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Fox T, Furnival-Adams J, Chaplin M, Napier M, Olanga EA

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[Intervention Review]

House modifications for preventing malaria

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ABSTRACT

Background

Malaria remains an important public health problem. Research in 1900 suggested house modifications may reduce malaria transmission. A previous version of this review concluded that house screening may be effective in reducing malaria. This update includes data from five new studies.

Objectives

To assess the effects of house modifications that aim to reduce exposure to mosquitoes 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 25 May 2022. We also searched the World Health Organization International Clinical Trials Registry Platform, ClinicalTrials.gov, and the ISRCTN registry to identify ongoing trials up to 25 May 2022.

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 sought studies investigating primary construction and house modifications to existing homes reporting epidemiological outcomes (malaria case incidence, malaria infection incidence or parasite prevalence). We extracted any entomological outcomes that were also reported in these studies.

Data collection and analysis

Two review authors independently 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.

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Main results

One RCT and six cRCTs met our inclusion criteria, with an additional six ongoing RCTs. We did not identify any eligible non-randomized studies. All included trials were conducted in sub-Saharan Africa since 2009; two randomized by household and four at the block or village level. All trials assessed screening of windows, doors, eaves, ceilings, or any combination of these; this was either alone, or in combination with roof modification or eave tube installation (an insecticidal "lure and kill" device that reduces mosquito entry whilst maintaining some airflow). In one trial, the screening material was treated with 2% permethrin insecticide. In five trials, the researchers implemented the interventions. A community-based approach was adopted in the other trial.

Overall, the implementation of house modifications probably reduced malaria parasite prevalence (RR 0.68, 95% CI 0.57 to 0.82; 5 trials, 5183 participants; moderate-certainty evidence), although an inconsistent effect was observed in a subpopulation of children in one study. House modifications reduced moderate to severe anaemia prevalence (RR 0.70, 95% CI 0.55 to 0.89; 3 trials, 3643 participants; high-certainty evidence). There was no consistent effect on clinical malaria incidence, with rate ratios ranging from 0.38 to 1.62 (3 trials, 3365 participants, 4126.6 person-years). House modifications may reduce indoor mosquito density (rate ratio 0.63, 95% CI 0.30 to 1.30; 4 trials, 9894 household-nights; low-certainty evidence), although two studies showed little effect on this parameter.

Authors' conclusions

House modifications – largely screening, sometimes combined with insecticide and lure and kill devices – were associated with a reduction in malaria parasite prevalence and a reduction in people with anaemia. Findings on malaria incidence were mixed. Modifications were also associated with lower indoor adult mosquito density, but this effect was not present in some studies.

PLAIN LANGUAGE SUMMARY

House modifications for preventing malaria

What is the aim of this review?

House modifications, such as screening (covering or closing potential house entry points for mosquitoes with mesh or other materials) or the use of specific house materials or designs, such as metals roofs instead of thatched roofs, or elevated rooms, may contribute to reducing the burden of malaria. They work by preventing mosquitoes from entering houses, and reducing the number of bites householders receive indoors. Some house modifications under consideration additionally aim to kill any mosquitoes that attempt to enter houses by incorporating insecticide into the modification.

Key messages

Modifying houses to prevent mosquitoes entering the home was associated with a reduction in the proportion of people with malaria parasites in their blood and reduced anaemia, based on evidence from seven studies conducted in Africa. The effect of house modifications on the number of cases of malaria identified during specific time periods was mixed, and the effect on indoor mosquito density was less clear due to differences between study results. Six 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 the parasites that cause malaria), or householders' views, we also summarized this data. After searching for relevant studies, we included seven published trials and six ongoing trials. All complete trials assessed screening (of windows, doors, eaves, ceilings, or any combination of these), either alone or in combination with roof modification or eave tube installation (a "lure and kill" device positioned in eave gaps to attract and kill mosquitoes). One trial incorporated insecticide into their house screening.

What are the main results of the review?

The seven included trials all assessed either the number of cases of malaria identified during specific time periods in people living in the house, the proportion of people with malaria parasites in their blood, or both. Overall, the studies showed that people living in modified houses were around 32% less likely to have malaria parasites in their blood, and were 30% less likely to experience moderate or severe anaemia. Our confidence in these results was moderate to high. The studies demonstrated 37% reduction in the number of mosquitoes trapped indoors at night in modified houses, although this result varied between trials. The trials showed mixed results for the likelihood of experiencing an episode of clinical malaria (caused by *Plasmodium falciparum* parasites), ranging from a 62% lower rate to a 68% higher rate of malaria for people living in modified houses. Due to the high inconsistency between these results, we have very low confidence in this evidence.

How up to date is this review?

The review authors searched for studies available up to 25 May 2022.

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SUMMARY OF FINDINGS

Summary of findings 1. Summary of findings table 1

Patient or population: children and adults at risk of malaria

Setting: sub-Saharan Africa (The Gambia, Ethiopia, Kenya, Malawi, Cote d'Ivoire)

Intervention: screening modifications alone (5 studies) or with other modifications (2 studies)[a]

Comparison: no modification

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	Nº of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Risk with control	Risk with house modification				
Malaria parasite prevalence Follow-up: range 6 months to 2 years	115 per 1000	78 per 1000 (65 to 94)	RR 0.68 (0.57 to 0.82)	5183 ** (5 RCTs)	⊕⊕⊕⊖ Moderate[b] *Due to imprecision*	House modifications probably reduce malaria parasite prevalence.
Anaemia prevalence Follow up: range 6 months to 2 years	131 per 1000	92 per 1000 (72 to 117)	RR 0.70 (0.55 to 0.89)	3643 (3 RCTs)	⊕⊕⊕⊕ High[c,d]	House modifications reduce the prevalence of anaemia (moderate or severe).
Clinical malaria incidence Follow-up: range 6 months to 2 years	Pooled analysis not appropriate due to substantial qualitative heterogeneity. Using the highest and lowest point estimates from the included studies, the rate of malaria incidence ranged from a 68% increase in screened houses (Pinder 2021; rate ratio 1.68, 95% CI 1.11 to 2.55) to a 62% decrease (Getawen 2018; rate ratio 0.38, 95% CI 0.18 to 0.82).			3365 (3 RCTs)	⊕⊖⊖⊖ Very low[e,f] *Due to inconsistency and indirectness*	Qualitative heterogeneity precluded a meta-analysis.
Indoor adult mosquito density	8.82 per house night	5.56 per house night (2.6 to 11.5)	Rate ratio 0.63 (0.30 to 1.30)	9894 household-nights (4 RCTs)	⊕⊕⊖⊖ Low[d,g,h]	House modifications may reduce indoor adult mosquito density.

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					Due to imprecision and inconsistency

* 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).

** Participant numbers for McCann 2021 and Ng'ang'a 2020 were calculated from the number of participants selected per survey, but some participants may have been selected for more than one survey.

CI: confidence interval; RCT: randomized controlled trial; RR: risk ratio

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.

[a]All studies implemented screening to protect homes from mosquito entry. In addition, one study also replaced thatch roofs with metal (Pinder 2021), and one study also installed eave tubes (Sternberg 2021).
[b]Downgraded by one level for imprecision due to wide CIs. If risk of bias had influenced the effect in the meta-analysis, we would have downgraded further for risk of bias.
[c]Not downgraded: 30% reduction in anaemia is an important effect, and the least optimistic effect of 11% is also an important effect.
[d]One study contributing to these outcomes was at high risk of bias due to doubt relating to the identification of participants and randomization of clusters. Sensitivity analysis shows no effect on the overall result, so we did not downgrade for risk of bias.
[e]Downgraded by two levels for inconsistency due to high qualitative heterogeneity between studies. One study (Pinder 2021) indicated a paradoxical increase in malaria incidence. The trial authors noted that high indoor temperatures in modified houses may have encouraged participants to go indoors to bed later, there was damage to the modifications, the study was carried out in a highly researched area that was receiving high coverage of other malaria interventions, and participants in modified houses left doors open for ventilation.
[f]Downgraded by one level for indirectness: one study reported that an eave closure campaign in the study area had preceded the trial, meaning the trial cohort consisted of individuals who ignored or were unaware of the campaign (Pinder 2021). This study cohort is unlikely to be representative of the general population.
[g]Downgraded by one level for imprecision due to wide CIs.
[h]Downgraded by one level for inconsistency due to qualitative heterogeneity between studies.

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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 96% of those deaths occur in Africa (WHO 2022). 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, and this has been exacerbated by the COVID-19 pandemic (WHO 2017a; WHO 2018; WHO 2021). In 2020, there were an estimated 241 million cases worldwide (14 million more cases than in 2019) (WHO 2021). In sub-Saharan Africa, the major malaria vectors are *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).

The most widely used malaria prevention tools over the past two decades include vector control tools such as indoor residual spraying (IRS) and insecticide-treated nets (ITNs), making notable contributions to the reductions in malaria observed in the early 21st century (Bhatt 2015). In 2020, 65% of sub-Saharan households owned at least one ITN, a 60% increase since 2000. The percentage of the at-risk population protected by IRS in malaria-endemic countries declined by 3.2% to 2.6% since 2010, which may represent a change in prevention strategy (WHO 2021). These interventions target malaria vectors once they have entered the home and can fail when there is inadequate coverage or usage of interventions, when interventions are not durable, or when vectors are not susceptible to the insecticide being used. Widespread insecticide resistance observed across Africa may be contributing to decreased susceptibility to the primary insecticides (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), in the late 1940s, large-scale IRS campaigns were implemented as dichlorodiphenyltrichloroethane (DDT) became available, which steered vector control programmes towards insecticidal tools. 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.

The 2020 Cochrane Review 'House modifications for preventing malaria' demonstrated the potential for house screening to reduce the incidence of clinical malaria for people living in modified houses, as well as the potential to reduce the prevalence of parasitaemia and anaemia (Furnival-Adams 2020; minor amendment published in Furnival-Adams 2021). Only two studies contributed results to this version of the review, meaning the evidence for the effect of house screening for preventing malaria was mainly low-certainty, due to imprecision.

Housing and protection

Screening of homes using wire gauze to protect against flying insects has been practised by communities since before malaria transmission by female *Anopheles* mosquitoes was discovered (Gachelin 2018; Wilson 2020). 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" using simple screening techniques, combined with covering exposed skin and use of antimalarial drugs, in railway workers in Italy, noting that the families in his study experienced fewer incidences of fever compared to the previous year when no house modifications were used (Celli 1901). Surveys conducted in America also suggested a link between house quality and malaria (Boyd 1926).

Systematic review of association (2015)

With the renewed interest in housing design and modification for malaria control, researchers collected data assessing housing as a risk factor for malaria in a range of geographical, epidemiological, and socioeconomic settings (Tusting 2015). In three cohort studies that evaluated mesh screening on windows, there was some evidence of a reduction in clinical malaria in screened houses, with an effect estimate (odds ratio; OR) of 0.56; but for malaria infection incidence, results were inconsistent.

Studies that compared malaria rates in ‘modern' houses against those in ‘traditional' houses, controlled for socio-economic status, consistently showed lower odds of malaria infection and clinical malaria in modern houses. Modern wall materials were associated with a 63% reduction in 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 noted, along with other limitations.

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 African countries that assessed the relationship between house quality and malaria (Tusting 2017). 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 or urban status. The analysis was rigorous and covered data from a large population of 284,532 children. 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 a causal relationship.

Systematic review and meta-analysis (2021)

More recently, a systematic review and meta-analysis of housing interventions to reduce mosquito-borne diseases collected data from randomized trials to assess whether housing interventions were effective in reducing mosquito densities in homes in malaria- or dengue-endemic areas (Kua 2021). This review demonstrated similar findings to the previous version of this Cochrane Review and to Tusting 2015. The small number of studies contributing to the

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meta-analyses and the pooling of non-equivalent clinical results limit the findings of this review.

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. Environmental modifications surrounding homes is a well-explored larval control strategy, utilizing source reduction strategies to minimise breeding habitats for malaria vectors. At a domestic level, physical modifications to the house design and structure may reduce mosquito entry. Together, these actions may help to reduce the vector-borne disease burden. The WHO describes such an approach as '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).

House modifications may be divided into two categories, described in Table 1.

- Design, detailing and material specifications for primary construction
- Modifications or additions to the physical structure of existing houses (retrofit)

Houses require a minimum level of structural integrity for modifications to be sustained, 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 communities accept the provision of modifications and encourage their use and maintenance.

How the intervention might work

Some major *Anopheles* species in Africa have evolved with humans to be endophilic and endophagic, meaning they typically bite when individuals are likely to be asleep at home (Gillies 1968). These behaviours make homes an area of high malaria risk and an important target for vector control interventions. House modifications aim to reduce the entry of mosquitoes into the home by reducing entry routes into the house, improving the structural integrity of the home, or targeting malaria vectors with insecticide, thus reducing the risk of mosquito bites to house dwellers.

Primary house construction

Certain house designs and materials used for house construction may minimize malaria risk by aiming to reduce 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), or how prone the materials of the house are to the development of holes (cracks in or gaps between building elements) (Lindsay 2019). Other considerations regarding primary construction include the following factors: whether the house is elevated or left at ground level, as previous studies suggest that indoor vector density is lower in houses raised on stilts compared to houses at ground level (Charlwood 2003); the presence or absence of eaves or gables.

Considering the expected doubling of the sub-Saharan African population by 2050, the construction of new homes should aim to utilize materials and designs that prevent mosquito entry and exposure while maintaining ventilation and being affordable (UN 2019). Ongoing projects such as The Star Homes Project are investigating the effect of a novel house design, with an elevated sleeping area, on the incidence of malaria in children (Mshamu 2022; Star Homes Project).

Modifications to existing houses

Screening

Existing homes may be modified to reduce the number of entry points for mosquitoes or cover existing entry points, known as screening. 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). Screening or closing up potential entry points may reduce the density of malaria vectors in the home, thereby reducing the exposure of the occupants to infective bites. Many of the interventions under consideration involve partial or full screening of openings such as windows, doors and ventilation openings, usually with polyvinyl chloride (PVC)-coated fibreglass or metal mesh. Gaps in wall structures may also be filled with a cement-based mortar, or with fine aggregate sand or stone. How effective the screening of doors and windows is will depend on their size and how often they are left open (Jawara 2018).

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). 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.

Other modifications

Eave tubes are an example of a mosquito-targeting house modification, whereby holes are drilled into the walls of houses under the eaves and tubes filled with electrostatic netting, coated with insecticide, are inserted into the wall (Andriessen 2015). This method aims to lure mosquito vectors towards the eave tube, attracted by carbon dioxideescaping the home, subsequently killing the mosquitoes due to contact with the insecticide.

Some modifications include replacing traditional thatched roofs with modern materials such as metal or tiles, which are less easily penetrable to malaria vectors and may increase difficultly of survival in the home (Charlwood 2003; Lindsay 2019). Methods such as this one potentially require greater costs and maintenance efforts than simple screening procedures.

Acceptability and implementation

House modifications for vector control are appealing in that they offer household-level protection; may be simple to instal and maintain; 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

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additional health benefits and may increase the attractiveness of the intervention to householders.

If house modifications are 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 and adhere to 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.

Why it is important to do this review

The evidence provided above shows clear potential for house modifications to reduce 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 update, we will summarize experimental, epidemiological studies that assess whether house modifications show an effect on malaria infection in humans. If variation in efficacy is observed, this review may additionally provide an ongoing summary of which approaches have been successful.

The previous version of this review reported data that demonstrated a protective effect of screening for clinical malaria incidence (rate ratio 0.38, 95% CI 0.18 to 0.82), parasite prevalence (RR 0.84, 95% CI 0.60 to 1.17), and anaemia (RR 0.61, 95% CI 0.42 to 0.89) compared to unscreened houses (Furnival-Adams 2021). Since publication of the first version of this Cochrane Review (Furnival-Adams 2020; minor amendment published in Furnival-Adams 2021), several new studies have become available, including four studies identified in Furnival-Adams 2021 that now offer published results.

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

OBJECTIVES

To assess the effects of house modifications that aim to reduce exposure to mosquitoes on malaria disease and transmission.

METHODS

Criteria for considering studies for this review

Types of studies

Randomized controlled trials (RCTs)

- 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.

Non-randomized studies of interventions (NRSI) are included since we expected to find a limited number of studies and, considering the laborious nature of some interventions, the feasibility of conducting RCTs may be limited. We therefore anticipated that there may be a higher number of non-randomized studies that would add to the evidence base. In this update, we found only new RCTs and no NRSI. We plan to exclude NRSI in future updates of this review.

Types of participants

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

Types of interventions

We planned to primarily group the modifications as either primary construction or modifications to existing homes. We only identified modifications to existing homes in our included studies, which we categorized into two groups (Table 2). All studies included screening modifications of various types, which aim to reduce entry points into the home for malaria vectors, and some additionally included other modifications aimed at increasing the structural integrity of the home by changing the roof material or targetting malaria vectors with insecticidal eave tubes. There should have been no major structural differences between the intervention and control arm other than the intervention itself that were likely to influence mosquito entry. Any co-interventions should have been balanced across the control and intervention arms.

We excluded: 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; and interventions not integral to the built structure, such as insecticide-treated curtains.

Types of outcome measures

We included data from all time points; studies commonly reported results for the overall study period.

Primary outcomes

Studies must have included one of the following primary outcomes.

