they all recruited households prior to randomization.

Baseline imbalance

Loss of clusters was minimal and balanced between control and intervention arms for three trials (Kirby 2009; Getawen 2018; Minakawa 2016 (completed, unpublished)). For the three trials where we only had access to the protocol, we were not able to assess this domain.

Incorrect analysis

Two trials did not adjust the results for clustering or other variables related to household differences in malaria risk (Kirby 2009; Getawen 2018). For the remaining four trials, we were not able to assess the risk of bias for this domain.

Comparability to village-randomized studies

Comparability between trials using different cluster types as units was generally not a cause for concern; the studies where a mass (herd) effect would be expected (those incorporating insecticide) were village-randomized (Minakawa 2016 (completed, unpublished); Sternberg 2018 (protocol)), and studies where a mass effect was not expected were household-randomized (Kirby 2009; Getawen 2018; McCann 2017 (protocol); Pinder 2016 (protocol)). However, in relation to Pinder 2016 (protocol), a subsequent publication that used entomological data from the trial suggested that the iron roofing used as part of the house modification may raise the temperature in the houses and kill mosquitoes, subsequently leading to a mass effect (Lindsay 2019). If true, this would make household- and village-randomized studies non-equivalent.

Effects of interventions

See: **Summary of findings 1** Summary of findings table 1

At the time of writing this review, only two of the six completed studies were in the public domain.

For all human outcomes (clinical malaria incidence, parasite prevalence, anaemia and bed net use), we adjusted the data for clustering using an estimated ICC, and performed sensitivity analyses using ranges of ICCs to assess whether these estimates impacted on the results. For each outcome, we did not find that using alternative ICCs greatly affected the adjusted effect size and we therefore consider the ICC estimates used in the primary analyses appropriate. The sensitivity analyses are reported on the same forest plots as the primary analysis for Analysis 1.1, Analysis 1.2 and Analysis 1.3. The sensitivity analyses for Analysis 1.4 are presented separately in Analysis 1.5 and Analysis 1.6.

Primary outcomes

Clinical malaria incidence

Of the two published trials, one reported data on malaria infection incidence (Getawen 2018). After adjusting for clustering, there was a significantly lower rate of malaria in screened houses compared to in unscreened houses (rate ratio 0.38, 95% CI 0.18 to 0.82; 477 participants (219.3 person-years); low-certainty evidence; Analysis 1.1).

Parasite prevalence

Of the two published trials, one reported data on parasite prevalence (Kirby 2009). After adjusting for clustering, there was a slightly lower parasite prevalence in screened houses (full screening or screened ceilings) compared to unscreened houses (RR 0.84, CI 0.60 to 1.17; 713 participants; moderate-certainty evidence; Analysis 1.2). Parasite prevalence in the full screening

and the screened ceiling arm were comparable, so we pooled these data.

Secondary outcomes

Epidemiological outcomes

Anaemia

One trial published data on anaemia prevalence (Kirby 2009). The trial compared anaemia prevalence after adjusting for clustering (assuming an ICC of 0.06). The data showed a significantly lower risk of anaemia in screened houses (full screening and screened ceilings) (RR 0.61, 95% CI 0.42 to 0.89; 705 participants; moderate-certainty evidence; Analysis 1.3). Anaemia prevalence in the full screening and screened ceiling arms were comparable, so we pooled these data.

Entomological outcomes

We were not able to meta-analyse the entomological data from the two trials due to differences in the unit of measurement and different follow-up periods.

Adult mosquito density

Both of the published trials reported the mean number of mosquitoes caught per CDC light trap per night as an indicator of adult mosquito density of the primary vector. In Kirby 2009, mosquito sampling took place in all study houses (462 houses in total) during the transmission season in each year of the study. After randomization, Getawen 2018, selected 10 sentinel houses for mosquito sampling. In Kirby 2009, there were on average 20.39 (95% CI 14.21 to 26.58) fewer mosquitoes per CDC light trap per night in screened houses (in houses with full screening and screened ceilings), compared to unscreened houses. For Getawen 2018, we were unable to calculate a mean difference because we were unable to estimate a standard deviation from the available data. We therefore used a rate ratio to estimate the effect size. On average, there was a 1.94 (95% CI 1.38 to 2.72) higher rate of mosquitoes caught per CDC light trap per night in unscreened houses compared to screened houses. The results from each trial are reported in Table 5.

Sporozoite rate

Both trials reported sporozoite rate. However, Kirby 2009 did not report sporozoite rate by intervention arm. The trial authors reported that there was no difference when comparing the control arm and the intervention arms, so they only reported the pooled sporozoite rates (0.24% in 2006 and 0.14% in 2007). In Getawen 2018, lower *P falciparum* sporozoite rates were observed in screened houses, although this was not statistically significant (RR 0.59, 95% CI 0.16 to 2.11). There was no significant difference in *P vivax* sporozoite rate (RR 0.98, 95% CIs 0.09, 10.73). The pooled sporozoite rates for *P falciparum* and *P vivax* show a 0.65 (95% CI 0.21 to 2.01) lower risk that mosquitoes caught in light traps were sporozoite-positive in screened houses compared to unscreened houses. The results from each trial are reported in Table 6.

Entomological inoculation rate (EIR)

Both trials reported a lower EIR in screened houses compared to unscreened houses. Kirby 2009 defined EIR as the mean number of sporozoite-infected *An gambiae* per person per transmission season. Getawen 2018 reported the number of sporozoite-positive *An arabiensis* per number of catches per three months. Due to differences in units of measurement, we were not able to pool the data. The results from each trial are reported in Table 7.

User acceptability

Community acceptance

Getawen 2018 used in-depth interviews to measure community acceptance of the interventions, and Kirby 2009 used focus group discussions for this purpose. In both studies, participants reported that the intervention reduced the number of indoor mosquitoes and house flies. Most participants in both trials chose to have screening after the duration of the trial. Additionally, participants in the study by Kirby 2009 reported a reduction in entry of other animals, such as bats, cockroaches, earwigs, geckos, mice, rats, snakes, and toads. In both trials, participants expressed concern that screening would be damaged by domestic animals and children, or that it would become dirty. In Getawen 2018, some participants reported that they made further efforts to reduce mosquito entry after screening installation, such as filling in wall openings with mud.

Quality assessment of both studies was low (Table 8). Kirby 2009 had made some attempts to increase rigor in sampling and the way data were collected, but did not explain the analysis clearly. Getawen 2018 scored low on all parameters.

Unintended effects

Bed net use

Pooled analysis of the trials showed that individuals living in fully screened houses (covered eaves, windows and doors) were around 16% less likely to sleep under a bed net (RR 0.84 95% CI 0.65 to 1.09; 2 trials, 203 participants). In Kirby 2009, individuals living in houses with screened ceilings were around 31% less likely to sleep under a bed net (RR 0.69 95% CI 0.50 to 0.95; 1 trial; 135 participants). The results are presented in Analysis 1.4.

None of the other pre-specified outcomes (all-cause mortality; other disease incidence; adverse effects; unintended effects other than bed net usage) were reported in the included studies.

DISCUSSION

Summary of main results

One trial showed a reduction in the incidence of clinical malaria caused by *P falciparum* in screened houses compared to unscreened houses. Another, larger trial showed a small reduction in parasite prevalence (*P falciparum*) in screened houses compared to unscreened houses. This trial also reported lower rates of anaemia in screened houses. Both trials reported lower EIRs in screened houses compared to unscreened houses. A pooled analysis showed a small reduction in bed net use in fully screened houses, and results from an arm of an individual trial showed a reduction in bed net use in houses with screened ceilings. See Summary of findings 1.

Overall completeness and applicability of evidence

In this review, we included data from both East and West African settings, and assessed the effect of house screening on malaria in children and adults against multiple malaria vector species within the *Anopheles gambiae* s.l. complex in sub-Saharan Africa. Both included studies installed screening in a range of

house types, located in both rural and urban areas. However, considering the limited number of studies, and the substantial geographical variation in African and non-African settings in areas affected by malaria in terms of: vector species' composition and behaviour; human behaviour; socioeconomic status; population age structure; malaria transmission intensity; and baseline housing characteristics, these results must be interpreted with caution when applying them to different epidemiological settings.

Researchers and policymakers are considering several novel house modifications that exist for malaria control, outlined in the methods section of this review; however, published trial results are not yet available. To date, published trials have only assessed the effects of screening (non-insecticidal) alone on malaria. The four included studies awaiting publication will assess a broader set of house modifications, including insecticide-based interventions, and screening combined with other house modifications, such as alternative roof types. One of the trials awaiting publication will also assess an alternative, community-based implementation method, deviating from the researcher-led implementation methods used in the other five trials. The results from these additional trials may allow us to identify contexts, intervention types, and implementation strategies in which house modifications may be most effective.

In addition to malaria, house modifications may affect other health outcomes that were not captured in the included studies. For example, house characteristics likely affect indoor temperature and humidity, and may therefore affect related outcomes such as respiratory disease infection (Jatta 2018). In two of the included protocols for trials not yet published, the researchers stated that they will monitor and report incidence of respiratory diseases, which will be of great value (Pinder 2016 (protocol); Sternberg 2018 (protocol)). House modifications may also protect against other vectors that transmit diseases such as dengue and lymphatic filariasis (Ogoma 2010), and diarrhoeal diseases caused by mechanical vectors of food-borne pathogens. The included studies did not assess the potential effects of the interventions on these secondary health outcomes. Monitoring this in future may provide stakeholders with a more holistic understanding of the effects of house modifications on health.

Certainty of the evidence

We appraised the certainty of evidence of the effect estimates for each outcome in these studies using the GRADE approach, presented in Summary of findings 1. We considered the evidence for house modifications against malaria to be of moderate or low quality.

For incidence of clinical malaria caused by *P falciparum*, we included one trial that assessed 184 participants; we graded the certainty of the evidence for this outcome as low. Outcome assessors conducting active case finding were not blinded to the intervention, so we downgraded the certainty of evidence for this outcome by one level for risk of bias. We also downgraded the certainty of this evidence by one level for serious imprecision, because the confidence intervals were very wide.

We identified moderate-certainty evidence for parasite prevalence, for which we included one trial that assessed 713 participants. We downgraded the evidence by one level due to serious imprecision; the confidence intervals were wide and included effect sizes representing both a positive and a negative effect, indicating little or no effect. The same trial assessed 705 participants for anaemia prevalence, and we considered this to provide moderate-certainty evidence. We downgraded the certainty of this evidence by one level for serious imprecision due to very wide confidence intervals.

We identified low-certainty evidence for EIR, which two trials reported. We downgraded the certainty of this evidence by two levels for very serious imprecision; confidence intervals for this outcome were extremely wide.

