Effective Malaria Control Through Durable Housing Improvements:
Can we learn new strategies from past experience?

Authors: Luke Anderson, Daniel Simpson and Mariana Stephens

White Paper No. 1
Global Programs Department

January 2014
January 2014

Habitat for Humanity International acknowledges Michael Macdonald, Sc.D. Roll Back Malaria and Steve Lindsay for their contributions to this white paper. Lauren Llerandi provided valuable research assistance. Daniel Simpson and Mariana Stephens are both members of the HFHI Global Programs, Program Design, Monitoring and Evaluation team and Luke Anderson did his internship with HFHI during the Summer 2013. This Malaria white paper is the first of a series that Global Programs launched to examine and conduct research in developing countries and manage innovative approaches to health issues as they relate to the build environment. The white papers provide an authoritative guide to help readers understand an issue, solve a problem or make a decision.
# Table of contents

Table of contents ........................................................................................................................................... 3
Introduction .................................................................................................................................................. 4
The parasite .................................................................................................................................................. 5
The vector .................................................................................................................................................... 5
History .......................................................................................................................................................... 5
  Ancient times ............................................................................................................................................. 6
  Modern times ............................................................................................................................................ 6
The emergence of insecticide resistance ................................................................................................. 8
  Additional challenges to current interventions ......................................................................................... 9
Drawing on history: Improving housing to reduce malaria cases ............................................................. 11
  Integrated Vector Management .................................................................................................................. 15
  Research challenges .................................................................................................................................. 15
Conclusion ................................................................................................................................................... 16
Bibliography ............................................................................................................................................... 17
Other resources ......................................................................................................................................... 20
Effective Malaria Control Through Durable Housing Improvements:
Can we learn new strategies from past experience?

Introduction

Malaria is one of the greatest threats to global public health — as has been the case for most of human history. The mosquito-transmitted parasitic infection threatened 3.4 billion people in 2012, nearly half of the world’s population of 7 billion. It costs Africa, the poorest continent on the planet, about US$12 billion in lost productivity and health expenditures each year. In 2012, malaria killed 627,000 people and infected almost a quarter of a billion. In 2008, malaria was the fifth most common cause of death in lower-income countries, accounting for 5.2 percent of deaths.

Today, the fight against malaria is based on preventing transmission and treating those who are infected. Indoor residual spraying of insecticides in homes, or IRS, and widespread coverage of insecticide-treated bed nets, or ITNs, are the primary strategies advocated by the World Health Organization to prevent transmission. These interventions have demonstrated effectiveness, but they also present risks. Widespread use of insecticides can promote insecticide resistance among mosquito vectors, which we now see in many malaria-endemic regions. Prevalent resistance could render our current strategies ineffective, threatening the gains we have made in malaria control over the past century. If we look to the past, however, we might find more sustainable ways to fight malaria. Durably improving housing to prevent malaria vector entry was an effective intervention in the early 20th century. Over the past 100 years, mosquito behaviors and dynamics of malaria transmission have changed (largely in response to vector control strategies). So is improving housing still an effective strategy? Are housing improvements durable enough to overcome the up-front expenditure? Are they effective in a variety of settings? Could mosquito-proofing itself lead to worrisome changes in vector behavior or speciation? Depending on the answers to these questions, housing improvements could be a long-term strategy to prevent malaria transmission in its most critical setting: the home.
The parasite

Malaria has a complex life cycle and is dependent on multiple hosts. The parasite, of the genus *Plasmodium*, is generally species-specific: A given species of parasite generally infects only another specific species of vertebrate. Five species of *Plasmodium* are able to infect humans — *P. falciparum*, *P. vivax*, *P. ovale*, *P. malariae* and *P. knowlesi* — with the majority of deaths caused by the first two. As in the chicken-and-egg dilemma, there is no clear beginning to the life cycle. *Anopheles* mosquitoes, the only genus capable of carrying the parasite, become infected after biting an infected human. The parasite then develops infective sporozoites within the mosquito, which are injected back into humans when the mosquito feeds. Inside the human, the sporozoites first infect liver cells and produce merozoites in vast numbers. These merozoites in turn infect red blood cells and further reproduce. Infected red blood cells then burst, spreading the infection to further cells. Some merozoites develop into gametes, which are picked up by feeding mosquitoes. Eventually, these gametes develop into infective sporozoites, which are transmitted back to humans if the mosquito feeds again.

The vector

Mosquitoes that transmit malaria fall into the genus *Anopheles*. The specific species vary by region, but they tend to fall into two categories: indoor feeding and outdoor feeding. Indoor-feeding mosquitoes, particularly *Anopheles gambiae*, target humans within dwellings and while we are asleep. Over time, these mosquitoes have developed behaviors to more efficiently feed on humans, both through preference for living inside and through specific behaviors to encourage home entry. These mosquitoes will fly upward when reaching a wall, while most other mosquitoes will fly sideways. Flying upward helps mosquitoes find openings such as windows, cracks around doors or open eaves. Outdoor-feeding mosquitoes are generally less effective and target humans less exclusively. Although these are dangerous vectors of malaria, they are also far less efficient.