- Parasite prevalence (clinical and subclinical malaria): the proportion of surveyed individuals with confirmed parasitaemia at a community household survey
- 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)

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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)

Secondary outcomes

Epidemiological

- Anaemia prevalence as per WHO cut-offs, based on haemoglobin measurements taken in community household surveys (Appendix 1; WHO 2011)
- All-cause mortality
- Other disease case incidence, including other vector-borne diseases or diarrhoeal diseases that may be influenced by house characteristics

Entomological

- Adult mosquito density
- Transmission intensity (measured using entomological inoculation rate; EIR)
- Sporozoite rate

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. We also sought data on the cost of interventions for individual participants or stakeholders.

Unintended effects

Any data within the trials suggesting whether the housing interventions influence: the proportion of time spent inside or outside the house; bed-net usage; damage to the intervention; 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, or adverse effects related to insecticide-based interventions, such as poisoning or changes in mosquito behaviour that reduce efficacy of vector control interventions.

Search methods for identification of studies

We searched for all relevant new trials regardless of or status (published, unpublished, in press and in progress) from the date of search of the previously published version of this review (1 November 2019) up to 25 May 2022.

Electronic searches

We searched the databases up to 25 May 2022 using terms described in Appendix 2: the Cochrane Infectious Diseases Group Specialized Register; Central Register of Controlled Trials (CENTRAL), Issue 4 of 12, April 2022, published in the Cochrane Library; MEDLINE (PubMed, from 1966); Embase (OVID, from 1947); Centre for Agriculture and Bioscience International (CAB) Abstracts (Web of Science; from 1973); and Latin American and Caribbean Sciences (LILACS) (BIREME, from 1982). We 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 (TF and JFA) independently assessed the titles and abstracts of studies identified by 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 they reported data 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 (MC) if necessary. We listed excluded studies, together with their reasons for exclusion, in the Characteristics of excluded studies table. The study selection process is illustrated in a PRISMA diagram (Figure 1). We managed the references using Endnote and screened them using Covidence.

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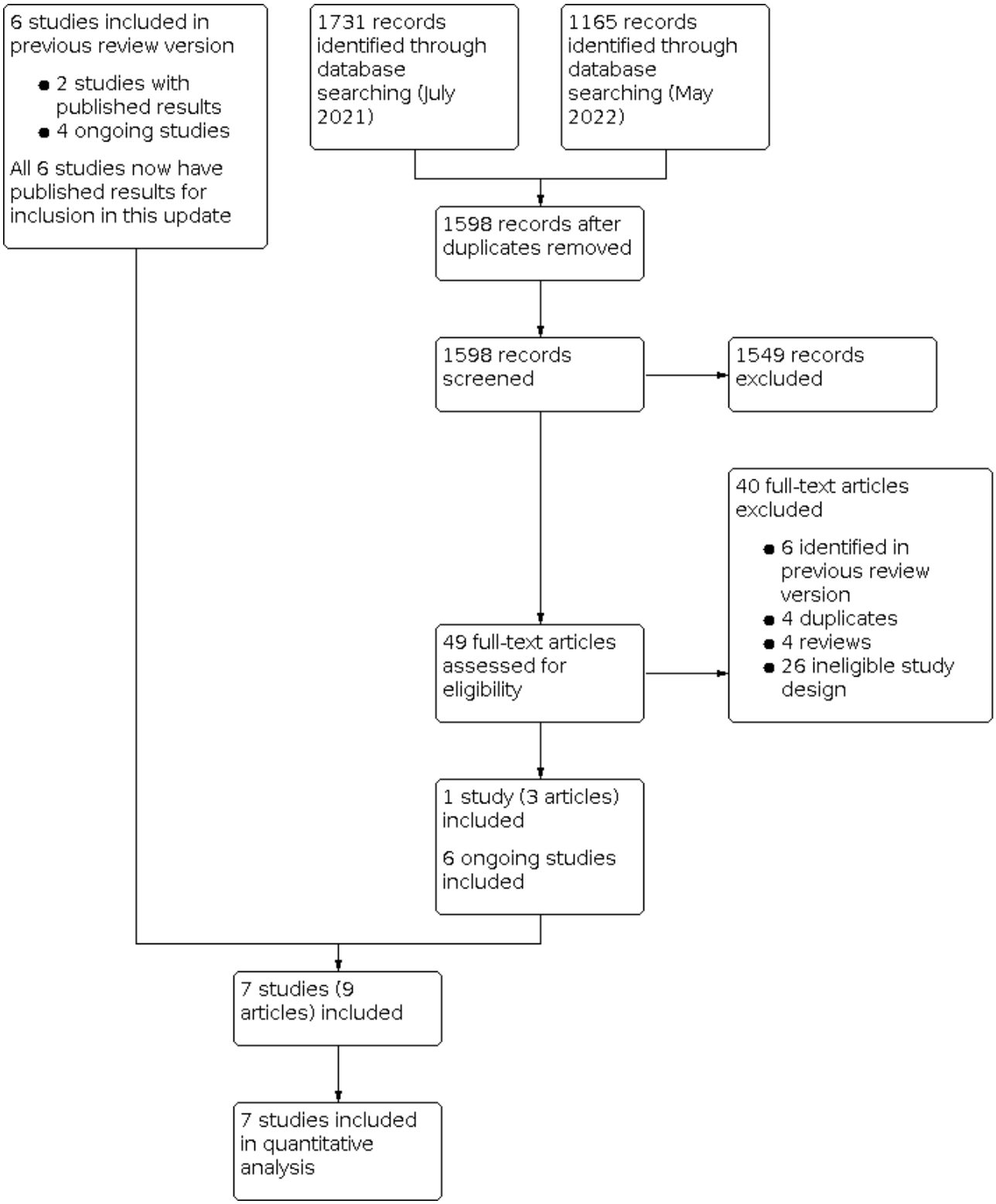
Figure 1. PRISMA diagram



Data extraction and management

Two review authors (TF and JFA) independently extracted information from the included studies using pre-piloted 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 (MC). In case of missing data, we contacted the original study author(s) for clarification.

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We extracted data on the following:

- study design: type of study; method of participant selection; sample size; details of sampling methodology; follow-up period. For cluster-RCTs (cRCTs): adjustment for clustering; number of clusters; unit of randomization; intracluster correlation coefficient (ICC);
- participants: study settings; population characteristics; withdrawal; and loss to follow-up;
- interventions: full details of intervention, co-interventions and any theory informing it; coverage of intervention and 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;
- entomological outcomes: primary and secondary vector(s) species; vector(s) behaviour; method(s) of mosquito collection; malaria endemicity; eco-epidemiological setting; population proximity and density; insecticide resistance status;
- other: primary construction materials; topography of study site; 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 where detail was provided.

Assessment of risk of bias in included studies

Two review authors (TF and JFA) independently assessed the risk of bias using the Cochrane risk of bias 2 tool (RoB 2) (Higgins 2022; Risk of Bias 2; Sterne 2019). We justified judgements made in the risk of bias tables. The effect of interest was the effect of assignment to the intervention at baseline, regardless of whether the interventions were received as intended (the 'intention-to-treat effect'). We managed the assessments using the RoB 2 Excel tool for cluster-randomized trials or randomized trials. For randomized cross-over trials, we planned to use the version of ROB2 for cross-over trials. We assessed risk of bias for four outcomes: parasite prevalence, clinical malaria incidence, anaemia prevalence, and indoor adult mosquito density. We used the following domains to assess bias arising from the randomization process:

- bias due to deviations from intended interventions;
- bias due to missing outcome data;
- bias in measurement of the outcome; and
- bias in selection of the reported result.

For trials that randomized clusters, we assessed an additional component, namely bias arising from identification or recruitment of individual participants within clusters.

We answered signalling questions as either yes; probably yes; probably no; no; or no information. We used these to determine the overall risk of bias for each domain (high, some concerns, low) and later, the overall risk of bias for each primary outcome from the included studies (high, some concerns, low). We judged study outcomes to have an overall low risk of bias if all domains were at low risk, some concerns if any domain had some concerns, and high if we assessed any domain to be at high risk of bias.

We did not find any observational or quasi-experimental studies suitable for inclusion; however, to assess 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 (Appendix 3; Sterne 2016), with interest in the 'intention-to-treat effect'. 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. We had intended to assess the risk of bias for the following domains for each outcome:

- confounding;
- selection of participants into the study;
- classification of interventions;
- deviations from intended interventions;
- missing data;
- measurement of outcomes;
- selection of the reported result.

We planned to judge risk of bias domains as 'low risk', 'moderate risk', 'serious risk', 'critical risk', or 'no information', and evaluate individual bias items as described in Sterne 2016. An overall judgement of risk of bias would have been made from the results of each domain: low risk of bias (the study is comparable to a well-performed RCT); moderate risk of bias (the study provides sound evidence for an NRS but cannot be considered comparable to a well-performed RCT); serious risk of bias (the study has some important problems); critical risk of bias (the study is too problematic to provide any useful evidence and should not be included in any synthesis); no information on which to base a judgement about risk of bias. The confounding domains and co-interventions that could be different between intervention groups and that could impact on outcomes have been outlined in Appendix 3.

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. Briefly, studies were assessed in terms of the following:

- rigour in sampling (an appropriate sampling strategy was used, a diverse sample was obtained, critical characteristics of the sample were presented);
- rigour in data collection (data collection tools were piloted, collection was comprehensive, flexible and sensitive, participants were able and willing to contribute)
- rigour in analysis (analysis methods were systematic, diversity was explored, analysis sought to rule out alternative explanations for findings);
- findings of the study supported by the data (data shows how author findings were reached, data presented fit the interpretation claims, data illustrate the findings, quotes are identified); and
- breadth and depth of study findings (range of issues covered, perspectives are fully explored, richness and complexity is portrayed, there is theoretical development).

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These domains were assessed as: Yes, a fairly thorough attempt was made; Yes, several steps were taken; Yes, a few steps were taken, and; No, not at all/Not stated/Can't tell.

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 planned to present 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 borrowed an ICC value from previous studies if they were conducted in similar contexts, or estimated the ICC ourselves. For clinical malaria incidence for Getawen 2018, we estimated an ICC of 0.02 based on a previous study (Foy 2019). For anaemia prevalence for Kirby 2009, the paper reported an estimated ICC of between 0.04 and 0.08, based on unpublished data. For bed-net use for both studies, 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, since we did not consider it possible to produce estimates that we could be confident had been appropriately adjusted for clustering. We summarized these data in tables.

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

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

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 assessed statistical heterogeneity in each meta-analysis using the I^2 statistic value and the Chi^2 statistic. 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 inspect the funnel plot visually, and use formal tests for funnel plot asymmetry (Harbord 2006). If we detected asymmetry in any of these tests or by 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 were meta-analysed, we used a fixed-effect meta-analysis to combine data where heterogeneity was absent. If considerable heterogeneity was present, we planned to combine data using random-effects meta-analysis and report an average treatment effect. We planned to decide whether to use a fixed-effect or random-effects model based on the consideration of clinical and methodological heterogeneity between trials.

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 sub-themes.

Subgroup analysis and investigation of heterogeneity

We did not plan to perform subgroup analysis on the data due to the anticipated small number of included studies and lack of evidence on the effect of house modifications in different populations and settings.

Sensitivity analysis

We planned to perform sensitivity analysis on the primary outcome of studies determined to be at high risk of bias, to see the effect of exclusion of trials at high risk of bias (for incomplete outcome data) on the overall results. However, this was not possible due to the small number of studies. For trials with estimated ICC values, we undertook sensitivity analyses to investigate the impact of varying the ICC value on meta-analysis results. These are presented in Appendix 4.

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 key outcomes as described by Balshem 2011; RCTs start as high-certainty evidence,

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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 the following outcomes (those considered most important to decision-making) in Summary of findings 1: parasite prevalence, clinical malaria incidence, anaemia prevalence, and indoor adult mosquito density.

RESULTS

Description of studies

Results of the search

We identified 2896 potentially relevant studies through our search strategy. After removing duplicates, we screened 1598 records, from which we considered 49 for full-text screening (Figure 1). Of these, seven studies met our inclusion criteria. Two published studies and four ongoing studies were included in the previous Cochrane Review (Furnival-Adams 2021). All six of these studies now have published results, which we have included in this review update (Getawen 2018; Kirby 2009; McCann 2021; Minakawa 2022; Pinder 2021; Sternberg 2021). One new study was included in this review update (Ng'ang'a 2020). The characteristics of the seven included studies are described in Included studies. Two included RCTs collected data on relevant secondary outcomes (user acceptability; unintended effects; cost) but published this in separate articles. We identified two articles associated with these RCTS; one reports a cost analysis for the trial by McCann 2021 (Phiri 2021), and the other provides data on user-acceptability and community acceptance from the trial by Pinder 2021 (Jones 2022). The six identified ongoing trials are detailed in Ongoing studies (Asale 2020; JPRN-UMIN000045079; Mshamu 2022; NCT04622241; Odufuwa 2022; Sangoro 2021).

Of the 49 studies that we assessed at full-text screening, we excluded 40: six were identified in the previous Cochrane Review (Furnival-Adams 2021), four were reviews, four were duplicates, and 26 had study designs that did not meet the inclusion criteria.

Included studies

Trial design and location

Of the seven published trials meeting our inclusion criteria, six were cRCTs (Getawen 2018; Kirby 2009; McCann 2021; Minakawa 2022; Ng'ang'a 2020; Sternberg 2021) and one was an RCT (Pinder 2021). Since we identified an increasing number of RCTs meeting our inclusion criteria and no non-randomized studies for our review, we plan to exclude non-randomized studies from any future updates.

Two cRCTs were household-randomized (Getawen 2018; Kirby 2009), and the other four were village- or block-randomized; with buffer sizes of 400 m (McCann 2021), 300 m (Minakawa 2022), and 2 km (Sternberg 2021). Ng'ang'a 2020 did not report the buffer size.

Two studies took place in The Gambia (Kirby 2009; Pinder 2021), one in Ethiopia (Getawen 2018), one in Cote d'Ivoire (Sternberg 2021), one in Malawi (McCann 2021), and two in Kenya (Minakawa 2022; Ng'ang'a 2020). Four were conducted in rural areas (McCann 2021; Minakawa 2022; Ng'ang'a 2020; Sternberg 2021), two in rural and urban settings (Kirby 2009; Pinder 2021), and one was conducted in an urban area (Getawen 2018).

Interventions

The interventions under consideration in each trial are detailed in Table 3.

All studies used screening with either PVC-coated fibreglass netting, wire mesh or aluminium screens, closed gaps using local materials, or closed the eaves. Screening was the only component incorporated into all studies, as described below:

- Four studies assessed non-insecticidal screening based modifications: one study had two intervention arms, one assessing full screening (screening of eaves, doors and windows), and one arm that assessed ceiling screening only (nets act as quasi-ceiling in houses with no permanent ceiling); three studies assessed one screening intervention each (doors and windows, eaves); one study assessed multiple screening interventions (doors and windows, other entry points, eave closure).
- One study assessed insecticide-treated screening, using 2% permethrin-treated nets.
- Two studies assessed non-insecticidal screening interventions plus other modifications, one of which incorporated insecticide (eave tubes) and the other which was non-insecticidal (roof replacement).

Insecticide-based

Minakawa 2022 used 2% permethrin-treated nets (OlysetNet, Sumitomo Chemical, Tokyo, Japan). Sternberg 2021 incorporated 10% wettable powder (WP) formulation of beta-cyfluthrin on the eave tube netting.

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Maintenance

Implementation strategy

In six trials, the research team implemented the interventions. In one study, volunteer community members engaged in the interventions and implemented the intervention themselves (McCann 2021).

Co-interventions

Getawen 2018 provided untreated bed nets to all participants. Minakawa 2022, Sternberg 2021, and Pinder 2021 provided insecticide treated bed nets to participants in both trial arms. Participants in one trial received insecticide treated bed nets as well as being involved in a community engagement and education program as part of a national malaria campaign (McCann 2021).

Participants

Five studies measured malaria in children to evaluate the intervention, and two studies examined both adults and children (Getawen 2018; Ng'ang'a 2020).

Outcomes

Epidemiological outcomes

All trials used active case detection (ACD) to survey participants for malaria. Three studies measured malaria incidence (Getawen 2018; Pinder 2021; Sternberg 2021), five studies measured parasite prevalence (Kirby 2009; McCann 2021; Minakawa 2022; Ng'ang'a 2020; Pinder 2021). Anaemia was a primary outcome in one of the trials (Kirby 2009). Four other studies measured anaemia as a secondary outcome (McCann 2021; Minakawa 2022; Pinder 2021; Sternberg 2021).

Entomological outcomes

All the studies measured indoor adult mosquito density, one using suna traps (McCann 2021), one using human landing catch sampling (Sternberg 2021), one using the pyrethrum spray catch method (PSC) (Minakawa 2022), and four using Centers for Disease Control and Prevention (CDC) light traps. Two studies also measured outdoor mosquito density (McCann 2021; Sternberg 2021). Five studies reported a sporozoite rate, three of which used enzyme-linked immunosorbent assay (ELISA) (Getawen 2018; Kirby 2009; Pinder 2021), and two used polymerase chain reaction (PCR) (McCann 2021; Sternberg 2021). Five studies calculated an entomological inoculation rate (EIR) from these indicators.

Other outcomes

User acceptability

Four studies measured indicators of user acceptability and community acceptance. One study reported the collection of user acceptability data (Pinder 2021), which was detailed in a separate article associated with this trial (Jones 2022).