Potential biases in the review process

Our search strategy was comprehensive, and we assessed search results for eligibility irrespective of language, date of publication or publication status. Two review authors independently screened search results, extracted data from included studies, and assessed risk of bias. For trials that had not adjusted data for clustering, we adjusted the data using an estimated ICC based on a previous study, and conducted a sensitivity analysis using a range of ICCs. We did not identify any potential sources of bias in the review process.

Agreements and disagreements with other studies or reviews

We identified one review and one meta-analysis that had been conducted prior to this review (Tusting 2015; Tusting 2017), which we reported and appraised in the background section. The results suggested that both modern housing and house screening were associated with a reduction in the risk of malaria infection. Despite controlling for socioeconomic status in the observational data included in these meta-analyses, there remains a risk of residual confounding by household wealth due to the inherent association between housing and socioeconomic status. For this reason, we chose to exclude observational studies and only included studies with experimental designs that reported epidemiological outcomes.

The results from our systematic review support the conclusions drawn from the review and meta-analysis by Tusting 2015 and Tusting 2017, suggesting that house modifications can reduce malaria risk. However, the strength of effect is still not clear. Although the two trials included in our review measured different outcomes, the size of effect was large in the Getawen 2018 trial and small in the Kirby 2009 trial. The existing review and meta-analysis also reported mixed results, with Tusting 2015 observing a large reduction in malaria odds in the included cohort studies, and Tusting 2017 observing a small reduction.

AUTHORS' CONCLUSIONS

Implications for practice

The two trials published to date suggest that house screening to protect against malaria is effective for children and adults in the sub-Saharan African settings in which the studies took place, and this is consistent with previous research. The consistency of this effect, the size of the effect, and factors that may enhance or mitigate the effects have not been clearly delineated.

The results of the four completed trials awaiting publication will substantially add to the evidence base.

Implications for research

House modifications may provide a very important, long-term sustainable option to reduce malaria. There should be no delay in the publication of the four trials that are in progress.

Further research will help delineate the best approaches to assure the effect. It will also identify co-interventions that may enhance the effect, and those factors which may mitigate the effects, including epidemiological, structural and social influences.

ACKNOWLEDGEMENTS

The Academic Editor is Dr Joseph Okebe and the Sign-off Editor is Professor Lisa Bero.

We are grateful to Vittoria Lutje, Information Specialist with the Cochrane Infectious Diseases Group (CIDG), for help with the literature search strategy.

JFA and PG are supported by the Research, Evidence and Development Initiative (READ-It) project. The CIDG editorial base and READ-It are funded by UK aid from the UK government for the benefit of low- and middle-income countries (project number 300342-104). The views expressed do not necessarily reflect the UK government's official policies.

EAO is supported by PIIVeC, the Partnership for Increasing the Impact of Vector Control. PIIVeC is funded by the Medical Research Council of the UK (grant number MR/P027873/1) through the Global Challenges Research Fund.

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CHARACTERISTICS OF STUDIES

Characteristics of included studies *[ordered by study ID]*

Getawen 2018

Study characteristics

Methods	**Status:** completed and published **Study design:** household-randomized controlled trial with two arms. • Intervention: doors and windows were screened with wire mesh • Control: doors and windows left without screening **Unit of allocation:** cluster (household) **Number of units:** control: 46; intervention: 46 **Outcome assessment/surveillance type:** Epidemiological Active case surveillance (ACS) was employed to test for malaria. Each household was visited twice every month for six months; from July to December 2016. Using a preprepared checklist that contained the list of all household members, clinical assessment was conducted by measuring the axillary temperature of all household members with a digital thermometer. Blood specimens were collected from participants whose axillary temperature was ≥ 37.5 °C, using a RDT. If the participants tested positive with RDT, thin and thick blood smears were prepared for later confirmation using microscopy. The positive cases were immediately treated for free using antimalaria drugs in line with the national guidelines. Entomological Ten houses with the maximum number of malaria mosquitoes from the baseline survey were selected for entomological monitoring. Selection was made after the randomization of houses into control and intervention arms (ten houses from each arm). Adult *Anopheles* mosquitoes were collected twice each month per house using CDC light traps. Ten traps were hung (one in each house) to collect mosquitoes that entered the houses at night (18:00 to 06:00). Sporozoite rate was measured using ELISA. **Length of follow-up:** 6 months (July to December 2016) **Adjustment for clustering:** not done
Participants	**Number of participants:** 477 (239 in the intervention arm and 238 in control houses), 219.3 person-years **Method of recruitment:** not reported **Recruitment rates:** not reported **Withdrawal and loss to follow-up:** no loss to follow-up; data on all participants was analysed **Age:** mean age of 19.7 years in the intervention arm and 19.1 years in the control arm **Sex:** male and female

Getawen 2018 *(Continued)*

	Ethnicity: not reported **Socioeconomic status:** not reported
Interventions	**Intervention type (Primary construction/modification to existing structure/insecticidal delivery system):** modification to existing structure **Detailed description of intervention and any theory informing it:** in the intervention arm, wire meshes were fitted onto doors and windows to reduce mosquito entry to the house. **For insecticidal interventions, insecticide used and dosage:** N/A **Coverage:** N/A **Co-interventions:** no co-interventions were administered **Coverage of co-interventions:** N/A **Implemented by:** researchers **Buffer size between clusters:** none **Economic information (intervention costs, changes in other costs as a result of intervention):** the total cost of screening per house was USD 29.13. As the average household size in the intervention group was 4.5 people, the cost of doors and windows screening per person protected was USD 6.47. **Resource requirements:** all the materials were locally bought. Information about staff who performed the installations was not reported. **Description of house features in control and intervention arms:** the household characteristics were comparable in each arm with respect to opening on the eaves, opening on the wall, window screening, door fitness and distance of the house from Kulifo river.
Outcomes	• Incidence of malaria • Community acceptance • Bed net use rate • Cost of screening • Durability of screening • Susceptibility status of malaria mosquito • Mean number of *An arabiensis* per light trapper night (indoor density)
Notes	**Location profile** **Study location (urban/rural, socioeconomic status, topology of landscape):** urban town in Ethiopia (low income country) The town is located at 06°05' latitude and 37°38′ longitude, with an average elevation of 1218 m above sea level. **Social context:** not reported **Malaria endemicity:** not reported **EIR:** not reported **Population proximity/density:** not reported ***Plasmodium* species:** *P falciparum* was the dominant species (13/16; 81.2%) and *P vivax* accounted for 18.8% (3/16); no mixed infection was identified. **Vector profile** **Primary (and secondary vector species):** *An arabiensis* accounted for 95.3%

Getawen 2018 *(Continued)*

Method of mosquito collection: mosquito sampling was carried out twice per household per month using CDC light traps, for six months. Postscreening mosquito collection was done in each household twice per month for three months.

For insecticidal interventions, resistance profile: N/A

Funding source

Study funding source: Norwegian Programme for Capacity Development in Higher Education and Research for Development is highly acknowledged for funding this study. The funding body played no role in study design, field data collection, data analysis and interpretation, and reporting.

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	"Proportional sampling of households was done in each sub-village; 32 houses from Gebeya Dar and 66 were from Georges sub-village. The first household was selected by lottery method and every Kth household was included in the study. K was calculated as K = N/n ; where, K is the gap between every household, N is the total number of households in the study villages, whereas n is the sample size. The sampling houses were allocated proportionally, thus K is the same for each village."
Allocation concealment (selection bias)	Low risk	"We made a list of all eligible households, and randomized the houses into intervention and control groups using SPSS software. While the study is done in Ethiopia, the randomization was done in Bergen in Norway. This was done to prevent selection bias by concealing the allocation sequence from the field researchers."
Blinding of participants and personnel (performance bias) Malaria case/infection incidence/parasite prevalence	High risk	Not possible to blind participants. "The study was not blinded because the screened doors and windows are visible"
Blinding of outcome assessment (detection bias) Malaria case/malaria infection incidence/parasite prevalence	High risk	Although the microscopists "were blinded to the identity, intervention status and RDT results of the study subjects." The field staff conducting active case finding were not blinded to the allocation group.
Incomplete outcome data (attrition bias) Malaria case/malaria infection incidence/parasite prevalence	Low risk	Minimal missing data, and balanced across arms (page 89 of Getawen 2018)
Selective reporting (reporting bias)	Unclear risk	The researchers did not publish a protocol prior to the start of the trial so the risk of reporting bias is unclear.
Recruitment bias	Low risk	Households were selected prior to randomization: "There were 318 houses in the Gebeya Dar (in Dilfana village) and Georges (in Kulifo village) sub-villages (Fig. 1), of which 98 were selected by systematic random sampling technique using a list obtained from the health post."
Baseline imbalance	Low risk	Baseline levels of malaria in the control and intervention groups were not different at baseline.

Getawen 2018 *(Continued)*

Loss of clusters	Low risk	Loss to follow-up was very minimal and balanced across all arms.
Incorrect analysis	High risk	Effect estimates were not adjusted to account for clustering.
Comparability with individually randomized trials	Low risk	No reason to believe a mass effect would be quantitatively important.