History

Malaria has infected people around the world since the dawn of human history, although most likely at low levels before the emergence of agriculture. The changes of the agricultural revolution created the perfect environment for a rapid proliferation of malaria. By settling into farming communities, human populations became “large, stable and accessible sources of blood in the midst of abundant mosquito-breeding sites” promoting anthropophilia (preference for human feeding) and endophilia (tendency to live and rest indoors) among malaria vectors. Some mosquitoes from the genus *Anopheles* adapted specific behaviors and traits to target humans. *Anopheles* mosquitoes primarily feed at night and indoors, targeting humans when we sleep and are least able to protect ourselves. Anthropophilic *Anopheles* mosquitoes are also well-adapted to enter human dwellings. By flying upward, they are able to find openings in homes, which are usually around windows, doors or eaves. Many *Anopheles* malaria vectors, particularly *Anopheles gambiae* sensu stricto (the most efficient malaria vector), rest indoors on walls or ceilings.
increasing the likelihood of contact with humans. Since anthropophilic and endophilic mosquitoes tend to be the most effective vectors of malaria, we focus most of our malaria prevention strategies in the home.

**Ancient times**

One of the earliest descriptions of malaria came around 2700 BCE in China. Later, malaria was blamed for the decline of many city-state populations and for rural depopulation in ancient Greece. In the marshy areas surrounding Rome, malaria created a “virtual desert” until the prosperity of the Roman Empire. During the empire, drainage, improved animal husbandry practices, and building development reduced or even eliminated malaria from the region. However, the decline of Rome and economic collapse once again created “hotbeds of *P. vivax* and especially *P. falciparum*” in the marshes around Rome, with malaria outbreaks following cycles of agricultural and economic prosperity. Malaria seems to have exerted extreme evolutionary pressure on humans, possibly selecting for conditions such as the sickle-cell trait and the thalassemias, blood disorders that cause the destruction of red blood cells. The frequency of the sickle-cell trait (hemoglobin S) exceeds 30 percent in many parts of Africa. In such a population, homozygosity of the sickle-cell gene, which causes sickle-cell anemia, can affect at least 10 percent of births. In the premodern world, anemia would likely have resulted in a 100 percent loss of reproductive fitness, killing most homozygotes before puberty. For heterozygotes, who suffer from milder symptoms, the sickle-cell gene can give approximately 90 percent protection against death from *P. falciparum* infection (the most deadly malaria parasite).

We have been fighting malaria since ancient times, even using some of the same strategies as today. Around the second century BCE, the plant Qinghao, or *Artemisia annua*, was first described, and its anti-fever properties were described in 340 CE. Now this plant is the basis for artemisinins, some of our most effective antimalarial drugs. Another historical drug used today is quinine. Discovered in the New World by Spanish explorers in the early 17th century, Peruvian Bark or Jesuits Bark (genus *Cinchona*) is the source of this medicine, which has been used to fight malaria ever since. However, neither of these treatments prevents transmission.

**Modern times**

The knowledge that mosquitoes transmit malaria, discovered by Ronald Ross in 1897, gave our fight a focus. In 1900 in Italy, two studies, one by Angelo Celli and the other by Patrick Manson, tested whether mosquito-proofing homes could effectively reduce malaria transmission. Concerned about malaria’s impact on industry and development in Southern Italy, Celli, an Italian hygienist, proposed a wide variety of protections, primarily focusing on preventing mosquito bites. Celli tested his proposals by screening porches, doors and chimneys and covering windows, and then whitewashing the inside walls of his test homes. Although in some houses where mosquitoes were noticed, pyrethrum (in its nonresidual form) was used as an insecticide and quinine was given, most did not receive this additional treatment. Compared with residents of unprotected control houses, who were infected 94 percent of the time, only 4 percent of those living in “mosquito-proofed” houses were infected. While Celli’s results are impressive, the fact that he did include basic insecticides and antimalarial drugs may have amplified the effects. In a concurrent study (released in September 1900; Celli published in October), Patrick Manson did not use...
EFFECTIVE MALARIA CONTROL THROUGH DURABLE HOUSING IMPROVEMENTS • CAN WE LEARN NEW STRATEGIES FROM PAST EXPERIENCE?

pyrethrum or quinine, instead relying entirely on the physical protections on homes. In his small study of five purpose-built huts, none of the residents of protected homes contracted malaria, despite living in a highly infected area.⁶

There is also real-world evidence of the efficacy of mosquito-proofing from the early 20th century. In Lahore, Pakistan, the British army reduced the incidence of malaria from 569 cases per 1,000 people in 1925 to 45 per 1,000 in 1927 after barracks were mosquito-proofed. British barracks in Amritsar, India, were also screened in 1925, reducing incidence from 613 per 1,000 to 48 per 1,000 by 1927. At this time in India, malaria was extremely deadly, claiming upward of 50 percent of all deaths in some regions. Because of the highly uneven distribution of malaria, highly infected areas could surpass these rates and become “uninhabitable through the presence of malaria.”⁴ The Spanish army in Procaccina, Spain, also screened their barracks, which reduced malaria incidence from 70 percent to 57 percent in one season, with the rate eventually sinking to 20 percent.