One study measured user acceptability and community acceptance through semi-structured questionnaires, with questions related to effect of screening, problems with screened doors, perception of screening on appearance of houses, 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). Jones 2022 (Pinder 2021) 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 policymakers); and 3) focus-group discussions. Sternberg 2021 used thematic analysis to evaluate ethnographic and focus-group information related to user acceptability, and they plan to present the findings in future publications.

Unintended effects

Four studies recorded bed-net usage (Getawen 2018; Kirby 2009; McCann 2021; Sternberg 2021).

Pinder 2021 recorded damage to the intervention by encouraging house owners in the intervention group to report bed-net damage to nurse field assistants during their twice-weekly visits. Two trials reported all-cause mortality during the trial period (Kirby 2009; Sternberg 2021). Due to concerns that screening houses may reduce airflow and exacerbate respiratory diseases, two studies reported incidence of respiratory infection (Pinder 2021; Sternberg 2021). Pinder 2021 and Sternberg 2021 reported adverse events.

Concomitant economic assessments

Five studies performed economic evaluations. In the protocol of one study, authors stated that economic data would be collected to determine cost-effectiveness (McCann 2021). These data were included in a secondary publication that was identified through our search (Phiri 2021). All other economic data in our included studies were presented in the primary publications.

McCann 2021 reported a cost-analysis from a societal perspective in a separate publication (Phiri 2021); Sternberg 2021 measured incremental economic and financial cost per malaria case averted, and cost per DALY averted in the intervention group and compared it to the control group with ITNs only; Kirby 2009 calculated costings for both interventions on a per-person basis; Getawen 2018 presented the cost of intervention per house; and Pinder 2021 planned to conduct a cost analysis in the protocol but has not reported this further.

Excluded studies

We excluded thirty-four articles at full-text screening for the reasons:

- twenty-six had an ineligible study design;
- four were duplicates; and
- four were reviews.

Risk of bias in included studies

Overall risk of bias

We assessed methodological and risk of bias for six cRCTs and one RCT contributing results to our outcomes using the RoB 2 tool. The studies contributed a total of 15 study results to four outcomes that we assessed using RoB 2 (Higgins 2022). The RoB 2 judgements are summarized below. Detailed risk of bias assessments are available on request.

Overall risk of bias by study

One study was at overall high risk of bias for all outcomes that it contributed results to (clinical malaria incidence, anaemia,

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adult mosquito density) due to a high risk of bias for timing of identification or recruitment of participants (Sternberg 2021). This is because villages were randomized to the control and intervention arms before enrolment of individual participants. However, we do not think this has a substantial effect on the study outcome as authors were able to recruit sufficient participants in both arms of the trial.

One study had some concerns for the overall risk for the clinical malaria incidence outcome (Getawen 2018). Two studies had some concerns for the overall risk of bias for the parasite prevalence outcome (Minakawa 2022; Ng'ang'a 2020). All other studies were at low risk of bias for these outcomes.

Overall risk of bias by outcome

Parasite prevalence

Five studies contributed results to the analysis of malaria parasite prevalence. We judged three of these to be at overall low risk of bias (Kirby 2009; McCann 2021; Pinder 2021). We rated one study as having some concerns overall for this outcome due to missing data from some participants (Minakawa 2022), although this was balanced across both arms, and due to bias in selection of the reported result as they did not publish a protocol a priori. We also had some concerns about another study for this outcome (Ng'ang'a 2020), due to bias in selection of the reported result, as they did not publish a protocol a priori.

Clinical malaria incidence

Three studies contributed results to the analysis of clinical malaria incidence. We assessed Pinder 2021 to be at low risk of bias for this outcome. There were some concerns for this outcome in Getawen 2018 due to bias in selection of the reported result, as no protocol was published a priori. We judged Sternberg 2021 to be at overall high risk of bias due to timing of identification or recruitment of participants.

Anaemia prevalence

Three studies contributed results to the analysis of anaemia prevalence. We assessed Kirby 2009 and Pinder 2021 to be at low risk of bias for this outcome. For Sternberg 2021, bias due to timing of identification or recruitment of participants was at high risk of bias.

Adult mosquito density

Four studies contributed results to the analysis of adult mosquito density. We assessed three studies to be at low risk of bias for this outcome (Kirby 2009; McCann 2021; Pinder 2021). Sternberg 2021 was at high risk of bias due to timing of identification or recruitment of participants.

Effects of interventions

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

Key outcomes are presented in Summary of findings 1.

For all human outcomes (clinical malaria incidence, parasite prevalence, anaemia and bed-net use), we present data adjusted for clustering in the meta-analyses. Data that were not adjusted for clustering in the primary studies are presented in tables (Table 4; Table 5). For studies presenting unadjusted data, we adjusted for clustering using an estimated ICC where appropriate and performed sensitivity analyses using ranges of ICCs to assess whether these estimates impacted on the results, presented in Appendix 4. 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.

Epidemiological outcomes

Parasite prevalence

Five trials reported data on malaria parasite prevalence (Kirby 2009; McCann 2021; Minakawa 2022; Ng'ang'a 2020; Pinder 2021). The pooled analysis demonstrated a protective effect of screening against malaria parasitaemia: participants in modified houses were observed to have 32% lower parasite prevalence compared to control houses (RR 0.68, 95% CI 0.57 to 0.82; P < 0.0001; 5183 participants; moderate-certainty evidence; Analysis 1.1). A subgroup from one study demonstrated an increased risk of malaria parasite prevalence in children aged 6 to 59 months in screened homes (OR 1.38, 95% CI 0.63 to 3.03; 631 participants), but another subgroup (women aged 15 to 49 years) in this study reported a substantial benefit of screening on parasite prevalence, although CIs were wide (OR 0.75, 95% CI 0.37 to 1.52; 831 participants) (McCann 2021).

Clinical malaria incidence

Three trials reported data on malaria infection incidence (Getawen 2018; Pinder 2021; Sternberg 2021). Substantial qualitative heterogeneity between studies was present (I^2 = 100%), with one study reporting a higher malaria infection incidence in the screened house group (Pinder 2021), and two studies reporting a lower infection incidence (Getawen 2018; Sternberg 2021); therefore, we did not present a pooled analysis of these results. Overall, the studies demonstrated clinical malaria incidence ranging from 0.09 to 1.43 per person-year in screened houses, and between 0.12 to 2.29 per person-year in unscreened houses (3365 participants; very low-certainty evidence; Table 4).

The result from the study with an increase in clinical malaria incidence in the screening group suggest that the rate of malaria in people in screened homes is 68% higher than in unscreened homes (rate ratio 1.68, 95% CI 1.11 to 2.55; Analysis 1.2). It is unexpected that the modifications implemented in this study (screening and roof replacement) would be associated with a large increase in malaria incidence. Authors reported that a high-uptake eave closure campaign in the study area had preceded the trial, meaning the trial cohort consisted of a minority population of individuals from households who ignored or were unaware of the previous campaign (Pinder 2021).

Anaemia

Five studies compared anaemia in screened houses with that in unscreened houses. Data on the prevalence of moderate to severe anaemia from three studies are included in the meta-analysis (Kirby 2009; Pinder 2021; Sternberg 2021). In the three studies, house modifications were associated with lower prevalence of moderate to severe anaemia compared to unmodified houses (RR 0.70, 95% CI 0.55 to 0.89; P = 0.004; 3643 participants; high-certainty evidence; Analysis 1.3). McCann 2021 presented data on mean difference from baseline in haemoglobin concentrations for each study

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arm, aggregated over the trial period. Minakawa 2022 reported haemoglobin concentrations and calculated differences between the screened and unscreened houses. Both studies suggest there is little effect of screening on haemoglobin concentration, with similar differences in haemoglobin concentration in participants in screened houses compared to unscreened houses in McCann 2021, and very similar median concentrations across groups in Minakawa 2022 (Table 5).

Entomological outcomes

We were only able to meta-analyse data on adult mosquito density due to differences in the unit of measurement and different follow-up periods for other entomological data.

Adult mosquito density

All seven trials reported the mean number of mosquitoes caught indoors per trap per night as an indicator of adult mosquito density of the primary vector.

Due to a methodological issue with the pre-trial power analysis, data for entomological outcomes in McCann 2021 were unable to demonstrate any effect. Another study was carried out in a highly researched area that was receiving high coverage of other malaria interventions (Pinder 2021). Due to this methodological heterogeneity, the data for indoor adult mosquito density from four studies were included in a random-effects meta-analysis (Analysis 1.4). Fewer mosquitoes were caught in modified houses compared to unmodified houses, suggesting that modifications may reduce mosquito entry, but CIs were wide (rate ratio 0.63, 95% CI 0.30 to 1.30; 9894 household-nights; low-certainty evidence; Analysis 1.4).

We were not able to obtain appropriate ICC estimates to adjust the data presented in two studies for clustering; however, one demonstrated a 95% increased mosquito density rate in unscreened houses, suggesting a large protective effect of screening modifications (rate ratio 1.94, 95% CI 1.38 to 2.72, favouring modification, Getawen 2018), and the other suggested no real difference between mosquito density in screened or unscreened houses (Ng'ang'a 2020) (Table 6). We were also unable to include the data from Minakawa 2022 in the pooled analysis, which demonstrated a protective effect of screening on indoor mosquito density (RR 0.73, 95% CI 0.53 to 0.92; P = 0.057) (Table 6).

Entomological inoculation rate (EIR)

Five trials reported EIR in screened houses versus unscreened houses. Results from all studies demonstrated a reduction in EIR in modified houses, although the size of the effect varied between studies (mean difference in EIR ranges 0.001 to 1.50; 5 trials). Sternberg 2021 presented adjusted indoor and outdoor EIR, demonstrating a reduced EIR in screened houses compared to unscreened houses (indoor OR 0.28, 95% CI 0.24 to 0.33; outdoor OR 0.33, 95% CI 0.27 to 0.40; Analysis 1.5). Unadjusted data are not included in analyses and are summarized in Table 7.

Sporozoite rate

Four trials reported sporozoite rate. Getawen 2018 reported sporozoite rates in both *P falciparum* and *P vivax* mosquitoes, demonstrating a lower *P falciparum* sporozoite rate in screened houses compared to unscreened houses (RR 0.59, 95% CI 0.16 to 2.11), but no difference in *P vivax* sporozoite rate between study arms (RR 0.98, 95% CI 0.09 to 10.73). Pinder 2021 also reported lower sporozoite rates in screened houses (OR 0.63, 95% CI 0.20 to 1.97). Due to no difference when comparing the sporozoite rate between trial arms (0.24% in 2006 and 0.14% in 2007), Kirby 2009 did not report sporozoite rate by intervention arm. Similarly, McCann 2021 did not report sporozoite rate by intervention arm, possibly due to complications with low power to detect this outcome. Unadjusted data are reported in Table 8.

User acceptability

Community acceptance

Few studies performed good-quality, detailed investigations of community views on house modifications. Getawen 2018 used in-depth interviews to measure community acceptance of the interventions, and Kirby 2009 used focus group discussions (FGD) for this purpose. In both studies, participants positively reported that the intervention reduced the number of indoor mosquitoes and houseflies. Most participants in both trials chose to include screening modifications in their homes after the duration of the trial. Additionally, participants in the study by Kirby 2009 positively reported a reduction in entry of other animals. In both trials, participants expressed concern that screening would be damaged by domestic animals and children, or that it would become dirty. The quality assessment we conducted on both studies was low (Table 9).

Views and experiences of participants in the trial by Pinder 2021 are described in detail in a separate paper (Jones 2022). Authors encouraged participants to highlight elements of a 'good' or 'bad' house through FGDs, photo voice data collection, and questionnaires. In general, modifications to prevent mosquito entry were associated with 'good' houses, particularly corrugated roofs and closure of gaps where animals and insects could enter the home. Participants were very supportive of the trial and perceived it as beneficial since most participants could not afford to 'modernize' their homes themselves. Many of the positive views of the modifications related to improved security and status, rather than health benefits, while many of the negative views related to poor construction and practicality of modifications. The authors report that they believed negative views were often rectified through good communication between researchers and participants. The quality assessment for this study was high (Table 9).

Cost analysis

Basic economic evaluation data for four studies have been summarized in Table 10, presenting the cost per person and cost per household of the modifications.

Unintended effects

Bed-net use

Five trials reported bed-net usage throughout the trial period. Pooled analysis of three of the trials demonstrated that individuals living in houses with modifications were around 5% less likely to sleep under a bed net (RR 0.95, 95% CI 0.92 to 0.98; 3 trials, 2508 participants; Analysis 1.6) (Getawen 2018; Kirby 2009; Minakawa 2022). Results from McCann 2021 and Sternberg 2021 are presented separately as we could not adjust for clustering. They demonstrate a similar pattern of effect, with lower bed-net use in screened houses compared to unscreened houses (Table 11).

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All-cause mortality

Two trials reported all-cause mortality during the trial period, which was low across all participants (screened houses mortality rate: Kirby 2009: 0.3%; Sternberg 2021: 0.24%; unscreened houses mortality rate: Kirby 2009: 1.5%; Sternberg 2021: 0.69%).

Respiratory disease

Due to concerns that screening houses may reduce airflow and exacerbate respiratory diseases, two studies reported incidence of respiratory infection (Pinder 2021; Sternberg 2021). Respiratory infection incidence was low and similar in both the screened and unscreened houses across both studies (Pinder 2021, adjusted rate ratio 0.85, 95% CI 0.65 to 1.11; P = 0.24; Sternberg 2021, hazard ratio (HR) 1.00, 95% CI 0.71 to 1.41; P = 0.99).

Damage to the intervention

Pinder 2021 encouraged participants to report damage or malfunctioning of modifications of bed nets to nurse field assistants who visited twice a week throughout the duration of the study period. By the end of the trial period, only 139/392 (35%) modified houses had intact screening, suggesting substantial damage to the intervention in this study setting. Due to lack of data from other studies, it is unclear if this effect applies to other study settings.

Other adverse effects

Pinder 2021 reported a similarly low frequency of serious adverse events (SAEs) in participants from both the screened houses and unscreened houses (screened: hospitalized n = 21, due to severe malaria n = 5; unscreened: hospitalized n = 20, due to severe malaria n = 3). Adverse events reported in Sternberg 2021 were also similar across both study groups. They reported that no SAEs associated with the intervention were reported during the trial by any study participant.

DISCUSSION

Summary of main results

This review is a substantive update to the previous version (Furnival-Adams 2021), with published data from five trials added. All studies investigated screening components to prevent mosquito entry to the home. Two had additional components: one study also incorporated the replacement of traditional roofs with modern materials, and one study inserted insecticidal eave tubes into study homes. See Summary of findings 1.

Screening houses was shown to probably reduce parasite prevalence of the people living in the modified homes by almost a third, although there was some quantitative heterogeneity between studies (RR 0.68, 95% CI 0.57 to 0.82; 5 trials, 5183 participants). Screening houses was also shown to effectively reduce the prevalence of moderate to severe anaemia by 30% (RR 0.70, 95% CI 0.55 to 0.89; 3 trials, 3643 participants).

We note high quantitative heterogeneity between study results for clinical malaria incidence: two studies demonstrated a protective effect of house screening on malaria incidence (Getawen 2018; rate ratio 0.38, 95% CI 0.18 to 0.82; Sternberg 2021; rate ratio 0.62, 95% CI 0.50 to 0.77), suggesting that house modifications may reduce clinical malaria. One study paradoxically demonstrated an increase in clinical malaria incidence in modified houses which reduces the certainty of evidence and suggests that the intervention may not always be effective (Pinder 2021; rate ratio 1.68, 95% CI 1.11 to 2.55).

House modifications demonstrated some effect on indoor adult mosquito density, but quantitative heterogeneity was high, suggesting the intervention may not always be effective (rate ratio 0.63, 95% CI 0.30 to 1.30; 4 trials, 9894 household-nights). In studies where indoor adult mosquito density was reduced, epidemiological outcomes appeared to demonstrate the protective effect of house modifications.

Overall completeness and applicability of evidence

This review includes evidence from across the African continent and assesses the effect of house modifications that aim to reduce exposure to mosquitoes on malaria outcomes in children and adults in rural and urban locations. We included studies with a broad set of screening-based modifications, including a variety of non-insecticidal screening modifications introduced to reduce mosquito entry and one study implementing insecticidal screening, as well as studies introducing modifications with other protective mechanisms, such as roof replacement with more robust modern materials, or insecticidal eave tubes as a lethal house lure. The pooled analysis of epidemiological outcomes demonstrated some substantial protective effects of house modifications against malaria, although heterogeneity was sometimes present.

Quantitative heterogeneity among malaria interventions is very common: indeed the review of artemisinin-based combination treatments in the Lancet that underpinned their introduction levels demonstrated high heterogeneity (International Artemisinin Study Group 2004). Conflicting results are more concerning, but in this case it may have been due to failed implementation of the intervention. The study authors suggested that damage to modifications was high; high indoor temperatures may have delayed bedtime for children, and participants often left doors open, allowing increased mosquito entry; or the result may have been due to chance (Pinder 2021). The trial cohort, consisting of a minority population of individuals from households who ignored or were unaware of a previous house modification campaign in the trial area, may also introduce methodological heterogeneity and affect the certainty of the evidence.