Kirby 2009

Study characteristics	
Methods	**Status:** completed and published **Study design:** household-randomized controlled trial with three arms: • full screening; • screening of the ceiling only; • control (no screening). **Unit of allocation:** cluster (household) **Number of units:** 462 (full screening = 188, screened ceilings = 178, control = 96) **Outcome assessment/surveillance type:** Epidemiological: A clinical cross-sectional survey of children was done at the end of each transmission season, at least six months after the screening was installed. Axillary temperature was measured and a rapid diagnostic test was used to test children with a temperature of 37.5 degrees or more for malaria. A finger-prick blood sample was taken from each child to measure haemoglobin concentration by use of a portable haemoglobin photometer and to make thin and thick films for detection and quantification of malaria parasites. To establish parasite presence and density (asexual stages per µL, assuming a blood volume of 0.002 µL per high-power field), Giemsa stained blood slides were examined (magnification × 1000). Two hundred fields were examined before a slide was declared negative. Children with haemoglobin concentration less than 80 g/L were classified as anaemic and given iron supplementation. Entomological: Each study house was sampled every two weeks during this surveillance period (26 June to 2 November 2006, or 16 July to 5 November 2007). Subsamples of *A. gambiae* mosquitoes from each trial group and each month of the surveillance period were taken for species identification by PCR. To identify infective mosquitoes, heads and thoraces of mosquitoes were homogenized in pools of 10 individuals and the presence of sporozoites identified by ELISA. **Length of follow-up:** for epidemiological data, one year (two distinct cohorts on two consecutive years). For entomological data, two years. **Adjustment for clustering:** "The study was designed to have 90% power to detect a difference of 5 g/L or more in the mean haemoglobin concentration of children in the intervention groups compared with the control group, assuming a standard deviation of 17 g/L, an average of 2.5 children per house, and an intraclass correlation of between 0.04 to 0.08 from earlier studies (Milligan PJ, unpublished data)"
Participants	**Number of participants:** 1085 (439 full screening, 421 screened ceilings, 225 control) **Method of recruitment:** MRC Farafenni ran a demographic surveillance system in the study area throughout the study, which included 46 residential blocks in Farafenni town and 23 surrounding villages. Lists of potentially eligible houses, and children sleeping in those houses, were generated from this census and visited to

Kirby 2009 *(Continued)*

	check criteria for recruitment. Houses had to be single-storey buildings, have open eaves, less than five rooms, no existing ceilings, no existing screening, and at least one child aged between 6 months and 10 years sleeping there at night. There were no other exclusion criteria for children. **Recruitment rates:** 500/595 houses **Withdrawal and loss to follow-up:** 38 houses were lost to follow-up **Age:** children aged from 6 months to 10 years **Sex:** female and male **Ethnicity:** Gambian (Wolof, Mandinka and Fula ethnic groups) **Socioeconomic status:** socioeconomic status score of 3.5 to 3.8
Interventions	**Intervention type (Primary construction/modification to existing structure/insecticidal delivery system):** modification to existing structures **Detailed description of intervention and any theory informing it:** full screening (screening of eaves, windows and doors), screened ceilings only, and control houses **For insecticidal interventions, insecticide used and dosage:** N/A **Coverage:** N/A **Co-interventions:** none **Coverage of co-interventions:** N/A **Implemented by:** researchers **Buffer size between clusters:** not reported **Economic information (intervention costs, changes in other costs as a result of intervention):** full screening (USD 9.98), screened ceiling (USD 8.69). If locally available netting was used, the mean cost per person would be USD 11.11 for full screening and USD 21.17 for screened ceilings. **Resource requirements:** two teams, each consisting of one leader and three assistants, installed full screening in two to three houses, or screened ceilings in four to five houses, per day. The screening was made from local timber and PVC coated fibreglass netting (1.2 m wide for doors, 2.4 m wide for ceilings and 1.0 m wide for windows), with a mesh size of 42 holes/cm^2 (Vestergaard Frandsen group, Denmark). **Description of house features in control and intervention arms:** houses had to be single-storey buildings, have open eaves, less than five rooms, no existing ceilings, no existing screening, and at least one child aged between 6 months and 10 years sleeping there at night.
Outcomes	• Parasitaemia • Haemoglobin concentration • Mean number of *An gambiae* s.l per night • EIR
Notes	**Location profile** **Study location (urban/rural, socioeconomic status, topology of landscape):** the study took place in both rural and urban areas of the Gambia (a low income country). The study area was situated approximately 170 km from the mouth of the Gambia River and covered 70 km^2 of the north bank, an area of open Sudan savanna. **Social context:** not reported **Malaria endemicity:** not reported

Kirby 2009 *(Continued)*

EIR: Entomological inoculation rate varies from 0 to 166 infective bites per person per rainy season

Population proximity/density: not reported

***Plasmodium* species:** *P falciparum*

Vector profile

Primary (and secondary vector species): *An gambiae*

Method of mosquito collection: CDC light traps positioned 1m to 2 m from the foot end of a bed protected with an untreated net used on that night only.

For insecticidal interventions, resistance profile: N/A

Funding source

Study funding source: Medical Research Council. The sponsor of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	**"**The randomization list was generated by use of Stata version 7 in permuted blocks of five (two houses with full screening, two with screened ceilings, and one control house without screening)."
Allocation concealment (selection bias)	Low risk	The authors indicated that participants were not made aware of which group they were assigned to prior to the start of the intervention: "PJM generated the allocation sequence and MJK enrolled participants and assigned them to trial groups."
Blinding of participants and personnel (performance bias) Malaria case/infection incidence/parasite prevalence	High risk	Not possible to blind participants. "The study was not blinded because the screened doors and windows are visible". Field staff were aware of the allocation of interventions: "Participants will therefore be enrolled into their respective groups by the project field staff."
Blinding of outcome assessment (detection bias) Malaria case/malaria infection incidence/parasite prevalence	Low risk	Outcome assessors were blinded: "Slides will be numbered with the date of finger-pricking and the subject's randomly generated ID number, and transported to MRC Laboratories Field Station, at Farafenni."
Incomplete outcome data (attrition bias) Malaria case/malaria infection incidence/parasite prevalence	Low risk	There were no missing data: "731 children had complete data for clinical outcomes and covariate data".
Selective reporting (reporting bias)	Low risk	The protocol stated that the study was powered to detect a difference in haemoglobin, and this was the main outcome reported in the study. "Our aim was to have 90% power to detect a difference in mean haemoglobin of 0.5 g/dl between the two intervention arms and the control arm in November, using a significance level of 2.5% for each of the two comparisons of intervention with control." (Kirby 2008)

Kirby 2009 *(Continued)*

Recruitment bias	Low risk	Eligible houses were selected prior to randomization: "Eligible houses were sorted by...to achieve implicit stratification before assigning to the treatment group."
Baseline imbalance	Low risk	Baseline levels of malaria were not significantly different.
Loss of clusters	Low risk	Outcome data were available for 462/500 houses. Loss of clusters was comparable in all arms: 188/200 houses in full screening arm, 179/200 in screened ceilings arm, 96/100 in control arm.
Incorrect analysis	High risk	Effect estimates were not adjusted to account for clustering.
Comparability with individually randomized trials	Low risk	No reason to believe a mass effect would be observed.

McCann 2017 (protocol)

Study characteristics	
Methods	**Status:** unpublished (anticipated date of last follow-up: 30 April 2018) **Study design:** cluster randomized controlled trial with four arms. 1. House improvements (HI) 2. Larval source management (LSM) 3. HI +LSM 4. Control We will only consider arms 1 and 4. **Unit of allocation:** cluster (village) **Number of units:** 182 villages in total (20 from arms 1 and 4: 7 control villages, 13 intervention villages) • Block A: Control: 2 villages, HI: 8 villages • Block B: Control: 3 villages, HI: 2 villages • Block C: Control: 2 villages, HI: 3 villages **Outcome assessment/surveillance type:** • parasite prevalence in children aged 6 to 59 months assessed through malaria indicator surveys (proportion of RDT tests positive for *P falciparum*); • incidence of clinical malaria in children aged 6 to 59 months assessed through incidence study cohorts (number of clinical malaria cases per child per year); • prevalence of anaemia in children aged 6 to 59 months through malaria indicator surveys (proportion of anaemia tests with Hb < 8.0). **Length of follow-up:** two years **Adjustment for clustering:** not known at protocol stage
Participants	**Number of participants:** not known at protocol stage **Method of recruitment: a**n area of high malaria transmission was selected as the study area, and communities were sensitized prior to recruitment. **Recruitment rates:** not known at protocol stage

McCann 2017 (protocol) *(Continued)*

	Withdrawal and loss to follow-up: not known at protocol stage **Age:** children aged 6 to 59 months **Sex:** male and female **Ethnicity:** not known at protocol stage **Socioeconomic status:** not known at protocol stage
Interventions	**Intervention type (Primary construction/modification to existing structure/insecticidal delivery system):** modification to existing structures **Detailed description of intervention and any theory informing it:** housing Improvements (HI) involving material modification of houses aimed at blocking entry of malaria vectors. Modifications consist of: closing all eaves using local material similar to that used to construct the house (i.e. bricks and extra mud for most houses); closing all holes in the wall not used for ventilation, using the same materials used for closing eaves; covering windows and other openings used for ventilation with aluminium screens that allow airflow; and modifying doors so as to fully cover doorways when closed. **For insecticidal interventions, insecticide used and dosage:** N/A **Coverage:** N/A **Co-interventions:** none **Coverage of co-interventions:** N/A **Implemented by:** community-based: an "animator approach" was used, adapted to the specific setting. Volunteers from the 65 villages (slightly more than one per village on average) were trained as "health animators" by the Majete Malaria project (a collaboration of the Ministry of Health, The Hunger Project (THP; a non-governmental organization specializing in community-based programmes), African ParksMalawi (which has run the Majete Wildlife Reserve as part of a public-private partnership since 2003), and the academic institutions of the principal investigators of this trial). Thereafter, these health animators led fortnightly malaria workshops in their communities. An essential component of this approach is empowering the community through a process of mindset change, leadership, vision, commitment, and action. In brief, this means that the community should perceive malaria as a challenge that can be actively addressed, and it provides a basis for community action planning towards malaria control. Furthermore, health animators followed a training manual, developed by the project, to cover a broad range of malaria topics at each of the community workshops. **Buffer size between clusters:** 400 m **Economic information (intervention costs, changes in other costs as a result of intervention):** no information **Resource requirements:** not reported in protocol. **Description of house features in control and intervention arms:** not reported in protocol
Outcomes	• Parasite prevalence • Incidence of clinical malaria • Prevalence of anaemia • EIR • Malaria vector community composition • Malaria vector human blood index • Peak malaria vector biting time • Larval mosquito density
Notes	**Location profile**

McCann 2017 (protocol) *(Continued)*

Study location (urban/rural, socioeconomic status, topology of landscape): the study site is in Chikhwawa District, a rural area of high malaria transmission in the Lower Shire River Valley region of southern Malawi. Chikhwawa covers an area of about 4800 km^2. Rain-fed farming is the main occupation, with maize, millet and sorghum as the major staple foods.

Social context: not reported

Malaria endemicity: high transmission

EIR: not reported

Population proximity/density: Chikhwawa has a population of over 530,000 people

***Plasmodium* species:** *P falciparum*

Vector profile

Primary (and secondary vector species): three malaria vector species are present: *An gambiae* s.s., *An arabiensis*, and *An funestus*

Method of mosquito collection:

Suna traps will be set up indoors and outdoors. Every two months from May 2016 to April 2018, 270 households will be selected for the epidemiological survey using a randomized inhibitory spatial sampling procedure. At the same time, 195 of those 270 households will be randomly selected for adult mosquito sampling. The lower number of households for mosquito sampling is necessary because mosquito traps will be set at each selected household for two nights, whereas the epidemiological survey requires one day per household. Data collection at the 270 households will be conducted over a six-week period.

Immature mosquitoes will be collected using a standardized area sampling method, where 300 ml dippers and plastic pipettes are used to collect all *Anopheles* larvae within a 0.5 m^2 sampling quadrat.