Screening and mosquito-proofing were also shown to be effective in the United States. In 1921, a survey in Missouri showed that people in well-made homes with screens contracted malaria at less than half the rate of those in well-built homes without screens (5 percent versus 12 percent). This reduction is similar for those in poorly built homes with or without screens (13 percent versus 24 percent). In poorly built homes, malaria reductions were achieved through screening even though other entry points remained (gaps in walls, floors, etc.). In the 1930s, once 700 northern Alabama homes were screened against mosquitoes, the incidence of malaria substantially fell compared with unscreened homes.⁷

Improving homes continued to be recognized as a highly effective technique through the middle of the century, even with the emergence of indoor residual spraying to fight malaria. In 1941, C.C. Kiker wrote in the “Symposium on Human Malaria” that “the improvement of homes by the application of mosquito-proofing … is probably the most practical, economical, and effective malarial control measure available.” In 1949 in “Malariology,” R. B. Watson found that “screening heretofore has been the single, most generally applicable, effective malaria control measure available.” However, as time has moved on, our focus has shifted to the “wonder tools” of antimalarial drugs and insecticides.⁴ Professor S. W. Lindsay of Durham University, Paul M. Emerson of the Carter Center and J.D. Charlwood of the Danish Bilharziasis Laboratory feel that this reflects society’s “perennial desire for a technological solution to provide a quick fix.” Although these new strategies failed to eliminate malaria, “the effectiveness of mosquito-proofing houses has remained largely forgotten.”⁷

Indoor residual spraying traces its history, or at least popularity, to malaria eradication efforts in the United States. The insecticidal properties of DDT were discovered in 1939, and the efficacy of spraying indoor walls to kill malaria vectors was soon realized. In 1947, a massive spraying campaign was started by the Communicable Disease Center (now the Centers for Disease Control and Prevention) in the Southern United States. After two years, 4.65 million homes had been sprayed with DDT, mosquito breeding sites had been drained and eliminated, and some insecticide spraying by aircraft had been performed. By 1949, malaria was no longer considered a public health concern in the United States, and the program was deemed a success. This great success led to emulation on a global scale, and the Global Malaria Eradication Program was started in 1955.
The emergence of insecticide resistance

The GMEP showed promise at its start. In many regions, malaria transmission was greatly reduced, and transmission was even eliminated in some places. However, the program was unable to eliminate malaria globally because of many of the same challenges we face today. In some areas, even when malaria had seemingly been controlled, the disease re-emerged, sometimes at epidemic levels. The program was also unable to prevent widespread DDT resistance among mosquitoes. Although concerns about emerging insecticide resistance to DDT were present from the start of the GMEP, they were used as a reason to speed up implementation of the program, rather than to examine alternatives. The “campaign managers knew that in mosquitoes, regular exposure to DDT tended to produce widespread resistance in four to seven years.”

Now “DDT resistance is widespread in Anopheles, as is resistance to many more recent pesticides.” Without alternative insecticides, the GMEP lost its most effective tool. Eventually, the “prohibitive economic and political costs of operating malaria control campaigns … combined with emerging resistance of the parasites and their vectors to the chemical used to attack them, led, from the early 1970s, to resurgence of malaria transmission” and “the emergence of multidrug-resistant P. falciparum.” These challenges effectively killed the GMEP by 1969, and the goal once again became malaria control instead of eradication.

Insecticide resistance, a major challenge for the GMEP, continues to be a major threat to our malaria control efforts. Resistance can develop quickly, and it has a severe effect on malaria control. There are four classes of insecticide used to fight malaria-carrying mosquitoes today, with only one class, pyrethroids, recommended for use in long-lasting insecticidal nets. Insecticide resistance emerges quickly, usually against an entire class of insecticides at one time. Widespread resistance could greatly reduce our ability to fight malaria, leading to as many as 26 million additional cases of malaria each year and 120,000 additional deaths each year. This is more than a 15 percent increase in deaths due to malaria. In just eight years, from 2004 to 2012, resistance has spread dangerously in certain areas. Janet Hemingway, chief executive of the Innovative Vector Control Consortium, states, “In 2004, there were pockets of resistance in Africa, and now there are pockets of susceptibility.”