The effectiveness of the intervention may depend on methodological study design, or may be due to factors relating to the study population, such as acceptability and adherence which may influence participant behaviours. A lack of data on user-implementation views and community acceptance prevents delineation of qualitative evidence for adherence to the intervention.

Researchers and policymakers are considering several novel house modifications that exist for malaria control, outlined in the methods' section of this review. Due to the limited number of studies and the implementation of multiple modifications, evidence from this review does not allow us to perform strong comparisons of different types of modification. Nonetheless, this evidence demonstrates the effectiveness of simple screening measures using wire mesh in preventing malaria disease and transmission. One ongoing trial in Uganda intends to pilot three types of modification in both modern and traditional homes (NCT04622241), before implementing up to two modifications

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in a cluster-randomized trial, which may be useful for further comparing the effect of different modification types.

Certainty of the evidence

We appraised the certainty of evidence of the effect estimates for the primary outcomes in these studies using the GRADE approach, presented in Summary of findings 1. We considered the evidence for house modifications for preventing malaria to be of high to very low certainty.

House modifications probably reduce malaria parasite prevalence (moderate-certainty evidence). We downgraded the certainty of the evidence by one level for imprecision. The 32% reduction in malaria demonstrated is an important effect, as is the least optimistic effect of 18% reduction in parasite prevalence.

House modifications reduce prevalence of moderate to severe anaemia (high-certainty evidence). The 30% reduction in moderate to severe anaemia demonstrated is an important effect, and the least optimistic effect of 11% is also an important effect. Results were consistent across all trials (I^2 = 3%).

Our effect estimate for incidence of clinical malaria in modified houses is probably markedly different from the true effect (very low-certainty evidence), therefore we do not know the effect of house modifications on clinical malaria incidence. We downgraded the certainty of this evidence by two levels for inconsistency due to high heterogeneity between studies and serious indirectness. GRADE assessment of this outcome determined that one study introduced serious indirectness since the study population was not representative of normal populations (Pinder 2021).

House modifications may reduce indoor mosquito density (low-certainty evidence); however, heterogeneity between study results means the true effect may be different from our estimate. We downgraded the certainty of this evidence by one level for imprecision, due to wide CIs, and by one level for inconsistency, due to quantitative heterogeneity.

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 two meta-analyses that had been conducted prior to this review (Kua 2021; 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-analyses, suggesting that house modifications can reduce malaria risk.

The effect size for house modification on parasite prevalence reported in this review is very similar to that reported in the 2018 Cochrane Review 'Insecticide-treated nets for preventing malaria', which demonstrated the protective effect of insecticidal bed nets against malaria parasitaemia (RR 0.83, 95% CI 0.71 to 0.98; 6 trials, 18,809 participants), an intervention which is now widely implemented for malaria prevention (Pryce 2018).

AUTHORS' CONCLUSIONS

Implications for practice

The trials published to date show in these studies that house modifications protect against anaemia and may reduce parasite prevalence for children and adults, and this is consistent with previous research. The evidence from studies to evaluate whether house modifications reduce clinical malaria incidence was mixed, and although pooled evidence suggested a reduction in indoor mosquito density, this was not always present.

Implications for research

House modifications may provide an important, long-term, sustainable option to reduce malaria. Further research will help delineate the best implementation 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. The success of implementation of modifications will likely be affected by perceived benefits by users, the cost of implementation, and the ability of home-owners to introduce modifications themselves. How best to optimize roll-out and facilitate communities to take charge of modifying their own houses would be useful operational research to maximise the potential of this strategy in malaria.

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Furnival-Adams 2019

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Furnival-Adams 2020

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]

Furnival-Adams 2021

Furnival-Adams J, Olanga EA, Napier M, Garner P. House modifications for preventing malaria. *Cochrane Database of Systematic Reviews* 2021, Issue 1. Art. No: CD013398. [DOI: 10.1002/14651858.CD013398.pub3]

* Indicates the major publication for the study

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

- Incidence of clinical malaria: 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 pre-prepared 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 rapid

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Getawen 2018 *(Continued)*

	diagnostic test (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 • Mosquito density: 10 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 (10 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:** none
Participants	**Number of participants:** 477 (239 in the intervention arm and 238 in control houses), 219.3 person-years. **Method of recruitment:** the first household was selected by lottery method and every K^{th} 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, and n is the sample size. The sampling houses were allocated proportionally, thus K is the same for each village. **Recruitment rates:** not reported. **Withdrawal and loss to follow-up:** no loss to follow-up; data on all participants were analysed. **Age:** mean age of 19.7 years in the intervention arm and 19.1 years in the control arm. **Sex:** intervention group, 115 males, 124 females; control group, 108 males, 130 females. **Ethnicity:** not reported. **Socioeconomic status:** not reported.
Interventions	**Intervention type (Primary construction/modification to existing structure/insecticidal delivery system):** screening doors and windows. **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:** untreated bed nets were provided to eligible households in both groups. **Coverage of co-interventions:** all modified and control households were provided with bed nets, and coverage of bed nets in the study area was already about 90% prior to study due to distribution from the government. **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. No further details.

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Getawen 2018 *(Continued)*

	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. All houses were in an urban setting.
Outcomes	• Incidence of malaria • Community acceptance • Bed-net use rate • Cost of screening • 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), close to the Kulifo River. The town is located at 06°05' latitude and 37°38' longitude, with an average elevation of 1218m above sea level. **Social context:** not reported. **Malaria endemicity:** not reported. **EIR:** not reported. **Population proximity/density:** indoor malaria prevalence in pre-intervention and pre-control groups, 3.3% (95% CI 1.7 to 5.5). ***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% of vectors. **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 3 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.

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)

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Kirby 2009 *(Continued)*

	Outcome assessment/surveillance type Epidemiological • Parasite prevalence: 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. 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. • Anaemia: 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. Children with haemoglobin concentration less than 80 g/L were classified as anaemic and given iron supplementation. Entomological • Adult mosquito density: 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. • Sporozoite rate: 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 ... an intraclass correlation of between 0.04 to 0.08 from earlier studies"
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 check criteria for recruitment. **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 (Study area participants: Wolof (n = 2984, 38%), Mandinka (n = 2199, 28%), and Fula (n = 2120, 27%)). **Socioeconomic status:** Socioeconomic status score of 3.5 to 3.8.
Interventions	**Intervention type (Primary construction/modification to existing structure/insecticidal delivery system):** Screening full (eaves, doors and windows) or partial (ceiling). **Detailed description of intervention and any theory informing it:** "In homes with full screening, timber framed doors and windows were constructed and covered with PVC-coated fibreglass netting... The gap between the top of the wall and roof (eaves) was filled with a mixture of sand, rubble, cement, and water". "In homes with screened ceilings, netting was stretched across the room below the eaves, fixed to the walls with wooden battens, and any small holes were filled with mortar". **For insecticidal interventions, insecticide used and dosage:** N/A

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Kirby 2009 *(Continued)*

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.

Description of house features in control and intervention arms: Single-storey buildings, 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

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 1 m 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.

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McCann 2021

Study characteristics

Methods	**Status:** completed and published **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:** 53 villages grouped into 18 clusters in total (9 from arms 1 and 4: 5 control clusters, 4 intervention clusters) • Block A: Control: 2 clusters, HI: 2 clusters • Block B: Control: 2 clusters, HI: 1 clusters • Block C: Control: 1 clusters, HI: 1 clusters **Outcome assessment/surveillance type** • Parasite prevalence in children aged 6 to 59 months and women aged 15 to 49 years assessed through malaria indicator surveys (proportion of RDT tests positive for *P falciparum*) • Incidence of clinical malaria in children aged 6 to 59 months and women aged 15 to 49 years assessed through incidence study cohorts (number of clinical malaria cases per child per year) • Prevalence of anaemia in children aged 6 to 59 months and women aged 15 to 49 years through malaria indicator surveys (proportion of anaemia tests with Hb < 8.0) **Length of follow-up:** 2 years **Adjustment for clustering:** "Differences were assessed at the cluster level, and every household was assumed to be fully covered by the interventions in the trial arm to which it was allocated (i.e. intention-to-treat)."
Participants	**Number of participants:** total 4558 households, 20,013 participants. Control: 1056 households, 4244 participants. Intervention: 1030 households, 4568 participants. **Method of recruitment:** an area of high malaria transmission was selected as the study area, and communities were sensitized prior to recruitment. **Recruitment rates:** 65 villages recruited (Block A, 21; Block B, 13; Block C, 31), 6 villages removed from Block A and Block B each to allow minimum spacing > 800 m between clusters. 55 villages included in the trial (Block A, 15; Block B, 13; Block C, 25) and villages within each block grouped into 6 clusters each. **Withdrawal and loss to follow-up:** not stated. **Age:** children aged 6 to 59 months and women aged 15 to 49 years. **Sex:** male and female. **Ethnicity:** not stated. **Socioeconomic status:** not stated.
Interventions	**Intervention type:** screening doors and windows plus eave closure. **Detailed description of intervention and any theory informing it:** housing Improvements (HI) modifications consist of: covering windows and other openings used for ventilation with aluminium screens

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McCann 2021 *(Continued)*

that allow airflow; 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; and modifying doors to fully cover doorways when closed.

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

Coverage: N/A

Co-interventions: trial interventions were implemented alongside Malawi National Malaria Control Programme (NMCP) interventions. This included a mass distribution of ITNs in the district during the study period in April 2016. The study site was also part of a community engagement and education program to increase community participation in malaria control.

Coverage of co-interventions: Implemented across the entire study site/population.

Implemented by: Community-based: an "animator approach" was used, adapted to the specific setting. Volunteers from the 65 villages 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 specialising in community-based programmes), African Parks Malawi (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). In some cases, a second health animator for a village was selected, with a total of 77 health animators. 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: 800 m

Economic information (intervention costs, changes in other costs as a result of intervention): Annual cost per person, USD 27.04. Annual cost per household USD 119.91. Major costs were staff costs (48.9%); transport (29.9%); materials (< 2%).

Resource requirements: health animators, HI committees and community leaders encouraged heads of households in their villages to carry out any necessary improvements on their own houses, with assistance when needed. Materials provided by the project for HI were aluminium screening and a set of basic hand tools. Bricks for filling large eave openings were prepared by communities.

Description of house features in control and intervention arms: not described, known to have open eaves in control arm.

Outcomes

- Parasite prevalence
- Incidence of clinical malaria
- Prevalence of anaemia
- EIR
- Malaria vector community composition
- *Anopheles* mosquito density

Notes

Location profile

Study location (urban/rural, socioeconomic status, topology of landscape): Rural study site is in Chikhwawa District, an 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: baseline malaria prevalence 19% to 33%.

EIR: Baseline EIR 0.21.

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McCann 2021 *(Continued)*

Population proximity/density: Chikhwawa has a population of over 530,000 people, and population of study villages around 25,000 people.

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

Vector profile

Primary (and secondary vector species): 3 malaria vector species are present: *An gambiae* s.s., *An arabiensis*, and *An funestus.*

Method of mosquito collection: Suna traps were set up indoors and outdoors. Every two months from May 2016 to April 2018, 270 households were selected for the epidemiological survey using a randomized inhibitory spatial sampling procedure. At the same time, 195 of those 270 households were randomly selected for adult mosquito sampling. The lower number of households for mosquito sampling is necessary because mosquito traps were set at each selected household for two nights, whereas the epidemiological survey requires one day per household. Data collection at the 270 households were conducted over a 6- to 8-week period.

For insecticidal interventions, resistance profile: N/A

Funding source

Study funding source: Dioraphte Foundation, The Netherlands.

Minakawa 2022

Study characteristics

Methods

Status: completed and published

Study design: household-randomized controlled trial with 2 arms

- Intervention: ceilings screening with insecticide-treated nets
- Control: ceilings left unscreened

Unit of allocation: cluster

Number of units: control, 4; intervention, 4

Outcome assessment/surveillance type

Epidemiological

- Incidence of clinical malaria: at baseline, 5 months, 12 months and 18 months postintervention, axillary temperature of each child was measured, and a finger prick blood sample was taken to conduct RDT for detecting *P falciparum* infection. Blood was also drawn into a capillary tube (20 µL) to standardize the blood volume and was preserved on a filter paper. Later, the sampled blood was examined to detect *P falciparum* using PCR.
- Anaemia prevalence: a finger prick blood sample was taken measure Hb concentration (g dL^{-1}) using a portable Hb photometer (baseline, 5 months, 12 months, 18 months).

Entomological

- Mosquito density: pyrethrum spray catch method (PSC) was used to collect monthly data from 80 sentinel houses (10 for each cluster) during the period between March 2011 and May 2012. A cross-sectional survey was completed with 25 randomly selected houses in each cluster in May 2011, at the end of the long rainy season.

Length of follow-up: 18 months (February 2011 to July 2012)

Adjustment for clustering: adjusted

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Minakawa 2022 *(Continued)*

Participants	**Number of participants:** 849 children enrolled with complete information at baseline (424 in control group, 425 in intervention group). **Method of recruitment:** completed a baseline survey and listed children from 7 months to 10 years old in the study area. Randomly selected 150 for each cluster (4 clusters per arm). Trained field assistants visited the households of the selected children and explained the study to their caretakers and obtained informed written consent. **Recruitment rates:** 1200 children recruited at baseline out of a possible 2504. **Withdrawal and loss to follow-up:** at 18 months postinstallation of intervention: 178 individuals randomly selected in the control arm were not found or did not show; 211 individuals randomly selected in the intervention arm were not found or did not show. **Age:** Aged 7 months to 10 years old **Sex:** 54% female at baseline **Ethnicity:** the majority of residents belong to the Luo ethnic group. **Socioeconomic status:** not reported, but fishing, small-scale farming and cattle breeding are the main income sources.
Interventions	**Intervention type (Primary construction/modification to existing structure/insecticidal delivery system):** screening ceilings. **Detailed description of intervention and any theory informing it:** ceiling nets treated with 2% permethrin (Olyset®Net, Sumitomo Chemical, Tokyo, Japan). Aimed at preventing mosquito entry via open eaves and also exposing mosquitoes to insecticide if they enter via doors and windows and prefer to rest in the upper areas of the house. The centre of the net was lifted and fixed it using a stapler at the highest point of the triangle roof to prevent any restriction to taller individuals. **For insecticidal interventions, insecticide used and dosage:** 2% permethrin (Olyset®Net, Sumitomo Chemical, Tokyo, Japan) **Coverage:** insecticide-treated ceiling nets implemented in 1073 of 1162 houses in the intervention group. **Co-interventions:** insecticide-treated bed nets were provided to eligible households in both groups (Olyset®Net). **Coverage of co-interventions:** all modified and control households were provided with bed nets, but coverage of bed nets in the study area was already about 90% due to distribution from the government. **Implemented by:** researchers. **Buffer size between clusters:** 300 m. **Economic information (intervention costs, changes in other costs as a result of intervention):** not reported. **Resource requirements:** ceiling nets and bed nets. None others reported. **Description of house features in control and intervention arms:** houses were constructed with a stick framework plastered with a mixture of mud and cow dung and a corrugated iron roof. All houses contained one room.
Outcomes	• Incidence of clinical malaria • Anaemia prevalence • Indoor mosquito density • Bed-net use
Notes	**Location profile**

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Minakawa 2022 *(Continued)*

Study location (urban/rural, socioeconomic status, topology of landscape): rural location, Gembe East of Homa Bay County in western Kenya. Total land area approximately 46 km^2, and coordinates of the geographical mid-point 0°30′ 24′′ S and 34°20′ 48′′ E.

Social context: not reported.

Malaria endemicity: not reported.

EIR: not reported.

Population proximity/density: not reported.

***Plasmodium* species:** *An arabiensis*, *An gambiae s.s*, and *An funestus s.s.* were identified.

Vector profile

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

Method of mosquito collection: mosquito sampling was carried out monthly using PSC was used to collect data from 80 sentinel houses (10 for each cluster) during the period between March 2011 and May 2012.

For insecticidal interventions, resistance profile: results from surveys published in 2011 suggested substantial resistance to pyrethroids in all three mosquito species.

Funding source

Study funding source: this study was funded as joint research between Nagasaki University and Sumitomo Chemical Co. Ltd, and partially supported by the Global Center of Excellence Program, Nagasaki University, Japan.

Ng'ang'a 2020

Study characteristics

Methods

Status: completed and published

Study design: cluster-randomized controlled trial with two arms

- Intervention: eave screening
- Control: unscreened

Unit of allocation: block (village)

Number of units: control: 16; intervention: 16

Outcome assessment/surveillance type

Epidemiological

- Malaria parasite prevalence: Cross-sectional household malaria parasitological surveys were conducted after every 3 months from September 2017 to November 2018. All members of the household received an RDT test for the presence of malaria parasite once every 3 months (4 consecutive times), including one baseline survey in September 2017. Malaria parasite rate was used as the secondary endpoint for assessing the efficacy of eave screening at household level.