For insecticidal interventions, resistance profile: N/A

Funding source

Study funding source: Dioraphte Foundation, The Netherlands

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Sets that allowed a minimum number of clusters were manually identified. "One of these sets of villages was randomly selected from among six sets of villages satisfying the inclusion criteria. The six sets were numbered from 1 to 6, six cards numbered 1 to 6 were placed in a dish, and a volunteer from the community blindly selected one card."
Allocation concealment (selection bias)	Low risk	A community raffle event was held in each focal area in June 2015 for allocation of villages to the trial arms indicating that researchers were not aware of treatment allocations prior to this event.
Blinding of participants and personnel (performance bias) Malaria case/infection incidence/parasite prevalence	High risk	Not possible to blind participants.
Blinding of outcome assessment (detection bias)	Unclear risk	Not clear whether outcome assessors were blinded.

McCann 2017 (protocol) *(Continued)*

Malaria case/malaria infection incidence/parasite prevalence		
Incomplete outcome data (attrition bias) Malaria case/malaria infection incidence/parasite prevalence	Unclear risk	Not possible to assess this at protocol stage.
Selective reporting (reporting bias)	Unclear risk	Not possible to assess this at protocol stage.
Recruitment bias	Low risk	Households were selected prior to the start of the intervention: we “manually” found alternative sets of villages which provided Nmax-1 to.....Finally, one set of villages was randomly chosen in each focal area as the first stage of a 2-stage community raffle drawing".
Baseline imbalance	Unclear risk	Not possible to assess this at protocol stage.
Loss of clusters	Unclear risk	Not possible to assess this at protocol stage.
Incorrect analysis	Unclear risk	Not possible to assess this at protocol stage.
Comparability with individually randomized trials	Low risk	This trial was village-randomized with a buffer size of 400 m – cross contamination between the control and house improvement arms unlikely.

Minakawa 2016 (completed, unpublished)

Study characteristics	
Methods	**Status:** completed, unpublished **Study design:** cluster-randomized controlled trial with two arms: • an untreated control (ITNs only); • eave gaps and ceilings screened with permethrin-treated bed net material. **Unit of allocation:** cluster (community) **Number of units:** eight clusters, four in the intervention arm, four in the control arm **Outcome assessment/surveillance type:** Epidemiological: A clinical cross-sectional survey of children was done at each transmission season, at one month before, and 6 months, 12 months and 18 months after the screening was installed. From each cluster, 150 children aged between 6 months and 10 years were randomly selected for each survey. PCR used to detect presence of malaria parasites. Entomological: For entomological outcomes CDC light traps were placed below the eave of randomly selected 25 houses within each cluster 4 months, 10 months and 16 months after the installation of nets. Indoor resting mosquitoes were also collected with the spray catch method in the same periods. **Length of follow-up:** 18 months

Minakawa 2016 (completed, unpublished) *(Continued)*

	Adjustment for clustering: pre-intervention data from each cluster was incorporated into the statistical models.
Participants	**Number of participants:** 849 at pre-intervention, 750 at 6 months, 722 at 12 months, 724 at 18 months **Method of recruitment:** Nagasaki University ran a demographic surveillance system in the study area throughout the study. Lists of potentially eligible houses, and children sleeping in those houses, were generated from this census and visited to check criteria for recruitment. Houses had to be single-storey buildings, have open eaves, no existing ceilings, no existing screening, and children aged between 6 months and 10 years sleeping there. There were no other exclusion criteria for children. 150 children were randomly selected from each cluster. **Recruitment rates:** 3045 out of 4800 randomly selected children **Withdrawal and loss to follow-up:** **Age:** children aged between 6 months and 10 years **Sex:** male and female **Ethnicity:** mostly Kenyan Luo **Socioeconomic status:** not reported
Interventions	**Intervention type (Primary construction/modification to existing structure/insecticidal delivery system):** modifications to existing structures **Detailed description of intervention and any theory informing it:** screened ceilings and eave gaps. **For insecticidal interventions, insecticide used and dosage:** N/A **Coverage:** not reported **Co-interventions:** LLINs and Combination therapy based on chloroquine and sulfadoxine-pyrimethamine was the first-line treatment for uncomplicated malaria throughout the trial in both arms. **Coverage of co-interventions:** not reported **Implemented by:** researcher-based **Buffer size between clusters:** researchers attempted to locate a community centre in the centre of each cluster, or separated the community centres more than 1 km from each other when the boundaries of the clusters were established. **Economic information (intervention costs, changes in other costs as a result of intervention):** not reported **Resource requirements:** three people took about one hour to install one ceiling net. **Description of house features in control and intervention arms:** houses had to be single-storey buildings, have open eaves, no existing ceilings, and no existing screening.
Outcomes	• Parasite prevalence
Notes	**Location profile** **Study location (urban/rural, socioeconomic status, topology of landscape):** the study took place in rural areas of Gambe East Location, Homabay County, Kenya. **Social context:** the main income sources are fishing, traditional small-scale farming and cattle breeding.

Minakawa 2016 (completed, unpublished) *(Continued)*

Malaria endemicity: high

EIR: not reported

Population proximity/density: not reported

***Plasmodium* species:** *P falciparum*

Vector profile

Primary (and secondary vector species): *An arabiensis*, *An gambiae, An funestus*

Method of mosquito collection: spray catch and CDC light trap

For insecticidal interventions, resistance profile: Kdr genes are detected from *An gambiae*, and *An arabiensis* and *An funestus* are known for metabolic resistance.

Funding source

Study funding source: Nagasaki University and provision of netting by Sumitomo Chemical Co.

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	The randomization list was generated by use of Excel 2007 and 2011 for selecting clusters and children.
Allocation concealment (selection bias)	Unclear risk	Not clear whether allocation was concealed from participants prior to the start of the intervention.
Blinding of participants and personnel (performance bias) Malaria case/infection incidence/parasite prevalence	High risk	Not possible
Blinding of outcome assessment (detection bias) Malaria case/malaria infection incidence/parasite prevalence	Low risk	Clinical assessments were undertaken by a team that was not involved in any other study procedures and that was masked to the intervention status of each child.
Incomplete outcome data (attrition bias) Malaria case/malaria infection incidence/parasite prevalence	Low risk	Loss to follow-up rates were similar in the control and intervention arms.
Selective reporting (reporting bias)	Unclear risk	Not possible to assess this without a published protocol.
Recruitment bias	Low risk	Participants were selected prior to the start of the intervention: "Nagasaki University ran a demographic surveillance system in the study area throughout the study. Lists of potentially eligible houses, and children sleeping in those houses, were generated from this census and visited to check criteria for recruitment."
Baseline imbalance	Low risk	Parasite prevalence was similar in the control and intervention arms at baseline.

Minakawa 2016 (completed, unpublished) *(Continued)*

Loss of clusters	Low risk	Loss to follow-up rates were similar in the control and intervention arms.
Incorrect analysis	Unclear risk	Not possible to assess this domain at this stage.
Comparability with individually randomized trials	Low risk	Researchers "tried to separate the community centres more than 1 km [from] each other when the boundaries of the clusters were established."

Pinder 2016 (protocol)

Study characteristics	
Methods	**Status:** unpublished (anticipated date of final clinical survey: December 2017) **Study design:** A household-cluster-randomized controlled study using a generalized, randomized, complete, block design, with the village as the block. **Unit of allocation:** cluster (house) **Number of units:** 400 houses in control, 400 houses in intervention arm **Outcome assessment/surveillance type:** Epidemiological: The baseline clinical survey of all study children was planned to take place in May/June 2016, to determine malaria infection, splenomegaly, and anaemia. Clinical follow-up was planned to start in June 2016, to cover both rainy seasons (June to December 2016 and 2017). Incidence of clinical malaria was planned to be determined by ACD during twice weekly house visits from June to November each year. Clinical respiratory disease will be determined at the same time. Clinical surveys of all study children was planned to be repeated at the end of each rainy season (November/December) and during June 2017. Entomological: Indoor mosquito collections made using CDC light traps in the bedrooms of the study children will be used to estimate the potential exposure to malaria vectors. This was planned to take place once a month for six months from June to December in 2016 and 2017. Mosquitoes will be identified by microscopy, and the numbers of *An gambiae* s.l. and other species will be recorded. The presence of sporozoites in *An gambiae* s.l. will be identified using ELISA, and *An gambiae* s.l. females, typed to species by PCR. **Length of follow-up:** 18 months (June 2016 to December 2017) **Adjustment for clustering:** not known at protocol stage
Participants	**Number of participants:** not known at protocol stage **Method of recruitment:** not known at protocol stage **Recruitment rates:** not known at protocol stage **Withdrawal and loss to follow-up:** not known at protocol stage **Age:** children aged between 6 months and 13 years **Sex:** male and female **Ethnicity:** not known at protocol stage **Socioeconomic status:** not known at protocol stage

Pinder 2016 (protocol) *(Continued)*

Interventions	**Intervention type (Primary construction/modification to existing structure/insecticidal delivery system):** modifications to existing houses **Detailed description of intervention and any theory informing it:** in the intervention arm, represented by modern housing, the trialists propose to modify existing rectangular-plan and circular-plan thatched roof houses, so they will have metal roofs, closed eaves, and screening on the doors and windows. The control arm, representing traditional houses, will be left with thatched roofs and open eaves. **For insecticidal interventions, insecticide used and dosage:** N/A **Coverage:** N/A **Co-interventions:** None **Coverage of co-interventions:** N/A **Level of community involvement:** researcher-based **Buffer size between clusters:** not specified **Economic information (intervention costs, changes in other costs as a result of intervention):** not clear at protocol stage **Resource requirements:** not clear at protocol stage **Description of house features in control and intervention arms:** thatched-roofed houses constructed with mud walls, open eaves, and without ceilings or screening
Outcomes	• Incidence rates of clinical malaria between arms • *P falciparum* parasite rates • Incidence of respiratory infection • Mean number of mosquitoes caught indoors • Haemoglobin density
Notes	**Location profile** **Study location (urban/rural, socioeconomic status, topology of landscape):** urban and rural areas of The Gambia **Social context:** not described **Malaria endemicity:** not described at protocol stage **EIR:** not described at protocol stage **Population proximity/density:** not reported in protocol ***Plasmodium* species:** *P falciparum* **Vector profile** **Primary (and secondary vector species):** *An gambiae* s.l **Method of mosquito collection:** not reported in protocol **For insecticidal interventions, resistance profile:** N/A **Funding source** **Study funding source:** funded by the MRC-DfID Wellcome Trust
Risk of bias	

Pinder 2016 (protocol) *(Continued)*

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Random sequence was computer generated "… stratified by village using a computer subroutine in a blinded…"
Allocation concealment (selection bias)	Low risk	"Houses will be randomized to the study arms by MP, stratified by village using a computer subroutine in a blinded manner so that an equal number of houses are selected in each arm of the study in each village at baseline"
Blinding of participants and personnel (performance bias) Malaria case/infection incidence/parasite prevalence	High risk	Not possible to blind participants and personnel.
Blinding of outcome assessment (detection bias) Malaria case/malaria infection incidence/parasite prevalence	Unclear risk	Not clear whether outcome assessors were blinded or not.
Incomplete outcome data (attrition bias) Malaria case/malaria infection incidence/parasite prevalence	Unclear risk	Not possible to assess this at protocol stage.
Selective reporting (reporting bias)	Unclear risk	Not possible to assess this at protocol stage.
Recruitment bias	Low risk	Households were selected prior to the start of the intervention: "From 2015-2016 we will...obtain household consent prior to recruiting an average of 10 thatched-roofed houses in approx 80 villages."
Baseline imbalance	Unclear risk	Not possible to assess this at protocol stage.
Loss of clusters	Unclear risk	Not possible to assess this at protocol stage.
Incorrect analysis	Unclear risk	Not possible to assess this at protocol stage.
Comparability with individually randomized trials	Unclear risk	The authors raise the question of whether the house modification may increase mosquito mortality by increasing the ambient temperature in houses-and thus cause a mass-effect.