Development of resistance can be fought, but it must be considered in the early stages of a program using insecticides. The WHO recommends rotating the use of various chemicals or use of interventions in combination (sprays with multiple insecticides, for example) to decrease chances of resistance. Unfortunately, once resistance emerges in a population, it is very hard to fix the problem. After DDT resistance has been established in a population, even discontinuation of use for years will not make resistance disappear. The insecticide may be useful for a time after the break, but resistance will re-emerge very rapidly, in as few as seven months. This is likely the same for other classes of insecticide. The WHO has an even bleaker outlook once resistance has become common and stable in a population: “the resistant gene will not recede even if use of the insecticide causing selection pressure is discontinued.” According to the WHO, resistance will disappear only if the trait providing resistance comes at a reproductive cost to mosquitoes. In this case, discontinued use of resisted insecticides will...
eventually cause resistance to begin dying out through natural selection. However, unless the resistance trait exerts the same negative selective pressure exerted by insecticides, resistance will linger for far longer than it took to emerge.

With spreading resistance, our tools in the fight against malaria are shrinking in number. In malaria-endemic regions, resistance to at least one of the four classes of insecticide has been detected. For example, in one region of Senegal, mosquitoes “swiftly developed resistance to bed nets treated with…a pyrethroid.” A new plan to fight insecticide resistance was developed by the WHO, but the cost is estimated at US$200 million a year. This level of funding is hard to locate when about US$1.5 billion already is spent each year fighting the disease.

**Additional challenges to current interventions**

Beyond promoting insecticide resistance, another challenge of IRS is effective implementation. IRS must reach a critical mass to achieve communitywide protection. Estimates of required coverage vary but can reach as high as 80 percent. Furthermore, homes must be sprayed regularly to maintain effectiveness. For most insecticides, effectiveness is reduced after six months, with complete dissipation after a year. This constant maintenance is an organizational challenge and requires constant financial support. Poorly implemented spraying programs, not achieving adequate coverage or re-application, can perpetuate insecticide resistance and drain already limited resources. If support for control programs dries up, malaria can easily re-emerge, as occurred in some regions after the failure of the Global Malaria Eradication Program. In the Garki region of northern Nigeria, even though malaria prevalence was reduced from 70 percent to 1 percent after 97 to 99 percent of homes were sprayed and 73 to 92 percent of people were provided with anti-malarial medication, malaria re-emerged after the program was stopped. Re-emergent malaria can be more threatening to human life, even if transmission rates are lower, because the population might have lost most of its acquired immunity.

Along with IRS, insecticide-treated bed nets and long-lasting insecticide-treated nets, or LLINs, have been the most commonly prescribed solution to endemic malaria. These nets are effective when used properly. However, use is not consistent, limiting effectiveness. As with IRS, widespread coverage and use are necessary to achieve community-level outcomes. It is estimated that only 53 percent of sub-Saharan African households own a single ITN, and only 33 percent of the population sleeps under an ITN each night. Furthermore, this rate is expected to decrease over time, because of “loss, physical degradation and inadequate replacement.” Physical degradation and retreatment are constant challenges for effective implementation of ITN programs. If properly used, ITNs will be slept under every night, often by children, and such frequent use will naturally damage the nets. Gaps develop, allowing mosquitoes inside and eventually defeating the purpose of the nets. Replacing damaged nets is costly, and although their lifespan is generally estimated at three years, long-lasting ITNs might not last as long as designed. As with IRS, to achieve communitywide effects, use must reach a certain level. This level is not agreed upon, however, with claims ranging from 35 to 75 percent.

A recent innovation in the fight against malaria is insecticide-treated plastic sheeting, or ITPS. In many ways, ITPS can be similar to screening: It can reduce mosquito entry points in walls or around windows and doors. Recent studies in Papua New Guinea, Burkina Faso and India have shown ways
this sheeting can be effective in fighting malaria transmission. ITPS was developed for use in refugee camps and temporary settings, but it can also be used to protect more permanent dwellings as an alternative to IRS. The studies in Burkina Faso and India compared ITPS protection with untreated plastic sheeting coverage and with unprotected control homes. Additionally, in Burkina Faso, various levels of coverage were tested: ITPS ceiling, coverage on two walls, coverage on four walls, and full coverage (four walls and ceiling). Dwellings receiving untreated sheeting received full coverage. In Papua New Guinea, residents were given the choice of screening windows with sheeting or not, and an effort was made to cover eaves when possible. There is no information about the protection of eaves or windows in the other two studies.

The results from these studies demonstrate effectiveness but also highlight some concerns. In Burkina Faso, more than 40 percent of mosquito entry was deterred with four-wall coverage and full coverage with ITPS. Untreated sheeting had no deterrent effect. In India, there was a much larger reduction, with rates ranging from 77.8 percent to 100 percent reduction in entry of various anopheline species of mosquito. In India, malaria incidence (not directly measured in the other studies) was reduced by 65 to 70 percent in homes treated with ITPS. These are remarkable rates of improvement, but they are accompanied by significant concerns. In Burkina Faso, it was found that “insecticide-treated plastic sheeting may favour the selection of pyrethroid resistance, as a higher proportion of mosquitoes homozygous for resistance survived in the ITPS huts.” The fact that this treatment may select for resistance is very threatening to future control efforts and to the longevity of ITPS as an intervention.