Entomological

- Adult mosquito density: Sampling of adult mosquitoes using CDC light traps was conducted from January 2017 to November 2018 for 16 days each month, with all 10 houses in a cluster being sampled in one night. Light traps were set up in occupied rooms and ran for 12h between 19:00 to 07:00. Collected mosquitoes were killed and identified, with subsamples of *Anopheles* mosquitoes being identified to

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Ng'ang'a 2020 *(Continued)*

	sex and species and physiologically identified as being fed or unfed. The number of female indoor *An gambiae* s.l. collected per trap per night were used as a primary outcome for assessing the effectiveness of the intervention. **Length of follow-up:** 2 years (January 2016 to November 2017) **Adjustment for clustering:** "The impact of house screening on infection prevalence was calculated and odds ratios (OR) estimated using multilevel mixed effects logistic regression model while accounting for household clusters."
Participants	**Number of participants:** 160 households, 80 control, 80 intervention. Median 4 participants per household. **Method of recruitment:** household enumeration exercise conducted and randomization carried out, in permuted blocks of 10 houses and 16 village blocks in the study site. In each village, 10 houses were randomly selected with half of them allocated treatment in a ratio of 1:1. **Recruitment rates:** not stated. **Withdrawal and loss to follow-up:** not stated. **Age:** individual socio-demographic information was collected but has not been published. **Sex:** male and female **Ethnicity:** individual socio-demographic information was collected but has not been published. **Socioeconomic status:** In 2015/16, overall poverty headcount rate was approximately 40.1%.
Interventions	**Intervention type:** screening of eaves **Detailed description of intervention and any theory informing it:** in the intervention arm, grey coloured fibre-glass coated wire mesh was tightly and firmly fitted over eaves to reduce entry points for malaria vectors into the home. **For insecticidal interventions, insecticide used and dosage:** N/A **Coverage:** N/A **Co-interventions:** none **Coverage of co-interventions:** N/A **Implemented by:** researchers and community project staff with local youth **Buffer size between clusters:** none **Economic information (intervention costs, changes in other costs as a result of intervention):** not stated **Resource requirements:** fibre-glass coated wire mesh, wooden frames, locally sourced elastic cloth lining **Description of house features in control and intervention arms:** the household characteristics in both arms were sheet roofs, mud walls and plaster finish on walls.
Outcomes	• Malaria parasite prevalence • Indoor female *An gambiae* s.l. density • Physiological state of collected indoor *An gambiae* (fed, unfed)
Notes	**Location profile** **Study location (urban/rural, socioeconomic status, topology of landscape):** Nyabondo, a rural plateau area located in Upper Nyakach sub-county of Kisumu County, about 30 km North-East of Lake

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Ng'ang'a 2020 *(Continued)*

Victoria, Kenya. Nyabondo lies between an altitude of 1520 m and 1658 m above sea level, and 0° 23′ 0 S and 34° 58′ 60 E.

Social context: largely dependent on agriculture and brick-making as economic activity. 31.9% of household heads/spouses had completed Primary education.

Malaria endemicity: baseline malaria prevalence 5.2 to 10%

EIR: not reported

Population proximity/density: 34,000 people with a high population density of nearly 460 persons per square km

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

Vector profile

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

Method of mosquito collection: sampling of adult mosquitoes using CDC light traps was conducted from January 2017 to November 2018 for 16 days each month, with all 10 houses in a cluster being sampled in one night.

For insecticidal interventions, resistance profile: N/A

Funding source

Study funding source: this research work was funded by Biovision (BV) Foundation, Project Number BV HH-07 / 2016-18, and core financial assistance to the International Centre of Insect Physiology and Ecology (ICIPE) provided by UK's Department for International Development (DFID), the Swedish International Development Cooperation Agency (Sida), the Swiss Agency for Development and Cooperation (SDC), the German Federal Ministry for Economic Cooperation and Development (BMZ), and the Kenyan and Ethiopian Governments.

Pinder 2021

Study characteristics

Methods

Status: completed and published

Study design: a household-randomized controlled study using a generalized, randomized, complete, block design, with the village as the block.

Unit of allocation: individual

Number of units: 800 houses from 91 villages, 400 per arm.

Outcome assessment/surveillance type

Epidemiological

- Clinical malaria incidence: incidence of clinical disease was assessed by active case detection during home visits by trained nurse field assistants twice a week (June 2016 to December 2017). Axillary temperature was taken and a rapid diagnostic test (RDT) was done immediately if the axillary temperature was 37.5 °C or more, if the child had had fever since the previous visit, or was feeling unwell.
- Parasite prevalence: a blood sample was collected for thick films for *P falciparum* detection only when the axillary temperature was 37.5 °C or more.
- Respiratory disease: presence of a cough, a raised age-specific respiratory rate or chest indrawing was also assessed.

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Pinder 2021 *(Continued)*

- Enlarged spleen: cross-sectional surveys were conducted in December 2016, June 2017, and December 2017 where a clinical examination was performed on all study children, axillary temperature collected, and spleen size assessed.
- Anaemia: fingerprick tests of children were performed for anaemia, and an RDT was done.

Entomological

- Adult mosquito density: Indoor mosquito collections were made using CDC light traps 1 m from the ground at the foot end of a study child's insecticide-treated net to estimate the potential exposure to malaria vectors. This took place once a month from June to December in 2016 and 2017. Mosquitoes were identified by microscopy, and the numbers of *An gambiae* s.l. and other species will be recorded.
- Sporozoite rate: The presence of sporozoites in *An gambiae* s.l. was 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 a cluster-RCT. An analysis adjusted for age, riverbank, month of the year and ethnicity was carried out.

Participants	**Number of participants:** 410 houses in control, 395 houses in intervention arm **Method of recruitment:** 800 houses randomly selected from 91 villages. Within each village the houses were randomly allocated to the control and intervention groups. One child was randomly selected from each house and stratified by age (younger or older than 72 months) for each group. At least four houses (two per study group) were enrolled in each village. **Recruitment rates:** 398 children randomly assigned to control group and 402 to intervention group at baseline. Control: further 8 children recruited in 2016 and 30 in 2017. Intervention: further 5 children recruited in 2016 and 16 in 2017. At least four houses (two per study group) were enrolled in each village. **Withdrawal and loss to follow-up:** Children who did not have at least 50% of clinical visits per year were excluded. 26 lost in control group, 28 lost in intervention group. **Age:** children aged between 6 months and 13 years, control median 6 years (IQR 4-8), intervention median 5 years (IQR 3 to 8) **Sex:** control 47% female, intervention 49% female **Ethnicity:** control: 64% Fula, 33% Mandinka, 2% Other. Intervention: 64% Fula, 32% Mandinka, 4% Other **Socioeconomic status:** Not stated
Interventions	**Intervention type:** screening doors and windows plus replace thatched roof. **Detailed description of intervention and any theory informing it:** in the intervention arm thatched roofs were replaced with metal roofs, eaves were closed, metal-louvered screened doors were fitted at the front of the house and wooden screened doors fitted at the back, windows screened. **For insecticidal interventions, insecticide used and dosage:** N/A **Coverage:** N/A **Co-interventions:** insecticide-treated nets were provided to all occupants in July 2016 by the National Malaria Control Programme (NMCP) in August 2017, as part of the national mass campaign. **Coverage of co-interventions:** across whole study site **Implemented by:** researchers **Buffer size between clusters:** not stated **Economic information (intervention costs, changes in other costs as a result of intervention):** not stated

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Pinder 2021 *(Continued)*

	Resource requirements: not stated **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 • EIR • Incidence of respiratory infection • Number of cases of severe malaria • Mean number of mosquitoes caught indoors • Sporozoite rate • Haemoglobin density • Adverse events
Notes	**Location profile** **Study location (urban/rural, socioeconomic status, topology of landscape):** urban and rural areas in the Upper River Region of The Gambia, an area of open Sudanian savanna with moderate levels of malaria transmission during the rainy season. **Social context:** not described **Malaria endemicity:** baseline parasite prevalence 2% to 5% **EIR:** not stated **Population proximity/density:** not stated ***Plasmodium* species:** *P falciparum* **Vector profile** **Primary (and secondary vector species):** *An gambiae* s.l **Method of mosquito collection:** indoor collection using CDC light traps for 16 days each month in 120 houses. **For insecticidal interventions, resistance profile:** N/A **Funding source** **Study funding source:** funded by the MRC-DfID Wellcome Trust.

Sternberg 2021

Study characteristics	
Methods	**Status:** completed and published **Study design:** two-armed, cluster-randomized controlled trial • Screening plus eave tubes (SET) + LLINs • LLINs only **Unit of allocation:** cluster (village) **Number of units:** 20 villages per arm **Outcome assessment/surveillance type**

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Sternberg 2021 *(Continued)*

	Epidemiological • Clinical malaria incidence: Measured epidemiological impact through active case detection, once per month during dry season November to April and twice per month during rainy season May to October, by systematically screening 50 children per cluster for malaria. The axillary temperature of the children was taken and if the child was febrile or had a history of fever in the past 48h or the parents reported that the child was sick, the child received a physical examination (symptoms, pulse, respiratory rate). A finger prick blood sample was taken from all febrile children for a rapid malaria test. • Anaemia: At the start and end of the rainy season in both study years, the children in the cohort received a general physical exam. Haemoglobin concentrations were measured in children aged 5 years or younger. Entomological • Adult mosquito density: on 1 night per month, human landing catch sampling was performed indoors and outdoors in 4 randomly selected houses per cluster. Volunteers sat with their legs uncovered from 18:00 to 08:00, trapping mosquitoes that landed on their legs via haemolysis tubes plugged with cotton. • Sporozoite rate and EIR: mean mosquito densities for indoor and outdoor catches and sporozoite rates were recorded and an EIR was calculated. **Length of follow-up:** 2 years **Adjustment for clustering:** Yes
Participants	**Number of participants:** Control total 1300 children enrolled (1076 year 1; 224 year 2). Intervention total 1260 children enrolled (1088 year 1; 172 year 2). **Method of recruitment:** a census in all clusters was conducted to collect details of all household members, number of ITNs available, and structure of houses. From the census list, 60 children were randomly selected from each cluster. All the households in the cluster assigned to SET were offered SET if the structure of their house was suitable. **Recruitment rates:** 60 children per cluster (20 control clusters, 20 intervention clusters). **Withdrawal and loss to follow-up:** control: 121 lost to follow-up and 6 deaths after year 1; 137 lost to follow-up and 3 deaths after year 2. Intervention: 102 lost to follow-up and 2 deaths after year 1; 117 lost to follow-up and 1 death after year 2. **Age:** 6 months to 8 years old. Control mean 4.6 years (range 0.5 to 9.6). Intervention mean 4.7 years (range 0 to 8.8). **Sex:** control 50.5% male, intervention 50.1% male. **Ethnicity:** not stated. **Socioeconomic status:** not stated.
Interventions	**Intervention type:** screening plus eave tubes. **Detailed description of intervention and any theory informing it:** modifications consist of: covering windows and other openings used for ventilation with aluminium screens that allow airflow; 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; modifying doors to fully cover doorways when closed; and inserting insecticide treated eave tubes into the walls outside all occupied rooms (20cm below the roof at 1.5 to 2 m intervals). **For insecticidal interventions, insecticide used and dosage:** eave tubes were treated with 10% wettable powder formulation of the pyrethroid β-cyfluthrin. **Coverage:** intervention arm only.

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Sternberg 2021 *(Continued)*

Co-interventions: polyester nets treated with 1.8g/kg deltamethrin (PermaNet 2.0) distributed during a campaign between 8 March and 19 March 2017 in all clusters, according to Côte d'Ivoire's National Malaria Control Program.

Coverage of co-interventions: whole study site

Implemented by: researchers

Buffer size between clusters: at least 2 km

Economic information (intervention costs, changes in other costs as a result of intervention): total economic costs of the interventions were USD 239.46 per house from the societal perspective and USD 215.38 per house from the provider perspective.

Resource requirements: work teams required to instal interventions: PVC tubes plus insecticide-treated eave tube inserts, custom-built wooden frames for windows with untreated UV-resistant PVC-plasticides glass-fibre enforced netting, brick, cement and plaster to seal open eaves.

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

- Incidence of clinical malaria
- Prevalence of anaemia
- EIR
- Malaria vector density
- Anaemia prevalence

Notes

Location profile

Study location (urban/rural, socioeconomic status, topology of landscape): rural study site 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 stated

Malaria endemicity: highly endemic area with year-round transmission, peaking during the rainy season (May through October). Baseline malaria infection prevalence 73.9% (control group), 72.4% (intervention group).

EIR: not stated

Population proximity/density: 8390 houses with 55,404 inhabitants in the study are at the time of the consensus.

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

Vector profile

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

Method of mosquito collection: human landing catch sampling.

For insecticidal interventions, resistance profile: area of intense pyrethroid resistance but initial assays showed 100% mortality of the pyrethroid β-cyfluthrin against wild-type mosquitoes using eave tubes.

Funding source

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

ACS: active case surveillance; **ACD:** active case detection; **CDC:** Centers for Diseases Control and Prevention; **DfID:** Department for International Development;**EIR:** entomological inoculation rate; **ELISA:** enzyme-linked immunosorbent assay; **Hb:** haemoglobin; **HLC:**

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human landing catches; **HI:** household improvement; **ITN**: insecticide-treated nets; **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; **PSC:** pyrethrum spray catch; **PVC:** polyvinyl chloride; **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.
Carrasco-Tenezaca 2021	Experimental hut trial, not a permanent dwelling.
Gouissi 2013	Study design did not meet the inclusion criteria.
Nguela 2020	No epidemiological outcomes.

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

Asale 2020

Study name	Asale 2020
Methods	**Status:** preprint protocol (not peer reviewed) **Study design:** household-randomized controlled trial with four arms • Arm 1: house screening + long-lasting insecticidal nets (LLINs) • Arm 2: Push-pull technology (PPT) + LLINs • Arm 4: House screening + PPT + LLINs • Arm 3: LLINs only (control) **Unit of allocation:** cluster (household) **Number of units:** 30 clusters, 838 households. 167 control, 246 HI **Outcome assessment/surveillance type** Epidemiological Incidence of clinical malaria will be assessed by active infection detection documented during fortnightly house to house visits over the course of the two-year study period. The axillary temperature will be taken fortnightly by CHWs from all enrolled study children; if the child shows ≥ 37.5 °C or history of fever in the past 48 hours, then a rapid diagnostic test will be conducted. The second epidemiological outcome will be the prevalence of anaemia among the study participants. Entomological Indoor and outdoor mosquito catches will be collected from 8 houses (4 indoor, 4 outdoor) in each study village using CDC light traps. Indoor traps will be hung from the ceiling at the foot end of the bed, 1.5 m from the floor, and outdoor traps will be hung under eaves. Collections will be made from 18:00 to 06:00. They will be used to determine the density of malaria vectors, and will be examined to identify whether they are fed or unfed, and determine sporozoite rates. **Length of follow-up:** 2 years (September 2020 to December 2022) **Adjustment for clustering:** "Mixed effects Poisson model will be used to test the difference in incidence rate among the study arms, to determine effects of the repeated measurements within house, village, the effect of year and village-intervention interaction effects. To control the effect of

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Asale 2020 *(Continued)*

	clustering or village and individual level confounding factors such as gender and age, these covariates will be fitted in to random effects during analysis."
Participants	**Number of participants:** 838 (167 control, 246 screening) **Method of recruitment:** a total of 500 metal-roofed houses constructed with mud walls, and without screening, with at least one child aged 6 months to 14 years, will be selected. Consent will be sought from the parents or guardians for them to join the study by field assistants. Stratified randomization by sub-kebeles will take out the kebele effect and the likelihood of chance imbalances between study arms. **Recruitment rates:** not reported **Withdrawal and loss to follow-up:** not reported **Age:** < 14 years **Sex:** male and female **Ethnicity:** not reported **Socioeconomic status:** not reported
Interventions	**Intervention type:** modification to existing structure, door and window screening **Detailed description of intervention and any theory informing it:** doors and windows screened with mesh. Household owners will be trained on the care needed to keep the screens intact and effective and avoid activities that could result into making holes in the mesh or cause the screen to slide and create spaces that could allow mosquito entry into the houses. **For insecticidal interventions, insecticide used and dosage:** N/A **Coverage:** N/A **Co-interventions:** LLINs **Coverage of co-interventions:** pyrethroid-based DuraNets will be provided to all households (treatment and control) at the rate of 1 bed net for 2 people following the NMCP and per WHO recommended universal net coverage. **Implemented by:** trained community members **Buffer size between clusters:** none **Economic information (intervention costs, changes in other costs as a result of intervention):** not stated **Resource requirements:** LLINs and locally acquired mesh for screening **Description of house features in control and intervention arms:** household characteristics included metal roofs and mud walls.
Outcomes	• Malaria case incidence • Splenomegaly • Anaemia • Mosquito density • Sporozoite rates • EIR
Starting date	null
Contact information	null

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Asale 2020 *(Continued)*

Notes	**Location profile** **Study location (urban/rural, socioeconomic status, topology of landscape):** Jabi-Tehnan districts of Amhara regional state, Western Ethiopia. The altitude of the district ranges from 900 to 2300 m above sea level. Much of the area lies in the higher altitude range, closer to 2300 m. Agro-ecologically, 88% of the district is classified as mid-land and the remaining 12% as low land. The topography of the district is dominated by areas of at plain. **Social context:** More than 90% of the people in the district live in rural areas practising mixed farming. **Malaria endemicity:** A cross-sectional active malaria prevalence survey from randomly selected kebeles of the district in 2013 showed the disease prevalence of 2.8%. **EIR:** not reported **Population proximity/density:** The population of the district was 211,516 in 2017 with an average annual growth rate of 2.8%. ***Plasmodium* species:** *P falciparum* and *P vivax* **Vector profile** **Primary (and secondary vector species):** *Anopheles gambiae* s.l. and *Anopheles pharoensis* **Method of mosquito collection:** Indoor and outdoor mosquito catches will be collected from 8 houses (4 indoor, 4 outdoor) in each study village using CDC light traps. **For insecticidal interventions, resistance profile:** not reported **Funding source** **Study funding source:** Norwegian Agency for Development Cooperation (NORAD) through the project Combating Arthropod Pests for Better Health, Food and Resilience to Climate Change (CAP-Africa)

JPRN-UMIN000045079

Study name	JPRN-UMIN000045079
Methods	**Status:** preprint protocol (not peer reviewed) **Study ID:** JPRN-UMIN000045079 **Study design:** household-randomized controlled trial with two arms. • Arm 1: Screening with OlysetPlus ceiling nets • Arm 2: Control **Unit of allocation:** cluster (household) **Number of units:** not reported **Outcome assessment/surveillance type** Epidemiological Methods of assessment not described, but authors intend to measure prevalence of *Plasmodium* infections in children 3 to 15 years 6 and 12 months after OlysetPlus ceiling net installation, incidence of malaria across all ages 12 months after net installation, haemoglobin levels in children 3 to 15 years 6 and 12months after net installation, and prevalence of antibodies against *Anopheles* salivary proteins and *Plasmodium* antigens across all ages twelve months after net installation.