Sternberg 2018 (protocol)

Study characteristics	
Methods	**Status:** unpublished (anticipated date of last clinical survey: May 2019) **Study design:** a two-armed, cluster-randomized controlled trial: • screening plus eave tubes (SET) + LLINs • LLINs only **Unit of allocation:** cluster (village)

Sternberg 2018 (protocol) *(Continued)*

Number of units: 20 villages per arm

Outcome assessment/surveillance type:

Epidemiological:

Once a month, a thick blood smear and blood spot will be taken from all children in the cohort to monitor for asymptomatic parasite infections.

Children enrolled in the ACD cohort will receive routine visits from the study team (a trained nurse and the community health worker) every two weeks (rainy season) or every month (dry season). All children will receive a three-day course of a first-line antimalarial recommended by the NMCP in Côte d'Ivoire (artesunate-amodiaquine or artemether-lumefantrine), to clear any existing malaria parasite infection. A thick blood smear will be taken on the next visit (two weeks later) to confirm parasite clearance. At all visits, the child's axillary temperature will be recorded. If the child is febrile (axillary temperature ≥ 37.5 °C), or has a history of fever in the past 48 hours, or if the parents report that the child is sick, a health exam will be carried out and a record will be made of the child's symptoms, pulse, and respiratory rate. A blood sample will be taken from febrile children by finger prick for a malaria rapid diagnostic test.

Twice a year, at the start and end of the rainy season, all children in the cohort aged five years or younger will be tested for anaemia.

Entomological:

Each month, mosquitoes will be sampled using human landing catches (HLC) both indoors and outdoors for one night at four randomly selected houses in each of the 40 study villages. Starting at 18:00, one capturer will sit inside the house in the living room area and one will sit outside the house. Mean mosquito densities for indoor and outdoor catches and sporozoite rates will be recorded and an EIR will be calculated.

Length of follow-up: 2 years

Adjustment for clustering: not known at protocol stage

Participants	**Number of participants:** not known at protocol stage **Method of recruitment:** "Community consent to participate in the study will be obtained through meetings with village leaders and inhabitants. A census will be carried out prior to the start of the study. Consent for the house modifications will be obtained from individual homeowners during door-to-door visits, following the randomization of villages to trial arms." **Recruitment rates:** not clear at protocol stage **Withdrawal and loss to follow-up:** not clear at protocol stage **Age:** 6 months to 8 years old **Sex:** not known at protocol stage **Ethnicity:** not known at protocol stage **Socioeconomic status:** not known at protocol stage
Interventions	**Intervention type (Primary construction/modification to existing structure/insecticidal delivery system):** modification to existing structures. **Detailed description of intervention and any theory informing it:** housing Improvements (HI) involving material modification of houses aimed at blocking entry of malaria vectors. Modifications consist of: closing all eaves using local material similar to that used to construct the house (i.e. bricks and extra mud for most houses); closing all holes in the wall not used for ventilation using the same materials used for closing eaves; covering windows and other openings used for ventilation with aluminium screens that allow airflow; and modifying doors so as to fully cover doorways when closed.

Sternberg 2018 (protocol) *(Continued)*

For insecticidal interventions, insecticide used and dosage: N/A

Coverage: N/A

Co-interventions: None

Coverage of co-interventions: N/A

Implemented by: researchers

Buffer size between clusters: 2 km

Economic information (intervention costs, changes in other costs as a result of intervention): no information

Resource requirements: not reported in protocol

Description of house features in control and intervention arms: all selected houses had roofs made out of metal sheeting and walls made out of concrete or brick.

Outcomes

- Parasite prevalence
- Incidence of clinical malaria
- Prevalence of anaemia
- EIR
- Malaria vector community composition
- Malaria vector human blood index
- Peak malaria vector biting time
- Larval mosquito density

Notes

Location profile

Study location (urban/rural, socioeconomic status, topology of landscape): the study site is situated in the Gbêkê region in central Côte d'Ivoire. Forty candidate villages have been identified within a 60 km radius around the town of Bouaké.

Social context: not reported in protocol

Malaria endemicity: it is a highly endemic area with year-round transmission, peaking during the rainy season (May through October).

EIR: not reported in protocol

Population proximity/density: not reported in protocol

***Plasmodium* species:** *P falciparum*

Vector profile

Primary (and secondary vector species): *An gambiae (coluzzi)*

Method of mosquito collection: Human Landing Catch and CDC Light Trap

For insecticidal interventions, resistance profile: not reported in protocol

Funding source

Study funding source: this research was supported by a grant from the Bill & Melinda Gates Foundation, grant number OPP1131603.

Risk of bias

Bias	Authors' judgement	Support for judgement

Sternberg 2018 (protocol) *(Continued)*

Random sequence generation (selection bias)	Unclear risk	Method of randomization not clear.
Allocation concealment (selection bias)	Unclear risk	Not clear whether researchers were aware of which cluster would receive which treatment prior to treatment allocation.
Blinding of participants and personnel (performance bias) Malaria case/infection incidence/parasite prevalence	High risk	Not possible to blind participants and personnel.
Blinding of outcome assessment (detection bias) Malaria case/malaria infection incidence/parasite prevalence	Low risk	"All laboratory work with samples will be blinded where possible...All analyses will be conducted on blinded data."
Incomplete outcome data (attrition bias) Malaria case/malaria infection incidence/parasite prevalence	Unclear risk	Not possible to assess this at protocol stage.
Selective reporting (reporting bias)	Unclear risk	Not possible to assess this at protocol stage.
Recruitment bias	Low risk	Participants were selected prior to the start of the intervention: "Consent for the house modifications will be obtained from individual homeowners during door-to-door visits, following the randomization of villages to trial arms."
Baseline imbalance	Unclear risk	Not possible to assess this at protocol stage.
Loss of clusters	Unclear risk	Not possible to assess this at protocol stage.
Incorrect analysis	Unclear risk	Not possible to assess this at protocol stage.
Comparability with individually randomized trials	Low risk	This was a village-randomized trial with a buffer zone of 2km.

ACS: active case surveillance; ACD: active case detection; CDC: Centers for Diseases Control and Prevention; DfID: Department for International Development; ELISA: enzyme-linked immunosorbent assay; EIR: entomological inoculation rate; HLC: human landing catches; HI: household improvement; LLIN: long-lasting insecticide-treated net; LSM: larval source management; MRC: Medical Research Council; N/A: not applicable; NMCP: National Malaria Control Programme ;PCR: polymerase chain reaction; RDT: rapid diagnostic test; SET: screening plus eaves tubes; SPSS: Statistical Package for the Social Sciences; USD: US dollars.

Characteristics of excluded studies *[ordered by study ID]*

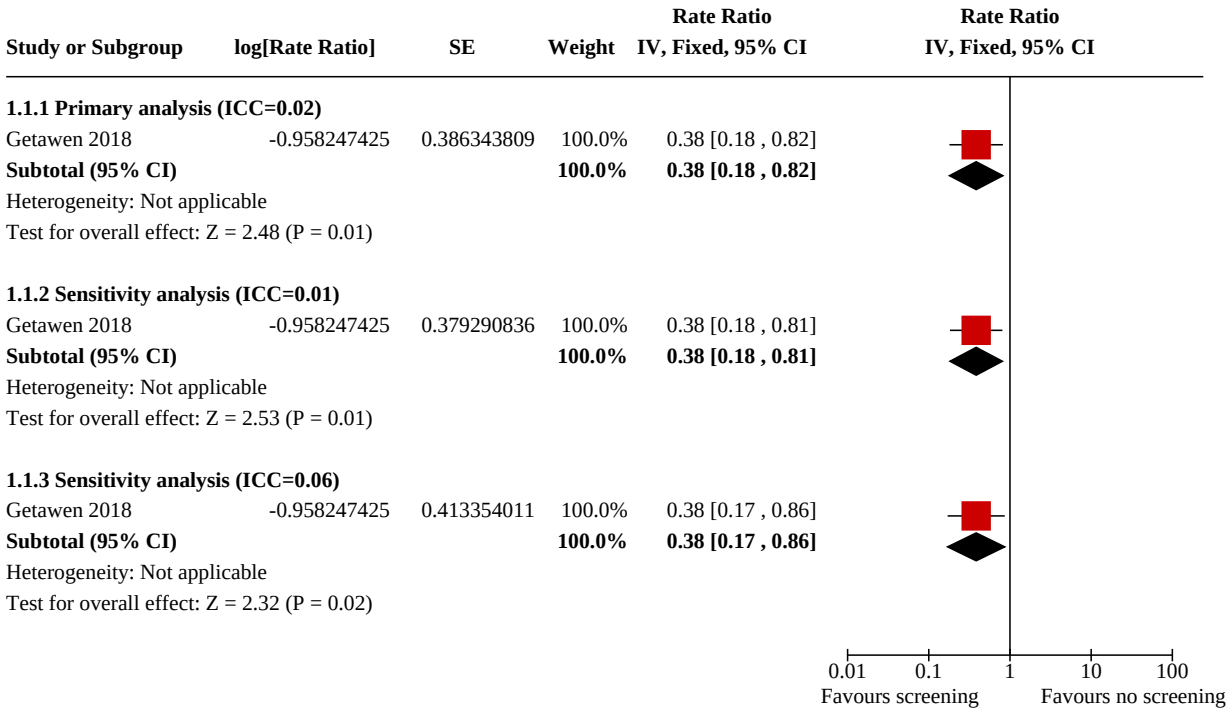
Study	Reason for exclusion
Berti 1960	Trial had multiple co-interventions.
Gouissi 2013	Study design did not meet the inclusion criteria.