A major question when considering ITPS is durability. In Papua New Guinea, no issues with durability were observed in the four-week trials, but ITPS is probably not efficient or cost-effective unless it can last for years. Residents in Papua New Guinea did express concerns and did not perceive the material as durable. Also, many took specific precautions to protect their sheeting, which may be forgotten or ignored over time, especially as the sheeting loses its effectiveness or begins to discolor and degrade over time. The home environment is another challenge for maintaining effectiveness. In many homes in Papua New Guinea, ITPS was exposed to smoke from unventilated fires within the home. Although the effect of smoke on ITPS is not known, it might reduce the effectiveness of the insecticide treatments. ITPS might be effective in some regions as a housing modification to control malaria, but longer-term studies evaluating its durability and effect on insecticide resistance should be performed before widespread implementation.

A review of cost-effectiveness studies of current malaria interventions was published in November 2011. Various measures of cost were evaluated, such as the cost to protect one person for one year and “the median incremental cost effectiveness ratio per disability adjusted life year.” The authors found 65 studies of both cost and cost effectiveness of malaria interventions. From these studies, the median costs to protect one person for one year in 2009 U.S. dollars were $2.20 (range 88 cents to $9.54) for ITNs and $6.70 (range $2.22 to $12.85) for IRS.
Drawing on history:
Improving housing to reduce malaria cases

Despite the problems and challenges associated with IRS and ITNs, these two methods have persisted as the most commonly prescribed solutions to control malaria. After the rise of DDT, the fight against malaria sought technological solutions for our ancient problem. During the GMEP, DDT and insecticides became extremely dominant, while other interventions fell to the wayside. Although about 80% of malaria transmissions occur indoors in Sub-Saharan Africa, in the years since the failure of the program, “the effectiveness of mosquito-proofing houses has remained largely forgotten.” Now there is a lack of modern research studying the impact of housing improvements on malaria control. Fortunately, some recent data does exist to examine the relationship between housing conditions and malaria.

Two studies by the Department of Parasitology at the University of Colombo in Sri Lanka have broadly examined this relationship. The first found “a strong association between the malaria incidence and house construction, independent of location.” Those in poorly constructed houses (“incomplete, mud, or cadjan (palm) walls, and cadjan thatched roofs”) contracted malaria at twice the rate of better-constructed dwellings (“complete brick and plaster walls and tiled roofs”), and the average mosquito densities were also about twice as high in these homes. In the second study of 343 houses (and 1,744 residents), the risk for those in poorly constructed houses was found to be 2.5 times higher. This study also suggested interventions to reduce the risk of malaria. The first creates a “buffer zone of 200 meters around bodies of water from which houses of poor construction (are) excluded.” A 21 percent reduction of malaria in the overall population (43 percent for those relocated) was estimated for this intervention. For houses in this “buffer zone,” improvement to a “good construction type” (“with completely plastered brick walls and tiled or corrugated iron roofs”) was recommended. The estimated reduction in malaria is even greater for this intervention: 36 percent in the entire population and 76 percent for those in improved homes. Because of decreased malaria control costs in the long term, the government was expected to make up its expenditure in 7.2 years and then begin to bring in a return on its investment, despite high up-front costs. This estimate assumes 66 percent effectiveness. The researchers consider this to be a conservative estimate of cost-effectiveness, since it focuses only on the government cost. The 1998 study estimated the cost of building new, low-risk housing to be $850. When the study was performed, the government of Sri Lanka was spending almost 60 percent of its $12 million malaria control budget on insecticides, which must be replenished regularly.

Multiple studies have shown the effectiveness of a simple housing improvement that can often be performed by the residents using locally available materials: the installation of ceilings. In one study by Lindsay, et al., ceilings reduced house entry by Anopheles gambiae by 59 to 80 percent. This study, in The Gambia, tested five treatments hypothesized to be effective against malaria-carrying mosquitoes. These ranged from treatments that are simple and achievable with local materials (plywood ceilings or eaves closed with mud blocks) to methods that are more advanced (“insecticide-treated synthetic-netting ceiling”). The study lasted for six weeks, and interventions were rotated among six huts. By the end of the study, every hut had been tested with each treatment and had been the control (untreated) for a week. The results were based on the numbers of mosquitoes caught in traps inside the room. Each intervention tested
reduced the number of mosquitoes by an appreciable amount, although blocking eaves did not quite reach statistical significance ($P=0.057$). Plywood ceilings reduced entry by 59 percent, and the nets and screening all reduced entries by about 80 percent. Furthermore, these interventions fought entrance by mosquitoes of the genus *Mansonia*, which is a vector of lymphatic filariasis and other arboviruses.