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JPRN-UMIN000045079 *(Continued)*

	Entomological Methods of assessment not described, but authors intend to measure density and composition of *Anopheles* vectors 6 and 12 months after net installation, and genomic profiles of *Plasmodium* parasites at 6 and 12 months after net installation. **Length of follow-up:** 12 months **Adjustment for clustering:** not described
Participants	**Number of participants:** 12,000 **Method of recruitment:** not reported **Recruitment rates:** not reported **Withdrawal and loss to follow-up:** not reported **Age:** 3 to 15 years **Sex:** male and female **Ethnicity:** not reported **Socioeconomic status:** not reported
Interventions	**Intervention type:** modification to existing structure, ceiling screening **Detailed description of intervention and any theory informing it:** not described **For insecticidal interventions, insecticide used and dosage:** N/A **Coverage:** screening will be installed to houses at a 1:1 ratio **Co-interventions:** none **Coverage of co-interventions:** N/A **Implemented by:** not reported **Buffer size between clusters:** not reported **Economic information (intervention costs, changes in other costs as a result of intervention):** not reported **Resource requirements:** screening fabric, other installation materials **Description of house features in control and intervention arms:** not reported
Outcomes	• Parasite prevalence • Clinical malaria incidence • Haemoglobin levels • Prevalence of antibodies against *Anopheles* salivary proteins and *Plasmodium* antigens • Indoor mosquito density
Starting date	1 September 2021
Contact information	Wataru Kagaya, Osaka Metropolitan University Graduate School of Medicine Akira Kaneko, Osaka Metropolitan University Graduate School of Medicine
Notes	**Location profile**

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JPRN-UMIN000045079 *(Continued)*

Study location (urban/rural, socioeconomic status, topology of landscape): Lake Victoria basin, Kenya

Social context: not described

Malaria endemicity: not reported

EIR: not reported

Population proximity/density: not reported

***Plasmodium* species:** not reported

Vector profile

Primary (and secondary vector species): not reported

Method of mosquito collection: not reported

For insecticidal interventions, resistance profile: not reported

Funding source

Study funding source: Japan International Cooperation Agency-Science and Technology Research Partnership for Sustainable Development (JICA-SATREPS)

Mshamu 2022

Study name	Mshamu 2022
Methods	**Status:** preprint protocol (not peer reviewed) **Study design:** household-randomized controlled trial with 2 arms • Newly constructed novel design houses • Traditional control houses **Unit of allocation:** cluster (household) **Number of units:** 110 intervention houses, 440 control houses **Outcome assessment/surveillance type:** Epidemiological For the active case surveillance trained research assistants will visit each child weekly and collect disease and travel history, temperature, and a rapid diagnostic test to detect *P falciparum* infections if there is history of fever since the last visit. Passive case detection will be conducted in all health care facilities serving the study population. To detect any difference in parasite prevalence between participants in the 2 study arms annual malaria surveys will be conducted. Dried blood spots (DBS) and a rapid test for malaria will be collected from all children participating in this study. This survey will be done 4 times throughout the 3-year study period (at the beginning, and once every year for 3 years). Entomological Standard CDC light traps will be used to estimate the potential exposure to malaria mosquitoes in the bedrooms of study children in 110 novel design houses and their nearest comparison house from October 2021 to December 2023. **Length of follow-up:** 3 years (2022 to 2024)

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Mshamu 2022 *(Continued)*

	Adjustment for clustering: "Since ICCs that accommodate village and household level clustering are rarely reported, we compensated clustering from both levels by choosing a conservatively high ICC of 0.6." Protective efficacy against clinical malaria will be assessed by comparing incidence rates between the two study arms adopting an intention-to-treat analysis.
Participants	**Number of participants:** 1650 children (1320 control, 330 intervention) **Method of recruitment:** Following the selection of 68 eligible villages a census of 14,600 households in the 68 villages was conducted, and eligible houses were recruited. All households meeting the eligibility criteria were invited to participate in a randomization process in the form of a village lottery. A total of 862 households were eligible to participate in a lottery to select: firstly the 110 new house owners and secondly the 440 household to serve as comparison houses. **Recruitment rates:** 550 out of 862 eligible households were recruited into the study. **Withdrawal and loss to follow-up:** not reported **Age:** < 13 years **Sex:** male and female **Ethnicity:** not reported **Socioeconomic status:** not reported
Interventions	**Intervention type:** novel house construction **Detailed description of intervention and any theory informing it:** novel house with an elevated sleeping area, shade-net as cladding to optimise airflow while minimising the entry of insects. Three doors with a spring powered closing mechanism to minimise the time that the doors stay open. The ground floor cooking area is screened to improved airflow and reduce the entry of flies. **For insecticidal interventions, insecticide used and dosage:** N/A **Coverage:** N/A **Co-interventions:** routine government health interventions include the distribution of ITNs. **Coverage of co-interventions:** all households in study area **Implemented by:** not reported **Buffer size between clusters:** none **Economic information (intervention costs, changes in other costs as a result of intervention):** construction costs of novel design houses will be estimated and used to assess incremental costs and cost-effectiveness of the interventions. **Resource requirements:** not reported **Description of house features in control and intervention arms** Control: Traditional house design constructed with mud walls, thatched roof and dirt floor. Intervention: elevation of the sleeping area by constructing double-storey buildings and the use of shade-net as cladding to optimise airflow while minimising the entry of insects. Three doors with a spring powered closing mechanism to minimise the time that the doors stay open. The ground floor cooking area is screened to improved airflow and reduce the entry of flies.
Outcomes	• Incidence of clinical malaria • Parasite prevalence • Indoor mosquito density • Acceptability of interventions • Bednet use

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Mshamu 2022 *(Continued)*

- Durability
- Cost-effectiveness

Starting date	2022
Contact information	Not reported
Notes	**Location profile** **Study location (urban/rural, socioeconomic status, topology of landscape):** Mtwara region, on the south-east coast of Tanzania. It is an area of forest and scrubland with two rainy seasons. **Social context:** Mtwara region is a leading cashew producer in Tanzania and more than 90% of its residents are engaged in cashew production, with a few fishers. **Malaria endemicity:** the population-adjusted *P falciparum* parasite rate standardized to the age group 2 to 10 years is high (PAPfPR 2 to 10 > 30%). **EIR:** not reported **Population proximity/density:** Mtwara has an area of 16,710 km^2 and comprises 5 districts and 9 councils with a population of 1,424,083 people in 2018. ***Plasmodium* species:** *Plasmodium falciparum* **Vector profile** **Primary (and secondary vector species):** *An gambiae* s.l., *An funestus* s.l. **Method of mosquito collection:** standard CDC light traps will be used to estimate the potential exposure to malaria mosquitoes in the bedrooms of study children in 110 novel design houses and their nearest comparison house from October 2021 to December 2023. Collections will be made from one cluster each week, with a different sub-cluster sampled on four consecutive nights each week, Monday night to Thursday night. At the end of the week all houses will be sampled in each cluster (i.e. 32 houses). **For insecticidal interventions, resistance profile:** not reported **Funding source** **Study funding source:** funded by the Hanako Foundation, Singapore

NCT04622241

Study name	NCT04622241
Methods	**Status:** study record detail (clinical trial) **Study ID:** NCT04622241 **Study design:** cluster-randomized controlled trial with up to two arms. Four arms to be investigated in pilot on both traditional and modern houses, then a cluster-randomized control trial of the most effective, scalable, and cost-effective interventions. - Arm 1: eave and window screening - Arm 2: eave or ceiling screening - Arm 3: eave tubes - Arm 4: eave ribbons **Unit of allocation:** cluster (village)

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NCT04622241 *(Continued)*

	Number of units: 60 clusters, 20 in arm 1, 20 in arm 2, 20 in control **Outcome assessment/surveillance type** Epidemiological Incidence of clinical malaria in children < 60 months will be assessed, as well as parasite prevalence, and prevalence of anaemia. Protocol not described. Entomological Entomology surveys will use CDC light traps. Vector density, sporozoite rate, EIR, proportion of mosquitoes with insecticide resistance. **Length of follow-up:** 12 months **Adjustment for clustering:** not stated
Participants	**Number of participants:** 9300 **Method of recruitment:** A cluster is defined as a segment of a village with ~100 households; method of recruitment not stated **Recruitment rates:** not reported **Withdrawal and loss to follow-up:** not reported **Age:** < 60 months **Sex:** male and female **Ethnicity:** not reported **Socioeconomic status:** not reported
Interventions	**Intervention type:** modification to existing structure, screening, eave tubes, eave ribbons **Detailed description of intervention and any theory informing it:** arm 1: full house screening includes screening eaves/ceilings, ventilation openings, and windows. Eaves/ceiling, air vents, and windows of eligible houses will be screened with wire mesh or other locally available screening materials. Arm 2: partial screening will include either screening of the eaves or installing a screened ceiling, where no ceiling is present. In traditional houses, a netting (either insecticide-impregnated or untreated) may be either fixed in multiple places in the rafters or by hanging from a single central point and attached to the walls. Arm 3: the eave tubes are PVC tubes with a diameter of 15 cm installed in the outer wall of occupied rooms at 1.5 to 2 m intervals, fitted with electrostatic mesh inserts coated with insecticides. Arm 4: eave ribbons are 15 cm-wide triple-layered hessian fabrics (burlap-line fabric woven from sisal fibres, procured locally), in lengths starting 1 m that can be attached to houses using nails, adhesives or Velcro, without completely closing eave-spaces. **For insecticidal interventions, insecticide used and dosage:** eave ribbons will be treated by study staff with a commonly used spatial repellent, transfluthrin. Insecticide for eave tubes not described. **Coverage:** N/A **Co-interventions:** all households will be provided with piperonyl butoxide (PBO) long-lasting insecticidal nets (LLINs). **Coverage of co-interventions:** all households, 1 for every 2 residents. **Implemented by:** not reported **Buffer size between clusters:** none

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NCT04622241 *(Continued)*

	Economic information (intervention costs, changes in other costs as a result of intervention): not reported **Resource requirements:** not reported **Description of house features in control and intervention arms:** interventions will be introduced to both modern and traditional homes.
Outcomes	• Incidence of clinical malaria in children < 60 months • Parasite prevalence • Prevalence of anaemia • Vector density • Sporozoite rate • EIR • Proportion of mosquitoes with insecticide resistance • Individual satisfaction • Costs
Starting date	September 2021
Contact information	Moses Kamya, Infectious Diseases Research Collaboration, Kampala Catherine Tugaineyo, Infectious Diseases Research Collaboration, Kampala
Notes	**Location profile** **Study location (urban/rural, socioeconomic status, topology of landscape):** Uganda. Study location not described. **Social context:** not reported **Malaria endemicity:** not reported **EIR:** not reported **Population proximity/density:** not reported ***Plasmodium* species:** not reported **Vector profile** **Primary (and secondary vector species):** not reported **Method of mosquito collection:** indoor collection using CDC light traps **For insecticidal interventions, resistance profile:** not reported **Funding source** **Study funding source:** sponsors and collaborators: Infectious Diseases Research Collaboration, Uganda Centers for Disease Control and Prevention, United States Agency for International Development (USAID), London School of Hygiene and Tropical Medicine, and University of California, San Francisco.

Odufuwa 2022

Study name	Odufuwa 2022
Methods	**Status:** preprint protocol (not peer reviewed)

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Odufuwa 2022 *(Continued)*

	Study design: household-randomized controlled trial with two arms • Arm 1: Screening with insecticide-treated window screens (ITWS) and insecticide-treated eave nets (ITENs) • Arm 2: Control **Unit of allocation:** cluster (household) **Number of units:** 450 households **Outcome assessment/surveillance type:** Epidemiological Prevalence of *P. falciparum* parasites will be assessed using qPCR in residents over 6 months of age at 6- and 12-months after installation of screening. Clinical malaria incidence will be diagnosed using an axillary temperature of 37.5 degrees or more (fever) and positive RDT at 6- and 12-months after installation of screening. Entomological Indoor mosquito catches will be collected using CDC light traps. They will be used to determine the density of malaria vectors and nuisance mosquitoes. **Length of follow-up:** 12 months **Adjustment for clustering:** not described
Participants	**Number of participants:** 1800 **Method of recruitment:** recruit households from Chalinze district, Tanzania upon written consent. No further details. **Recruitment rates:** not reported **Withdrawal and loss to follow-up:** not reported **Age:** < 6 months **Sex:** male and female **Ethnicity:** not reported **Socioeconomic status:** not reported
Interventions	**Intervention type:** modification to existing structure, window and eave screening **Detailed description of intervention and any theory informing it:** insecticide-Treated Eave nets (ITENs) in combination with insecticide-treated window screens (ITWS), coated with a dual active ingredient (dual AI): deltamethrin at 3g AI/kg, which corresponds to 144 mg/m^2 and PBO synergist at 10g/kg which corresponds to 480 mg/m^2, as used in the so-called dual-AI LLIN or "resistance breaking" nets for resistance malaria vector control. **For insecticidal interventions, insecticide used and dosage:** deltamethrin at 3g AI/kg, which corresponds to 144 mg/m^2, and PBO synergist at 10g/kg, which corresponds to 480 mg/m^2 **Coverage:** screening will be installed to houses at a 1:1 ratio **Co-interventions:** none **Coverage of co-interventions:** N/A **Implemented by:** not reported **Buffer size between clusters:** not reported

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Odufuwa 2022 *(Continued)*

	Economic information (intervention costs, changes in other costs as a result of intervention): material cost and time to instal intervention will be recorded. **Resource requirements:** insecticide treated fabric, other installation materials **Description of house features in control and intervention arms:** intact walls, opened eaves, and those without screens or nets on the windows
Outcomes	• Parasite prevalence • Clinical malaria incidence • Indoor mosquito density • Cost of intervention • Adverse effects • Community views • Insecticide bioefficacy
Starting date	9 July 2021
Contact information	Zawadi Mboma: zmageni@ihi.or.tz Rose Philipo: rphilipo@ihi.or.tz
Notes	**Location profile** **Study location (urban/rural, socioeconomic status, topology of landscape):** Chalinze district, Tanzania **Social context:** not described **Malaria endemicity:** not reported **EIR:** not reported **Population proximity/density:** not reported ***Plasmodium* species:** *P falciparum* **Vector profile** **Primary (and secondary vector species):** not reported **Method of mosquito collection:** indoor mosquito catches using CDC light traps. **For insecticidal interventions, resistance profile:** not reported **Funding source** **Study funding source:** sponsor: Ifakara Health Institute; Collaborators: London School of Hygiene and Tropical Medicine, Swiss Tropical & Public Health Institute

Sangoro 2021

Study name	Sangoro 2021 (protocol)
Methods	**Status:** published protocol **Study design:** multi-country, two-armed household-randomized controlled trial. House screening + LLINs, versus LLINs only. **Unit of allocation:** cluster (household)

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Sangoro 2021 *(Continued)*

	Number of units: 800 households. 400 control, 400 intervention **Outcome assessment/surveillance type:** Epidemiological Clinical malaria incidence in participating children by active case detection - body temperature measurement every fortnight for 3 to 6 months in high malaria transmission season (January to May) for 2 years. Children with temperatures above 37 °C or febrile illness with have an RDT for malaria. Parasite prevalence assessed in children at start and end of the transmission season for 2 years. Entomological Vector biting and resting indoor densities will be measured using CDC light traps and PSC techniques in 120 intervention and control houses. **Length of follow-up:** 2 years **Adjustment for clustering:** "A mixed-effects model will be used to compare clinical malaria incidence rates between the intervention and control arms, to allow for repeated measures within households, villages, and the effect of year. Possible confounders such as the age of child, gender, ethnicity, and season will be included in the models... A Poisson distribution model with a log link function will be used, and a random factor for each data point will be included in the model to adjust for excess variation between data points (over-dispersion)."
Participants	**Number of participants:** 800 (400 control, 400 intervention) **Method of recruitment:** study participants will be recruited by the national project team in consultation with local health workers. For allocation of the households, a computer-generated list of random numbers was used. Households were randomly assigned following simple randomization procedures (computerized random numbers) to either the intervention or control group. The allocation was stratified by the village. Households must include at least 1 child aged 6 months to 13 years, be 50 m apart and be of a 'semi-modern' character. **Recruitment rates:** not reported **Withdrawal and loss to follow-up:** not reported **Age: 6 months to 13 years** **Sex:** male and female **Ethnicity:** not reported **Socioeconomic status:** not reported
Interventions	**Intervention type:** modification to existing structure, full screening **Detailed description of intervention and any theory informing it:** all mosquito entry points screened, including doors, windows and eaves **For insecticidal interventions, insecticide used and dosage:** N/A **Coverage:** N/A **Co-interventions:** LLINs **Coverage of co-interventions:** all households **Implemented by:** "Community implemented" **Buffer size between clusters:** none

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Sangoro 2021 *(Continued)*

	Economic information (intervention costs, changes in other costs as a result of intervention): not stated **Resource requirements:** LLINs and locally acquired mesh for screening **Description of house features in control and intervention arms:** houses that have either a tin or tiled roof; mud, stone, or wooden walls and earthen or cemented floors (semi-modern) with few open spaces for potential mosquito entry and screening; the houses should not be in such a debilitated state that it is impossible to cover up the mosquito entry points.
Outcomes	• Clinical malaria incidence • Parasite prevalence • Indoor vector density • Incremental costs • Acceptability in the community
Starting date	Participant recruitment started February 2019
Contact information	psangoro@icipe.org
Notes	

ACS: active case surveillance; **ACD:** active case detection; **CDC:** Centers for Diseases Control and Prevention; **CHW**: community health worker; **DfID:** Department for International Development;**ELISA:** enzyme-linked immunosorbent assay; **EIR:** entomological inoculation rate; **Hb:** haemoglobin; **HI:** household improvement; **HLC:** human landing catches; **ITENs:** insecticide-treated eave nets; **ITWS:** insecticide-treated window screens; **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; **PPT**: push-pull technology; **PSC:** pyrethrum spray catch; **PVC:** polyvinyl chloride; **RDT:** rapid diagnostic test; **SET:** screening plus eaves tubes; **SPSS:** Statistical Package for the Social Sciences; **USD:** US dollars.