DATA AND ANALYSES

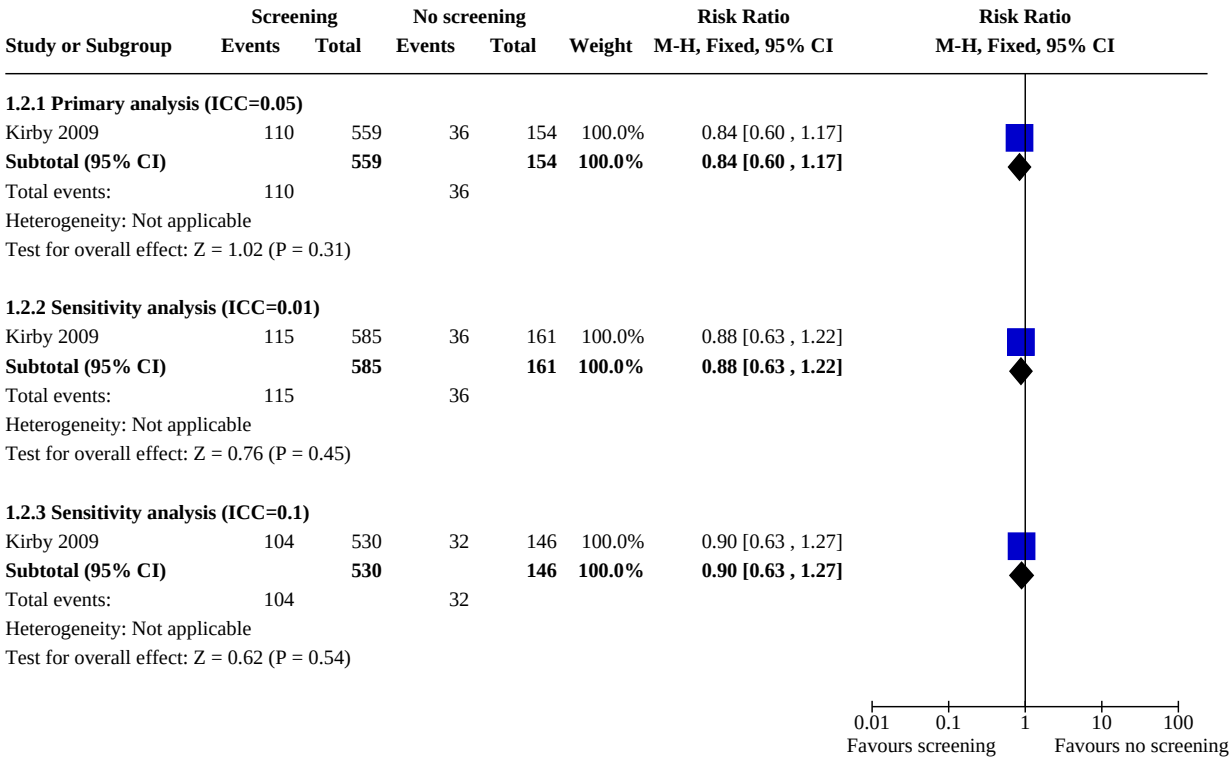
Comparison 1. Screening versus no screening

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1.1 Clinical *P falciparum* malaria incidence	1		Rate Ratio (IV, Fixed, 95% CI)	Subtotals only
1.1.1 Primary analysis (ICC=0.02)	1		Rate Ratio (IV, Fixed, 95% CI)	0.38 [0.18, 0.82]
1.1.2 Sensitivity analysis (ICC=0.01)	1		Rate Ratio (IV, Fixed, 95% CI)	0.38 [0.18, 0.81]
1.1.3 Sensitivity analysis (ICC=0.06)	1		Rate Ratio (IV, Fixed, 95% CI)	0.38 [0.17, 0.86]
1.2 Malaria parasite prevalence	1		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
1.2.1 Primary analysis (ICC=0.05)	1	713	Risk Ratio (M-H, Fixed, 95% CI)	0.84 [0.60, 1.17]
1.2.2 Sensitivity analysis (ICC=0.01)	1	746	Risk Ratio (M-H, Fixed, 95% CI)	0.88 [0.63, 1.22]
1.2.3 Sensitivity analysis (ICC=0.1)	1	676	Risk Ratio (M-H, Fixed, 95% CI)	0.90 [0.63, 1.27]
1.3 Anaemia (haemoglobin conc <80g/L) prevalence	1		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
1.3.1 Primary analysis (ICC=0.06)	1	705	Risk Ratio (M-H, Fixed, 95% CI)	0.61 [0.42, 0.89]
1.3.2 Sensitivity analysis (ICC=0.04)	1	695	Risk Ratio (M-H, Fixed, 95% CI)	0.62 [0.42, 0.91]
1.3.3 Sensitivity analysis (ICC=0.08)	1	602	Risk Ratio (M-H, Fixed, 95% CI)	0.61 [0.41, 0.92]
1.4 Bed net use (primary analysis, assuming ICC of 0.375)	2		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
1.4.1 Full screening	2	188	Risk Ratio (M-H, Fixed, 95% CI)	0.84 [0.65, 1.09]
1.4.2 Screened ceilings	1	127	Risk Ratio (M-H, Fixed, 95% CI)	0.69 [0.50, 0.95]
1.5 Bed net use (sensitivity analysis, ICC=0.3)	2		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
1.5.1 Full screening	2	203	Risk Ratio (M-H, Fixed, 95% CI)	0.86 [0.67, 1.11]
1.5.2 Screened ceilings	1	135	Risk Ratio (M-H, Fixed, 95% CI)	0.71 [0.52, 0.98]
1.6 Bed net use (sensitivity analysis, ICC=0.45)	2		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
1.6.1 Full screening	2	176	Risk Ratio (M-H, Fixed, 95% CI)	0.84 [0.64, 1.10]
1.6.2 Screened ceilings	1	120	Risk Ratio (M-H, Fixed, 95% CI)	0.70 [0.50, 0.97]

Analysis 1.1. Comparison 1: Screening versus no screening, Outcome 1: Clinical *P falciparum* malaria incidence

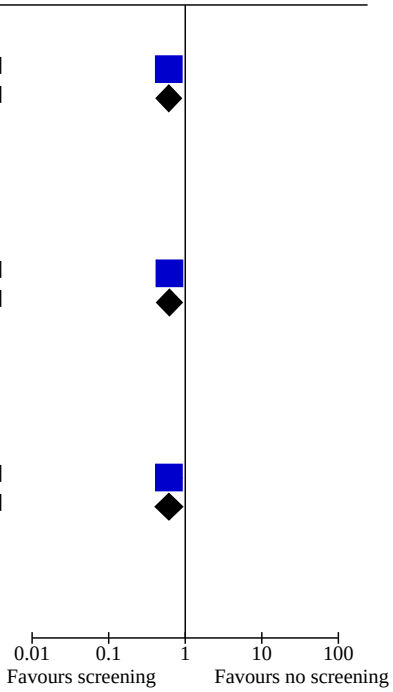


Analysis 1.2. Comparison 1: Screening versus no screening, Outcome 2: Malaria parasite prevalence



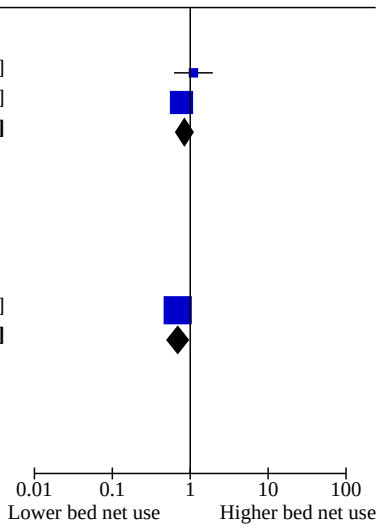
Analysis 1.3. Comparison 1: Screening versus no screening, Outcome 3: Anaemia (haemoglobin conc <80g/L) prevalence

Study or Subgroup	Screening Events	Screening Total	No screening Events	No screening Total	Weight	Risk Ratio M-H, Fixed, 95% CI
1.3.1 Primary analysis (ICC=0.06)						
Kirby 2009	71	553	32	152	100.0%	0.61 [0.42 , 0.89]
Subtotal (95% CI)		**553**		**152**	**100.0%**	**0.61 [0.42 , 0.89]**
Total events:	71		32			
Heterogeneity: Not applicable						
Test for overall effect: Z = 2.57 (P = 0.01)						
1.3.2 Sensitivity analysis (ICC=0.04)						
Kirby 2009	70	545	31	150	100.0%	0.62 [0.42 , 0.91]
Subtotal (95% CI)		**545**		**150**	**100.0%**	**0.62 [0.42 , 0.91]**
Total events:	70		31			
Heterogeneity: Not applicable						
Test for overall effect: Z = 2.44 (P = 0.01)						
1.3.3 Sensitivity analysis (ICC=0.08)						
Kirby 2009	60	472	27	130	100.0%	0.61 [0.41 , 0.92]
Subtotal (95% CI)		**472**		**130**	**100.0%**	**0.61 [0.41 , 0.92]**
Total events:	60		27			
Heterogeneity: Not applicable						
Test for overall effect: Z = 2.34 (P = 0.02)						



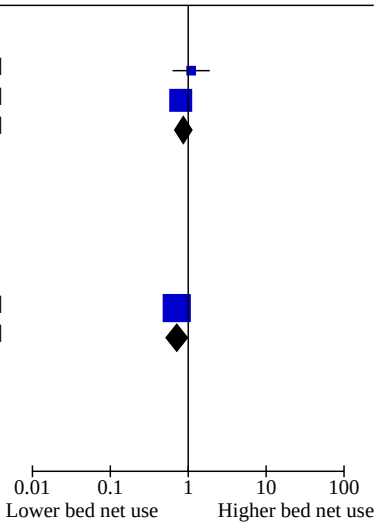
Analysis 1.4. Comparison 1: Screening versus no screening, Outcome 4: Bed net use (primary analysis, assuming ICC of 0.375)