During the study in The Gambia, the acceptability of treatments to residents and the cost of implementation were examined. Although net and screen ceilings reduced airflow, making rooms feel stuffy, “group interviews showed that ceilings were considered to improve houses, and were widely associated with reduced disturbance by mosquitoes.” Many of the interventions are of very low cost or achievable with local materials. Using mud blocks to close eaves is almost free, and using locally made ceilings costs only 70 cents to $1.14 (in 2009 U.S. dollars) (originally £0.42 to £0.69 per person per year. This assumes a lifespan of three to five years for ceilings and four people per room. Based on this study, the cost of screening is significantly lower than that of both IRS and ITNs.

A 2009 joint study performed by the Kenya Medical Research Institute, the Moi University School of Public Health, and the Department of Entomology of the University of California, Davis, tested the effectiveness of papyrus mat ceilings in western Kenya. The mats were locally produced using local materials and were purchased at the market price of US$1 per mat. These mats were installed below open eaves of traditional homes, and a small, insecticide-treated net was fixed into the ceiling. The ITN was placed in a small opening in the ceiling as a decoy trap to kill mosquitoes attempting to enter the room. The scent of sleeping humans in the hut could drift through the trap, into the ceiling, and out through eaves, attracting mosquitoes but killing them without allowing them inside the room. The addition of ceilings provided a large reduction in *Anopheles gambiae* and *Anopheles funestus* mosquitoes entering the hut. Compared with controls, the ceilings reduced entry of *A. gambiae* by 76 to 82 percent and densities of *A. funestus* by 86 percent.

Unlike the screens used in the Lindsay, et al., study in The Gambia, papyrus mats did not reduce airflow or make huts stuffy. This is perhaps due to the ITN “window” in the ceiling, which allows airflow into the eave space. Houses were slightly cooler during the day and slightly warmer at night, which could be positive for residents. Furthermore, “focus group interviews indicate that ceilings were cheap, considered to beautify homes, widely associated with reduced temperatures and less associated with disturbance by mosquitoes.” Responses seem to indicate that ceilings would receive widespread support among communities. These ceilings are cheap and support the local economy, since they are locally produced. Assuming a lifespan of 10 years with three people in each house, the cost is low: about US$1 per person. The mats themselves cost $1 each, with the remainder of the cost coming from insecticide for the “trap” in the ceiling. Again, this cost is lower than that of IRS and ITNs.

In a study published in The Lancet in 2009, the authors recognized that many previous studies examining screening often included other variables (such as the ITN “trap” in the previous study), so they designed a study purely around screening interventions. This study, in The Gambia, tested the effects of two different screening strategies against a control (unprotected) group. Full screening (screening of windows and doors, and closing of eaves) and installation of screened ceilings were both tested as ways to reduce house entry of malaria-carrying mosquitoes. In all, 188 houses were fully screened, 178 received screened ceilings, and 96 were left unscreened as the control cohort. Success was measured by the number of female *Anopheles gambiae* collected per trap per night. The objective was to determine “the
EFFECTIVE MALARIA CONTROL THROUGH DURABLE HOUSING IMPROVEMENTS • CAN WE LEARN NEW STRATEGIES FROM PAST EXPERIENCE?

efficacy of the house screening interventions against *A. gambiae* house entry, and to assess whether the interventions were comfortable, durable, and acceptable to local communities.\(^{26}\) The ability to restrict mosquito house entry was an important factor, but the willingness of residents to continue with interventions and the durability of screens (measured by damage shown at six and 12 months) also were considered. The researchers prepared criteria before performing the study to determine a positive (and recommendable) outcome: House entry should be reduced by at least 50 percent, and the intervention should be acceptable to 67 percent of households. The criteria for houses included in the study were as follows: “Houses had to be single-story buildings, have open eaves, less than five rooms, no existing ceilings, no existing screening, and at least one child aged between 6 months and 10 years sleeping there at night.”\(^{27}\) In addition to measuring mosquito entry to determine efficacy, rates of parasitaemia (>5000 parasites per µL) and rates of anemia in children were measured. Children are at particular risk of anemia caused by malaria infection, and it is an important cause of death in many malaria-endemic regions. Lowered rates of anemia are related to lower infection rates of malaria.