RISK OF BIAS

Legend: ✓ Low risk of bias ✗ High risk of bias ~ Some concerns

Risk of bias for analysis 1.1 Parasite prevalence

	Bias					
Study	**Randomisation process**	**Deviations from intended interventions**	**Missing outcome data**	**Measurement of the outcome**	**Selection of the reported results**	**Overall**
Kirby 2009	✓	✓	✓	✓	✓	✓
McCann 2021	✓	✓	✓	✓	✓	✓
Minakawa 2022	✓	✓	✓	✓	~	~
Ng'ang'a 2020	✓	✓	✓	✓	~	~
Pinder 2021	✓	✓	✓	✓	✓	✓

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Risk of bias for analysis 1.2 Clinical malaria incidence

	Bias					
Study	**Randomisation process**	**Deviations from intended interventions**	**Missing outcome data**	**Measurement of the outcome**	**Selection of the reported results**	**Overall**
Getawen 2018	✓	✓	✓	✓	~	~
Pinder 2021	✓	✓	✓	✓	✓	✓
Sternberg 2021	✓	✓	~	✓	✓	✗

Risk of bias for analysis 1.3 Moderate to severe anaemia prevalence

	Bias					
Study	**Randomisation process**	**Deviations from intended interventions**	**Missing outcome data**	**Measurement of the outcome**	**Selection of the reported results**	**Overall**
Kirby 2009	✓	✓	✓	✓	✓	✓
Pinder 2021	✓	✓	✓	✓	✓	✓
Sternberg 2021	✓	✓	✓	✓	✓	✗

Risk of bias for analysis 1.4 Adult mosquito density

	Bias					
Study	**Randomisation process**	**Deviations from intended interventions**	**Missing outcome data**	**Measurement of the outcome**	**Selection of the reported results**	**Overall**
Subgroup 1.4.1 Primary analysis						
Kirby 2009	✓	✓	✓	✓	✓	✓
McCann 2021	✓	✓	✓	✓	✓	✓
Pinder 2021	✓	✓	✓	✓	✓	✓

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	Bias					
Study	Randomisation process	Deviations from intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported results	Overall
Sternberg 2021	✓	✓	✓	✓	✓	✗

DATA AND ANALYSES

Comparison 1. Modification versus no modification

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1.1 Parasite prevalence	5	5183	Risk Ratio (IV, Fixed, 95% CI)	0.68 [0.57, 0.82]
1.2 Clinical malaria incidence	3		Rate Ratio (IV, Fixed, 95% CI)	Totals not selected
1.3 Moderate to severe anaemia prevalence	3	3643	Risk Ratio (IV, Fixed, 95% CI)	0.70 [0.55, 0.89]
1.4 Adult mosquito density	4		Rate Ratio (IV, Random, 95% CI)	0.63 [0.30, 1.30]
1.4.1 Primary analysis	4		Rate Ratio (IV, Random, 95% CI)	0.63 [0.30, 1.30]
1.5 Entomological inoculation rate	1		Odds Ratio (IV, Fixed, 95% CI)	0.30 [0.27, 0.34]
1.6 Bed net use	3		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
1.6.1 Bed net use	3	2508	Risk Ratio (M-H, Fixed, 95% CI)	0.95 [0.92, 0.98]

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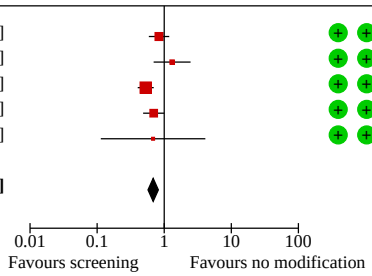
Analysis 1.1. Comparison 1: Modification versus no modification, Outcome 1: Parasite prevalence

Study or Subgroup	log[RR]	SE	Screening Total	Control Total	Weight	Risk Ratio IV, Fixed, 95% CI	Risk Ratio IV, Fixed, 95% CI	Risk of Bias A B C D E F
Kirby 2009	-0.178146	0.178569	591	164	25.7%	0.84 [0.59 , 1.19]		+ + + + + +
McCann 2021 (1)	0.27025	0.32329	931	531	7.8%	1.31 [0.70 , 2.47]		+ + + + + +
Minakawa 2022	-0.634878	0.140081	339	385	41.7%	0.53 [0.40 , 0.70]		+ + + + ? ?
Ng'ang'a 2020	-0.36071	0.185277	1034	403	23.8%	0.70 [0.48 , 1.00]		+ + + + ? ?
Pinder 2021	-0.382457	0.915352	395	410	1.0%	0.68 [0.11 , 4.10]		+ + + + + +
Total (95% CI)			**3290**	**1893**	**100.0%**	**0.68 [0.57 , 0.82]**		



Heterogeneity: Chi² = 8.64, df = 4 (P = 0.07); I² = 54%
Test for overall effect: Z = 4.19 (P < 0.0001)
Test for subgroup differences: Not applicable

Footnotes

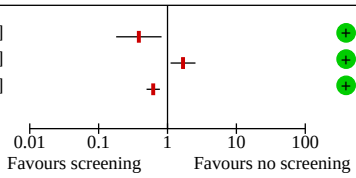
(1) Participant numbers for McCann 2021 and Ng'ang'a 2020 were calculated from the number of participants selected per survey, but some participants may have been selected

Risk of bias legend

(A) Bias arising from the randomization process
(B) Bias due to deviations from intended interventions
(C) Bias due to missing outcome data
(D) Bias in measurement of the outcome
(E) Bias in selection of the reported result
(F) Overall bias

Analysis 1.2. Comparison 1: Modification versus no modification, Outcome 2: Clinical malaria incidence

Study or Subgroup	log[Rate Ratio]	SE	Screening Total	Control Total	Rate Ratio IV, Fixed, 95% CI	Rate Ratio IV, Fixed, 95% CI	Risk of Bias A B C D E F
Getawen 2018	-0.958247	0.38683	239	238	0.38 [0.18 , 0.82]		+ + + + ? ?
Pinder 2021	0.518794	0.212181	395	410	1.68 [1.11 , 2.55]		+ + + + + +
Sternberg 2021	-0.478036	0.113442	1041	1042	0.62 [0.50 , 0.77]		+ + ? + + -



Risk of bias legend

(A) Bias arising from the randomization process
(B) Bias due to deviations from intended interventions
(C) Bias due to missing outcome data
(D) Bias in measurement of the outcome
(E) Bias in selection of the reported result
(F) Overall bias

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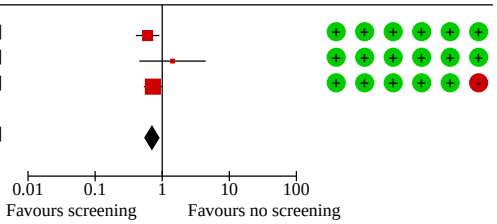
Analysis 1.3. Comparison 1: Modification versus no modification, Outcome 3: Moderate to severe anaemia prevalence

Study or Subgroup	log[RR]	SE	Screening Total	Control Total	Weight	Risk Ratio IV, Fixed, 95% CI
Kirby 2009 (1)	-0.502041	0.205397	591	164	35.5%	0.61 [0.40 , 0.91]
Pinder 2021	0.353383	0.579917	395	410	4.4%	1.42 [0.46 , 4.44]
Sternberg 2021	-0.319539	0.157831	1041	1042	60.1%	0.73 [0.53 , 0.99]
Total (95% CI)			**2027**	**1616**	**100.0%**	**0.70 [0.55 , 0.89]**

Heterogeneity: Chi² = 2.06, df = 2 (P = 0.36); I² = 3%
Test for overall effect: Z = 2.90 (P = 0.004)
Test for subgroup differences: Not applicable



Footnotes
(1) ICC = 0.06. Pooled data from full screening and screened ceilings arms.

Risk of bias legend
(A) Bias arising from the randomization process
(B) Bias due to deviations from intended interventions
(C) Bias due to missing outcome data
(D) Bias in measurement of the outcome
(E) Bias in selection of the reported result
(F) Overall bias

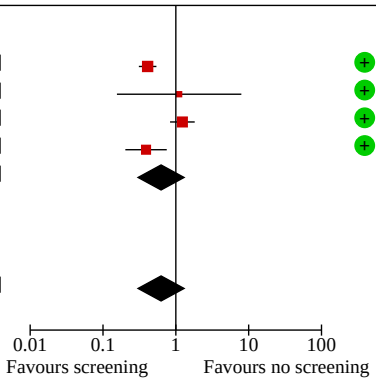
Analysis 1.4. Comparison 1: Modification versus no modification, Outcome 4: Adult mosquito density

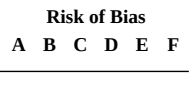
Study or Subgroup	log[Rate Ratio]	SE	Weight	Rate Ratio IV, Random, 95% CI
1.4.1 Primary analysis				
Kirby 2009 (1)	-0.891598	0.141583	32.5%	0.41 [0.31 , 0.54]
McCann 2021	0.10436	1.003348	9.7%	1.11 [0.16 , 7.93]
Pinder 2021	0.207014	0.198896	31.1%	1.23 [0.83 , 1.82]
Sternberg 2021	-0.941609	0.333765	26.7%	0.39 [0.20 , 0.75]
Subtotal (95% CI)			**100.0%**	**0.63 [0.30 , 1.30]**

Heterogeneity: Tau² = 0.40; Chi² = 22.10, df = 3 (P < 0.0001); I² = 86%
Test for overall effect: Z = 1.26 (P = 0.21)

Total (95% CI)			**100.0%**	**0.63 [0.30 , 1.30]**

Heterogeneity: Tau² = 0.40; Chi² = 22.10, df = 3 (P < 0.0001); I² = 86%
Test for overall effect: Z = 1.26 (P = 0.21)
Test for subgroup differences: Not applicable





Footnotes
(1) Pooled data from full screening and screened ceilings arms.

Risk of bias legend
(A) Bias arising from the randomization process
(B) Bias due to deviations from intended interventions
(C) Bias due to missing outcome data
(D) Bias in measurement of the outcome
(E) Bias in selection of the reported result
(F) Overall bias

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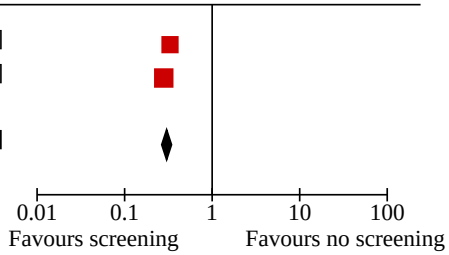
Analysis 1.5. Comparison 1: Modification versus no modification, Outcome 5: Entomological innoculation rate

Study or Subgroup	log[OR]	SE	Weight	Odds Ratio IV, Fixed, 95% CI
Sternberg 2021 (1)	-1.108663	0.096939	45.9%	0.33 [0.27 , 0.40]
Sternberg 2021 (2)	-1.272966	0.089286	54.1%	0.28 [0.24 , 0.33]
Total (95% CI)			**100.0%**	**0.30 [0.27 , 0.34]**

Heterogeneity: Chi² = 1.55, df = 1 (P = 0.21); I² = 36%
Test for overall effect: Z = 18.23 (P < 0.00001)
Test for subgroup differences: Not applicable



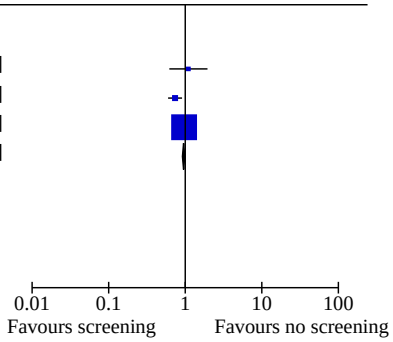
Footnotes
(1) Outdoor EIR
(2) Indoor EIR

Analysis 1.6. Comparison 1: Modification versus no modification, Outcome 6: Bed net use

Study or Subgroup	Screening Events	Screening Total	No screening Events	No screening Total	Weight	Risk Ratio M-H, Fixed, 95% CI
1.6.1 Bed net use						
Getawen 2018 (1)	11	19	10	19	1.0%	1.10 [0.62 , 1.95]
Kirby 2009 (1)	101	203	50	74	7.0%	0.74 [0.60 , 0.91]
Minakawa 2022	880	1035	1019	1158	92.0%	0.97 [0.93 , 1.00]
Subtotal (95% CI)		**1257**		**1251**	**100.0%**	**0.95 [0.92 , 0.98]**
Total events:	992		1079			

Heterogeneity: Chi² = 6.80, df = 2 (P = 0.03); I² = 71%
Test for overall effect: Z = 2.88 (P = 0.004)

Test for subgroup differences: Not applicable



Footnotes
(1) ICC = 0.375

ADDITIONAL TABLES

Table 1. Types of house modifications to prevent malaria

Intervention	Modification
Primary construction	
Wall	Mud or thatch replaced with wood, cement or brick
Door	Different door 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
Elevation	House built above ground level on stilts
Windows	Fewer or smaller windows

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Table 1. Types of house modifications to prevent malaria *(Continued)*

Modifications to existing homes	
Screening	Covering of potential entry points (ceilings, eaves, doors, windows gable ends) with: commonly PVC-coated fibreglass or metal mesh, or alternative materials found around the home
Roof	Thatch replaced with corrugated iron or tiles
Eave tubes	Eaves are closed and tubes with insecticide-coated electrostatic netting are inserted

PVC: polyvinyl chloride

Table 2. Modifications to existing homes

Intervention	**Description**
Screening modifications: reducing mosquito entry points	
Doors and windows	Screening or complete closure of potential entry points with PVC-coated fibreglass, metal mesh, or alternative materials found around the home[a]
Eaves	
Ceiling	
Other openings	
Other modifications: replacement of house features with the intention of increasing structural integrity of the home against vectors or targetted killing of mosquitoes	
Roof	Thatch replaced with metal or tiles
Door	Door designs that reduce mosquito entry
Windows	Fewer or smaller windows
Eave tubes	Eaves are closed and tubes screened with insecticide-coated electrostatic netting are inserted to lure-and-kill mosquitoes

[a]Screening may be with or without insecticide.
PVC: polyvinyl chloride

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Table 3. Intervention components of included studies

Study	House structure before modification	Screening					Other modifications	
		Eave screening	Eave closure	Ceiling	Doors and windows	Gaps and holes	Roof replacement	Eave tubes
Getawen 2018	Metal roof, mud walls				Yes			
Kirby 2009 - full screening arm	Thatched roof, open eaves, mud walls	Yes			Yes			
Kirby 2009 - ceiling screening arm	Thatched roof, open eaves, mud walls			Yes				
McCann 2021	Open eaves		Yes		Yes	Yes		
Minakawa 2022	Stick framework plastered with mud and cow dung, metal roof			Yes[a]				
Ng'ang'a 2020	Sheet roof, mud walls with plaster finish	Yes						
Pinder 2021	Thatched roof, mud or cement walls		Yes		Yes		Yes	
Sternberg 2021	Metal roof, cement walls		Yes		Yes[b]	Yes		Yes

Screening or complete closure of potential entry points done with polyvinyl chloride-coated fibreglass, metal mesh, or alternative materials found around the home.
[a]Minakawa 2022 screening with insecticide treated netting
[b]Sternberg 2021 screening on windows only

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Table 4. Clinical malaria incidence