Study or Subgroup	Screening Events	Screening Total	No screening Events	No screening Total	Weight	Risk Ratio M-H, Fixed, 95% CI
1.4.1 Full screening						
Getawen 2018	11	19	10	19	21.0%	1.10 [0.62 , 1.95]
Kirby 2009	59	113	25	37	79.0%	0.77 [0.58 , 1.03]
Subtotal (95% CI)		**132**		**56**	**100.0%**	**0.84 [0.65 , 1.09]**
Total events:	70		35			
Heterogeneity: Chi² = 1.18, df = 1 (P = 0.28); I² = 15%						
Test for overall effect: Z = 1.32 (P = 0.19)						
1.4.2 Screened ceilings						
Kirby 2009	42	90	25	37	100.0%	0.69 [0.50 , 0.95]
Subtotal (95% CI)		**90**		**37**	**100.0%**	**0.69 [0.50 , 0.95]**
Total events:	42		25			
Heterogeneity: Not applicable						
Test for overall effect: Z = 2.31 (P = 0.02)						
Test for subgroup differences: Chi² = 0.91, df = 1 (P = 0.34), I² = 0%						



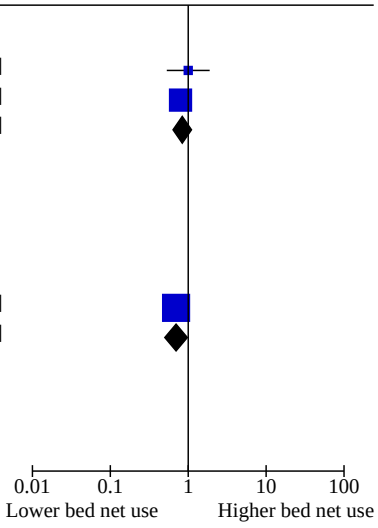
Analysis 1.5. Comparison 1: Screening versus no screening, Outcome 5: Bed net use (sensitivity analysis, ICC=0.3)

Study or Subgroup	Screening Events	Screening Total	No screening Events	No screening Total	Weight	Risk Ratio M-H, Fixed, 95% CI
1.5.1 Full screening						
Getawen 2018	12	21	11	21	22.0%	1.09 [0.63 , 1.89]
Kirby 2009	63	121	26	40	78.0%	0.80 [0.60 , 1.06]
Subtotal (95% CI)		**142**		**61**	**100.0%**	**0.86 [0.67 , 1.11]**
Total events:	75		37			
Heterogeneity: Chi² = 0.96, df = 1 (P = 0.33); I² = 0%						
Test for overall effect: Z = 1.13 (P = 0.26)						
1.5.2 Screened ceilings						
Kirby 2009	44	95	26	40	100.0%	0.71 [0.52 , 0.98]
Subtotal (95% CI)		**95**		**40**	**100.0%**	**0.71 [0.52 , 0.98]**
Total events:	44		26			
Heterogeneity: Not applicable						
Test for overall effect: Z = 2.12 (P = 0.03)						



Analysis 1.6. Comparison 1: Screening versus no screening, Outcome 6: Bed net use (sensitivity analysis, ICC=0.45)

Study or Subgroup	Screening Events	Screening Total	No screening Events	No screening Total	Weight	Risk Ratio M-H, Fixed, 95% CI
1.6.1 Full screening						
Getawen 2018	9	17	9	17	20.6%	1.00 [0.53 , 1.88]
Kirby 2009	56	107	23	35	79.4%	0.80 [0.59 , 1.07]
Subtotal (95% CI)		**124**		**52**	**100.0%**	**0.84 [0.64 , 1.10]**
Total events:	65		32			
Heterogeneity: Chi² = 0.41, df = 1 (P = 0.52); I² = 0%						
Test for overall effect: Z = 1.27 (P = 0.20)						
1.6.2 Screened ceilings						
Kirby 2009	39	85	23	35	100.0%	0.70 [0.50 , 0.97]
Subtotal (95% CI)		**85**		**35**	**100.0%**	**0.70 [0.50 , 0.97]**
Total events:	39		23			
Heterogeneity: Not applicable						
Test for overall effect: Z = 2.12 (P = 0.03)						



ADDITIONAL TABLES

Table 1. Types of intervention

Intervention		Modification
Primary construction		
Construction materials	Wall	Mud or thatch replaced with wood, cement, or brick

Table 1. Types of intervention *(Continued)*

	Roof	Thatch replaced with corrugated iron or tiles
	Door	Different designs for doors and door frames exist, and some may reduce the space or time period at which mosquitoes can enter compared to traditional designs
	Eave	Closure of eaves
Design	Elevation	House built above ground level on stilts
	Windows	Fewer or smaller windows
Modifications to existing houses		
Non-insecticidal		
Screening		Covering of potential entry points (ceilings, eaves, doors, windows gable ends) with: commonly PVC-coated fibreglass or metal mesh, or with alternative materials found around the home
Eaves		Eaves commonly filled in with either mud or with a sand/rubble/cement mixture
Wall maintenance		Filling in of cracks and crevices with mud or sand/rubble/cement mixture
Insecticidal		
Eave tubes		Eaves are closed and tubes with insecticide-coated electrostatic netting are inserted
Insecticidal screening		Screening potential entry points with insecticidal materials such as treated mosquito netting

PVC: polyvinyl chloride

Table 2. Types of interventions included in review

Intervention	Comparison
Primary construction	
Alternative wall, roof, door type, or eave closure	Traditional/standard wall, roof, door type, eave open
Elevated house	House at ground level
Reduced number of windows per household	An increased number or size of windows
Modifications to existing houses	
Non-insecticidal	
Screening of ceilings, doors, eaves, windows, or any combination of these	No screening or a quantifiable reduction in the extent of screening
Closure of eaves	Open eaves
Filling in of cracks and crevices in walls or ceilings	No filling in of cracks and crevices

Table 2. Types of interventions included in review *(Continued)*

Insecticidal	
Any structural house modification that incorporates an insecticide	No incorporation of insecticidal delivery system to house structure

Table 3. Haemoglobin levels used to diagnose anaemia[a]

Population	**Non-anaemic[b]**	**Anaemia[b]**		
		Mild	**Moderate**	**Severe**
Children 6 to 59 months of age	≥ 110	100 to 109	70 to 99	< 70
Children 5 to 11 years of age	≥ 115	110 to 114	80 to 109	< 80
Children 12 to 14 years of age	≥ 120	110 to 119	80 to 109	< 80
Non-pregnant women (15 years of age and above)	≥ 120	110 to 119	80 to 109	< 80
Pregnant women	≥ 110	100 to 109	70 to 99	< 70
Men (15 years of age and above)	≥ 130	110 to 129	80 to 109	< 80

[a] WHO 2011.
[b]Haemoglobin (g/L).

Table 4. Intervention components

Study	Type of housing						Main components of intervention				Community-implemented (C)[a]/researcher-implemented (R)[b]?
	Eaves	Ceiling	Windows Wall openings	Doors	Wall type	Roof	Blocking entry through eaves (eave closure/screening of ceiling or eaves/other)	Blocking entry through doors and windows	Blocking other potential routes of entry	Insecticide used?	
Kirby 2009 (full screening) (Published)	Present	Absent	Mean number windows/house: 0.3	Mean number/house: 2.6	Mud, brick or concrete	NR	Screening of eaves (with PVC-coated fibreglass netting)	Yes – screening of windows and doors	None	None	R
Kirby 2009 (screened ceiling) (Published)	Present	Absent	Mean number windows/house: 0.3	Mean number/house: 2.6	Mud, brick or concrete	NR	Screening of ceiling (with PVC-coated fibreglass netting)	None	None	None	R
Getawen 2018 (Published)	Absent in 82% houses	NR	Yes –unclear number of windows. 30% had "wall openings"	Yes – unclear how many doors. 30% had "well-fitting" doors	Mud	Corrugated iron	Not applicable	Screening of windows and doors (with wire mesh)	None	None	R
Minakawa 2016 (com-	Present	Absent	NR	NR	NR	NR	Screening of eaves and ceilings	None	None	Permethrin	R

Table 4. Intervention components *(Continued)*

pleted, unpublished) (Unpublished[c])							(with insecticide-treated bed net material)			thrin-treated netting used for screening (Olyset Net)	
Pinder 2016 (protocol) (Unpublished)	Present	Present	Windows present, unclear how many	Present	Mud	Thatched	Eave closure	Screening of doors and windows (unclear which material). A metal-louvred door installed at front, and wooden-screened door at back.	Thatched roofs replaced with iron roofs	None	R
Sternberg 2018 (protocol) (Unpublished)	Present	NR	Yes, unclear how many	Yes, unclear how many	Concrete or brick	Metal sheeting	Eave closure and eave tube installation (tubes drilled into wall with insecticide treated-netting insert)	Window screening (with aluminium) and damaged doors repaired with wood	Maintenance of eave tubes and screening every 2 months	10% WP formulation of beta-cyfluthrin on the eave tube netting	R
McCann 2017 (protocol)	Present	Present	Yes, unclear	Yes, un-	Brick or mud	NR	Eave closure	Screening of windows	Closure of holes	None	C

Table 4. Intervention components *(Continued)*

(Unpublished)	(% houses with ceiling not clear)	how many	clear how many	using the same material used for house construction	and other openings used for ventilation with aluminium screens. Modification of doors so as to fully cover doorways when closed.	in the wall not used for ventilation

[a]Community-implemented refers to cases where the communities/participants were responsible for carrying out the house modifications.
[b]Researcher-implemented refers to cases where researchers/field staff were responsible for carrying out the house modifications.
[c]For unpublished studies, characteristics were obtained either from an abstract (Minakawa 2016 (completed, unpublished)) or from a published protocol (all other unpublished studies)
C: community-implemented; NR: not reported; PVC: polyvinyl chloride; R: researcher-implemented; WP: wettable powder

Table 5. Adult mosquito density

Trial	Assessment method	Comparison	Mean no. mosquitoes/night/trap (95% CIs)		Effect size[a] (95% CIs)
			Intervention	Control	
Kirby 2009	Mosquitoes sampled from CDC light traps placed in every study house during the transmission period of each year (2-year follow-up)	Full screening versus no screening	15.2 (12.9-17.4)	37.5 (31.6-43.3)	Mean difference: 22.3 (15.98, 28.62), favouring the intervention
		Screened ceilings versus no screening	19.1 (16.1-22.1)	37.5 (31.6-43.3)	Mean difference: 18.4 (11.79, 25.01), favouring the intervention
		Any screening versus no screening			Mean difference: 20.39 (14.21, 26.58), favouring the intervention
Getawen 2018	Mosquitoes sampled from CDC light traps placed in 10 sentinel houses/study arm that were selected after randomization (6-month follow-up)	Screening versus no screening	0.85 (0.45-2.15)	1.65 (0.80-6.80)	Rate ratio: 1.94 (1.38, 2.72) higher rate of mosquitoes caught per night per trap in control

[a]These effect sizes have not been adjusted for clustering
CDC: Centers for Disease Control and Prevention; CI: confidence interval