Both interventions reduced the numbers of vector mosquitoes by an appreciable amount. Full screening achieved a mean of 15.2 *Anopheles gambiae* per trap per night, compared with 19.1 per trap per night in houses with a screened ceiling. Considering that a mean of 37.5 *Anopheles gambiae* per trap per night were caught in control houses, both were effective. Actually although the means appear different, there was no statistically significant difference between the two types of screening, so there was no difference between the different types of screening, but full screening is preferred by households. The researchers hypothesized that most mosquitoes found inside fully screened homes entered while screened doors were left propped open during the day, a common practice in village settings. Many of the mosquitoes found inside these homes (about half) were not *Anopheles gambiae* and were not malaria vectors, supporting their hypothesis, since *A. gambiae* mosquitoes are more active at night. Anemia and hemoglobin concentrations were also reduced. Although there was no statistical difference in severe anemia, “its frequency was lower in the screening groups compared with the control, suggesting a larger study might show that screening is also protective against severe anemia.”\(^{27}\) When combining intervention groups, rates of anemia were significantly lower than for the control group. In screened groups, the increase in hemoglobin concentration compared similarly to the results of six randomized controlled studies of insecticide-treated bed nets, showing similar protective efficacy.

At the end of the study, residents were surveyed to determine the acceptability of each treatment. Residents tolerated both interventions, and generally had favorable reactions to full screening. It was reported to improve privacy, improve home appearance, reduce entry by mosquitoes and other pests, and reduce dust. The primary concern of residents was keeping screens clean (reported by 48 percent of the fully screened group). At the end of the trial, participants were given the option of keeping their existing intervention or switching to another included in the study. Ninety-four percent of the fully screened group retained their screens, and 46 percent of the ceiling group kept their ceilings. However, most of the group who had been given ceilings upgraded to full screening, along with most of the control group, showing that this intervention is acceptable to and desired by residents of the study site.

The condition of treatments was examined after six months and again after 12 months, in order to help determine durability. Although most houses had some damage, it was considered minor. Most windows (80 percent) had little or no damage, and the proportion without damage was even higher for
mortar blocking of eaves (90 percent). Doors showed the highest rate of damage, although in the second year of the study, rates of damage declined. Even with some damage, 89 percent of screened doors did not contain gaps large enough to allow mosquitoes to pass through. All rates of damage declined in the second year of the study, suggesting that participants learned the effectiveness of screening and also learned ways to care for screens from neighbors who had participated in the first year.

The durability, along with the cost of roughly US$10 per person (assuming four people per household) compares favorably with IRS (average of US$6.70 per person per year) and ITNs (average of US$2.20 per person per year) when spread over the lifetime of the interventions. The effectiveness of screening was estimated at three to four years, longer than some other interventions. Using these estimates, the price per person per year is roughly US$2.50, very close to the cost of ITNs and much lower than the cost of IRS. With proper care and durable materials, the lifespan could be even longer. The study already showed an improvement in durability in the second year, showing that with education and experience, screens can be durable and long-lasting. In this study, Kirby, et al., find that “full screening can be a sustainable control method: the interventions were largely made with use of locally available materials and installed by local carpenters.” The ability to use local materials and tradespeople means that, with education, screening can be independently implemented by households.

One concern with this study was decreased use of bed nets in, primarily, fully screened houses. The researchers hypothesize that residents believe screening acts as a replacement for bed nets. They advocate house screening to augment, rather than replace, the use of insecticide-treated bed nets. Despite this recommendation, they note, “estimates of the direct effect of the intervention were almost identical to estimates of the combined effect, suggesting that indirect effects through bednet use are of limited significance.” In this study, the number of participants might not have been enough to pick up the extra protection from a multiple, redundant system. Local and individual factors may determine whether a bed net adds protection in a fully screened home. When coverage of ITNs is already high, installing screened ceilings without teaching homeowners to continue use of their bed net could increase risk of transmission. In fully screened homes, most invasions by mosquitoes come when doors are propped open. However, when screening is effectively implemented, it can protect more people at once than a bed net.

In these studies, housing improvements appear to hold promise for the fight against malaria. However, there are few studies examining the effect these improvements can have in a wide variety of settings or on a large scale. Compared with our current strategies, housing interventions may have additional protective effect, with fewer risks related to insecticide resistance. In a fully screened house (when doors are not left open), everyone indoors should be protected as long as they are inside, not only when sleeping under a net. When sleeping under an ITN in a screened home, a person is under two layers of protection. Any mosquitoes that may have entered through an open door are still blocked and possibly killed by the net. If gaps develop in screening, the ITN will continue to protect residents against invading mosquitoes. When fewer mosquitoes enter homes and are affected by insecticides, the development of insecticide resistance may be slowed.

One risk of widespread home improvements might be a change in the behaviors of malaria vector mosquitoes. Although the home is the primary location of malaria transmission, outdoor vectors exist and can maintain lower-level, “residual” transmission. However, most studies suggest that our interventions promote changing vector population ratios to favor outdoor vectors, rather than promoting changed
behaviors among individual vector species. This is promising, since outdoor vectors such as *A. arabiensis* are less effective carriers of malaria. Although housing improvements are unlikely to lead to eradication because of these residual vectors, it is likely that the burden of malaria will drastically decline when the primary site of transmission is protected. If housing improvements are proven to be a long-term solution to indoor transmission, we might be able to shift our fight to these outdoor vectors, leading to further gains.