Study	Rate of disease (event/person-year)		Rate ratio (95% CI)
	Screened houses	Unscreened houses	
Getawen 2018	0.09	0.24	0.38 (0.18 to 0.82)
Pinder 2021	0.20	0.12	1.68 (1.11 to 2.55)
Sternberg 2021	1.43	2.29	0.62 (0.50 to 0.77)

CI: confidence interval

Table 5. Haemoglobin levels

Study	Measurement	Screening	No screening
McCann 2021 Women (15 to 19 years)	Mean difference from baseline in haemoglobin level g/dL (95% CI)	12.61 (12.49 to 12.72)	12.46 (12.31 to 12.61)
McCann 2021 Children (6 to 59 months)	Mean difference from baseline in haemoglobin level g/dL (95% CI)	11.29 (11.16 to 11.42)	11.08 (10.89 to 11.27)
Minakawa 2022	Median concentration[a] (g/dL^{-1}) (IQR)	11.0 (0.2)	10.9 (0.2)

CI: confidence intervals; **IQR:** interquartile range
[a]Cluster-level median haemoglobin concentration

Table 6. Indoor adult mosquito density

Trial	Assessment method	Measurement	Screened houses	Unscreened houses	Effect size[a] (95% CIs)
Getawen 2018	Mosquitoes sampled from CDC light traps placed in 10 sentinel houses/study arm that were selected after randomization (6-month follow-up)	Mean no. mosquitoes/night/trap (95% CIs)	0.85 (0.45 to 2.15)	1.65 (0.80 to 6.80)	Rate ratio: 1.94 (1.38 to 2.72) higher rate of mosquitoes trapped per night in control
Ng'ang'a 2020	Number of adult mosquitoes collected from CDC light traps in every study house (2-year follow-up)	Mean no. mosquitoes/night/trap (95% CIs)	Total mosquitoes collected 3100 (mean per house 4.57; SD = 13.83)	Total mosquitoes collected 12,186 (mean per house 4.29; SD = 10.84	Adjusted difference (students t-test: t = 0.567, P = 0.571
Minakawa 2022	Number of adult mosquitoes collected from pyrethrum spray catches monthly from 80 sentinel houses (14-month follow-up)	Median vector density (IQR)	0.5 (0.3)	2.5 (1.9)	Adjusted risk ratio: 0.73 (0.53 to 0.92), P = 0.057, higher rate of mosquitoes trapped per night in control

[a]These effect sizes have not been adjusted for clustering unless stated as adjusted.
CI: confidence interval; **CDC:** Centers for Disease Control and Prevention;**IQR:** interquartile range; **SD:** standard deviation

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Table 7. Entomological inoculation rates

Trial	Outcome definition	Assessment method	Comparison	Mean EIR (95% CI)		Effect size[a] (95% CI)
				Screened houses	Un-screened houses	
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 to 0.96)	2.27 (1.38 to 3.16)	Mean difference: 1.50 (0.59 to 2.41), favouring the intervention
			Full screening versus no screening 2007	0.42 (0.24 to 0.63)	1.35 (0.74 to 1.97)	Mean difference: 0.93 (0.30 to 1.56), favouring the intervention
			Screened ceilings versus no screening 2006	1.14 (0.85 to 1.42)	2.27 (1.38 to 3.16)	Mean difference: 1.13 (0.20 to 2.06), favouring the intervention
			Screened ceilings versus no screening 2007	0.90 (0.22 to 1.57)	1.35 (0.74 to 1.97)	Mean difference: 0.45 (-0.46 to 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.	Screening versus no screening	1.75 (0.35 to 5.30)	6.32 (2.46 to 10.50)	Mean difference: 4.57 (3.81 to 5.33) favouring the intervention
McCann 2021		EIR was calculated as the product of the sporozoite rate and the number of host-seeking *Anopheles* mosquitoes collected per house using indoor and outdoor Suna traps.	Screening versus no screening	0.00 (0.00 to 0.004)	0.001 (0.000 to 0.008)	Mean difference: 0.001[b] favouring the intervention
Pinder 2021		EIR was calculated using female *A gambiae* adult mosquito density from indoor collections during monthly CDC light trap collections in 120 randomly selected houses and sporozoite rate. Infective bites per transmission season.	Screening plus other modification versus no screening	1.23	1.79	Mean difference: 0.57 (-1.86 to 3.00) favouring the intervention

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

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Table 8. Sporozoite rates

Trial	Outcome definition	Assessment method	Reported results		Risk ratio[a] (95% CI)
			Screened houses	Unscreened houses	
Kirby 2009	Proportion of *Anopheles* infected with sporozoites	Identified by ELISA	19/13146 (0.14%)[b]		Not reported
Getawen 2018 (*P falciparum*)			3/190 (1.58%)	10/372 (2.69%)	0.59 (0.16 to 2.11)
Getawen 2018 (*P vivax*)			1/190 (0.5%)	2/372 (0.5%)	0.98 (0.09 to 10.73)
McCann 2021		Identified by real-time PCR	49/657 (7.46%)[c]		Not reported
Pinder 2021		Identified by ELISA	5/2644 (0.2%)	7/2317 (0.3%)	OR: 0.63 (0.20 to 1.97)

[a]These effect sizes have not been adjusted for clustering.
[b]Sporozoite rates in sampled mosquitoes reportedly did not differ between trial groups and data were therefore pooled.
[c]Sporozoite rate calculated for whole study area only.
CI: confidence interval; **ELISA:** enzyme-linked immunosorbent assay; **OR:** odds ratio; **PCR:** polymerase chain reaction

Table 9. Quality assessment for community acceptance [a]

Quality assessment	Getawen 2018	Kirby 2009	Pinder 2021 (Jones 2022)
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	Yes, a fairly thorough attempt was made
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	Yes, several 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	Yes, several steps were taken
d) Were the findings of the study grounded in/supported by the data?	Not applicable	Not applicable	Yes, a fairly thorough attempt was made
e) Please rate the findings of the study in terms of their breadth and depth	Poor	Poor	Yes, several steps were taken

[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.

Table 10. Cost of interventions

Study	Modification	Annual per person cost (USD)	Annual per household cost (USD)	Total intervention cost (USD)
Getawen 2018	Screening (door and window)	6.47	29.13	-
Kirby 2009	Screening (eaves, ceiling, door and window)	11.11 (full screening)	-	-

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Table 10. Cost of interventions *(Continued)*

		21.17 (screening ceiling)		
McCann 2021 (Phiri 2021)	Screening (door and window, eave closure)	27.04	119.91	123,503
Sternberg 2021	Screening (window, eave closure) plus eave tubes	21.47 (societal) 19.62 (provider)	239.46 (societal) 215.38 (provider)	645,641 per year

USD: United States Dollars

Table 11. Bed net use

Bed net use throughout study period	Measurement	Screened houses	Unscreened houses
McCann 2021 (women aged 15 to 49 years)	Percentage slept under a bed net the previous night (95% CI)	79.0 (75.3 to 82.3)	81.0 (76.3 to 85.0)
McCann 2021 (children aged 5 to 59 months)	Percentage slept under a bed net the previous night (95% CI)	80.0 (75.9 to 83.6)	85.6 (80.3 to 89.7)
Sternberg 2021	Percentage slept under a bed net the previous night (95% CI)	59.0 (58.1 to 59.9)	67.2 (66.1 to 68.4)
Minakawa 2022	Median bed net use (IQR)	0.85 (0.02)	0.88 (0.02)

CI: Confidence intervals; **IQR:** interquartile range

APPENDICES

Appendix 1. 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).

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Appendix 2. Detailed search strategies

Search Name: Cochrane Central Register of Controlled Trials

Issue 4 of 12, April 2022

#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

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(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:

---

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*))

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(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 3. ROBINS-I tool, confounders and co-interventions

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, prevalence of anaemia, indoor adult mosquito density

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).

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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.

Appendix 4. Intracluster correlation coefficient sensitivity analyses

Table 1: Clinical malaria incidence (ICC value = 0.01 for Getawen 2018)

Study	Log[Rate ratio]	SE	Weight	Rate ratio (95% CI)
Getawen 2018	-0.958247	0.37929	6.5%	0.38 (0.18, 0.81)
Sternberg 2021	-0.48036	0.113442	72.7%	0.62 (0.50, 0.77)
Pinder 2021	0.518794	0.212181	20.8%	1.68 (1.11, 2.55)
Subtotal (95% CI)	-	-	100%	0.74 (0.61, 0.89)

Heterogeneity: $Chi^2 = 20.25$, df = 2 (P < 0.0001); $I^2 = 90\%$

Test for overall effect: Z = 3.10 (P = 0.002)

ICC: intracluster correlation coefficient; **SE:** standard error; **CI:** confidence interval

Table 2: Clinical malaria incidence (ICC value = 0.06 for Getawen 2018)

Study	Log[Rate ratio]	SE	Weight	Rate ratio (95% CI)
Getawen 2018	-0.958247	0.413354	5.5%	0.38 (0.17, 0.86)
Sternberg 2021	-0.48036	0.113442	73.5%	0.62 (0.50, 0.77)
Pinder 2021	0.518794	0.212181	21.0%	1.68 (1.11, 2.55)
Subtotal (95% CI)	-	-	100%	0.74 (0.61, 0.89)

Heterogeneity: $Chi^2 = 19.89$, df = 2 (P < 0.0001); $I^2 = 90\%$

Test for overall effect: Z = 3.04 (P = 0.002)

ICC: Intracluster correlation coefficient; **SE:** standard error; **CI:** confidence interval

Table 3: Parasite prevalence (ICC value = 0.01 for Kirby 2009)

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Study	Modification Events	Modification Total	No modification Events	No modification Total	Weight	Odds ratio (95% CI)
Kirby 2009	115	585	36	161	6.1%	0.85 (0.56, 1.30)
McCann 2021	626	4568	768	4244	92.8%	0.72 (0.64, 0.81)
Ng'ang'a 2020	2	80	5	80	0.7%	0.38 (0.07, 2.04)
Pinder 2021	2	348	3	354	0.4%	0.68 (0.11, 4.07)
Subtotal (95% CI)	745	5581	812	4839	100.0%	0.72 (0.65, 0.81)

Heterogeneity: $Chi^2 = 1.12$, df = 3 (P = 0.77); $I^2 = 0\%$

Test for overall effect: Z = 5.73 (P < 0.00001)

ICC: intracluster correlation coefficient; **CI:** confidence interval

Table 4: Parasite prevalence (ICC value = 0.1 for Kirby 2009)

Study	Modification Events	Modification Total	No modification Events	No modification Total	Weight	Odds ratio (95% CI)
Kirby 2009	104	530	32	146	5.5%	0.87 (0.56, 1.36)
McCann 2021	626	4568	768	4244	93.4%	0.72 (0.64, 0.81)
Ng'ang'a 2020	2	80	5	80	0.7%	0.38 (0.07, 2.04)
Pinder 2021	2	348	3	354	0.4%	0.68 (0.11, 4.07)
Subtotal (95% CI)	745	5581	812	4839	100.0%	0.72 (0.65, 0.81)

Heterogeneity: $Chi^2 = 1.22$, df = 3 (P = 0.75); $I^2 = 0\%$

Test for overall effect: Z = 5.70 (P < 0.00001)

ICC: intracluster correlation coefficient; **CI:** confidence interval

Table 5: Prevalence of anaemia (ICC value = 0.04 for Kirby 2009)

Study	Modification Events	Modification Total	No modification Events	No modification Total	Weight	Odds ratio, 95% CI
Kirby 2009	70	545	31	150	38.5%	0.57 (0.35, 0.90)

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(Continued)

Pinder 2021	7	348	5	354	4.1%	1.43 (0.45, 4.56)
Sternberg 2021	55	519	82	550	60.1%	0.68 (0.47, 0.97)
Subtotal (95% CI)	132	1412	118	1054	100.0%	0.67 (0.50, 0.88)

Heterogeneity: $Chi^2 = 2.16$, df = 2 (P = 0.34); $I^2 = 7\%$

Test for overall effect: Z = 2.83 (P = 0.005)

ICC: Intracluster correlation coefficient; **CI:** confidence interval

Table 6: Prevalence of anaemia (ICC value = 0.08 for Kirby 2009)

Study	Modification Events	Modification Total	No modification Events	No modification Total	Weight	Odds ratio, 95% CI
Kirby 2009	60	472	27	130	32.7%	0.56 (0.34, 0.92)
Pinder 2021	7	348	5	354	4.3%	1.43 (0.45, 4.56)
Sternberg 2021	55	519	82	550	63.0%	0.68 (0.47, 0.97)
Subtotal (95% CI)	122	1339	114	1034	100.0%	0.67 (0.50, 0.88)

Heterogeneity: $Chi^2 = 2.19$, df = 2 (P = 0.33); $I^2 = 9\%$

Test for overall effect: Z = 2.74 (P = 0.006)

ICC: Intracluster correlation coefficient; **CI:** confidence interval

Table 7: Bed-net use (ICC value = 0.3 for Getawen 2018and Kirby 2009)

Study	Modification Events	Modification Total	No modification Events	No modification Total	Weight	Odds ratio, 95% CI
Getawen 2018	12	21	11	21	12.7%	1.09 (0.63, 1.89)
Kirby 2009[a]	44	95	26	40	42.2%	0.71 (0.52, 0.98)
Kirby 2009[b]	63	121	26	40	45.1%	0.80 (0.60, 1.06)
Subtotal (95% CI)	119	237	63	101	100.0%	0.80 (0.66, 0.97)

[a]Full screening

[b]Partial screening

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(Continued)

Heterogeneity: $Chi^2 = 1.74$, df = 2 (P = 0.42); $I^2 = 0\%$

Test for overall effect: Z = 2.22 (P = 0.03)

ICC: intracluster correlation coefficient; **CI:** confidence interval

Table 8: Bed-net use (ICC value = 0.45 for Getawen 2018and Kirby 2009)

Study	Modification Events	Modification Total	No modification Events	No modification Total	Weight	Odds ratio, 95% CI
Getawen 2018	9	17	9	17	11.8%	1.00 (0.53, 1.88)
Kirby 2009[a]	56	107	23	35	45.5%	0.80 (0.59, 1.07)
Kirby 2009[b]	39	85	23	35	42.7%	0.70 (0.50, 0.97)
Subtotal (95% CI)	104	209	55	87	100.0%	0.78 (0.63, 0.96)

[a]Full screening

[b]Partial screening

Heterogeneity: $Chi^2 = 1.03$, df = 2 (P = 0.60); $I^2 = 0\%$

Test for overall effect: Z = 2.33 (P = 0.02)

ICC: intracluster correlation coefficient; **CI:** confidence interval

WHAT'S NEW

Date	Event	Description
28 September 2022	New citation required and conclusions have changed	This review update includes seven studies in total. The updated search identified seven new records, including one published trial and six ongoing studies, since the last published version (Furnival-Adams 2021). Four trials that were included in the previous version of this review but were not yet completed are now published, and the author team included data from these studies in this review version.
28 September 2022	New search has been performed	An updated search was performed to 25 May 2022. The authors used Risk of bias 2 to assess the risk of bias in included studies.

HISTORY

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

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Date	Event	Description
5 January 2021	Amended	We corrected the certainty of the evidence for malaria parasite prevalence to low-certainty.
5 January 2021	New citation required and conclusions have changed	The certainty of the evidence for malaria parasite prevalence was corrected. It was downgraded by two levels, to low-certainty evidence.

CONTRIBUTIONS OF AUTHORS

For this review update version, Tilly Fox (TF) and Joanna Furnival-Adams (JFA) selected studies, extracted study data and characteristics, and assessed the risk of bias and certainty of the evidence. Marty Chaplin (MC) and TF analysed the data. Evelyn Olanga (EO) and Mark Napier (MN) contributed to the development of the review update. TF updated the text of the review update.

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

DECLARATIONS OF INTEREST

TF is a CIDG Research Associate, and was not involved in the editorial process. She has no known conflicts of interest to declare.
JFA has no known conflicts of interest to declare.
MC is a CIDG Editor, and was not involved in the editorial process. She has no known conflicts of interest to declare.
MN has no known conflicts of interest to declare.
EAO has no known conflicts of interest to declare.

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 2021).

Differences between review and review update

Martha Chaplin (MC) was added as a new author, and Paul Garner (PG) removed as an author.

We used Risk of bias 2 to assess the risk of bias in included studies.

We used the same search strategy to identify new studies published or registered from 1 November 2019 to 25 May 2022. This resulted in the inclusion of seven new records, including one published trial and six ongoing studies. Four trials that were included in the previous version of this review but were not yet completed are now published, and we included data from these studies in this review version. As a result, we were able to perform a meta-analysis on the data for six of our outcomes, compared to one meta-analysis for bed-net use in the previous version of this review (Furnival-Adams 2021).

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INDEX TERMS

Medical Subject Headings (MeSH)

Africa South of the Sahara [epidemiology]; Anemia [diagnosis] [epidemiology]; Architecture; *Construction Materials; *Housing; Incidence; Insecticides; Malaria, Falciparum [epidemiology] [parasitology] [*prevention & control]; Mosquito Nets; Mosquito Vectors; Plasmodium falciparum; Prevalence; Randomized Controlled Trials as Topic [methods] [statistics & numerical data]

MeSH check words

Adolescent; Adult; Animals; Child; Child, Preschool; Female; Humans; Infant; Male; Pregnancy

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