Table 6. Sporozoite rates

Trial	Outcome definition	Assessment method	Comparison	Reported results		Risk ratio[b] (95% CI)
				Intervention	Control	
Kirby 2009	Proportion of *Anopheles* infected with sporozoites	Identified by ELISA	Screening versus no screening[a] 2006	60/25180 (0.24%)		Not reported
			Screening versus no screening[a] 2007	19/13146 (0.14%)		Not reported
Getawen 2018 (*P falciparum*)			Screening versus no screening	3/190 (1.58%)	10/372 (2.69%)	0.59 (0.16, 2.11)
Getawen 2018 (*P vivax*)				1/190 (0.5%)	2/372 (0.5%)	0.98 (0.09, 10.73)

[a]Sporozoite rates in sampled mosquitoes reportedly did not differ between trial groups and data were therefore pooled.
[b]These effect sizes have not been adjusted for clustering.
CI: confidence interval: ELISA: enzyme-linked immunosorbent assay

Table 7. Entomological inoculation rates

Trial	Outcome definition	Assessment method	Comparison	Mean EIR (95% CI)		Effect size[a] (95% CI)
				Inter-vention	Control	
Kirby 2009	Number of infective bites received per person in a given unit of time, in a human population	Adult mosquito density (CDC light traps from all study houses) and sporozoite rates (ELISA) were used to calculate mean number of infective mosquitoes per person per season	Full screening versus no screening 2006	0.77 (0.57-0.96)	2.27 (1.38-3.16)	Mean difference: 1.50 (0.59, 2.41), favouring the intervention
			Full screening versus no screening 2007	0.42 (0.24-0.63)	1.35 (0.74-1.97)	Mean difference: 0.93 (0.30, 1.56), favouring the intervention
			Screened ceilings versus no screening 2006	1.14 (0.85-1.42)	2.27 (1.38-3.16)	Mean difference: 1.13 (0.20, 2.06), favouring the intervention
			Screened ceilings versus no screening 2007	0.90 (0.22-1.57)	1.35 (0.74-1.97)	Mean difference: 0.45 (-0.46, 1.36), favouring the intervention
Getawen 2018		The EIR was calculated using adult mosquito density and sporozoite rate from CDC light traps in 10 sentinel houses per arm	Full screening versus no screening	1.75 (0.35 to 5.30)	6.32 (2.46 to 10.50)	Mean difference: 4.57 (3.81, 5.33)

[a]These effect sizes have not been adjusted for clustering.
CDC: Centers for Disease Control and Prevention; CI: confidence interval: EIR: entomological inoculation rate; ELISA: enzyme-linked immunosorbent assay;

Table 8. Quality assessment for qualitative outcomes[a]

Quality assessment	Getawen 2018	Kirby 2009
a) Were steps taken to increase rigour in the sampling?	No, not at all/Not stated/ Can't tell	Yes, a few steps were taken
b) Were steps taken to increase rigour in the data collected?	No, not at all/Not stated/ Can't tell	Yes, a few steps were taken
c) Were steps taken to increase rigour in the analysis of the data?	No, not at all/Not stated/ Can't tell	No, not at all/Not stated/ Can't tell
d) Were the findings of the study grounded in/ supported by the data?	Not applicable	Not applicable
e) Please rate the findings of the study in terms of their breadth and depth.	Poor	Poor

[a]This is a modified version of the quality assessment tool developed by the Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI-Centre), outlined in (Eshun-Wilson 2019).

APPENDICES

Appendix 1. Detailed search strategies

Search Name: Cochrane Central Register of Controlled Trials

Issue 11 of 12, November 2019

#1 (malaria or anopheles or mosquito):ti,ab,kw (Word variations have been searched)

#2 (House or houses or housing or hut or huts or building* or dwelling* or shelter or shelters):ti,ab,kw (Word variations have been searched)

#3 (roof* or eave* or wall* or window* or door*):ti,ab,kw (Word variations have been searched)

#4 (ceiling* or floor or floors or gable or gables or stilts:ti,ab,kw (Word variations have been searched))

#5 (elevation or elevated or “netting barrier*”):ti,ab,kw (Word variations have been searched)

#6 architecture:ti,ab,kw (Word variations have been searched)

#7 #2 or #3 or #4 or #5 or #6

#8 #1 and #7

Medline (Pubmed)

Search set	Search terms
1	Search Malaria* Field: Title/Abstract OR “Malaria” [MeSH]
2	Search Plasmodium Field: Title/Abstract OR “Plasmodium” [MeSH]
3	Search Anopheles Field: Title/Abstract OR “Anopheles” [MeSH]
4	Search "Mosquito Control"[MeSH]
5	Search 1 or 2 or 3 or 4
6	Search House or houses or housing or hut or huts or building* or dwelling* or shelter or shelters Field: Title/Abstract
7	Search roof* or eave* or wall* or window* or door* or ceiling* or floor or floors or gable or gables or stilts or elevation or elevated or “netting barriers” Field: Title/Abstract
8	Search "living environment" or construction* Field: Title/Abstract
9	Search "Housing "[MeSH]
10	Search "Architecture"[MeSH] or architect* Field: Title/Abstract
11	Search 6 or 7 or 8 or 9 or 10
12	Search 5 and 11
13	Search "Randomized Controlled Trial" [Publication Type] OR "Controlled Clinical Trial" [Publication Type] OR "Prospective Studies"[MeSH]
14	Search (intervention* or effect or trial* or assessment or improvement or improve* or crossover or random* or cohort* or control) Field: Title/Abstract

(Continued)

15	Search "Cohort Studies"[MeSH]
16	Search field trial Field: Title/Abstract
17	Search 13 or 14 or 15 or 16
18	Search 12 and 17

Database: Embase 1947-Present, updated daily

Search Strategy:

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1 malaria.mp. or *Malaria/

2 anopheles.mp. or *Anopheles/

3 1 or 2

4 (roof or roofs or roofing or eave* or wall or walls or window* or door or doors).ab. or (roof or roofs or roofing or eave* or wall or walls or window* or door or doors).ti.

5 (ceiling* or floor or floors or gable or gables or stilts).ab. or (ceiling* or floor or floors or gable or gables or stilts).ti.

6 (House or houses or housing or hut or huts).ab. or (House or houses or housing or hut or huts).ti.

7 (building* or dwelling* or shelter or shelters).ab. or (building* or dwelling* or shelter or shelters).ti.

8 housing.mp. or *Housing/

9 architecture.mp. or *Architecture/

10 4 or 5 or 6 or 7 or 8 or 9

11 3 and 10

12 randomized controlled trial/ or controlled clinical trial/

13 prospective study/

14 (intervention* or effect or trial* or assessment or improvement or improve* or crossover or random* or cohort* or control*).mp.

15 cohort analysis/

16 field trial.mp.

17 time series.mp.

18 12 or 13 or 14 or 15 or 16 or 17

19 11 and 18

Indexes=CAB Abstracts Timespan=All years

#1	**TOPIC:** (malaria or anopheles) AND **TOPIC:** (housing or roofs or doors or windows or eaves or ceiling)
#2	**TOPIC**: (malaria or mosquito*) AND **TOPIC:** (hous* and (improvement* or modification*))

(Continued)

#3	**TOPIC:** (malaria or mosquito*) AND **TOPIC:** (eave* or building* or dwelling* or gables or stilts
#4	**TOPIC**: (malaria or mosquito*) AND **TOPIC:** (walls or windows or ceilings or floor*)
#5	#4 OR #3 OR #2 OR #1

Database :	**LILACS**
Search on :	housing or roof$ or eave$ or stilts or building [Words] or "HOUSING" [Words] and malaria or anopheles or mosquito [Words]

Clinicaltrials.gov, WHO ICTRP, ISRCTN registry: Malaria and housing, Malaria and Houses, Malaria and building*

Appendix 2. ROBINS-I tool

Specify the review question

Participants	All age groups living in an area with malaria
Experimental intervention	Modifications to primary construction design and specifications, including: choice of material used for walls, roofs, or doors; house elevation; closed eaves versus open eaves Modifications or additions to existing houses including: screening of ceilings, doors, eaves, windows, or any combination of these; changes to size or number of windows or doors per household; filling in of cracks and crevices in walls or ceilings Any structural house modification incorporating insecticide
Comparator	For modifications to primary construction design and specification: wall, roof, or door types traditionally/most commonly used in the local area; house at ground level or open eaves For modifications or additions to existing houses: no screening or a quantifiable reduction in screening; a quantifiable difference in the number of or size of windows or doors; no filling in of cracks and crevices For incorporation of insecticidal delivery systems: no incorporation of insecticidal delivery system to house structure For all of these comparators, there should be no major structural differences between the intervention and control arm other than the intervention itself that are likely to influence mosquito entry.
Outcomes	Malaria case incidence, incidence of new malaria infections, malaria parasite prevalence

List the confounding domains relevant to all or most studies

Socioeconomic status: people of lower socioeconomic status may be less likely to live in houses with walls appropriate for house modifications and therefore less likely to be selected for the intervention group. Socioeconomic status is considered a prognostic factor for malaria (Somi 2007).

Geographical location: people living in certain geographical regions may live in houses that are more appropriate or more convenient for implementation of house interventions and therefore may be more likely to be selected for the intervention group. Malaria transmission is also heterogenous across different geographical regions and can therefore be a predictor of malaria risk (Bousema 2012).

List co-interventions that could be different between intervention groups and that could impact on outcomes

Use of other (non-insecticidal) vector control tools: individuals receiving the intervention may be less inclined to use other vector control interventions such as bed nets.

HISTORY

Protocol first published: Issue 8, 2019
Review first published: Issue 10, 2020

CONTRIBUTIONS OF AUTHORS

All authors contributed to the review design and approved the final version. All review authors read and approved the final draft.

DECLARATIONS OF INTEREST

JFA has no known conflicts of interest to declare.
EAO has no known conflicts of interest to declare.
MN has no known conflicts of interest to declare.
PG is the Director of the Research, Evidence and Development Initiative (READ-It) project (project number 300342-104) and CIDG Co-ordinating Editor.

SOURCES OF SUPPORT

Internal sources

- Liverpool School of Tropical Medicine, UK

External sources

- Foreign, Commonwealth and Development Office (FCDO), UK

  Project number 300342-104
- Partnership for Increasing the Impact of Vector Control (PIIVeC), UK

  Provided support to EAO. PIIVeC is funded by the Medical Research Council of the UK (grant number MR/P027873/1) through the Global Challenges Research Fund.

DIFFERENCES BETWEEN PROTOCOL AND REVIEW

We changed the title from 'Housing interventions for preventing malaria' to 'House modifications for preventing malaria' (Furnival-Adams 2019).