**Integrated Vector Management**

Considering the potential effects on multiple diseases beyond malaria, such as dengue, housing improvements might become an important part of Integrated Vector Management. Integrated Vector Management is becoming an important element of the anti-malaria campaign. According to the WHO, IVM “encourages a multidisease approach, integration with other disease control measures, and the considered and systematic application of a range of interventions.” IVM encourages more durable solutions for malaria control, with less focus on chemical strategies unless others are ineffective or prohibitively costly. Housing improvements fit well within this framework. Beyond potential durability and cost-effectiveness, housing improvements can help fight other diseases, too. In the Lindsay, et al., study from The Gambia, housing improvements were found to reduce entry of lymphatic filariasis other arbovirus vectors. The specific improvements associated with mosquito-proofing may also reduce transmission of other mosquito-borne diseases such as dengue. Additionally, improved housing reduces incidence of disease in general, mosquito-borne or not. In Ekwendeni, Malawi, 98 houses that had been improved by Habitat for Humanity International were compared with 114 traditional houses to study health outcomes for children younger than 5. The odds of contracting a respiratory infection, gastrointestinal illness or malaria for those in improved homes were reduced by 44 percent compared with those in traditional homes. This is even more notable, since those in improved housing were 7 percent less likely to have access to a safe water source. Access to safe water or a private latrine was significantly associated with a further reduced risk of illness. Ceilings and netting were not installed in the Habitat for Humanity-improved housing in this study, so researchers hypothesize that further malaria reductions could be made. Since many housing improvements can be implemented using local materials and labor — and are expected to be more durable — these interventions have the potential to become an integral part of IVM campaigns.

**Research challenges**

Before housing improvements can be considered an element of IVM or an effective strategy for fighting malaria, we must answer some questions. First, in what settings are housing improvements effective at preventing malaria transmission? The studies cited in this paper found housing improvements to be effective, but most of these studies were relatively small and unvaried geographically. Many of these studies also investigated only the reduction in the number of mosquitoes entering the home, rather than directly measuring changes in the incidence of malaria.

Second, how durable are housing improvements in the real world? Study participants might be more likely to care for their screens and other improvements because they know someone will return to check
their condition. Residents also might do a better job caring for any improvements immediately after installation. As the years go by, maintenance could be neglected, especially if mosquitoes are perceived to be less of a nuisance as malaria rates decline. This concern is common for other interventions, such as bed nets. As malaria seems to become less of a threat, support for control or eradication programs can decline. In the Global Malaria Eradication Program, declining support led to the re-emergence of malaria and the failure of the program. Training local residents in installation and using locally sourced materials and labor might help prevent this by giving local communities the tools needed to maintain programs independently. To ensure the durability and longevity of interventions, residents should also be educated from the outset on the importance of proper maintenance.

Related to the previous question of durability, the long-term efficacy and cost-effectiveness must be studied. In the aforementioned studies, housing improvements are perceived to be durable and cost-effective. Again, this must be shown on a large scale. With widespread implementation, housing improvements might become more cost-effective if the manufacture of needed materials achieves economies of scale and installation becomes more efficient. Local communities might be able to implement this strategy on their own, with minimal government support. When local materials are available and local manufacture is possible, outside support might not even be necessary beyond training residents in correct installation. Local economies may be improved if manufacturing or installation jobs are created.

**Conclusion**

Since the link between malaria and mosquitoes was discovered, the home has been a major battleground in the fight against the disease. Early on, housing improvements and mosquito-proofing were emphasized and implemented in a variety of settings. Although these experiences showed effectiveness, there is a lack of modern evidence showing the protective effect of improved housing to fight malaria. Some recent studies have shown the applicability of improved housing, but large-scale studies or trials must be performed before improved housing can be considered an effective intervention against malaria. If these studies substantiate earlier results, housing improvements might find a place in anti-malaria programs. With proven effectiveness, anti-malaria protections should also be included in existing housing improvement programs, such as slum upgrading, microfinance or direct building programs. Widespread implementation from multiple sectors will help fight malaria in a variety of settings, possibly leading to a greater communal effect. The recent Roll Back Malaria “Multisectoral Action Framework for Malaria” provides a roadmap for supplementing the current vector control measures of ITNs and IRS through complementary interventions, one being incremental improvements to housing.31
Bibliography


Other resources


EFFECTIVE MALARIA CONTROL THROUGH DURABLE HOUSING IMPROVEMENTS

• CAN WE LEARN NEW STRATEGIES FROM PAST EXPERIENCE?
EFFECTIVE MALARIA CONTROL THROUGH DURABLE HOUSING IMPROVEMENTS

• CAN WE LEARN NEW STRATEGIES FROM PAST EXPERIENCE?
EFFECTIVE MALARIA CONTROL THROUGH DURABLE HOUSING IMPROVEMENTS

CAN WE LEARN NEW STRATEGIES FROM PAST EXPERIENCE?